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THE TRIPARTITE CONFERENCES ON RADIATION PROTECTION

CANADA, UNITED KINGDOM, UNITED STATES
(1949 – 1953)

PUBLISHED BY THE
ASSISTANT SECRETARY FOR POLICY, SAFETY AND ENVIRONMENT

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OFFICE OF SCIENTIFIC AND TECHNICAL INFORMATION
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THE TRIPARTITE CONFERENCES ON RADIATION PROTECTION

CANADA, UNITED KINGDOM, UNITED STATES (1949 – 1953)

BY

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1984

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FOREWORD

In 1979, Dr. Lauriston S. Taylor completed for the Department of Energy a report entitled Organization for Radiation Protection, The Operations of the ICRP and NCRP, 1928-1974. This report has been invaluable in establishing historical perspective regarding the development of radiation protection standards. Recent congressional and judicial interest in historical standards has further prompted Dr. Taylor to compile and document the discussions and conclusions of three tripartite conferences held with the United States, the United Kingdom, and Canada between 1949 and 1953. Dr. Taylor, upon having difficulty in finding a sponsor to assist in publishing this work, contacted my office to ascertain interest. Because this activity is of prime concern, the Nevada Operations Office of the Department of Energy agreed to provide funding for typing the manuscript and printing of the report. This report is the result of that effort.

I personally appreciate the effort Dr. Taylor has exerted in preparing these documents for publication for which he has received no remuneration other than the personal satisfaction of contributing to the scientific literature.

Bruce W. Church
Bruce W. Church, Director
Health Physics Division
Nevada Operations Office
U.S. Department of Energy
April 1984

THE TRIPARTITE CONFERENCES ON RADIATION PROTECTION STANDARDS

Canada, United Kingdom, and United States

1949 to 1953

AUTHOR'S PREFACE

Despite potential radiation hazards of a kind and magnitude never before encountered by man, the Manhattan Engineer District adequately safeguarded its workforce while developing atomic bombs during World War II. Wartime protection standards, derived chiefly from the pre-war recommendations of the U.S. Advisory Committee on X-Ray and Radium Protection, extended pragmatically, as needed, to cover novel hazards. The Advisory Committee itself had suspended operation during the war, but reassembled in 1946 as the National Committee (later Council) on Radiation Protection (NCRP). It was already clear that the massive amounts of radiobiological data accumulated under government auspices during and after the war required digestion, and that the vastly expanded scope of potentially hazardous work with radioactive materials might demand revised protection standards.

To meet this demand, the NCRP formed several subcommittees, which began studying the problems and drafting proposals for new standards for protection against the effects of ionizing radiation. Members of the new Atomic Energy Commission (AEC), many of whom also served on NCRP subcommittees, fully accepted the necessity of revised and expanded protection standards. Both Canada and the United Kingdom had participated in the wartime development program, and, like the United States, both had established permanent radiation research programs when the war ended.

With the post-war re-establishment of normal intercourse between scientists in the field of ionizing radiation, the need for a new look at protection standards was recognized. To further this, and to prepare for the rebuilding of the International Commission on Radiological Protection(ICRP), Dr. G. Failla and H. Lisco were invited to attend a meeting of the Tolerance Dose Panel of the Protection Subcommittee of the British Medical Research Council on 17 September, 1948 (see Appendix 5). This followed some exploratory correspondence in which Failla had informed the Panel of the new permissible doses which the NCRP was proposing, and some correspondence between Taylor and W. V. Mayneord regarding the reorganization of the ICRP.

As a result of these largely informal contacts between scientists from the three countries, it became evident to their governments that, to insure compatible protection practices, closer technical cooperation must be established. This led to a two-day conference between representative of the three governments at Chalk River, Ontario in September 1949; it was the first of what became known as the Tripartite Conferences.

The initial talks led quickly to agreement on the new NCRP proposals for a basic permissible dose for the exposure of workers to external sources of radiation. However, only tentative agreement could be reached on acceptable body burdens or environmental concentrations of radioactive materials that might enter the body. For example, it turned out that some early proposed values for plutonium appeared to be so strict as to threaten closure of the U. S. Atomic Energy programs (see Appendix 15). A second meeting in Harwell, England, during the summer of 1950 reached tentative agreement on the outstanding problems. The third and last Tripartite Conference took place at Harriman, New York, in early spring 1953. This meeting produced the final recommendations, insofar as they involved agreements between the three countries, for new protection standards.

Questions regarding the proceedings of the conferences and interpretations of their findings have arisen over the succeeding years; even as recently as 1983. Continued interest and consequent inquiries emphasized the desirability of providing more permanent documentation of those very important conferences. This author, a member of the United States delegation to all three conferences, came into possession of most of the working papers and final reports, hence he has felt the obligation to assemble this material for both technical and historical reference.

Therefore, communications were directed to each of the conference participants, giving a list of the material in hand and requesting any additional material that was known to exist and might be available (see Appendix 26). Responses came mostly from the conference members in Canada and the U.S., and included some copies of correspondence between individual members, centering on questions primarily raised at the Chalk River conference. This correspondence (Appendix 25) is important to the ultimate understanding of the standards, but coming mostly from the U.S. participants, it may be in some imbalance of individual interests. It should also be recognized that the retention of correspondence and notes over a period of thiry years since their origin must be very much a matter of the particular interests and storage habits of the individual.

This report will comprise mainly of a brief discussion of the conferences themselves, with some background information leading up to their organization. The remainder of the material, in a series of appendixes, will be verbatim copies of notes, minutes, and proceedings of the meetings, together with any subsequent correspondence that may have taken place. Permission to publish this correspondence has been granted by each individual concerned, with the exception of Dr. Wright Langham, for which permission was given by Mrs. Julie L. Grilly, Dr. Langham's widow. She supplied me with Dr. Langham's own files on the Chalk River conferences.

The conference material is presented with no current interpretations of what took place. Comment is limited to noting occasional uncertainties as to the material's exact origin. Conference preparatory materials and the subsequent papers are presented in chronological order. Correspondence is also added in the chronological order; it is primarily from the 1949 conference in Chalk River. In a few cases, the correspondence lacks the initial or final letters. Very few references, other than those used during the conferences or in correspondence will be included. Particularly for the Chalk River conference, there were several sets of minutes made by the three delegations, all, of course, based on the same material. For this reason, there is a considerable duplication of overall presentation. However, various small differences are scattered throughout, and for that reason each has been included. It is left to the reader to interpret any significance that may be associated with the differences in the detail.

Lauriston S. Taylor

March 1983

THE TRIPARTITE CONFERENCES

I. The Early Status of Radiation Protection Standards

Given in the next pages will be a very brief review of the radiation protection philosophy and standards as they had developed prior to the Chalk River conference in 1949. The details have been covered in depth in at least four books and a number of miscellaneous publications over the past decade. (1-6) These will be listed at the end together with some pertinent references. Published works by R. G. Hewlett and O. E. Anderson, and by R. G. Hewelt and F. Duncan describe the early history of the AEC safety programs. In addition, it is known that detailed historical writings covering some aspects of government work related to radiation protection during the early post-war period are currently in process by J. N. Standard and by B. C. Hacker. There are also many available books and papers, especially those prepared in the years shortly after the war, that cover protection-related aspects of the Atomic Energy Project.

Until 1934, radiation protection recommendations largely took the form of equipment design and shielding, operating procedures and the lead-shielding thicknesses for rooms and enclosures. Numerical standards to express dose limits or maximum permissible doses such as we know them today were not used for the simple reason that, until 1928, there was no international agreement as to how to express radiation exposure or dose. Moreover, during that period and for some years afterwards, the distinction between exposure and dose was very unclear. In 1928, the Second International Congress of Radiology, meeting in Stockholm, adopted a definition for the roentgen, then referred to as the "international unit of x radiation." At this same congress was organized the first committee dealing with x-ray and radium protection. The first recommendations of this committee were issued under that title and over the name of the International Congress of Radiology. Its present name--International Commission on Radiological Protection (ICRP)--came some years later. (1-5)

The first quantitative recommendation for radiation protection, proposed by Mutscheller in 1925 was called tolerance dose and was expressed as 1/100 of a threshold skin erythema dose per month. (7) It was not until1934 that the threshold erythema dose was translated by the U.S. Advisory Committee on X-ray and Radium Protection (later the National Committee on Radiation Protection, or NCRP) into a dose measured in roentgens. The Advisory Committee expressed the tolerance dose, as it was then called, as 0.1 roentgen per day measured free in air. Some six months later, the ICRP, then known as the International X-ray and Radium Protection Commission, using the same data and information as that by the NCRP, adopted a value of 0.2 roentgens per day, also measured free in air. In 1948, the U.S. value was changed to 0.3 rem per week, a value also adopted by the ICRP when it was reorganized in 1950. (1-5, 7)

Until May 1941, all of the proposed numerical radiation protection standards related to radiation sources external to the body. This was, of course, because of the manner in which radiation was used in diagnostic and therapeutic radiology. The only deviation occurred when radium or radon in sealed tubes or containers, was inserted into body tissues to increase the exposure of the tumor under treatment. Since no radioactive material or radon gas was allowed to enter the body systems and tissue this, for all practical purposes, could be treated as an external source.

The first recommendation for dealing with the problems of radioactive material entering the body and the body systems were made by the U.S. Advisory Committee, which undertook a study in 1940 on the safe handling of radioactive luminous compounds. This activity followed recognition of the very serious injuries that were being incurred by radium dial painters, a problem about which increasing concern had been developing over the preceding decade. (8)

This committee made two critical recommendations. The first was an upper limit for the amount of radium that might be contained within the body (body burden) without producing unacceptable injury. In fact, the proposed level of 0.1 microgram of radium as a permissible body burden has not since that time been demonstrated to produce any ill effect on the recipient. Another milestone recommendation was designed to limit the radon content in the air of work places; it was recommended that the concentration not be allowed to exceed 10^{-11} curies per liter at any place, at any time. (8)

It was also in 1940 that the Advisory Committee recognized the possibility of irreversible genetic effects that might be caused by ionizing radiation and recommended a reduction in the tolerance dose by a factor of about 10. A report to this effect was adopted by the committee in 1940, and was to have been published in conjunction with the U.S. Public Health Service. By this time, however, most of the members of the Advisory Committee had become involved in war work and the recommendation ended up in a file not to be found until many years later. In any case, the genetics question was picked up immediately by the newly reorganized NCRP in about 1946. This will be dealt with below. (2)

In the meantime, the Manhattan Engineer District operations to develop the atomic bomb were organized in 1942 and everything connected with radiation became highly secret until after the war.

It is important to note that, from the outset, the atomic energy program adopted both the external protection standards established in 1934 and the radium protection standards recommended in 1941.

Interestingly the body burden standard for radium, as proposed in 1941, is today still regarded as acceptable. There are no known cases of individuals showing any kind of injury related to body burdens of radium of that amount or less. Also, because radium is primarily a bone seeker, its properties and its metabolism in the body were later explored as a possible pattern for the behavior of ingested or inhaled plutonium and strontium. A considerable portion of the discussion in the Tripartite Conferences centered around the possible parallels of radium and the other elements.

Since the early standards were only for external x rays and gamma rays, it was obvious that a number of entirely new types of standards would be required for alpha particles, neutrons and beta rays. While the dosimetry for neutrons had been studied before the war by Paul Aebersold and Robert Stone, it was not considered to be a satisfactory state at the time of the Manhattan Engineer District work. New philosophies and systems were developed by the project and were the subject of key discussions during the the Tripartite Conferences.

In addition to the three radionuclides mentioned above, there was, of course, the rapidly increasing number of other radionuclides having widely ranging properties, for each of which any possible medical effects would have to be evaluated. This, in turn, called for the acquisition of a large amount of entirely new data, the digestion of which was a major purpose of the conferences.

During the war years, there had been heavy research programs on the biological effects of radiation on animals. While this was probably concentrated more in the United States, there had been important work going forward in both Canada and England. In fact, some of the very early work carried out before the project was organized was done in England.

Collaboration between the countries occurred during the war, but it was severely hampered by security restrictions and the heavy manpower drain brought about by preoccupation with day-to-day aspects of war. Although communication was spotty and incomplete because of these largely political considerations, there was substantial cooperation between individuals.

II. Radiation Protection in the Immediate Post-War Period

Exchange of research information between the United States and the other countries during the immediate post-war period began slowly, still largely limited by difficulties in communications. Because travel was not easy and in some cases, just not possible, much of the exchange of information was personal, between colleagues who had known each other during the pre-war period. These included such individuals as Failla, Mayneord, Taylor, Gray, Parker, and Evans. They were the "old timers," but for each of them there were dozens of other people new to the field of measurement of, and protection against, ionizing radiation.

The U.S. Advisory Committee on X-ray and Radium Protection had remained relatively intact but, of course, small. Prior to the war, it had included practically all the interested persons in the country--a dozen in all--and their interests were primarily oriented to medical applications. Few of its members had been involved full-time with Manhattan District operations. Of those mentioned above, Parker was probably the only one engaged full time with the Manhattan District although most of the others were involved through various advisory or consulting arrangements. Taylor had become preoccupied in 1940 with the organization of an entirely different type of military research program and later spent a little over two years in Europe with the Air Force.

The ICRP had been almost completely decimated between its last meeting in 1937 and 1950, when it was reorganized. Of its original members in 1937, Rolf Sievert and Taylor alone survived, and neither had had any connection with atomic energy projects during the war.

The U.S. Advisory Committee was re-established and reorganized in 1946 as The National Committee on Radiation Protection. It maintained the same general organizational pattern; that is, a committee consisting of two representatives named by each organization participating in its work. These had been primarily radiological organizations, but after the war a number of other organizations joined the list of sponsors. They included the U.S. Public Health Service, the U.S. Atomic Energy Commission, the U.S. Air Force, Army, and Navy, and the Federal Civil Defense Administration. Each organization was entitled to name two members of the NCRP. In general the background of one was to be medicine, the other physics, chemistry, or similar field. Some of the AEC representatives were named from their national laboratories, thus providing a valuable source of communication, even though regarded as informal. Those individuals were aware of the security restrictions of their own organizations, but at the same time knew what they could discuss. This opened up entirely new possibilities in the field of radiation protection and measurements.

The Atomic Energy Company, Ltd., in Canada and the British Medical Research Council expanded their own organizations and carried out very valuable and active programs. They were less restricted than the Untied States with regard to issuing reports. As a result, when the Tripartite Conferences began, most of the specialized contributory reports seemed to have come from England. Those used as backdrops for the conferences are included in this volume.

III. Radiation Protection 1946 - 1949

It is suggested that an examination of this period of activity may benefit from direct reference to two more detailed sources. The first of these would be Radiation Protection Standards, published by the CRC Press in 1971. (1) This is a small book of about 100 pages, in effect a detailed outline for the forthcoming larger and more extensive treatment of the same material. The second source would be Organization for Radiation Protection: The Operations of the ICRP and NCRP from 1928 to 1974. (2)

The first meeting of the National Committee on Radiation Protection (NCRP) took place in December, 1946, at which time it was enlarged and organized into seven subcommittees. Subcommittee No. 1, dealing with radiation from external sources, working under the chairmanship of Dr. G. Failla, had the prime responsibility for developing the basic radiation protection philosophy for the NCRP. By June 1948 it had drafted a new report which contained most, if not all, the essential points that were covered in its final report, published in 1954. (See Appendix 2). Much of its work was carried out by correspondence, with only a few meetings. For the first time, a protection report dealt with the basic philosophy and biological reasoning involved in radiation protection matters. The new basic permissible levels adopted by the NCRP were later adopted essentially intact by the ICRP when it was reorganized in the summer of 1950. In the meantime, the new recommendations were well known to the AEC, as well as to the British and Canadian groups, and for all practical purposes were put into effect by the AEC in this country in early 1949. This rapid evolution could take place because the membership of the NCRP included scientists from the AEC. It later became a matter of general policy for the AEC to adopt and put into effect recommendations developed by the NCRP.

At the same time that Subcommittee No. 1 on radiation doses from external sources was organized, Subcommittee No. 2 was organized to deal with doses from internal radiation sources. This was under the chairmanship of Dr. K. Z. Morgan; coordination between the two committees was assured by some planned overlap in their membership. A major portion of the work of Failla's subcommittee was essentially in place by the time of the Chalk River Conference although some small adjustments in philosophical approaches were made as a result of the conference discussions. The first draft of Morgan's subcommittee was less far along at that time because of the complexity of the problems and the wide variety of radionuclides that had to be individually considered. The first full report of this subcommittee was published in 1953. It contained numerical values for the maximum permissible amounts of radioactive isotopes in the human body and the maximum permissible concentration in air and water for some 75 of the more important radionuclides. Much of the information feeding into this work derived from the Manhattan Engineer District research during and shortly after the war.

British information available at the time of the first conference dealt mainly with basic phenomena that had to be developed and understood before reaching general agreement on standards either for external or internal radiation sources. Primarily through visits during the late 1940s, between G. Failla, W. V. Mayneord, and L. S. Taylor, preliminary exchange of information and understandings contributed much to the general agreement on basic philosophies among the several countries.

As events developed, Subcommittee No. 3 on Medical X-ray Protection up to Two Million Volts was the first to issue a report after the war. This happened naturally; the subcommittee itself was a regrouping of one which had operated for over a decade before the war, and hence had a developed pattern for getting its work done. Its report in 1949 was the source of the first official release of the new basic permissible dose numbers proposed by the NCRP in 1946. This was a change in permissible dose from 0.1 R/day to 0.3 rem/week. Most other changes related back to that one. (2)

IV. The Tripartite Conferences

The initial conference held in Chalk River, Ontario, quickly reached agreement on the new permissible dose structure originally proposed by the NCRP and subsequently by the British Medical Research Council. It also accepted the concept of a permissible body burden and the value of 0.1 microgram of radium proposed by the U. S. Advisory Committee in 1941. Agreements on standards for the great host of new radionuclides were far more difficult to achieve, less because of basic disagreements than because of the newness and complexity of the problems of internal emitters. Tentative agreements were nonetheless reached on most of them.

However, following the Conference the laboratories of the three governments had to examine the recommendations in detail to insure their basic soundness and to assess impact upon operations, especially military. Some problems necessitating further study of a few radionuclides appear in correspondence between conference members. (See Appendix 25).

In July 1950, less than a year after the Chalk River Conference, the ICRP was reorganized in London and set up a subcommittee structure very similar to that of the NCRP. Since several conference members were also members of the new ICRP, a special session of the Tripartite Conference was organized by the British Atomic Energy Research Establishment at Buckland Hall, near Harwell. The attendees, acting in concert with the ICRP reached tentative agreement on maximum permissible body burdens for a dozen radioactive isotopes. These were published as a supplement to the 1950 ICRP report. (See Appendix 19).

It was an unusual but useful step in combining the interests of these governments with an international non-governmental organization. Since that time, a close but strictly unofficial collaboration had continued between them as well as other governments added later.

Nearly three years of study and research on the overall problems of standards for internal emitters of ionizing radiation followed the 1950 meeting. At the same time, Subcommittees No. 1 and 2 of both the NCRP and ICRP extended their early studies. The basic standards philosophy, oriented toward radiation from external sources, was sharpened and critically tested in practical operations. The number of radionuclides for which permissible doses could be prescribed, substantially increased and it appeared desirable to make a final examination of the situation in relation to both national defense and non-military applications.

It was under these circumstances that the third and last Tripartite Conference was held at Arden House, Harriman, N.Y. in March 1953. All studies of the past four years were critically reviewed. No major changes were made, but the conference achieved a much firmer sense of agreement and understanding about the overall problem of protecting people against harm from ionizing radiation. By then, better understanding of the radiation protection problem precluded expectations of absolute safety against harm to man. At the same time, assurance developed that radiation exposure of man could be kept within acceptable bounds, comparable with or superior to the many other risks that we all live with.

With this brief review of the background of radiation protection standards, it is now appropriate to proceed with the information prepared for or by the Tripartite Conferences.

V. The Appendixes

Material prepared in advance by the delegations--predominantly the United Kingdom--is included in Appendixes 1 to 26. Minutes of the conferences, prepared by the several delegations are covered in several appendixes. At the risk of severe repetition, verbatim copies of the minutes are included because there are some differences between them which may carry a significance not to be judged by this author. A listing of the available papers of concern to the conferees was circulated to all of the participants, together with a request for information on papers mentioned or referenced but not available. The response was slight (see Appendix No. 26).

It will, of course, be noted that amongst the various papers there is considerable inconsistency in the terminology used. No attempt has been made to correct these inconsistencies, since their existence gives some indication of the state of flux of our thinking during that period. An example would include such terms as tolerance, tolerance dose, permissible dose, maximum permissible dose, levels, dose, or amount, all referring to the same or similar concepts. Similar inconsistencies occurs in connection with units of radiation measurement, e.g., roentgen, R, r, rep, or rem. (It will be noted that the rad had not been officially introduced at the time of the final Tripartite Conference.) Also the terms, relative biological effect, relative biological effectiveness, etc., were variously used but it is believed without introducing any confusion or misinterpretation.

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8. Safe Handling of Radioactive Luminous Compound. Adv. Com. on X-Ray and Radium Protection, NBS, HB17. May, 1941. (Now listed as NCRP Report No. 5.)
9. Medical X-ray Protection up to Two Million Volts. NCRP Report No. 6. NBS, HB41, March 1949.

APPENDIX 1
PRELIMINARY MEETING (3-29-48)
Report on the United Kingdom, Canadian and United States Meeting
March 29 and 30, 1948

Representatives of the United Kingdom, Canada and the United States convened at the Atomic Energy Commission, Washington, D.C., to discuss various health and safety aspects of the Atomic Energy Commission program which are of mutual interest to these countries. The representatives were as follows: Dr. Loutit, Dr. Cipriani, Dr. Mitchell, Dr. Easton, Dr. Catchside, Dr. Shields Warren, Dr. Failla, Dr. L. Taylor, Dr. Bowers.

1. Tolerance Values - Considerable time was spent in discussing optimum values as to tolerance. It was agreed by all present that 0.05 R per day is preferable and that this could be expressed as 0.30 R per week. It is interesting that the Biophysics Section of the Division of Biology and Medicine of the Atomic Energy Commission and the United Kingdom group had independently agreed on this figure. Dr. Mitchell reported that the number of sperm was decreased in dogs with exposure to 0.10 R per day for one to two years. It was agreed that certain factors should always be considered in determining tolerance: (1) Effect on bone marrow with respect to blood count; (2) reduction of fertility; (3) genetic injury. It was further agreed that a factor of 5 should be introduced for fast neutrons when 50% of the ionization is produced by protons and other recoils.

2. Radioactive Isotope Work - It was agreed that one should consider the tissue which is liable to accumulate, the isotope in question and the relative sensitivity of the tissue. Perhaps a safe procedure is to assume all tissues have the same sensitivity and introduce safety factors as necessary.

It was agreed that the following problems needed clarification: (1) Relative effects of slow and fast neutrons; (2) effects of neutrons.

It was suggested that dogs be used as the experimental animal. It was agreed that the United Kingdom group would study fast neutron reactions.

Dr. Shields Warren reported verbally on the findings of the Atomic Casualty Commission. It was noted that the 3-week survivors had received approximately 500 to 600 R and that with radiation exceeding that level, there were no survivors. It was further noted that the heat extended further than the ionizing radiation; that with leukopenia below 1,000 per cubic millimter there was no recovery, and that the time required for hemotological recovery is quite variable. There were no osseous changes specific for atomic radiation in the skeleton other than growth scars compatible with any severe illness.

It was generally agreed that the conference was valuable to all participants.

John Z. Bowers, M.D., Assistant to Director, Division of Biology and Medicine

APPENDIX 2
U.S. PREPARATORY REPORT (9-49)
Preliminary Draft of Report of Subcommittee on Permissible Dose from External Radiation of National Committee on Radiation Protection
Prepared by G. Failla
September 1949

Introduction

In 1928 (1931?) the International Committee on X-ray Protection adopted 0.2 r/day or 1 r/week as the "tolerance dose". No statement was made as to whether the dose should be measured "in air" or on the surface of the body to include back-scattered radiation. Following local practice of x-ray dosage, in Europe and particularly in England, the tolerance dose was assumed to include back scatter, whereas in the United States it was taken to represent the dose measured in air. In all subsequent discussions of the problem by committees of American radiological societies and the Advisory Committee on X-ray Protection, it has been taken for granted that the tolerance dose was to be measured in air. The first specific statement to this effect appears in the 1946 "Safety Code for the Industrial Use of X-rays" prepared by the American Standards Association. Thinking in terms of air dose most of those concerned with the protection problem felt that 0.2 r/day was too high and since 1937 (?) the generally accepted value in this country has been 0.1 r/day. Bearing in mind that in the range of x-ray quality commonly employed, back scatter increases the skin dose considerably, the true difference between the British tolerance dose 0.2 r/day or 1 r/week measured on the skin and the American 0.1 r/day measured in air, becomes quite small and indeed irrelevant.

At the time that the 0.1 r/day value was adopted and for some years thereafter, the chief concern was the protection of radiologists and technicians operating "deep therapy" x-ray machines at voltages of about 200 kv. It was realized that exposure of the whole body to the lower voltage x-rays used for diagnostic purposes was relatively safer, but for the sake of simplicity no distinction was made and the same limit has been used for all qualities of x-rays (and gamma rays). In recent years, however, the situation has changed radically and a re-examination of the whole problem has become imperative.

In the first place, ionizing radiations other than x- and gamma rays have come into common use. The conditions under which persons can be exposed to radiation are more numerous and varied. The distribution of the radiation in the body - from external sources alone - may differ enormously; the radiation being limited to the surface of the skin in the case of ordinary alpha rays and being at a maximum in the internal organs of the body in the case of multi-million volt x-rays. Also, more is known about the biological action of radiation.

When the daily tolerance dose of 0.1 r was adopted, it was thought that this was a conservative value, involving a large factor of safety. Observation of persons occupationally exposed to radiation within this limit has revealed no deleterious effects of any kind attributable to radiation. However, the period of observation is not yet sufficiently long to be <u>sure</u> that exposure at this rate can be continued safely throughout life. The results of large scale experiments with mice and rats (and more limited experiments with other animals) lead to the conclusion that probably the factor of safety involved in the daily tolerance dose of 0.1 r, is not as large as it was thought at first. From the genetic point of view a revision downward is indicated because of the larger percentage of the total population now being exposed to radiation. An additional reason is provided by the large dose delivered to internal organs when the body is exposed to the very high energy radiations now available.

General Considerations

In setting up new limits of exposure, many practical factors must be taken into account. It is obviously true that the less the exposure, the better. This should always be borne in mind by those working with radiation, since in most cases it is within their power to minimize exposure by meticulous adherence to the principles of protection. Thus a worker should never allow his exposure to reach the prescribed limit, if he can avoid it. On the other hand, the limit cannot be set so low as to interfere seriously with important work. There is an element of danger in every human activity and it is unreasonable to expect complete immunity from harm in working with radiation. Be that as it may, the fact remains that in the present state of the art, any limit of exposure that is considerably higher than the background level of radiation must be considered to involve some element of danger - whether it is actually so or not. In other words, in the absence of factual knowledge of complete safety based on statistically valid observations extending over a number of generations, it is impossible to guarantee that lifetime exposure of the whole body to penetrating radiation at a level considerably higher than background radiation, is absolutely harmless. It is, therefore, necessary to assume that any practical limit of exposure that may be set up today, will involve some risk of possible harm. The problem then is to make this risk so small that it is readily acceptable to the average normal individual; that is, to make the risk essentially the same as is present in ordinary occupations not involving exposure to radiation.

The solution of the problem even on this more liberal basis is still difficult. Lack of extensive long term practical experience under controlled conditions, precludes an a priori accurate determination of the risk for any exposure level that may be adopted. The only thing that can be done at present is to adopt a value that in the light of all available information may be confidently expected to conform with the criterion of acceptable risk.

The acceptability of a risk by the average normal individual depends largely on the probability of escaping injury altogether. It is well known that susceptibility to radiation damage varies markedly among apparently identical members of a large group. Therefore, for any given type and degree of injury there is an exposure level that will produce such injury only in the most susceptible individuals. If the injury is of minimal degree, the others will not be aware of any injury at all. Accordingly, with a sufficiently low exposure level the probability of escaping injury altogether can be made very high. Since at present there is no way of determining in advance who is most susceptible to radiation, each individual has, in effect, the same chance of escaping injury as anybody else. Under these conditions and in this sense, then, the risk of radiation injury has essentially the same characteristics as more common risks readily accepted by the average normal individual in his ordinary pursuits.

There are, however, important differences that arise largely from: 1) lack of perception of the radiation by our senses, 2) long delay between exposure and manifestation of injury, 3) newness of the subject with consequent imperfect knowledge. There are also potent psychological factors that increase the fear of radiation injury beyond justifiable boundaries. These are based mainly on the tragic experience of the early workers with radiation and the effects of the atomic bomb on the Japanese - both of which have been dramatically publicized. All these factors help to create an atmosphere of mystery around the radiation protection problem and promote skepticism on the part of those not familiar with radiation effects. It may be well, therefore, to point out some pertinent facts.

The detailed mechanism of the action of ionizing radiation on the living cell is not known. This statement, which is often made, leads the uninitiated to think that if "nothing" is known about the "mechanism" very little indeed must be known about the effects of radiation on man. One should bear in mind the sharp distinction between knowing what happens and explaining how it happens. Nobody knows what life is or how it originated, but a great deal is known about the human body and its behavior in health and disease.*

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*To give a homely example, many people can be good drivers without knowing anything about the mechanism of the automobile engine.

There is at present a large body of information about the effects of radiation on living organisms and on man. Every living cell can be damaged and killed by radiation if the dose delivered to it is large enough. Many different kinds of effect have been observed and studied. All such effects can can be produced by any type of ionizing radiation provided it reaches the cell or organ in sufficient amount. Thus there is no uniqueness about any one type of ionizing radiation as to the kind of effect it will produce, although there is in some cases a difference in the dose required to produce a certain degree of effect by two different types of radiation. This is important because most of our information has been obtained from work with x-rays and can, therefore, be applied to other types of ionizing radiation by making suitable modifications of dosage. Even when the relative biological effectiveness is not known, one can make a conservative estimate of it to be on the safe side in the protection of personnel.

The advantage of being able to make use of the large body of information obtained with x-rays is very great. This type of radiation has been used extensively for the diagnosis and treatment of disease in man for about 50 years. Many doctors and technicians have been continually exposed to it for years. Some have suffered injuries of various types and degrees, leading to premature death in some instances, and some have shown no ill effects. There is, therefore, a very large background of practical experience based on observations made on human beings. In addition, there is, of course, a vast amount of information derived from experiments on laboratory animals and other living organisms.

As a matter of principle it is sound to avoid all unnecessary exposure to ionizing radiation, because it is desirable not to depart from the natural conditions under which man has developed by evolutionary processes. However, man has always lived in a field of ionizing radiation due to the presence of radioactive material in the earth and to cosmic rays. Whether exposure to this level of radiation is beneficial or deleterious to man (and the race) is a matter of speculation. The obvious fact is that it cannot be avoided and it is, therefore, normal for man to live in this environment. We have then a lower limit of continuous exposure to radiation that is (unavoidably) tolerated by man. There is, on the other hand, a much higher level of exposure that is definitely known to be harmful. In between these two extremes there is a level of exposure, - in the neighborhood of 0.1 r/day - which all experience to date shows to be safe, but the time of observation of large nubmers of people exposed at this rate under controlled conditions, is too short to permit a categorical assertion to this effect. It should be noted in this connection that lowering the level of exposure by a factor of two (as recommended later in this report) or even ten, does not alter the situation materially, insofar as making a positive statement of absolute safety is concerned. In strict scientific language, the only statement that can be made at the present time about the lifetime exposure of persons to penetrating radiation at a level considerably higher than the background radiation level, is that appreciable injury manifestable in the lifetime of the individual is extremely unlikely. Furthermore, on the basis of present knowledge it may be expected that if there should be any injury, it would manifest itself only in the most susceptible individuals. Obviously, the closer the level of exposure approaches the background level, the greater the probability that no injury at all will occur.

In the foregoing nothing has been said about genetic injury, for reasons that will be apparent presently. Ionizing radiations are capable of producing changes in individual genes and breaks in chromosomes in all nucleated body cells. The subsequent manifestations of these primary effects (when sufficiently marked) are generally deleterious to the individual in his lifetime and to future generations when they occur in the term cells. It has been shown experimentally that genetic changes can be produced with low doses of radiation. The frequency of occurrence increases linearly with the dose in the case of gene mutations and is independent of the duration of the exposure. In the case of chromosome breaks with subsequent abnormal union of some fragments (e.g. cross-over) the frequency of occurrence depends also on the dosage rate, within certain limits. It is evident that whether an individual is particularly susceptible or not, some injury of this type is unavoidable. Some cells in his body - including some germ cells - will be genetically altered. However, genetic changes <u>of the same kind</u> occur spontaneously and we are not dealing with a mysterious injury of an entirely new type. The main point is to control exposure in such a way that the eventual manifestation of genetic injury is not too large in comparison with the occurrence of spontaneous genetic abnormalities. Insofar as the welfare of the race is concerned (i.e. future generations) recessive gene mutations play the most important part. The controlling factor is then the number of undesirable genes (both spontaneous and radiation induced ones) present in the general population in which intermarriage occurs. It is, therefore, immaterial in this case whether in one generation the undesirable genes are present largely in a few individuals or are distributed throughout the population in correspondingly smaller number per individual. Accordingly, the amount of radiation received by the gonads of one individual up to the time of conception of the last child in his family, can be very large - provided that only a very small fraction of the whole population is exposed to this extent. Under present conditions and for some time to come, genetic damage manifestable in future generations is not a limiting factor in setting up a permissible level of exposure to ionizing radiation. For other reasons the level must be considerably lower than might be set on the above grounds. However, it is well to bear in mind that this factor assumes greater importance as the percentage of the population exposed to radiation increases. It is very desirable to initiate now a program calculated to decrease exposure of the gonads to radiation as regards both the number of individuals and the dose per exposed person. In many instances (e.g. radiological diagnosis) irradiation of the gonads can be avoided or greatly reduced with very little effort.

Considering new genetic damage manifestable in the lifetime of the individual or in the first generation offspring, it is obviously necessary to limit the exposure of <u>every</u> individual. Chromosomal damage in somatic cells may be responsible, at least in part, for radiation injuries that become evident in the lifetime of the exposed individual. Very little is known about this (which in essence has to do with the mechanism of the action of radiation) but a great deal is known about the observable effects themselves. For purposes of protection it is sufficient to choose a level of exposure that will effectively prevent the occurrence of the injurious effects no matter how they are produced. Genetic changes manifestable in the first generation offspring are of concern to the exposed individual, since his well being depends in no small degree on psychological factors in his family life. Sterility, still births and abnormal children may be produced by overexposure to radiation. Most of the information on these effects has been obtained from animal experiments, but it may be taken for granted that the same effects occur in man. However, practical experience indicates that undesirable effects of this nature are negligible in the case of radiologists and technicians who have been occupationally exposed to radiation - sometimes excessively, as shown by other more obvious injuries. It should be noted in this connection that sterility, stillbirths, and abnormal children occur in nature spontaneously or for reasons in which exposure to radiation plays no part. In any particular instance, it is, therefore, extremely difficult to attribute any such effect to radiation. All that can be said with definite assurance is that no obvious increase in sterility, stillbirths and abnormal children has been observed among those exposed to radiation even before the danger of overexposure was generally recognized.

Experiments performed with laboratory animals (chiefly mice and rats) show that exposure to radiation in sufficient amounts shortens the average life span. This has been found to be true under a variety of different conditions of irradiation, including daily exposures and single treatments. In all these experiments survival curves of the irradiated animals are compared with survival curves of a control group. Since there is always considerable biological variability, small differences in survival curves may occur in the control groups themselves. Hence small differences caused by exposure to radiation are obscured and cannot be considered significant. In order to establish small differences it is necessary to use very large numbers of animals (of the order of thousands rather than dozens) and to take many precautions. Since the number of animals used in such experiments has been too small, attempts have been made to extrapolate to smaller doses the results obtained with doses so large that significant differences could be established. Following this procedure it may be shown that an appreciable shortening of the life span occurs in mice and rats exposed daily to doses of x-rays in the neighborhood of 0.1 r. This extrapolation is questionable on at least two grounds: 1) The daily doses that gave significant shortening of the life span were ten to one hundred times larger. 2) Frequently the survival curve of animals actually exposed daily to doses of the order of 0.1 r was slightly above that of the control group, that is, the experimentally determined life-span was <u>longer</u> than for the controls. While in any case the difference is not statistically significant (because of the small number of animals used) the fact that it was plus or minus throws considerable doubt on the validity of the extrapolation.

Experimental data on life span obtained with other laboratory animals are quite fragmentary and extrapolation to low daily doses is even more uncertain. No quantitative information is available in the case of men. However, an obvious shortening of life has not been observed among radiologists and technicians who were poorly protected - at least in the early years of their careers - excepting, of course, those who developed cancer. The only available statistical study shows that the proportion of radiologists between the ages of 65 and 75 is essentially the same as in the case of other medical specialists.* This indicates that the exposure to x-rays to which radiologists have been subjected in the past has not shortened their life appreciably, if at all.

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*The percentage of 1595 full time roentgenologists and radiologists living in 1940 that had ages between 65 and 74, was 6.1. For orthopedic surgeons, proctologists, urologists, industrial surgeons, taken together, the corresponding percentage was 5.8. For obstetricians and gynecologists, it was 5.9. For pathologists, it was 6.0. The average for all specialists was 8.8%. "Mortality of Medical Specialists, 1938-1942" by Louis I. Dublin, Ph.D. and Mortimer Spiegelman, F.A.S., Journ. A.M.A.,August 21, 1948, Vol. 137, pp. 1519-1524.

Essentially the same situation exists in connection with the interpretation of other effects produced by continued exposure of the whole body to penetrating radiation. No matter what effect (e.g. body weight, blood count changes) - observable in the individual - has been studied by animal experiments, statistically significant differences have been obtained only when the daily dose has been considerably greater than 0.1 r. In the range of 0.1 r/day the differences may be plus or minus, which means that, if there is a difference at all, it must be small. Even if a small unfavorable difference were to be established by careful experiments using very large numbers of animals, the question would still remain as to whether the result is applicable to man. There is for one thing a big difference in the normal life span of man and laboratory animals and the problem of chief concern is one in which periodic exposure throughout adult life is involved. A daily dose that produces a given effect in measurable degree in rats may or may not produce the same degree of effect in man. The effect may be more marked or it may be less marked. Before the results of animal experiments can be extrapolated to man, it is necessary to derive certain generalizations that apply at least to different species of mammals, including animals with a long life span. This cannot be done at the present time and, from the nature of the problem, it is evident that many years will elapse before sufficient data are accumulated. In the meantime, it is best to interpret conservatively the existing information derived from animal experiments. Therefore, it must be assumed that it indicates the desirability of lowering the permissible daily dose for lifetime exposure of the whole body to penetrating radiation.

<u>Critical Tissues and Biological Criteria of Protection</u>

For the purpose at hand it is necessary to consider only injuries initially of a minor degree, since in the present state of the art no serious acute injuries should occur, except through accident or recklessness. Also, the case of most practical importance is one in which the exposure occurs at a slow intermittent rate over a period of years. In this group there have been many individuals who developed cancer of the skin definitely attributable to radiation. In all such cases the skin manifested typical radiation changes and cancer developed later - sometimes many years later - in one or more of the affected areas. It is important to note that in some cases the precancerous lesions were of a very minor character and the skin in the immediate vicinity had a practically normal appearance. It is also important to note that cancer develops (according to clinical experience to date) always in some area in which abnormal cell growth has been apparent for some time. Numerous such abnormal skin areas have been removed surgically and histological examination has established the fact that they were not cancerous. Other areas initially similar to these have been found to be cancerous.* A similar situation is known to exist as to the occurrence of cancer of the skin in

*It may be well to point out that some people with marked skin abnormalities caused by radiation, and of very long duration, have not developed cancer of the skin.

persons exposed to sunlight and dust in a dry climate (e.g. Australian farmers). Accordingly, it may be expected with confidence - justified by clinical experience - that if the exposure to radiation is insufficient to cause perceptible skin changes, no cancer attributable to radiation will develop at any time.

Mention has already been made of the fact that in some cases minor skin changes lead to cancer. Such changes in localized areas would hardly be considered objectionable in themselves by the average individual. Nor has the appearance of the rest of the skin in the exposed region (usually the hand) changed appreciably. The changes are objectionable because in susceptible individuals they may lead to the development of cancer of the skin. Therefore, insofar as the skin is concerned, the essential criterion of protection is prevention of cancer attributable to radiation.

Experience has shown that in badly overirradiated hands in which cancer finally develops, the neoplasm arises almost invariably in the skin (and is usually of the squamous cell type). In these cases, mainly radiologists who had done fluoroscopy for many years, the tissue dose in the bones of the fingers must have been considerably larger than in the skin, because of the small difference in depth and the much greater absorption by bone of the soft x-radiation used. Since it is known that radiation can produce bone tumors, it must be concluded that, under the conditions obtaining in these cases, skin is the critical tissue as regards the danger of eventual cancer formation, in the case of exposure of the hands. When the radiation is of such low penetrating power, that it is almost entirely absorbed by the skin, this organ is also the critical tissue, even for exposure of the whole body.

When the whole body is exposed to penetrating radiation, the relative radiosensitivity of different tissues and organs comes into play. Under certain conditions of exposure the distribution of radiation throughout the body could be nearly uniform, in which case the greatest primary damage from overexposure would occur in the most sensitive tissue. The manifestation of injury would not necessarily be in the same tissue or organ. In view of the delicate balance of biological processes that is required to maintain health and the complexity of these phenomena in the human body, it is impossible at the present time to appraise the relative importance of possible damage to different organs in relation to an overall deleterious effect of radiation. Nevertheless it is possible to decide what may be considered to be the critical tissue in the case of exposure of the whole body, on the basis of observations made on radiologists and technicians.

The incidence of leukemia in radiologists has been found to be considerably higher than in other physicians. While the number of cases is really too small to permit reliable statistical conclusions, other evidence (such as animal experiments and the well known high radiosensitivity of the blood forming organs) supports this finding. Therefore, it is well to assume that a causal relation existed in these cases. Since the exposure began many years ago, it is impossible to estimate the amounts of radiation received in their lifetime. However, in many cases the individual enjoyed normal health and was not aware of any injury (except possibly for skin changes caused by local overexposure) until the leukemia process started late in life. It may be concluded, therefore, that in susceptible individuals* leukemia may result from whole body exposure

*That is, "susceptible to radiation induced leukemia". Some of the radiologists had also marked skin changes on the hands of very long duration, but did not develop cancer of the skin.

to radiation in amounts too small to cause subjective indications of general radiation damage. Accordingly, in the case of whole body exposure to penetrating radiation it may be well to take prevention of radiation induced leukemia as the criterion of protection. The blood forming organs will then constitute the critical tissue in this case.

Considering the conditions under which the early radiologists did their work, it may be taken for granted that those who died of leukemia must have had significant alterations of the blood count at one time or another during the extended period of exposure - and long before the onset of the terminal disease. The question arises, however, as to whether radiation induced leukemia would eventually develop in susceptible individuals occupationally exposed to radiation in amounts so small that no perceptible changes in the blood count would occur beforehand. Considering the differences in blood count that exist among normal individuals and the marked fluctuations that normally occur in the same person, the answer to this question depends in no small degree on what constitutes a "perceptible change". Since fluctuations do occur for no apparent reason in non-exposed individuals, and changes caused by radiation are not unique, the only way in which a small change can be observed is by making tests at definite intervals during the period of occupational exposure and noting the trends of the counts of the different blood components.* This means that where the change becomes detectable some definite (albeit slight) alteration has occurred in the bloodforming organs. A smaller alteration would not cause a perceptible change in blood count, but it might be sufficient to produce leukemia later in susceptible individuals. Accordingly the question cannot be answered categorically at the present time. On the other hand, extremely few of the old radiologists and technicians have died of leukemia. It may be confidently expected, therefore, that when the exposure level is low enough to prevent perceptible changes in the blood count, no leukemia will develop.

*It should be noted that changes in blood count similar to those produced by radiation may arise from other causes, e.g. sulfa drugs. This makes more difficult the detection of change definitely attributable to radiation.

Dose of Ionizing Radiation and Unit of Dose.

In radiology doses of x-rays and gamma rays are expressed in roentgens, - this being the internationally accepted unit of quantity of x- or gamma radiation. However, a distinction is made between air dose and tissue dose. The former is determined as follows: Given a constant beam of ordinary x-rays, the dosage rate at the desired point in the center of the beam is determined by placing at this point a suitable measuring device, in air and without the presence of other solid material that might scatter radiation into the device. Let us say that the dosage rate thus determined is 20 r/min. If a patient is now placed in the path of the beam with the surface of the skin proximal to the source at the same point in the beam, and a treatment of 10 minutes is given, the air dose administered to the patient is 200 r. The tissue dose at the surface of the skin is larger because at the point in question there is now in addition radiation scattered backward by the patient's body. It might be 200 r or perhaps 300 r, depending on factors irrelevant to the present discussion. Since for the same air dose the skin dose may vary considerably, it follows that, other conditions being equal, the biological effect produced in the skin is related more directly to the skin dose than to the air dose. The same conclusion applies with more force to the dose obtaining at different depths in the patient's body, because the difference between air dose and tissue dose may be very large.

There is an implied assumption in this statement that requires elucidation. The assumption is that the effect on a particular tissue or organ is due entirely or largely to the tissue dose delivered to it. When the whole body is irradiated uniformly, innumerable changes can occur and it is conceivable that an organ may be damaged because some other organ does not function properly, or because some deleterious agent produced by the radiation has been released into the ciculatory system. If such were the case the effect in some hypothetical tissue would not be related to the tissue dose delivered to that tissue. While there must be interdependence among different body organs and tissues, the available experimental and clinical information indicates that the dose received by a tissue plays the predominant part in the effect produced in that tissue. However, this statement must not be interpreted too literally. For instance, a permanent change in blood count is not due to the dose received by the circulating blood but by the blood-forming organs. Be that as it may, there is direct experimental evidence to show that very large doses of beta rays administered to animals by external sources, produce marked damage to the skin without causing any changes in blood count. In this case the radiation is not penetrating enough to reach the blood-forming organs. In view of these considerations and remembering the great difference in penetrating power of all the different types of ionizing radiation to which people may be exposed nowadays, it is evident that the significant dose in the problem of protection is the tissue dose received by various organs and particularly the critical tissues.

It is important to note that dose (air dose or tissue dose) according to radiological usage, refers to exposure to radiation of a certain dosage rate for a certain length of time. The dose per se does not involve the size of the beam or, in other words, the area of the surface exposed to radiation. Accordingly, for the same dosage rate and time of exposure, the dose is the same whether one finger only, or the entire body, is exposed to the radiation. In therapeutic radiology this causes no difficulty because the complete specification of a treatment includes, among other things, the area of the irradiated field. It does, however, introduce certain complications in the protection problem. These will be clarified later in this report.

It should be noted, also, that the air dose - or skin dose for that matter - does not give any idea of the depth distribution of the radiation in the body, or part thereof, exposed to radiation. In this respect the tissue dose within any desired region is more specific and is much to be preferred for protection purposes.

In the case of x-rays and gamma rays tissue doses are expressed in roentgens. However, there is no internationally accepted unit for other ionizing radiations. It is probable that a unit based on energy absorbed, applicable to all ionizing radiations, will be adopted at the next International Congress of Radiology. Since it is desirable to make the magnitude of the new unit coincide with the tissue dose produced by one roentgen of ordinary x-rays in the predominant body tissues, it is probable that the future unit of tissue dose will represent an energy absorption of 93 ergs per gram of tissue. Tentatively such a unit may be called the "energy roentgen" or "ren" (r. energy) and may be defined as follows: The tissue dose at a point in a tissue exposed to ionizing radiation shall be one ren when the energy absorbed per gram of tissue at the point in question is 93 ergs. All tissue doses in this report will be expressed in rens according to this definition.

Permissible Dose.

The concept of a tolerance dose involves the assumption that if the dose is lower than a certain value - the threshold dose - no injury results. Since it seems well established that there is no threshold dose for the production of gene mutations by radiation, it follows that strictly speaking there is no such thing as a tolerance dose when all possible effects of radiation on the individual and future generations are included. In connection with the protection problem the expression has been used in a more liberal sense, namely, to represent a dose that may be expected to produce only "tolerable" deleterious effects, if they are produced at all. Since it is desirable to avoid this ambiguity the expression "permissible dose" is much to be preferred.

It is now necessary to give this expression a more precise meaning, irrespective of what values of the permissible dose will be recommended in this report. In the first place it is well to state explicitly that the concept of a permissible dose envisages the possibility of radiation injury manifestable during the lifetime of the exposed individual or in subsequent generations. However, the probability of the occurrence of such injuries must be so low that the risk would be readily acceptable to the average normal individual. Permissible dose may then be defined as the dose of ionizing radiation that causes no appreciable bodily injury to the average normal individual at any time during his lifetime. As used here "appreciable bodily injury" means any bodily injury or effect that the average normal person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well being of the individual. In general in this report permissible doses will be expressed in terms of tissue doses in the critical tissues, or as specified, and will be given in rems. In special cases alternative recommendations in terms of other units will be made.

Permissible Weekly Dose

Permissible weekly dose is the weekly dose of ionizing radiation that the average normal person may receive for the rest of his life without suffering appreciable bodily injury at any time during his lifetime.

Maximum Permissible Tissue Dose Limits in "Rems" per Week

Type of Radiation	At Any Point Within the Body	In the Basal Layer of the Epidermis	
		Exposure of Entire Body	Exposure of Hands Only
X-rays and Gamma Rays	0.3	0.5	1.5
Beta Rays	0.3	0.5	1.5
Protons (R.B.E.= 5)	0.06	0.1	0.3
Alpha Rays (R.B.E.=15)	0.02	0.033	0.1
Fast Neutrons (R.B.E.=10)	0.03	0.05	0.15
Thermal Neutrons (R.B.E.=5)	0.06	0.1	0.3

APPENDIX 3

U.K. - RADIOACTIVE CONTAMINATION OF DRINKING WATER (5-31-46)

NOTE ON NP/P/11

THE SAFE LEVEL FOR RADIOACTIVE CONTAMINANTS IN DRINKING WATER
by J. S. MITCHELL, Cambridge, 5-31-46

The establishment of a safe concentration of the radio-active effluents from the A.E.R.E. at Harwell is of extreme importance. No direct experimental evidence is available upon which to base the tolerance level. The only relevant information appears to be that dealing with the industrial toxicity of radium, the unpublished (confidential) experiments on the production of sarcoma of bones in animals by radio-strontium (Sr^{89}) and the natural β-ray activity of potassium in the body.

Probably the most important hazard to be envizaged from radioactive contamination of drinking water is the production of sarcoma of bone by the fission products Sr^{89} and $B_a{}^{140}$ + $L_a{}^{140}$ selectively absorbed over long periods of time of the order of 50 years. Great caution must be exercised because so little is known of other possible dangers.

The radioactive isotopes of interest fall into two groups from the pharmacological point of view:-

1. Those selectively absorbed in particular cells and tissues:-

   (a) bones, of which the most important isotopes are probably Sr^{89} and $B_a{}^{140}$, with which the daughter product $L_a{}^{140}$ is in transient equilibrium.

   (b) thyroid; where I^{131} will be selectively concentrated.

   (c) kidney and liver, e.g. Co^{60}

2. Those more or less uniformly distributed.
   Experiments on the absorption, excretion and distribution in tissues of all the fission products including the less common elements are urgently required.

It is agreed that there must be no plutonium in the effluent. It has also been stated that there will be no Co^{60} in the effluent.

Calculation of the safe level of Sr^{89} in Drinking Water.

It is assumed that all Sr^{89} taken in drinking water is deposited in bones; this assumption is probably true as a first approximation and is not likely to introduce a safety factor greater than 2.

Sr^{89} has a half-life of 55 days and emits a beta particle of maximum energy 1.32 Mev.

With any short lived isotope, such as Sr^{89}, the stationary amount in the skeleton corresponding to equilibrium between intake and decay and equivalent to a long-lived source is given by the relation:-

$$Vc = r\lambda$$

where V is the volume of water in litre taken per day
c is the concentration of radioactivity in the drinking water in Curies per litre.
r is the total effective stationary amount of radio-active material in the skeleton in Curies
λ is the disintegration constant in $days^{-1}$

Thus, introducing the half-life $T_{1/2}$ (days)

$$C = \frac{r}{V} \cdot \frac{0.693}{T_{1/2}}$$

The comparison of a short lived isotope with radium must be introduced with great caution from the biological point of view. It is commonly believed that 0.1 µgm. of radium stored in the skeleton is the threshold amount for safety. This value should be regarded as referring to a period of order of 20 years so that for the 50 year period envisaged, one should reduce the total stored radium by a factor of 2, i.e. to $\frac{1}{20}$ µgm.

This amount of radium is considered as uniformly distributed in the bone. As a first approximation only the radiations from the RaB RaC and RaE are effective, since the ranges of the alpha particles are of the order of 20 - 35μ in bone of approximate density 2 and the order of thickness of the thinnest trabeculae is 200μ. The mean range of the β particles from RaC is approximately 1.7 mms. in bone. It is assumed that much of the stored radium is ineffective because of the small contribution to the total absorption made by the living cells. A rough estimate of this proportion is given by the fraction of the mean range of the β particles spent in crossing spaces or Haversian canals, which can be estimated as of the order of $\frac{1}{5}$. This factor reduces the effective stored radium to be compared with, e.g. Sr^{89}, to $\frac{1}{100}$ μgm. It must be pointed out that the structure of adult bone is in a condition of slow turnover. For any element such as Ca, Sr, Ba or R_a, the most recently deposited atoms are in the superficial labile layers so that with a mean life of approximately 80 days, of the order to the total Sr^{89} present is effective. The total energy of the β rays from the R_a and its disintegration products is approximately 5.0 Mev, so that the total effective stationary amount of Sr^{89} in the skeleton corresponding to borderline safety:

$$r = \frac{5.0}{1.3} \times 10^{-8} = 3.8 \times 10^{-8} \text{ curies.}$$

The daily intake of drinking water is approximately 1.2 litres (2.1 pints), so that the borderline safe concentration of Sr^{89} in drinking water is given by:-

$$C = \frac{3.8 \times 10^{-8}}{1.2 \times 79} = 4 \times 10^{-10} \text{ curies per litre.}$$

This value contains no certain safety factor. I suggest that a safety factor of 10 should be introduced, so that it is reasonably certain that for Sr^{89}, 4×10^{-11} curies per litre of drinking water is afe.

Safe level for other selectively absorbed radioactive isotopes in drinking water.

For B_a^{140} of half-life 12.7 days with its daughter product L_a^{140} in transient equilibrium, the total beta ray energy is 2.6 Mev., so that the borderline safe concentration of $B_a^{140} + L_a^{140}$ in drinking water is given by:-

$$C = \frac{\frac{5.0}{2.6} \times 10^{-8}}{1.2 \times 18.3} = 0.9 \times 10^{-9} \text{ curies per litre.}$$

Again introducing a safety factor of 10, it is reasonably certain that for $Ba^{140} + L_a^{140}$, 1×10^{-10} curies per litre of drinking water is safe. Similar calculations for Co^{60} are rather uncertain, but on account of the long half-life of approximately 2,000 days, the borderline safe concentration may be 7×10^{-11} curies per litre. It is essential to introduce a safety factor of 10, so that for Co^{60}, 7×10^{-12} curies per litre of drinking water is probably safe.

In the case of I^{131} of half-life 8 days, no biological information is available on which to base calculations. I suggest that it is desirable that there should be no I^{131} in the effluent.

Calculation of the safe level for B-active isotopes which are uniformly distributed in tissues

It is evident that the β-ray activity due to K in tissues in a safe level for application to isotopes which are uniformly distributed within the tissues. The potassium content of human serum is 20 mgms. per ccs, of red blood corpuscles, 420 mgms per 100 ccs, and of striated muscle approximately 400 mgms. per 100 secs.

The naturally occurring radioactive isotope K^{40} is present to the extent of 0.023%; the half-life is approximately 4×10^8 years and the maximum energy of the β ray emitted is 1.3 Mev.

Thus, for serum, the number of disintegrations per litre per second

$$= \frac{2.4 \times 10^{-5} \times 6.02 \times 10^{23}}{40 \times 5.75 \times 10^{8} \times 365 \times 24 \times 60 \times 60} = 20$$

This corresponds to 5.4×10^{-10} curies per litre.

For human red blood corpuscles and striated muscle, the value is approximately 20 times as great, so that for K in tissues the safe level is 1×10^{-8} curies per litre.

Until much further biochemical information is available, it would be wise to introduce a safety factor of not less than 100 for fission products other than Sr^{89}, B_a^{140} or I^{131}, so that it is reasonably certain that the safe concentration is 10^{-10} curies per litre.

It is of interest to note that the natural radioactivity of river water is stated to be equivalent to

10^{-12} - 10^{-13} curies of radium per litre.

The results of the above calculations are summarized in the following Table:-

TABLE

Radioactivity in drinking water in Curies per litre

Isotope	Borderline Safety	Reasonably certain safety
Sr^{89}	4×10^{-10}	4×10^{-11}
$B_a^{140} + L_a^{140}$	0.9×10^{-19}	1×10^{-10}
Co^{60}	? 7×10^{-11}	? 7×10^{-12}
K	-	1×10^{-8}
Other fission products (except Sr^{89}, B^{140}, I^{131})	-	1×10^{-10}

CONCLUSIONS-

1. The safe level for Sr^{89} in drinking water is approximately 4×10^{-11} curies per litre.
2. The safe level for other fission products except I^{131} (and also excepting Co^{60}) is approximately 1×10^{-10} curies per litre.
3. Owing to the uncertainties of present knowledge and the serious nature of the hazards involved it would be unwise to exceed these values.
4. Experimental investigation of these problems is urgently required.

APPENDIX 4

U. K. - CARCINOGENIC EFFECTS OF INGESTED RADIOACTIVE MATERIALS (5-18-47)

MEDICAL RESEARCH COUNCIL

Research Committee on the Medical and Biological Applications of Nuclear Physics

IP/P/TD/18

Tolerance Doses Panel of the Protection Sub-Committee

Memorandum by Dr. A. Glucksmann on the Carcinogenic Effects of Ingested and Injected Radioactive Substances, 5-18-47

Patients suffering from chronic poisoning with radioactive compounds (Ra and Th) show as terminal clinical symptoms a regenerative anemia, bone necrosis, radiation osteitis and tumour formation in bones and air passages. A radium burden of the human body of 1 μ g or more is said to be fatal while concentrations up to 0.5 μ g did not produce any apparent harmful effects for a period of 7 to 25 years.

Table 1 gives a survey of the type of lesion produced by various doses of radioactive compounds in some human cases:

Table 1

Lesion	'Latent' period in years	Radium concentr. retained	Site of Radium deposit	Comments
Bone sarcoma (1)	6-10	6-50 μ g	whole body	Ra ingested
Bone sarcoma (2)	10	3-4 μ g	knee joint	Site of injection
Ca of antrum (3)	?10	2 μ g	skeleton	
Ca of lung (4)	?	7.5×10^{-6} μ g	lung tumour	Inhaled
Osteitis (5)	11	?	shoulder joint	Injected 3.64 μ g into joint
Spontaneous fractures (6)	?	2-3 μ g	whole body	Taken as radio-active water
Teeth trouble and pains (7)	?	1 μ	" "	" "
Anemia and local necrosis (8)	10	0.001 μ g + MTh 0.25 μ g	lesion	Intramuscular injection of 1 mg. ThX

Necrosis of jaws and an aplastic anemia was observed in a number of patients who died 'early' after poisoning with larger doses.

All the symptoms described in accidental human cases have been observed in animal experiments. Table 2 sets out the minimal carcinogenic doses for various species and for various forms of applications.

The necrosis of jaw bones which develops in patients and in experimental animals after the ingestion of Radium sulfate is thought to be correlated with the prevalence of infections at these sites.

In patients and in animals osteosarcomas develop in areas of radiation osteitis. The localisation of these tumours varies with the species and with the type of radioactive compound. Table 3 shows the percentage incidence of tumours in various parts of the skeleton.

Table 2

Species	Substance	Minimal dose µ g (total)	Form of Application	Type of lesion	'Latent' period in months
mice(1)	Thorotrast =	0.008 Ra	2 subcut. inj.	sarcoma	15-18
mice(2)	Ra	0.75	1 " "	osteosarc.	?
mice(3)	Sr^{89}	2.5 (µc)	" " (monthly)	"	23
mice(4)	Plutonium	0.5	1 " "	"	?
rats(5)	Thorotrast =	.024 Ra	2 " "	sarcoma	14.5
rats(6)	Ra	10.0	oral	osteosarc.	12
rats(7)	Ra	12.0	1 subcut. inj.	"	?
guinea pig(8)	Thorotrast =	0.04 Ra	4 " "	sarcoma	37
rabbit(9)	MTh	20.0	1 intrav. "	osteosarcoma	16
rabbit(10)	Ra	1.0	injected into bone marrow	"	23
rabbit(11-13)	Ra	100.0	oral	osteitis	3
rabbit(11-13)	Ra	100.0	"	jaw necrosis	9
rabbit(11-13)	Ra	100.0	"	spontaneous fractures	10

(The total dose is calculated for an assumed weight of 25 g of mice and of 200 g for rats)

Table 3

Species	Substance	Percent of all tumours in: (femur + (humerus	pelvis	spine	other bones
man(1)	Ra	40	30	0	30
rats(2)	Ra	20	27	53	-
rats + mice(3)(4)	Sr^{89}	70	30		
rats + mice(3)(4)	Plutonium	+	+++++		

In man as in experimental animals osteosarcomas tend to arise in areas of new bone formation subsequent to single or repeated fractures. Thus of 9 human cases of osteosarcoma following Ra poisoning two had spontaneous fractures and tumours at the site of these fractures. Two out of three rabbits injected intravenously with Ra produced tumours at the site of experimental bone fractures.

Shortly after the intake of radioactive substances all bones of the skeleton seem to show a fairly uniform degree of radioactivity. Subsequently the radioactive material is concentrated in areas of new bone formation such as the epi- and metaphysical region and bone tumours. The non-malignant areas of radiation osteitis have lost their Radium content owing presumably to the radiation-induced death of the bone cells and the consequent process of decalcification. Thus the initially uniform deposits of radioactive material are gradually transformed into discrete accumulations and external factors such as fractures and inflammations determine the localisation of the deposits and enhance their carcinogenic activity. This is well illustrated by the experiments with Thorotrast - injections in which the foreign-body reaction and inflammation increases the carcinogenic effect of the radioactive substances by a factor of 100. Chemical differences between the radioactive compounds (of Table 3) as well as the composition of the diet (Ca/P ratio for instance) may determine the degree of retention as well as the localisation of the radioactive deposits.

The available evidence of accidental human cases shows a surprisingly small gap between a lethal dose of 2 μg Ra (or possibly of even 1.2 μg) and the absence of ill effects from a whole body burden of 0.5 μg. Observations on human cases and on experimental animals demonstrate a wide variation in the local concentration of radioactive deposits and their dependence on external 'localising' factors. Thus in a rat with osteosarcoma 10% of the total Ra-content was found in a tumour weighing 1.5 g. The local concentrations of radioactive compounds are of paramount importance for their carcinogenic effect. A local concentration of ThO_2 equivalent to a Ra conc. of 0.008 μg is known to induce sarcomas in 30% of mice; the Ra content of a rat osteosarcoma weighing 1.5 g was 0.055 μg and was probably much less at the time of tumour induction; a fraction of a dose of 1 μg Ra introduced in a vaseline paste into the skull was sufficient to produce an osteosarcoma of the femur of a rabbit.

Whether the sensitivity of human tissue per cc of bone is the same as that of rodents is not known. Evans et al. have estimated that the human lung is 25 X more sensitive to the carcinogenic action of radioactive material than human bone and that man is 40 X more sensitive than rats and mice. This estimate may be of the right order since the concentration of Ra in a rat osteosarcoma is given as 0.055 μg while that of a human lung cancer is reported as 7.5×10^{-6} μg. Assuming that only a tenth of the Ra content was present in the rat osteosarcoma at the time of its induction and that the rest was accumulated during the growth of the tumour then a factor of about 1000 : 1 obtains between rat bone tumour and human lung tumour as estimated by Evans.

(A calculation of the relative sensitivity of man and rat to the carcinogenic action of radioactive material might be based on the following data: The ratio Ra/Ca in a patient with osteosarcoma was determined as 6.0×10^{-9} and that for a rat with osteosarcoma as 1.5×10^{-6}. The daily requirement of Ca (depending on the intake of P, Mg etc. is 600-700 mg for man and 40-50 mg for rats).

It is obvious, however, that the 'diluting' effect of the volume of the human skeleton as compared with that of rats and mice might be greatly reduced or even nullified by the counteraction of 'concentrating' effects of fractures and inflammatory processes. To arrive at a safe 'whole body tolerance dose' for radioactive substances, detailed information is required about the degree of variations in local concentrations and about the extent of the effects of external concentrating factors such as diet, inflammations and fractures.

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APPENDIX 5

U.K. - MRC TOLERANCE DOSES PANEL 9-17-48

MEDICAL RESEARCH COUNCIL

Research Committee on the Medical and Biological Applications of Nuclear Physics

NP/P/TD/71

Tolerance Doses Panel of the Protection Sub-Committee

MINUTES

Fourteenth meeting held at 38, Old Queen Street, London, S.W.1 at 10.30 a.m. on 17th September, 1948

Present:- Professor W.V. Mayneord (Chairman), Mr. W. Binks (Secretary), Sir Ernest Rock Carling, Dr. D.G. Catcheside, Sir John Cockcroft, Dr. E. F. Edson, Dr. L. H. Gray, Dr. J. F. Loutit, Professor J.S. Mitchell

Dr. G. Failla)
Dr. K. Fuchs) (by invitation)
Dr. A. Glucksmann)
Dr. H. Lisco)

Apologies for absence were received from Dr. E.R.A. Merewether and Sir Ernest Kennaway.

The Chairman welcomed Drs. Failla and Lisco to the meeting and expressed the hope that, as a result of the discussion on values for maximum permissible doses of various types of radiation, it might be possible for the U.S.A. and Great Britain to reach agreement.

14.1 Minutes of the thirteenth meeting (Paper NP/P/TD/67)

Amendment:-
Dr. Catcheside noted that, at the last meeting, it had been agreed to amend the words "deer mouse" (Minutes Paper NP/P/TD/65. Items 12.2 (b)) to "dormouse". The former was, in fact, correct.

With this amendment, the Minutes were approved and signed as a correct record.

14.2 Matters arising out of the Minutes

(a) Item 13.2(b)

The Secretary reported that sections of Dr. Catcheside's report (NP/P/TD/64) had been sent to Dr. Loutit for circulation to Professors Haldane and Waddington, prior to calling a meeting of geneticists.

Dr. Loutit believed it would be possible to arrange such a meeting in the near future.

(b) Item 13.2(d)

Sir Ernest Rock Carling reported that a letter had been sent to the Ministry of Supply concerning the strengthening of Health Physics teams at Harwell and at atomic energy production plants. An acknowledgment had been received from the Ministry.

(c) Item 13.3

(i) Sir Ernest Rock Carling reported that he had referred the question of possible re-organisation of the various Protection Committees in this country to the Second Secretary, Ministry of Health. The view of the Ministry was that this matter should be left in abeyance until after the appointment of the Statutory Committee under the Radioactive Substance Act.

(ii) Dr. Loutit said that the M.R.C. had not so far been able to find a suitable person to take over the secretarial duties of the Protection Sub-Committee and Tolerance Doses Panel. The Chairman thought that this was a matter of extreme urgency and asked the Secretary to see Dr. Landsborough Thomson, prior to the meeting of the Council that afternoon, and press for the appointment of a personal assistant.

(d) Item 13.4

The Secretary reported that Drs. Fuchs and Gray had, as requested, re-drafted sections of the "Draft Agreement concerning the Harwell Effluent". Copies of the final draft and of the covering letter prepared by the Panel had been sent by Sir Ernest Rock Carling to the Metropolitan Water Board, Thames Conservancy and Ministry of Health.

14.3 Correspondence

(a) The Secretary reported that Dr. Landsborough Thomson had raised the question of preparing summaries describing the factors governing the safe dosage of different individual radioactive isotopes. After consultation with the Chairman, he had replied that, whilst the Panel had in mind producing a report on this matter, it was felt that there was still a lot of work to be done in establishing the basic figures and the Panel would prefer, at this stage, to avoid drawing up safe dosage limits for individual isotopes.

Dr. Gray said that values were required for clinical research. The Chairman said that he was reluctant to issue separate figures but suggested that the Panel intensify its efforts to produce a summary. This was agreed.

(b) The Secretary reported that Dr. Fuchs had confirmed a request he made at the last meeting that, in order to complete the design of the chemical plant for the extraction of plutonium, Harwell would like to know the maximum permissible concentrations of certain volatile fission products in air.

The Panel agreed to deal with this matter as soon as possible.

(c) The Secretary reported that a number of requests had been received by Harwell for a value for the maximum permissible concentration of thorium in the atmosphere. Dr. Loutit had referred this matter to the Panel.

It was agreed to deal with this at a future meeting

(d) The Secretary said that, subsequent to the circulation of the Agenda for the meeting, Dr. Loutit had submitted a memorandum on the "Tolerance level of Co^{60} in drinking water". The Secretary had informed Dr. Loutit that he would circulate the document (NP/P/TD/69) but felt that there would be no opportunity to discuss it at the forthcoming meeting.

Dr. Loutit said that his main desire at this stage was that the document should be brought to the notice of the Panel, so that it might be prepared to arrive at decision at a future future meeting.

(e) The Chairman stated that he had received a memorandum from Dr. Glucksmann, commenting on R.D. Boche's paper M.D.D.C.204 on "Observations on populations exposed to chronic röntgen radiation". The Chairman said there were one or two points he would like to take up with Dr. Glucksmann prior to the circulation of the document to the Panel.

14.4. Discussion on maximum permissible doses

(a) Total body irradiation by X and γ rays

The Secretary briefly summarised the correspondence between U.S.A. and this country regarding the maximum permissible dose of X and gamma rays from external sources. Subsequent to the last meeting of the Panel, the Chairman and he had drafted a letter for Sir Edward Mellanby to send to Dr. Failla, bringing the following points to his notice.

(1) The M.R.C. Protection Sub-Committee was very desirous of reaching agreement on a basic figure, particularly as there seemed to be no clear cut evidence to enable a firm decision to be made as between 0.5 and 0.3r. per week.

(2) The Sub-Committee explicitly recommended that the dose of 0.5r. per week should be measured on the surface of the body, that is, by implication, with backscatter. It was understood that the American figure referred to measurements in air. Accordingly the total energy absorbed in the body would be substantially the same in the two cases.

(3) The Sub-Committee noted that, whereas its recommendation extended to 5 MeV radiation, the American figure extended only to 2 MeV.

(4) The Sub-Committee had particularly in mind the problems of industrial radiology and thought that, in this field, the lower figure might involve some hardship.

Dr. Failla had reported that the difference between the figures adopted by the two groups was more apparent than real, and that the British interpretation that the American figure of 0.3r. per week applied to measurements in air was correct. His Committee had not made any final recommendations but were, at present, reviewing the whole situation. He agreed with the proposal that he should discuss these matters fully with the M.R.C. Tolerance Doses Panel during his forthcoming visit to England.

The Chairman then invited Dr. Failla to open the discussion.

Dr. Failla said that his group proposed to accept the weekly dose, and asked whether the Panel agreed to express the basic figure in terms of weekly dose. This was agreed. Dr. Failla then presented the American claim that dose measurements in air were better than measurements with backscatter. He said that, in practice, surveys were made of the radiation at various points in radiological plants. The Chairman suggested that measurements on the individual workers were more significant. Sir John Cockcroft felt that it would be difficult to control the exposures of individual members of any organisation on the basis of spot measurements in the laboratories.

Dr. Failla contended that the ultimate aim was to base measurements on tissue dose and not on air dose. That raised the question as to which tissues would be regarded as the most critical. The American view was that the blood-forming organs should be regarded as the critical mechanism. The Panel agreed with this view.

Dr. Failla said that a decision had then to be made as to the maximum permissible dose which should be given to the blood-forming organs. This might be 0.5r. per week as measured on the skin or 0.3r. per week as tissue dose in bone marrow, but measured in air. He suggested that a figure of 0.3r. or r.e.p. per week be taken as the permissible dose in bone marrow. Professor Mitchell considered that it was better to think in terms of air dose and integral dose, but Dr. Failla believed that this would lead to complications at high voltages, say, 20 MeV. It was decided, however, that high voltage problems must be considered separately.

The Chairman said that, from the point of view of the physicist, bone marrow was one of the worst sites to choose. Dr. Lisco proposed that the lymph nodes, which are more accessible and might be more sensitive, should be considered. They also might simplify matters for the physicist. Dr. Failla said that lymph nodes were included in the term bone marrow.

Dr. Fuchs pointed out that experimental measurements do not give the dose in tissue but give either the dose in air or on the body. Dr. Gray preferred to think in terms of mean dose rather than integral dose since the latter was dependent on the weight of the individual. It seemed to him that the two countries had come to almost the same conclusion about the permissible limit. He thought it feasible, therefore, to express the dose on the basis of either 0.5r. on the skin or 0.3r. in air.

The Chairman asked whether the policy was to have a statement based on simplified conditions or whether complex conditions should be introduced. Sir John Cockcroft maintained that complex conditions should be avoided. Dr. Failla pointed out certain difficulties in adhering to a simple statement, e.g., a woman working with 20 k.V. X rays might sue for sterility if she received 0.4r. when the recommended limit was 0.3r. Yet in this case the radiation could not reach the ovaries. Dr. Fuchs submitted that a simple statement was required even if, in some cases, workers were over-protected. Dr. Failla believed it was desirable to base the legal dose on tissue dose, but, Dr. Loutit contended that the permissible dose should be based on scientific fact and not on the legal aspects. Dr. Failla suggested that tissue dose is the scientific basis. The American group believed that the dose should not exceed 0.3r. per week at any point within the body, with one exception, namely, skin.

Dr. Fuchs said that, if tissue dose is used, conversion factors were introduced twice. That is to say, the basic figure for tissue dose had to be derived from measurements in air or on the surface of the body. Subsequently it would be necessary to apply conversion factors to the figure for tissue dose in order to have practical figures on which to base measurements in air or or on the body. Dr. Gray said there are tremendous difficulties in the case of points in tissue close to bone. It would thus be necessary to keep the surface dose below 0.3r. There did not, however, appear to be any hazard by specifying the basic figure either as 0.5r. on the skin or 0.3r. in air. Dr Glucksmann pointed out that, if tissue dose were accepted on the basis that the most critical tissue was bone marrow, it would be necessary to specify which bone marrow was comtemplated.

Dr. Lisco agreed with the view that, for operational problems, it was better to have a simple specification. Dr. Failla said that it appeared practical to express permissible dose in terms of air or surface measurements and to convert to tissue dose rather than to specify the dose in terms of tissue dose.

Dr. Lisco asked the Panel whether they had any views on the best position on the body for the film badges. Dr. Gray thought it best to wear the film above the sternum. Mr. Binks said that, in the N.P.L. film service, it was recommended that the films be carried in the breast (or waistcoat) pocket. At Chalk River, he had observed that the practice was to carry the film badges on the waistband. He felt that, in many instances, the lower part of the body was better protected than the upper part e.g. by benches, and therefore thought that the film should be worn in a position which would give some indication of the highest level of whole body irradiation.

Returning to the question of maximum permissible dose for X and γ rays, the Chairman suggested using the double statement, i.e., 0.5r. per week on the skin and 0.3r. per week in air. Somewhere in the text of the accompanying notes it should be stated that we were interested most in tissue dose, but that circumstances were so complex that it was necessary to measure either on the skin or in air.

As regards the maximum of the energy range covered by such a definition, Dr. Failla said that U.S. had avoided any reference to a maximum of 2 or 3 MeV. Professor Mitchell suggested a ceiling of 2 MeV. It was, however, felt desirable to adopt a maximum which would include the γ rays from Ra (+C) and accordingly the Panel agreed to fix the maximum at 3 MeV. It was also agreed to treat the high-voltage problem separately. Furthermore it did not necessarily follow that the permissible limit for high-voltage radiation would be expressed in terms of the röntgen.

It was agreed that the Chairman and Secretary should meet Drs. Failla and Lisco to prepare a draft definition.

(b) Irradiation of the hands by X, γ and β rays.

Turning to the question of irradiation of the hands by X and γ rays, Dr. Failla said that the U.S. proposed to allow a factor of about 3. Accordingly they recommended a permissible dose of 1r. per week measured in air. If the same factor was adopted, the British figure would be 1.5r. per week measured on the skin. Professor Mitchell asked whether it was proposed to group β rays with X and γ rays. Dr. Failla said that, if β rays are included, it is necessary to specify where they are measured, since they may be absorbed by an inert layer of skin. Professor Mitchell stated that he allowed a factor of 10. Dr. Gray asked what was the experimental basis for the factor 3. Dr. Failla replied that there was none. Sir John Cockcroft enquired whether it was based on observations on personnel, to which Dr. Failla replied that it was, but that the measurements in the early days were not accurate. Mr. Binks said that in the handling of radium containers the dose on the hands (γ rays and secondary β rays) was many times greater than the dose on the body. It was possible to get doses up to 10r. even though the total body dose was below the accepted limit.

Dr. Lisco suggested that, if there were two different sets of standards, one for total body irradiation and the other for the hands, difficulties might arise. Dr. Edson remarked that if there were two standards, it would involve the use of two films. Mr. Binks said that in many instances, the wearing of films on the hands would lead to a false result. For example, in the case of workers with radioactive luminous compound, dust would settle on the film envelope each day and, whereas the operators would wash their hands several times a day in accordance with the regulations, the powder would accumulate throughout the week on the film wrapping, and produce a blackening which did not correspond to the actual dose received by the hands.

Dr. Fuchs enquired whether industrial processes could be designed so that the dose on the hands was known. Dr. Edson said that this was not feasible, as there was very little repetitive work. Mr. Binks also draw attention to the impossibility of assessing, in advance, the doses received by the hands in diagnostic radiology.

The Chairman asked whether the position of the film on the hands could be specified and a monitoring procedure laid down. Dr. Edson, however, criticised the compulsory monitoring of fingers. He said that films, worn in the form of signet rings on the fingers, would trap radioactive matter. Dr. Loutit suggested that pilot operations might be carried out and radiation tests made. Dr. Gray thought this was desirable in the case of certain operations where high intensities were involved and exposures would have to be short.

Referring to the question of the relative sensitivities of skin and of the blood-forming organs, Dr. Lisco said that experimental evidence indicated there was an absence of skin cancers in animals exposed to Ra rays. The animals actually died from other malignancies. As regards the question of the similarity or otherwise of the skin of the mouse and of man, Dr. Lisco said that he believed that the ducts of the sweat glands in the dermis were very sensitive. Doses higher than those under present consideration had been found to bring about metaplastic changes in nine days. These particular sites were about as sensitive as the lymph nodes. In his opinion, the factor of 3 was not too conservative.

Sir John Cockcroft asked whether practical evidence on the doses received by the hands could be obtained from selected workers, using signet-ring films. He suggested that some of the Chemists at Harwell might be selected. Meanwhile he thought it unwise to introduce into the regulations a value for the permissible dose for the hands until more evidence had been obtained. Dr. Gray and Professor Mitchell maintained that the hazard could not be ignored.

The Chairman felt that it would be a great advantage if the Panel could agree with the U.S. group on this matter. Accordingly, Dr. Failla proposed a value of 1.5r. per week, as estimated in the basal layer. This, he pointed out, would involve agreement as to the depth in the basal layer. The Americans had specified a thickness of 7 mg per sq. cm., but they did not know whether this was correct. After some discussion, it was agreed to define the dose as 1.5r. per week with backscatter in basal layer of the epidermis.

Dr. Loutit asked whether any work was in progress at Los Alamos on metaplastic effects of other radiations. Dr. Lisco replied that the work in progress included investigations on a large number of animals on the effect of γ rays on the life span. Studies of skin effects had been incidental to other work. Dr. Loutit asked whether any experiments on man were being planned. Dr. Lisco said that he hoped to get pieces of skin from colleagues who had been given known doses of radiation. He suggested that valuable information could be obtained from patients undergoing radiotherapeutic treatment. He made a strong appeal for the use of clinical material. Dr. Glucksmann said he had used this material for some years. For single doses below 200r., there were no skin effects. He had used 200 k.V X radiation, γ rays from radium beam units and β rays. Dr. Failla said that there were several cases of injury of persons who received radiation for cosmetic purposes. Some 15 years later, these persons had developed cancer of the skin. Sir John Cockcroft asked what doses these people had received. Dr. Failla said it was not easy to say but they may have had about 500 r. of soft X rays.

Dr. Lisco said that Dr. Barrett Brown (St. Louis) had presented a large amount of clinical evidence on skin effects. Skin sensitivity for low voltage X rays was very great indeed. In view of all this evidence. Dr. Lisco regarded the figure of 1.5r. per week for X and γ rays as generous. He asked Professor Mitchell for his views. Professor Mitchell replied that he took the same view as Dr. Glucksmann. The skin was much less sensitive than other organs. He asked whether Dr. Lisco had any information on March's work on leukemia. Was it known how many skin cancers? Dr. Lisco said he did not know. Pathologists were not normally interested in skin and accordingly very valuable material was probably lost.

(c) Total dose during the lifetime

The Chairman asked Drs. Failla and Lisco whether there were any other items on which agreement might be obtained, e.g., the total dose during the life-time of a worker. Dr. Failla said that, from the genetic point of view, they had suggested that the total dose be restricted to 300 r. He would like to have Dr. Catcheside's view on this. Dr. Catcheside said that it depended on the fraction of the population involved. If the fraction was 1% or less, it would be alright. He thought, however, that the value for the total dose should be based on physiological effects on the individual and not on the racial genetic effects. Dr. Gray asked whether Dr. Failla's figure referred to air dose, and whether therefore the British figure should be 500r. with backscatter. Dr. Failla said the value was 300r. on the skin. It was agreed that this was a reasonable value, but it was generally felt that there was no need to make any regulations at this stage.

Dr. Edson asked whether the total dose was 300r., irrespective of sex. Dr. Failla said that they had not differentiated between the sexes. Mr. Binks thought that the fixing of a life dose might lead to difficulties when a decision had to be made on the future career of a man who had received the recommended total. As this was linked with genetic effects, the question as to whether the person was married or likely to have any further children would have to be considered. Dr. Fuchs considered that these matters are taken into account in the statistics.

It was agreed not to put forward any recommendation about life dose at the present stage.

(d) Radium and other radioisotopes in the body

Dr. Glucksmann asked whether Dr. Failla had any figures for radioactive substances in the body. Dr. Failla said that, in the case of radium in the body, the accepted limit was 0.1 μg. Professor Mitchell wondered whether this was too high. Dr. Gray believed it was. He would not like to recommend subjecting the population to drinking water which would increase the incidence of osteogenic sarcoma by more than 20%. This meant that Ra, in drinking water should not give rise to an incidence of more than 1 in 10,000. The evidence which Dr. R.D. Evans had

APPENDIX 6

U. K. - HAZARD OF INGESTED RADIUM (1948)

MEDICAL RESEARCH COUNCIL

Research Committee on the Medical and Biological Applications of Nuclear Physics

- -

NP/P/TD/73

Tolerance Doses Panel of the Protection Sub-Committee

A CONSIDERATION OF THE HAZARD ASSOCIATED WITH THE INGESTION OF RADIUM TOGETHER WITH A RECONSIDERATION OF THE DERIVED ESTIMATES OF THE PERMISSIBLE CONCENTRATION OF PLUTONIUM AND STRONTIUM IN DRINKING WATER

by
L.H. Gray

SUMMARY

It is suggested that when large sections of the population are at risk the basic figure for the permissible amount of Radium fixed in the skeleton should be lowered by a factor of 100, from 0.1 μgm to 0.001 μgm. On this basis, the permissible concentrations of Pu and Sr in drinking water are computed to be 3.10^{-17} C/ml and 4.10^{-15} C/ml respectively compared with the Panel's present figures, $1.6.10^{-16}$ C/ml and 4.10^{-14} C/ml respectively. Since previous calculations of the permissible discharge of radioactive material into the Thamës at Harwell include in effect an additional safety factor of 10 by employing in the calculations the minimum dry weather instead of the mean flow of the Thames, the adoption of the proposed figures for the maximum permissible concentration of material in drinking water would not call for any revision of the agreement which has been entered into between Harwell and the Metropolitan Water Board.

I. INTRODUCTION

The hazards associated with the ingestion of radium, strontium and plutonium have been discussed in a number of the Protection Committee and Panel's papers, notably NP/P/11 ("Note on the Safe Level for Radioactive Contaminants in Drinking Water" by J.S. Mitchell); NP/P/TD/10 ("Carcinogenic Action of Some Substances which may be a Problem in Certain Future Industries" by A.M. Brues, H. Lisco and M. Finkel); NP/P/TD/17 ("Notes on a Discussion with Dr. A.M. Brues" by J.D. Cockcroft); NP/P/TD/18 ("The Carcinogenic Effects of Ingested and Injected Radioactive Substances" by A. Glucksmann); and NP/P/TD/59 ("The Harwell Effluent" by K. Fuchs). The numerical assessments which have been made of the permissible concentration of these elements in drinking water, namely,

Strontium (NP/P/TD/22 and NP/P/TD/27

The total activity of Sr^{90} and Y^{90} in equilibrium in drinking water should not exceed 4.10^{-14} Curies/cc.

Plutonium (NP/P/TD/40)

The activity of plutonium in drinking water shall not exceed $1{\cdot}6.10^{-16}$ Curies/cc.

are effectively based on the following assumption:-

Radium (assumed basic tolerance)

It is considered that a radium burden of 0.1 μgm Ra fixed in the skeleton may be carried indefinitely without significant likelihood of injury.

This basic figure for radium has not so far been critically examined by the Panel. It has generally been adopted as the basis of estimates of Sr and Pu hazards in the U.S.A. and appears to be derived from statements made by Robley Evans epitomising the conclusions reached by himself and his colleagues from a survey of cases of radium poisoning in man, in which definite information is available as to the amount of radium fixed in the body. The data, together with two general statements which were made by Robley Evans at the Panel meeting on 20th June, 1947, as to the expected incidence of osteogenic sarcoma at the 5 μgm and 1 μgm level are given in the first three columns in Table I.

TABLE I

Analysis of 24 Cases of Radium Poisoning

together with generalisations by Robley D. Evans

Radium Burden	Period under Observation	Robley Evans' Assessment	Percentage Sarcoma Incidence Computed on the Assumption that 0.1 μ gm gives an expectation of 1.4%
5-20 μgm	?	Several deaths from radium poisoning. Numerous cases of osteogenic sarcoma and other disorders.	75%
5 μgm	?	"Fatal in almost every case"	50%
1-2 μgm	8-15 years	3 Radiation Ostoitis	19%
		1 Osteogenic sarcoma and generalised bone necrosis	
1 μgm		"Osteogenic sarcoma in a reasonable percentage of cases"	14%
0.05-0.5 μgm	7-25 years	No observable abnormality	2%

It is proposed that the assessment of osteogenic sarcoma incidence due to radium ingestion in humans is best made by considering the analysis of the 24 human cases of radium poisoning for which data have been given by Robley Evans, and interpreting these in the light of the two generalisations from animal experiments, formulated by Brues, Lisco and Finkel, namely

(a) Probability that a sarcoma shall be induced within a given period is proportional to the administered dose.

$$P \propto \text{Dose}$$

(b) Probability of sarcoma incidence by the end of a given period is proportional to the square of the time after the end of the latent period, which itself depends to a small extent on the dose.

$$P \propto (t - t_0)^2$$

Robley Evans himself summarised his data by saying: "We feel that 1 μ gm of radium in the body is likely to produce osteogenic sarcoma in a reasonable percentage of cases" and again, "5 μgm was fatal in almost every case". The right-hand column of Table I shows that these two statements are mutually consistent and a fair summary of the data in the light of the proportionality between tumour incidence and dose observed by Brues, Lisco and Finkel. The data as a whole are consistent with an expected incidence of 1.4% (or 1 : 71) due to 0.1 μgm Ra fixed in the body for a period of time for which Robley Evans' cases have been under observation (7-25 years). In view of the second generalisation of Brues, Lisco and Finkel, the expectation would be much higher if the radium is carried by the skeleton for a normal life span.

A 1% probably incidence of osteogenic sarcoma may possibly be regarded as an insignificant industrial hazard but it would seem to be inadmissible as a hazard to which a large section of the population might be exposed, as a result of drinking slightly active water.

II. THE ASSESSMENT OF THE PERMISSIBLE EXPOSURE OF A LARGE SECTION OF THE POPULATION

The natural incidence of osteogenic sarcoma is about 1 : 100,000 of the population per annum, or 1 : 1670 per generation (60 years). It is proposed that an exposure which does not raise the natural incidence by more than 20% should be regarded as "permissible". That is, exposure to radium should not in itself give rise to an expectation of incidence of osteogenic sarcoma of greater than 1 : 5 X 1670 or 1 : 8400.

We *infer that the evidence available indicates that* 0.1 μgm Ra *fixed in the skeleton over a* period of not more than 25 years will give rise to a sarcoma incidence at least $\frac{8400}{71}$ or 120 times greater than that which can be regarded as "permissible". Accordingly, it is suggested that this tolerance should be reduced by a factor of 100 to 0.001 μgm Ra fixed in the skeleton as the amount which may be permitted to be carried for periods of up to 15 years. It is to be noted that this allows no provision to cover additional hazards which may arise from (a) a possibly greater susceptibility of children as compared with adults or (b) the influence of inflammatory reactions, fractures, etc., in causing local accumulations, the importance of which has been emphasised by Glucksmann (NP/P/TD/18).

Deduction as to the Permissible Concentration of Radium in Drinking Water

Data employed:-

The total amount of radium fixed in the skeleton is not to exceed 0.001 μgm.

Water intake - 4 litres/day.

Of the radium taken into the body 5% goes to the bones (Morgan - "Tolerance Concentrations of Radioactive Substances", J. Phys. and Colloid Chem., 51, 984, 1947).

The effective (biological) half life of radium in bone is 10 years (Morgan).

If C_{max} is the permissible concentration of radium in drinking water in gms/ml. then at equilibrium

$$C_{max} \times 4.10^3 \times 365 \times 0.05 - 10^{-9} \lambda$$

where λ is the effective decay constant in years.

Hence,

$$C_{max} = \frac{10^{-9}}{4.10^3 \times 365 \times 0.05} \times \frac{\cdot 693}{10} \text{ gms/ml}$$

$$= 0{\cdot}95.10^{-15} \text{ gms/ml}$$

In connection with this estimate the following points may be noted:-

(1) Intake of Ra through drinking slightly active water is likely to result in a gradual increase in the total burden carried, three quarters of equilibrium being reached in about 20 years. In a normal individual nearly the whole burden could therefore be carried for a period of 40-50 years. In most of Robley Evans' cases a large initial dose was administered, most of which would be excreted in a few weeks, and throughout the much more limited period of observation (7-25 years; average, say, 16 years) the burden would be falling. If a latent period of ∿ 8 years is postulated, the difference in the duration of the burden could, according to Brues' square law, result in the drinking water hazard being greater in the ratio $\frac{(45-8)^2}{(16-8)^2}$ or 22.

(2) Radium, once located in bone, may not be excreted at a rate represented by the assumed half life of 10 years. If it is assumed that there is no excretion, and that the relevant quantity is the burden accumulated by the age of 40, the permissible concentration in drinking water would have to be reduced by a factor of $40 \times \frac{\cdot 693}{10}$ or 2.8.

(3) No allowance has been made for the possible greater susceptibility of children or for the influence of inflammatory reactions, fractures, etc.

Considerations (1) and (2) amount to an adverse factor of 62. Allowance for (3) cannot as yet be made numerically. On the other hand, if the present recommendations are regarded as provisional only, to cover a five year period, only about one-third of the ultimate burden will have been accumulated (assuming excretion) or one-eighth (assuming no excretion) before the recommendations are reconsidered.

It is therefore proposed that an overall safety factor of 10 be introduced, reducing the figure $0{\cdot}95.10^{-15}$ gm/ml arrived at above by direct calculation to 10^{-16} gms/ml.

The following is therefore proposed for discussion:-

That for a five year period only, a provisional figure of 10^{-16} gm Ra per ml of drinking water be agreed as permissible, and that the corresponding figures for Sr and Pu be derived from this, taking into account the available estimate of relative toxicity, uptake and excretion of these elements.

Deduction as to the Permissible Concentration of Sr^{90} in Drinking Water

Ancillary data:-

Sr is intrinsically 10 times less hazardous than an equal number of microcuries of Ra (Brues - NP/P/TD/10).

Of the total Sr taken into the body 7.5% goes to bone (Morgan).

The effective (biological) half life of Sr^{90} is 197 days (Morgan).

Let C_{max} be the concentration in Curies/ml of Sr^{90} in drinking water which will accumulate at equilibrium an amount equal in hazard to 10^{-9} gms Ra.

Then

$$C_{max} \times 4.10^{3} \times 0{\cdot}075 = 10 \times 10^{-9} \times \lambda$$

where λ *is the effective decay constant in days.*

Hence

$$C_{max} = \frac{10 \times 10^{-9}}{4.10^{3} \times 0{\cdot}075} \times \frac{{\cdot}693}{197}$$

$$= 1{\cdot}2.10^{-13} \text{ Curies/ml.}$$

It is important to note that if the Sr which reaches the bones were not, in fact excreted at all, the burden would be greater than that calculated by a factor $\frac{40 \times 365 \times {\cdot}693}{197} = 52.$

Moreover, if the effective half life is 197 days, as assumed, the equilibrium burden will be effectively established within the 5 year period under consideration, by contrast with radium in which only one-third or one-eighth of the burden would be built up in this period.

It is therefore suggested that in addition to the safety factor of 10 introduced in the case of radium, an additional factor of 3 should be introduced, reducing the permissible concentration of Sr^{90} in drinking water to $\frac{1{\cdot}2.10^{-13}}{30} = \underline{4.10^{-15} \text{ Curies/ml.}}$

Deduction as to the Permissible Concentration of Pu in Drinking Water

Ancillary data:-

1 μgm Pu ($0{\cdot}063$ μC) is equivalent in hazard to 1 μgm Ra (Brues).

Of the Pu taken into the body by mouth it is estimated that $0{\cdot}03\%$ is deposited in the bones (Morgan).

The effective (biological) half life in bone is $\sim$ 10 years (Morgan).

If C_{max} is the permissible concentration of plutonium in drinking water in gms/ml, then at equilibrium

$$C_{max} \times 4.10^{3} \times 365 \times 0.0003 = 10^{-9}\lambda$$

$$C_{max} = \frac{10^{-9}}{4.10^{3} \times 365 \times 0.0003} \times \frac{{\cdot}693}{10} \text{ gms/ml} = \underline{1{\cdot}6.10^{-13} \text{ gms/ml}} = \underline{10^{-14} \text{ Curies/ml}}$$

The circumstances of accumulation are similar to those which obtain in the case of radium. Some allowance should, however, be made for uncertainty in the toxicity equivalence of Ra and Pu, and for uncertainty in the degree of absorption from the gut. The relatively high figure arrived at for the permissible concentration in drinking water results from the allowance for absorption from the gut, the figure for which is derived from animal experiments. It seems wise to allow factors 3 and 10 respectively for the two uncertainties mentioned, in addition to the general safety factor of 10 applied in the case of radium. We therefore arrive at the estimated permissible concentration of Pu in drinking water $\frac{10^{-14}}{3 \times 10 \times 10} = 3 \cdot 10^{-17}$ Curies/ml

Calculation of the Amounts of Ra, Sr and Pu which might be discarded into The Harwell Effluent consistent with the proposed permissible levels in Drinking Water

Previous calculations of the permissible discharge into the Thames at Harwell have been based on the estimated minimum dry weather flow of the Thames of $2\frac{1}{4} \cdot 10^{11}$ ml/day. The average flow is reported to be about 10 times as great as this. In view of the fact that the hazards under consideration are such as might arise through the drinking of active water over a period of many years, it seems an unnecessary restriction to use the figure for dry weather flow if safety factors have already been introduced into the calculations. If the figure $2 \cdot 10^{12}$ ml/day is adopted as the estimated mean flow of the Thames at Harwell, the discharge figures which would be consistent with the computed permissible concentration in drinking water are

Radium	$10^{-16} \times 2.10^{12}$ gms/day	= 0·2 mC/day
Strontium^{90}	$4.10^{15} \times 2.10^{12}$ Curies/day	= 8 mC/day
Plutonium	$3.10^{-17} \times 2.10^{12}$ Curies/day	= 60 µC/day

The proposals made in this memorandum are compared with the previous recommendations of the Panel in Table II.

TABLE II

Basic Figure for Radium Fixed in the Skeleton			Provisionally Accepted	Proposed
			0.1 µgm	0.001 µgm

	Permissible Concentration in Drinking Water		Maximum Daily Discharge into Harwell Effluent	
	Former Panel Recommendation	Now Proposed	Former Panel Recommendation	Consistent with Drinking Water Tolerance
Radium	-	10^{-16} gm/ml	All α Activities other than Natural U and Po 20µC	200 µC
Plutonium	$1 \cdot 6.10^{-16}$ C/ml	3.10^{-17} C/ml		60 µC
Strontium^{90}	4.10^{-14} C/ml	4.10^{-15} C/ml	2¼ mC	8 mC

APPENDIX 7

U. K. - MRC. DEFINITION OF MAXIMUM PERMISSIBLE DOSE (10-22-48)

MEDICAL RESEARCH COUNCIL

Research Committee on the Medical and Biological Applications of Nuclear Physics.

NP/P/TD/76

Tolerance Doses Panel of the Protection Sub-Committee.

REPORT

Meeting of Chairman and Secretary of the Panel with Dr. G. Failla on 20th September, 1948.

Purpose To draft a definition of the maximum permissible dose for whole body irradiation by X and γ rays from external sources, and to discuss future procedure with regard to recommended values for permissible doses of other types of ionising radiations.

Action It had been agreed at the meeting of the Panel on 17th September, 1948 that, as a basis of agreement between U.S.A. and Great Britain, the maximum permissible dose for whole body irradiation by X and γ rays from external sources should be fixed at either 0.5 r per week measured on the surface of the body or 0.3 r per week measured in air. It was also agreed that the maximum of the energy range to be covered by the definition should be 3 MeV.

Following further discussion with Dr. Failla, it was agreed to modify the definition previously put forward by the Panel (see memorandum dated 5.5.48 and also paper NP/P/37) to read as follows:-

The Panel is of the opinion that, in circumstance in which the whole body may be exposed over an indefinite period, to X or gamma radiation of quantum energy less than 3 MeV, the maximum permissible dose received by the surface of the body shall be 0.5 röntgen in any one week. This corresponds substantially with a dose of 0.3 r of X or γ rays measured in air and delivered to the whole body in any one week.

Dr. Failla thought it unlikely that his Committee would adopt the same phrasing but he would recommend that, in addition to specifying the dose as 0.3 r per week measured in air, they should also give the alternative form, namely, 0.5 r per week measured on the surface of the body. Prior to the 6th International Congress of Radiology, it might be possible to achieve agreement on the phrasing, and the definition could then be submitted for international adoption.

It was agreed that the explanatory notes should include some reference to "tissue dose."

As regards the maximum permissible dose of X, γ and β rays on the hands it was agreed to base the definition on a value of 1.5 r per week (with backscatter) at the basal layer of the epidermis.

Dr. Failla promised to let the Panel have a copy of the final U. S. draft, but pointed out out that further amendments may not then be possible. He will, however, attempt to guide his Committee along lines which will lead to definitions which are substantially in agreement with the British views. The Chairman also undertook to keep Dr. Failla informed of important decisions of the Tolerances Doses Panel.

22.10.48

APPENDIX 8

U.K. - INAPPLICABILITY OF BRUES LAW (11-25-48)

NP/P/TD/81
T.D.G. 52
HS 1333

THE INAPPLICABILITY OF BRUES LAW FOR THE INCIDENCE OF SARCOMA IN THE TOLERANCE RANGE

BY
K. FUCHS

AERE, Harwell
11-25-48

1. INTRODUCTION

In two papers (NP/P/TD/11 and NP/P/TD/73) L. H. Gray has derived maximum permissible doses for the ingestion of various activities, including strontium and radium. Gray uses for this purpose the law proposed by Brues, Lisco and Finkel that the incidence of osteogenic sarcoma is proportional to the dose and the square of the time elapsed after a latent period.

The use of this law in the tolerance range involves such a large extrapolation from the range of doses with which Brues, Lisco and Finkel were concerned, that it appears appropriate to query the justification of such a procedure. It is the purpose of this note to examine the validity of Brues law in the light of the available evidence at low doses. It is found that Brues law is contradicted by the available facts.

Brues appears to have been very reluctant to express any opinion about the extrapolation of his law to low doses (NP/P/TD/17). Gray also emphasised the uncertainty of such an extrapolation, but employed it since it appeared to be one of the few pieces of available evidence, which - however slender its support - should not be disregarded. The present paper is not intended to criticise this attitude, but to produce definite evidence against the validity of Brues' law in the tolerance range.

The first contradiction arises from a comparison of the incidence of sarcoma for the 24 human cases reported by R. D. Evans with the natural incidence and the natural Ra content of the human body. Extrapolation from the 24 cases by means of Brues law to the natural Ra content gives an incidence about 10 times larger than the natural incidence, which in turn may be due only in part to radioactivity.

The second contradiction arises if the mice experiments on which Brues law is based, are extrapolated to the human life-time and low doses. In the case of Sr 89 a direct comparison with extrenal γ-radiation and cosmic radiation can be made; in order to get reasonable results it is necessary to assume strongly non-uniform distribution of the activity; however in view of the long range of the β-rays from Sr.89, this assumption would in fact not assist in explaining the contradictions.

At the end of the report, we include a brief discussion of the implications of the hypothesis that radio-activity might accumulate in fractures. This is not part of the discussion of Brues' law, since the evidence referred to above is independent of the exact mechanism by which the damage is done. The discussion is included, because the fracture theory has been used as additional independent support for the extremely low tolerance doses which result from the application of Brues' law.

2. Brues' data on mice

Brues summarises his data on the treatment of mice by monthly doses of Sr 89 by the following formula:

(1) $\frac{dP}{dt} = Kd\ (t - t_0)$ $\qquad K - 1.5 \times 10^{-3}/\text{day}^2 = 200/\text{year}^2$

(2) $t_0 = K_1\ (- \log_{10} d)$ $\qquad K_1 = 200 \text{ days} = 0.55 \text{ years}$

Here d is the dose of Sr.89 expressed as a fraction of the lethal dose, and dP/dt is the fraction of mice developing sarcoma per unit time (i.e. P is the fraction of mice which have developed sarcoma up to the time t).

Integration of (1) gives the formula used by Gray

(3) $P = \frac{1}{2} Kd\ (t - t_0)^2$

The monthly repetition of the dose was required in Brues' experiments owing to the decay of Sr.89 by nuclear disintegration and by biological elimination. For our purposes we may assume that d is approximately a constant amount of Sr.89 in the mouse.

The times extended to periods of the order of several months and the doses from about 1/100 to 1/10 lethal dose. The lethal dose is given as 8μ curie per gram of total body weight.

If the formula is applied to man (total body weight 70 kg) and the dose D is expressed as the total number of μ curie in the body, we obtain.

(4) $P = \frac{1}{2} H D (t - t_0)^2$

(5) $H = 200/70 \times 10^3 \times 8 = 3.6 \times 10^{-4}$ /year^2/μ curie

Brues states that his formula also applies to Ra, and 10 μ curie of Sr.89 is equivalent to 1 μ curie of Ra. Hence H for Ra is ten times larger.

3. Analysis of 24 human cases

L. H. Gray has indicated that the 24 human cases reported by R. D. Evans are consistent with the formula

(6) $P - \alpha D$, $\alpha = 0.14/$ μ curie

If linearity with dose is assumed, and if the 24 cases analysed by Evans are a representative sample, then α must be of this order of magnitude. It should however be pointed out that the data are insufficient to prove linearity with the dose.

4. The natural incidence of sarcoma

The natural incidence of sarcoma is 6×10^{-4} per individual, and most cases occur between 15 - 20 years of age.

If it is assumed that this is due to the natural Ra content in the human body (the smallest quoted value is 1/1000 μ curie) one obtains

(7) $\alpha = 0.6/$ μ curie (t = 15 - 20 years)

5. Superficial consistency of data

Applying Brues' formula to the conditions under para. 4 and 5, the latent period is about 3 - 4 years. Taking $t - t_0 = 15$ years one finds

(8) $\alpha = \frac{1}{2} H (t - t_0)^2 = 1.8 \times 10^{-3} \times 15^2 = 0.4/$μ curie ($t \sim 18 - 19$ years)

in good agreement with the value (7).

If on the other hand we take $t - t_0 - 60$ years, we find

(9) $\alpha = 6/$μ curie ($t \sim 64$ years)

Extrapolating Gray's value (periods of observation from 8 - 15 years) in a similar fashion one finds

(10) $\alpha = 4 - 20/$μ curie ($t \sim 64$ years).

These data appear to be in superficial agreement. In particular the agreement with Brues mice formula is impressive, since it involves an extrapolation by many orders of magnitude.

6. Discrepancy between Gray's α-value and the natural incidence

The first discrepancy arises if we consider the α-value for a life time derived from the natural incidence. Since the natural incidence has a peak at 15 - 20 years, it must be assumed that adults are less sensitive so that the decrease in sensitivity outweighs the increase in incidence due to the square law in exposure time. Hence the α-value for adults at about 60 years is not more than 0.6 /μ curie. Gray's value is at least ten times larger.

Thus, if we extrapolate Gray's value by means of Brues' law, we are led to the conclusion that the natural radium content of the human body gives rise to a natural incidence of sarcoma 10 times in excess of the observed value. The latter includes sarcomas from all causes and therefore the discrepancy is larger than a factor 10.

If the analysis of the 24 human cases is accepted as admissible evidence, it follows that Brues' law is not valid in this range.

7. Critic of Brues' formula for Sr.89

If D μ curie are spread over the skeleton (10 kg) the resultant dose is

(11) $D \times 10^{-6} \times \frac{1}{2} R/10^4 = 5 \times 10^{-11}$ DR curie MeV/gm $= 3 \times 10^{-3}$ DR roentgen/day

The factor ½ represents the average energy of the β-rays and the factor R is introduced to allow for non-uniform distribution of the activity.

External irradiation by γ-rays of the same intensity must give rise at least to the same effects.

If I is the intensity of γ-rays in roentgen/day, it follows that the resultant incidence of sarcoma for a life time is (compare formula (9) and reduce by factor 10, since we are dealing with Sr)

$$\alpha > \frac{0.6}{3 \times 10^{-3} R} \text{ /(roentgen/day)}$$

(12) $\alpha > \frac{200}{R}$ /(roentgen/day)

For the accepted maximum permissible dose of 0.07 roentgen/day the incidence would be

(13) $P > \frac{14}{R}$

Since it has been accepted after careful consideration of the available evidence that in the conditions stated the incidence of sarcoma is exceedingly small, it follows that R must be very large indeed.

The incidence to be expected from cosmic radiation (about 1 milli roentgen/day) is

(14) $P > 0.2/R$

In order to reduce this value below the natural incidence we require

(15) $R > 300$

It should be noted that this value of R must apply to the starting point of our argument, i.e. Brues' experiments with mice.

In view of the long range of the Sr.89 β-rays (maximum range = 3/4 cm) such a value of R is impossible.

8. The fracture theory

That R must be very large has of course been recognised by those who proposed that even very small doses of Ra could give rise to an intolerable increase in the incidence of sarcoma and it has been proposed that in this case the large value of R is due to accumulation of the activity in fractures.

This hypothesis does not affect the conclusions drawn above. In the case of the mice experiments with Sr 89 local accumulation of the activity has little effect, since the β-rays have a long range (quite apart from the fact that the fracture theory is unlikely to be sound from these short term experiments). In the case of Ra our argument rests on a comparison of the 24 human cases with the natural radium content. The times of exposure are of the same order in both cases and the fracture theory if applied at all should be applied to both. Our argument rests only on the assumption that the conditions in the two cases are comparable; it does not depend on whether the fracture theory applies.

Nevertheless it may be convenient at this stage to point out some implications of the fracture theory, since it has been quoted as independent support in favour of very low tolerance values.

The first question which arises is whether the activity remains permanently fixed or stays in the fracture only until it is healed. In the latter case local accumulations would occur only for relatively short periods and consequently the effect is greatly reduced. (It would furthermore lead to the conclusion that the fracture theory and Brues' t^2 are incompatible for times exceeding the time of healing, i.e. several weeks).

The fracture theory therefore could lead to an appreciable effect only if we assume that the activity remains more or less permanently fixed. If that is correct for the activity in fractures, it is difficult to see why it should not apply to activity in other parts of the bone. It follows that only the activity which is absorbed by the human body during the period of healing is accumulated in the fracture.

Thus the fracture theory could lead to a serious increase in risk only if the total tolerance amount is absorbed in a relatively short time and if in addition the activity has a long half life.

If we are concerned with short lived activities, or with the intake of activity spread over many years, the possibility of accumulation in fractures does not appear to constitute a serious additional hazard.

A.E.R.E.
Harwell

APPENDIX 9

U.K. - TOLERANCE AMOUNTS OF Ra, Sr AND Pu. 11-26-48

NP/P/TD/82
T.D.C. 53

HS 1334

THE TOLERANCE AMOUNT OF Ra, Sr AND Pu IN THE HUMAN BODY

by

K. Fuchs, AERE, Harwell
11-26-48

1. The tolerance for Ra

The radiation intensity from $\frac{1}{20}$ μ gramme of radium at uniform distribution over the skeleton is

$$\frac{1}{20} \frac{10^{-6} \times 5}{10^4} = 2.5 \times 10^{-11} \text{ curie MeV/gm}$$

$$= 1.5 \times 10^{-3} \text{ rep/day}$$

Here only the α -energy of the Ra disintegration has been taken into account. The first product Rn has sufficient time to spread appreciably (in fact about 45% is lost by exhalation, R.D. Evans, NP/P/TD/45). The later products have either a very short half-life or else they are isotopes of Po (3m RaA, 138d Po 210), Pb (27m RaB, 22 y RaD) or Bi (20m RaC, 5d Ra E). These elements should all be expected to behave similar to Pb.

Pb is believed to be deposited in the bone; contrary results with the Pb isotope ThB have been reported in the FIAT series. It was found that the main concentration is in the blood, liver, and kidney; the concentration in the skeleton was lower.

In order to be on the safe side we shall assume that half the decay products remain in the skeleton. This gives a total decay energy of 20 MeV (instead of 5 MeV), resulting in a dose rate of 6×10^{-3} rep/day.

It may be argued that this is too close to the maximum permissible dose and that a safety factor for non-uniform distribution should be allowed. However we are concerned with several different isotopes, which should produce a more uniform distribution, even if each single isotope is not distributed uniformly. Furthermore we shall produce evidence below that the biological efficiency is probably over-estimated and we have therefore in fact a safety factor in hand.

2. Evidence from human cases

It may be noted that the smallest dose for which osteogenic sarcoma has been reported by R. D. Evans is one μ gramme, and no observable abnormality was found in several cases ranging from 1/20 - ½ μ gramme which have been under observation for periods ranging from 7 to 25 years.

Admittedly the number of cases analysed by R. D. Evans is too small to prove conclusively that an incidence of the order of one in a thousand could not occur at the proposed level. However, this is only negative evidence, and provided we keep well below the level at which sarcoma has been observed, we should rely on other evidence.

Finally it should be noted that a tolerance level of $\frac{1}{10}$ μ gramme has been operative in the radium industry for many years; a statistical survey in the U.S. has shown that a good percentage of workers exceeded this limit; these were taken off the work. However, a fair percentage of those remaining must evidently have come close to the limit.

Since protective measures have been improved in the course of time, it must be assumed that many of the older workers have come close to or have exceeded the limit. It would seem strange that not a single case is on record when either doctor or patient has connected a sarcoma with previous employment in the Ra industry, unless such cases did in fact not exist.

3. Evidence from Brues mice experiments

Brues has found in his experiments with mice that 10 curie of Sr89 is equivalent to 1 gm of Ra. One should have expected a ratio of 100:1, since the energy release from Sr 89 is 10 times smaller and the biological efficiency of Ra is ten times larger. If the daughter products of Ra are included the factor should be 400:1.

In view of the long range of the β-rays from Sr 89 (maximum 3/4 cm) it is impossible to account for the discrepancy by assuming non-uniform deposition of Sr 89. This suggests that the biological efficiency of Ra is appreciably less than 10, possibly due to absorption of the α-particles in radiation insensitive parts of the bone.

It is therefore concluded that the assumption of a factor 10 for biological efficiency coupled with the assumption of uniform distribution is pessimistic by a factor 10, or by a factor 40 if in addition allowance is made for the daughter products. These arguments show that the tolerance of 1/20 μ gram does in fact contain a large safety factor.

4. The tolerance for Sr 89

Turning from mice to men it is conceivable that deposition of Sr 89 at the end of a long bone might lead to non-uniform irradiation. In view of the short half-life of Sr 89 (55d) most of the activity present at any given instant has entered the skeleton a relatively short time ago, and since Sr is deposited preferentially in the growing parts of the bone, non-uniform distribution is to be expected. We shall allow a factor 10 for this effect.

It should be noted that the accumulation of Sr 89 will gradually shift position whilst the bone grows and we are therefore concerned with irradiation for fairly short periods. A considerable safety factor is therefore introduced by applying the standards for a continuous irradiation for a life time. (This favourable factor evidently is not apparent in experiments which utilise doses in the lethal range).

The resultant maximum permissible amount is 2 μ curie, which at uniform distribution is equivalent to a dose rate

$$\frac{2 \times 10^{-6} \text{ curie } 0.5 \text{ MeV}}{10^{4} \text{ gm}} = 0.05 \text{ roentgen/week}$$

$$= 10^{-10} \text{ curie MeV/gm.}$$

5. The tolerance for Sr 90

If we are concerned with the intake of a tolerance amount of Sr 90 within a relatively short time, the arguments for Sr 89 apply. A correction is to be applied for the smaller energy and also for the shorter range.

This correction factor is

$$\frac{0.65 \text{ MeV}}{1.5 \text{ MeV}} \quad \frac{7.5 \text{ mm}}{2.5 \text{ mm}} = 1.3$$

Assuming that the daughter product Y 90 has the same distribution the correction factor is

$$\frac{2.2 \text{ MeV}}{1.5 \text{ MeV}} \quad \frac{7.5 \text{ mm}}{12 \text{ mm}} = 0.9$$

The total correction factor is the sum of these two, i.e. 2.2. The maximum permissible amount is therefore 1 μ curie.

If however we are concerned with a continuous intake extending over a life-time, we should expect a more uniform distribution. It is suggested that in this case a factor 5 for non-uniform distribution is ample and the maximum permissible amount for this case is then 2 μ curie.

6. The tolerance for Pu

The evidence for Pu consists essentially of Brues result that weight for weight Pu is as effective as Ra in producing lethal effects in 30 days. The lethal dose for death in 150 days on the other hand was 5 times larger in the case of Pu. Since the half-life of the two activities is in the ratio 15, this implies that for equal activity Pu is 15 times more efficient than Ra in producing lethal effects in 30 days and 3 times more efficient in producing lethal effects in 150 days.

The change from 15 to 3 could be explained either by a more favourable re-distribution of Pu in the course of time, or by the assumption that we are concerned with the superposition of two effects, one of which is more important at high doses and the other more important at low doses. In either case we are playing safe in assuming the factor 3. Since we allowed a factor 4 for the decay products of Ra, this assumption implies a total factor 12 for non-uniform distribution of Pu (in fact the factor is nearer 15, since $\frac{1}{20}$ μ gram of Ra was still below the maximum permissible level).

It is therefore suggested that the maximum permissible amount of Pu is $\frac{1}{60}$ μ curie or ¼ μ gram.

Again we should expect a more uniform distribution for a continuous intake. However, since the evidence in the case of Pu is more restricted than the available evidence for Ra and Sr, it is suggested that the factor 15 be retained as a safety factor.

In the case of Ra we have produced evidence to show that $\frac{1}{20}$ μ gram does in fact give rise to irradiation appreciably below the maximum permissible. Since the suggested Pu tolerance is based on a comparison with Ra, it follows that the resultant radiation dose is also appreciably below the maximum permissible. It is an open question, whether this implies that the safety factor for non-uniform distribution is excessive, or that the most plausible explanation in the case of Ra applies also to Pu, i.e. absorption of the alpha's in insensitive parts of the bone.

7. Recommendations

The final recommendations are summarised in the following table:

Activity	Maximum permissible amount in μ curie	Safety factor for non-uniform distribution
Ra	$\frac{1}{20}$	(see note below)
Sr 89	2	10
Sr 90	2	5
Pu	$\frac{1}{60}$	15

In the case of Ra a safety factor is introduced by the assumption that all alpha particles are effective.

A P P E N D I X

THE TOLERANCE AMOUNT OF Ra, Sr and Pu IN DRINKING WATER

We assume the following maximum permissible amounts in the human body:

Ra: $\frac{1}{20}$ μ curie

Sr 89: 2 μ curie

Sr 90: 2 μ curie

Pu : $\frac{1}{60}$ μ curie

For Sr we take the highest figure given by Hamilton for absorption from the gut, namely 60%, and observe that 65% of this amount goes to the bone. Assuming a daily consumption of 4 litres, the tolerance concentration is for Sr 89.

$$2 \times 10^{-6} \ \frac{0.693}{55} \ \frac{1}{4 \times 10^3 \times 0.65 \times 0.60} = 1.6 \times 10^{-11} \text{ curie/cc}$$

and for Sr 90

$$2 \times 10^{-6} \times \frac{0.693}{25 \times 365} \ \frac{1}{4 \times 10^3 \times 0.65 \times 0.60} = 10^{-13} \text{ curie/cc}$$

For Pu Morgan gives an absorption of 0.03% from the gut and a half-life of 10 years. However it is known that the rate of elimination decreases with time and the concept of a half-life does not appear to be applicable. Cantril gives a value of 0.05% absorption and Hamilton gives 0.007% of which 65% goes to the bone.

It would appear safe to use the highest quoted figure for absorption and to disregard elimination altogether. Then one finds for a 70 years exposure

$$\frac{1}{60} \times 10^{-6} \ \frac{1}{70 \times 365} \ \frac{1}{4 \times 10^3 \times 5 \times 10^{-4}} = 3 \times 10^{-13} \text{ curie/cc}$$

For the radium the following figures for absorption from the gut have been given

Morgan	5%	(J. Phys. and Colloid Cham. 51, 984, 1947)
R. D. Evans	0.1% - 10%	(NP/P/TD/45)
Cantril	0.5% - 2%	(MDDC - 601)
Rajewski	0.5% - 1%	(Radiology 32, 57, 1939)

Morgan assumes a biological half life of 10 years. This appears pessimistic in view of the statement by R. D. Evans that 90 - 99% are excreted rapidly and after several years only 1 - 2% remain. From a long term point of view we need only consider the amounts which remain in the skeleton for considerable periods. We shall take therefore the largest value quoted for absorption, i.e. 10% and and assume that 2% of this amount remains indefinitely in the skeleton. Then the tolerance concentration is

$$\frac{1}{20} \times 10^{-6} \ \frac{1}{70 \times 365} \ \frac{1}{4 \times 10^3 \times 0.10 \times 0.02} = 2.5 \times 10^{-13} \text{ curie/cc}$$

Our recommendations are

Sr.89: 1.6×10^{-11} curie/cc
Sr.90: 10^{-13} curie/cc
Pu: 3×10^{-13} curie/cc
Ra: 2.5×10^{-13} curie/cc

A.E.R.E., Harwell. 26th November, 1948. H.S. 1334.

APPENDIX 10

R. EVANS LETTER : RADIUM BODY BURDENS. (12-1-48)

NP/P/TD/83.

Extract from letter from Professor Robley D. Evans to Dr. L. H. Gray on the question of human tolerance for radium

December 1, 1948.

"1. Our series of patients surely must contain a greatly distorted distribution of Ra burdens. Drs. Aub, Martland, and I would see mainly these individuals who show symptoms of Ra effects and hence are referred by their physicians. This accentuates those whose Ra burdens are large. A less numerous group of subjects includes those who have no symptoms but are referred for Ra measurements because of anxiety, usually occasioned by knowledge of disease in a friend or former working associate.

To these two groups is to be added the more than 600 individuals on whom breath radon tests have been done in my laboratory as part of a national, but voluntary, personnel monitoring program. In this group no new cases exhibiting clinical symptoms have appeared, although in June, 1945, there were 159 individuals who were or had been above the permissible level of 1 $\mu\mu$c Rn/liter of expired air. I have not been able to complete a statistical re-examination of these files in time to send to you for your forthcoming meeting.

In any case, this industrial group contains several (I would guess perhaps a dozen or two) individuals who are "veterans" in Ra work, and whose breath Rn is consistently more than 10 $\mu\mu$c Rn/liter. We take this to mean more than 1 μg Ra burden and regard it as fixed in the body since, roughly World War I. I expect some of these people to get into trouble eventually, but mostly from bone necrosis and radiation osteitis, with only some minor proportion of osteogenic sarcomas.

2. As you say, the evidence presented by Rajewsky and Krebs that normal people contain 0.015 μg Ra is not compelling. In members of our laboratory staff who are in their thirties, we have never been able to detect a positive breath Rn content. Although we have never pushed for ultimate sensitivity, this should mean something definitely less than 0.05 $\mu\mu$c Rn/liter (which corresponds to about 50 per cent of our background count) or 0.005 μg Ra for the few people tested.

I have talked with Brues by phone about this question, and I am going to see him next week in Chicago. We both are intrigued by the need for really good measurements on the normal Ra content of the human, and are beginning a collection of bones obtained at amputation, or otherwise, for such tests.

3. I would agree that Binks probably has the decimal point right when he finds Thames river water to have about 2 to 5 x 10^{-16} g Ra/g water. You will remember that values in the range of 1 x 10^{-16} g Ra/g water were obtained in my studies about 1934 (Amer. Jour. Sci.) of ocean water. Measurements at these concentrations present many technical difficulties and pitfalls for the unwary. We are currently analyzing Mississippi river waters, but do not expect to have any final numbers available for several months.

4. I know of no data on even the geographical distribution of osteogenic sarcoma, let alone any correlation of it with the (unmeasured) radium content of urban water supplies. Clarence Mills, in his "Medical Climatology" does not present osteogenic sarcoma. I have written him, in the hope that he will undertake a study of the geographical distribution of this disease. Just how interpretable such data would be is questionable because people move about a good deal in this country. Perhaps the fraction who spend their entire life in one geographical area is insufficient. If he comes up with anything we would expect to follow through with radium measurements.

I seem to remember seeing somewhere that the water in Bath, England, is high in Ra. Is this really so? And what of the osteogenic sarcomas there?

There are reports of radium contents as high as 283 x 10^{-16} g Ra/g water in some Colorado mineral springs, but I do not know whether the measurements were accurate, or whether the springs are important as domestic water supply (Mineral Waters of Colorado, Bulletin 11, Colorado Geological Survey, 1920).

5. I do not seem to have a copy of my remarks at the meeting of your Tolerance Doses Panel, but I surely agree with your suggested rewording. As under item 2 above, probably 10^{-14} curies Rn/liter could be substantiated, but special techniques involving collection of Rn from many liters of breath would be required to push down to 10^{-15}.

Now to your memorandum NP/P/TD/73:

(A) Table I makes me pause, because of the rather high incidence of osteogenic sarcoma which is proposed. Here is one place where a critical re-examination of all our published clinical data would help a good deal. I have continued to press Dr. Aub to get these clinical data written up, so far without success because of his heavy overload. I hope for better luck soon.

I believe you have one of my typed summary tables of about 24 unpublished subjects, 11 of whom are dead or seriously ill. Necrosis appears often as the central clinical picture, but only a few cases of osteogenic sarcoma are seen. Patient C1 died with a sarcoma at the knee after carrying 5 μg Ra for 27 years. HB died at home after 23 years of professional work as a radium chemist, of lung carcinoma which was probably (but not definitely proved) a metastasis, and with about 5 μg Ra as estimated in New York by Failla. KM died at home of a tumour of the jaw (without pathology) 15 years after exposure as a dial painter, and with 1.5 μg Ra terminally. Thus only 3 of these 11 cases of frank radium poisoning were malignant.

Of three new cases seen this year, one has a surgically and pathologically confirmed sarcoma of the humerus, 18 years after medical administration of radium, and with a present burden of 11 μg Ra. The other two cases present generalized necrosis, but no tumor, after 18 years with 8 μg, and after 20 years with 4 μg Ra.

A survey of a fertile but small fraction of our "personnel monitoring" files shows 12 persons with breath Rn in the range of 7 to 50 μμg Rn/Liter, hence body Ra of about 0.7 to 5 μg, who are not included in your list of 24 people and who have no symptoms. At least half of these people I know to have been exposed to Ra ingestion for 25 years or more, and one for 40 years (he has about 2 μg Ra).

Thus if we distinguish between malignancy and other symptoms such as bone necrosis, the tumour incidence would seem lower than that of Table I, perhaps by as much as a factor of 10.

(B) Bottom of page 2. The mice of Brues, Lisco and Finkle, which were on the highest dosage rates, did seem to show a tumour incidence proportional to dosage rate. It is conservatively safe to assume that this linearity holds at very low dosage rates. However, my guess is that the law will break down at very low dosage rates, as did the linear law of genetic effects when Curt Stern went to very low dosage rates.

(C) In part II, the values of 0.001 μg Ra in the skeleton of an average adult may actually be less than the normal value. If the skeleton weighs about 7000 grams, this would give an average concentration of about 0.15×10^{-12} g Ra/g bone. Most terrestrial materials (rocks, soil, etc) have a Ra concentrationin the domain of 0.1 to 1×10^{-12} g Ra/g. I would suggest a higher value, in view of (A) above, of, say, 0.01 μg Ra, or even higher, as a tentative "permissible" value in a large population.

(D) Morgan's value of 5 per cent retention for ingested Ra is merely a guess. In some of our patients who were given Ra by physicians, we do know roughly how much Ra was administered and therefore, what fraction was retained. One patient retained 2.5 per cent following intravenous injection of Ra. Two patients who ingested Ra retained 0.1 per cent and something between 0.3 to 3 per cent (dose uncertain by a factor of 10). Three other patients who ingested a mixture of Ra and MsTh, retained 0.1, 1, and 10 per cent of the amount drunk, and contained respectively 0.1, 3.8 and 10 μg Ra a decade or so later. Here, as in our rat experiments, we have noted that the fractional retention appears to definitely decrease with decreasing dose! Therefore, at low dosage levels, I would expect a retention more like 0.1 to 1 per cent.

(E) The average daily excretion of Ra in chronic Ra poisoning is close to 0.005 per cent of the amount fixed in the skeleton. Thus the biological half-period of Ra in the human skeleton is about 40 years. Morgan's guess of 10 years is untenable.

In your calculations on page 4, the factors in (D) and (E) Play in opposite directions, but leave you with a somewhat higher permissible level.

(F) I think a latent period of 8 years is much too short, especially for low doses. The cases which I have briefed in (A) above suggest something more like 15 + 5 years even at high dosages. Brues found in his mice on Sr-89 that the latent period was significantly lengthened as the dose was reduced. Although his data do not extrapolate unambiguously to any other case, you will note by numerical substitution in his formula $t_1 = 200$ lot (1/d) that very approximately his observed latent periods, t_1, doubled for each reduction of a factor of 10 in dosage. I think you therefore would be justified in using a much longer latent period, easily as great as 30 years, for the low dosages under discussion.

(G) At the bottom of your page 4, the factor of 10 presumably refers to Sr-89, which is the isotope Brues used, and which has a maximum beta ray energy of 1.5 Mev, rather than Sr-90 whose beta rays extend to only 0.65 Mev. This may give you back a factor of 2.5 or so, unless you decide that the Y-90 daughter stays in the bone.

Some calculations which I made last year comparing Finkle's Sr-89 mice with our Ra rats suggested that rep for rep the two agents were about equally effective in bone tumour production. Such calculations involve uncertainties especially because Brues' doses and Finkle's doses are only given in terms of μc/g body weight, rather than per gram of skeleton. In any case, the relative-biological-effectiveness of about 5, which I expected, did not show up in this small number of animals.

However, Ra delivers more rep/ μc in man than in the rat or mouse. This is because man exhales close to 45 per cent of the Rn produced in the body, as compared with 85 per cent for the rat. The mouse is unmeasured, but is probably a bit higher than the rat. Thus the effective energy delivered per Ra disintegration in man is
Ra+ 0.45 (Rn + RaA + RaC') = 4.88 + 0.55 (5.59 + 6.11 + 7.83) = 15.6 Mev.
In the rat, however, only 4.88 + 0.15 (5.59 + 6.11 + 7.83) = 7.3 Mev is delivered per Ra disintegration. Here is a clear-cut factor of 2. Thus the effectiveness ratio of Sr/Ra will be about one half as great in man as in the rodents. Your factor of 10 can thus go at least up to 20.

Another approach suggests even much larger values. Assuming all the Y-90 remains in the bone, the average energy per Sr-90 disintegration is about (0.65 + 2.16)/3 = .9 Mev, compared with 15.6 Mev per Ra disintegration, for the case of man. This Sr/Ra ratio of 0.9/15.6 is 1/17/3. If an RBE of 5 is taken for α to β radiation, then the Ra/Sr effectiveness ratio per μc/g bone would be 17.3 x 5 = 86.

(H) On page 5, the fraction of Sr and Pu going to bone, and their biological half-periods are taken from Morgan's guesses. Hamilton's measurements, though fragmentary (Radiology, 49, 325 (1947)) may be preferable. For example, Pu retention is 0.03 per cent according to Morgan, and 0.005 per cent according to Hamilton.

(I) On page 6, no allowance is made for adsorption or absorption of Ra, Sr and Pu in clay and mud, nor by algae, plants or fish. Especially the clay may be expected to remove a great fraction of anything Harwell puts into the Thames long before the water gets to London. If MDDC 1160 of Hamilton on "Metabolism of Fission Products and the Heaviest Elements in Rats and Plants" has not reached your desk, the following paragraph from Joe's page 10 may be of interest:

"A very high degree of adsorption and retention of strontium, yttrium, zirconium, columbium, cerium, and plutonium was observed to take place with the clay minerals of most common types of soils. Once these radio-elements in the carrier-free state come in contact with soil, they cannot be removed by leaching even with strongly acid solutions. There was a very high degree of accumulation of all six of these radio-elements by the root of plants grown in soils previously treated with these materials. A considerable fraction of the strontium accumulated by the plants was found to be translocated to the leaves and stems. From the known facts of plant physiology, it can be anticipated that barium and cessium will behave in a similar manner to strontium, yttrium, zirconium, columbium, cerium and plutonium showed a relatively small degree of accumulation in the leaves and stems but a measurable degree of trans-location of these elements took place." (sic.)

(J) I certainly agree that no detectable injury should result to anybody if the daily discharge from Harwell is comparable with the numerical values on Page 6. It seems to me that you are safe by several orders of magnitude, and that if these limits are restrictive to Harwell's operations, an upward revision of the values could be considered."

H.4841

APPENDIX 11

UK-MRC-MALIGNANT TUMORS OF BONE (12-9-48)

NP/P/TD/85.
Sloane 5756 9th December 1948.

To G. J. Neary:

I enclose some extracts from an unpublished report on Bone Sarcoma, prepared for the Clinical Cancer Research Committee of the British Empire Cancer Campaign, from which you will see that there were 123 primary cases, 74 of which were osteogenic sarcoma clinically, and in 31 there was a histological report.

I have given the whole of each table so that you can see the contrasts between the age of incidence and distribution of the different groups. The most striking point about the osteogenic sarcomata is the occurrence of two periods of maximum incidence, one between 5 and 24 years of age, and another at 60-64, the latter being associated with Paget's Disease in a high proportion of patients. 13 (17.6 per cent.) of the 74 patients diagnosed as osteogenic sarcoma suffered from Paget's Disease, their mean age was 64.0 for males and 67.7 for females.

The next table shows the bones affected in each pathological type, and in the last table, the data for osteogenic sarcoma and chondrosarcoma are dissected into age-groups at 10-year intervals. This shows how the incidence of osteogenic sarcoma in the early years was almost entirely in the lower end of the femur and upper end of the tibia, whereas in the later years the incidence was more widespread, with maximum incidence in the bones of the pelvis. No such differences in incidence were found in the case of chondrosarcoma.

Signed: W. L. Harnett.
Medical Secretary
Clinical Research Committee
British Empire Cancer Campaign

BRITISH EMPIRE CANCER CAMPAIGN

TABULATION OF CASES OF MALIGNANT TUMOURS OF BONE

1. Number of Cases

Primary	...	123	132
Recurrent		9	

2. Types of Growth and Sex Ratios

The primary cases were grouped on a pathological basis, as far as available data permitted.

	No.	Per cent. of total	Males	Females	Males as per cent. of group, with Standard Error
Osteogenic sarcoma	74	60.2	41	33	54.4 ± 5.8
Chondrasarcoma ..	12	9.8	8	4	66.6 ± 13.6
Ewing's Tumour ..	7	5.7	6	1	85.7 ± 13.2
Myeloma	10	8.1	2	8	20.0 ± 12.6
Osteoclastoma ..	7	5.7	1	6	14.3 ± 13.2
Parosteal sarcoma	5	4.1	3	2	60.0 ± 21.9
Miscellaneous ..	8	6.5	4	4	50.0 ± 17.7

The greater incidence of osteogenic sarcoma amongst males is in accord with published statistics, though most writers find the percentage of males higher than that given above.

Ewing (1940) gives 60 per cent. of 376 cases as the usual figure. Ewing's tumour and myeloma are both said to be twice as common in males as in females (Cade 1940), but the numbers in the above series are too small for the figures to be statistically significant. The miscellaneous group comprises 2 patients with reticulum cell sarcoma, 2 with haemangeio-endothelioma, 1 with chordema and 3 in which the pathology of the tumour remains doubtful.

3. Age Distribution

	Osteogenic sarcoma		Chondro-sarcoma		Ewing's tumour		Myeloma		Parosteal sarcoma		Osteo clastoma		Miscellaneous	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0- 4	1	-	-	-	-	1	-	-	-	-	-	-	-	-
5-14	5	6	-	-	2	-	-	-	-	1	-	1	1	1
15-24	10	3	1	2	2	-	-	-	-	-	1	1	-	-
25-34	4	3	3	-	-	-	-	-	-	-	-	1	1	-
35-39	-	-	-	-	-	-	-	-	1	-	-	2	-	-
40-44	1	4	-	1	-	-	-	-	-	-	-	1	1	-
45-49	2	3	1	-	2	-	1	-	-	1	-	-	-	-
50-54	3	2	1	-	-	-	-	1	-	-	-	-	-	1
55-59	3	3	1	-	-	-	-	4	2	-	-	-	-	-
60-64	7	2	-	-	-	-	1	3	-	-	-	-	-	1
65-69	2	3	-	-	-	-	-	-	-	-	-	-	-	-
70-74	1	3	1	1	-	-	-	-	-	-	-	-	1	1
75-79	1	1	-	-	-	-	-	-	-	-	-	-	-	-
80	1	-	-	-	-	-	-	-	-	-	-	-	-	-

	Osteogenic sarcoma		Chondro-sarcoma		Ewing's tumour		Myeloma	
	M	F	M	F	M	F	M	F
Mean age	40.4 ±3.6	43.3 ± 3.8	41.0 ±6.6	38.2 ±11.8	24.5 ±6.6	-	54.5 ±6.1	58.6 ±1.1
Standard Deviation	23.3	21.6	18.5	22.1	15.8	-	8.5	3.1

	Parosteal sarcoma		Osteo-clastoma		Miscellaneous	
	M	F	M	F	M	F
Mean age	50.0 ±4.6	25.0 ±14.0	-	29.0 ±4.5	37.7 ±10.7	47.5 ± 12.2
Standard Deviation	7.8	19.5	-	10.9	21.5	24.5

Osteogenic sarcoma affected patients of all ages, but the maximum incidence was in the years 5-24, and of 74 patients 32 were under 35. Ewing (1940) states that the highest incidence is at the age of 15, and Kolodny (1927) found that nearly half the cases occur round about 20 years of age. Many of the older patients were suffering from Paget's Disease. As the mean ages of these patients and of those suffering from chondrosarcoma were high, the cases in which the diagnosis was supported by histological reports were tabulated separately with the result that all the means are lower.

Age Group	Osteogenic sarcoma M	Osteogenic sarcoma F	Chondrosarcoma M	Chondrosarcoma F
Total Nos.	17	14	4	3
0- 4 ..	1	-	-	
5-14 ..	3	3	-	-
15-24 ..	6	1	1	2
25-34 ..	1	1	2	-
35-39 ..	-	-	-	-
40-44 ..	1	4	-	-
45-49 ..	1	1	1	-
50-54 ..	1	1	-	-
55-59 ..	-	-	-	-
60-64 ..	2	1	-	-
65-69 ..	1	-	-	-
70-74 ..	-	1	-	1
75-79 ..	-	1	-	1
Mean age ..	29.8	40.5	29.5	37.0

Of the 7 patients diagnosed as Ewing's tumour (histological reports in 6), 5 were under 25 years of age, all those with myeloma (histological reports in 6 out of 10) were in the age groups 45-64; whilst those with osteoclastoma were in the younger groups 5-44. These age distributions are in accord with general experience. There were no statistically significant differences of mean age between males and females.

4. Findings on Examination

	O.S.	C	E.T.	My	P.S.	O.	Miscellaneous
Tumour							
Palpable tumour present ..	64	12	4	5	4	4	6
" " not present ..							
diagnosis made by X rays ..	6	-	2	5	-	2	1
Not stated..	4	-	1	-	1	1	1
Bones affected							
Skull bones	3	-	-	5	1	-	1
Mandible	2	-	-	-	-	1	-
Vertebrae and Sacrum ..	3	1	-	4	-	3	3
Bones of pelvis	13	5	2	2	1	1	1
Ribs and sternum	2	1	-	7	-	-	1
Scapula	4	1	-	2	1	-	1
Humerus, upper end ..	5	1	1		-	-	-
" shaft ..	1	-	-		-	-	-
" lower end ..	-	-	-		-	-	-
Radius, lower end ..	1	-	-		-	-	-
" upper end ..	1	-	-		-	-	-
Femur, upper end ..	9	-	1		-	-	1
" shaft ..	2	-	-		-	-	-
" lower end ..	12	2	1		1	-	-
Tibia, upper end ..	10	-	-		1	2	-
" lower end ..	1	-			-	-	-
Fibula, upper end ..	4	-	1		-	-	-
" lower end ..	-	-	1		-	-	-
Tarsus ..	1	-	-		-	-	-
Metatarsus and phalanges ..	-	1	-		-	-	-

Of 74 cases of osteogenic sarcoma, the femur was the bone affected in 23 (31.1 per cent.), the pelvic bones in 13 (17.6 per cent.), the tibia 11 (14.9 per cent.), and the humerus in 6 (8.1 per cent.). In Christensen's (1925) series of 1,000 bone tumours there were 441 osteogenic sarcomas and the most frequent sites were the femur 39.4 per cent., tibia 18.8 per cent., humerus 12.2 per cent., and the pelvic bones 4.5 per cent. Amongst the the chondrosarcomas the pelvic bones were affected in 5 out of 12 cases, 41.7 per cent. The myelomas affected chiefly the skull, vertebrae, ribs and sternum, but in 2 cases the whole skeleton was affected and in all except one patient the tumours were multiple. The other groups were too small in numbers to allow of any conclusions to be drawn from their distribution.

The sites affected by osteogenic sarcoma and chondrosarcoma differed at different ages. It will be seen from the following table that under the age of 25, the lower end of the femur or upper end of the tibia were the sites in 18 out of 25 patients (72 per cent.) with osteogenic sarcoma, whilst the highest incidence in the pelvic bones was in the decade 55-65, when Paget's Disease is most commonly met with. Five of the 12 chondrosarcomas affected the pelvic bones, 3 in the decade 25-34, 1 in the decade 55-64, and 1 over 65.

Location of osteogenic sarcoma and chondrosarcoma, by age groups

Age group ...	0-14		15 -24		25 -34		35-44		45-54		55-64		65-	
*	O.S.	C.	O.S.	C.	O.S.	C.	O.S.	C.	O.S.	C.	O.S.	C.	O.S.	C.
Skull and maxillae..	-	-	-	-	-	-	-	-	1	-	-	-	2	-
Mandible ..	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Vertebrae and sacrum	-	-	-	1	-	-	-	-	1	-	1	-	1	-
Pelvic Bones ..	1	-	1	-	2	3	-	-	2	-	5	1	2	1
Ribs and sternum ..	-	-	1	-	-	-	-	-	-	1	1	-	-	-
Scapula and clavicle	-	-	-	-	1	-	1	-	2	-	-	-	-	1
Humerus, proximal end	1	-	-	-	1	-	1	1	-	-	2	-	-	-
" shaft ..	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Radius, proximal end	-	-	-	-	-	-	-	-	1	-	-	-	-	-
" distal end..	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Femur, proximal end	-	-	-	-	1	-	1	-	-	-	2	-	5	-
" shaft ..	2	-	-	-	-	-	-	-	-	-	-	-	-	-
" distal end	3	-	6	2	-	-	1	-	1	-	-	-	1	-
Tibia, proximal end	4	-	3	-	-	-	-	-	-	-	3	-	-	-
" distal end	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Fibula, proximal end	-	-	1	-	1	-	-	-	1	-	-	-	-	-
Tarsus	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Metatarsus and phalanges ..	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Totals (cf. para.3)	12	-	13	3	7	3	5	1	10	2	15	1	12	2

* O.S. = osteogenic sarcoma
C. = chondrosarcoma.

APPENDIX 12

UK-MRC DEATHS FROM BONE SARCOMA (12-23-48)

NP/P/TD/86
HS 1417

23 rd December, 1948.

To Dr. Neary,

We have prepared the attached table showing the deaths from sarcoma of bone (except the jaw) in England and Wales during each year 1945-1947, according to sex and age. Also, for comparative purposes, the numbers of deaths from sarcoma in all parts of the body in 1945 (distinguishing lymphosarcoma). In the last two columns these are expressed as mean annual death rates per million population at the age group in question.

The rates of osteogenic sarcoma, in the last column, rise to a peak at 15-25 for each sex, and then fall again, but from about 40 onwards they increase steadily with age. This suggests a mixture of two distinct causations, one operating rapidly in early life, and the other more slowly throughout life.

I am sorry that we have no information at present as to the particular bones affected.

Signed: PERCY STOCKS.

NP/P/TD/86.

Sarcoma of Bone - Deaths and Rates per million in England and Wales, 1945-47 (with comparative data for Sarcoma of all sites in 1945 and 1943-45)

Sex and Age	Number of deaths* from Sarcoma (including lymphosarcoma)					Mean annual death rates from Sarcoma per million living	
	All sites		Bone (except jaw) (international No.56b)			All sites 1943-45	Bone (except jaw) 1945-47
	Lympho sarcoma 1945	Other sarcoma 1945	1945	1946	1947		
Males							
0-	4	42	5	1	7	) 21 (	2.6
5-	8	36	13	12	13	) (	4.5
15-	14	63	33	31	43	28	11.4
25-	21	84	13	15	26	30	5.5
35-	47	133	24	21	26	48	7.1
45-	34	190	50	51	43	93	18.9
55-	59	306	68	55	61	166	30.7
65-	49	242	68	66	55	227	46.7
75 and over	14	110	34	35	28	220	60.3
All ages	250	1,206	308	287	302	69	14.5
Females							
0-	5	39	3	8	6	) 18(	3.6
5-	7	30	12	12	9	) (	4.0
15-	5	43	22	22	21	16	7.0
25-	15	66	15	14	7	19	3.6
35-	22	95	10	19	12	32	4.0
45-	20	176	29	34	30	68	10.5
55-	39	215	46	54	45	111	19.9
65-	35	213	62	51	59	148	33.4
75 and over	12	121	35	32	33	161	39.5
All ages	160	998	234	246	222	52	10.6

*Including those of non-civilians, registered in England and Wales.

APPENDIX 13

UK MRC - MAXIMUM PERMISSIBLE FLUX FOR NEUTRONS (1949)

NP/P/TD/94.

TDC 60. H.5670

A Note on the Maximum Permissible Flux for Fast Neutrons in Relation to the Induction of Cataract, and a Preliminary Estimate of the Maximum Permissible Flux for Neutrons in the Region of 180 MeV

by

G. J. NEARY

Summary

The present maximum permissible flux of 40 fast neutrons per cm^2 per sec. corresponds to approximately 46 physical röntgens over a working lifetime of 40 years. Only very faint signs of lens change were found in cyclotron workers at twice this dose. It is doubtful whether twice this dose produced any lens changes in mice in 1 to 2 years. The threshold dose of gamma radiation for cataract formation is about 1000r. A preliminary extimate suggests that the figure of 40 neutrons/cm^2/sec. should also apply satisfactorily in the very high energy range, both as regards general effects and cataract formation.

I. UNITS

The present maximum permissible flux for fast neutrons at A.E.R.E., laid down in Station Circular No. 115 is:

40 neutrons/cm^2/sec. for energies 2 to 20 MeV
and 80 " " " " " 0.5 MeV.

These figures, taken from the calculations of J. S. Mitchell (1947) are based on:

(i) A gamma-ray permissible dose of 0.1 r per 8 hour day
(ii) A biological efficiency of the proton recoils relative to gamma radiation of the order of 10
(iii) A safety factor of 2, introduced because of uncertainty in this biological efficiency factor.

The calculations of Mitchell should strictly be amended for the mean energy loss per collision, so that the permissible fluxes are increased by about 25%. When this is done, a flux of 40 neutrons/cm^2/sec. corresonds to a physical dose (in Gray's energy units or physically equivalent röntgens = 93.1 ergs/gram) of approximately 0.005 "r" per 8 hour day for energy range 1 to 10 MeV. This gives a weekly dose of 0.025 "r" and a yearly dose (46 working weeks) of 1.15 "r". The accumulated dose over a working lifetime of 40 years is thus 46 "r" (physical).

Two arbitrary units of neutron dose have been used in America, the "n" and the "N" units. The "n" unit corresponds to the readings of a 100R Victoreen Condenser dosemeter, while the "N" unit relates to a 25r dosemeter. The cavities of the air-filled ionisation chambers are respectively 0.7 and 1.1 cm in diameter, the walls being of bakelite containing about 4 to 5% of hydrogen. The chambers thus correspond approximately to "small cavity" chambers for neutrons of a few MeV, and the ionisation observed is approximately a measure of the neutron energy absorption in the walls. These units are related to physical doses in tissue approximately by the ratio of the hydrogen contents of the bakelite wall and of tissue, plus some correction for the finite size of the chamber. The "n" unit has been regarded as approximately equivalent to 2.5 tissue röntgens (physical) (Aebersold and Anslow, 1946). The "N" unit on account of the larger size of the chamber might be conventionally taken as equivalent to 3 tissue röntgens (physical).

II. Induction of Cataracts

A. Neutrons

(i) Clinical data. The recent "Cataract Survey" from the National Research Council, Washington gives information on lens damage by neutrons in the range 0 to 10 MeV. The neutron doses are variously quoted in "n" and "N" units. The results are:

3 severe cases,	average dose	95 n ≐ 238 "r" (physical)
4 minor cases,	" "	44 n ≐ 110 "r" (")
3 trivial cases,	" "	33 n = 82 "r" (")

It will be observed that the lifetime dose at A.E.R.E., 46 "r", is only about half that in the last group, where, moreover, the irradiation was concentrated into a year or two.

The recommendation in the Cataract Survey is that the weekly dose of neutron radiation should not exceed 0.006 rep, though the committee was not unanimous and suggested values ranged from 0.012 to 0.06. The value at A.E.R.E. is 0.025.

(ii) Experimental data. The only material at present available appears to be that of T.C. Evans (1948). Mice were irradiated by neutrons "produced by a 36 cyclotron". Assuming that deuteron ions of about 8 MeV were used to bombard beryllium, the average neutron energy would have been about 4 MeV. The chronic results reported include:

Accumulated dose 190 "N" = 570 "r" (physical) .... in 27 weeks (.7N per week)	26% of eyes with severe cataract at end of period
Accumulated dose 48 "N" = 144 "r" (physical)	large number of unimportant cataracts, only detectable by opthalmological examination at end of period.
Accumulated dose 24 "N" = 72 "r" (physical) .... in 69 weeks (.7N per week)	very doubtful whether any cataracts due to radiation.

The last two observations seem to be in reasonable agreement with the human data in (i). (Note: A.E.R.E. lifetime dose = 46 "r")

B. X and Gamma Radiation

It has not been possible at short notice to survey the very extensive literature in this field. The effect of X rays on the eyes of rabbits was being investigated as early as 1897 (Chalupecky) and there has been a constant flow of material, both clinical and experimental, ever since.

A very detailed review of the earlier work was given by Desjardins (1931). The conclusions, summarized briefly, were that the lens in young animals is particularly sensitive to radiation, but that it becomes comparatively insensitive in adult animals.

It appeared later that the latter view arose because of the relatively short periods of observation.

The subject has been reviewed again recently by Hunt (1947), with reliable figures for dosage. The latent period for the formation of cataract may be from ½ to 8 years and the threshold dose appears to be about one skin unit ("threshold erythema dose"), i.e. of the order of 1000r for gamma rays, when given in a short time.

The biological efficiency factor of neutron radiation for cataract production has not been experimentally determined. Evans' results indicate that it is very large for chronic irradiation in mice, perhaps 50 or even more. There would be every reason to assume that the threshold dose of gamma radiation for cataract production would be appreciably larger than 1000 R for chronic irradiation. Supposing it to be doubled, and taking a biological efficiency factor of 50, the neutron threshold dose would be 40 "r" (physical). The basis of this estimate is, however, quite insecure.

III. The Special Problem of the Harwell Cyclotron

The cyclotron is designed to produce protons of 180 MeV energy. These particles will produce neutron radiation up to 180MeV. The very limited experimental information on neutrons of such energies only permits of the crudest estimate of the maximum permissible flux.

It may be assumed that in collisions with atomic nuclei, these very energetic neutrons will react with the individual nucleons independently, that is, the effect of nuclear binding will be negligible, at least for the light nuclei mainly composing tissue. Thus, it will be assumed that the collisions will result in the production of fast protons and/or neutrons. Owing to the exchange nature of the neutron proton interaction, the incident neutron will transfer nearly the whole of its energy to a proton in an appreciable proportion of collisions. To err on the safe side, it will be assumed that the neutron loses all its energy in every collision with the production of a fast proton.

Cook, McMillan, Peterson and Sewell (1949) have given total cross section figures for 90MeV neutrons and a variety of nuclei. Further Hadley, Kelly, Leith, Segré, Wiegand and York, have given values for the total cross-section for neutron-proton scattering at 90 and 40 MeV. They also quote results of Sleater at 20 to 24 MeV. From this material it would appear that the (n - p) cross section is falling with energy slightly more rapidly than 1/E.

The interaction of fast neutrons with tissue will therefore be calculated from the cross sections of Cook et al at 40 and 90 MeV. extrapolated by a 1/E law. For a flux F/cm^2/sec. of neutrons of energy E MeV, the equilibrium energy per gram of tissue per 8 hours is:

$$FE \Big[0.083 \times 10^{-24} \times \frac{90}{E} \times 6.6 \times 10^{22} + 0.55 \times 10^{-24} \times \frac{90}{E} \times 1.02 \times 10^{22}$$

$$+ 0.656 \times 10^{-24} \times \frac{90}{E} \times 1{,}08 \times 10^{21} + 0.765 \times 10^{-24} \times \frac{90}{E} \times 2.44\times10^{22} \Big]$$

$$\times 1.602 \times 10^{-6} \times 2.88 \times 10^{4} \text{ ergs/g.}$$

$$= 0.127 \text{ F ergs/g.}$$

Thus the physical dose (units of 93.1 ergs/g) is

$$1.36 \text{ F} \times 10^{-3} \text{ "r"/8 hours (physical)}$$

which is independent of neutron energy.

It remains to insert an appropriate biological efficiency factor. Assuming that this depends on ion density only, the equivalent quality of X rays may be deduced for which the secondary electron ion density is the same as that of the secondary protons produced by the neutron beam.

Thus,

180MeV neutrons are equivalent biologically to X rays generated at 700kV

90MeV " " " " 440kV " " "

45MeV " " " " 276kV. " " "

The biological efficiency factor of neutrons of these energies will therefore be very little greater than unity. Therefore a flux of 40 neutrons/cm^2/sec. will correspond roughly to a biological dose of 0.055 "r"/day(biological), which corresponds substantially to the criterion laid down by Mitchell for neutrons up to 20MeV. It may be noted that in the region 40 to 20 MeV, the rising biological efficiency factor will be approximately compensated by a fall in the effective cross sections due to the reappearance of elastic scattering by whole nuclei.

The foregoing simplified argument would thus suggest that the existing figure of 40 neutrons/cm^2/sec. might also apply moderately well in the very high energy range.

In particular, the lifetime dose would be 500r which may be directly compared with the supposed threshold dose for cataract formation by gamma radiation of 1000r.

IV. Conclusion

It would seem that in the neutron energy range up to 20MeV, the risk of cataract formation from a lifetime exposure to a flux of 40 neutrons/cm^2/sec. per 8 hour day is not serious.

Preliminary estimates suggest that the same flux figure may be reasonably satisfactory in the very high energy range up to 180MeV.

There would seem to be little risk in adopting the provisional figure of 40 neutrons/cm^2/sec. for a limited period of a few years until further evidence is obtained.

References

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APPENDIX 14

US MINUTES OF CHALK RIVER CONFERENCE (NO DATE)

MINUTES
of the

PERMISSIBLE DOSES CONFERENCE

R.M.-10

held at

Chalk River, Canada

September 29th-30th, 1949.

The conference was formally opened by Dr. D. A. Keys who then turned the chair over to Dr. Shields Warren.

The attendance was as follows:

United Kingdom	Prof. J. S. Mitchell Mr. A. C. Chamberlain Dr. G. J. Neary Dr. E. F. Edson
United States	Dr. Shields Warren Dr. G. O. Failla Dr. J. G. Hamilton Dr. L. Hempelman Dr. H. M. Parker Dr. K. Z. Morgan Dr. B. S. Wolf Dr. Austin Brues Dr. L. S. Taylor Dr. Wright Langham Dr. De Hoffman
Canada	Dr. W. B. Lewis Dr. A. J. Cipriani Dr. G. C. Laurence Dr. H. Carmichael Dr. G. H. Guest Dr. E. Renton Dr. G. E. McMurtrie Dr. A. O. Braaten

Item 1 - "Standard Man".

(a) The "standard man" was first considered from the viewpoint of the mass of the organs and tissues. The discussion was based on the figures presented by H. Lisco in 1948 (ANL-4253) and these in turn included earlier estimates by both Lisco and Parker (1947) MDDC Report 783.

In the course of the discussion it became apparent that while some rounding off of figures was desirable, nonetheless a reasonably close approximation to the actual should be maintained. It was emphasized that the tissues of major importance were the skeleton, red bone marrow, liver, spleen, thyroid and lymphoid tissue.

The following figures were accepted:

Standard Man - Mass of Organs

Organs	Grams
Muscles	30,000
Skeleton, Bones	7,000
Red Marrow	1,500
Yellow Marrow	1,500
Blood	5,000
Gastro-Intestinal Tract	2,000
Lungs	1,000
Liver	1,700
Kidneys	300
Spleen	150
Pancreas	70
Thyroid	20
Testes	40
Heart	300
Lymphoid tissue	700
Brain	1,500
Spinal Cord	30
Bladder	150
Salivary glands	50
Eyes	30
Teeth	20
Prostate	20
Adrenals	20
Thymus	10
Skin and subcutaneous tissue	8,500
Other tissues and organs not separately defined	8,390
Total body weight	70,000

After further discussion these figures were unanimously accepted. It was noted that figures were given only for males and it was agreed that this would be regarded as the standard for the present. The figure for total blood does not include the small residual amount which cannot be extracted from the organs. It was recommended that additional data be obtained on the above figures, particularly in the case of the red bone marrow.

(b) Secondly the chemical composition of the human body was considered. The following values were accepted for the present for the chemical composition of the "standard man":

Standard Man - Chemical Composition of the Human Body

	Per Cent	Approximate Amount in grams in a 70 Kg. Man
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulphur	0.25	175
Sodium	0.15	105

Standard Man - Chemical Composition of the Human Body (Cont)

	Per Cent	Approximate Amount in grams in a 70 Kg. Man
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

Practical Physiological Chemistry, Hawk, Oser, and Summerson, 12th Edition (1947)

The discussion brought out that the figures actually available were based on relatively few analyses carried out forty or more years ago when the probability of error was more likely. Moreover, data are not available on the presence of trace elements, specifically boron, which would be of interest in whole body neutron exposures.

It was agreed that a large scale effort be made to obtain accurate data on the chemical composition of the various organs in the human body, including information on the trace elements. Drs. Morgan, Cipriani and Mitchell were asked to correlate this effort. In this study normal organs, including the ovaries, preferably from cases of sudden death, should be examined. Relevant medical history should be available; analyses should be made on homogenized tissue and slices of organs should not be used. Dr. Morgan agreed to circulate the information which he had collected on this subject.

(b) The third aspect of the "standard man" to be considered was his applied physiology. The Conference agreed that all applied physiology figures be labeled "Averages for normal activity in temperate zone". All data suggested below are broad averages for normal activity and do not allow for changes caused by abnormal circumstances or environment. The following figures were accepted for both water intake and water output:

Total Water Intake - per day		2.5 litres	
	In food	1.0 "	(including water of oxidation)
	In fluid	1.5 "	
Total Water Output - per day		2.5 litres	
	Sweat	500 cc.	
	Lungs	400 cc.	
	Faeces	100 cc.	
	Urine	1,500 cc.	

Overall water content of body 50 litres (70% of 70 Kg.)

There was some discussion of the importance of the impurities in water used for cooking. It was felt that this should not be taken into consideration here but should be included in the general safety factor.

Respiration

The following tabulation was accepted:

Total Surface Area of Respiratory Tract	70 sq. metres.
Respiratory interchange area	50 sq. metres.
Non-respiratory area (Upper tract, trachea, bronchioles)	20 sq. metres

Respiratory Exchange

Physical Activity.	Hrs/day	Tidal Air	Resp/min.	M^3air/8 hrs.	Total
At work	8	1 litre	20	10	20
Not at work	16	0.5 litre	20	5	m^3/day

Note The 16 hours "not-at-work" is split up into 8 hours sleep and 8 hours incidental activities.

Carbon Dioxide Content of Dry Air

As inhaled	0.03%
Alveolar air	5.5 %
Exhaled air	4.0 %

(d) The duration of occupational exposure in the standard man was considered and it was agreed that it be:

8 hours/day	-	standard day.
48 hours/week	-	standard week.
50 weeks/year (thus 2000 hours/year	-	standard year.

No agreement was reached on a value for the "lifetime" duration of continuous occupational exposure. It was felt, though not formally agreed, that the proportion of workers remaining in continuous occupational contact with radiation for more than twenty years is likely to be small. For purposes of calculation the duration of life of the standard man is assumed to be 70 years.

The question of terminology was then considered and it was felt that the units at present used for definition of permissible values of radioactive substances vary widely. After considerable discussion the following recommendation was unanimously accepted. It was agreed that all formal statements of permissible volumes should be expressed in microcuries per cc. or microcuries per gram whether in air, water or other medium. Where other units are now in common use, they should be included in brackets.

A number of times in the discussion on the standard man, questions were raised as to whether organ weights or elemental composition should be considered as maximum or minimum rather than as mean weights in order to give a factor of safety to radiation dose calculations. It was unanimously agreed that safety factors should be clearly labelled as such and not incorporated in the data used for basic calculations.

(e) In relation to the "standard man", the retention of particulate matter in the lungs was considered at some length. Evidence exists of a bimodal peak in the retention curve for particulate matter. Reference was made to UR.67 as one source of basic data. It was brought out that particulate matter varied greatly in size and solubility. It was noted that particles of UF-6, 0.1 micron or less in diameter or Uranyl nitrate particles of 4 microns or less diameter were heavily retained in the lungs.

A considerable discussion of the radiation hazard from exposure to Uranium followed. It was brought out that Joachimsthal miners developed lung cancer not in the alveoli but in the bronchi, and after a mean occupational exposure of 17 years, Sikl assumed that radon was the chief hazard and Dr. Mitchell mentioned calculations he had made which indicate that these miners has got the equivalent of 1 to 3 r/day from inspired radon.

Dr. Hamilton cited a case of Yttrium oxide inhalation where 90% of the particles from 0.1 to 1 microcurie were retained in the lung initially but 80% appeared in the faeces in the next 48 yours. After further discussion the following recommendation was unanimously adopted:

It was agreed for purposes of calculation that 50% of any aerosol reaches the alveoli of the lungs. If the particles are soluble, they are considered to be totally absorbed; if insoluble, then the 50% amount is to be regarded as retained for 24 hours, after which only 25% of the inhaled amount is retained in situ.

It was recognized that it is difficult to consider the matter of retention by itself when it is not clear whether a single radioactive particle retained could cause cancer. In this respect, two possibilities for the cause of cancer were advanced: (a) mutations of single cell, in which case a single particle could become the cause and (b) disorder of the surrounding tissue, in which case a single particle would not cause cancer.

While no direct evidence was available, the group seemed to believe that possibility (b) was more likely. This is supported by evidence that external irradiation of small areas does not cause cancer but that an overdose causes the particular skin area cells to die off. There was agreement that attempts should be made to perform autopsies on people dying of other than radioactive causes, who are believed to have radioactive particles in their lungs.

During the discussion of particle retention, it was brought out that particles of about ten microns size would be swept out of the bronchial tree by ciliary action and excreted in the sputum or faeces. It was admitted that the shape of the particles in addition to their size, plays a considerable role.

Item 2 - Relative Biological Effectiveness

This subject was discussed during the afternoon session of the first day's meeting. The definition of the term 'relative biological effectiveness' was considered. It was agreed that this should be the ratio between the quantities of different types of radiation (measured in ergs/gram) required to produce the same biological effect. It was pointed out that the relative biological effectiveness of any given type of radiation may vary for different biological reactions and for acute and chronic forms of the same response. After considerable discussion, it was agreed by the members of the committee to regard the effects of radium gamma rays (filtered by 0.5 mm. platinum) as unity and to compare all other measurements of relative biological effectiveness to this value. An objection to the use of gamma ray effect as unity was based on the fact that most of the data about chronic radiation effects on the bone marrow was gained by observation of persons exposed to 200 Kv x-rays and that the relative biological effectiveness for this response of gamma rays has not been determined experimentally. The reason for choosing radium in spite of this objection was because of the convenience and reliability of radium sources and because of their wide acceptance as radiation standards. It was agreed by the Committee to consider the relative biological effectiveness for the bone marrow effect of radium gamma rays and 200 Kv x-rays as 1:1, while that for acute skin effects is 1:1.5 as has been shown experimentally.

The following table for the relative biological effectiveness for bone marrow and skin effects of different types of radiations was approved by the Committee:

Type of Radiation	Bone Marrow	Skin
Alpha	20	
Beta	1	
Gamma (Radium)	1	1
X-rays (200 Kv)	1	1.5
Fast neutrons of $\angle$ 20 MeV.	10	
Thermal neutrons $<$ 0.025 eV.	5	
Protons	10	

The terms fast and thermal neutrons in this table are used in the following arbitrary sense according to the agreement of the Committee:

Fast neutrons are those whose biological action is due primarily to proton recoil while thermal neutrons are those whose action on tissue results primarily from nuclear reaction. The reason for increasing the figure is to maintain the same ratio between neutrons and alpha particles originally measured by Zirkle. In view of the recent data concerning the greater biological effectiveness of fast neutrons as compared to radium gamma rays and x-rays, it seems reasonable to raise this value for alpha particles on this scale even though this will modify the tolerance values for plutonium and other alpha emitters.

Item 3 - Permissible Exposure to External Radiation

The first subject of discussion on the second day, Friday, September 30th, was Item 3 on the Agenda.

The discussion was lead by Dr. Failla and was based largely on a preliminary draft of a report of the Sub-committee on Permissible Dose from External Radiation of the U.S. National Committee on Radiation Protection. The philosophy expressed in this report, in brief, consists of basing the tolerance of externally originating radiation on the dosage delivered to certain critical tissues which appear to be the most easily damaged. This concept was accepted by the Committee. (See Agreement 1.)

In the course of the morning discussion about permissible exposure to external radiation, it was necessary for the Committee to reach agreements on a number of subjects. The agreements are now given and some of the discussion on which they were based is mentioned:

1. It was agreed to regard the blood-forming organs as the critical tissue when the body is exposed to hard x-rays or gamma rays, while the skin is to be considered the critical tissue in the case of soft x-rays or beta rays.

This is in agreement with the proposal made by Dr. Failla in his preliminary report. Damage to the blood-forming organs caused by over-exposure to penetrating radiations over a period of many years is manifested by the development of leukemia, while epitheliomas are the end results of skin over-exposure.

2. It was agreed for purposes of health monitoring that whole body radiation should normally be assumed for any radiation exposure other than that known to be limited to the hands and forearms.

It was decided to exclude diagnostic and therapeutic exposures to x-rays from this discussion.

3. It was agreed that for purposes of calculation the average depth of the blood-forming tissues should be considered to be 5 cm. below the skin surface.

It was pointed out in the discussion that blood formation in the marrow takes place in both the flat bones and in the vertebral bodies with little active blood formation normally taking place in the long bones. The average depth below the body surface of the marrow of the ribs and other flat bones was estimated by Dr. Warren to be approximately 1.5 cm., while that for the vertebral bodies was thought to be between 8 and 10 cm. The figure 5 cm. represents a guess which is based on the two values given above and on the proportion of blood-forming tissue estimated to be present in each. In the course of this discussion the question came up as to whether irradiation of part of the bone marrow was as serious as exposure of the entire bone marrow insofar as eventual development of leukemia is concerned. It was pointed out by Dr. Warren that acute localized radiation of up to 25 per cent of the marrow did not seem to cause leukemia, while exposure of the whole body resulted in this disease. Dr. Failla also said that mice in which irradiation was limited to the lower part of the body did not develop leukemia.

4. It was agreed that the unit of dosage to be used in describing permissible radiation exposures should be a roentgen equivalent physical value based on 93 ergs absorbed per gram of tissue, subject to subsequent revision by international agreement".

Although this unit is referred to in Dr. Failla's report as the "rep", it was agreed not to give a name to this unit since it would probably receive offical recognition and designation at the International Conference on Radiology next year.

5. It was agreed to differentiate between acute and chronic exposures without making an exact definition of each term. It was decided to express chronic exposures in terms of roentgen equivalent per week with no minimum time designated for the period of delivery of the weekly dosage.

Although Dr. Failla proposed limiting acute exposures to that amount of radiation received within a period of 24 hours, this was not accepted by the Committee. It seemed to be the consensus of the members of the Committee that acute exposure meant that amount of radiation received at a single sitting, although no formal vote was taken.

6. It was agreed that for chronic exposure of the total body to penetrating radiation, the maximum permissible dose shall be 0.3 rep per week as calculated for the critical tissue (bone marrow), or as measured in air. In the case of exposures limited to the hands and forearm, the maximum permissible dose was accepted as 1.5 rep per week measured at the basal layer of skin, which for purposes of calculation should be considered to be covered by a layer of epidermis equivalent in radiation absorption properties to 7 mg. per sq. cm.

It was further agreed that chronic exposure should be expressed on a weekly basis.

7. It was agreed that in the light of present knowledge, no manifest permanent injury is to be expected from a single exposure of the whole body to 25 r. or less, with a possible exception in the case of pregnant women.

Although Dr. Failla originally proposed that persons over 45 years of age could receive 50 r without suffering bodily damage, it was thought best by the Committee not to differentiate between older and younger persons. It was pointed out that in the United States of America persons under 18 years of age are excluded by law from occupations which involve exposure to radioactive materials. Therefore, at least in the United States of America persons under 18 years of age are excluded by law from occupations which involve exposure to radioactive materials. Therefore, at least in the United States, the above statement refers to persons over 18 years. While arriving at this figure of 25 r. as representing a non-damaging amount of total body radiation if delivered in a single exposure it was emphasized that this is not the value recommended by the Committee for the dose of radiation to be accepted in an emergency.

Dr. Edson stated that the policy of the United Kingdom was to allow a person to take up to 13 r. in one dose in case of emergency in a period of six months. The combined acute and further chronic exposure during this period, however, was not allowed to exceed this figure, which is based on 0.1 r. per day as the maximum permissible radiation skin dose regardless of whether the radiation dosage is protracted or given as a single exposure.

Dr. Lewis stated that the emergency dose in Canada was 10 r. It was agreed by the Committee that emergency doses had to be decided by administrative policy and that no recommendations would be made for safe single exposures other than that mentioned above.

8. The 300 rep limit of total life-time exposure to penetrating radiation mentioned in Dr. Failla's report was considered but not acted upon at this meeting. This value was chosen according to Dr. Failla, mainly in order to take into account the probable linear genetic effects of radiation. This dose was acceptable to the geneticists as long as it applied only to small proportions of the total population.

It was the feeling of the members of the Committee that the cumulative life-time dose did not require an immediate decision and could be considered again at a later date.

9. It was agreed that no relaxation of the standard permissible dose be allowed in the case of radiation of the head alone in view of the risk of cataract formation.

10. It was agreed to be unnecessary at the Conference to work out explicit figures

for maximum permissible fluxes for neutron exposures in view of the agreed figures for relative biological efficiencies.

Item 4 - Internal Irradiation

This item on the agenda was concerned with permissible exposure to radiation originating from internally deposited radioactive materials of several types. The discussion was led by Dr. Hamilton who reviewed briefly the metabolism of the most important fission products and alpha emitters. The values for absorption and tissue deposition used in this discussion were taken from his article published in the Review of Modern Physics, Volume 20, Page 718, October, 1948.

It was decided by the Committee to present in table form - 1. The minimal dose of radioactive isotopes known or estimated to cause damage when fixed in the body. 2. the best estimate of the safe dose; and 3. the maximum permissible concentration for inspired air and drinking water.

Internally deposited radium is the only radioisotope for which the minimal damaging dose in humans over a long period of time has been determined. The figures for the other radioisotopes are therefore based on a comparison with the minimal damaging dose of radium. Where there are animal experiments comparing the effects of radium with another element, the ratio of the damaging doses is used in estimating the minimal damaging dose of the element even though the ratio is based on acute experiments.

It was agreed that the best evidence from animal experiments indicates that Pu^{239} is 15 times and Po^{210} is 20 times as toxic as radium, curie for curie, both for acute and chronic effects. Hence it was deduced that the minimum damaging amounts would be 1/15 microcurie for Pu^{239} (= 1 microgram) and 1/20 microcurie for Po.

It was suggested that the best value for the minimal damaging amount of natural uranium is 120 micrograms of soluble compound on the basis of chemical toxicity, or 150 milligrams of insoluble compound on the basis of irradiation of the lung.

It was agreed that there are no convincing data available on thorium.

TABLE I

Amounts of Internally Deposited Radioisotopes
(Alpha Emitters and Fission Products)
and Maximum Permissible Doses in Inspired AIr and Drinking Water

Radioisotope	Known or Estimated Fixed Minimal Damaging Dose	(1) Best Estimate of Safe Dose Fixed in Body (Plant Personnel)	Maximum Permissible Dose	
			(2) In Air (24 Hr. Day)	In Drinking Water
Radium^{226}	1 μg (3)	0.1 μg	(8) 4×10^{-12} μg/cc	(8) 4×10^{-8} μg/cc
Uranium (natural)	-	-	(7) (1.7×10^{-11} μc/cc (25 $\mu g/m^3$	-
Uranium^{233}	6 μg (4)	0.6 μg	Soluble salts: 6×10^{-9} μg/cc Insoluble salts: 2.5×10^{-11} μg/cc	2×10^{-3} μg/cc
Plutonium^{239}	5 μg (5)	0.5 μg	2.5×10^{-11} μg/cc 1.5×10^{-12} μc/cc	2×10^{-5} μg/cc 1.2×10^{-6} μc/cc
Polonium^{210}	- (6)	-	-	-
Thorium^{234}	6-8 μc	0.6 - 0.8 μc	-	-
Strontium^{90}) Yttrium^{90})	10 μc (5)	1.0 μc	2×10^{-10} μc/cc	4×10^{-6} μc/cc
Strontium^{89}	20 μc	2 μc	-	-

(1) Maximum permissible dose for large center of population (10^7) is 1/100 of this amount.
(2) Where these values are based on a 30 year working time, 365 days/year, 24 hr. per day, they are not proposed as absolute working tolerances. Actual working tolerances should be calculated therefrom to fit actual working hours.
(3) Observations on exposed humans.
(4) Calculated on energy basis, using metabolism as the only experimentally determined factors.
(5) Based on experiments in animals comparing acute lethal effects of this isotope with radium (see p. 14 - 15.)
(6) We believe that available data are insufficient to justify setting a value.
(7) Based on New York Laboratory values for 8-hr. day exposures.
(8) We prefer not to accept these values for the present, pending re-survey of public water supplies in the United States, known to contain relatively high concentrations of radium (survey now in progress).

It was agreed that the minimum damaging amount of U^{233} in the body would, by analogy with Pu^{239}, be about 6 micrograms.

It was initially agreed that Th^{234} (i.e. UX$_1$ + UX$_2$) be considered in relation to Pu^{239}, making allowance for the ratio of the energies emitted and the r.b.e. factor of 20 for the alpha particles. This was stated to lead to a value of $\frac{5.5}{0.8} \times 20 \times 1 = 140$ microcuries for the minimum damaging amount of Th^{234} in the body. There would appear to have been a numerical error, however, in that the minimum damaging amount of Pu^{239} was taken as 1 microcurie instead of 1/16 microcurie. The correct value should therefore have been 8.5 microcuries of Th^{234}.

When the question of Sr^{89} and Sr^{90} was discussed, however, it was realized that the argument based on ratio of energy emission and r.b.e. in a comparison of the equivalence of a beta emitter in bone to an alpha emitter, may lead to values at variance with the experimental data on Sr^{89}. The latter data were preferred as a basis of calculation, and it was then suggested that Th^{234} be compared with Sr, but the actual alterations were not made in the figures. The final value for the minimum damaging amount of Th^{234} in the body should thus have been $\frac{0.5}{0.8} \times 10 = 6$ microcuries.

It was agreed that on the basis of comparisons of the acute and chronic toxicities in small animals of Sr^{89} and radium, the minimum damaging amount of Sr^{89} in the body be taken as 10 microcuries, while that of Sr^{90} be taken as 5 microcuries, to allow for the greater energy release from this isotope in combination with its daughter Y^{90}. It was noted that these amounts uniformly distributed in the skeleton of mass 7 kg. would give a dose of 0.03 rep per week.

It was agreed that it would be reasonably safe in the case of plant and other special workers to take the maximum permissible amounts of the above isotopes in the body as one tenth the above values for the minimum damaging amounts, i.e.

Ra^{226}	0.1 microgram
U^{233}	0.6 "
Pu^{239}	0.1 "
Po^{210}	0.005 microcuries
Sr^{89}	1.0 "
Sr^{90}	0.5 "
Th^{234}	14.0 "

It should be noted, however, that a numerical error exists in the Th^{234} which should have been 1 microcurie; while a more satisfactory estimate, which was proposed but not pursued, is 0.6 microcurie.

In the compilation of Table I an important policy was agreed upon by the Committee. This policy, which was proposed by Dr. Mitchell, concerned the exposure of large populations to radioactive materials such as might result from discharging the effluent from the plutonium plant at Harwell into the Thames River, above the source of the London water supply. It was agreed by the Committee that in cases where large centers ofpopulations were potentially exposed to radioactive materials the maximum permissible dose should be considerably lower than that for small numbers of people, such as project workers. Thus, in the case of large centers of populations of the order of 10^7 the maximum permissible dose fixed in the body should be one-hundredth of that for plant personnel. The reasoning behind this philosophy is that it has not definitely been established that all radiation reactions are threshold responses & therefore one must base exposures of large numbers of people on a possible linear type of response. The larger the number of exposed persons, the greater the probability of certain radiation effects such as bone tumors. Although agreement on this point was not unanimous, it was accepted by a majority vote.

It was the impression that the Conference wished to apply this ratio at the present time only to cases which could be considered parallel to radium toxicity and in which the limiting hazard is alleged to be the production of osteogenic sarcoma.

Considerable discussion was devoted to the question of radiation induced osteogenic sarcomas.

It should be pointed out at this time that the minimum damaging dose for radiostrontium varied by a factor of 15 depending upon whether one derives this value from energy relationships or if one used the ratios of toxicity of strontium and radium in animals. This emphasizes the speculative nature of many of these figures. There was also considerable discussion of the inaccuracy of calculations in those cases where insoluable particles, e.g., plutonium oxide, are retained in the lung or pulmonary lymph nodes. The dose calculations assume the tissue ionization to occur uniformly throughout the lung whereas actually the irradiation is limited to the tissue immediately adjacent to the particles.

The discussion of internal irradiation continued into the evening of September thirtieth, at which time Table II was drawn up. This table depicts the "safe" amounts of internally deposited radioisotopes and maximum permissible doses in inspired air and in drinking water. Although Column 2 "Best Estimate of Safe Internally Deposited Dose in Plant Personnel" was designated during the conference as "Maximum Permissible Dose of Plant Personnel", the present terminology was suggested after the meeting by Dr. Warren and Dr. Hempelman, to avoid having these values, which, after all, are based on very little experimental evidence, from being regarded as well-founded dosages. The figures in Table II for the estimates of safe dosages of these radioelements are based almost entirely on calculations from animal experiments of radiation dosagesin critical organs, since no human data were available.

All values for air and water concentrations in this as well as in Table I are based on assumed exposure of 24 rather than 8 hours per day.

TABLE II

Amounts of Internally Deposited Radioisotopes and Maximum Permissible Doses in Inspired Air and Drinking Water for Plant Personnel

Element	Best Estimate of Safe Dose (includes safety factors)	Maximum Permssible Dose*	
		In Air	In Water
$Hydrogen^{3}$	1 mc	1×10^{-6} μc/cc	1×10^{-2} μc/cc
$Carbon^{14}$	30 μc	1×10^{-6} μc/cc	--
$Sodium^{25}$	15 μc	1×10^{-6} μc/cc	.005 μc/cc
$Phosphorus^{32}$	10 μc	2×10^{-8} μc/cc	2×10^{-4} μc/cc
$Sulphur^{35}$	200 μc	1×10^{-6} μc/cc	10^{-2} μc/cc
$Argon^{41}$	--	10^{-6} μc/cc	--
$Iodine^{131}$	0.07 μc (thyroid) 0.1 μc (body)	1×10^{-9} μc/cc	10^{-5} μc/cc
$Cobalt^{60}$	1.0 μc	2×10^{-9} μc/cc	1×10^{-5} μc/cc
$Xenon^{133}$	--	1×10^{-5} μc/cc	--
$Xenon^{135}$	--	3×10^{-6} μc/cc	

* Based on 24-hour continuous exposure - not to be confused with periodic exposure such as occurs in clinical experimentation.

Notes and Comments on Table II.

H^3 Since the mean energy of H^3 is approximately 5 kev, the concentration per cc. of water to result in 0.3 rep/week is 0.23 μc/cc.

Hence, in a 70 kg. man, the total permissible amount of H^3 is approximately 70 x 0.23 = 10 mc. The alveolar air contains 50 mg. of water vapour per litre and hence the permissible concentration in inhaled air is:

$$0.23 \times 0.05 \times 10^{-3} \ \mu c/cc = 12 \times 10^{-6} \ \mu c/cc.$$

Note

The calculation above should be amended to take account of the water vapour content of exhaled air, rather than that of alveolar air, the former being about 50% of latter. Thus, the permissible concentration should be reduced to about 6.0×10^{-6} μc/cc.

Note further that possibility of isotopic dilution exists in relation to the other routes of water excretion, i.e. the concentration could be increased in proportion 2.5/0.4, leading to 22×10^{-6} μc/cc in inhaled air

An alternative approach is to consider the mean life of water in the body i.e. 50/2-1/2 = 2- day, so that concentration in inhaled air could be 25 μc/cc. Experimentally, the half-life of tritium water is said to be 6 or 7 days.

Safety factor - This discussion is in violation of the firm agreement to exhibit all added safety factors as such. Thus a value of 10 mc H^3 is the "just safe" dose which is comparable with 0.1 μc I^{131}. (comment by H. M. Parker)

APPENDIX

C^{14} as CO_2

The argument (presented by Dr. Brues) relating to C^{14} is as follows:

0.3 rep per week corresponds to 0.014 μc of C^{14} per gram of tissue. If the highest proportion of carbon in tissue is 10%, probably in bone carbonate (but note that average for Standard Man is 18%), then the maximum permissible concentration of C^{14} in carbon is 0.14 μc per gram of carbon. The postulated route of entry of C^{14} into the body is via the alveoli of the lungs, and, therefore the concentration of C^{14} in carbon in the alveolar air must not be greater than 0.14 μc per gram of carbon. Since alveolar air contains 5.5% of CO_2 (by volume), the maximum permissible concentration of C^{14} in alveolar air is:

$$\frac{0.14 \times 0.055 \times 12}{2.24 \times 10^4} \text{ per cc or } 4.1 \times 10^{-6}\ \mu c/cc.$$

Hence an upper limit to the permissible concentration of C^{14} in the atmosphere is 4×10^{-6} μc/cc. Since the concentration of C^{14} in the alveolar air may be expected to be somewhat less than in the atmosphere, the above figure has a small safety factor. On the other hand, the possible concentration of carbon in tissue might reach a value of up to 50% in fat, so that the permissible concentration above should be reduced by a factor of 5.

The figure of 10^{-6} μc/cc was accordingly felt to be reasonable.

Na^{24}

Assuming that the effective energy (beta and gamma) absorbed in the body is 2.7 MeV, the maximum permissible amount of Na^{24} in the body is 15 μc. Since the mean radioactive half-life is nearly 1 day, and since the biological excretion mean life is much greater (about 20 days), the maximum permissible daily intake is approximately 15 μc. Thus, for drinking water, the maximum permissible concentration of Na^{24} is approximately 0.005 μc/cc, and for air the maximum permissible concentration is approximately 10^{-6} μc/cc.

It may be noted that for total immersion the maximum permissible concentration for Na^{24} is approximately 10^{-4} μc/cc which is lower than the drinking water figure.

P^{32}

Since the mean energy of the P^{32} beta radiation is 0.7 MeV, the concentration in critical tissue to produce 0.3 rep/week is 1.1 μc/kg. Since it is known clinically that the concentration of P^{32} in bone marrow per gram reaches only about three times the average concentration for the whole body, most of the P^{32} is diffused throughout the whole body. If the relative concentration of three fold in red bone marrow is then allowed for, the mass of the critical tissue can be somewhat artificially expressed as 70/3 kg.

This argument would suggest a permissible amount of P^{32} in the body of approximately 25 μc. It may be that higher concentrations of P^{32} in bone marrow may obtain, and so a figure of 10 μc as maximum permissible amount was adopted.

The daily intakes in air and water were determined by assuming radioactive decay only. The figure given for air would appear to correspond nearly to complete retention, rather than 50% retention as agreed for soluble aerosols.

Since the mean energy of the S^{35} beta radiation is 0.17/3 MeV, the concentration in the critical tissue to give 0.3 rep/week is 14 μc/kg.

If the critical tissue were bone, then the maximum permissible amount would be approximately 100 μc; if liver, then 17 μc (a better figure would appear to be 23 μc); if skin, then 89 μc. It was therefore assumed that the total permissible body content would be 200 μc if there were equal concentrations in the three tissues mentioned. If radioactive decay only and 100% uptake is considered, the corresponding maximum permissible concentration of S^{35} in air would be 10^{-7} μc/cc and in drinking water 6.4 x 10^{-4} μc/cc.

The figures proposed, however, were 10^{-6} μc/cc for air, and 10^{-5} - 10^{-2} μc/cc for drinking water, and it is not clear how they were obtained.

A^{41}

The radiation hazard in the case of A^{41} is due to external irradiation.

Xe^{133}

The radiation hazard in the case of Xe^{133} is also believed to be determined by external irradiation. The concentration in fat would need to be about 10^4 times that in water, before internal radiation became a comparable hazard.

I^{131}

The effective total energy absorbed in the thyroid gland is 0.22 MeV so that a dose of 0.3 rep/week is produced by 3.5 x 10^{-3} μc per gram of tissue. Hence the maximum permissible amount of I^{131} in the thyroid is 0.06 μc. Since the half-life of iodine in the body excluding the thyroid is very much shorter than in the thyroid, it may be estimated that the total amount of iodine in the body corresponding to 0.07 μc in the thyroid alone is 0.1 μc. Assuming that 20% of absorbed iodine is deposited in the thyroid, the values for air and water concentrations are obtained.

Pu^{239} *

The maximum permissible amount fixed in the body is, by analogy with radium taken to be 0.5 μgm. For soluble compounds the evidence indicates that about 10% of the inhaled amount is retained. Assuming a mean life of 10^4 days (= 27 years), the maximum permissible concentration in air is 25 x 10^{-12} μgm/cc or 15 x 10^{-13} μc/cc. If the mean life in the lung for insoluble compounds is 200 days, the maximum permissible amount in air relative to lung irradiation is very considerably higher than for the soluble compounds. Thus the figure for soluble compounds was adopted for both cases.

For drinking water, a figure of 0.01% absorption and a mean life of 10^4 days leads to a figure of 20 x 10^{-5} μg/cc. In view of evidence that absorption may be higher than 0.01% at low concentrations, a safety factor of 10 was introduced, giving a final figure of 20 x 10^{-6} μg/cc or 12 x 10^{-7} μc/cc.

Co^{60}

All the Co absorbed is assumed to be deposited in the liver. The effective energy absorbed in the liver is assumed to be 1.3 MeV, so that the maximum permissible amount of

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Co^{60}

All the Co absorbed is assumed to be deposited in the liver. The effective energy absorbed in the liver is assumed to be 1.3 MeV, so that the maximum permissible amount of

Co^{60} in the liver is 1 μc. The half-life in the liver is 20 days so that the figures for water and air follow directly, assuming 100% and 50% absorption respectively.

U (natural)

The maximum permissible concentration for uranium compounds in air is taken to be 50 $\mu g/m^3$ on the basis of the chemical toxicity of the soluble compounds. This value was erroneously expressed as 3.3×10^{-11} μc/cc, whereas it should have been 1.7×10^{-11} μc/cc.

Ra^{226}

The maximum permissible amount fixed in the body is accepted to be 0.1 μg on clinical grounds. For inhalation of soluble compounds, a final retention of 12-1/2% was assumed and a mean life of 10^4 days (27 years), leading to a maximum permissible concentration in air for soluble compounds of 4×10^{-12} μg/cc.

For oral ingestion, a final retention of 10% was assumed, and a mean life of 27 years, leading to a maximum permissible level in drinking water of 4×10^{-8} μg/cc.

Sr^{90} (+ Y^{90})*

By analogy with radium, the maximum permissible amount of Sr^{90} in the body is taken to be 1.0 μc. The figures quoted for the levels in air and water would appear to correspond to a final retention of approximately 1%.

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* All values for Pu^{239} should be multiplied by 5, on the basis of the following reasoning:

The relative permissible values for plutonium and radium fixed in the body (0.1 microgram of each) were agreed upon at Chlak River on the basis of evidence presented by Dr. Brues that the toxicity ratio between equal microcurie amounts of plutonium and radium is approximately 15 to 1.

Further facts now presented by Dr. Brues lead to a greater permissible amount of Pu as compared to Ra, as follows:

1. The toxicity ratio of 15:1 was based on injected dose. But 75% of the plutionium is retained in the body of the rat, and 25% of the radium. This consideration leads to a factor of 3, making the toxicity ratio actually 5: 1.
2. Further, about 50% of the radon is retained in the human, but only 15-20% in the rodent, leading to another factor of about 2 in favor of plutonium. That is, the alpha energy delivered from the radium chain to the human is 4.8 + 0.5 (5.5 + 6.0 + 7.7) = 14.4 MeV and to the rodent is 4.8 + 0.15 (5.5 + 6.0 + 7.7) = 7.7 MeV

Hence, the "estimated fixed minimal damaging doses" of Pu for the human, based on 1 microgram of Ra is

$$1 \ \mu g \ \text{Ra} \quad 1 \ \mu g \ \text{Pu} \times \frac{24000}{1600} \times \frac{1}{15} \times \frac{1}{3} \times \frac{1}{2} = 6 \ \mu g \ \text{Pu}$$

The value of 0.5 μg Pu for the maximum permissible dose, as compared with 0.1 μg Ra, is therefore a conservative estimate.

On the basis of 0.5 μg Pu permissible dose, 10^4 days mean life, 10% retention and 20 cubic meters of air breathed per day, permissible air concentration becomes:

$$0.5\ \mu g\ Pu = conc \times 10^4\ days \times 20 \times 10^6\ cc/day \times 10\%$$
$$conc = 2.5 \times 10^{-11}\ \mu g\ Pu/cc$$
$$= 1.5 \times 10^{-12}\ \mu c\ Pu/cc$$

On the basis of 2.5 liters of drinking water per day for 10^4 days, and assuming 0.1% absorption at low concentrations, the permissible concentration of Pu in drinking water is

$$0.5\ \mu g\ Pu = conc \times 10^4\ days \times 2.5 \times 10^3\ cc/day \times .001$$
$$conc = 2 \times 10^{-5}\ \mu g\ Pu/cc$$
$$= 1.2 \times 10^{-6}\ \mu c/cc$$

Following is a preliminary report of the Chalk River Conference prepared in the AEC Division of Biology and Medicine. It is very nearly the same as the preceding version but is now included in case any small difference may carry some nuances of unsuspected significance.

L.S.T.

Langham to T. L. Shipman:

October 24, 1949

CHALK RIVER PERMISSIBLE DOSE CONFERENCE NOTES

For your information I have reproduced the preliminary report of the Chalk River Permissible Dose Conference held September 29-30, 1949. I have also included a table comparing the present Los Alamos tolerances with those adopted at the conference.

I wish to emphasize that this report is a preliminary one, and must not in any sense be considered otherwise. The plan of the conference was that the American delegation, the British delegation, and the Canadian delegation would each write a version of the meeting. The three versions would then be worked into a final report. The enclosed information represents a preliminary write-up of the American version by Shields Warren's office in Washington, and should not be considered as having any official status at the present time.

PERMISSIBLE DOSES CONFERENCE

Chalk River, September 29-30, 1949

The conference was formally opened by Dr. D. A. Keys who then turned the chair over to Dr. Shields Warren. The attendance was as follows:

United Kingdom	Prof. J. S. Mitchell Mr. A. C. Chamberlain Dr. G. J. Neary Dr. E. F. Edson
United States	Dr. Shields Warren Dr. G. O. Failla Dr. J. G. Hamilton Dr. L. Hempelmann Dr. H. M. Parker Dr. K. Z. Morgan Dr. B. S. Wolf Dr. Austin Brues Dr. L. S. Taylor Dr. Wright Langham Dr. D. Hoffman
Canada	Dr. W. B. Lewis Dr. A. J. Cipriani Dr. G. C. Laurence Dr. H. Carmichael Dr. G. H. Guest Dr. E. Renton Mr. G. E. McMurtrie Dr. A. O. Braaten

The Agenda for the meeting is appended.

Item 1--Standard Man: The "standard man" was first considered from the viewpoint of the mass of the organs and tissues. The discussion was based on the figures presented by H. Lisco in 1948 (ANL-4253) and these in turn included earlier estimates by both Lisco and Parker (1947) MDDC Report 783. In the course of the discussion it became apparent that while some rounding off of figures was desirable, nonetheless a reasonably close approproximation to the actual should be maintained. It was emphasized that the tissues of major importance were the skeleton, red bone marrow, liver, spleen, thyroid and lymphoid tissue.

The following figures were accepted:

Standard Man - Mass of Organs

Organs	Grams
Muscles	30,000
Skeleton, Bones	7,000
Red Marrow	1,500
Yellow Marrow	1,500
Blood	5,000
Gastrointestinal Tract	2,000
Lungs	1,000
Liver	1,700
Kidneys	300
Spleen	150
Pancreas	70
Thyroid	20
Testes	40
Heart	300
Lymphoid Tissue	700
Brain	1,500
Spinal Cord	30
Bladder	150
Salivary Glands	50
Eyes	30
Teeth	20
Prostate	20
Adrenals	20
Thymus	10
Skin and Subcutaneous Tissue	8,500
Other Tissues and Organs not Separately defined	8,390
Total Body Weight	70,000

After further discussion these figures were unanimously accepted. It was noted that figures were given only for males and it was agreed that this would be regarded as the standard for the present. Total blood is minus that small residual amount which cannot be extracted from the organs. The total blood volume constitutes 7.71% (5,400 gms.) of the total body weight. It is believed that additional data should be obtained relative to all these weights particularly in the case of the red bone marrow.

Secondly, the chemical composition of the human body was considered. The following values were accepted for the chemical composition of the standard man.

Standard Man -- Chemical composition of the human body.

	Per Cent	Approximate Amount in grams, in a 70 kg. Man
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulfur	0.25	175
Sodium	0.15	105
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

Practical Physiological Chemistry, Hawk, Oser & Summerson 12th Edition (1947)

The discussion brought out that the figures actually available were based on relatively few analyses and many analyses were made at a time forty or more years ago when the probability of errors in analysis were more likely.

Moreover, data is not available with regard to many of the trace elements in which we are particularly interested at the present time, specifically boron. The need for accurate data from the standpoint of elemental analysis hinges on possible total body neutron exposures. It is recommended by the Committee that elemental analyses be undertaken by organs, that full attention be given to the geographic, occupational and medical history of each subject.

It was further suggested that the U.K. group clear progress in this field with Dr. Mitchell, the Canadian group with Dr. Cipriani and the U.S. group with Dr. Morgan.

It was felt that in addition to information on the chemistry of the organs of the male, data on ovaries should be obtained. It was further recommended that the data be given by mass precent and by number of atoms per cubic centimeter. It was further suggested that analyses be made on complete homogenates rather than slices of organs.

The third aspect of the standard man to be considered was his applied physiology. All data suggested below are broad averages of normal activity in the temperate zone and do not allow for changes caused by abnormal circumstances or other environment. There was a discussion of the total water intake and after some variation in viewpoint the following figures were accepted for both water intake and water output:

Total Water Intake	2.5 liters	
In food	1.0 "	(including water of oxidation)
In fluid	1.5 "	
Total Water Output	2.5 liters	
Sweat	500 cc.	
Lungs	400 cc.	
Feces	100 cc.	
Urine	1,500 cc.	
Overall water content of body	50 liters (70% of 70 kg.)	

There was some discussion of the importance of the chemistry of water in which food was boiled. It was felt that this should not be taken into consideration here, but should be weighed when the factor of safety was taken into consideration.

In the discussion on respiration there was general agreement, with the exception of carbon dioxide in dry air where certain changes were made. The following tabulation was accepted:

Total surface area of respiratory tract	70 sq. meters
Respiratory interchange area	50 sq. meters
Non-respiratory area (upper tract, trachea, bronchioles)	20 sq. meters

Respiratory Exchange

Physical Activity	Hours/day	Tidal Air	Resp./min.	m^3 air/8 hr.	Total
At work	8	1 Liter	20	10	20
Not at work	16	0.5 "	20	5	m^3/day

Note: The 16 hours "not at work" is split up into 8 hours sleep and 8 hours incidental activities.

Carbon dioxide content of dry air

As inhaled	0.03%
Alveolar air	5.5%
Exhaled air	4.0%

The duration of occupational exposure in the standard man was considered, and it was agreed that

it be: 8 hours/day
40 hours/week
50 weeks/year (thus 2000 hours/year)

The typical mean duration of occupational contact with radiation was set at 20 years for the standard man. The lifetime of the standard man was then considered; for purposes of calculation the duration of life of the standard man is assumed to be 70 years.

The question of terminology was then considered and it was felt that the units at present used for definition of permissible values of radioactive substances vary so widely as to constitute a source of error and non-confidence. After considerable discussion the following recommendation was unanimously accepted. All formal statements shall be expressed in μc./cc or μc./g. whether in air, water or other medium. Where other units are now in use, the value of μc./cc. or μc./g. should be followed in brackets by its equivalent. A number of times in the discussion on the standard man, questions were raised as to whether organ weights or elemental composition should be considered as maximum or minimum rather than as mean weights in order to give a factor of safety to radiation dose calculations. It was unanimously agreed that safety factors should be clearly labeled as such and not incorporated in the data used for basic calculations such as in that given for the standard man.

In relation to the standard man, the retention of particulate matter in the lungs was considered at some length. Reference was made to UR.67 as one source of basic data. It was brought out that particulate matter varied greatly in size and in solubility. It was noted that particles of UF_6, 0.1 μ. or less in diameter, or Uranyl nitrate particles of 4 μ. or less diameter, were heavily retained in the lungs. That in the case of UF_6, those particles of 0.5 μ. in diameter were retained three times as much as those 1 micron in diameter.

A considerable discussion of the radiation hazard from exposure to Uranium followed. It was brought out that Joachmisthal miners developed lung cancer not in the alveoli, but in the bronchi, and after a mean occupational exposure of 17 years, Sikl assumed that radon was the chief hazard and Dr. Mitchell mentioned claculations he had made which indicate that these miners had got the equivalent of 2 to 3 r/day from inspired radon.

Dr. Hamilton cited a case of Yttrium oxide inhalation where 90% of the particles from 0.1 to 1 μ. were retained in the lung initially, but 80% appeared in the feces in the next 48 hours. After further discussion the following recommendation was unanimously adopted:

In calculating retention of particulate aerosols, it was accepted that for soluble particles, the retention would be considered to be 50%. for insoluble particles, 50% would be assumed to be trapped and remain in the lung for 24 hours; after 24 hours, 25% of inhaled insoluble particles would be considered to be retained.

In conjunction with this phase of the discussion, there was consdierable discussion of the hazards of radioactive particles. It was emphasized that radioactivity involving relatively minute masses of tissue does not have carcinogenic effect comparable to that of radiation involving large masses of tissue. In view of the importance of particle shape, it will be assumed that the particles of interest will be roughly spherical.

Just prior to the noon recess, the conferees inspected with much interest the various types of radiation measurement instruments in use at Chalk River.

Item 2--Relative Biological Effectiveness: This subject was discussed during the afternoon session of the first day's meeting. The definition of the term relative biological effectiveness was considered. It was agreed that this referred to the ratio between the quantity of different types of radiation (measured in ergs./gram) required to produce some biological effect. It was pointed out that the relative biological effectiveness of any given type of radiation may vary for different biological reactions and for acute and chronic forms of the same response. After considerable discussion it was agreed by the members of the committee to regard the effects of radium gamma rays (filtered by 0.5 mm. platinum) as unity and to compare all other measurements of relative biological effectiveness to this value. An objection to the use of gamma ray effect as unity was based on the fact that most of the data about chronic radiation effects on the bone marrow was gained by observation of persons exposed to 200 Kv x-rays and that the relative biological effectiveness for this response of gamma rays and x-rays has not been determined experimentally. The reason for choosing radium in spite of this objection was because of the convenience and reliability of radium sources and because of their wide acceptance as radiation standards. It was agreed by the committee to consider the relative biological effectiveness for the bone marrow effect of radium gamma rays and 200 Kv x-rays as 1:1, while that for acute skin effects is 1.5 as has been shown experimentally.

The following table for the relative biological effectiveness for bone marrow and skin effects of different types of radiations was approved by the Committee.

Type of Radiation	Bone Marrow	Skin
Alpha	20	
Beta	1	
Gamma (radium)	1	1
X-rays (200 Kv)	1	1.5
Fast neutrons	10	
Slow neutrons	5	
Protons	10	

The terms fast and slow neutrons in this table are used in the following arbitrary sense according to the agreement of the Committee: Fast neutrons are those whose biological action is due primarily to proton recoil effect while slow neutrons are those whose action on tissue results primarily from nuclear reaction. The principal change in the values for relative biological effectiveness occurs in that for the alpha particle. The relative biological effectiveness for this radiation is double its former value. The reason for increasing the figure is to maintain the same ratio between neutrons and alpha particles originally measured by Zirkle. In view of the recent data concerning the greater biological effectiveness of fast neutrons as compared to radium gamma rays and x-rays, it seems reasonable to raise this value for alpha particles on this scale even though this will modify the tolerance values for plutonium and other alpha emitters.

Item 3: The first subject of discussion on the second day, Friday, September thirtieth, was Item 3 on the Agenda, the Permissible Exposure to External Radiation. The discussion was lead by Dr. Failla and was based largely on a preliminary draft of a report of the Sub-committee on Permissible Dose from External Radiation of the U. S. National Committee on Radiation Protection. The philosophy expressed in this report, in brief, consists of basing the tolerance of externally originating radiation on the dosage delivered to certain critical tissues which appear to be most easily damaged. This concept was accepted by the Committee. (See Agreement 1.)

In the course of the morning discussion about permissible exposure to external radiation, it was necessary for the Committee to reach agreements on a number of subjects. The agreements are now given and some of the discussion on which they were based is mentioned.

1. It was agreed to regard the blood-forming organs as the critical tissue when the body is exposed to hard x-rays or gamma rays, while the skin is to be considered the critical tissue in the case of soft x-rays or beta rays.

This is in agreement with the proposal made by Dr. Failla in his preliminary report. Damage to the blood-forming organs caused by over-exposure to penetrating radiations over a period of many years is manifested by the development of leukemia, while epitheliomas are the end result of skin overexposure.

2. It was agreed for purposes of health monitoring that whole body radiation should normally be assumed for any radiation exposure other than that known to be limited to the hands and forearms.

It was decided to exclude diagnostic and therapeutic exposures to x-rays from this discussion.

3. It was agreed that for purposes of calculation the average depth of the blood-forming tissues should be considered to be 5 cm. below the skin surface.

It was pointed out in the discussion that blood formation in the marrow takes place in both the flat bones and in the vertebral bodies with little active blood formation normally taking place in the long bones. The average depth below the body surface of the marrow of the ribs and other flat bones was estimated by Dr. Warren to be approximately 1.5 cm., while that for the vertebral bodies was thought to be between 8 and 10 cm. The figure 5 cm. represents a guess which is based on the two values given above and on the proportion of blood-forming tissue estimated to be present in each. In the course of this discussion the question came up as to whether irradiation of part of the bone marrow was as serious as exposure of the entire bone marrow insofar as eventual development of leukemia is concerned. It was pointed out by Dr. Warren that acute localized radiation of up to 25 per cent of the marrow did not seem to cause leukemia, while exposure of the whole body resulted in this disease. Dr. Failla also said that mice in whom irradiation was limited to the lower part of the body did not develop leukemia.

4. It was agreed that the unit of dosage to be used in describing permissible radiation exposures should be a roentgen equivalent value based on 93 ergs. per gram energy absorption.

Although this unit is referred to in Dr. Failla's report as the "rem", it was agreed not to give a name to this unit since it would probably receive official recognition and designation at the International Conference on Radiology next year.

5. It was agreed to differentiate between acute and chronic exposures without making an exact definition of each term. It was decided to express chronic exposures in terms of roentgen equivalent

per week with no minimum time designated for the period of delivery of the weekly dosage.

Although Dr. Failla proposed limiting acute exposures to that amount of radiation received within a period of 24 hours, this was not accepted by the Committee. It seemed to be the consensus of the members of the Committee that acute exposure meant that amount of radiation received at a single sitting, although no formal vote was taken.

6. It was agreed that, for chronic exposure of the total body to penetrating radiation, the maximum permissible dose in the critical tissue (bone marrow) should be 0.3 rep. per week. This was accepted as being equivalent to a skin surface dose of 0.5 rep. per week for x-rays whose peak energy lay between the values of 0.3 and 3 mev. In the case of exposures limited to the hands and forearm, the maximum permissible dose was accepted as 1.5 rep. per week measured at the basal layer of the skin which for purposes of calculation should be considered to be covered by a layer of epidermis equivalent in radiation absorption properties to 7 mg. per square cm.

7. It was agreed that in the light of present knowledge no permanent injury is to be expected from an acute single exposure of a person to 25 r. or less with the possible exception of pregnant women.

Although Dr. Failla originally proposed that persons over 45 years of age could receive 50 r. without suffering bodily damage, it was thought best by the Committee not to differentiate between older and younger persons. It was pointed out that in the United States of America persons under 18 years of age are excluded by law from occupations which involve exposure to radioactive materials. Therefore, at least in the United States the above statement refers to persons over 18 years. While arriving at this figure of 25 r. as representing a non-damaging amount of total body radiation if delivered in a single exposure, it was emphasized that this is not the value recommended by the Committee for the dose of radiation to be accepted in an emergency. Dr. Edson stated that the policy of the United Kingdom was to allow a persons to take up to 13 r. in case of emergency in a period of six months. The combined acute and further chronic exposure during this period, however, was not allowed to exceed this figure, which is based on 0.1 r. per day as the maximum permissible radiation skin dose regardless of whether the radiation dosage is protracted or given as a single exposure. Dr. Lewis stated that the emergency dose in Canada was 10 r. It was agreed by the Committee that emergency doses had to be decided by administrative policy and that no recommendations would be made for safe single exposures other than that mentioned above.

8. The 300 rep. limit of total life-time exposure to penetrating radiation mentioned in Dr. Failla's report was considered but not acted upon at this meeting. This value was chosen according to Dr. Failla mainly in order to take into account the probably linear genetic effects of radiation. This dose was acceptable to the geneticists as long as it applied only to small proportions of the total population. It was the feeling of the members of the Committee that the cumulative life-time dose did not require an immediate decision and could be considered again at a later meeting.

9. The problem of tolerance for fast and slow neutrons was not discussed at this meeting.

Item 4: This item on the Agenda was concerend with permissible exposure to radiation originating from internally deposited radioactive materials of several types. The discussion was lead by Dr. Hamilton who reviewed briefly the metabolism of the most important fission products and alpha emitters. The values for absorption and tissue deposition used in this discussion were taken from his article published in the REIVEW OF MODERN PHYSICS, Volume 20, Page 718, October,1948. It was decided by the Committee to present in table from the minimal dose of radioactive isotopes known or estimated to cause damage when fixed in the body, the best estimate of the safe dose, and the maximum permissible concentration for inspired air and drinking water. Table 1 is appended.

Since internally deposited radium is the only radioisotope for which the minimal damaging doses in humans have been determined, it is obvious that most of the values are estimates. All of the figures are based on comparison with the minimal damaging dose of radium. Where there are animal experiments comparing the effects of radium and another element, the ratio of the damaging doses is used in estimating the minimal damaging dose of the element even though the ratio is based on acute experiments. Where such animal experiments are not available, the calculations of the minimal damaging dose fixed in the body of the radioisotope is based on the amount of the isotope known to be deposited in the critical tissue in animals (when human data are not available) and on the calculated radiation dosage derived therefrom extrapolated to humans.

In the case of most of the fission products and alpha emitters (Table 1) bone is the critical tissue and comparisons of radiation dosage can be made directly with the minimal fixed damaging dose of radium. It was arbitrarily decided upon by the Committee to consider the safe radiation dose in all cases in plants and under medical supervision as one-tenth of the known or estimated minimal damaging dose. The maximum permissible dose of radioisotope in the air and water is based on animal studies of the amount of material absorbed from the lung or gastrointestinal tract or deposited in the lung in the case of insoluble compounds. The only elements of this series in which studies of metabolism in humans have been carried out are uranium, plutonium and radium.

In the making of this table an important policy was agreed upon by the Committee. This policy, which was proposed by Dr. Mitchell, concerned the exposure of large populations to radioactive materials such as might result from discharging the effluent from the plutonium plant at Harwell into the Thames River, above the source of the London water supply. It was agreed by the Committee that in cases where large populations were potentially exposed to radioactive materials that the maximum permissible dose should be considerably lower than that for small numbers of people. Thus, in the case of large populations the maximum permissible dose fixed in the body should be one-hundredth of that for plant personnel. The reasoning behind this philosophy is that it has not definitely been established that all radiation reactions are threshold responses and therefore, one must base exposures of large numbers of people on a possible linear type of response. The larger the number of exposed persons, the greater the possibility of certain conceivable radiation effects such as bone tumors. Although agreement was not unanimous in favor of having two permissible doses, one for plant personnel and one for large populations, it was voted to follow this policy wherever possible.

Considerable discussion was devoted to the question as to whether osteogenic sarcomas might be due to radiation.

The method of calculation of the minimal damaging dose is indicated on the chart. It should be pointed out at this time that the minimal damaging dose for radiostrontium varied by a factor of 15, depending upon whether one derives this value from energy relationships or if one used the ratios of toxicity of strontium and radium in animals. This emphasizes the speculative nature of many of these figures. There was also considerable discussion of the inaccuracy of calculations in those cases where insoluble particles, e.g., plutonium oxide, are retained in the lung or pulmonary lymph nodes. The dose calculations assume the tissue ionization to occur uniformly throughout the lung whereas actually the irradiation is limited to the tissue immediately adjacent to the particles.

The discussion of internal irradiation continued into the evening of September thirtieth at which time Table 2 was drawn up. This table depicts the amounts of internally deposited radioisotopes and maximum permissible doses in inspired air and in drinking water. Although column 2, "Best Estimate of Safe Internally Deposited Dose in Plant Personnel" was designated during the conference at Maximum Permissible Dose of Plant Personnel, the present terminology was suggested after the meeting by Dr. Warren and Dr. Hempelmann, to avoid having these values which, after all, are based on very little experimental evidence, from being regarded as well-founded dosages. The figures for the estimates of safe dosages of these radioelements are based almost entirely on calculations from animal experiments of radiation dosages in critical organs since no human data were available.

All values for air and water concentrations in this, as well as in Table 1, are based on assumed exposure of 24 rather than 8 hours per day.

TABLE 1

Amounts of Internally Deposited Radioisotopes (Alpha Emitters and Fission Products) and Maximum Permissible Doses in Inspired Air and Drinking Water

Element	Known or Estimated Fixed Minimal Damaging Dose	Best Estimate of Safe Dose Fixed in Body: Plant Personnel	Best Estimate of Safe Dose Fixed in Body: Large Population	Maximum Permissible Dose * Plant Personnel: In Air	Maximum Permissible Dose * Plant Personnel: In Drinking Water
Radium^{226}	1 μgm**	0.1 μgm	.001 μgm	2×10^{-12} μgm/cc	4×10^{-8} μgm/cc
Radon^{222}	--	--	--	--	--
Uranium (nat.)	--	--	--	25 μgm/M^3 ++ or 1.65×10^{-11} μc/cc	--
Uranium^{233}	6 μgm +	0.6 μgm	0.0006 μgm	soluble salts: 6×10^{-9} μgm/cc insoluble salts: 2.5×10^{-11} μgm/cc	2×10^{-3} μgm/cc
Plutonium^{239}	1 μgm***	0.1 μgm	.001 μgm	5×10^{-12} μgm/cc	4×10^{-6} μgm/cc
Polonium	0.05 μc***	0.005 μc	5×10^{-5} μc	--	--
Thorium^{234}	5 μc+	0.5 μc	.005 μc	--	--
Strontium^{89}	10 μc	1 μc	.01 μc	--	--
Strontium^{90} and Ytterium^{90}	5 μc***	0.5 μc	.005 μc	10^{-10} μc/cc	2×10^{-6} μc/cc
Samarium^{90}	10 μc +	1 μc	0.01 μc	--	--

* Maximum permissible dose for large populations is 1/100th of this amount.
** Experimentally determined in humans.
*** Based on experiments in animals comparing acute lethal effects of this isotope with radium.

\+ Calculated on energy basis using metabolism in amounts as only experimentally determined factor.
++ Although the figure 50 μgm/M^3 or 3.3×10^{-11} μc/cc was given by Dr. Wolf at the time of the meeting, this was corrected later so as to take into account the 24-hour exposure rather than 8-hour exposure day.

TABLE 2

Amounts of Internally Deposited Radioisotopes and Maximum Permissible Doses in Inspired Air and Drinking Water For Plant Personnel

Element	Best Estimate of Safe Dose	Maximum Permissible Dose for Off-site Personnel (?) * In Air	In Water
Hydrogen^{3}	1 mc	1×10^{-6} μgm/cc	1×10^{-2} μc/cc
Carbon^{14}	30 μc	1×10^{-6} μgm/cc	---
Sodium^{24}	15 μc	1×10^{-6} μgm/cc	.005 μc/cc
Phosphorus^{32}	10 μc	2×10^{-8} μc/cc	2×10^{-4} μc/cc
Sulfur^{35}	200 μc	1×10^{-6} μc/cc	10^{-2} μc/cc
Argon^{41}**	---	10^{-6} μc/cc	---
Iodine^{131}	0.1 μc	1×10^{-9} μc/cc	10^{-5} μc/cc
Cobalt	1.0 μc	2×10^{-9} μc/cc	1×10^{-5} μc/cc

*Based on 24-hour continuous exposure--not to be confused with periodic exposure such as occurs in clinical experimentation.

**Based solely on calculations of gaseous exchange.

Table 3

A Comparison of Present Los Alamos Tolerances With Those Proposed by the American-British-Canadian Chalk River Conference Sept. 29-30, 1949

SUBSTANCE	PRESENT LOS ALAMOS TOLERANCES				A.B.C. COMMITTEE PROPOSALS*			
	Body Deposition	Urine d/m/24 hours	Air d/m/M^3	Water d/m/l.	Body Deposition	Urine d/m/24 hours	Air d/m/M^3	Water d/m/l.
Ra	0.1 μgm	---	---	---	0.1 μgm	---	4.4	88
Pu	1.0 μgm	14	70	1400	0.1 μgm	1.4	0.7	550
Po	0.2 μc.	500	1400	1400	0.005 μc.	12	36	---
$U^{(nat.)}$	---	300	400	---	(8.4 mg)	(6)	36	---
$U^{235} + 2\%^{234}$	---	300	400	---	(43 μgm)	(6)	Sol. salts 130 Insol. 0.6	(400)
U^{233}	---	300	400	---	0.6 μgm.	(6)	Sol. salts 130 Insol. 0.6	(400)
T	---	---	---	---	1 mc.	$(10^8?)$	2.2×10^6	2.2×10^7

*Values in parenthesis were not proposed at the conference, but were calculated from some conference-accepted value.

APPENDIX 15

UK - MINUTES OF CHALK RIVER CONFERENCE

NP/P/TD/122
(Nov 1949)

PERMISSIBLE DOSES CONFERENCE

Chalk River, September 29-30, 1949

Report of the United Kingdon Delegation

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AGENDA FOR THE CONFERENCE

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   b. Chemical composition
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2. Relative Biological Efficiency

   a. Beta Particles
   b. Protons
   c. Alpha Particles
   d. Fast Neutrons
   e. Slow Neutrons.

3. Permissible Exposure to External Radiation

   - X- and Gamma Rays, beta particles, fast neutrons, slow neutrons.

   a. Whole body, long continued exposure.
   b. Whole body, single exposure.
   c. Hands, long continued exposure.
   d. Head, long continued exposure.

4. Internal Irradiation by: -

   Group I Radium, Radon, Uranium, Plutonium, Thorium, Polonium
   Group II Fission Products
   Group III H^3, C^{14}, Na^{24}, P^{32}, S^{35}, A^{41}, Sr^{89}, Sr^{90}, I^{131}, Co^{60}.

   a. Amount of radioisotope permitted fixed in the body.
   b. Concentration of radioisotope permitted in inspired air.
   c. Concentration of radioisotope permitted in drinking water.

Present at Conference:

UNITED STATES.
Dr. Shields Warren (Chairman)
Dr. Austin M. Brues
Dr. G. Failla
Dr. J. G. Hamilton
Dr. L. Hempelmann
Dr. de Hoffmann (Secretary)
Dr. Wright Langham (Secretary)
Dr. K. Z. Morgan
Dr. H. M. Parker
Dr. L. S. Taylor
Dr. B. S. Wolf

CANADA.
Dr. W. B. Lewis
Dr. H. Carmichael
Dr. A. J. Cipriani
Dr. G. H. Guest
Dr. G. C. Laurence
Mr. G. E. McMurtrie (Secretary)
Col. C. A. Nelson
Dr. E. Renton
Dr. E. O. Braaten.

UNITED KINGDOM. Prof. J. S. Mitchell
Mr. A. C. Chamberlain
Dr. E. F. Edson
Dr. G. J. Neary (Secretary)

The Conference was formally opened by Dr. D. A. Keys, who, after welcoming the visitors to the Chalk River Establishment, asked Dr. Shields Warren to commence his duties as Chairman.

I. Standard Man

The desirability of adopting a common set of values for the basic anatomical and physiological data required in calculations of permissible levels was generally agreed, even though some of these values might have to be of a provisional character owing to lack of complete scientific information. It was agreed that the figures submitted by Dr. Cipriani should form the basis of the discussion.

(a) Mass of Organs

The figures presented were based on those of H. Lisco (ANL Report 4253, and "Science and Engineering of Nuclear Power", Vol. 2, 1949), which include some earlier estimates by Lisco and Parker (MDDC Report 783). There was considerable discussion of the importance of the variability of the masses of organs and tissues. Of various proposals, it was agreed that the most useful and practicable course was to give the average figures, and if necessary to consider the variability along with other factors of uncertainty when assessing the safety factor for any particular calculation. Furthermore it was agreed that while some rounding off of figures was desirable, a reasonably close approximation to the original values should be maintained.

Particular items in the table were next discussed in detail. The figure of 700g. adopted for lymphoid tissue was felt to be one of the more uncertain quantities. It was recognised that the thyroid is a very variable organ, its size showing an inverse correlation with the proximity to the sea. While the general opinion was that the mass lay between 20 and 30g., Dr. Morgan quoted figures obtained by Dr. Keating at the Mayo Clinic giving an average of 15g. Dr. Shields Warren said that the number of cases in this series was probably ten to twelve thousand. A figure of 20g. was finally adopted. The mass of the gastro-intestinal tract was also recognised to be a very variable quantity, about which there was not very extensive evidence. The figure of 2000g. which was adopted was understood to include the oesophagus. It was felt that since the average age of the population is 30 to 33 years, a figure of 10g. for the mass of the thymus gland would be reasonable, about two thirds of this being made up of fat and fibrous tissue. It was generally agreed that there was considerable uncertainty in the figures 1500g. each for red and for yellow bone marrow, and that further data were needed. The figure of 5000g. adopted for the total blood excludes that small residual amount of blood which cannot be extracted from the organs, and which is understood to be included in the figures for the masses of the organs themselves. Dr. Morgan quoted figures for the mass of the heart given by Dr. Keating from a series at the Mayo Clinic, namely 294g. in the male and 250g. in the female. Dr. Shields Warren pointed out that at necropsies any mass in excess of 350g. is generally regarded as abnormal. A value of 300g. was adopted. Dr. Cipriani's proposed values for the adrenal and prostate glands represent rounded off figures somewhat higher than Dr. Lisco's original, a procedure felt to be justifiable in view of the increase in mass of these glands with age. Finally it was agreed that the tabulation of the Standard Man could be confined to the male at present. The following values were then formally agreed.

I. Standard Man. (a) Mass of Organs

Organs	Grammes
Muscles	30,000
Skeleton, Bones	7,000
Red Marrow	1,500
Yellow Marrow	1,500
Blood	5,000
Gastro-intestinal tract	2,000
Lungs	1,000
Liver	1,700
Kidneys	300
Spleen	150
Pancreas	70
Thyroid	20
Testes	40
Heart	300
Lymphoid Tissue	700
Brain	1,500
Spinal cord	30
Bladder	150
Salivary Glands	50
Eyes	30
Teeth	20
Prostate	20
Adrenals	20
Thymus	10
Skin and subcutaneous tissues	8,500
Other tissues and organs not separately defined	8,390
Total Body Weight	70,000

(b) Chemical Composition

The figures for the chemical composition of the body presented for discussion by Dr. Cipriani are taken from "Practical Physiological Chemistry" by Hawk, Oser and Summerson (12th Edn. 1947). Professor Mitchell stated that the figures were in reasonable agreement with figures which he had proposed previously for neutron dosage calculations, but pointed out that the nitrogen content of dividing cells of the basal layer of the skin might be nearer 6%, rather than 3%. Dr. Brues commented that the normal carbon content of organs was about 12%, so that the figure of 18% presented here must include the fatty tissue of the body. Both these speakers and others emphasised the importance of the difference between the chemical composition of a given organ and the average for the whole body, and stressed the fact that very little detailed information exists. Much of that information was obtained a considerable time ago, before the development of modern analytical techniques, with a considerable possibility of error. Data on some of the trace elements, of importance for whole body slow neutron exposure, appear to be entirely lacking. Accordingly, it was agreed that each delegation should recommend that a large scale effort be made to obtain accurate data for the mass and the chemical composition of the organs and tissues of the human body, having regard to all the elements of possible importance in radiation effects. Normal organs, preferably from cases of sudden death should be examined, and analyses should be made on homogenised tissue and not merely on slices of organs. Full details of the geographic, occupational and medical history of each subject are desirable. It was felt that in addition to the organs and tissues tabulated above for the Standard Man, data on ovaries should be obtained. Dr. Morgan, Dr. Cipriani, and Prof. Mitchell agreed to be resonsible for liaison on these problems, and Dr. Morgan agreed to circulate the data he has already accumulated. For the present it was formally agreed to adopt the figures for chemical composition presented by Dr. Cipriani.

I. Standard Man (b) Chemical Composition of the Human Body

Element	Proportion Per cent	Approximate amount in grammes in a 70kg. man.
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulphur	0.25	175
Sodium	0.15	105
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

(c) Applied Physiology

It was formally agreed to adopt the data below as broad averages for normal activity in the temperate zone, recognising that changes caused by abnormal circumstances or environment are not allowed for:-

(i) Water balance

	Daily average.
Total Water Intake	2.5 litres
In food	1.0 litres (including water of oxidation)
As fluids	1.5 litres

It was agreed to base calculations of maximum permissible levels for radioactive isotopes in water on the 2.5 litres per day figure, recognising that in some cases a separate safety factor might be required to allow for the concentration of an isotope in the food from cooking water.

Total Water Output	2.5 litres
(Sweat	0.5 litres
(From lungs	0.4 "
(In faeces	0.1 "
(Urine	1.5 "
Overall water content of body	50 litres.

(ii) Respiration

Total surface area of respiratory tract 70 sq. metres

Respiratory interchange area ... 50 " "

Non-respiratory area (upper tract, trachea to bronchioles) ... 20 " "

Respiratory exchange

Physical Activity	Hours/day	Tidal air	Resp/min.	m^3 air/8 hrs.	Total
At work	8	1 litre	20	10	20 m^3/day
Not at work	16	0.5 litre	20	5	

Note: The 16 hours "not at work" is split up into 8 hours sleep and 8 hours incidental activities.

Carbon dioxide content of air

Inhaled air	...	0.3% (dry air, sea level)
Alveolar air	...	5.5%
Exhaled air	...	4.0% (depends on activity)

(iii) Duration of Occupational Exposure.

It was formally agreed to adopt the following figures for the duration of occupational exposure:

8 hours/day
40 hours/week
50 weeks/year (thus, 2000 hours/year)

The view was widely held that the adoption of a definite figure for the working lifetime for continuous occupational exposure to radiation might have undesirable psychological repercussions. At the same time, it was generally recognised that the proportion of workers receiving continuous occupational exposure to radiation for more than twenty years is likely to be small.

(iv) Duration of "Lifetime" for Non-occupational Exposure.

It was formally agreed that for the purposes of calculation the duration of life for the standard man be assumed to be 70 years.

(d) Standardised Terminology

It was agreed that all formal statements of permissible values should be expressed in microcuries per cubic centimetre (μc/cc) or microcuries per gramme (μc/g.) whether in air, water, or other medium. Where other units are now in use, the value in microcuries per cubic centimetre or microcuries per gramme should be followed in brackets by its equivalent.

(Note: It was generally understood that for the present the term "microcurie" would be interpreted as 3.7×10^4 disintegrations per second)

(e) Retention of Particulate Matter in the Lungs.

There was considerable discussion of several aspects of the general problem of hazard from inhalation of radioactive particulates.

On the question of the retention of such particulates, the influecne of size, surface area, and solubility were emphasized. Dr. Brues mentioned that, in general, retention was high for 1μ particles, but considerably lower for 10μ. Dr. Wolf mentioned the report UR67 from the Rochester group as a source of considerable experimental information. Particles of uranyl nitrate up to 4μ in diameter were heavily retained. The work of the Columbia group with ratioactive sodium has demonstrated that there may be a bimodal distribution of retention with particle size. Dr. Shields Warren pointed out that in cases of silicosis or asbestosis, very few particles greater than 1.5μ in diameter are found; it is also known that only a very small percentage of the inhaled material is permanently retained.

Long fibres of material are much less likely to be eliminated than large spherical particles. For example, particles 45μ in length may be found in cases of asbestosis or in the sugar cane disease bagassosis. Dr. Hamilton mentioned that insoluble particles of yttrium oxide (coated with gold) in the size range 0.1 to 1μ gave 95% immediate retention but after 24 hours, 75% of the material was eliminated in the faeces.

After further discussion, it was formally agreed that if specific data were lacking, the convention be adopted that 50% of any aerosol reaches the alveoli of the lungs. If the particles are soluble they are considered to be totally absorbed; if insoluble then the 50% amount is to be regarded as retained for 24 hours, after which only half of it, i.e. 25% of the inhaled amount, is retained in situ indefinitely; further that the particles be assumed spherical.

In relation to the possible pathological effects of radiation particulates in the lungs, Dr. Hamilton pointed out that the cells in the immediate neighbourhood of a dust particle containing 1 or 2% of plutonium would be subjected to a dose of about 400r/day. The general opinion which emerged from the discussion was that the carcinogenic effect per unit volume is probably considerably less for the irradiation of small masses of tissue than for large. Dr. Shields Warren pointed out that alveolar tumours do not normally occur. The lung tumours in the Joachimstahl miners are bronchogenic, and the mean latent period appears to be 17 years. The majority of investigators have regarded radon as the principal causative factor. Professor Mitchell mentioned that he had calculated that the radon level in the mines would, by the deposition of active decay products on bronchial epithelium, result in a dose of several roentgens per day to the latter.

A brief discussion of the proportion of insoluble particulate material transported from the lung to the lymph nodes merely served to indicate that this factor is rather dependent on the nature and size of the particles.

2. Relative Biological Efficiency

There was some initial discussion of the relative advantages of adopting 200kV X-rays or the radium gamma rays as the reference radiation for purposes of comparison. It was pointed out that there is probably a greater number of experimental comparisons of other radiations relative to X-rays, but on the other hand, the radium gamma rays provide a reference point of more definite character, and probably none of the radiations to be considered has a lower absolute biological efficiency than that of these rays. Moreover, a radium standard is more easily reproducible in the laboratory than an X-ray standard.

It was therefore formally agreed that the relative biological efficiency of any given radiation be defined by comparison with the gamma radiation from radium filtered by 0.5 millimetres of platinum, and measured as the inverse ratio of the doses in ergs per gramme of tissue required to produce equal biological effects of specified character. The need for considering relative biological efficiencies for a variety of different effects was mentioned, but it was not considered practicable to do more than consider chronic bone marrow and skin damage, to which a common set of relative efficiencies were regarded as applicable for purposes of calculation.

The relative biological efficiency of X-rays in the normal deep therapy region (i.e. around 200kV) was next considered, and Professor Mitchell pointed out that the production of skin erythema and the healing of malignant tumours, a value of 1.5 applied. For the production of leukaemia, it might well be that previous gross damage to the blood forming organs was necessary and that integral dose rather than dose to the bone marrow alone was involved. In view of the uncertainties, it was therefore formally agreed to take the relative biological efficiency of 200kV X-rays as unity. It was also agreed that this same value applied to beta radiation. In the discussion on heavy particle effects it was agreed that the relative biological efficiency for fast neutrons of energy not greater than 20 MeV be taken as 10. Dr. Failla felt that, for alpha particles, there was insufficient evidence to justify a figure as high as 35. Dr. Wright Langham mentioned that in studies of acute effects on the liver with plutonium and gamma radiation, a relative biological efficiency of 4½ had been found. Professor Mitchell pointed out that for the densely ionising particles, there was every reason to expect that the relative biological efficiencies would be considerably higher for chronic than for acute effects if these depended on the production of chromosome abberations, and there was some experimental evidence for this expected rise in efficiency; he proposed a figure of 20 for alpha particles. Dr. Hamilton commented that values for alpha particles and fast neutrons in the ratio of 20 to 10 would correspond with the data of Zirkle. When U^{235} in colloidal form was injected, it was deduced that the fission recoil particles were five times as efficient as fast neutrons. The practical and economic aspects of a figure of 20 for alpha particles were briefly considered after which it was formally agreed to adopt the value of 20 for the relative biological efficiency of alpha particles.

Protons were next discussed and it was pointed out by Dr. Laurence that there was some reason for taking a lower figure than for fast neutrons because for a given dose, there would be a greater number of protons involved in the second case and so a greater effect from the densely ionising regions at the end of the tracks. It was, however, finally agreed to take a value of 10 for the relative biological efficiency of protons. Since thermal neutrons produce their effect by a mixture of gamma and proton radiation, it was agreed to take a value of 5 for the relative biological efficiency.

These decisions on relative biological efficiency may be summarized thus:

Radiaton	Relative Biological Efficiency
Gamma rays from Radium (0.5 mm. Pt)	1
X rays around 200kV	1
Beta radiation	1
Protons	10
Fast neutrons of energy not greater than 20 MeV	10
Alpha radiation	20
Thermal neutrons	5

3. Permissible Exposure to External Radiation

Dr. Failla offered as a basis for discussion a preliminary draft of a report which he had prepared for submission to his Sub-Comittee on Permissible Dose from External Radiation of the National Committee on Radiation Protection and this was accepted. The question of the unit in terms of which the dose should be expressed was discussed, and it was formally agreed to adopt the "rep", defined as 93 ergs per gramme of tissue, subject to subsequent revision by international agreement. It was further agreed that chronic exposure be expressed on weekly basis.

It was also agreed that any recommendation on maximum permissible exposure for external radiation made at this conference was not intended to apply to diagnostic and therapeutic irradiation. The question of what constituted "whole body" exposure was carefully considered. Professor Mitchell stated that in radiotherapeutic experience, irradiation of more than half the trunk is effectively whole body irradiation. Dr. Hamilton pointed out that the therapeutic irradiation of a fairly limited area, even to high doses, does not have consequences at all comparable to those of whole body irradiation. In this connection, Dr. Shields Warren remarked that this was still true for very protracted irradiations, for example, the treatment of carcinoma of the breast may extend over 3½ years. There was general agreement that irradiation of the hands and forearms does not constitute a whole-body irradiation, and sveral other examples were cited. It was felt, however, to be impracticable to include in a definition all the various possibilities and so it was formally agreed that for the purpose of health monitoring whole body exposure should normally be assumed for exposure other than on the hands and forearms. It was clearly understood, however, that this was merely a working convention adopted without prejudice to the medico-legal aspects of any particular instance which might arise. Dr. Shields Warren expressed the opinion that if an irradiation is known to involve less than one third of the body, it need not be regarded as "whole-body". It was understood that in such circumstances, the dose could not be increased pro rata.

Following Dr. Failla's proposal, it was formally agreed that for any exposure to external penetrating radiation, the blood forming organs should be regarded as the critical tissue, the principle hazard probably being leukaemia. The estimated depth of the blood-forming organs for purposes of calculation was next discussed. Dr. Shields Warren stated that leukaemia probably arises out of changes in the marrow and spleen and rarely in the lymph nodes primarily; Professor Mitchell and Dr. Cipriani concurred. The question of the importance of variation of the dose to different parts of the marrow was discussed. Dr. Shields Warren stated that normally there is not much functioning red marrow in the long bones. He proposed, and it was formally agreed that for purposes of calculation, the blood forming organs be assumed to lie at an effective depth of 5 centimetres.

Dr. Failla then proposed that the maximum permissible exposure for external penetrating radiation should correspond to a dose of 0.3 rep/week to the critical tissue (bone marrow). In the discussion it was noted that the existing U.S. recommendation of a weekly surface dose of 0.3r measured in air is approximately equivalent to the British figure of 0.5r measured at the surface of the body (i.e. with backscatter) and that both are approximately equivalent to a dose of 0.3 rep to the bone marrow. It was therefore formally agreed that the maximum permissible dose for exposure to external penetrating radiation be 0.3 rep. per week to the critical tissue, corresponding approximately to 0.5 rep per week to the surface of the body when measured with backscatter and 0.3 rep. per week when measured in air. It was also agreed that the maximum permissible dose for internal radiation should be 0.3 rep. per week to the critical tissue, except in cases where experimental evidence exists to show that some other criterion is more suitable. It was emphasized that the permissible dose referred to the energy absorption in the critical tissue itself, and that in principle, the measurement of the dose would be made in a small cavity ionisation chamber with walls equivalent in composition to the tissue in question. The question of lifetime dose was considered and Dr. Failla proposed a figure of 300 rep. to the blood forming organs: he stated that he desirability of some such figure depended partly on genetical considerations. Dr. Shields Warren suggested that the genetic argument is already met by the fact that by the time a dose of 300 rep. has been accumulated, most people will have passed the active reproductive period. Dr. Hamilton mentioned the difficulty of the large numbers of existing workers who may have already approached or even exceeded the dose in question. Dr. Parker asked about the possible shortening of life span in relation to total accumulated dose. Dr. Shields Warren pointed out that the application of the data from animal experiments on this subject to the problem of their permissible dose for man involved a considerable extrapolation. The more direct evidence is the fact that the average life of radiologists is equal to that of other medical specialists. It was finally agreed to leave open the question of a maximum lifetime dose.

It was formally agreed that for external irradiation by beta rays, the skin be regarded as the critical tissue.

It was also agreed that for purposes of calculation the depth of the critical tissue, namely the basal layer of the epidermis be assumed to correspond to 7 mg/cm^2.

It was further agreed that for external whole body irradiation by beta rays, the maximum permissible dose be 0.5 rep per week to the basal layer of the epidermis.

It was agreed to be unnecessary at the Conference to work out explicit figures for maximum permissible fluxes for neutron exposures in view of the agreed figures for relative biological efficiencies.

The exposure of the hands alone was discussed and Dr. Failla proposed a maximum weekly dose of 1.5 rep. stating that doses of less than 10 or 15 r/week produce no observable changes in the fingers. Professor Mitchell mentioned that radium surgeons commonly exceed the figure of 1.5 rep. per week, but that they accepted the risk consciously. Dr. Braaten doubted whether radium factories could be operated at this level, in view of the fact that the wrist films at present indicate 10 rep. per week. The possibility that some of this apparent dose might be due to blackening of the film by contamination was mentioned. Dr. Parker stated that there is definite evidence of damage to the hands at a dose level of 4 rep per week. Finally it was agreed that for external radiation of the hands by X, gamma or beta irradiation the maximum permissible dose be 1.5 rep. per week. Arising out of the same discussion it was agreed that no relaxation of the standard permissible dose could be allowed in the case of irradiation of the head alone in view of the risk of cataract formation.

The maximum permissible dose in a single exposure was next discussed. Dr. Failla proposed the figures of 25 rep for a person under the age of 45 and 50 rep over this age. Professor Mitchell stated the view of the Medical Research Council's Tolerances Doses Panel that the single emergency dose be not greater than 10r. and that the total dose in any period of six months should not exceed the normal maximum permissible average of 13r. Dr. Lewis stated that in the Chalk River Establishment, a single dose of 10r. was the limit in extreme emergencies. Dr. Parker felt doubtful whether any relaxation of the normal restrictions was needed for atomic energy plants. Dr. Shields Warren said it was clear that all were agreed that single high exposures should be limited to grave emergencies. A variety of different eventualities might arise, but as the problems were largely administrative, he felt that the details need not be discussed at the Conference. On the other hand, a problem of general interest, for example to Civil Defense Authorities, was the assessment of the single dose which will produce no permanent harm. The N.E.P.A. report summarizes some of the basic information. The LD 50 dose for man is around 400r, and at this dose a person would be rapidly incapacitated. Professor Mitchell stated that a consideration of mortality probits as a function of the logarithm of the dose and of the integral dose, and certain clinical data, would lead to a figure of 25r, in agreement with Dr. Failla's proposal. In the ensuing discussion there was some question as to whether a smaller limit was needed for children and women, and it was noted that in the U.S. atomic energy plants no person under the age of 18 is employed. Dr. Morgan mentioned the observation of Jacobson that a dose of 50r given in 4 hours to mice aged 5 months was followed by a significant increase in ovarian tumours. The general opinion seemed to be that mice are probably peculiar among mammals in this respect, and that the observation had no significance for the present problem of the permissible single dose for women.

After some further discussion it was agreed that in the light of present knowledge, no manifest permanent injury is to be expected for a single exposure, of the whole body to 25 rep. or less, with a possible exception in the case of pregnant women. It was generally understood but not specifically stated that such exposure was contemplated once only in a lifetime.

4. Permissible Exposure to Internal Irradiation

Dr. Hamilton introduced the subject of hazards from internal irradiation with a brief survey of his resutls on the metabolism of fission products and radioactive elements in animals, reported in Reviews of Modern Physics, Volume 20, No. 4., from which he reproduced the following table.

Radioelement	Oral Absorption	Organ and Percentage deposition	Biological Half-life
Sr^{89}, Sr^{90}, Ba^{140}	5 - 60%	Bone, 60 - 70%	>200 days
Y^{91}, Zr^{95}, La^{140} Ce^{144}, Pr^{143} Nd^{147}, Pm^{147}	<0.05%	Bone, 25 - 70%	>100 days
La^{140}, Ce^{144} Pr^{143}, Nd^{147} Pm^{147}	<0.05%	Liver, 50 - 70%	10 days
Cb^{95}	<0.05%	Bone, 30%	30 days
Ru^{106}	0.05%	Kidney, 3.5%	20 days
I^{131}	100%	Thyroid, 20%	>30 days
Cs^{135}	100%	Muscle, 45%	15 days
Xe^{133}	-	~ Fat Content	2 hours
U^{233}	<0.05%	Bone, 20%	60 days
Pu^{239}	0.007%	Bone, 75%	>2 years

Note: The biological half life is calculated independently of the radioactive decay.

Some 80% of the total energy of mixed fission products is associated with the group of elements which concentrate in the skeleton, Sr, Ba, Y, Zr, Cb, La, Ce, Pr, Nd, Pm, Sm, Eu. The deposition in bone is about 70% for Y and Zr, and about 25% for the other elements in this group. The alpha emitting isotopes, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, are also concentrated in the skeleton. All the bone seeking elements have long biological half lives. A number of these isotopes are also concentrated in the liver, including La, Ce, Pr, Nd, Pm, Sm, Eu among the beta emitters and Ac, Am, Cm among the alpha emitters. Ruthenium and uranium are concentrated in the kidney, and iodine in the thyroid. The absorption of Sr following the inhalation of soluble compounds is probably about 50%. In young animals 16 days after the administration of Sr, the distribution in the skeleton was found to be uniform, but in older animals a much longer period is necessary for transport of the element from the periosteal and enosteal surfaces into the mineral bone. The elements Ac, Am and Cm, which are trivalent show a spotty distribution in bone like that of Ce and other rare earths, due to the deposition in blood vessels in the compact bone; there is deposition in trabecular bone also. The radioautographs for thorium are indistinguishable from those for plutonium. Radium D in adult female rats gave similar distribution, as did radium itself but with the latter, transference into mineral bone was commencing.

The absorption of plutonium from the gastro-intestinal tract was next discussed. The experiments of Dr. Wright Langham gave a figure of 0.01% while those of Dr. Brues gave the same order. Dr. Parker said that his experiments had indicated an increased absorption at low ionic concentrations. For example, rats given a dose of 4×10^{-5} μg per day, of Pu^{238} in 400λ solution with 0.5 ml. of wash water for 20 days showed an absorption of 0.02%, while at 1×10^{-5}μg per day the absorption was 0.1%. Dr. Wright Langham stated that one person drank a solution of Pu^{239} at about the "tolerance" concentration and found all the material in the faeces. This suggests that absorption in man is less than in the rat. Dr. Hamilton gave some data obtained by the intravenous injection into a man of a mixture of Pu^{239} and Pu^{238} equivalent in activity in 50μg of Pu^{239}. The excretion in the urine and also in the faeces were each about 0.01% per day at 16 days, while at 256 days the daily urinary excretion was slightly more than 0.001% and the faecal excretion 0.0004%. In rats, the faecal excretion alone at 256 days was 0.01 to 0.02% per day, so that the human figures are about one tenth the rat figures. Dr. Wright Langham confirmed that he had found comparable figures. Dr. Parker mentioned the case of a man exposed 4 years ago, with a dose of 2μg. The present excretion rate agrees with Dr. Langham's formula and corresponds to a biological half-life of 10^5 years.

Dr. Hamilton then referred to data on radium indicating 5~20% oral absorption and 30 or 40% of the absorbed amount retained in the skeleton with a very long biological half life. Dr. Hempelmann stated that one year after intravenous injection, 90 to 95% was excreted. Dr. Hamilton showed radio-autographs of the thyroid tissue of animals injected with astatine, the short lived alpha emitter which is chemically a member of the halogen group of elements. One third to one fifth of the material concentrates in the thyroid. Profound histological changes are apparent one month after doses between 2000 and 7000 rep. while complete destruction follows doses between 10,000 and 35,000 rep. Such data might give interesting evidence on the relative biological efficiency of alpha radiation.

Dr. Shields Warren next proposed that the elements set down in the agenda be considered individually.

Group I

Ra^{226}, Ur(natural) Ur^{233}, Pu^{239}, Th^{232} (natural), Th^{234} (UX_1) Po^{210}

The discussion was initiated by Professor Mitchell who outlined the standpoint taken up by the Medical Research Council's Tolerance Doses Panel. For the evaluation of the hazards from bone seeking isotopes, radium is regarded as the crucial isotope, because clinical data exists only for radium, while an estimate for several of the other isotopes may be made from the experimental data on the relative toxicities of these isotopes and radium. If 1μg often proposed as a "tolerance" figure, the incidence of disease might be of the order of 0.1%, though it would probably be lower. This level of 0.1μgm. had in fact been adopted provisionally by the Medical Research Council for plant operatives and other special workers under continuous medical supervision. In the case of a large population, such as the ten million persons in London dependent for drinking water on the river Thames which takes a limited amount of effluent from the establishment at Harwell, it seemed essential to introduce a further factor of 100 to provide reasonable safety. A short discussion followed of the general implications of such a viewpoint. Dr. Brues felt that a factor of the order of 100 was reasonable for large populations. The practical difficulties of monitoring at the low levels of activity involved was mentioned and it was pointed out by Mr. Chamberlain that it was necessary to monitor the effluent before dilution in the river, etc. Dr. Morgan gave examples of certain springs with concentrations of activity a billion times higher than those proposed by the Medical Research Council's Panel. Dr. Failla drew attention to a feature of the data from the luminising workers which was not normally considered, namely, that the radium content was in many cases measured when symptoms of injury had appeared. The quantity of radium held in the body would have been considerably higher initially and it was not certain whether the pathological effects were to be correlated with the radium content at some previous epoch. Dr. Brues stated that about 1% of cases with 1μg of radium fixed in the body would be likely to show some bone damage on radiological examination. It was agreed that 1μg might reasonably be regarded as the minimum amount of radium known to produce damage, and it was decided that before the question of safety factors was considered, the equivalent amounts for the other isotopes should be evaluated.

Dr. Hamilton stated that the hazard from natural uranium is mainly chemical; there is some evidence that U^{233} concentrates in cancellous bone and so it might be reasonable to consider the irradiation of the red bone marrow, since, the yellow marrow is mainly in the hollow portion of the shaft. Alternatively, it might be argued that the U^{233} hazard should be evaluated from a consideration of the data on acute toxicities and equivalence to radium. Dr. Brues stated that for acute lethal effects, Pu^{239} is 15 times and Po^{210} is 20 times as toxic as radium measured in terms of activity. Dr. Hamilton pointed out that for chronic effects, the radium is more uniformly distributed in the bone and so even higher equivalence figures might be expected. Dr. Wright Langham pointed out on the other hand that for sub-acute lethal effects, plutonium had appeared relatively less effective. Dr. Brues said that it was not certain how the chronic toxicity would vary from acute toxicity but for the production of tumours, the evidence did not warrant the adoption of a lower relative efficiency. Dr. Wright Langham was in favour of calculating the permissible levels for all the elements on the basis of radiation energy absorption, but it was pointed out that this gives results at variance with the experimentally determined equivalence for radium and strontium. Mr. Chamberlain stated that a dose of 0.3 biologically equivalent roentgens would be produced by 2×10^{-2}μg of radium distributed throughout the 7 kg. skeleton assuming an effective energy per disintegration of 15 MeV and a relative biological efficiency for alpha particles of 20. Dr. Failla remarked that the distribution of radium in bone is not uniform even 10 years after ceasing radium work, while Dr. Wright Langham mentioned a case examined by Professor Robley Evans in which seven bone samples gave an average concentration twice that for the whole skeleton. He therefore urged that in assessing the equivalent quantities of isotopes known to be deposited non-uniformly, care be taken to avoid over-estimating the safety factors. He knew of 12 cases with 5μg of plutonium, 12 with 1μg and 26 with 0.3μg, all without ill effects, while Dr. Hamilton's case had the equivalent of 50μg. Dr. Shields Warren summed up this discussion by saying that at present there is insufficient direct evidence for man, and that the data from animal experiments has still to be relied on. It should therefore be assumed that the minimum damaging amount of material fixed in the body is 1μg for plutonium just as for radium, the risk being of the order of 1 per cent.

In the discussion on polonium it emerged that there was no known case of damage in man. Dr. Lewis proposed that 0.05μc be adopted as the minimum damaging amount, but Dr. Wright Langham observed that the kidney has a higher concentration than the bone and that the maximum histological damage occurs in that organ; it was not clear what the chronic effects from polonium would be. Dr. Hamilton proposed that U^{233} be considered as equivalent to plutonium, so that allowing for the difference in the radioactive half lives, the minimum damaging amount would be about 6μg. Dr. Wolf observed that for chronic exposure to natural uranium, the concentration in bone is about three times that in the kidney;

the biological half-life is about 300 days. Dr. Hamilton doubted whether these data would apply exactly to U^{233}, where the gross chemical quantities involved are so much smaller. Dr. Shields Warren summed up this phase of the discussion, saying that there appeared to be no choice but to accept figures of 0.05μc for Po^{210} and 6μg for U^{233}. Professor Mitchell said that in the United Kingdom, there are no known cases of occupational disease attributable to natural thorium dioxide. Dr. Wolf confirmed that a survey in the U.S. had revealed no cases. Dr. Shields Warren stated that observations with thorotrast in animals were of doubtful applicability to the present problem; injections of an apparently inert substance like indian ink may produce tumours. It seemed best to leave thorium aside for the present. Dr. Hamilton pointed out that Th^{234} (i.e. Ux_1) is exactly similar metabolically to Pu. He therefore proposed that, allowing for the average energy of the beta radiation which is 0.8 MeV. as against 5.5 MeV for the alpha radiation from plutonium, and taking a relative biological efficiency of 20 for the alpha radiation, the minimum damaging amount of Th^{234} be taken as 140μc (Secretary's note: an arithmetical slip entered here because the minimum damaging amount of plutonium was taken as 1μc instead of 1μg; the figure for Th^{234} should therefore have been ~8μc). Dr. Wolf stated that for soluble compounds of natural uranium the principal hazard is chemical, and 120μg fixed in the kidney appears to be the minimum injurious amount; for insoluble compounds the principal hazard would appear to be radiation effects from particles fixed in the lung. A dose of 0.3 biologically equivalent roentgens per week would be produced by 150 mg. of uranium in the lungs.

It was then formally agreed to adopt the following figures for the minimum damaging amounts of material continuously present in the body:

	Ra^{226}	1 microgramme
	Pu^{239}	1 "
	U^{233}	6 "
	Po^{210}	0.05 microcurie
x	Th^{234}	140 "

x Note: the figure should have been 8μc.

The meeting then proceeded to consider how maximum permissible amounts of material should be deduced from the foregoing minimum damaging amounts. Dr. Parker said he was not in favour of having two different sets of figures, one for plant workers and the other for the general population, and after some general discussion it was decided to consider the former class first. The present figure for radium of 0.1μg corresponds to a safety factor of 10 and it was suggested by Dr. Hamilton that by comparison with the practice for other noxious agents, such a factor was reasonable. Dr. Lewis on the other hand felt that if the relation between damage and "dose" were indeed linear for radium, then the factor of 10 does not represent a very great margin of safety; after further discussion, Dr. Edson proposed that a factor of 10 be adopted, and this was formally agreed, leading to the figures:

Maximum Permissible Amounts of Isotopes continuously present in the Body, for Plant and other special workers.

	Ra^{226}	... ...	0.1 microgramme
	Pu^{239}	... ...	0.1 "
	U^{233}	... ...	0.6 "
	Po^{210}	... ...	0.005 microcurie
x	Th^{234}	... ...	14

x Note: the figure should have been 0.8μc.

The question of the general population was not reconsidered, and Dr. Shields Warren pointed out that the Columbia River and the Clinch River presented problems comparable with those of the River Thames. Dr. Brues said that the magnitude of the safety factor required for the general population, depended on the avoidance of a statistically significant increase of pathological effects. Consequently, since it could not be ruled out that such effects were linearly related to the dose, he would propose a safety factor of 10 for populations of the order of 10^5 and 100 for populations of the order of 10^7 on the figures accepted for plant and other special workers. He considered that it would be unsafe to draw conclusions from the existence of natural waters with very high radioactive content, since the populations exposed to such waters were very limited. He felt it was undesirable to double the natural radium content of the skeleton. Professor Mitchell referred to the recent work of Dr. Bale and Dr. Hursh indicating a radium content of the skeleton of the order of $2 \times 10^{-4}\mu g$. He felt that an increase of 10 on that figure was the absolute limit of what was justifiable. The question of a possible correlation between the natural incidence of osteogenic sarcoma and the natural radium content of the skeleton was mentioned, and Dr. Hamilton suggested that the idea was not in accord with the fact that the disease occurred predominantly in young people. Dr. Brues quoted Swedish statistics, and Dr. Neary quoted British statistics showing that the peak of incidence in youth is followed by a greater rise in middle and old age. Dr. Warren pointed out that this latter effect is related to the appearance of Paget's disease of bone (osteitis deformans) in later life, which appears to be associated with metabolic changes unconnected with radioactive effects. The practicability of proposals based on the large safety factor, and the difficulty of public opinion on the existence of different levels for different sections of the population were mentioned. At this point, Dr. Brues reminded the meeting that the Medical Research Council's proposals for the River Thames were confidential. Mr. Chamberlain stated that the proposals for the River Thames are practicable. He pointed out that in the neighbourhood of a plant, it is impossible to draw a hard and fast defining line between the plant population and the general population. A proposal to apply a safety factor of 100 to say the gaseous effluent from a plant would certainly not be practicable.

Finally, it was formally agreed that a safety factor of 100 on the permissible levels for plant and other special workers should be applied when dealing with all large centres of population.

The following figures were therefore adopted:

Maximum Permissible Amounts of Isotopes continuously Present in the Body, for all large centres of population.

	Ra^{226}	... ...	0.001 microgramme
	Pu^{239}	... ...	0.001 "
	U^{233}	... ...	0.006 "
	Po^{210}	... ...	0.00005 microcurie.
x	T^{234}	... ...	0.14 "

x Note: the figure should have been 0.008 μc.

Group II

Fission Products.

In view of the limitations of time, it was decided to consider only the most dangerous of the fission products, namely, strontium. Dr. Hamilton observed that the mean energy per disintegration of $Sr^{90} + Y^{90}$ is 1.1 MeV, or about one fifteenth of the effective energy for radium in the skeleton. Then the relative biological efficiencies are also taken into account, the ratio of biologically equivalent amounts (in curies) of Sr^{90} and radium would appear to be 300. Dr. Brues pointed out however that acute toxic effect and the carcinogenic effect in animals gave a ratio of only 10 for Sr^{89} which would indicate a ratio of approximately 20 for $Sr^{90} + Y^{90}$. Mr. Chamberlain said that some of the alpha radiation is effectually expended in mineral bone and so if the harmful effect of radiation is dependent on integral dose as well as on the dose at particular points an extrapolation on energy grounds is unsound. Dr. Shields Warren stated that the mean diameter of the trabeculae in man is 30 to 35μ. Dr. Hamilton then observed that it would have been better to consider Th^{234} (UX_1) in relation to the strontium data rather than the plutonium data (Secretary's Note: if this were done, then the minimum damaging amount of Th^{234} (UX_1) in relation to the strontium data rather than the plutonium data (Secretary's Note: if this were done, then the minimum damaging amount of Th^{234} would be six tenths of that for Sr^{89}). He calculated that 7μc of Sr^{90} in the bone and marrow gives a dose of 0.3r per week; the range of the beta rays is sufficient to average out the effect of any non-uniform distribution of the strontium. Dr. Brues stated that the figure of 7μc as a permissible amount seemed too high on the basis of the experimental comparisons. Dr. Hamilton observed that some of the beta rays in man will be ineffectually absorbed in mineral bone so that the efficiency relative to radium will be smaller than in mice. Professor Mitchell remarked that the problem was related to the discrepancy between the empirically determined permissible radium burden in the body and the permissible dose for external penetrating radiation. Dr. Brues pointed out that the disagreement could be reduced if a smaller relative biological efficiency for alpha radiation were adopted; for example, a value of 5 would lead to a permissible level (plant workers) of 2μc for Sr^{89}, of 1μc for Sr^{90} + Y^{90}, values which he was prepared to accept. After some further discussion, it was formally agreed to adopt 10μc of Sr^{89} or 5μc of Sr^{90} (in equilibrium with Y^{90}) as the minimum damaging amount.

The foregoing conclusions for the isotopes in Group I and II may therefore be summarized as follows:

Element	Minimum damaging amount continuously present	Maximum permissible amount for Plant and other special workers	Maximum permissible amount for all large centres of population
Ra^{226}	1 microgramme	0.1 microgramme	0.001 microgramme
Pu^{239}	1 "	0.1 "	0.001 "
U^{233}	6 "	0.6 "	0.006 "
Po^{210}	0.05 microcurie	0.005 microcurie	0.00005 microcurie
xTh^{234}	140 "	14	0.14 "
Sr^{89}	10 "	1.0 "	0.01 "
Sr^{90} (+Y^{90})	4 "	0.5 "	0.005 "

x These figures for Th^{234} should be 8, 0.8 and 0.008μc., or alternatively 6, 0.6 and 0.006μc.

At this point, the time officially alloted for the Conference had expired. Dr. Shields Warren proposed that in view of the importance of the common isotopes in Group III, a further informal session be held to consider them, and this was agreed.

Before concluding this session, Dr. Shields Warren suggested that each national delegate might prepare draft notes on the Conference which could then be circulated with a view to getting a final agreed statement of the proceedings. He further suggested that the necessary liaison might be effected through Dr. Cipriani and Mr. McMurtrie. These proposals were agreed.

Group III

H^{3}, C^{14}, Na^{24}, P^{32}, S^{35}, A^{41}, Sr^{90}, I^{131}, Co^{60}

C^{14} The problem of C^{14} as carbon dioxide in the atmosphere was discussed by Dr. Brues. A dose rate of 0.3 rep. per week would be produced by 0.014μc of C^{14} per gramme of tissue. If the highest proportion of carbon in tissue is 10%, as in bone carbonate, then the maximum permissible concentration of C^{14} in carbon in the body is 14μc per gramme of carbon. The postulated route of entry of C^{14} into the body is via the alveoli of the lungs, and the isotopic concentration of C^{14} in the carbon of the body can never be greater than the concentration in the alveolar air, which must therefore be limited to 0.14μc per gramme of carbon. Since alveolar air contains 5.5% by volume of carbon dioxide, the maximum permissible concentration of C^{14} in alveolar air is

$$\frac{0.14 \times 0.055 \times 12}{2.24 \times 10^4} \ \mu c/cc. \text{ or } 4.1 \times 10^{-6} \mu c/cc.$$

Hence the maximum permissible concentration of C^{14} in the atmosphere may be taken as 4×10^{-6} μc/cc, with a small safety factor since the actual concentration of C^{14} in the alveolar air may be expected to be somewhat less than that prevailing in the atmosphere. On the other hand, the concentration of carbon in some tissues may be higher than 10%, perhaps up to 50% in fat. Dr. Brues, therefore, proposed the adoption of a figure of 10^{-6} μc/cc for maximum permissible concentration of C^{14} as carbon dioxide in the atmosphere for continuous breathing; the corresponding permissible amount of C^{14} in the body is 30μc. These figures were formally agreed.

Dr. Brues went on to describe some of the actual experimental evidence on the metabolism of C^{14}. Mice were exposed for two months to an atmosphere containing C^{14} as carbon dioxide. The concentration of C^{14} in the tissues rose during the first week and then soon reached limiting equilibrium values. The maximum local concentration found in bone was not more than five times the average concentration in bone. In Shubert's experiments, the isotopic concentration in bone carbonate reached a value one seventh of that in expired air.

H^3 The question of tritium as a gas rather than as water vapour was first briefly mentioned; Dr. Lewis stated that the exchange of the gas with water seems to be briefly rapid.

Dr. Brues stated that since the energy of the tritium radiation is about one tenth that of the C^{14} radiation, it follows that a concentration of 0.14 μc per gramme of tissue will result in a dose of 0.3 rep/week. Therefore the total amount in a 70kg. man would be 10mc. Following the same argument as for C^{14}, and taking the water vapour content of alveolar air as 50mg/litre, the maximum permissible concentration of H^3 in alveolar air (and therefore in inhaled air) is

$$0.14 \times 5 \times 10^{-5} \ \mu c/cc \text{ or } 7 \times 10^{-6} \ \mu c/cc$$

where the body has been regarded as entirely composed of water.

An alternative approach is to consider the 50kg. of water in the body as turned over at the rate of 2-1/2kg per day (Standard Man), that is with a mean life of 20 days. Since the maximum permissible amount of tritium in the body was calculated above as 10mc, the concentration in inhaled air (assuming complete absorption) would be

$$\frac{10^4}{20 \times 20 \times 10^6} \ \mu c/cc \text{ or } 25 \times 10^{-6} \ \mu c/cc$$

Experimentally, the half life of tritium water in the body is about 5 days. Dr. Parker stated that a value of 6 or 7 days had been found.

(Secretary's notes: In the first calculation above by the method of isotopic dilution, it is implied that water entering the body by exchange in the lungs may not mix freely with the total water of the body. If complete mixing takes place, then the appropriate value for the maximum permissible concentration of H^3 in air is 25×10^{-6}μc/cc.)

Dr. Morgan said that he calculated the maximum permissible amount of H^3 in the body as 6mc.

Dr. Brues considered the question of the relative biological efficiency of the soft β radiation from tritium. It is observed that the lethal dose of tritium water for mice is such as to give a dose of about 300 rep. per day initially, falling with a five day half life. Thus the dose is comparable to that for X or γ radiation, and the relative biological efficiency is not greater than 2.

Finally, it was proposed by Dr. Brues that safety factors be introduced, leading to the following figures which were formally agreed:

Maximum permissible amount in the body	1mc.
" concentration in air	1×10^{-6} μc/cc
" " in drinking water	1×10^{-2} "

Na^{24} Dr. Hamilton remarked that experimentally 25% of the gamma radiation of Na^{24} is absorbed in passing through the body. Dr. Morgan calculated the effective energy (β and γ) per disintegration as 2.7MeV. This leads to a figure of 15μc as the maximum permissible amount in the body. Dr. Hamilton pointed out that the biological half life corresponds to about 5% loss per day; this may be ignored in comparison with the radioactive decay for which the mean life is approximately 1 day. Therefore the maximum permissible concentrations in air and drinking water are approximately 10^{-6} μc/cc and 5×10^{-3}μc/cc. respectively. These figures were formally agreed.

(Secretary's note: the immersion tolerance for Na^{24} in water is approximately 10^{-4} μc/cc, which is lower than the drinking water figure).

P^{32} Dr. Neary stated that the Medical Research Council's Panel recommends a figure of 10^{-4} μc/cc for P^{32} in drinking water. The calculation is based on the assumption that half of all the absorbed phosphorus is concentrated in the red bone marrow where the equilibrium amount is controlled by radioactive decay only, and is required not to exceed 3μc. Dr. Hamilton said that the LD 50 is 20mc, while Dr. Shields Warren stated that 250μc gives no perceptible haematological effect. Drs. Failla and Morgan were in favour of calculating the dose for the equilibrium distribution of phosphorous, i.e. with 98% in the skeleton, which they said would lead to a maximum permissible amount of 5μc. Dr. Hamilton pointed out that months are required for equilibrium to be reached. Dr. Parker quoted a recommendation from the National Research Council's Maximum Permissible Internal Dose Committee that the permissible amount of P^{32} in the skeleton, be limited to 1.2×10^{-3}μc/g, corresponding to 8.4μc in a 7kg. skeleton, which is supposed to contain 90% of the body phosphorus.

At this point, Dr. Shields Warren suggested that in view of the lateness of the hour, the meeting should break up into separate groups to consider the remaining isotopes, and this was agreed. Dr. Brues, Dr. Hamilton and Mr. Chamberlain reported on P^{32} as follows:

It is known both experimentally and clinically that at times of the order of the mean life of P^{32} in red bone marrow reaches a value only about three times the average concentration for the whole body, and so most of the P^{32} is diffused throughout the body. In order to allow for the threefold relative concentration in red bone marrow, the total phosphorus may be regarded as contained in a hypothetical critical tissue of mass 70/3 kg. This argument would suggest a permissible amount of P^{32} λ in the body of approximately 25 μc. It may be that somewhat higher concentrations of P^{32} in bone marrow may occur and so a figure of 10μc as maximum permissible amount was proposed. The corresponding figure for air was 2×10^{-8}μc/cc, and for water 2×10^{-4}μc/cc assuming radioactive decay only. These values were formally agreed.

Line 8, last para.
i.e. about 20 days, the concentration of P^{32}

S^{35} Drs. Braaten, Hempelmann, Wright Langham, Morgan and Wolf reported on S^{35} as follows:

Since the mean energy of the S^{35} beta radiation is 0.17/3 MeV; the concentration in the critical tissue to give 0.3 rep/week is 14μc/kg. If the critical tissue were bone, then the maximum permissible amount would be approximately 100μc; if liver, then 17μc. (Note: 23μc would appear to be a more precise figure); if skin, then 89μc. It was therefore assumed that the total permissible body content would be

200μc, for equal concentrations in the three tissues mentioned. The figures proposed for the permissible concentrations in air and water were 10^{-6}μc/cc. and from 10^{-5} to 10^{-2} μc/cc respectively.
(Note: If 100% uptake, and radioactive decay only are assumed the figures would be 10^{-7}μc/cc and 6 x 10^{-4}μc/cc.)

A^{41} and Xe^{133} It was agreed that the hazard from these isotopes was from external irradiation so that the figures for the maximum permissible concentrations in air are 10^{-6}μc/cc for A^{41} and 10^{-5}μc/cc for Xe^{133}.

I^{131} Dr. Edson, Dr. Failla, Prof. Mitchell and Dr. Parker reported on I^{131}:

The effective total energy absorbed in the thyroid gland is estimated to be 0.27MeV per disintegration, so that a dose of 0.3 rep/week is produced by 3 x 10^{-3}μc per g. of tissue; the maximum permissible amount of I^{131} in the thyroid is therefore 0.06 c. It was stated that the biological half life of iodine in the thyroid is very much longer than in the rest of the body and it was estimated that the total amount of iodine in the body corresponding to 0.06μc in the thyroid alone is 0.1μc. The absorption of iodine into the body is assumed to be 100%, and 20% of the absorbed amount is assumed to be deposited in the thyroid gland. On this basis the maximum permissible concentration of iodine in air is 10^{-9}μc/cc and in water is 10^{-5}μc/cc. These figures were formally agreed.

It was noted that a calculation based on isotopic dilution of the I^{131} with the normal daily intake of iodine would give unduly low permissible concentration because the radioactive decay is in fact much more rapid than the rate of biological turnover in the gland. The isotopic ratio of I^{131} for the stationary amount of iodine in the gland is therefore lower than for the daily intake of iodine.

Co^{60} Drs. Carmichael, Laurence and Neary reported on Co^{60}. It is assumed that the cobalt which is absorbed is all deposited in the liver, following the indications of some animal experiments. The effective energy absorbed in the liver is assumed to be 1.3MeV. per disintegration, so that the amount to give 0.3 rep/week is 1μc. The half life in the liver is taken to be 20 days. The maximum absorption of 50% for a soluble aerosol is assumed, leading to a maximum permissible concentration in air of 2 x 10^{-9}μc/cc. The absorption from drinking water is assumed to be 100% so that the maximum permissible concentration in water is 1 x 10^{-5} μc/cc.

These figures were formally agreed.

U (Natural

The maximum permissible concentration for uranium compounds in air is taken to be 50μg/m^3 on the basis of the chemical toxicity of the soluble compounds. This value was taken to be equivalent to 3.3 x 10^{-11}μc/cc, which was formally agreed.

(Note: the latter figure is in error; it should be 1.7 x 10^{-11}μc/cc).

Ra^{226} The maximum permissible amount fixed in the body was accepted above on clinical evidence to be 0.1μg. Dr. Hamilton suggested that 25% of the absorbed material was finally retained with a half-life of the order of 10^4 days (= 27 years). Allowing 50% absorption for a soluble aerosol, the maximum permissible concentration in air for soluble compounds is 4 x 10^{-12}μc/cc. Mr. Chamberlain proposed that for inhalation the permissible levels should be adjusted proportionally in circumstances where less than the full 24 hours exposure occurred, and this was agreed. For oral ingestion, Dr. Hamilton suggested a final overall retention of 10%, with a mean life greater than 10 years. A value of 10^4 days would lead to a maximum permissible level in drinking water of 4 x 10^{-8}μc/cc.

It was formally agreed to adopt these values.

Pu^{239} The maximum permissible amount of Pu^{239} fixed in the body was agreed above to be 0.1μg. Dr. Hamilton stated that for soluble compounds, e.g. $PuO_2(NO_3)_2$, the absorption from the lungs is about 10% of the inhaled material. Assuming a mean life in the body of 10^4 days, the maximum permissible concentration in air is therefore 5×10^{-12}μg/cc. or 3×10^{-13}μc/cc.

For insoluble compounds, Dr. Hamilton calculated that if the mean life in the lung is is 200 days, the maximum permissible concentration in air to produce a dose to the lung biologically equivalent to 0.3 rep week is 2.5×10^{-11}μg/cc. if the particulate nature of the hazard may be ignored. Mr. Chamberlain mentioned that Abrams had reported that 6% of the initial "dose" of an insoluble aerosol of plutonium found its way to the skeleton. Dr. Hamilton replied that in his experiments the amount had been less than 1%. Dr. Lewis stated that a figure of 3×10^{-11}μg/cc had been calculated for use at the Establishment; it was based on a 60 day half life in the lung, and a breathing rate of 10cm. per day. Dr. Parker said that the Hanford figure is 10^{-11}μg/cc. for an 8 hour day. After some further discussion Dr. Shields Warren proposed that a figure of 5×10^{-12}μg/cc or 3×10^{-13}μc/cc be adopted for soluble and insoluble compounds and this was formally agreed.

For oral ingestion, Dr. Hamilton calculated that for 0.01% absorption and a biological half life of 10^4 days, the permissible concentration in drinking water would be 4×10^{-5}μg/cc. Dr. Parker suggested that for the low concentrations involved, the absorption be taken as 0.1%. Dr. Brues was also in favour of the insertion of this safety factor of 10.

After further discussion, a figure of 4×10^{-6}μg/cc. or 2.4×10^{-7}μc/cc for drinking water was formally agreed.

$Sr^{90}(+Y^{90})$

Dr. Hamilton stated that he calculated the maximum permissible levels for $Sr^{90}(+Y^{90})$ to be 10^{-10}μc/cc. in air and 2×10^{-6}μc/cc in drinking water.

(Note: these figures would appear to correspond to a final retention of approximately 1%).

U^{233} Dr. Hamilton also mentioned figures for U^{233}. For soluble compounds in air, he calculated a maximum permissible level of 6×10^{-9}μg/cc. or 6×10^{-11}μc/cc, while for involuble compounds, the figure is 2.5×10^{-11}μg/cc or 2.5×10^{-13}μc/cc.

For ingestion, a figure 2×10^{-3}μg/cc or 2×10^{-5}μc/cc was obtained.

These recommendations are summarized:

Maximum permissible levels for Plant and Other Workers under Medical Supervision

Element	Maximum Permissible Amount in body	Maximum Permissible concentration in Air (24 hour day)	Maximum Permissible Concentration in drinking water
H^3	1 millucurie	1×10^{-6} microcurie/cc	1×10^{-2} microcurie/cc
C^{14}(as CO_2)	30 microcurie	1×10^{-6} "	
Na^{24}	15 "	1×10^{-6} "	5×10^{-3} "
P^{32}	10 "	2×10^{-8} "	2×10^{-4} "
S^{35}	200 "	1×10^{-6} "	1×10^{-2} "
I^{131}	(0.06 " (thyroid) (0.1 " (body)	1×10^{-9} "	1×10^{-5} "
Co^{60}	1 "	2×10^{-9} "	1×10^{-5} "
A^{41}		1×10^{-6} "	
Xe^{133}		1×10^{-5} "	
Xe^{135}		5×10^{-6} (a) "	
U (Natural)		3.3×10^{-11}(b) " (50 microgramme/m^3)	
Ra^{226}	0.1 microgramme	4×10^{-12} for soluble compounds	4×10^{-8} "
Pu^{239}	0.1 "	3×10^{-13} microcurie/cc (5×10^{-12} microgramme/cc) for soluble and insoluble compounds	2.4×10^{-7} " (4×10^{-6} microgramme/cc)
U^{233}	0.6 "	6×10^{-11} microcurie/cc (6×10^{-9} microgramme/cc) for soluble compounds. 2.5×10^{-13} microcurie/cc (2.5×10^{-11} microgramme/cc) for insoluble compounds	2×10^{-5} microcurie/cc 2×10^{-3} microgramme/cc)
Sr^{90}(+ Y^{90})	0.5 microcurie	1×10^{-10} microcurie/cc	2×10^{-6} microcurie/cc
Po^{210}	0.005 "		
Th^{234}(UX_1)	4 (c) "		

(a) 3×10^{-6} corrected to 0.3 r per week.
(b) More correctly 1.7×10^{-11}
(c) There is an arithmetical error in this figure; it should be 0.8.

Dr. Shields Warren reminded members of the Conference, that there would be an opportunity for further comments on the foregoing figures when the notes on the Conference were circulated according to the procedure already agreed.

The business of the Conference then terminated.

HD. 189.

APPENDIX 16

CANADA-MINUTES OF CHALK RIVER CONFERENCE (MAY 1950)

PERMISSIBLE DOSES CONFERENCE RM-14

held at

Chalk River, Contario, September 1949

The following is based on the "Report of the United Kingdom Delegation" AP/P/TD/122. The report has been moidified in accordance with the numerous suggestions and criticisms that have been received from the various delegates. It was not always possible to reconcile differences of opinion or conflicting information and in such cases only one version is given which is not necessarily the correct one. In other instances all parties agree that the information is unacceptable but cannot offer any alternative. It is anticipated that this report is justified as a basis for future discussion.

G. E. McMurtrie, Secretary
Chalk River, Ontario,
May 1950.

AGENDA FOR THE CONFERENCE

1. Standard Man

   a. Mass of organs

   b. Chemical composition

   c. Physiology

   d. Working time

   e. Retention of particulate matter in the lungs.

2. Relative Biological Efficiency

   a. Beta Particles

   b. Protons

   c. Alpha Particles

   d. Fast Neutrons

   e. Slow Neutrons.

3. Permissible Exposure to External Radiation

   - X- and Gamma Rays, Beta Particles, Fast Neutrons, Slow Neutrons.

   a. Whole Body, long continued exposure.

   b. Whole body, single exposure.

   c. Hands, long continued exposure.

   d. Head, long continued exposure.

4. Internal Irradiation by:-

Group I Radium, Radon, Uranium, Plutonium, Thorium, Polonium.

Group II Fission Products

Group III H^3, C^{14}, Na^{24}, P^{32}, S^{35}, A^{41}, Sr^{89}, I^{131}, Co^{60}.

a. Amount of radioisotope permitted fixed in the body.

b. Concentration of radioisotope permitted in inspired air.

c. Concentration of radioisotope permitted in drinking water.

Present at Conference:

United States:	Dr. Shields Warren (Chairman) Dr. Austin M. Brues Dr. G. Failla Dr. J. G. Hamilton Dr. L. Hempelmann Dr. de Hoffman (Secretary) Dr. Wright Langham (Secretary) Dr. K. Z. Morgan Dr. H. M. Parker Dr. L. S. Taylor Dr. B. S. Wolf Col. C. A. Nelson
Canada:	Dr. W. B. Lewis Dr. H. Carmichael Dr. A. J. Cipriani Dr. G. H. Guest Dr. G. C. Laurence Mr. G. E. McMurtrie (Secretary) Dr. E. Renton Dr. E. O. Braaten
United Kingdom:	Prof. J. S. Mitchell Mr. A. C. Chamberlain Dr. E. F. Edson Dr. G. J. Neary (Secretary)

The Conference was formally opened by Dr. D. A. Keys, who, after welcoming the visitors to the Chalk River Establishment, asked Dr. Shields Warren to commence his duties as Chairman.

I. Standard Man

The desirability of adopting a common set of values for the basic anatomical and physiological data required in calculations of permissible levels was generally agreed, even though some of these values might have to be of a provisional character owing to lack of complete scientific information. It was agreed that the figures submitted by Dr. Cipriani should form the basis of the discussion.

(a) Mass of Organs

The figures presented were based on those of H. Lisco (ANL Report 4253, and "Science and Engineering of Nuclear Power", Vol. 2, 1949), which include some earlier estimates by Lisco and Parker (MDDC Report 783). There was considerable discussion of the importance of the variability of the masses of organs and tissues. Of various proposals, it was agreed that the most useful and practicable course was to give the average figures, and if necessary to consider the variability along with other factors of uncertainty when assessing the safety factor for any particular calculation. Furthermore, it was agreed that while some rounding off of figures was desirable, a reasonably close approximation to the original values should be maintained.

Particular items in the table were next discussed in detail. The figure of 700g. adopted for lymphoid tissue was felt to be one of the more uncertain quantities. It was recognized that the thyroid is a very variable organ, its size showing an inverse correlation with the proximity to the sea. While the general opinion was that the mass lay between 20 and 30g., Dr. Morgan quoted figures obtained by Dr. Keating at the Mayo Clinic giving an average of 15g. Dr. Shields Warren said that the number of cases in this series was probably ten to twelve thousand. A figure of 20g. was finally adopted. The mass of the gastro-intestinal tract was also recognized to be a very variable quantity, about which there was not very extensive evidence. The figure of 2000g. which was adopted was understood to include the oesophagus. It was felt that since the average age of the population is 30 to 33 years, a figure of 10g. for the mass of the thymus gland would be reasonable, about two thirds of this being made up of fat and fibrous tissue. It was generally agreed that there was considerable uncertainty in the figures 1500g. each for red and for yellow bone marrow, and that further data were needed. The figure of 5000g. adopted for the total blood excludes that small residual amount of blood which cannot be extracted from the organs, and which is understood to be included in the figures for the masses of the organs themselves. Dr. Morgan quoted figures for the mass of the heart given by Dr. Keating from a series at the Mayo Clinic, namely, 294g. in the male and 250g. in the female. Dr. Shields Warren pointed out that at necropsies any mass in excess of 350g. is generally regarded as abnormal. A value of 300g. was adopted. Dr. Cipriani's proposed values for the adrenal and prostate glands represent rounded off figures somewhat higher than Dr. Lisco's original, a procedure felt to be justifiable in view of the increase in mass of these glands with age. Finally it was agreed that the tabulation of the Standard Man could be confined to the male at present. The following values were then formally agreed:-

I. Standard Man. (a) Mass of Organs

Organs	Grammes
Muscles	30,000
Skeleton, Bones	7,000
Red Marrow	1,500
Yellow Marrow	1,500
Blood	5,000
Gastro-intestinal Tract	2,000
Lungs	1,000
Liver	1,700
Kidneys	300
Spleen	150
Pancreas	70
Thyroid	20
Testes	40
Heart	300
Lympoid Tissue	700
Brain	1,500
Spinal Cord	30
Bladder	150
Salivary Glands	50
Eyes	30
Teeth	20
Prostate	20
Adrenals	20
Thymus	10
Skin and subcutaneous tissues	8,500
Other tissues and organs not separately defined	8,390
Total Body Weight	70,000

(b) Chemical Composition

The figures for the chemical composition of the body presented for discussion by Dr. Cipriani are taken from "Practical Physiological Chemistry" by Hawk, Oser and Summerson (12th Edn. 1947). Professor Mitchell stated that the figures were in reasonable agreement with figures which he had proposed previously for neutron dosage calculations, but pointed out that the nitrogen content of dividing cells of the basal layer of the skin might be nearer 6%, rather than 3%. Dr. Brues commented that the normal carbon content of organs was about 12%, so that the figure of 18% present here must include the fatty tissue of the body. Both these speakers and other emphasized the importance of the difference between the chemical composition of a given organ and the average for the whole body, and stressed the fact that very little detailed information exists. Much of that information was obtained a considerable time ago, before the development of modern analytical techniques, with a considerable possibility of error. Data on some of the trace elements, of importance for whole body slow neutron exposure, appear to be entirely lacking. Accordingly, it was agreed that each delegation should recommend that a large scale effort be made to obtain accurate data for the mass and the chemical composition of the organs and tissues of the human body, having regard to all the elements of possible importance in radiation effects. Normal organs, preferably from cases of sudden death should be examined, and analyses should be made on homogenised tissue and not merely on slices of organs. Full details of the geographic, occupational and medical history of each subject are desirable. It was felt that in addition to the organs and tissues tabulated above for the Standard Man, data on ovaries should be obtained. Dr. Morgan, Dr. Cipriani and Prof. Mitchell agreed to be responsible for liaison on these problems, and Dr. Morgan agreed to circulate the data he has already accumulated.

Standard Man. Chemical Composition of the Human Body

Element	Proportion Per Cent	Approximate amount in grammes in a 70kg. man
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulphur	0.25	175
Sodium	0.15	105
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

(c) Applied Physiology

It was formally agreed to adopt the data below as broad averages for normal activity in the temperate zone, recognizing that changes caused by abnormal circumstances or environment are not allowed for:-

(i) Water Balance

Average daily water intake

In food	1.0 litre (including water of oxidation)
In fluids	1.5 litres
Total	2.5 litres

It was agreed to base calculations of maximum permissible levels for radioactive isotopes in water on the 2.5 litres per day figure, recognizing that in some cases a separate safety factor might be required to allow for the concentration of an isotope in the food from cooking water.

Average daily water output

Sweat	0.5 litres
From lungs	0.4 litres
In faeces	0.1 litres
Urine	1.5 litres
Total	2.5 litres

Overall water content of Body 50 litres

(ii) Respiration

Area of respiratory tract

Respiratory interchange area	50 sq. metres.
Non-respiratory area (upper tract, trachea to bronchioles)	20 sq. metres.
Total	70 sq. metres

Respiratory exchange

Physical Activity	Hours/Day	Tidal Air	Resp/Min.	m^3 air/8 hrs.	Total
At work	8	1 litre	20	10	20
Not at work	16	0.5 litre	20	5	m^3/day

Note: *The 16 hours "not at work" is split up into 8 hours sleep and 8 hours incidental activities.*

Carbon dioxide content of air

Inhaled air - 0.03% (dry air, sea level)

Carbon dioxide content of air (contd)

Alveolar air - 5.5%

Exhaled air - 4.0% (depends on activity)

(iii) Duration of Occupation Exposure

It was formally agreed to adopt the following figures for the duration of occupational exposures:

8 Hours/day
40 Hours/week
50 Weeks/year (thus, 2000 hours/year)

The view was widely held that the adoption of a definite figure for the working lifetime for continuous occupational exposure to radiation might have undesirable psychological repercussions. At the same time, it was generally recognized that the proportion of workers receiving continuous occupational exposure to radiation for more than twenty years is likely to be small.

(iv) Duration of "Lifetime" for Non-occupational Exposure

It was formally agreed that for the purposes of calculation the duration of life for the standard man be assumed to be 70 years.

(d) Standardized Terminology

It was agreed that all formal statements of permissible values should be expressed in microcuries per cubic centimetre (μc/cc) or microcuries per gramme (μc/g) whether in air, water, or other medium. Where other units are now in use, the value in microcuries per cubic centimetre or mircrocuries per gramme should be followed in brackets by its equivalent.

(Note: it was generally understood that for the present the term "microcurie" would be interpreted as 3.7×10^4 disintegrations per second.)

(e) Retention of Particulate Matter in the Lungs

There was considerable discussion of several aspects of the general problem of hazard from inhalation of radioactive particulates.

On the question of the retention of such particulates, the influence of size, surface area, and solubility were emphasized. Dr. Brues mentioned that, in general, retention was high for 1μ particles, but considerably lower for 10μ. Dr. Wolf mentioned the report UR67 from the Rochester group as a source of considerable experimental information. Particles of uranyl nitrate up to 4μ in diamater were heavily retained. The work of the Columbia group with radioactive sodium has demonstrated that there may be a bimodal distribution of retention with particle size. Dr. Shields Warren pointed out that in cases of silicosis or asbestosis, very few particles greater than 1.5μ in diameter are found; it is also known that only a very small percentage of the inhaled material is permanently retained. Long fibres of material are much less likely to be eliminated than large spherical particles. For example, particles 45μ in length may be found in cases of asbestosis or in the sugar cane disease bagassosis. Dr. Hamilton mentioned that insoluble particles of yttrium oxide (coated with gold) in the size range 0.1 to 1μ gave 95% immediate retention but after 24 hours, 75% of the material was eliminated in the faeces.

After further discussion, it was formally agreed that if specific data were lacking, the convention be adopted that 50% of any aerosol reaches the alveoli of the lungs. If the particles are soluble they are considered to be totally absorbed; if insoluble then the 50% amount is to be regarded as retained for 24 hours, after which only half of it, i.e., 25% of the inhaled amount, is retained in situ indefinitely; further that the particles be assumed spherical.

In relation to the possible pathological effects of radioactive particulates in the lungs, Dr. Hamilton pointed out that the cells in the immediate neighbourhood of a dust particle containing 1 or 2% of plutonium would be subjected to a dose of about 400r/day. The general opinion which emerged from the discussion was that the carcinogenic effect per unit volume is probably considerably less for the irradiation of small masses of tissue than for large. Dr. Shields Warren pointed out that alveolar tumours do not normally occur. The lung tumours in the Joachimstahl miners are bronchogenic, and the mean latent period appears to be 17 years. The majority of investigators have regarded radon as the principal causative factor. Professor Mitchell mentioned that he had calculated that the radon level in the mines would, by the deposition of active decay products on the bronchial epithelium, result in a dose of several roentgens per day to the latter.

A brief discussion of the proportion of insoluble particulate material transported from the lung to the lymph nodes merely served to indicate that this factor is rather dependent on the nature and size of the particles.

2. Relative Biological Efficiency

There was some initial discussion of the relative advantages of adopting 200kV X-rays or the radium gamma rays as the reference radiation for purposes of comparison. It was pointed out that there is probably a greater number of experimental comparisons of other radiation relative to X-rays, but on the other hand, the radium gamma rays provide a reference point of more definite character, and probably none of the radiations to be considered has a lower absolute biological efficiency than that of these rays. Moreover, a radium standard is more easily reproducible in the laboratory than an X-ray standard.

It was therefore formally agreed that the relative biological efficiency of any given radiation be defined by comparison with the gamma radiation from radium filtered by 0.5 millimetres of platinum, and measured as the inverse ratio of the doses in ergs per gramme of tissue required to produce equal biological effects of specified character. The need for considering relative biological efficiencies for a variety of different effects was mentioned, but it was not considered practicable to do more than consider chronic bone marrow and skin damage, to which a common set of relative efficiencies were regarded as applicable for purposes of calculation.

The relative biological efficiency of X-rays in the normal deep therapy region (i.e., around 200kV) was next considered, and Professor Mitchell pointed out that the production of skin erythema and the healing of malignant tumours, a value of 1.5 applied. For the production of leukemia, it might well be that previous gross damage to the blood forming organs was necessary and that integral dose rather than dose to the bone marrow alone was involved. In view of the uncertainties, it was therefore formally agreed to take the relative biological efficiency of 200kV X-rays as unity. It was also agreed that this same value applied to beta radiation. In the discussion on heavy particle effects it was agreed that the relative biological efficiency for fast neutrons of energy not greater than 20 MeV be taken as 10. Dr. Failla felt that, for alpha particles, there was insufficient evidence to justify a figure as high as 35. Dr. Wright Langham mentioned that in studies of acute effects on the liver with plutonium and gamma radiation, a relative biological efficiency fo 4½ had been found. Professor Mitchell pointed out that for the densely ionizing particles, there was every reason to expect that the relative biological efficiencies would be considerably higher for chronic than for acute effects if these depended on the production of chromosome abberations, and there was some experimental evidence for this expected rise in efficiency; he proposed a figure of 20 for alpha particles. Dr. Hamilton commented that values for alpha particles and fast neutrons in the ratio of 20 to 10 would correspond with the data of Zirkle. When U^{235} in colloidal form was injected, it was deduced that the fission recoil particles were five times as efficient as fast neutrons. The practical and economic aspects of a figure of 20 for alpha particles were briefly considered after which it was formally agreed to adopt the value of 20 for the relative biological efficiency of alpha particles.

Protons were next discussed and it was pointed out by Dr. Laurence that there was some reason for taking a lower figure than for fast neutrons because for a given dose, there would be a greater number of protons involved in the second case and so a greater effect from the densely ionizing regions at the end of the tracks. It was, however, finally agreed to take a value of 10 for the relative biological efficiency of protons. Since thermal neutrons produce their effect by a mixture of gamma and proton radiation, it was agreed to take a value of 5 for the relative biological efficiency.

These decisions on relative biological efficiency may be summarized thus:

Relative Biological Efficiencies

Type of Radiation	Bone Marrow	Skin
Alpha	20	
Protons	10	
Fast Neutrons <20 MeV	10	
Thermal Neutrons <0.025 ev	5	
Beta	1	
Gamma (Radium)	1	1
X-ray (∿200 Kv)	1	1.5

3. Permissible Exposure to External Radiation

Dr. Failla offered as a basis for discussion a preliminary draft of a report which he had prepared for submission to his Sub-Committee on Permissible Dose from External Radiation of the National Committee on Radiation Protection and this was accepted. The question of the unit in terms of which the dose should be expressed was discussed, and it was formally agreed to adopt the "rep", defined as 93 ergs per gramme of tissue, subject to subsequent revision by international agreement. It was further agreed that chronic exposure be expressed on a weekly basis.

It was also agreed that any recommendation on maximum permissible exposure for external radiation made at this conference was not intended to apply to diagnostic and therapeutic irradiation. The question of what constituted "whole body" exposure was carefully considered. Professor Mitchell stated that in radiotherapeutic experience, irradiation of more than half the trunk is effectively whole body irradiation. Dr. Hamilton pointed out that the therapeutic irradiation of a fairly limited area, even to high doses, does not have consequences at all comparable to those of whole body irradiation. In this connection, Dr. Shields Warren remarked that this was still true for very protracted irradiations, for example, the treatment of carcinoma of the breast may extend over 3½ years. There was general agreement that irradiation of the hands and forearms does not constitute a whole-body irradiation, and several other examples were cited. It was felt, however, to be impracticable to include in a definition all the various possibilities and so it was formally agreed that for the purpose of health monitoring whole body exposure should normally be assumed for exposure other than on the hands and forearms. It was clearly understood, however, that this was merely a working convention adopted without prejudice to the Medico-legal aspects of any particular instance which might arise. Dr. Shields Warren expressed the opinion that if an irradiation is known to involve less than one third of the whole body, it need not be regarded as "whole-body." It was understood that in such circumstances, the dose could not be increased pro rata.

Following Dr. Failla's proposal, it was formally agreed that for any exposure to external penetrating radiation, the blood forming organs should be regarded as the critical tissue, the principal hazard probably being leukaemia. The estimated depth of the blood-forming organs for purposes of calculation was next discussed. Dr. Shields Warren stated that leukaemia probably arises out of changes in the marrow and spleen and rarely in the lymph nodes primarily; Professor Mitchell and Dr. Cipriani concurred. The question of the importance of variation of the dose to different parts of the marrow was discussed. Dr. Shields Warren stated that normally there is not much functioning red marrow in the long bones. He proposed, and it was formally agreed that for purposes of calculation, the blood forming organs be assumed to lie at an effective depth of 5 centimetres.

Dr. Failla then proposed that the maximum permissible exposure for external penetrating radiation should correspond to a dose of 0.3 rep/week to the critical tissue (bone marrow). In the discussion it was noted that the existing U.S. recommendation of a weekly surface dose of 0.3r. measured in air is approximately equivalent to the British figure of 0.5r. measured at the surface of the body (i.e., with backscatter) and that both are approximately equivalent to a dose of 0.3 rep to the bone marrow. It was therefore formally agreed that the maximum permissible dose for exposure to external penetrating radiation be 0.3 rep. per week to the critical tissue, corresponding approximately to 0.5 rep per week to the surface of the body when measured with backscatter and 0.3 rep. per week when measured in air. It was also agreed that the maximum permissible dose for internal radiation should be 0.3 per week to the critical tissue, except in cases where experimental evidence exists to show that some other criterion is more suitable. It was emphasized that the permissible dose referred to the energy absorption in the critical tissue itself, and that in principle, the measurement of the dose would be made in a small cavity ionization chamber with walls equivalent in composition to the tissue in question. The question of lifetime dose was considered and Dr. Failla proposed a figure of 300 rep. to the blood forming organs: he stated that the desirability of some such figure depended partly on genetical consideration. Dr. Shields Warren suggested that the genetic argument is already met by the fact that by the time a dose of 300 rep. has been accumulated, most people will have passed the active reproductive period. Dr. Hamilton mentioned the difficulty of the large numbers of existing workers who may have already approached or even exceeded the dose in question. Dr. Parker asked about the possible shortening of life span in relation to total accumulated dose. Dr. Shields Warren pointed out that the application of the data from animal experiments of this subject to the problem of the permissible dose for man involved a considerable extrapolation. The more direct evidence is the fact that the average life of radiologists is equal to that of other medical specialists. It was finally agreed to leave open the question of a maximum lifetime dose.

It was formally agreed that for external irradiation by beta rays, the skin be regarded as the critical tissue.

It was also agreed that for purposes of calculation the depth of the critical tissue, namely the basal layer of the epidermis be assumed to correspond to 7 mg/cm^2.

It was further agreed that for external whole body irradiation by beta rays, the maximum permissible dose be 0.3 rep per week to the bone marrow or critical tissue.

It was agreed to be unnecessary at the Conference to work out explicit figures for maximum permissible fluxes for neutrons exposures in view of the figures for relative biological efficiencies.

The terms "fast" and "thermal" as applied to neutrons in the table "Relative Biological Efficiencies" were agreed on by the Committee to mean neutrons whose biological effect are primarily by proton recoil and by nuclear reaction respectively.

The exposure of the hands alone was discussed and Dr. Failla proposed a maximum weekly dose of 1.5 rep. stating that doses of less than 10 or 15 r/week produce observable changes in the fingers. Professor Mitchell mentioned that radium surgeons commonly exceed the figure of 1.5 rep. per week, but that they accepted the risk consciously. Dr. Braaten doubted whether radium factories could be operated at this level, in view of the fact that some of this apparent dose might be due to blackening of the film by contamination was mentioned. Dr. Parker stated that there is definite evidence of damage to the hands at a dose level of 4 rep. per week. Finally it was agreed that for external radiation of the hands by X, gamma or beta irradiation the maximum permissible dose be 1.5 rep. per week. Arising out of the same discussion it was agreed that no relaxation of the standard permissible dose could be allowed in the case of irradiation of the head alone in view of the risk of cataract formation.

The maximum permissible dose in a single exposure was next discussed. Dr. Failla proposed the figures of 25 rep for a person under the age of 45 and 50 rep over this age. Professor Mitchell stated the view of the Medical Research Council's Tolerances Doses Panel that the single emergency dose be not greater than 10r. and that the total dose in any period of six months should not exceed the normal maximum permissible average of 13r. Dr. Lewis stated that in the Chalk River Establishment, a single dose of 10r. was the limit in extreme emergencies. Dr. Parker felt doubtful whether any relaxation of the normal restrictions was needed for atomic energy plants. Dr. Shileds Warren said it was clear that all were agreed that single high exposures should be limited to grave emergencies. A variety of different eventualities might arise, but as the problems were largely administrative, he felt that the details need not be discussed at the Conference.

On the other hand, a problem of general interest, for example to Civil Defense Authorities, was the assessment of the single dose which will produce no permanent harm. The N.E.P.A. report summarizes some of the basic information. The LD 50 dose for man is around 400r, and at this dose a person would be rapidly incapacitated. Professor Mitchell stated that a consideration of mortality probits as a function of the logarithm of the dose and of the integral dose, and certain clinical data, would lead to a figure of 25r, in agreement with Dr. Failla's proposal. In the ensuing discussion there was some question as to whether a smaller limit was needed for children and women, and it was noted that in the U.S. atomic energy plants no person under the age of 18 is employed. Dr. Morgan mentioned the observation of Jacobson that a dose of 50r. given in 4 hours to mice aged 5 months was followed by a significant increase in ovarian tumours. The general opinion seemed to be that mice are probably peculiar among mammals in this respect, and that the observation had no significance for the present problem of the permissible single dose for women.

After some further discussion it was agreed that in the light of present knowledge, no manifest permanent injury is to be expected for a single exposure, of the whole body to 25 rep. or less, with a possible exception in the case of pregnant women. It was generally understood but not specifically stated that such exposure was contemplated once only in a lifetime.

4. Permissible Exposure to Internal Irradiation

Dr. Hamilton introduced the subject of hazards from internal irradiation with a brief survey of his results on the metabolism of fission products and radioactive elements in animals, reported in Reviews of Modern Physics, Volume 20, No. 4., from which he reproduced the following table.

RadioElement	Oral Absorption	Organ and Percentage deposition	Biological Half-life
Sr^{89}, Sr^{90}, Ba^{140}	5 - 60%	Bone, 60 - 70%	>200 days
Y^{91}, Zr^{95}, La^{140} Ce^{144}, Pr^{143}, Nd^{147}, Pm^{147}	<0.05%	Bone, 25 - 70%	>100 days
La^{140}, Ce^{144}, Pr^{143}, Nd^{147}, Pm^{147}	<0.05%	Liver, 50 - 70%	10 days
Cb^{95}	<0.05%	Bone, 30%	30 days
Ru^{106}	0.05%	Kidney, 3.5%	20 days
I^{131}	100%	Thyroid 20%	>30 days
Ca^{135}	100%	Muscle 45%	15 days
Xe^{133}	-	Fat Content	2 hours
U^{233}	<0.05%	Bone, 20%	60 days
Pu^{239}	0.007%	Bone, 75%	>2 years

Note: The biological half life is calculated independently of the radioactive decay.

Some 80% of the total energy of mixed fission products is associated with the group of elements which concentrate in the skeleton, Sr, Ba, Y, Zr, Cb, La, Ce, Pr, Nd, Pm, Sm, Eu. The deposition in bone is about 70% for Y and Zr, and about 25% for the other elements in this group. The alpha emitting isotopes, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, are also concentrated in the skeleton. All the bone seeking elements have long biological half lives. A number of these isotopes are also concentrated in the liver, including La, Ce, Pr, Nd, Pm, Sm, Eu, among the beta emitters and Ac, Am, Cm among the alpha emitters. Ruthenium and uranium are concentrated in the kidney, and iodine in the thyroid. The absorption of Sr following the inhalation of soluble compounds is probably about 50%. In young animals 16 days after the administration of Sr, the distribution in the skeleton was found to be uniform, but in older animals a much longer period is necessary for transport of the element from the periosteal and endosteal surfaces into the mineral bone. The elements Ac, Am and Cm, which are trivalent show a spotty distribution in bone like that of compact bone; there is deposition in trabecular bone also. The radioautographs for thorium are indistinguishable from those for plutonium. Radium D in adult female rats gave similar distribution, as did radium itself but with the latter transference into mineral bone was commencing.

The absorption of plutonium from the gastro-intestinal tract was next discussed. The experiments of Dr. Wright Langham gave a figure of 0.02% while those of Dr. Brues gave the same order. Dr. Parker said that his experiments had indicated an increased absorption at low ionic concentrations. For example, rats given a dose of 4 x 10^{-5} µg per day, of Pu^{238} in 400 λ solution with 0.5ml. of wash water for 20 days showed an absorption of 0.02%, while at 1 x 10^{-5} µg per day the absorption was 0.1%. Dr. Wright Langham stated that one person drank a solution of Pu^{239} at about the "tolerance" concentration and found all the material in the faeces. This suggests that absorption in man is less than in the rat. Dr. Hamilton gave some data obtained by the intravenous injection into a man of a mixture of Pu^{239} and Pu^{238} equivalent in activity to 50 µg of Pu^{239}. The excretion in the urine and also in the faeces were each about 0.01% per day at 16 days, while at 256 days the daily urinary excretion was slightly more than 0.001% and the faecal excretion 0.0004%. In rats, the faecal excretion alone at 256 days was 0.01 to 0.02% per day, so that the human figures are about one tenth the rat figures. Dr. Wright Langham confirmed that he had found comparable figures. Dr. Parker mentioned the case of a man exposed 4 years ago, with a dose of 2 µg. The present excretion rate agrees with Dr. Langham's formula and corresponds to a biological half-life of 10^5 years.

Dr. Hamilton then referred to data on radium indicating 5∿ 20% oral absorption and 30 or 40% of the absorbed amount retained in the skeleton with a very long biological half life. Dr. Hempelmann stated that one year after intravenous injection 90 to 95% was excreted. Dr. Hamilton showed radio-autographs of the thyroid tissue of animals injected with astatine, the short lived alpha emitted which is chemically a member of the halogen group of elements. One third to one fifth the material concentrates in the thyroid. Profound histological changes are apparent one month after doses between 2000 and 7000 rep. while complete destruction follows doses between 10,000 and 35,000 rep. Such data might give interesting evidence on the relative biological efficiency of alpha radiation.

Dr. Shields Warren next proposed that the elements set down in the agenda be considered individually.

Group I

Ra^{226}, Ur(natural), Ur^{233}, Pu^{239}, Th^{232} (natural), Th^{234} (UX_1) Po^{210}

The discussion was initiated by Professor Mitchell who outlined the standpoint taken up by the Medical Research Council's Tolerance Doses Panel. For the evaluation of the hazards from bone seeking isotopes, radium is regarded as the crucial isotope, because clinical data exists only for radium, while an estimate for several of the other isotopes may be made from the experimental data on the relative toxicities of these isotopes and radium. If 1 µg of Ra fixed in the skeleton leads to serious disease in 1% of cases, an estimate compatible with the available clinical data, then at the level of 0.1 µg often proposed as a "tolerance" figure, the incidence of disease might be of the order of 0.1%, though it would probably be lower. This level of 0.1 µgm had in fact been adopted provisionally by the Medical Research Council for plant operatives and other special workers under continuous medical supervision. In the case of a large population, such as the ten million persons in London dependent for drinking water on the river Thames which takes a limited amount of effluent from the establishment at Harwell, it seemed essential to introduce a further factor of 100 to provide reasonable safety. A short discussion followed of the general implications of such a viewpoint. Dr. Brues felt that a factor of the order of 100 was reasonable for large populations. The practical difficulties of monitoring at the low levels of activity involved was mentioned and it was pointed out by Mr. Chamberlain that it was necessary to monitor the effluent before dilution in the river, etc. Dr. Morgan gave examples of certain springs with concentrations of activity a billion times higher than those proposed by the Medical Research Council's Panel. Dr. Failla drew attention to a feature of the data from luminising workers which was not normally considered, namely, that the radium content was in many cases measured when symptoms of injury had appeared. The quantity of radium held in the body would have been considerably higher initially and it was not certain whether the pathological effects were to be correlated with the radium content at some previous epoch. Dr. Brues stated that about 1% of cases with 1 µg of radium fixed in the body would be likely to show some bone damage on radiological examination. It was agreed that 1 µg might reasonably be regarded as the minimum amount of radium known to produce damage, and it was decided that before the question of safety factors was considered, the equivalent amounts for the other isotopes should be evaluated.

Dr. Hamilton stated that the hazard from natural uranium is mainly chemical; there is some evidence that U^{233} concentrates in cancellous bone and so it might be reasonable to consider the irradiation of the red bone marrow, since the yellow marrow is mainly in the hollow portion of the shaft. Alternatively, it might be argued that the U^{233} hazard should be evaluated from a consideration of the data on acute toxicities and equivalence to radium. Dr. Brues stated that for acute leth-lethal effects, Pu^{239} is 5 times and Po^{210} is 20 times as toxic as radium measured in terms of activity. Dr. Hamilton pointed out that for chronic effects, the radium is more uniformly distributed in the bone and so even higher equivalence figures might be expected. Dr. Wright Langham pointed out on the other hand that for sub-acute lethal effects, plutonium had appeared relatively less effective. Dr. Brues said that it was not certain how the chronic toxicity would vary from acute toxicity but for the production of tumours, the evidence did not warrant the adoption of a lower relative efficiency. Dr. Wright Langham was in favour of calculating the permissible levels for all the elements on the basis of radiation energy absorption, but it was pointed out that this gives results at variance with the experimentally determined equivalence for radium and strontium. Mr. Chamberlain stated that a dose of 0.3 biologically equivalent roentgens would be produced by 2×10^{-2} μg ofradium distributed throughout the 7 kg. of skeleton assuming an effective energy per disintegration of 15 MeV and a relative biological efficiency for alpha particles of 20.

Dr. Failla remarked that the distribution of radium in bone is not uniform even 10 years after ceasing radium work, while Dr. Wright Langham mentioned a case examined by Professor Robley Evans in which seven bone samples gave an average concentration twice that for the whole skeleton. He therefore urged that in assessing the equivalent quantities of isotopes known to be deposited non-uniformly, care be taken to avoid over-estimating the safety factors. He knew of 12 cases with 5 μg of plutonium, 12 with 1μg and 26 with 0.3 μg, all without ill effects, while Dr. Hamilton's case had the equivalent of 50 μg. Dr. Shields Warren summed up this discussion by saying that at present there is insufficient direct evidence for man, and that the data from animal experiments has still to be relied on. It should therefore be assumed that the minimum damaging amount of material fixed in the body is 1 μg for plutonium just as for radium, the risk being of the order of 1 per cent.

In the discussion on polonium it emerged that there was no known case of damage in man. Dr. Lewis proposed that 0.05 μc be adopted as the minimum damaging amount, but Dr. Wright Langham observed that the kidney has a higher concentration than the bone and the maximum histological damage occurs in that organ; it was not clear what the chronic effects from polonium would be. Dr. Hamilton proposed that U^{233} be considered as equivalent to plutonium, so that allowing for the difference in the radioactive half lives, the minimum damaging amount would be about 6 μg. Dr. Wolf observed that for chronic exposure to natural uranium, the concentration in bone is about three times that in the kidney; the biological half-life is about 300 days. Dr. Hamilton doubted whether these data would apply exactly to U^{233}, where the gross chemical quantities involved are so much smaller. Dr. Shields Warren summed up this phase of the discussion, saying that there appeared to be no choice but to accept figures of 0.05 μc for Po^{210} and 6 μg for U^{233}. Professor Mitchell said that in the United Kingdom, there are no known cases of occupational disease attributable to natural thorium dioxide. Dr. Wolf confirmed that a survey in the U.S. had revealed no cases. Dr. Shields Warren stated that the observations with thorotrast in animals were of doubtful applicability to the present problem; injections of an apparently inert substance like indian ink may produce tumours. It seemed best to leave thorium aside for the present. Dr. Hamilton pointed out that Th^{234} (i.e., UX_1) is exactly similar metabolically to Pu, he therefore proposed that, allowing for the average energy of the beta radiation which is 0.8 MeV. as against 5.5 MeV for the alpha radiation from plutonium, and taking a relative biological efficiency of 20 for the alpha radiation, the minimum damaging amount of Th^{234} be taken as 8 μc. Dr. Wolf stated that for soluble compounds of natural uranium the principal hazard is chemical, and 120 μg fixed in the kidney appears to be the minimum injurious amount; for insoluble compounds the principal hazard would appear to be radiation effects from particles fixed in the lung. A dose of 0.3 biologically equivalent roentgens per week would be produced by 105 mg. of uranium in the lungs.

It was then formally agreed to adopt the following figures for the minimum damaging amount of material continuously present in the body:

Ra^{226}	1 microgramme
Pu^{239}	1 "
U^{233}	6 "
Po^{210}	0.05 microcurie
Th^{234}	8 "

The meeting then proceeded to consider how maximum permissible amounts of material should be deduced from the foregoing minimum damaging amounts. Dr. Parker said he was not in favour of having two different sets of figures, one for plant workers and the other for the general population, and after some general discussion it was decided to consider the former class first. The present figure for radium of 0.1 μg corresponds to a safety factor of 10 and it was suggested by Dr. Hamilton that by comparison with the practice for other noxious agents, such a factor was reasonable. Dr. Lewis on the other hand felt that if the relation between damage and "dose" were indeed linear for radium, then the factor of 10 does not represent a very great margin of safety; after further discussion, Dr. Edson proposed that a factor of 10 be adopted, and this was formally agreed, leading to the figures:

Maximum Permissible Amounts of Isotopes continuously present in the Body, for Plant and other special workers.

Ra^{226}	0.1 microgramme
Pu^{239}	0.1 "
U^{233}	0.6 "
Po^{210}	0.005 microcurie
Th^{234}	0.8 "

The question of the general population was now reconsidered, and Dr. Shields Warren pointed out that the Columbia River and the Clinch River presented problems comparable with those of the River Thames. Dr. Brues said that the magnitude of the safety factor required for the general population, depended on the avoidance of a statistically significant increase of pathological effects. Consequently, since it could not be ruled out that such effects were linearly related to the dose, he would propose a safety factor of 10 for populations of the order of 10^5 and 100 for populations of the order of 10^7 on the figures accepted for the plant and other special workers. He considered that it would be unsafe to draw conclusions from the existence of natural water with very high radioactive content, since the populations exposed to such waters were very limited. He felt it was undesirable to double the natural radium content of the skeleton. Professor Mitchell referred to the recent work of Dr. Bale and Dr. Hursh indicating a radium content of the skeleton of the order of 2×10^{-4} μg. He felt that an increase of 10 on that figure was the absolute limit of what was justifiable. The question of a possible correlation between the natural incidence of osteogenic sarcoma and the natural radium content of the skeleton was mentioned and Dr. Hamilton suggested that the idea was not in accord with the fact that the disease occurred predominantly in young people. Dr. Brues quoted Swedish statistics, and Dr. Neary quoted British statistics showing that the peak of incidence in youth is followed by a greater rise in middle and old age. Dr. Warren pointed out that this latter effect is related to the appearance of Paget's disease of bone (osteitis deformans) in later life, which appears to be associated with metabolic changes unconnected with radioactive effects. The practicability of proposals based on the large safety factor, and the difficulty of public opinion on the existence of different levels for different sections of the population were mentioned. At this point, Dr. Brues reminded the meeting that the Medical Research Council's proposals for the River Thames were confidential. Mr. Chamberlain stated that the proposals for the River Thames are practicable. He pointed out that in the neighbourhood of a plant, it is impossible to draw a hard and fast defining line between the plant population and the general population. A proposal to apply a safety factor of 100 to say the gaseous effluent from a plant would certainly not be practicable.

Finally, it was formally agreed that a safety factor of 100 on the permissible levels for plant and other special workers should be applied to all elements when dealing with large centres of population. The following figures were therefore adopted for Group I:

Maximum Permissible Amounts of Isotopes continuously Present in the Body, for all large centres of population.

Ra^{226}	0.001 microgramme
Pu^{239}	0.001 "
U^{223}	0.006 "
Po^{210}	0.00005 microcurie
Th^{234}	0.008 "

Group II

Fission Products

In view of the limitations of time, it was decided to consider only the most dangerous of the fission products, namely, strontium. Dr. Hamilton observed that the mean energy per disintegration of $Sr^{90} + Y^{90}$ is 1.1 MeV, or about one fifteenth of the effective energy for radium in the skeleton. Then the relative biological efficiencies are also taken into account, the ratio of biologically equivalent amounts (in curies) of Sr^{90} and radium would appear to be 300. Dr. Brues pointed out however that acute toxic effect and the carcinogenic effect in animals gave a ratio of only 10 for Sr^{89} which would indicate a ratio of approximately 20 for $Sr^{90} + Y^{90}$. Mr. Chamberlain said that some of the alpha radiation is effectually expended in mineral bone and so if the harmful effect of radiation is dependent on integral dose as well as on the dose at particular points an extrapolation on energy grounds is unsound. Dr. Shields Warren stated that the mean diameter of the trabeculae in man is 30 to 35 μ. Dr. Hamilton then observed that it would have been better to consider Th^{234} (UX_1) in relation to the strontium data rather than the plutonium data. (Secretary's note: if this were done, then the minimum damaging amount of Th^{234} would be six tenths of that for Sr^{89}). He calculated that 7 μc of Sr^{90} in the bone and marrow gives a dose of 0.3r per week; the range of the beta rays in sufficient to average out the effect of any non-uniform distribution of the strontium. Dr. Brues stated that the figure of 7 μc as a permissible amount seemed too high on the basis of the experimental comparisons. Dr. Hamilton observed that some of the beta rays in man will be ineffectually absorbed in mineral bone so that the efficiency relative to radium will be smaller than in mice. Professor Mitchell remarked that the problem was related to the discrepancy between the empirically determined permissible radium burden in the body and the permissible dose for external penetrating radiation. Dr. Brues pointed out that the disagreement could be reduced if a smaller relative biological efficiency for alpha radiation wereadopted; for example, a value of 5 would lead to a permissible level (plant workers) of 2 μc for Sr^{89}, of 1 μc for $Sr^{90} + Y^{90}$, values which he was prepared to accept. After some further discussion, it was formally agreed to adopt 10 μc of Sr^{89} or 5 μc of Sr^{90} (equilibrium with Y^{90}) as the minimum damaging amount.

The foregoing conclusions for the isotopes in Group I and II may therefore be summarized as follows:

Element	Minimum damaging amount continuously present.	Maximum permissible amount for Plant and other special workers.	Maximum permissible amount for all large centres of population.
Ra^{226}	1 microgramme	0.1 microgramme	0.001 microgramme
Pu^{239}	1 "	0.1 "	0.001 "
U^{233}	6 "	0.6 "	0.006 "
Po^{210}	0.05 microcurie	0.005 microcurie	0.00005 microcurie
Th^{234}	8.0 "	0.8 "	0.008 "
Sr^{89}	10 "	1.0 "	0.01 "
$Sr^{90}(+Y^{90})$	5 "	0.5 "	0.005 "

At this point, the time officially alloted for the Conference had expired. Dr. Shields Warren proposed that in view of the importance of the common isotopes in Group III, a further informal session be held to consider them, and this was agreed.

Before concluding this session, Dr. Shields Warren suggested that each national delegate might prepare draft notes on the Conference which could then be circulated with a view to getting a final agreed statement of the proceedings. He further suggested that the necessary liaison might be effected through Dr. Cipriani and Mr. McMurtrie. These proposals were agreed.

Group III

H^3, C^{14}, Na^{24}, P^{32}, S^{35}, A^{41}, Sr^{89}, Sr^{90}, I^{131}, Co^{60}

C^{14} The problem fo C^{14} as carbon dioxide in the atmosphere was discussed by Dr. Brues. A dose rate of 0.3 rep. per week would be produced by 0.014 μc of C^{14} per gramme of tissue. If the highest proportion of carbon in tissue is 10%, as in bone carbonate, then the maximum permissible concentration of C^{14} in carbon in the body is 0.14 μc per gramme of carbon. The postulated route of entry of C^{14} into the body is via the alveoli of the lungs, and the isotopic concentration of C^{14} in the carbon of the body can never be greater than the concentration in the alveolar air, which must therefore be limited to 0.14 μc per gramme of carbon. Since alveolar air contains 5.5% by volume of carbon dioxide, the maximum permissible concentration of C^{14} in alveolar air is

$$\frac{0.14 \times 0.055 \times 12}{2.24 \times 10^4} \ \mu c/cc. \text{ or } 4.1 \times 10^{-6} \ \mu c/cc.$$

Hence the maximum permissible concentration of C^{14} in the atmosphere may be taken as 4×10^{-6} μc/cc. with a small safety factor since the actual concentration of C^{14} in the alveolar air may be expected to be somewhat less than that prevailing in the atmosphere. On the other hand, the concentration of carbon in some tissues may be higher than 10%, perhaps up to 50%/fat. Dr. Brues, therefore, proposed the adoption of a figure of 10^{-6} μc/cc. for maximum permissible concentration of C^{14} as carbon dioxide in the atmosphere for continuous breathing.

A dose rate of 0.3 rep per week is produced by 0.014 μc of C^{14} per gramme of tissue. If the carbon content of tissue can be as high as 50%, then 0.028 μc of C^{14} per gramme of carbon is the maximum concentration that can be permitted. If we take 18% by weight of the standard man as carbon then

$$0.028 \times 12{,}600 = 350 \ \mu c.$$

Dr. Brues went on to describe some of the actual experimental evidence on the metabolism of C^{14}. Mice were exposed for two months to an atmosphere containing C^{14} as carbon dioxide. The concentration of C^{14} in the tissues rose durina the first week and then soon reached limiting equilibrium values. The maximum local concentration foundin bone was not more than five times the average concentration in bone. In Shubert's experiments, the isotopic concentration in bone carbonate reached a value of one seventh of that in expired air.

H^3 The question of tritium as a gas rather than as water vapour was first briefly mentioned; Dr. Lewis stated that the exchange of the gas with water seems to be fairly rapid.

Dr. Brues stated that since the energy of the tritium radiation is about one tenth that of the C^{14} radiation, it follows that a concentration of 0.23 μc per gramme of tissue will result in a dose of 0.3 rep/week. Therefore the total amount in a 70 kg. man would be 16 mc. Following the same argument as for C^{14}, and taking the water vapour content of alveolar air as 50 mg/litre, the maximum permissible concentration of H^3 in alveolar air (and therefore in inhaled air) is

$$0.23 \times 5 \times 10^{-5}\ \mu c/cc \text{ or } 12 \times 10^{-6}\ \mu c/cc$$

where the body has been regarded as entirely composed of water.

An alternative approach is to consider the 50 kg. of water in the body as turned over at the rate of 2½ kg per day (Standard Man), that is with the mean life of 20 days. Since the maximum permissible amount of tritium in the body was calculated above as 16 mc, the concentration in inhaled air (assuming complete absorption) would be

$$40 \times 10^{-6}\ \mu c/cc.$$

Experimentally, the half life of tritium water in the body is about 5 days. Dr. Parker stated that a value of 6 or 7 days had been found.

Dr. Morgan said that he calculated the maximum permissible amount of H^3 in the body as 6 mc.

Dr. Brues considered the question of the relative biological efficiency of the soft beta radiation from tritium. It is observed that the lethal dose of tritium water for mice is such as to give a dose of about 300 rep. per day initially, falling with a five day half life. Thus the dose is comparable to that for X or gamma radiation, and the relative biological efficiency is not greater than 2.

Maximum permissible amount in the body	10 mc.
Maximum concentration in air	40×10^{-6} μc/cc.
Maximum concentration in drinking water	1×10^{-2} μc/cc.

<u>Na^{24}</u> Dr. Hamilton remarked that experimentally 25% of the gamma radiation of Na^{24} is absorbed in passing through the body. Dr. Morgan calculated the effective energy (beta and gamma) per disintegration as 2.7 MeV. This leads to a figure of 15 μc as the maximum permissible amount in the body. Dr. Hamilton pointed out that the biological half life corresponds to about 5% loss per day; this may be ignored in comparison with the radioactive decay for which the mean life is approximately 1 day. Therefore the maximum permissible concentrations in air and drinking water are approximately 10^{-6} μc/cc and 5×10^{-3} μc/cc. respectively. These figures were formally agreed.

(Secretary's note: the immersion tolerance for Na^{24} in water is approximately 10^{-4} μc/cc, which is lower than the drinking water figure.)

P^{32} Dr. Neary stated that the Medical Research Council's Panel recommends a figure of 10^{-4} μc/cc for P^{32} in drinking water. The calculation is based on the assumption that half of all the absorbed phosphorus is concentrated in the red bone marrow where the equilibrium amount is controlled by radioactive decay only, and is required not to exceed 3 μc. Dr. Hamilton said that the LD-50 is 20μc, while Dr. Shields Warren stated that 250 μc gives no perceptible haematological effect. Drs. Failla and Morgan were in favour of calculating the dose for the equilibrium distribution of phosphorus, i.e., with 98% in the skeleton, which they said would lead to a maximum permissible amount of 5 μc. Dr. Hamilton pointed out that months are required for equilibrium to be reached. Dr. Parker quoted a recommendation from the National Research Council's Maximum Permissible Internal Dose Committee that the permissible amount of P^{32} in the skeleton, be limited to 1.2×10^{-3} μc/g, corresponding to 8.4 μc in a 7 kg. skeleton, which is supposed to contain 90% of the body phosphorus.

At this point, Dr. Shields Warren suggested that in view of the lateness of the hour, the meeting should break up into separate groups to consider the remaining isotopes, and this was agreed. Dr. Brues, Dr. Hamilton and Mr. Chamberlain reported on P^{32} as follows:

It is known both experimentally and clinically that at times of the order of the mean life of P^{32} in red bone marrow reaches a value only about three times the average concentration for the whole body, and so most of the P^{32} is diffused throughout the body. In order to allow for the threefold relative concentration in red bone marrow, the total phosphorus may be regarded as contained in a hypothetical critical tissue of mass 70 kg. This argument would suggest a permissible amount of P^{32} in the body of approximately 25 μc. It may be that somewhat higher concentrations of P^{32} in bone marrow may occur and so a figure of 10 μc as maximum permissible amount was proposed. The corresponding figure for air was 5×10^{-8} μc/cc, and for water 2×10^{-4} μc/cc assuming radioactive decay only. These values were formally agreed.

<u>S^{35}</u> Drs. Braaten, Hempelmann, Wright Langham, Morgan and Wolf reported on S^{35} as follows:

Since the mean energy of the S^{35} beta radiation is 0.173 MeV; the concentration in the critical tissue to give 0.3 rep/week is 14 μc/kg. If the critical tissue were bone, then the maximum permissible amount would be approximately 100 μc; if liver, then 17 μc. (Note: 23 μc would appear to be a more precise figure); if skin, then 89 μc. It was therefore assumed that the total permissible body content would be 200 μc. for equal concentrations in the three tissues mentioned. The figures proposed for the permissible concentrations in air and water were 2×10^{-6} μc/cc. and from 10^{-5} to 10^{-2} μc/cc respectively. (Note: If 100% uptake, and radioactive decay only are assumed, the figures would be 10^{-7} μc/cc and 6×10^{-4} μc/cc.)

A^{41} and Xe^{133} It was agreed that the hazard from these isotopes was from external irradiation so that the figures for the maximum permissible concentrations in air are 10^{-6} μc/cc for A^{41} and 10^{-5} μc/cc for Xe^{133}. (Note: the concentration of Xe^{133} in fat would need to be about 10^4 times that in water before internal irradiation became a comparable hazard.)

I^{131} Dr. Edson, Dr. Failla, Prof. Mitchell and Dr. Parker reported on I^{131}

The effective total energy absorbed in the thyroid gland is estimated to be 0.222 MeV per disintegration, so that a dose of 0.3 rep/week is produced by 3.5×10^{-3} μc per gramme of tissue; the maximum permissible amount of I^{131} in the thyroid is therefore 0.06 μc. It was stated that the biological half life of iodine in the thyroid is very much longer than in the rest of the body and it was estimated that the total amount of iodine in the body corresponding to 0.07 μc in the thyroid alone is 0.1 μc. The absorption of iodine into the body is assumed to be 100%, and 20% of the absorbed amount is assumed to be deposited in the thyroid gland. On this basis the maximum permissible concentration of iodine in air is 10^{-9} μc/cc and in water is 10^{-5} μc/cc. These figures were formally agreed.

It was noted that a calculation based on isotopic dilution of the I^{131} with the normal daily intake of iodine would give unduly low permissible concentration because the radioactive decay is in fact much more rapid than the rate of biological turnover in the gland. The isotopic ratio of I^{131} for the stationary amount of iodine in the gland is therefore lower than for the daily intake of iodine.

Co^{60} Drs. Carmichael, Laurence and Neary reported on Co^{60}.

It is assumed that the cobalt which is absorbed is all deposited in the liver, following the indications of some animal experiments. The effective energy absorbed in the liver is assumed to be 1.3 MeV per disintegration, so that the amount to give 0.3 rep/week is 1 μc. The half life in the liver is taken to be 20 days. The maximum absorption of 50% for a soluble aerosol is assumed, leading to a maximum permissible concentration in air of 20×10^{-9} μc/cc. The absorption from drinking water is assumed to be 100% so that the maximum permissible concentration in water is 1×10^{-5} μc/cc. These figures were formally agreed.

U (Natural) The maximum permissible concentration for uranium compounds in air is taken to be 50 g/m^3 on the basis of the chemical toxicity of the soluble compounds. This value was taken to be equivalent to 3.3×10^{-11} μc/cc, which was formally agreed. (Note: The latter figure is in error; it should be 8.7×10^{-12} μc/cc.)

Ra^{226} The maximum permissible concentration in air for soluble compounds is 4×10^{-12} μc/cc.
Mr. Chamberlain proposed that inhalation the permissible levels should be adjusted proportionally in circumstances where less than the full 24 hours exposure occurred, and this was agreed.
For oral ingestion, Dr. Hamilton suggested a final overall retention of 10%, with a mean life greater than 10 years. A value of 10^4 days would lead to a maximum permissible level in drinking water of 4×10^{-8} μc/cc. It was formally agreed to adopt these values.

Pu^{239} The relative permissible values for plutonium and radium fixed in the body (0.1 microgram of each) were agreed upon at Chalk River on the basis of evidence presented by Dr. Brues that the toxicity ratio between equal microcurie amounts of plutonium and radium is approximately 15 to 1.

Further facts now presented by Dr. Brues lead to a greater permissible amount of Pu as compared to Ra, as follows:

1. The toxicity ratio of 15:1 was based on injected dose. But 75% of the plutonium is retained in the body of the rat, and 25% of the radium. This consideration leads to a factor of 3, making the toxicity ratio actually 5:1.

2. Further, about 50% of the radon is retained in the human, but only 15-20% in the rodent, leading to another factor of about 2 in favour of plutonium. That is, the alpha energy delivered from the radium chain to the human is 4.8 + 0.5 (5.5 + 6.0 + 7.7) = 14.4 MeV and to the rodent is

$4.8 + 0.15\ (5.5 + 6.0 + 7.7) = 7.7$ MeV

Hence, the "estimated fixed minimal damaging dose" of Pu for the human, based on 1 microgram of Ra is

$$1\ \mu g\ Ra \times 1\ \mu g\ Pu \times \frac{24000}{1600} \times 3 \times 2 = 6\ \mu g\ Pu$$

The value of 0.5 μg Pu for the maximum permissible dose, as compared with 0.1 μg Ra, is therefore a conservative.

On the basis of 0.5 μg. Pu permissible dose, 10^4 days mean life, 10% retention and 20 cubic metres of air breathed per day, persmissible air concentration becomes:

$$0.5\ \mu g\ Pu = conc \times 10^4\ days \times 10^6\ cc/day \times 10\%$$

$$conc = 2.5 \times 10^{-11}\ \mu g\ Pu/cc.$$

$$= 1.5 \times 10^{-12}\ \mu c\ Pu/cc.$$

On the basis of 2.5 litres of drinking water per day for 10^4 days, and assuming 0.1% absorption at low concentrations, the permissible concentration of Pu in drinking water is

$$0.5\ \mu g\ Pu = conc \times 10^4\ days \times 2.5 \times 10^3\ cc/day \times .001$$

$$conc = 2 \times 10^{-5}\ \mu g\ Pu/cc$$

$$= 1.2 \times 10^{-6}\ \mu c/cc$$

$Sr^{90}(+Y^{90})$ Dr. Hamilton stated that he calculated the maximum permissible levels for Sr^{90} $(+Y^{90})$ to be 2×10^{-10} μc/cc in air and 4×10^{-6} μc/cc in drinking water. (Note: these figures would appear to correspond to a final retention of approximately 1%)

U^{233} Dr. Hamilton also mentioned figures for U^{233}. For soluble compounds in air, he calculated a maximum permissible level of 6×10^{-9} μg/cc, or 6×10^{-11} μc/cc, while for insoluble compounds the figure is 2.5×10^{-11} μg/cc or 2.5×10^{-13} μc/cc. For ingestion, a figure 2×10^{-3} μg/cc or 2×10^{-5} μc/cc was obtained.

These recommendations are summarized:

Maximum permissible levels for Plant and Other Workers

under Medical Supervision

Element	Maximum Permissible Amount in Body	Maximum Permissible Concentration in Air (24 hour day)	Maximum Permissible Concentration in Drinking Water
H^3	10 mc.	40×10^{-6} μc/cc	1×10^{-2} μc/cc
C^{14} (as CO_2)	300 μc.	1×10^{-6} μc/cc	
Na^{24}	15 μc.	1×10^{-6} μc/cc	5×10^{-3} μc/cc
P^{32}	10 μc.	5×10^{-8} μc/cc	2×10^{-4} μc/cc
S^{35}	200 μc.	2×10^{-6} μc/cc	1×10^{-2} μc/cc
I^{131}	(0.07 μc. (thyroid) (0.1 μc. (body)	2×10^{-9} μc/cc	1×10^{-5} μc/cc
Co^{60}	1 μc.	2×10^{-9} μc/cc	1×10^{-5} μc/cc
A^{41}		1×10^{-6} μc/cc	
Xe^{133}		1×10^{-5} μc/cc	
Xe^{135}		3×10^{-6} μc/cc	
U (Natural)		8.6×10^{-12} μc/cc (25 $\mu gm/m^3$)	
Ra^{226}	0.1 μg.	4×10^{-12} μgm/cc for soluble compounds	4×10^{-8} μc/cc
Pu^{239}	0.5 μg.	1.5×10^{-12} μc/cc 2.5×10^{-11} μg/cc for soluble & insoluble compounds.	1.2×10^{-6} μc/cc (2×10^{-5} μg/cc)
U^{233}	0.6 μg.	6×10^{-11} μc/cc (6×10^{-9} μg/cc) for soluble compounds 2.5×10^{-13} μc/cc (2.5×10^{-11} μg/cc) for insoluble compounds	2×10^{-5} μc/cc (2×10^{-3} μg/cc)
$Sr^{90}(+Y^{90})$	1.0 μc.	2×10^{-10} μc/cc	4×10^{-6} μc/cc
Sr^{89}	2.0 μc.		
Po^{210}	0.005 μc.		
$Th^{234}(UX_1)$	0.8 μc.		

Dr. Shields Warren reminded members of the Conference that there would be an opportunity for further comments on the foregoing figures when the notes on the Conference were circulated according to the procedure already agreed.

The business of the Conference then terminated.

APPENDIX 17

ICRP-MINUTES OF BUCKLAND HOUSE CONFERENCE (AUG., 1950)

TOLERANCE CONFERENCE

To be held on 4th, 5th, 6th August, 1950, at Buckland House, near Faringdon, Berks.

D E L E G A T E S

United States

Dr. Shields Warren
Professor Robley D. Evans (Part-time)
Dr. R. D. Marinelli
Dr. Lauriston Taylor.

Canada

Dr. A. Cipriani
Dr. G. C. Laurence.

United Kingdom

Sir John Cockcroft
Mr. W. T. Binks (Part-time)
Mr. A. C. Chamberlain
Dr. E. F. Edson
Dr. A. Glücksmann (Part-time)
Dr. L. H. Gray (Part-time)
Dr. J. F. Loutit
Dr. W. G. Marley
Professor W. V. Mayneord (part-time)
Dr. G. J. Neary
Professor F. W. Spiers (Part-time).

A G E N D A

Friday, 4th August, 1950

1. Radium and Mesothorium toxicities.
2. Plutonium and Radium relative toxicities.
3. Strontium and Radium relative toxicities.
4. Uncertainties in the figures proposed at the Chalk River Conference, e.g. H^3, Po^{210}, S^{35}, Sr^{90}, U^{233} (insoluble compounds).

Saturday, 5th August, 1950.

1. Radioactive dusts.
2. Low energy beta-emitters.
3. Permissible fluxes for neutrons.

Sunday, 6th August, 1950 Meeting in association with M.R.C. Tolerance Doses Panel.

1. Genetic factors in radiation hazards and in relation to existing exposure levels.
2. Safety factors for large populations for bone-seeking isotopes.
3. Organization of future tolerance work.

H.9309.

TOLERANCE CONFERENCE

Friday Afternoon Session

The toxicities of plutonium and strontium relative to radium were discussed.

The final report of the Chalk River Conference refers to the different absolute toxicity of radium in man and in rats because of the greater proportional release of radon in the latter. Dr. Evans stated that this difference had been established in his laboratory when the man and the rat were at comparable stages of pathological change. Assuming that damage arises from the alpha radiation of both radium and the residual decay products in the bone it would appear that the effective energy release from radium in man is about twice that in rats. In consequence, the estimated toxicity of plutonium and strontium relative to radium, derived from experiments on rats and mice, should be doubled in the case of man.

Furthermore, the relative toxicity of plutonium and radium was originally expressed by Dr. Brues on the basis of injected amounts. If retained amounts are taken into account, it would appear in rats and mice that radium is three times as toxic on a mass basis as plutonium. Dr. Shields Warren said that the detailed evidence existed and would be made available.

The maximum permissible amounts fixed in the body are therefore:-

2 μc of Sr^{89}
1 μc of Sr^{90}
0.04 μc of Pu^{239}

Uncertainties in the Chalk River figures for H^3, S^{35}, Sr^{90}, U^{233} and Po^{210} were discussed.

$\underline{H^3}$ It was assumed that the maximum permissible amount of H^3 in the body to give 0.3 rep/week would be 10 mc. The experiment evidence that the mean life of water in the body is 10 days was accepted. This leads to permissible concentrations in air and in drinking water of 5×10^{-5} μc/cc and 4×10^{-1} μc/cc respectively.

$\underline{S^{35}}$ Work was quoted suggesting that the concentration of sulphur in the skin is about ten times the average concentration for the whole body. The maximum permissible amount in the body would therefore be 100 μc. It was felt that it would be impracticable to derive universally applicable figures for concentrations in air and water.

$\underline{Sr^{90}}$ It was believed that Dr. Hamilton intended the retention of strontium to be about 10% instead of 1% as assumed at Chalk River. The biological mean life is assumed to be 10^4 days (27 years) and so the effective mean life in the body is about 15 years. The permissible concentrations in air and in drinking water are therefore 8×10^{-11} μc/cc and 7×10^{-7} μc/cc respectively.

$\underline{U^{233}}$ It is believed that there was a numerical error of a factor of ten too low in the Chalk River figure for insoluble compounds of U^{233}. Further, the permissible amount of U^{233} in the body was assumed to be the same as for plutonium. In view of the revision of this latter figure, the U^{233} figures should be

Permissible amount in the body 0.04 μc.
Permissible concentration in air 4×10^{-10} μc/cc for soluble compounds.
Permissible concentration in air for insoluble compounds 1×10^{-11} μc/cc.
Permissible concentration in drinking water 1×10^{-4} μc/cc.

$\underline{Po^{210}}$ Dr. Shields Warren reported that chronic experiments were in progress, but results were not yet available. It was agreed that there was at present no reason to change the Chalk River figure of a 20 to 1 toxicity ratio as compared with radium.

Note: All figures above have been expressed as for plant personnel.

BUCKLAND CONFERENCE (1950)

Isotope	Sr^{90}	H^{3}	Na^{24}	P^{32}	I^{131}
Half life	25y	12.1y	14.8hrs	14.3d	8d
M.p.l. in body (μc)	1	$1x10^{4}$	15	10	0.1 (0.06 in thyroid)
Effective mean life (days)	5000	10	0.8	20	12
Permissible daily Deposition in body (μc)	$2x10^{-4}$	$1x10^{3}$	20	0.5	0.005 (to thyroid)
Proportion absorbed and retained by lungs.	0.10	1			0.2 (to thyroid)
M.p.l. in air (μc/cc)	$2x10^{-10}$	$5x10^{-5}$			$1x10^{-9}$
Proportion retention from gut	0.1	1	1	1	0.2
M.p.l. in water (μc/cc)	$8x10^{-7}$	0.4	$8x10^{-3}$	$2x10^{-4}$	$1x10^{-5}$

Isotope	Ra^{226}	Pu^{239}	(soluble)	U^{233}	(insoluble)
Half life	1622y	$2.4x10^{4}y$		$1.6x10^{5}y$	
M.p.l. in body (μc)	0.1	0.04	0.04(bone)		0.008 (lung)
Effective mean life (days)	10^{4}	10^{4}	100		200
Permissible daily Deposition in body (μc)	10^{5}	$4x10^{-6}$	$4x10^{-4}$		$4x10^{-5}$
Proportion absorbed and retained by lungs.	0.06	0.1	0.025		.125
M.p.l. in air (μc/cc)	$8x10^{-12}$	$2x10^{-12}$	$8x10^{-10}$		$6x10^{-11}$
Proportion retention from gut	0.1	0.001	0.001		--
M.p.l. in water (μc/cc)	$4x10^{-8}$	$1.5x10^{-6}$	$1.5x10^{-4}$		--

Factor of 100

(See revised table, page 17-5)

TOLERANCE CONFERENCE

Saturday Sessions

The hazard from radioactive dusts was discussed with special reference to their particulate character. Considerable emphasis was placed on the possible high solubility of normally insoluble compounds when present in finely divided state in the lungs. In consequence it seems unlikely that any particular group of cells will be irradiated by a given active particle over a prolonged period. The value of nose swab counts was mentioned, with special reference to plutonium. There was no instance of an individual showing a high urine assay who had not also exhibited a high count for the nose swab. Animal experiments are in progress at Rochester on the effects of plutonium particulates, pile stack dusts, and dusts from chemical separation plants.

The intrinsic radio-resistance of the lung tissue was emphasized, and the example quoted of cases of carcinoma of the breast treated by radiation, and free from symptoms of lung damage 10 to 20 years after. No cases of lung abscess have been found at Los Alamos. The high incidence of bronchial carcinoma in some uranium mines may be associated with the chronic character of the irradiation and the irradiation of the bronchi by active deposit from radar, rather than by active particulates. The desirability was stressed of obtaining data on the retention of active dusts in the lungs and any pathological consequences therefrom, by means of post-mortem examination on workers.

Dr. Shields Warren summarized the position as follows:

(1) There is no evidence as yet of specific injury from inspired plutonium.
(2) The present permissible doses contain adequate safety factors.
(3) There is no evidence of low grade injury to the lung that might indicate minor damage.
(4) The permissible doses recommended at present do not present excessive engineering problems.

It was therefore agreed that no increased precautions were required with regard to particulate hazard.

Dr. Marinelli proposed reconsideration of the figures for retention in the lung and for absorption from the lung. It was pointed out that the evidence on which the 50% immediate retention was based was open to question, and after analysis of the data, it was agreed to alter the values on p. 9 of the Chalk River Report, R.M. 14 as follows:

> If specific data are lacking, the convention should be adopted that 25% of any aerosol reaches the alveoli of the lungs. If the particles are soluble they are considered to be totally absorbed; if insoluble, then the 25% amount is to be regarded as retained for 24 hours, after which only half of it, i.e. 12½% is retained in situ indefinitely.

In the light of this and related data, the values for radium, plutonium, strontium and uranium 233 were reconsidered and the provisional table amended to read as on the attached sheet.

The factor of R.B.E. for low energy beta-emitters was discussed and it was agreed that the data showed that even for tritium, a value of unity is sufficient.

Individual isotopes were considered in detail and with the exception of I^{131}, to be discussed again, no changes were required, as no additional data were adduced.

Some data on radioactivity levels in river and sea water and concentration of isotopes in algae and fish were discussed.

The problem of permissible fluxes of neutrons were discussed and the recommendation of the International Commission on Radiological Protection were noted. It was felt that insufficient evidence existed to change the figures adopted for R.B.E. at the Chalk River Conference. It was agreed that the detailed calculations of Tait for the M.R.C. Tolerance Doses Panel would be circulated. The question of maximum single permissible doses was left open. As a guide, 25r was considered not to incapacitate the person exposed. In general, it was felt that persons receiving above permissible doses should not be further exposed until compensating time had elapsed, but that their employment should not be interrupted.

Isotope	Sr^{90}	H^3	Na^{24}	P^{32}	I^{131}
Half life	25y	12.1y	14.8hrs	14.3d	8d
M.p.l. in body (μc)	1	$1x10^4$	15	10	0.3 (0.18 in thyroid)
Effective mean life (days)	5000	10	0.8	20	12
Permissible daily Deposition in body (μc) per day	$2x10^{-4}$	$1x10^3$	20	0.5	0.015 (to thyroid)
Proportion absorbed via lungs and retained in body	0.06	1			0.2 (to thyroid)
M.p.l. in air (μc/cc)	$2x10^{-10}$	$5x10^{-5}$			$3x10^{-9}$
Proportion retention from gut	0.1	1	1	1	0.2
M.p.l. in water (μc/cc)	$8x10^{-7}$	0.4	$8x10^{-3}$	$2x10^{-4}$	$3x10^{-5}$

Isotope	Ra^{226}	Pu^{239}	(soluble	U^{233}	(insoluble)
Half life	1622y	$2.4x10^4y$		$1.6x10^5y$	
M.p.l. in body (μc)	0.1	0.04	0.04 (bone)		0.008 (lung)
Effective mean life (days)	10^4	10^4	100		200
Permissible daily Deposition in body (μc) per day	10^{-5}	$4x10^{-6}$	$4x10^{-4}$		$4x10^{-5}$
Proportion absorbed via lungs and retained in body	0.06	0.1	.025		0.125
M.p.l. in air (μc/cc	$8x10^{-12}$	$2x10^{-12}$	$8x10^{-10}$		$1x6\text{-}10^{-11}$
Proportion retention from gut	0.1	0.001	0.001		
M.p.l. in water (μc/cc)	$4x10^{-8}$	$1.5x10^{-6}$	$1.5x10^{-4}$		

Notes by L. S. Taylor on Tolerance Conference

(As Secretary of ICRP)

Buckland House, Harwell, UK

Aug. 4-6, 1950

Friday, 4 Aug. - Harwell, 1950

Evans -

1917 - 1923 1.0 Ra : 1.3 mesothorium used by dial painters (mixes varied)

1 person with 8 μg Ra now in good health

1940 - 0.1 μg Ra fixed in body - based on 3 dial painters

1949 - Pure Ra of > 5 μg show no symptoms - 3 cases

27 cases above 1 μg on Evans' plot

Data suggests mesothorium considerably more toxic than Ra by factor of (2-10, μc for μc)

Radon 45% exhaled
Thoron .01-.1 % exhaled, hence all α rad remains in body -

(1) α radiation Me - 32 MeV delivered to body per disintegration

(2) α radiation Ra - 15 MeV delivered to body per disintegration

(3) The dosage administered quickly (6.7 yr. half life), therefore damage concentrated in first period.

The measuring technique very complicated - can detect down to about 10^{-13} curies of Thorium

(?) 2 cases below 0.1 μc showing no symptoms

Note: check with geneticists on Perm. Dose Committees -

Loutit - recommends 0.1 μg fixed Ra in body be retained

Binks - suggests idea of evaluation on basis of fixed and floating levels

Am. Standards Assoc. Z-39 code refers to radon levels in industry (Radium Prot. Code)

Consistency of Ra breath sampling over a day or week - check on sampling methods and procedures, previous exercize, living habits, exposure, etc. - also check on decay.

Repeat breath radon and body gamma ray content (Marinelli/Evans/Sievert)

Activity of stream levels seems to be very dependent upon who reports it - see June or July issue of Nucleonics 1950.

Make a link between Ra standards between NBS and NPL to be sure of Ra water sampling techniques. This is being done. (Exchange with L. M. Gray, also) Much of this water, bone, etc. analysis should be made at NBS instead of MIT - tie in with P.H.S. (?)

Evans & Mitchell recommend use of μμc or μμg per liter instead of per cc.

Pu, Ra and Sr toxicities--

Question as to whether α or β radiation from Ra does the damage

Friday, 4 Aug. - Harwell, 1950 - LST Notes (Continued)

In comparing Ra and Pu use factor of 2 on basis radon inhalation.

Pu and Ra comparisons (expt) injections were made--Ra fixes 25% and Pu fixes 75%, thus giving another factor of 3 in favor of Pu. This gives total factor of 6 (or 5 to be conservative)

Question left open--

Will use 5.0 factor for Pu--

Will use 2.0 factor for Sr^{89} (radiation toxicity)

2 μc Sr^{89}
1 μc Sr^{90} based on 0.1 μc for Ra

For Pu 1μg = .063 μc

Change ICRP report to μc for permissible dose in place of μg

(?) T.D. for Pu ≡ 4 μμc Pu/day excreted by urine (something missing)

H^3 Morgan has proposed 0.23 μc/cc instead of .14 μc/cc but this is questioned

See ICRP sheet

S^{35} (not in ICRP)

Uncertainty as to how it gets into body. Body burden = 100 μc

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Sr^{90} 1 μc permissible body burden - 1% retention is too low, but 10% seems better; therefore, reduce by factor of 10.

concentrations in water and 12 1/2% in air

maximum concentration in water = 7 x 10^{-7} μc/cc; in air = 8 x 10^{-11} μc/cc

U^{233}

(?) Possibly factor of 10 too high in ICRP

(?) Were Chalk R. values calculated against Pu ? New figure for body burden for uranium to be recalculated.

Po^{210} 0.005 μc figure comes from short term rat experiments in comparison with Ra, μc for μc

Sat., Aug. 5

Dusts:

Main hazard in those dusts that lodge in the lungs.

Nose count tolerances at Los Alamos taken arbitrarily as 50 c/min. in each nostril.

For Pu

1) No evidence of specific injury from respired Pu at present.
2) At present we have fair degree of safety factors.
3) No evidence of increased obvious respiratory infections as evidence of low grade injury.

Low energy β emitters: (Eniwetok, accident to hands) 14 days latent period - β rays from mixed fission products

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C^{14}

Present levels apply to $C^{14}O_2$ only. Cockcroft suggests need for levels of carbonates and other soluble compounds in water - would involve study of inactive carbonates in water also - no information available.

Na^{24}

95% of activity in Hanford river (Columbia) is Na^{24}

0.5×10^{-12} c/gram average activity

1×10^{-12} c/gram peak

20×10^{-12} c/gram average fish

800×10^{-12} c/gram peak "

[Mostly P^{32} (80%) in fish, liver, bone]

Note that this is small compared with P^{32} body burden - (Less for salt fish) Algae is 300 x fish - mostly P^{32}

I^{131} - note that latest values for air are lower than Chalk R. by factor of 2. Thyroid value seems low (?) 0.06 μc

Could increase by factor of 3 unless Gray objects.

Ra^{226} reduce retention of Ra^{226} from 0.12 to 0.06

This changes Sr^{90} from 0.2 to 0.06 M.P.L.

Sr^{90} - See changes on p. 7 in accord with changes in Ra^{226}

Permissible fluxes for neutrons

See pg. 2 of N P/ P/TD/148

Pg. 3 of ICRP recs (revised)

Tate's values of RBE vary from 10 to 4

Look up paper by TATE

Can't measure 20 $\eta/cm^2/sec$

Is Cataract committee using mice or rabbits for experimental animals?

Keep ICRU value of R.B.E. = 10

10 for fast neutrons

5 for slow neutrons (need to know composition of tissue, etc.)

Emergency Dose

Weapons Effects Handbook gives 50 r (?)

Sun., Aug. 6

Meeting of Tolerance Panel

Mayneord presiding: Discussion of genetic effects - (Muller's talk at Oberlin)

Sun., Aug. 6 (cont)

S. W. Panel discussions in Washington - Of 19,000 persons having known exposure, chances of change are small in 5 generations:

Catcheside calculations based on 1 r in 25 yrs - Gray recalculated on basis of 2.5 r for population of 50 million.

How many G.I. series made per week in Washington, etc? Make a survey as to total radiation administered to a city population.

Measure radiation to gonads for a chest examination, G.I. series, etc.

Catcheside coming to U.S. in Sept.

Ra content of river water -

See Eisenbud (N.Y.D.O.)

Also Marinelli for information from Argonne.

Exchange samples of water as a comparison of techniques 1-5 μμc/liter.

British:

Factor of 100 for large populations would reduce level to just detectable levels in several generations.

- based on 2.5 liters/day and standard man -

Applies mainly to P, Na, C, and not bone seekers -

Warren: Civil defense problem
Insurance and labor relations

Some mention of Chalk River figures including 100 factor, mentioned in recent number of Nucleonics.

Factor of 100 taken for discharge point with no allowance for clean-up of the river - studies should be made in individual rivers to see if there are any common factors--

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Express levels in terms of maximum permissible increment -

Bone-seeking isotopes - no important discussion.

Future Organization

APPENDIX 18

UK-MRC MINUTES OF BUCKLAND HOUSE CONFERENCE (AUG. 1950)

NP/P/.
TD/156

REPORT ON PERMISSIBLE DOSES CONFERENCE

Buckland House

A.E.R.E. Harwell

August 4th, 5th and 6th 1950

BY

G. J. NEARY

MEDICAL RESEARCH COUNCIL
RADIOBIOLOGICAL RESEARCH UNIT
A.E.R.E. HARWELL
DIDCOT BERKS
NOVEMBER 1950

AGENDA

Friday, 4th August, 1950

1. Radium and Mesothorium Toxicities.
2. Plutonium and Radium relative toxicities.
3. Strontium and Radium relative toxicities.
4. Uncertainties in the figures proposed at the Chalk River Conference, e.g.

   H^3, Po^{210}, S^{35}, S^{90}, U^{233} (insoluble compounds).

Saturday, 5th August, 1950

5. Radioactive dusts
6. Low energy beta-emitters.
7. Permissible fluxes for neutrons.

Sunday, 6th August, 1950. Meeting in association with M.R.C. Tolerance Doses Panel

8. Genetic factors in radiation hazards and in relation to existing exposure levels.
9. Safety factors for large populations for bone-seeking isotopes.
10. Organisation of future tolerance work.

CONTENTS

CONTENTS (Cont.)

The Conference was formally opened by Sir John Cockcroft, who welcomed the visitors, and expressed his pleasure and satisfaction that it had been possible to arrange a conference, following on a proposal by Dr. Shields Warren. Sir John suggested that the chair be occupied in rotation, and called on Dr. Loutit for the first day, Dr. Shields Warren for the second day, and Professor Mayneord for the third day when the Conference was meeting in association with the M.R.C. Tolerance Doses Panel; Dr. Neary would act as secretary to the Conference.

1. Radium and Mesothorium Toxicities

Professor Evans summarised new evidence on 27 cases known to contain radium in excess of 0.1μg. Dr. Hemplemann had noted in February of this year an anomaly in the clinical data, namely, that the degree of injury in the different cases was not related to the radium content in a regular manner. This observation, together with a previous discussion with Dr. Loutit on the possible influence of mesothorium on the toxicity of luminous paints, suggested to Professor Evans that the 27 cases fell into two groups, one having been exposed to pure radium and one to a mixture of radium and mesothorium. Owing to the comparatively short half life of mesethorium I (6.7 yr) the initial level of activity in the latter group would normally be appreciably higher than at the time of measurement after symptoms had occurred. It has been ascertained that in the principal luminising plants during the years 1917 to 1923, 1.3 curies of mesothorium and 1 curie of radium had been used, although the precise formula of the paint was varied from time to time. One luminiser in the present series now had 8 μg. of radium, 32 years after commencement of work; osteitis of the jaw had developed 20 years ago. She worked for 8 months only, at a time when no mesothorium was available. In 1940, a figure of 0.1μg of radium fixed in the body was suggested as a permissible level on the basis of three dial painters who had approximately 1 μg. of radium in the body and exhibited clinical signs and symptoms of injury. These three cases are now known to have been exposed to a mixture consisting mainly of mesothorium. All those cases of the 27, who have had symptoms, with less than 5 μg. of radium fixed are known to have had some mesothorium, while all cases who have had symptoms after exposure to pure radium, mainly from medicinal treatment, have had more than 5 g. fixed. Although the evidence is not yet complete, it is now believed that the minimum damaging amount of radium is 5μg. permanently fixed, while in the mesothorium cases, damage has occurred down to approximately 1μg. of the associated permanently fixed radium it is believed that the mesothorium is from 2 to 10 times more toxic than radium for equal amounts of activity. This difference is partly associated with the difference in the total energy release; for mesothorium the amount of thoron escaping, from one tenth to one hundredth of 1 per cent, is negligible and the energy release is 32 MeV per disintegration; while for radium, with one fewer alpha ray, less energetic particles on the average, and 45 per cent radon excretion, the energy release is about 15 MeV per disintegration. Further, the Alpha-emitting radiothorium, being an isotope of thorium, will tend to be distributed like that element, with probably greater toxic effect than if it remained universally distributed in the mineral bone. There is also a possible factor arising from the different time-distribution of the dose due to meothorium and to radium. The latent periods in the present series of 27 cases do not vary appreciably with dosage, but if the comparatively few pure radium cases are considered, the rather scanty data are not inconsistent with the Brues type of inverse correlation between dosage and latent period. Finally, Professor Evans stated that he now considered that the figure of 0.1μg. for the permissible level of radium fixed in the body contains a safety factor of about 50. In addition he stressed the importance of large scale animal experiments with pure mesothorium.

Dr. Loutit remarked that, after examining the detailed records of the 27 cases, he was impressed by the fact that the pathology of the injury was almost always osteitis, and that new growths were comparatively infrequent. For example, among 12 dial painters with symptoms, there were only four cases of neoplasm - one classical osteosarcoma, one unusual type of jaw tumour, one epidermoid carcinoma of the ear, and one leukaemia. In nine cases to whom radium had been administered medically, there were only two new growths, consisting of one typical osteosarcoma (radium burden 11μg.) and one atypical fibrosarcoma of the capsule of the knee (radium burden 5μg.) in a case treated for arthritis of the knee with radium water, 6μg/day, for 3 years.

Dr. Shields Warren felt that there was only a very slight chance that such a tumour would arise spontaneously, since none had turned up in a register of some 1200 sarcomas; on the other hand, epidermoid carcinoma of the ear is much more likely to arise spontaneously. Prof. Evans pointed out that neither case could be attributed to the effect of alpha rays arising in bone because of their short range, and it was doubtful whether sufficient local concentrations of radium could arise for the beta rays to be effective; it had been shown by Dudley with injections of pure radium in dogs, that the dose rate in the "hot-spots" is usually about ten times the average value, and is never more than fifteen times. Dr. Gray noted that of these fully documented cases, there were only five with pure radium burdens below 5µg. He felt that with such a small number, it would not be justified at present to increase the maximum permissible amount of radium fixed in the body above 0.1µg.

Professor Evans remarked that if the variability of individual sensitivity is no greater than that found by radiologists in therapy, i.e. by a factor not greater than 2, then only a few radium cases are needed to establish the toxic level. This conclusion was questioned by various delegates. It was felt that the variation would be greater when variations in general health and other concurrent factors were taken into account, and in particular, a distinction should be made between plant workers and the population at large.

Dr. Loutit felt that the evidence suggested that the development of osteitis followed a fairly uniform pattern but that the development of a neoplasm was a highly individual response. There also seemed to be evidence of greater injury in the younger age groups, but Professor Evans felt that this was due to the correlation of age and occupation; the younger groups were mainly dial painters, while the older groups were largely arthritics, treated with pure radium. Dr. Shields Warren cited the example of phenol or barbiturate poisoning, in which about 90 per cent of cases showed a uniform response but the remainder showed wide variations. Dr. Marinelli mentioned the work in progress at Chicago on the follow-up of the series of mental cases treated with radium by Schlundt; these cases were all young at the time of treatment about 20 years ago. An attempt to trace cases who worked in the luminising industry in Great Britain in the last war had yielded only 7 cases all with very minor amounts of radium. The importance of obtaining records on cases free from symptoms was stressed.

It was agreed for the present to retain the figure of 0.1µg. for the maximum permissible amount of radium fixed in the skeleton, remembering at the same time that the figure probably has a higher factor of safety than thought previously. It was noted that the International Commission on Radiological Protection had come to the same conclusions.

It was agreed not to adopt a figure for a mximum permissible amount of radium not permanently fixed in the body, because this Conference should avoid making recommendations involving the actual health measures to be adopted in regard to hazards. At the same time, there was an exchange of views and a brief survey of the available data on excretion of radium in man.

Dr. Loutit and Dr. Edson felt that it was desirable to adhere to a maximum figure of 0.1µg. even for the floating radium. Dr. Shields Warren stated that a figure of 1µg. had been in use at Los Alamos; about 20 or 30 operatives had reached this level and had been transferred to other work.

Professor Evans quoted the American Standard Z 39:

Ra (fixed) $\leqslant$ 0.1µg/50kg.

$\leqslant 10^{-12}$ c. Radon/litre.

Test: pre-employment.
end of first month.
every six months.

Anyone over 10^{-12}c. Radon/litre retest monthly until either: three consecutive results $> 10^{-12}$, signifying persistence and requiring transfer from exposure to radium, or two successive results below "allowable concentration".
Radium dust $\leqslant 10^{-11}$ c/cc. (10^{-14} c/litre)
Radon $\leqslant 10^{-8}$ c/cc. (10^{-11} c/litre).

Mr. Binks felt that it was unsafe to base a test on the breath measurements only, since the latter would vary with the physical activity of the patient.

Dr. Cipriani reported that Professor Ferguson, University of Toronto, is investigating the consistency of the radon excretion in a given person.

Professor Evans gave details of a case in which radium dust had been accidently inhaled. One month after the exposure, there remained 0.8µg. in the body and the gamma ray and breath radon tests indicated the same radon elimination as found in chronic cases. Three or four months after exposure some therapeutic measures to promote elimination of radium were adopted, but there was no fall during this period. The residual amount at seven months was 0.3 µg. while now after fourteen years, it is 0.01µg.

The well-known case described by Stevens was also mentioned, in which an intended dose of 400µg. was injected; 9µg, or 2½ per cent was still retained after 25 years. It was generally found that there was a rapid fall in the retained radium in over-exposed workers after cessation of exposure. The long term excretion rate (about twenty years after exposure) is from three to five thousandths of a per cent of the retained amount per day; 90 per cent of the excretion is via faeces and 10 per cent via the urine. Dr. Shields Warren stated that experiments with radium, mesothorium and plutonium, using several hundred dogs have been planned by Dr. Wright Langham of Los Alamos and members of the Utah Medical School. Acute and chronic exposures up to a year with injected material will be made. The quantities will cover a broad range, and in the case of radium will, allowing for the difference in weight of dog and man, correspond to fixed amounts in man of 1, 10 and 100μg. Dr. Gray suggested that experiments with pure radiothorium would also be of interest, while Dr. Neary pointed out the interest of using UX_1, a beta-emitting isotope of thorium.

The possibility of obtaining data on the effect of radium on man from an investigation of drinking water supplies was next discussed. Dr. Marinelli raised the question of reported radioactive waters in Germany. It is stated by Rajewsky that the drinking water at Frankfurt does not have a high radium content, but the water from certain radioactive wells at Baden Baden is drunk by the local population. Sir John Cockcroft stated that measurements by Jacobi at A.E.R.E. on samples of Stockholm water showed a total alpha activity equivalent to 50 x 10^{-12}μg. of radium per litre, while the Thames at Teddington has only 0.5 x 10^{-12}g. Ra/litre, and the London tap water only 0.2 x 10^{-12}g/litre. It was noted that Hursh, in a recent number of "Nucleonics" gives a figure for radium in the New York tap water of 12 x 10^{-12}g/litre; measurements by the National Bureau of Standards range between 2.5 x and 0.5 x 10^{-12} g/litre, with an average of 15 x 10^{-12}g/litre. Mr. Binks stated that he had exchanged standards with Dr. Curtis. Dr. Shields Warren mentioned that a comprehensive survey of the radioactivity of air and water is in progress in the Colorado Plateau, together with public health studies. Wells at the new A.E.C. site at Arco are also being surveyed.

Professor Evans stated that it had been found that when a small amount of radium was added to a river, the activity was down to normal background at about fifteen miles downstream, showing that the radium was absorbed on the mud. Professor Evans pointed out the suitability of a unit "micromicrocuries per litre"for expressing the very low concentrations of activity frequently met with in tolerance problems.

2 and 3. Relative toxicities of Plutonium and Radium and of Strontium and Radium

Dr. Loutit pointed out that since the last conference at Chalk River, arguments had been advanced for modifying the assessment of the biologically equivalent amounts of radium, plutonium, and strontium. One factor not previously taken into account was that the experiments of Brues on relative toxicities were carried out on rodents (mainly mice) in which the fractional retention of radon, and consequently the presumed absolute toxicity of radium is lower than in man. A further factor affecting the interpretation of the experiments with plutonium was that the relative toxicity was stated in terms of injected dose, whereas the true figure should be based on retained dose.

Professor Evans stated that the figure of 85 per cent elimination of radon in exhaled breath in rats came from experiments in his own laboratory. An independent check had been made by subsequent examination of the skeleton to determine the true radium content. He did not believe that the proportion of radon exhaled decreased with age, and the figure of 85 per cent certainly applied at one year after injection. The figure of 45 per cent elimination in man is well established from data on about a dozen cases. Thus the total alpha ray energy released in man is 14.4 MeV per disintegration while in the rat it is only 7.7 MeV. Therefore the absolute toxicity of radium should be at least twice as great in man as in the rat, and as a corollary, the relative toxicity of strontium to radium or plutonium to radium in man should only be one half the value in the rat. Dr. Loutit commented that this argument assumed that the decay products of radium contributed to the toxic effect, and there was no positive evidence for this assumption. Dr. Gray remarked that if the beta rays alone were effective, the appropriate ratio between man and rat would be 55/15 or nearly 4. He wondered whether there was any difference in radon elimination as between rats and mice; the latter were mainly used in Brues' experiments. Dr. Marley pointed out the value of an experiment with an isotope of radium such as mesothorium which would act for some time as a source of beta rays substantially free from alpha rays.

Dr. Marley pointed out the value of an experiment with an isotope of radium such as mesothorium I which would act for some time as a source of beta rays substantially free from alpha rays. (sic) Mr. Chamberlain observed that the greater elimination of radon from the small bones of the rat or mouse was reasonable on physical grounds, but it also suggested a compensating factor, namely that a greater fraction of the energy of the alpha rays would be released outside the sensitive tissues such as bone marrow. Professor Evans replied that radiation osteitis arises from effects in the bone itself, but Dr. Loutit pointed out on the other hand that osteogenic sarcoma arises from cells in the periosteum and endosteum.

Professor Evans gave evidence that in bone biochemistry radium behaves like calcium. For example, Ca^{45} exhibits in dogs the same concentration ratio in the "hot spots" as radium, namely ten to one. A rat which had a fracture of the leg sometime after exposure was subsequently found to have a considerable concentration of radium at the site of the fracture. In one human case, the ratio of radium to calcium throughout the body was found to be practically constant. It was mentioned that the amount of radium circulating in the blood is approximately equal to the amount excreted daily.

Finally, it was agreed to accept the factor of 2 deriving from the difference in elimination of radon in the rat and in man.

The futher factor affecting the assessment of the toxicity of plutonium was next discussed. Dr. Brues has estimated that in his experiments 75 per cent of the injected amount of plutonium was retained in the skeleton while only 25 per cent of the injected amount of radium was retained. Thus the true relative toxicity of plutonium is only one third the value estimated on the basis of injected amounts. Dr. Loutit mentioned the work of Anthony, Lathrop and Finkle who found that for acute toxic effects with radiostrontium the injected amount seems to be the important factor. Dr. Shields Warren remarked that in the experiments of Brues, the period of observation extended certainly beyond 200 days, and long enough for tumour production. The data had recently been reviewed in detail at a meeting in Washington, and it was felt that the evidence for the reduction of the estimated relative toxicity of plutonium by a factor of three was quite clear.

These data would be made available to members of the Conference.

It was agreed to accept the revised figure for the relative toxicity of plutonium. The Conference then formally agreed on the following values of the maximum permissible amounts of the isotopes fixed in the body:

Ra^{226}	0.1μc
Sr^{89}	2.0μc
Sr^{90}	1.0μc
Pu^{239}	0.04μc

4. Uncertainties in the figures proposed at the Chalk River Conference. (Final Report, R.M. 14)

H^3 It was noted that the figures for maximum permissible concentration of tritium in air and water seemed to be inconsistent; and that no evidence is given for changing the maximum permissible amount in the body from the figure of 10mc to 16mc.

There seemed no reason not to accept the experimental figure of 10 days for the mean life of tritium water in the body. On the basis of 10mc in the body and a mean life of 10 days, the maximum permissible concentration in air for 24 hours exposure per day is 50 x 10^{-6}μc/cc. while in drinking water the figure is 4 x 10^{-1}μc/cc. These values were agreed.

S^{35} Dr. Marinelli mentioned work reported by Engstrom in which the maximum concentration of sulphur in the skin, determined by microradiography, was found to be 2 or 3 per cent. Other work was mentioned as showing that the highest initial concentration of sulphur occurs in the bone marrow. Mr. Chamberlain observed that a concentration of 2 or 3 per cent of sulphur in the skin represents about ten times the average concentration for the whole body (see "Standard Man"). Since a dose of 0.3 rep per week is produced by 14uc of S^{35} per kg. of tissue, the maximum permissible amount of S^{35} in the body, allowing for the tenfold concentration in skin is 14 x 70 ÷ 10 or 100μc. This figures was agreed. It was felt that no single figures could be calculated for the maximum permissible concentrations of S^{35} in air and water because of the importance of the chemical state and its influence on the mode of metabolism. The most that could be done would be to state a figure of maximum permissible specific activity for any compound. In view of the fact that the total activities of S^{35} at present used in tracer work are quite small in relation to the maximum permissible body content of 100μc, the lack of definite figures for permissible concentrations in air and drinking water was not felt to be serious.

Sr^{90} It was felt that the figures for absorption of Strontium implied in the report of the Chalk River Conference were too low, and that there was no obvious reason for making any major distinction between the metabolism of strontium and radium. Hence, the effective mean life of Sr^{90} in the body (biological excretion and radioactive decay) is about 15 years or 5 x 10^3 days approximately. The figure of 10 per cent final retention following ingestion then leads to a maximum permissible concentration in drinking water of 8 x 10^{-7} μc/cc.

The fraction of material in the lungs transferred to and retained in the skeleton was taken to be 25 per cent as for radium. The fraction of inhaled material absorbed in the lungs was previously taken as 50 per cent, but a revised figure of 25 per cent is now to be adopted, see Section 5 below. Hence 6 per cent of the inhaled material becomes fixed in the skeleton and so the maximum permissible concentration in air is 1.6 x 10^{-10}μc/cc; this figure was rounded off to 2 x 10^{-10}μc/cc.

U^{235} Mr. Chamberlain pointed out that the Chalk River figure for insoluble compounds of U^{233} in air was too low due to a numerical error of a factor of 10. The maximum permissible amount of U^{233} in the lung to produce the biological equivalent of 0.3 rep per week is 0.008μc. The mean life in the lung according to Hamilton is 200 days. The revised figure for retention of insoluble particles in the lung after 24 hours is 12½ per cent of the inhaled amount (see Section 5 below), and so the maximum permissible concentration of insoluble compounds of U^{233} in air is 1.6×10^{-11} μc/cc.

The hazard for soluble compounds arises from deposition in the skeleton, and since uranium is assumed to be distributed like plutonium, the maximum permissible amount of U^{233} fixed in the skeleton is 0.04μc (see Section 2 above); the mean life in the skeleton is 100 days.

For inhalation of a soluble compound, 25 per cent of the inhaled material is assumed to be absorbed in the lung (see Section 5 below) and 10 per cent of this absorbed U^{233} is stated by Hamilton to be transferred to the skeleton. The maximum permissible concentration for soluble compounds of U^{233} in air is therefore 8×10^{-10} μc/cc. For ingestion, the proportion of uranium absorbed and transferred to the skeleton is taken by Hamilton to be 0.1 per cent. The maximum permissible concentration of U^{233} in drinking water is therefore 1.6×10^{-4} μc/cc.

Po^{210} Dr. Shields Warren stated that it is not yet possible to say whether the 20 to 1 relative toxicity ratio between polonium and radium applies to chronic effects. Chronic studies are in progress but no results can be reported yet. Some acute and subacute data are given in report UR-44. The equivalence, based on injected amounts, for acute effects on life span is 20 to 1 while for effects at 300 or 400 days it is 1 to 1. Lesions in the kidney, consisting in injury to the epithelium of the tubules, show up in about three weeks after exposure. Since the cells of the tubular epithelium have a rapid turnover, of the order of a few weeks, the chance of a damaged cell remaining long enough to become neoplastic is slight. It was agreed that for the present, the figure of 0.005μc of Po^{210} fixed in the body should be retained.

5. Radioactive Dusts

Dr. Shields Warren remarked that there is little precise data on the occurrence of active particulates, particularly from chemical separation processes. The particles present may contain a considerable number of different substances in widely varying proportions. Dr. Edson stressed the importance of the problem of active dusts, pointing out that most industrial poisoning is largely contributed to by dusts. It now seems quite practicable and straightforward to control the exposure of operatives to external radiation and the contamination of the hands, and the greatest problem still remaining is probably the inhalation hazard. Effort was needed to obtain data on the period of lodgment of dusts in the lungs in man, and on carcinoma of the lung in man, and to supplement these enquiries, more animal experiments were required. It is necessary to consider what dusts are likely to affect the largest number of people, and among these uranium, radium, plutonium, and fission products would seem of prime concern. Sir John Cockcroft pointed out the importance in this connection of industrial applications of isotopes and instanced the use of strontium 90 and polonium.

It was generally agreed that, although there is no direct evidence on what would be the effect of small active particles (of the order of 1 micron in size) in fixed positions in the lung tissue, it might be expected on general grounds that neoplasms would not be likely to develop in the minute zones of highly irradiated tissue. Moreover, even very "insoluble" compounds may have sufficient solubility to ensure that small particles do not remain in one position in the lung indefinitely. Dr. Edson cited the insoluble substances uranium metal and uranium tetrafluoride, exposure to which at levels in excess of 50μg/m^3. leads to detection of uranium in the urine within a few days.

Dr. Shields Warren also mentioned Dr. Wright Langham's finding that all Los Alamos cases showing a positive urine count for plutonium had also shown high nose swab count. The tolerance figure is taken to be 50 counts/min. for each nostril. Among these workers with considerable exposure to high specific activity particles there have so far been no lung tumours, no lung absesses, and one carcinoma of the larynx, quite possibly unrelated to the exposure. By contrast, there had been many cases of beryllosis. In fact, there are indications that the lung tissue is radio-resistant, and that doses of 8000 or 9000r to large volumes are required before fibrosis is produced. There is the clinical evidence of some cases of carcinoma of the breast free from symptoms and signs of lung injury 10 to 20 years after treatment by radiotherapy in which the lung tissue must have been irradiated.

Dr. Marinelli confirmed that no cases of lung damage from plutonium had been found at the Argonne National Laboratory, but these exposures were under laboratory rather than plant conditions. Dr. Loutit pointed out that on the other hand, the existence of bronchial carcinoma in uranium miners would not be ignored. Dr. Shields Warren considered that a possible difference arose because of the different factors of acute and chronic doses. Certainly primary carcinoma of the lungs as distinct from the bronchus is a very rare disease, with a natural incidence only a few per cent of that of bronchial carcinoma. It was recalled that Mitchell has suggested the possibility that the bronchial tumours in uranium miners are caused by the irradiation of the bronchial epithelium by active deposit thereon from the radon in the mine atmosphere. Dr. Edson commented on the fact that the only evidence of lung damage comes from the miners at Joachimstahl and Jachymov; nothing has been reported from Port Hope or Haut Katanga. It should be remembered that the particles in uranium mines are of low specific activity.

Dr. Shields Warren stated that the only respiratory disorder encountered among the miners in the Colorado Plateau was silicosis. He summarised the general position on active dusts as follows:-

(1) There is no evidence yet of specific injury to the lung from inspired plutonium (at occupational levels).

(2) The present assumptions in the calculation of permissible exposure levels contain adequate safety factors.

(3) There is no evidence of low-grade injury such as might lead to an increase of respiratory infections.

It was therefore agreed that the possible occurrence of activity in air in particulate rather than gaseous form is not likely to increase the hazard, and that therefore, no downward revision of the existing permissible concentrations for various isotopes in air is required. At the same time, it was felt that a relaxation was not warranted. It was noted that existing levels were not such as to present insuperable engineering difficulties.

Dr. Marinelli felt that the conventional figure of 50% adopted at Chalk River for the proportion of an aerosol reaching the lungs was too high. He criticised Wilson and LaMer's interpretation of their experiments with an aerosol labelled with $sodium^{24}$ (x). According to experiments by Quimby, the amount of material absorbed in the lungs in Wilson and LaMer's experiments was only one half their own estimate. After some discussion, it was agreed to modify the resolution on aerosols on p. 9 of the Chalk River Report, R.M.14 as follows:

It was formally agreed that if specific data were lacking, the convention be adopted that 25% of any aerosol reaches the alveoli of the lungs. If the particles are soluble they are considered to be totally absorbed; if insoluble then the 25% amount is to be regarded as retained for 24 hours, after which only half of it, i.e. 12½ per cent of the inhaled amount, is retained in situ indefinitely.

6. Low Energy Beta-emitters

H^3 Dr. Marinelli reported that comparative experiments on survival in mice injected with tritium water or irradiated with X rays suggest a relative biological efficiency for the soft beta radiation from tritium of unity. No change is therefore called for in the figures for maximum permissible concentration adopted (see Section 4, above), namely,

Air...... 50×10^{-6} μc/cc; Water ...... 4×10^{-1} μc/cc.

It is easy to monitor exposed individuals by urine counts.

It was clear that in view of the finding of a value of unity of R.B.E. of the tritium beta radiation, the same value would apply to the other isotopes of interest, all having more energetic beta radiation. It was nevertheless decided to review the maximum permissible levels adopted at the Chalk river Conference for beta-emitting isotopes.

Dr. Shields Warren commented on some clinical facts on the effect on the hands of the beta radiation from mixed fission products in an accidental exposure at Eniwetok. Two features of special interest were the relatively long latent period of about 14 days before any reaction appeared, and the fact that the first sign was not epithelial damage but vascular damage manifested in ecchymoses. An estimate of the dose is given in an article in the Journal of the American Medical Association.

C^{14} It was noted that the report R.M.14 gives a figure of 300μc as the maximum permissible amount of C^{14} as carbon dioxide in the body. Such a figure has little practical usefulness and what is wanted is a figure for the maximum permissible amount of C^{-4} in any chemical form, as a guide in tracer experiments. This seems to have been the intention behind Dr. Brues' proposal of 30μc.

Dr. Shields Warren felt that it would be safer to leave the recommending of a figure to the appropriate Tracer Isotope Committee. The U.S. committee had recently relaxed their rule against the allocation of C^{14} for human tracer experiments. The need for extending the recommendations on C^{14} beyond a single figure for carbon dioxide, for example carbon dusts in air, was stressed. It was agreed that a figure

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(x) Wilson, I.B., and LaMer, U.K. (1948), J. Ind. Hyg. Tox. 30, 265 for carbonate in water could be deduced on the same basis as the carbon dioxide figure in air but that the problem of other chemical forms of C^{14} in air or water was indefinite.

Dr. Shields Warren stated that he would search for additional information on these problems and communicate it subsequently. The permissible concentration in air as carbon dioxide was left unchanged at $1 \times 10^{-6}\mu c/cc$.

Na^{24} No fundamental changes in the permissible levels for Na^{24} seemed necessary, but allowance was made for the lower figure for absorption of an aerosol, and minor arithmetical corrections, leading to $3 \times 10^{-6}\mu c/cc$ in air and $8 \times 10^{-3}\mu c/cc$ in drinking water.

P^{32} No new data on P^{32} were brought forward, and so after correction for the aerosol retention figure, the figures are $1 \times 10^{-7}\mu c/cc$ in air and $2 \times 10^{-4}\mu c/cc$ in drinking water.

I^{131} Dr. Shields Warren stated that the gradual accumulation of new data on the effect of radioiodine on the thyroid, for example in the treatment of hyperthyroidism, probably justified some relaxation in the permissible levels. Data is being obtained on inhalation by animals in the neighbourhood of the Hanford plant; no histologic changes have been detected in the thyroids of rabbits, coyotes, etc., which must have been picking up appreciable amounts of I^{131}. The average air figures in this area conform to the recommended permissible level. There is collected evidence on the effect of X rays on the thyroid up to 25 years after exposure, and the indications are that the thyroid is very resistant to radiation damage.

In view of these observations and the localised character of the irradiation, it was felt that a relaxation by a factor of three was reasonable. This proposal was referred to Dr. Gray at a later stage of the Conference, and after discussion it was agreed to adopt the following figures:

Maximum permissible amount of I^{131} in the thyroid	0.18μc
" " " " " " body	0.03μc
" " concentration in air	$3 \times 10^{-9}\mu c/cc$
" " in drinking water	$3 \times 10^{-5}\mu c/cc$

It may be noted that the figure for air assumes 100 per cent absorption of inhaled iodine, since the iodine is more likely to exist as a vapour than as an aerosol.

Co^{60} This isotope was not discussed specifically, but if the correction for aerosol retention is applied, the permissible levels are:

Air	$7 \times 10^{-9}\mu c/cc$
Drinking water ...	$1 \times 10^{-5}\mu c/cc$.

A^{41}, Xe^{133}, Xe^{135}, U (natural)
The figures for these isotopes were not changed - see R.M.14

Ra^{226} The change in the aerosol retention figure necessitates a change in the permissible concentration of radium in air to $8 \times 10^{-12}\mu c/cc$. The water figure is unchanged at $4 \times 10^{-8}\mu c/cc$.

Pu^{239} Minor arithmetical changes only were made in the figures given in R.M.14, as follows:

Air	$2 \times 10^{-12}\mu c/cc$
Drinking water	$1.5 \times 10^{-6}\mu c/cc$

7. Permissible Fluxes for Neutrons

Dr. Cipriani stated that the figures in the Canadian Atomic Energy project for the maximum permisslbe flux for neutrons were:

50 neutrons/cm²/sec.	for neutrons above 1 MeV in energy
750 " " "	for thermal neutrons.

Professor Mayneord quoted the British figures

30 neutrons/cm²/sec.	for neutrons between 2 and 20 MeV.
50 neutrons " "	" " " 0.5 and 2. MeV.
1200 neutrons " "	" " thermal neutrons.

These had been submitted to the International Commission on Radiological Protection at its recent meeting. The specific values had not been adopted by that body but an interim recommendation was made that the maximum permissible energy absorption per gramme of tissues exposed to fast neutrons should not be greater than one tenth of that permitted for high energy quantum radiation.

Dr. Taylor stated that one reason why the Commission had not adopted the British figures was that the Cowie Committee in the U.S. had also subdivided neutrons into various energy groups and information on this classification was required.

It was decided that definite figures could not at present be agreed but that the papers of Dr. J. H. Tait, A.E.R.E., which formed the basis of the British figures should be circulated to the delegates (Action Dr. Neary)

Dr. Shields Warren stated that there was no new evidence available at present on the production of cataract by neutrons. Dr. T. C. Evans is carrying out further experimental work. In Japan, no cataracts have yet appeared except in individuals who had shown transient apilation, the X-ray dose for which is usually taken to be about 400r. One Los Alamos accident case had unilateral epilation and incipient cataract. Dr. Marinelli remarked that Poppe's work suggests that a dose of 150r of X rays can cause cataract in the rabbit.

Dr. Laurence commented on the value of 5 previously adopted for the relative biological efficiency of thermal neutrons. It was generally felt better to derive the total effect from a separate assessment of the contributions from the protons (with a factor of 10) and the gamma rays. The importance of multiple reflections between the source and the body, leading to a considerable increase in effective flux was stressed. Most personnel monitoring devices would measure the effective flux.

Emergency doses were briefly discussed. Dr. Shields Warren said that in the U.S. they were endeavouring to avoid a statement on such doses because of the variability of possible circumstances. The figure of 25r suggested at the Chalk River Conference serves as some guide but occasions for higher doses could arise. Dr. Loutit said that it would generally be accepted that 25r was a harmless dose but data was needed on the percentage of cases incapacitated at various higher doses. Dr. Shields Warren replied that it was estimated that about half of the Japanese cases who were exposed to 100r were incapable of heavy duty. A clinical case of lymphosarcoma was known in which a dose of 137r to the whole body was fatal. The data in the NEPA report 1019-IER-117 were of doubtful basis. Dr. Loutit enquired the views of the Conference on the use of the dose-mortality curve to give the shape of the dose-invalidity curve. Dr. Shields Warren felt that much would depend on the time factor.

In further discussion, it became clear that the emergency dose of 25r, should be regarded as not repeatable. In general, it was felt that persons receiving doses above normal permissible levels should not be exposed further until compensating time had elapsed, but that their employment should not be interrupted.

8 and 9. Genetic factors in radiation hazards and in relation to existing exposure levels.

Safety factors for large populations for bone-seeking isotopes.

Professor Mayneord said that in view of discussions which had taken place at the meetings of the International Commission on Radiological Protection and informally, it seemed doubtful whether a comprehensive decision on the genetic problem of radiation hazards would be possible at this Conference. Considerably more scientific data were needed, and further, there had been objections in some quarters to the adoption of two different standards of exposure for occupational groups and large populations because of anticipated unfavourable public reaction. The report of the International Commission on Radiological Protection in fact contained no reference to the genetic problem for large populations, though the decision was felt to be regrettable by some individuals both inside and outside the Commission.

Dr. Shields Warren gave some information from the summary report of a conference on geneticists and of a National Research Council Panel which had been asked to consider the data from Hiroshima and Nagasaki. It seemed rather unlikely that even a doubling in the number of abnormalities would become apparent in five generations. Five abnormalities have been observed in 21,000 births so far recorded, a proportion no higher than in the control city of Kure. In another committee, Neel was collecting data on the spontaneous mutation rate in the population of Michigan for comparison with the estimate of 10^{-5} per generation per locus from Haldane's data. It was felt by Beadle that some well-known mutations are much less frequent. Neel is also preparing to survey the spontaneous rate at Denver, Colorado, where the cosmic ray background is about doubled owing to the high altitude.

It has been shown that in maize and Drosophila, different spontaneous mutation rates occur at different loci. There are some indications of a species variation of the induced mutation rate and in the induced rates at different loci. Beadle has shown that in Neurospora, not all the mutations are disadvantageous. Dr. Glucksmann remarked that Haldane had estimated that 98 per cent of the mutations in wheat are harmful. Dr. Shields Warren went on to say that it was thought that chromosome aberrations leading to semi-sterility were not likely to be a serious factor in man. The six year data at Rochester are still being analysed; Charles' figure of 50r for the "doubling dose" is still tentative. A considerable expansion of the long range mouse experiment at Oak Ridge is now envisaged. Dr. Russell has chosen seven well-recognised mutations (marked recessives) for recording the natural and induced rates. Dr. Shields Warren would ask him to send details of his experiment to the British group.

Dr. Gray referred to the paper by Sewall Wright[(x)] in which it is suggested that the spontaneous mutation rate at a number of loci is of the order of 10^{-7} instead of the value of 10^{-5} from Haldane's data. If the induced mutation rate is approximately constant at all loci, and it should be remembered that a tenfold variation at most was found for visible mutations in Drosophila, then the relative increase of mutations due to radiation is greater, though the absolute increase is unaltered. Catcheside, using Charles's data, has estimated that a dose of 2½r per generation in the whole population would lead to a 5 per cent increase in the number of mutations. Haldane had criticized Catcheside's conclusions, for though he accepted the estimate of 50r for the "doubling dose", he suggested that perhaps there are about ten times as many dominant mutations as are actually observed in mice, and that many of them will significantly affect fitness. Sir John Cockcroft suggested that the papers of Catcheside and Haldane should be circulated to members of the Conference.

Dr. Loutit stated that the limited work done so far at the Institute of Animal Genetics at Edinburgh does not permit an estimate of the mutation rate in the mouse, but it does show that the "doubling dose" can hardly be less than 70r.

There was general agreement on the need for data on the average exposure of the general population in diagnostic X-ray examinations. Professor Mayneord urged the desirability of liaison between the American and British groups of geneticists considering the radiation problem. Dr. Shields Warren replied that such liaison would be welcomed on his side.

Professor Mayneord referred to the particular problems in Great Britain, mainly involving drinking water supplies. The British Group had suggested at the International Commission on Radiological Protection that in view of the genetic considerations the permissible level for isotopes in the drinking water of large populations should be lower by a factor of 100 than the levels calculated for occupational groups on the basis of 0.3 rep/week; the factor of 100 corresponded roughly to the ratio of the "occupational" dose of 375r per generation (25 years) and the figure of 2.5r taken from Catcheside's calculations. Dr. Shields Warren emphasized again the political difficulties of having two standards, and also the need to envisage war time emergencies. In answer to these points, Sir John Cockcraft stated that in fact only one drinking water figure would be used, namely that for the large population, while Dr. Loutit remarked that the permissible levels referred to life time exposure and so did not conflict with possible relaxations required in war-time emergencies.

Dr. Shields Warren stated that it was believed that no large populations in the United States were likely to be exposed via water from contaminated rivers, even when isotope users were taken into account. No need was seen therefore for the formal adoption of a specific figure of permissible concentration of activity. It was not clear whether the Atomic Energy Commission or the Public Health Service is responsible for the rivers. Oak Ridge Laboratory accepts active waste which users cannot dispose of, and the National Bureau of Standards is shortly issuing a report on disposal. A group at the Johns Hopkins University is working on the uptake of activity from river water. One example was known where there was no detectable activity in the river water fifteen miles below the point of discharge. It was possible that considerable individual variations between rivers would be found. A study of the Clinch River has been commenced. Dr. Cipriani mentioned that P^{32} in the Ottawa River was detectable in clams some miles down stream, but the activity soon disappeared when no more was discharged into the river. It was stated that activity once fixed on mud stays fixed, e.g. during dredging operations, and that activity adsorbed on material in suspension is not removed in passing through the digestive tract in fish.

On the question of bone-seeking isotopes, it was felt that no fundamental change had taken place in the evidence discussed at the Chalk River Conference. There were now details of only two cases showing injury with less than 5μg of pure radium fixed in the body. Sir John Cockcroft noted that the British figure for large populations is 0.4 μμg/l increment in activity; the actual level of the New York tap water is 2.5 μμg/l, and he felt that careful consideration should be given to the need for a standard five times lower than the New York water.

Dr. Shields Warren said that the bone tumour registry in the United States had not yet revealed significant local variations in incidence.

(x) "Discussion on Population Genetics and Radiation", Sewall Wright, Symposium on Radiation Genetics, Oak Ridge, 1948.

Professor Mayneord summed up the position by saying that the problems in Great Britain are not the same as those in the U.S. and Canada and a solution on individual lines was necessary. He felt that the American delegates agreed in principle with the factor of 100 for the exposure of large populations, but that not having this problem, they quite understandably did not wish to limit their freedom of decision in the future by a formal adoption of the factor now.

10. Organisation of future tolerance work

Professor Mayneord said that the International Commission on Radiological Protection had come to the conclusion that the wide field of problems now involved in protection should be divided up for consideration by sub-committees under the following headings:-

1. Permissible dose for external radiation.
2. Permissible dose for internal radiation. (Including handling of radio-isotopes).
3. Protection against X-rays generated at potentials up to 2 million volts.
4. Protection against gamma-rays, beta-rays and X-rays above 2 million volts.
5. Protection against heavy particles including neutrons and protons.
6. Disposal of radioactive wastes.

The Commission had further recommended that a parallel structure of organization should be adopted at the national level. The type of classification was suggested that a view to facilitating the drawing up of codes of practice, though the first two sub-committees would clearly be responsible for the basic information. The International Commission had not felt able to adopt values for permissible levels of individual isotopes. Instead, it proposed to circulate the values in use in the United States, Canada, and Great Britain. The Commission had therefore arranged to meet again shortly after the present Conference in order to receive the latest figures.

Some discussion ensued as to what figures should be communicated to the International Commission in view of the divergencies noted above in Sections 8 and 9 dictated by the differing needs of the various national groups. It was finally decided to give only a table of figures calculated for occupational exposure, without explicit reference to medical supervision or to the genetic risks of exposure of considerable proportions of the population. This table is given in Appendix I. Dr. Neary was asked to prepare a report of the proceedings of the Conference to supplement the daily bulletins which had been circulated (here reproduced in Appendix II.)

Finally, Professor Mayneord expressed the thanks of all members of the Conference to Sir John Cockcroft for arranging the Conference and for his hospitality.

APPENDIX I

Maximum Permissible Levels for Occupational Exposure Agreed at Conference

Isotope	Maximum Permissible Amount in Body μc	Maximum Permissible concentration in air (24 hour day) μc/cc	Maximum Permissible concentration in drinking water μc/cc
H^3	1×10^4	5×10^{-5}	4×10^{-1}
C^{14} (as CO_2 in air)		1×10^{-6}	
Na^{24}	15	3×10^{-6}	8×10^{-3}
P^{32}	10	1×10^{-7}	2×10^{-4}
S^{35}	100		
I^{131}	(0.18 (thyroid)) (0.3 (body))	3×10^{-9}	3×10^{-5}
Co^{60}	1	7×10^{-9}	$3 \times 1-^{=5}$
A^{41}		1×10^{-6}	
Xe^{133}		1×10^{-5}	
Xe^{135}		3×10^{-6}	
Ra^{226}	0.1	8×10^{-12}	4×10^{-8}
Pu^{239}	0.04	2×10^{-12}	1.5×10^{-6}
U^{233} (soluble)	0.04	8×10^{-10}	1.5×10^{-4}
Sr^{90}	1	2×10^{-10}	8×10^{-7}
Sr^{89}	2		
Po^{210}	0.005		

APPENDIX II

SUMMARIES OF DISCUSSIONS ISSUED DURING CONFERENCE

Morning, 4th Aug.

Professor Evans summarised the evidence of 27 cases exposed either to pure radium or radium-mesothorium mixture, from which it is concluded that with pure radium, signs of intoxication only begin to appear at levels of about 5 μg permanently fixed, while for mesothorium, damage occurs at around 1 μg of associated permanently fixed radium. It was evident that the damage is primarily osteities, and that only a comparatively small percentage of cases develop neoplasms. The evidence on this series of cases is not yet complete, and it was agreed that for the present, no change should be recommended in the existing permissible figure of 0.1 μg of pure radium permanently fixed in the body, though it was realised that this figure probably carries a larger safety factor than was previously thought.

It was not felt practicable for this committee to recommend permissible levels for the floating radium in a plant operative. The recommendations of the American Standard Z39 were noted, and it was also pointed out that American practice depended on the previous history of the worker concerned.

It was recognized that there exist very few data on poisoning by pure radium and that further data, including records of symptom free cases, are urgently needed. In this connection, Dr. Marinelli described briefly the investigations planned in Chicago on Schlundt's series of cases. Dr. Shields Warren described experiments with dogs about to be undertaken shortly by the Los Alamos Laboratory and the Utah Medical School on poisoning by radium, pure mesothorium, and plutonium.

It was noted that the use of pure radiothorium would give valuable additional results. The radium and alpha-ray activity of various natural waters were discussed.

The toxicities of plutonium and strontium relative to radium were discussed.

The final report of the Chalk River Conference refers to the different absolute toxicity of radium in man and in rats because of the greater proportional release of radon in the latter. Dr. Evans stated that this difference had been established in his laboratory when the man and the rat were at comparable stages of pathological change. Assuming that damage arises from the alpha radiation of both radium and the residual decay products in the bone it would appear that the effective energy release from radium in man is about twice that in rats. In consequence, the estimated toxicity of plutonium and strontium relative to radium, derived from experiments on rats and mice, should be halved in the case of man.

Furthermore, the relative toxicity of plutonium and radium was originally expressed by Dr. Brues on the basis of injected amounts. If retained amounts are taken into account, it would appear in rats and mice that radium is three times as toxic on a mass basis as plutonium. Dr. Shields Warren said that the detailed evidence existed and would be made available.

The maximum permissible amounts fixed in the body are therefore:-

2 μc of Sr^{89}

1 μc of Sr^{90}

0.04 μc of Pu^{239}

Uncertainties in the Chalk River figures for H^3, S^{35}, Sr^{90}, U^{233} and Po^{210} were discussed.

<u>H^3</u> It was assumed that the maximum permissible amount of H^3 in the body to give 0.3 rep/week would be 10 mc. The experiment evidence that the mean life of water in the body is 10 days was accepted. This leads to permissible concentrations in air and in drinking water of 5×10^{-5} μc/cc and 4×10^{-1} μc/cc respectively.

<u>S^{35}</u> Work was quoted suggesting that the concentration of sulphur in the skin is about ten times the average concentration for the whole body. The maximum permissible amount in the body would therefore be 100 μc. It was felt that it would be impracticable to derive universally applicable figures for concentrations in air and water.

<u>Sr^{90}</u> It was believed that Dr. Hamilton intended the retention of strontium to be about 10% instead of 1% as assumed at Chalk River. The biological mean life is assumed to be 10^4 days (27 years) and so the effective mean life in the body is about 15 years.

<u>U^{233}</u> It is believed that there was numerical error of a factor of ten too low in the Chalk River for insoluble compounds of U^{233}. Further, the permissible amount of U^{233} in the body was assumed to be

the same as for plutonium. In view of the revision of this latter figure, the U^{233} figure should be

Permissible amount in the body 0.04 μc.

Po^{210} Dr. Shields Warren reported that chronic experiments were in progress, but results were not yet available. It was agreed that there was at present no reason to change the Chalk River figure of a 20 to 1 toxicity ratio as compared with radium.

Note: All figures above have been expressed as for plant personnel.

VALUES OF PERMISSIBLE LEVELS AGREED ON FIRST DAY BUT LATER MODIFIED IN RELATION TO AEROSOL RETENTION

Isotope	Sr^{90}	H^3	Na^{24}	P^{32}	I^{131}	Ra^{226}	Pu^{239}	U^{233} (soluble)	(insoluble)
Half life	25y	12.1y	14.8hrs.	14.3d	8d	1622y	$2.4x10^4$y	1.6×10^5y.	
M.p.l.in body(μc)	1	$1x10^4$	15	10	0.1 (0.06 in thyroid)	0.1	0.04	0.04(bone)	0.008 (lung)
Effective mean life (days)	5000	10	0.8	20	12	10^4	10^4	100	200
Permissible daily									
Deposition in body (μc)	2×10^{-4}	$1x10^{-3}$	20	0.5	0.005	10^{-5}	$4x10^{-6}$	$4x10^{-4}$	$4x10^{-5}$
Proportion retention from lungs	0.1	1			0.2 (to thyroid)	0.12	0.1	0.05	0.25
M.p.l. in air (μc/cc)	$1x10^{-10}$	$5x10^{-5}$			$1x10^{-9}$	$4x10^{-12}$	$2x10^{-12}$	$4x10^{-10}$	$8x10^{-12}$
Proportion retention from gut	0.1	1	1	1	0.2	0.1	0.001	0.001	
M.p.i. in water (μc/cc)	$8x10^{-7}$	0.4	$8x10^{-3}$	$2x10^{-4}$	$1x10^{-5}$	$4x10^{-8}$	$1.5x10^{-6}$		

5th Aug. The hazard from radioactive dusts was discussed with special reference to their particular character. Considerable emphasis was placed on the possible high solubility of normally insoluble compounds when present in finely divided state in the lungs. In consequence it seems unlikely that any particular group of cells will be irradiated by a given active particle over a prolonged period. The value of nose swab counts was mentioned, with special reference to plutonium. There was no instance of an individual showing a high urine assay who had not also exhibited a high count for the nose swab. Animal experiments are in progress at Rochester on the effects of plutonium particulates, pile stack dusts, and dusts from chemical separation plants.

The intrinsic radio-resistance of the lung tissue was emphasized and the example quoted of cases of carcinoma of the breast treated by radiation, and free from symptoms of lung damage 10 to 20 years after. No cases of lung abscess have been found at Los Alamos. The high incidence of bronchial carcinoma in some uranium mines may be association with the chronic character of the irradiation and the irradiation of the bronchi by active deposit from radon, rather than by active particulates. The desirability was stressed of obtaining data on the retention of active dusts in the lungs and any pathological consequence therefrom.

Dr. Shields Warren summarized the position as follows.

(1) There is no evidence as yet of specific injury from inspired plutonium.
(2) The present permissible doses contain adequate safety factors.
(3) There is no evidence of low grade injury to the lung that might indicate minor damage.
(4) The permissible doses recommended at present do not present excessive engineering problems.

It was agreed that no increased precautions were required with regard to particulate hazard.

Dr. Marinelli proposed reconsideration of the figures for retention in the lung and for absorption from the lung. It was pointed out that the evidence on which the 50% immediate retention was based was open to question, and after analysis of the date, it was agreed to alter the values on p. 9 of the Chalk River Report R.M. 14 as follows:

If specific data are lacking, the convention should be adopted that 25% of any aerosol reaches the alveoli of the lungs. If the particles are soluble they are considered to be totally absorbed, if insoluble, then the 25% amount is to be regarded as retained for 24 hours, after which only half of it, i.e. 12½% is retained in situ indefinitely.

In the light of this and related data, the values for radium, plutonium, strontium and uranium 233 were reconsidered and the provisional table amended to read as on the attached sheet.

The factor of R.B.E. for low energy beta-emitters was discussed and it was agreed that the data showed that even for tritium, a value of unity is satisfactory.

Individual isotopes were considered in detail and with the exception of I^{131}, to be discussed again, no changes were required, as no additional data were adduced.

Some data on radioactivity levels in river and sea water and concentration of isotopes in algae and fish were discussed.

The problem of permissible fluxes of neutrons were discussed and the recommendation of the International Commission on Radiological Protection was noted. It was felt that insufficient evidence existed to change the figures adopted for R.B.E. at the Chalk River Conference. It was agreed that the detailed calculations of Tait for the M.R.C. Tolerance Doses Panel would be circulated. The question of maximum single permissible doses was left open. As a guide, 25r was considered not to incapacitate the person exposed. In general, it was felt that persons receiving above permissible doses should not be further exposed until compensating time had elapsed, but that their employment should not be interrupted.

PERMISSIBLE LEVELS - FINAL REVISED VALUES

Isotope	Sr^{90}	H^3	Na^{24}	P^{32}	I^{131}	Ra^{226}	Pu^{239}	U^{233} (soluble)	U^{233} (insoluble)
Half life	25y	12.1y	14.8hrs	14.3d	8d	1622y	2.4×10^4y		1.6×10^5y
M.p.l. in body (μc)	1	1×10^4	15	10	0.3 (0.18 in thyroid)	0.1	0.04	0.04(bone)	0.008 (lung)
Effective mean life (days)	5000	10	0.8	20	12	10^4	10^4	100	200
Permissible daily deposition in body (μc) per day	2×10^{-4}	1×10^3	20	0.5	0.015 (to thyroid)	10^{-5}	4×10^{-6}	4×10^{-6}	4×10^{-5}
Proportion absorbed via lungs and retained in body	0.06	1			0.2 (to thyroid)	0.06	0.1	.025	0.125
M.p.l. in air (μc/cc)	2×10^{-10}	5×10^{-5}			3×10^{-9}	8×10^{-12}	2×10^{-12}	8×10^{-10}	1.6×10^{-11}
Proportion retention from gut	0.1	1	1	1	0.2	0.1	0.001	0.001	
M.p.l. in water (μc/cc)	8×10^{-7}	0.4	8×10^{-3}	2×10^{-4}	3×10^{-5}	4×10^{-8}	1.5×10^{-6}	1.5×10^{-4}	

APPENDIX 19

ICRP-MAXIMUM PERMISSIBLE AMOUNTS OF RADIOIACTIVE ISOTOPES (Apr., 1951)

SUPPLEMENT ON MAXIMUM PERMISSIBLE AMOUNTS OF RADIOACTIVE ISOTOPES. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (JULY, 1950)

Report Prepared by Members of the International Commission on Radiological Protection as Follows:

E. Rock Carling, Chairman, Great Britain; L. S. Taylor, Acting Secretary, United States; W. Binks, Great Britain; E. L. Chérigié, France; A. J. Cipriani, Canada; R. G. Jaeger, Germany; W. V. Mayneord, Great Britain; R. R. Newell, United States; R. Sievert, Sweden

The International Commission on Radiological Protection finds that, at present, it is not in a position to make firm recommendations regarding the maximum permissible amounts of radioactive isotopes that may be taken into, or retained in the body. It is possible, however, on the basis of the general principles set forth in "International Recommendations on Radiological Protection," as revised by I.C.R.P. at the Sixth International Congress of Radiology, July, 1950, to make reasonable calculations of the maximum permissible amounts of several of the more important radioactive isotopes.

In the meantime the I.C.R.P. draws attention to the following data on maximum permissible exposures to radioactive isotopes for occupational workers, presently used in the United States, Canada and the United Kingdom. The radioactive isotopes can enter the body either by inhalation, or by ingestion. Accordingly figures are also given for the maximum permissible levels (m.p.l.) of various isotopes in air and in liquid media.

Ra^{226}.

Clinical observations on chronic radium poisoning in man indicates that the most serious effects are anemia and damage to bone, including osteogenic sarcoma. Both effects appear to have a threshold of the order of 1 µc. fixed in the skeleton. Accordingly it is accepted that:

(a) The maximum permissible amount of radium fixed in the body is 0.1 µc.

(b) For radium appearing in the atmosphere as a soluble aerosol, assuming that 25 per cent of the inhaled amount is absorbed and that 25 per cent of the absorbed amount is retained with a mean life of about 10^4 days, the maximum concentration in air for soluble compounds is 8×10^{-12} µc./cc.

(c) If radium enters the body through liquid media, assuming 10 per cent of the ingested amount is retained with a mean life of about 10^4 days, the maximum permissible concentration of the liquid is 4×10^{-8} µc./cc.

Pu^{239}.

On the basis of the relative biological effects of plutonium and radium, as observed in animal experiments, it is accepted that :

(a) The maximum permissible amount of Pu^{239} fixed in the body is 0.04 µc.

For soluble compounds of plutonium in the atmosphere, it is estimated that 10 per cent of the inhaled material is absorbed, with a mean life of 10^4 days. The maximum permissible concentration in air is, therefore, 2×10^{-12} µc./cc.

For insoluble compounds, it is estimated that the mean life in the lung is 200 days. If the irradiation of the lungs by alpha rays were limited to the biological equivalent of 0.3 r per week, the corresponding concentration of the plutonium in air would be 7.5×10^{-12} µc./cc. In view of the possibility of the transference of some of the insoluble material from the lungs to the skeleton, it is suggested that:

(b) The maximum permissible concentration of Pu^{239} in air is 2×10^{-2} µc./cc., for soluble and insoluble compounds.

(c) For Pu^{239} in liquid media, assuming that 0.1 per cent of the ingested amount is retained in the skeleton with a mean life of 10^4 days, the maximum permissible concentration is 1.5×10^{-6} µc./cc.

Sr^{89} and Sr^{90} ($+Y^{90}$).

On the basis of the observed relative biological effects of Sr^{89} and Ra on animals, it is accepted that:

(a) The maximum permissible amount of Sr^{89} in the body is 2.0μ c.

Since the combined disintegration energy of the Sr^{90}+Y^{90} pair is twice that of Sr^{89}, the maximum amount of Sr^{90} which can be permitted in the body is only one-half that of Sr^{89}. Accordingly:

(b) *The maximum permissible amount of* Sr^{90} *in the body is 1.0* μc.

If strontium is assumed to behave like radium as regards uptake, then

(c) For Sr^{90} in air, assuming that 25 per cent of the inhaled amounts is absorbed and 25 per cent of the absorbed amount is retained with a mean life of about 15 years, the maximum permissible concentration is $2x10^{-10}$μc./cc.

(d) For Sr^{90} in liquid media, assuming 10 per cent of the ingested amount is retained with a mean life of about 15 years the maximum permissible concentration is $8x10^{-7}$μc./cc.

Natural Uranium.

As the specific activity of natural uranium is so low, it is considered that the hazards arising from its use are mainly chemical.

Po^{210}.

Although polonium is not a bone-seeking isotope, some data exist on its toxicity relative to radium in animals. On this basis, it is accepted that:

The maximum permissible amount of Po^{210} in the body is 0.005 μc.

H^3.

It is assumed that tritium will be encountered in chemical forms in which free exchange takes place with ordinary hydrogen in the aqueous vapor in the lungs. If the mean energy of the beta radiation is 5.5 kv., a concentration of 0.14 μc. per gram of tissue will result in the biological equivalent of 0.3 r per week. The mean life of H^3 in the body is taken to be 10 days. A concentration of 0.14 μc./gram of tissue corresponds to 10 mc. uniformly distributed in the 70 kg. of the Standard Man. It is, therefore, accepted that:

(a) The maximum permissible amount of H^3 in the body is 10 mc.

(b) The maximum concentration of H^3 in air, based on a permissible daily intake of 1 mc. and complete absorption in the lungs, is $5x10^{-5}$μc./cc.

(c) The maximum concentration of H^3 in liquid media, based on a permissible daily intake of 1 mc., and complete absorption in the body, is 0.4 μc./cc.

C^{14} (as CO_2 in air).

A rate of energy absorption biologically equivalent to 0.3 r per week would be produced by 0.014 μc. of C^{14} per gram of tissue. If the highest proportion of carbon in any tissue is 50 per cent then the maximum permissible concentration of C^{14} in carbon in the body is 0.028 μc. per gram of carbon. The postulated route of entry of C^{14} in the CO^2 of the alveolar air is about 1 X 10^{-6}μc./cc.

Accordingly:

The maximum permissible concentration of C^{14} as carbon dioxide in air is $1x10^{-6}$μc./cc.

Na^{24}.

The energy (beta and gamma) absorbed in the body per disintegration of Na^{24} is estimated to be 2.7 mev. Since sodium is uniformly distributed throughout the body:

(a) The maximum permissible amount of Na^{24} in the body, corresponding to a dose rate biologically equivalent to 0.3 r per week, is 15 μc.

Since biological excretion may be neglected in comparison to the radioactive decay, for which the mean life is 0.8 day:

(b) For Na^{24} in liquid media, the maximum permissible concentration, assuming complete absorption, is $8x10^{-3}\mu c./cc.$

P^{32}.

Experimental and clinical data in man show that at times of the order of the mean life of P^{32}, i.e. about 20 days, the concentration of P^{32} in red bone marrow reaches a value only about three times the average concentration for the whole body. As most of the P^{32} is still diffused throughout the body, a dose rate biologically equivalent to 0.3 r per week in the critical tissue (red bone marrow) is therefore produced by a total quantity of approximately 25 μc. of P^{32} in the whole body. In order to allow for the possible occurrence of higher local concentrations in bone marrow:

(a) The maximum permissible amount of P^{32} in the body is 10 μc.

(b) The maximum permissible concentration of P^{32} in liquid media assuming that 100 per cent is absorbed and that the biological excretion can be neglected in comparison to the radioactive decay is $2x10^{-4}\mu c./cc$

Co^{60}.

Making the assumption that all the cobalt which is absorbed is deposited in the liver and that the effective energy in the liver is 1.3 mev. per disintegration, the amount of Co^{60} to give a dose rate biologically equivalent to 0.3 r per week is 1 μc. It is, therefore, accepted that:

(a) The maximum permissible amount of Co^{60} in the body is 1 μc.

(b) The maximum permissible concentration of Co^{60} in liquid media, assuming 100 per cent absorption and a half-life in the liver of 20 days, is $1x10^{-5}\mu c./cc$

I^{131}.

The energy absorbed in the thyroid gland per disintegration of I^{131} is estimated to be 0.27 mev., and so the amount of I^{131} in the gland to give a dose rate biologically equivalent to 0.3 r per week, is 0.18 μc., which would correspond to about 0.3 μc. in the body. It is, therefore, accepted that:

(a) The maximum permissible amount of I^{131} in the body is 0.3 μc.

(b) The maximum permissible concentration of I^{131} in air assuming that 100 per cent is absorbed, that 20 per cent of the absorbed amount is deposited in the thyroid, and that biological excretion from the gland can be neglected in comparison to radioactive decay, is $3x10^{-9}\mu c./cc.$

(c) The maximum permissible concentration if I^{131} in liquid media, assuming that 100 per cent is absorbed, that 20 per cent of the absorbed amount is deposited in the thyroid gland, and that biological excretion from the gland can be neglected in comparison to radioactive decay, is $3x10^{-5}\mu c./cc.$

All the preceding permissible amounts of isotopes refer to occupational exposure, and are summarized in the table.

Vol. 65, No. 4 Maximum Permissible Amounts of Radioactive Isotopes

	Ra^{226}	Pu^{239}	Sr^{89}	Sr^{90} (+Y90)	Po^{210}	H^3	C^{14} (as CO_2 in air)	Na^{24}	P^{32}	Co^{80}	I^{131}
Maximum permissible levels in body (μc.)	0.1	0.04	2.0	1.0	0.005	$1x10^4$	--	15	10	1	0.3 (0.18 in thyroid)
Effective mean life (days)	10^4	10^4	--	5000	--	10	--	0.8	20	20	12
Permissible daily deposition in body (μc.)	10^{-5}	$4x10^{-6}$	--	$2x10^{-4}$	--	$1x10^{-3}$	--	20	0.5	0.05	0.015 (to thyroid)
Proportion absorbed via lungs and retained in body	0.06	0.1	--	0.06	--	1	--	--	--	--	0.2 (to thyroid)
Maximum permissible levels in air (μc./cc.)	$8x10^{-12}$	$2x10^{-12}$	--	$2x10^{-10}$	--	$5x10^{-5}$	$1x10^{-6}$	--	--	--	$3x10^{-9}$
Proportion retained from intestine	0.1	0.001	--	0.1	--	1	--	1	1	1	0.2
Maximum permissible levels in liquid media (μc./cc)	$4x10^{-8}$	$1.5x10^{-6}$	--	$8x10^{-7}$	--	0.4	--	$8x10^{-3}$	$2x10^{-4}$	$1x10^{-5}$	$3x10^{-5}$

APPENDIX I

Standard Man

(a) Mass of Organs

Organs	Grams
Muscles	30,000
Skeleton, Bones	7,000
Red marrow	1,500
Yellow marrow	1,500
Blood	5,000
Gastrointestinal tract	2,000
Lungs	1,000
Liver	1,700
Kidney	300
Spleen	150
Pancreas	70
Thyroid	20
Testes	40
Heart	300
Lymphoid tissue	700
Brain	1,500
Spinal cord	30
Bladder	150
Salivary glands	50
Eyes	30
Teeth	20
Prostate	20
Adrenals	20
Thymus	10
Skin and subcutaneous tissues	8,500
Other tissues and organs not separately defined	8,390
Total Body Weight	7,000

(b) Chemical Composition

Element	Proportion Per Cent	Approximate mass in grams in the body
Oxygen	65.0	45,500
Carbon	18.0	12,600
Hydrogen	10.0	7,000
Nitrogen	3.0	2,100
Calcium	1.5	1,050
Phosphorus	1.0	700
Potassium	0.35	245
Sulphur	0.25	175
Sodium	0.15	105
Chlorine	0.15	105
Magnesium	0.05	35
Iron	0.004	3
Manganese	0.0003	0.2
Copper	0.0002	0.1
Iodine	0.00004	0.03

The figures for a given organ may differ considerably from these averages for the whole body. For example, the nitrogen content of the dividing cells of the basal layer of skin is probably nearer 6 per cent than 3 per cent.

(c) Applied Physiology

Average data for normal activity in temperate zone.

(i) Water balance

Daily Water Intake	
In food (including water of oxidation)	1.0 liter
As fluids	1.5 liter
	2.5 liters

Calculations of maximum permissible levels for radioactive isotopes in water have been based on the total intake figure of 2.5 liters per day.

Daily Water Output	
Sweat	0.5 liter
From lungs	0.4 liter
In feces	0.1 liter
Urine	1.5 liters
	2.5 liters

Total Water Content of Body 50 liters

(ii) Respiration

Area of Respiratory Tract	
Respiratory interchange area	50 m^2
Non-respiratory area (upper tract and trachea to bronchioles)	20 m^2
Total	70 m^2

Respiratory Exchange

Physical Activity	Hours per Day	Tidal Air (liters)	Respirations per Minute	Volume per 8 Hours (m^3)	Volume per Day (m^3)
At work	8	1.0	20	10	20
Not at work	16	0.5	20	5	

Carbon Dioxide Content (by Volume) of Air	
Inhaled air (dry, at sea level)	0.03%
Alveolar air	5.5%
Exhaled air	4.0%

(iii) Retention of particulate matter in the lungs

In those cases where specific data are lacking, the convention has been adopted that 50 per cent of any aerosol reaches the alveoli of the lungs. If the particles are soluble, they have been considered to be completely absorbed; if insoluble, then the 50 per cent amount has been regarded as retained for 24 hours, after which only half of it, i.e., 25 per cent of the inhaled amount, is retained *in situ* indefinitely.

(d) Duration of Exposure

(i) Duration of occupational exposure

The following figures have been adopted in calculations pertaining to occupational exposure:

8 hours per day
40 hours per week
50 weeks per year

(ii) Duration of "lifetime" for non-occupational exposure

A conventional figure of 70 years has been aopted.

APPENDIX II

Relative Biological Efficiency

The relative biological efficiency of any given radiation has been defined by comparison with the gamma radiation from radium filtered by 0.5 mm. of platinum. It has been expressed numerically as the inverse of the ratio of the dose of the two radiations (in ergs per gram of tissue) required to produce the same biological effect under the same conditions. It has been assumed, for purposes of calculation, that the relative biological efficiency of a given radiation is the same for all effects mentioned in the Introduction, with the single exception of gene mutations.

The following values have been adopted:

Radiation	Relative Biological Efficiency
Gamma rays from radium (filtered by 0.5 mm Pt)	
Roentgen rays of energy 0.1 to 3.0 mev.	1.0
Beta rays	
Protons	10
Fast neutrons of energy not greater than 20 mev.	10
Alpha rays	20

The effective figure for slow neutrons should be derived in any given case from an evaluation of the separate contributions to the biological effect by protons arising from the disintegration of the nitrogen nuclei and by gamma rays arising from the capture of neutrons by hydrogen nuclei.

L. S. Taylor, Acting Secretary
Radiation Physics Laboratory
National Bureau of Standards
Washington 25, D. C.

APPENDIX 20

ALPHA RAY DOSAGE IN BONE CONTAINING RADIUM (8-24-51)

by F. W. Spiers

MRC.51/497
PIRC/IR/5

Introduction

When bone is irradiated, by external or internal sources of radiation, the vulnerable parts are presumably the living soft tissues included in the bony matrix. These are the osteocytes and the small vessels feeding them via the canals of the Haversian systems. Under these circumstances the dose received by a given soft tissue structure depends on the size of that structure in relation to the range of the ionising particle. Such considerations have been used to evaluate the physical dose to the living structures in bone, when irradiated with X-rays and γ-rays in the range 50 kV to 2 MeV. (see Spiers 1949, 1950 & Munson 1950). Similar calculations can be applied to the case of bone containing radium if the distribution of the radium is known with sufficient accuracy.

A recent paper by two American workers (Hoecker & Roofe, 1951), gives important data on the distribution of radium in parts of the bone of two persons, who died from osteogenic sarcoma associated with radium poisoning. It is possible to calculate the dose received by osteocytes and other structures in the bone sections of these two cases and to relate them to the total body content of radium. The radium burden which, for example, delivers a dose of 0.3 rep per week to selected soft tissues in bone can then be deduced from these data. Alternatively a range of "permissible" radium burdens can be calculated in terms of assumptions as to the concentration of radium in the bone.

Hoecker & Reefe's Paper

The bones examined by these authors were from two cases described in detail by Martland (1939); both persons had been employed as dial painters, handling luminous paint containing radium. The details of years of exposure and radium content are set out in Table I.

TABLE I

Martland's Case	Employment as Dial Painter	Date of Death	Tumour Diagnosis	Estimated Ra Content at Death
E.E.	1917 - 1920	1927	Sarcoma R. Scapula	50 μg.
I.L. (Case 5)	1917 - 1921	1931	Oesteogenic sarcoma L. os. pubis	8 μg.

The investigations by Hoecker & Roofe were therefore made on bones which had been preserved for some 20 years.

Thin sections of bone were cut from pieces of femur and α-track photographs made on nuclear emulsions. The main points brought out in Hoecker & Roofe's paper are summarized below:-

1. The α-ray tracks are confined to the matrix and canals of the Haversian systems, but not all the systems are affected.

2. In case E.E.10% of the Haversian systems in the sections examined contain radium. In case I.L. only 2.2% of the systems examined bear radium. These figures relate only to the limited portions examined and are not intended to be representative of the skeleton as a whole.

3. Where a Haversian canal branches the radium may follow one branch only.

4. By counting the number of α-tracks per unit area the number of α-particles per unit volume can be deduced. Such counts are then used to deduce the total α-ray energy released per unit volume per day, and this is concerted into rep per day. The localised dose rates received in selected areas of radium deposition are calculated by H and R as 10 - 23 rep/day for case E.E. and 1 - 14 rep/day for case I.L. These dose-rates are said by Hoecker & Roofe to be for the larger concentrations of radium observed, but they emphasize that they are not necessarily the highest values present.

Comments on Hoecker & Roofe's Results

1. The relevant α-ray doses should be those to the small soft tissue elements (as deduced later). They will be less than those corresponding to the energy loss per unit volume of the bone matrix.

2. The photographs show α-tracks throughout the whole Haversian system - in the large canals as well as in the matrix. This effect indicates that radon and its decay products have diffused in the 20 years since death, throughout the entire system. In life, the concentration of radon in the blood will be low compared with the concentration of radium in the bone, and hence the dose to the soft tissue inclusions will be due almost entirely to α-particles arising in the matrix.

3. In the case of bone samples, preserved for some 20 years, it is likely that radon will have been maintained nearly in equilibrium with the radium and that Ra D and the remainder of the radium series will have accumulated to about half their equilibrium amounts. Hoecker & Roofe suggest that, in cutting the bone sections, possibly half the radon escapes from the surface layer responsible for the α-track photograph.* At the worst this would mean that the α-tracks are due to the radium α's together with half the equilibrium numbers from Rn, Ra A and Ra C' and about half those from Ra F - a total of 3 α's per disintegration of radium. The exposures used for the α-track photographs, however, were between 16 and 17 days, in which time the radon equilibrium in the layer pressed close to the photographic plate would be nearly fully restored. In such a case the number of α-particles averaged throughout the exposure would be due to the Ra α's, together with about 5/6 of the equilibrium numbers from Rn, Ra A & Ra C' and half those from Ra F - a total of about 4 α's per initial Ra disintegration.

In life it appears possible also that about half the radon escapes via the blood stream and, in the early years of radium deposition, the amount of Ra F present will be small. In this case there will be an average release in the bone matrix of about 2.5 α-particles per disintegration of Ra. Hence it seems reasonable to suggest that the dose rates to the bone in life will have been approximately 2.5/4 or 60% of the dose rates calculated from the present counts of α-tracks.

Calculation of α-ray Dose to Soft Tissue near Bone containing Radium

1. Interpretation of autoradiograph.

If the thickness of the bone section is greater than the range of the α-ray's in bone, the number of α-particles emitted per unit volume of the bone can be deduced from the number of tracks recorded per unit area of the nuclear emulsion.

Let N = number of α's per unit volume of bone.
R_B = range of α's in bone.
n = number of α's crossing area SA of the bone surface - i.e. number of tracks recorded on area SA of the emulsion.

Then $$n = \frac{N . R_B \, SA}{4}$$

or $$N = \frac{4 \times \text{number of } \alpha\text{'s per unit area}}{R_B} \qquad (1)$$

2. Dose at a Point in Soft Tissue.

In calculating the α-ray dose at a point in soft tissue, at distance d from a plane surface of bone containing a uniform concentration of radium, the expression given by Munson (1950) will be used; it will also be convenient to express distances in microns and to use a time scale in days.

The dose rate at d microns from the bone surface is then given by:-

$$\text{ergs}/\mu^3/\text{day} = \frac{N\sigma \; R_T}{2\rho}\left(1 + \frac{d}{R_T}\left(\log \frac{d}{R_T} - 1\right)\right) \qquad (2)$$

Where N = α-particles emitted per μ^3 per day.
σ = average energy loss of the α's in ergs/μ of soft tissue
R_T = range of α's in microns.
ρ = range in tissue/range in bone = R_T/R_B

* A further paper by those authors has just appeared in Nucleonics in which they give the especial evidence for this. (Ref: Nucleonics 8, No. 5, 44. 1951.)

This expression can be evaluated by finding appropriate values for σ, R_t and ρ and finally converted into rep/day.

3. Values of σ and R_T

Assuming 50% retention of Rn the average energy for the particles is 5.75 MeV.

The value given by Lea for the range in tissue of any particle of this energy is 44 μ - whence:

RT = 44 μ and σ =21 x 10^{-6} ergs/μ.

4. Values of ρ and R_B

Using the Geiger formula $\rho = \frac{\sqrt{\text{atomic number}}}{\text{density}}$

we have $\rho = \sqrt{\frac{7.42}{13.8}} \times \frac{1.85}{1.00} = 1.36$

Where the average atomic numbers of bone and tissue, 13.8 and 7.42 and the density of bone 1.85 are taken from earlier measurements by the writer (Spiers 1946).

This value of ρ agrees with that deduced from a list of α-particles stopping powers relative to air, given in Siri (1949) p.85. Using values for a 6 MeV α-particle and interpolating the figures in the table for effective atomic numbers 7.42 and 13.8 the value deduced for ρ is 1.37 in good agreement with that derived from the Geiger formula.

The range of the α particles in bone then becomes

$$R_B = \frac{44}{1.36} = 32$$

in agreement with the figure used by Hoecker & Roofe.

5. Dose Rate in rep/day.

In order to compare the present calculations with those of Hoecker & Roofe, it is convenient to express the dose rates in rep/day and to introduce a factor for the relative biological efficiency of α radiation at a later stage. Using the above values of σ, R_T and ρ and, taking 1 rep as 83 ergs absorbed per cc of tissue, expression (2) becomes:

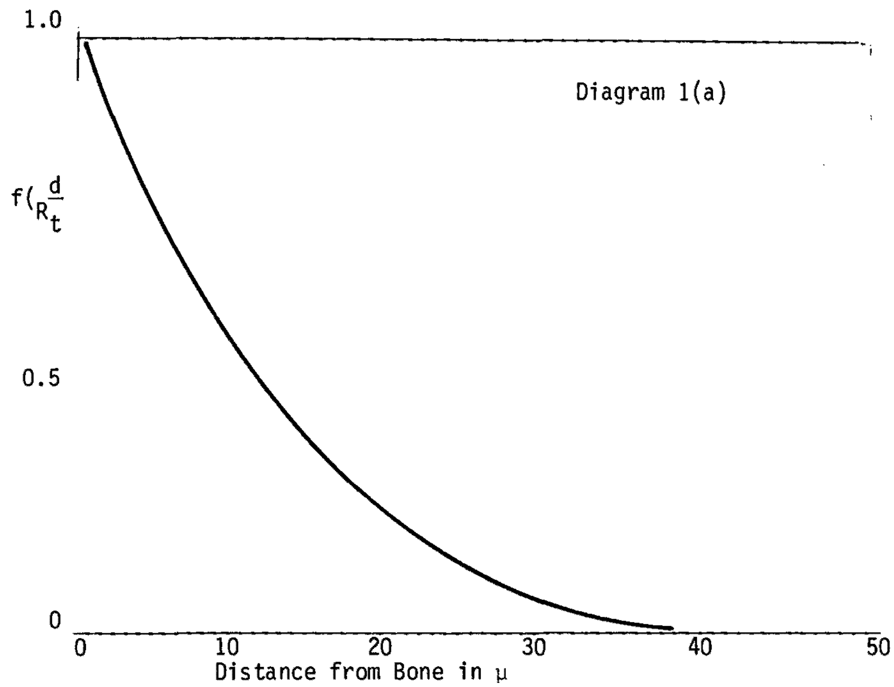
$$\text{Dose-rate} = 40.9 \times 10^3 \times N \left(1 + \frac{d}{R_T}\left(\log \frac{d}{R_T} - 1\right)\right) \text{ rep/day} \quad (3)$$

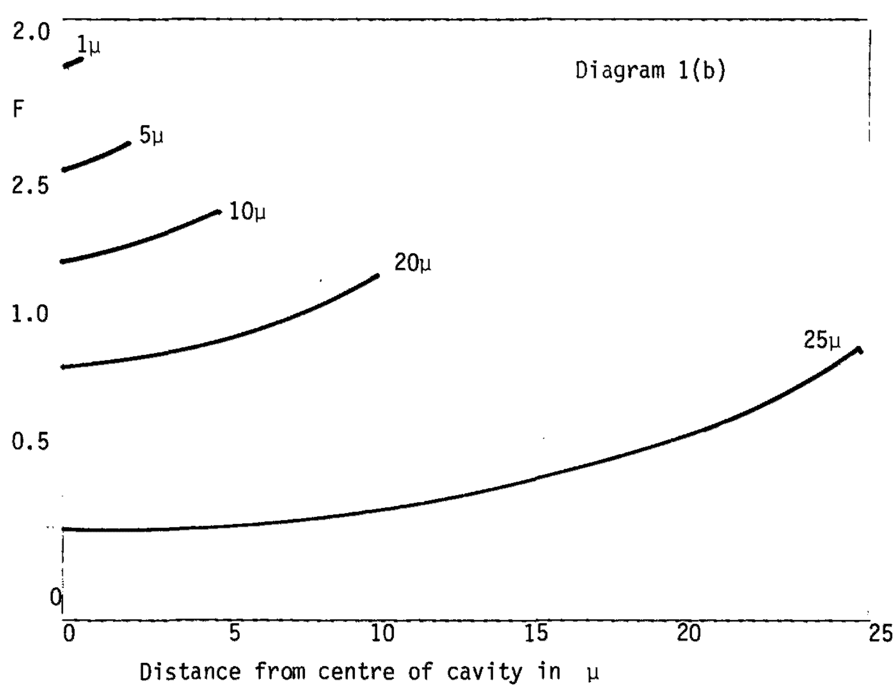
6. Summation of Dose from Two Plane Bone Surfaces

The variation of dose across a small cavity can be estimated approximately by adding together the effects of two plane pieces of bone, having soft tissue included between them. The appropriate part of equation (3) to be used is:-

$$\int \frac{(d)}{(R_T)} = 1 + \frac{d}{R_T}\left(\log \frac{d}{R_T} - 1\right) \quad (4)$$

This function is shown graphically in Diagram 1(a) where it is plotted against d in microns for R_T = 44μ.


1.0
Diagram 1(a)
f(R d/t
0.5
0
0
10
20
30
40
50
Distance from Bone in μ


2.0
1μ
Diagram 1(b)
F
5μ
2.5
10μ
20μ
1.0
25μ
0.5
0
0
5
10
15
20
25
Distance from centre of cavity in μ

If soft tissue lies between two α-emitting planes and no appreciable radon concentration exists in the soft tissue, the dose at a point in the "cavity" between the bone surfaces can be calculated from the function:-

$$F = \int \frac{(d_1)}{(R_T)} + \int \frac{(d_2)}{(R_T)} \qquad (5)$$

where d_1 and d_2 are the distances of the point from the two bone surfaces and $d_1 + d_2$ = total cavity width. This function is shown in Diagram 1(b) where it is plotted against the distance of the point from the centre of the cavity.

The function has the value 2.0 for a very small cavity of the type considered by Gray and falls below this value for cavities of finite size. It is theoretically zero at the centre of cavities greater than 2 R_T across.

Dose Rates Calculated for Cases in Hoecker & Roofe's Paper

1. Calculated Dose Rates for Section N^o^ 0057, Case E. E.

Data given in Table 1 of Hoecker & Roofe's paper record 950 α-particle tracks on an area 2.5 x 10^4 sq. microns in an exposure of 423 hours. Hence:-

$$\text{No. of } \alpha\text{'s per } \mu^3 \text{ per day} = N - 4 \times \frac{950}{2.5\times10^4} \times \frac{24}{423} \times \frac{1}{32}$$

$$= 2.70 \times 10^{-4}$$

The average value of the dose rate throughout a cavity is then given by:-

$$\text{Dose per day} \simeq 40.9 \times 10^3 \times 2.70 \times 10^{-4}\ \bar{F} = 11.0 \times \bar{F}$$

where $\bar{F}$ is the value of F in equation (5) averaged over the cavity width.

Table 2 below gives the values $\bar{F}$ for a series of cavity sizes, the resulting dose rates calculated from the present counts of α-tracks and the estimated dose rates some 20 years ago when the bone was part of a living body. This last figure is taken as 60% of the dose deduced in column 3 of the Table.

TABLE 2

Cavity Size	$\bar{F}$ (average)	Dose Rate	Hoecker & Roofe	Estimated Dose Rate when living
		rep/day		per/day
0	2.00	22.0	)	13.2
5 μ) oesteo-	1.60	17.6	)	10.6
10 μ) cytes	1.35	14.8	) 23	8.9
20 μ) Haver-	1.00	11.0	) rep/day	6.6
50 μ) sian	0.55	6.0	)	3.6
) canals			)	

The dose rates calculated for cavities of finite size are less than the figures given by Hoecker & Roofe which relate only to the energy absorption in the bone matrix. Allowing for the R.B.E. of 20 for α radiation, the dose rates when living will be twenty times those given in the last column of Table 2. An osteocyte in a lacuna 5 μ across (there is one in Fig. 6 of Hoecker & Roofe's paper, measuring 17 μ x 5 μ), would have received 10.6 rep/day or the equivalent of about 210 r/day of hard ρ or γ radiation:

2. Dose Rates and Local Concentrations of Radium for All Sections given by Hoecker & Roofe.

Since the α-track counting leads to a determination of N the number of α-particles omitted per unit volume of bone, it is possible to use this value of N to deduce the local concentration of radium in the area examined and to compare this with the concentration expected if the radium content of the body were distributed uniformly throughout the mass of bone.

If the concentration of radium in the locality considered is m μgm per gm bone and the α-track counts are assumed due to a total of 4 α's per disintegration, the value of N deduced from the α-tracks can be inserted in the expression:-

$$N = m \times (4 \times 3.7 \times 10^4) \times (1.85 \times 10^{-12}) \times 3600 \times 24$$

$$\text{i.e. } m = 42.3 \times N \ \mu gm \qquad (6)$$

The dose rates are derived from equations (3) & (5) putting in the value 1.35 for $\overline{F}$ for a 10μ cavity and a factor of 0.6 to allow for the α emission when living; namely:-

$$\text{Dose rate in rep/day} = 40.9 \times 10^3 \times N \times 1.35 \times 0.6 = 33.1 \times 10^3 \times N \text{ in } 10\mu \text{ cavity} \qquad (7)$$

Tables 3 and 4 give the values of N, the concentrations m deduced from them, and the calculated values of the dose rates in a 10μ cavity, when living, for all the sections reported in Hoecker & Roofe's paper. The average concentration corresponding to uniform distribution of the total skeletal content is also given.

TABLE 3

Case E.E. Sections of Femur

Section	N α's/μ^3/day	Concentration M μg Ra/gm bone	Dose Rate when living
0575	2.64×10^{-4}	11.1×10^{-3}	8.7 rep/day
0557	2.70	11.4	8.9
0559	1.81	7.6	6.0
0561	1.60	6.8	5.3
0563	2.23	9.4	7.4
0592	1.38	5.8	4.6
0572	1.25	5.3	4.1
0603	1.14	4.8	3.8
Means:-		7.5×10^{-3}	6.1

Mean concentration if 50 μg Ra distributed uniformly in 7 kg bone = 7.1×10^{-3} μg Ra/gm bone.

TABLE 4

Case I.L.

	Section	N α's/ μ^3/day	Concentration m μg Ra/gm bone	Dose Rate when living
Femur Shaft	0604	1.13×10^{-5}	0.48×10^{-3}	0.37 rep/day
	0613	4.35	1.84	1.44
	CL322	2.38	1.01	0.79
	CL319	3.20	1.35	1.06
	CL	2.98	1.26	0.99
	0609	2.21	0.93	0.73
	0605	1.19	0.50	0.39
	Means:-		1.05×10^{-3}	0.82
Epiphyses of Femur	0577	7.59×10^{-3}	3.21×10^{-3}	2.57 rep/day
	0617	16.15	6.82	5.34
	0583	9.53	4.03	3.15
	0581	6.15	2.60	2.14
	0585	5.28	2.23	1.74
	0587	7.13	3.01	2.36
	Means:-		3.65×10^{-3}	3.88

Mean concentration if 8 μg Ra distributed uniformly in 7 kg bone = 1.1×10^{-3} μg Ra/gm bone.

3. Summary of Hoecker & Roofe's Results & a Deduction of Permissible Body Content

Table 5 summarizes the average dose rates in rep/day in a 10 μcavity, estimated from the data given in Hoecker & Roofe's paper for the two cases of radium poisoning. Allowing for the greater biological effect of α radiation (RBE 20), these mean dose rates are also given as the equivalent dose rates for hard β or γ radiation. If 0.3r per week is taken as the permissible dose to the osteocytes in bone, the permissible body content of radium can be deduced from these results and are listed in the last column of the Table.

TABLE 5

Case	Ra Content of Body	Estimated Dose Rates to Osteocytes when living: rep/day	r/day (equiv. hard β & γ rad.)	Body Content to give 0.3r/ week
E.E. Femur Shaft	50 μg	6.1	122	18×10^{-3} μg Ra
I.L. Femur Shaft)	8 μg	0.8	16	22×10^{-3} μg Ra
Femur epiphyses)		2.9	58	6×10^{-3} μg Ra

Alternative Considerations of Permissible Body Content

Instead of deducing values of the permissible body content in terms of the measured data given for the cases considered by Hoecker & Roofe, the above methods of calculation can be used to derive the values of the radium burden which will give the permitted dose rate to soft tissues in cavities of various size for different degrees of radium concentrations in the bone matrix.

The simplest case of uniform distribution will be first considered. If M μg of radium are distributed uniformly throughout the 7 kg skeleton and 2.5 α-particles are assumed effective per initial radium disintegration, (50% escape of radon), the dose rate is derived from expressions (3) and (5) as:-

$$\text{Dose rate} = 0.0863 \times M \times \bar{F} \text{ rep/day} \qquad (8)$$

where $\bar{F}$, as before, refers to the average of F for a particular cavity size.

Using a factor 20 for the R.B.E. to convert this dose rate to equivalence with hard β or γ radiation and equating to a permissible level of 0.043 r/day, M is derived as:-

$$M = \frac{24.8 \times 10^{-3}}{F} \ \mu\text{g radium} \qquad (9)$$

The values of M for cavities of different size and a radium concentration factor of unity are given in the first column of figures in Table 6. Hoecker & Roofe suggest that a concentration factor of 10 may occur although the highest concentration factors deduced from their results would appear to be about 1.5 for the observations on case E.E. (Table 3) and about 6 for Case I.L. (Table 4). Accordingly values of M are also given in Table 6 for cases in which the radium depositions are respectively 2 and 10 times the concentration averaged for the whole mass of the skeleton.

TABLE 6

Type & Size of Cavity	Total Body Contents for Concentration Factors:		
	1	2	10
	all x 10^{-9} gm Ra		
Haversian Canal - 50μ	45	23	4.5
Lacunae with (10μ	18	9.2	1.8
Osteocytes (5μ	16	7.8	1.6
Canaliculi 1μ	13	6.6	1.3

General Discussion of Results given in Tables 5 & 6

1. Carcinogenic Action.

Both cases E.E. & I.L. died of osteogenic tumours which, in view of the high radium burdens, could fairly be attributed to the action of radiation. The high values of the "equivalent" dose rates given in Table 5 would seem to make the eventual development of osteogenic cancer inevitable. If a dose rate of 10 r/day (equivalent hard β or γ radiation) is regarded as one giving a high probability of tumour development, the data of Table 5 would indicate that this is achieved with radium burdens in the region of 1 - 5 μ g. Moreover this estimate, based on 10 r/day continuous radiation, appears to be a conservative evaluation of the "carcinogenic" level of the radium burden; it may possibly be lower.

2. "Permissible" Radium Burden.

The permissible levels of radium content given in Table 5 & 6 are very small but are based on a severe limitation as to tissue dosage. It is not suggested that the permissible dose rate of 0.3r/week should necessarily apply to tissues as small as osteocytes, which, by the nature of the radium deposition, are not all equally affected. The calculations, however, show the limits imposed on the permissible radium content of the body by the application of this criterion. If bone is the structure concerned in radium poisoning, the osteocytes may possibly be the critical tissue involved and, in this case, there is clearly need for information as to the proportion of osteocytes affected and the "permissible" level at which they may be irradiated. If, for example, the level for a limited volume of critical tissue - 1.5r/week - were adopted, the values in Table 6 would all be five times greater. If bone marrow were regarded as the important tissue and blood damage taken as the indicator, a permissible level of 0.3 r/week would probably be more relevant. In this case, however, the marrow inclusions are in much larger cavities and the dose rates from radium deposition would be very much lower even than those calculated for the larger Haversian canals. The resulting implications as to total radium burden would probably be much less stringent than the figures given in the first line of Table 6.

References:

Hoecker, F.E. & Roofe, P.G., Radiology, (1951), lvi, 89.
Martland, H.S., I.L.O., Occupation and Health, (1939), pl.
Munson, R.J., Brit. Journ. Rad., (1950), xxiii, 505.
Spiers, F.W., Brit. Journ. Rad., (1946), xix, 52.
Brit. Journ. Rad., (1949), xxii, 521.
Brit. Journ. Rad., (1950), xxiii, 743.

24th August, 1951.

TRIPARTITE CONFERENCE

1. Basic dose of X and γ rays up to 3 MeV.

It is recommended that:

The present level of 300 mrep in the critical organ be unchanged. The wording of the present organ be unchanged. The wording of the present international recommendations should be scrutinised.

2. Basic dose for X and γ rays above 3 MeV.

For X or γ rays of quantum energy greater than 3 MeV, it is not possible to base the permissible whole body exposure on a measurement of surface dose. (A dose of 0.5r to the surface for energies less than 3 MeV was based primarily on an estimated dose of 0.3r or 30 ergs/g to the critical tissues, taken to be several cm. below the surface. For high energy radiation, the dose a few cm. below the surface may be many times greater than that at the surface). Accordingly, the maximum permissible exposure for ionising radiations of quantum energy greater than 3 MeV shall be that which causes an energy absorption not greater than 30 ergs/g in any part of the body in any one week.

3. Permissible exposure for β rays

(a) wide areas of body - existing level of 1.5 rep/week should be retained.
(b) restricted areas of body, e.g. hands - the British delegation recommend a relaxation of the present level to one of 5 rep/week.

4. R.B.E. Values

It is recommended that the existing I.C.R.P. values be retained.

5. Neutrons

(a) permissible exposures (ergs/gm).
(b) permissible fluxes - see P.I.R.C./HER 18 attached.

6. Life Doses

No original data will be presented by the British but some discussion is desirable.

7. Exposure of large populations (to include genetic effects).

The main effort of the External Radiation Sub-committee has been directed to the problem of assessing for general population the mean radiation dose at the gonads as a result of diagnostic examination.

(a) The values given for men were obtained by direct measurements at the gonads. For women the data were calculated on the basis of skin measurements. The data for women may have to be revised as a result of present experimental work being carried out.

(b) It appears from this information that, on the average, each person below the age of 30 has had about one diagnostic examination.

The data available were collated and various sources of radiation were considered, including diagnostic examination, and an estimate made of the average gonad per head of population up to the age of 30 years, which is taken as the mean age of reproduction. The table showing the main conclusions is reproduced overleaf.

Type of exposure	Average gonad dose per head of population received in first 30 years of life			
	Males	% of total	Females	% of total
Natural radiations	3000 mr	74%	3000 mr	70.5%
K^{40}	900 mr	22%	900 mr	21%
Occupational	60 mr	1.5%	60 mr	1.5%
Diagnostic examination	100 mr	2.5%	300 mr	7%
	4.06r	100%	4.26r	100%

It appears from the Table above that diagnostic examination makes only a small contribution to the average gonad dose per head of population received from all sources. Even although the methods of assessment of the diagnostic dose have been very approximate it is unlikely that new methods of assessment would make any very great difference to the total gonad dose from all sources.

One fact which has emerged from the experimental data on dose received at the goands is that a large proportion of the diagnostic dose burden is borne by the relatively few individuals who have been subject to particular types of radiographic examination, such as hysterosalpingography in women, where a gonad dose of up to 50 r has been reported.

The Sub-committee has realised that the dosage data on which the conclusions have been based refer to techniques as carried out at four hospitals and that this may not be representative of the country as a whole. However, efforts are being made to obtain more representative data. In view of the fact that the major part of the dose received in diagnostic examinations results from a few particular types of examination, it may be possible to concentrate only on these for wider analysis.

The Sub-committee wish to draw attention to recent altering trends in diagnostic procedures following on the shortage of films, leading possibly to an increase in fluoroscopy with a consequent large increase in the dose received by the patient. Some extension of indirect radiography is also possible which might increase the dose to the patient.

8. Emergency Doses

It is suggested that consideration be given to maximum permissible exposures arising from a plant emergency: external irradiation; mixed fission product inhalation and ingestion; Pu, Sr^{89} and Sr^{90} retention.

9. Permissible levels for radioactive isotopes

The attached table (marked Appendix to P.I.R.C. 15b amended) summarises the recommendations of the Sub-committee on Internal Radiation for 21 isotopes, other than those given by I.C.R.P. Many of the differences between these levels and the U.S.A. recommendations can be accounted for by 2 factors.

If the maximum permissible level of Sr^{89} is assessed on the basis of its observed biological effect relative to 0.1 μ C Ra, a value of 2.0 μC is obtained. (This is the present I.C.R.P. value.) If, however, the Sr^{89} level is assessed as the amount which will produce 0.3 equivalent r in tissues, the value obtained is 11μC. The M.R.C. Sub-committee has chosen the former basis and has extended this to other bone seeking isotopes. The U.S. sub-committee has taken 0.3 equivalent r in tissue as the basis for estimating m.p.l.'s for bone-seeking isotopes. Thus there arises a difference by a factor of 5. For some of the isotopes, e.g. Y, Zr, Ce, Pr, Pm, Sm and Eu, the M.R.C. Sub-committee has allowed a further factor of 5 for uneven distribution of the isotopes within the bone. Accordingly in some cases, there is a factor of 25 difference between the British and U.S. figures.

In some cases (e.g. Y^{91} and Ru^{106}), calculations indicate that the damage to lung and to gut by temporarily retained isotopes is greater than that to the ultimate organ of storage. The British figures are based on the damage to the lung and gut, the U.S. figures on the damage to the organ of storage.

The British delegation wishes most strongly to retain the existing figure of 0.1 μg of radium as a permissible body burden and to base the tolerance structure on the clinical and experimental evidence from radium rather than on a calculated dose to the bone. (See attached paper P.I.R.C./IR/5 by

F. W. Spiers which is relevant.)

10. Review of Standard Man.

The K content of the body appears to have been overestimated: a better figure would be 0.2%.

11. Miscellaneous.

The maximal permissible levels for I^{131} and Sr^{89} in grass for grazing animals needs discussion and from the view of normal operations of and accidents to atomic energy plants.

APPENDIX 21

HIGH ENERGY RADIATION AND HEAVY PARTICLES (6-16-52)

MRC.52/440
PIRC/HER/18

SUB-COMMITTEE ON HIGH ENERGY RADIATION

AND HEAVY PARTICLES

Maximum Permissible Exposure to Neutrons in the Energy Range Thermal to 5 MeV

It is the purpose of this paper to put forward definite proposals for the permissible exposure to neutrons in the range from thermal energies up to 5 MeV. These may be expressed either in terms of the maximum permissible flux of neutrons (neutrons/cm^2 x sec) to which personnel may be exposed for 40 hours per week; or in terms of the maximum permissible weekly dose (ergs/gram) to personnel for neutrons in the energy range considered. Each method has certain advantages, the former being more convenient for the design of protective barriers for specified neutron sources, and the latter more convenient where ionisation methods of monitoring are in use. There are therefore good reasons for expressing the permissible exposure to neutrons in both forms. In health protection calculations accuracy to within 10% is entirely adequate, and the alternative methods of specifying permissible exposure should not lead to inconsistencies greater than this.

The maximum permissible exposure to X- or gamma-radiation has been set at 0.5 r (46 ergs/gram) per week to the surface of the body. This was based on a dose of 0.3 r (28 ergs/gram) per week to the critical tissue - the bone marrow, which was assumed to lie 5 cm below the skin. The depth of the critical tissue below the skin may often be less than 5 cm, however, and it seems wise to take its depth as 2 cm. The energy deposition by neutrons of energy greater than .01 MeV is mainly due to the transference of neutron kinetic energy to protons; for lower energies the radiations produced when the neutron is thermalised and captured contributes mainly to the dose. If the r.b.e. of the recoil or disintegration protons be taken (provisionally) as 10 over the whole energy range, in accordance with the present international agreement, then the maximum permissible energy may be expressed as 5 ergs/gm to the surface of the body, or 3 ergs/gm at a depth of 2 cm, whichever is the lower. For fast neutron beams practically all the energy is dissipated by such fast recoil nuclei, and an ionisation measurement in a chamber with tissue-like walls provides an immediate measure of the permissible intensity. If gamma-radiation is also present, either from the source or from neutron capture, the proton and gamma-ray components of the total ionisation must be determined separately, since the r.b.e. of 10 applies only to the former. In a neutron beam of mixed energies ranging from thermal up to 5 MeV, the criterion of 3 ergs/gm at a depth of 2 cm will nearly always be the more stringent (see Table I). One may therefore specify the permissible exposure to neutrons per 40 hour week as that exposure which would produce an energy absorption of 3 ergs/gm at a depth of 2 cm below the surface of tissue.

The alternative method of expressing permissible exposure involves the determination of the neutron flux which in 40 hours would produce a superficial energy absorption equivalent to .05 r or energy absorption at 2cm below the surface equivalent to .03 r. In the calculations which have been made (vide PIRC/HER/4 and 10 for references), it is assumed that the neutrons enter normally to the tissue; but it is shown that, provided the neutron flux and not the neutron current is specified, the energy absorption in tissue, even in the worst case, should not exceed 2.3 times that corresponding to normal incidence. Table I**presents for a range of neutron energies the neutron flux (neutrons/cm^2 x sec) which, if incident normally on tissue, would give an energy absorption at the surface equivalent to .05 r in 40 hours, and also the flux which would give an energy absorption equivalent to .03 at 2 cm depth. The final column gives the recommended values for the maximum permissible flux at eacy energy. The values for neutron energies of 10 keV and 10 eV are approximate.

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* It has been suggested that the r.b.e. for neutron irradiation should be taken as 20. If this suggestion were adopted the permissible exposure figures recommended in the present paper would all have to be divided by 2.

** Taken from PIRC/HER/10.

Table I

Neutron Energy	Flux giving surface dose equivalent to .1r in	Flux giving dose equivalent to .06r at 2 cms	Recommended permissible flux	Permissible flux adopted
	Neutrons/ cm^2 x sec	neutrons/ cm^2 x sec	neutrons/ cm^2 x sec	
10 MeV	-	-	-	30
5 MeV	60	44	50	30
4 MeV	60	44	50	30
3 MeV	76	48	50	30
2 MeV	90	64	50	40
1 MeV	126	94	100	60
.5 MeV	160	148	150	80
.1 MeV	410	530	400	200
10 keV	2300	1900	2000	1000
10 eV	7580	2380	2000	1000
.025 eV	3300	1990	2000	2000

16th June, 1952.

APPENDIX TO PIRC 15B-AMENDED.

Estimation of Maximum Permissible Levels

Column

2 Radioactive half-life T_r, taken from Nuclear Data N.B.S. Circular No. 499.

4 Effective energy $\bar{E}$. In the case of nuclides which are selectively concentrated in smaller organs with dimensions not greater than a few centimetres the effective energy is taken as being ($1/3\ \beta + 2/3\gamma$).

6 The effective half-life in the organ (Te) is taken as being given by

$$\frac{1}{T_e} = \frac{1}{T_b} + \frac{1}{T_r} \quad \text{where} \quad T_b = \text{biological half-life}, \quad T_r = \text{radioactive half-life.}$$

7 The proportion P_a of the nuclide in the lung which is retained (at least temporarily) in the lung.

8 The proportion q_a of the nuclide retained in the lung which is transferred to the organ of deposition.

9 The proportion P_w of the nuclide in food or drink which is taken up in the gut.

10 The proportion q_w of the nuclide ingested which is transferred to the organ of deposition.

11 The amount of nuclide in the organ of concentration which will give a dose of 0.3 rep/week.

12 The maximum permissible level in the organ. For organs of deposition other than the skeleton columns 11 and 12 are the same. The m.p.l's of the long-lived nuclides which are deposited preferentially in the skeleton, namely Ca, Sr., Y., Zr., Ba., Ce., Pr., Pm., Sm., and Eu. have been estimated by reference to the experimental evidence of Brues of the toxicity of Sr., and by making allownace for the relative energies of decay. For Y., Zr., Ce., Pr., Pm., Sm., and Eu. a further factor of 5 is allowed for uneven distribution within the bone.

13-14 For most nuclides the m.p.l's are estimated for more than one organ. The lowest level is underlined in each case, and is quoted in the summary.

NUCLIDES FOR WHICH OFFICIAL MAXIMUM

(1) Nuclide	(2) Radioactive Half-life T_r	(3) Organ of concen-tration	(4) Effective Energy (mev.)	(5) Biological half-life T_b (days)	(6) Effective half-life T_e (days)	(7) Proportion temporarily retained in lung	(8) Proportion of uptake from lung to organ
Ca.45	152d.	Bone	0.087	-	152	0.25	0.5
Sr.89	53d.	Bone	0.5	-	53	0.25	0.5
Y.91	57d	Bone	0.51	-	57	0.25	0.3
		Gut		1	1		
Zr.95 + Cb.95	65d.	Bone	0.48	-	65	0.25	0.3
		Gut		1	1		
Ru.103	42d	Kidney	0.22	10	20	0.25	0.03
		Lung		1	14		1
		Gut		1	1		
		Liver			10		0.07
Ru.106 + Rh.106	1.0y. 30s.	Kidney	1.17		20	0.25	0.03
		Lung			48		1
		Gut		1	1		
		Liver		10	10		0.07
Sb.125	2.7y.	Liver	0.23	20	20	0.25	0.5
		Lung		1	1		
Te.127* + Te.127	90d. 9.3h.	Kidney	0.27	15	13	0.25	0.06
		Blood		15	13		0.15
		Lung		1	1		
Te.129* + Te.129	32d. 70m.	Kidney	0.82	15	10	0.25	0.06
		Blood		15	10		0.15
		Lung		1	1		
Cs.134	2.3y.	Muscle	1.20	15	15	0.25	0.45
Cs.135	2×10^6 y.	Muscle	0.07	15	15	0.25	0.45
Cs.136	13.7d	Muscle	0.69	15	7	0.25	0.45

(1)	(9)	(10)	(11)	(12)	(13)	(14)
Nuclide	Proportion of uptake from water in gut	Proportion of uptake from gut to organ (μ curies)	Amount in organ to give 0.3 rep/week (μ curies)	Maximum permissible level in organ (μ curies)	Maximum permissible level in air (μ curies/cc)	Maximum permissible level in water (μ curies/cc)
Ca.45	1	0.8	63	13	2×10^{-8}	3×10^{-5}
Sr.89	0.6	1	11	2	1×10^{-8}	2×10^{-5}
Y.91	0.001 1	0.65	11 3	0.4 3	3×10^{-9}	3×10^{-3} 8×10^{-4}
Zr.95 + Cb.95	0.001 0.001	0.35 0.3	11 3	0.4 3	3×10^{-9}	5×10^{-3} 8×10^{-4}
Ru.103	0.001 1	0.035	1.1 3.5 7.1 6.0	1.1 3.5 7.1 6.0	2×10^{-7} 4×10^{-8} 1×10^{-6}	4×10^{-1} 2×10^{-3}
Ru.106 + Rh.106	0.001 1	0.035	0.2 0.7 1.3 1.1	0.2 0.7 1.3 1.1	5×10^{-8} 2×10^{-9} 2×10^{-7}	8×10^{-2} 4×10^{-4}
Sb.125	1	0.15	5.8 3.4	5.8 3.4	8×10^{-8} 5×10^{-7}	5×10^{-4}
Te.127*+ Te.127	0.25	0.06 0.15	0.9 14 2.9	0.9 14 2.9	1×10^{-7} 9×10^{-7} 4×10^{-7}	1×10^{-3} 7×10^{-3}
Te.129*+ Te.129	0.25	0.06 0.15	0.28 4.8 0.95	0.28 4.8 0.95	6×10^{-8} 4×10^{-6} 1×10^{-7}	5×10^{-4} 3×10^{-5}
Cs.134	1	0.45	20	20	4×10^{-7}	1×10^{-3}
Cs.135	1	0.45	330	330	7×10^{-6}	1×10^{-2}
Cs.136	1	0.45	34	34	1×10^{-6}	3×10^{-3}

NUCLIDES FOR WHICH OFFICIAL MAXIMUM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nuclide	Radioactive Half-life T_r	Organ of concen-tration	Effective Energy (mev.)	Biological half-life T_b (days)	Effective half-life T_e (days)	Proportion temporarily retained in lung	Proportion of uptake from lung to organ
Cs.137 + Ba.137	37y. 2.6m.	Muscle	0.62	15	15	0.25	0.45
Ba.140 + La.140	12.8d. 40h.	Bone	1.28	-	12.8	0.25	0.5
Ce.141	28d.	Bone	0.17	-	28	0.25	0.2
		Lung		17	10.6		
		Gut		1	1		
Pr.143	13.8	Bone	0.31	-	13.8	0.25	0.4
		Liver		10	5.8		0.3
		Lung		17	7.6		
		Gut		1	1		
Ce.144 + Pr.144	275d. 17.5m.	Bone	1.17	-	275	0.25	0.2
		Liver		10	10		0.55
		Lung		40	40		
		Gut		1	1		
Pm.147	3.7y.	Bone	0.07	-	1300	0.25	0.2
		Lung		40	40		
		Gut		1	1		
Sm.151	20y.	Bone	0.02	-	20y.	0.25	0.2
		Lung		40	40		
		Gut		1	1		
Eu.155	1.7y.	Bone	0.07	-	620	0.25	0.2
		Lung		40	40		
		Gut		1	1		
Tl.204	2.7y.	General Distri-bution	0.27	100	100	0.25	0.5

PERMISSIBLE LEVELS ARE REQUIRED

APPENDIX TO PIRC 15B-Amended

(1)	(9)	(10)	(11)	(12)	(13)	(14)
Nuclide	Proportion of uptake from water in gut	Proportion of uptake from gut to organ (μ curies	Amount in organ to give 0.3 rep/week (μ curies	Maximum permissible level in organ (μ curies)	Maximum permissible level in air (μ curies/cc)	Maximum permissible level in water (μ curies/cc)
Cs.137 + Ba.137	1	0.45	36	38	8×10^{-7}	2×10^{-3}
Ba.140 + La.140	0.6	0.6	4.3	0.78	2×10^{-8}	5×10^{-5}
Ce.141	0.001	0.25	32	1.2	3×10^{-8}	5×10^{-2}
			4.6	4.6	6×10^{-8}	
	1		9.2	9.2		3×10^{-3}
Pr.143	0.001	0.25	17.6	0.7	2×10^{-8}	6×10^{-2}
	0.001	0.25	4.3	4.3	3×10^{-7}	0.8
			2.5	2.5	5×10^{-8}	
	1		5.0	5.0		1×10^{-3}
Ce.144 + Pr.144	0.001	0.25	4.7	0.2	5×10^{-10}	8×10^{-4}
	0.001	0.25	1.1	1.1	3×10^{-8}	0.1
			0.67	0.67	2×10^{-9}	
	1		1.3	1.3		4×10^{-4}
Pm.147	0.001	0.25	80	3	2×10^{-9}	3×10^{-3}
			11	11	4×10^{-8}	
	1		22	22		6×10^{-3}
Sm.151	0.001	0.25	273	10	9×10^{-10}	2×10^{-3}
			39	39	1×10^{-7}	
	1		78	78		2×10^{-2}
Eu.155	0.001	0.25	78	3	3×10^{-9}	5×10^{-3}
			11	11	4×10^{-8}	
	1		22	22		6×10^{-3}
Tl.204	0.5		150	15	1×10^{-8}	1×10^{-4}

APPENDIX 22

PROGRAM PROPOSALS FOR ARDEN HOUSE CONFERENCE ON 30 MAR., 1953

MEDICAL RESEARCH COUNCIL

MRC, 53/126
PIRC/24

COMMITTEE ON PROTECTION AGAINST IONISING RADIATIONS

Programme for the U.K. Delegation to the Tripartite Conference on Permissible Levels of Radiation to be held in Washington, D.C., U.S.A., on the 30th and 31st March and 1st April, 1953
W. Binks (no date)

A. Previous Conferences

At the Chalk River Conference (September, 1949), the following matters were discussed:-

(1) Basic anatomical and physiological data on "Standard Man".

(2) R.B.E.'s for α and β particles, fast and slow neutrons, and protons.

(3) Permissible exposures to external radiations (x and γ rays, β rays, fast and slow neutrons):-

(a) Whole body irradiation - long continued exposure.

(b) Whole body irradiation - single exposure.

(c) Hands - long continued exposure.

(d) Head - long continued exposure.

(4) Permissible exposures to internal radiations (m.p.l.'s in body, in air, and in water):-

Group I - Ra^{226}, Rn^{222}, natural U, U^{233}, Pu^{239}, natural Th^{232}, $Th^{234}(UX_1)$, and Po^{210}.

Group II - Fission products.

Group III - H^3, C^{14}(as CO_2), Na^{24}, P^{32}, S^{35}, A^{41}, Co^{60}, Sr^{89}, Sr^{90}(+ Y^{90}), I^{131}, Xe^{133} and Xe^{135}.

At the Buckland House Conference (August, 1950) further discussions took place on many of the above items and on some new problems. In the main, these dealt with internal radiation hazards. The permissible levels for H^3, C^{14} (as CO_2), Na^{24}, P^{32}, S^{35}, A^{41}, Co^{60}, Sr^{89}, Sr^{90} (+ Y^{90}), I^{131}, Xe^{133}, Xe^{135}, Po^{210}, Ra^{226}, U^{233} (soluble and insoluble forms), and Pu^{239} were reviewed. Other items discussed were:

(1) whether radioactivity in particulate rather than in gaseous form is likely to increase the hazard,

(2) permissible fluxes for fast and slow neutrons (fluxes expressed in neutrons per sq. cm. per sec.); and

(3) genetic factors in radiation hazards.

B. International Commission on Radiological Protection

Many of the findings of the above Tripartite Conferences were incorporated in the Recommendations of I.C.R.P. in 1950.

Since that time, there has been a Radiobiological Conference in Stockholm. A report (PIRC/18 on the Conference has previously been presented to the M.R.C. Protection Committee. It will be recalled that the main findings were:-

(1) That the basic figure of 0.3r. in any one week, recommended in 1950 by I.C.R.P. for the maximum permissible exposure of the critical tissue (blood-forming organs), remain unchanged.

(2) That, below a certain weekly exposure level, routine blood counts need not be made.

(3) That, in circumstances in which exposure of large populations occurs, it is necessary to apply a considerable factor of safety to reduce the permissible level below that of 0.3r. per week in tissue allowed to persons occupationally exposed.

C. Recent work

At the last meeting of the M.R.C. Committee on Protection against Ionising Radiations, reports were presented by the various Sub-Committees, summarising their work in their respective fields during the past year or so.

(1) Report PIRC/15 (Amended) deals with the work on high energy radiations and heavy particles. The Sub-Committee made the following recommendations:-

(a) Permissible exposure to X and γ rays above 3 MeV:-
For X or γ rays of quantum energy greater than 3 MeV, it is not possible to base the permissible whole body exposure on a measurement of surface dose. (A dose of 0.5r. to the surface for energies less than 3 MeV was based primarily on an estimated dose of 0.3r. or 30 ergs/g. to the critical tissues, taken to be several cm. below the surface. For high energy radiation, the dose a few cm. below the surface may be many times greater than that at the surface). Accordingly, the maximum permissible exposure for ionising radiations of quantum energy greater than 3 MeV shall be that which causes an energy absorption not greater than 30 erg/g. in any part of the body in any one week.

(b) Permissible exposure to neutrons:-
(i) The r.b.e. for neutrons in the energy range from thermal to 5 MeV is taken to be 10 as in the current recommendations of I.C.R.P.). The Sub-Committee deferred for further consideration the reasons put forward by some members for raising the r.b.e. to 20.

(ii) Exposure in the energy range thermal to 5 MeV can be expressed either as that which would produce an energy absorption of 3 erg/g. per 40-hour week at a depth of 2 cm. below the surfaces of soft tissue, or as that which, for periods not exceeding 40 hours per week, corresponds to the following fluxes.

Neutron energy	Permissible flux (neutrons/cm^2/sec)
0.025 eV to 10 KeV	2000
0.1 MeV	400
0.5 MeV	150
1 MeV	100
2 to 5 MeV	50

(2) Report PIRC/15A (Amended deals with the work of the Sub-Committee on External Radiation. Efforts have been concentrated mainly on assessing, for the general population, the mean radiation dose at the gonads as a result of diagnostic examination. It was found that the average gonad dose per head of the population in this country is, at present, small compared with the contribution from natural radiation.

(3) Report PIRC/15B (Amended) deals with the work of the Sub-Committee on Internal Radiation.

Maximum permissible levels have been provisionally recommended for 20 isotopes, other than those given by I.C.R.P. Consideration has also been given to the importance of such elements as boron and lithium in the lens of the eye, to dosimetry of radioactive isotopes in tissues, and to the radiation toxicity of Thorotrast.

Simultaneously, the Sub-Committee on Internal Dose of the U.S. National Committee on Radiation Protection has been working to establish maximum permissible levels for a number of isotopes. It is ultimately envisaged that their findings will be published in a National Bureau of Standards Handbook (No. 52). A few pre-publication copies of the report have been received in this country and reveal that about 70 isotopes have been given consideration. (The number includes those dealt with at Chalk River and Buckland House.) It has been noted that there are some important differences in the principles adopted by the M.R.C. Sub-Committee and by the U.S. Sub-Committee. Mrs. J. I. Palmer (of A.E.R.E.) has produced a summary of the two sets of recommendations and has pointed out that many of the differences between them can be accounted for by two facts:-

(a) If the maximum permissible level of Sr^{89} is assessed on the basis of its observed biological effect relative to 0.1 μC Ra, a value of 2.0 μC is obtained. (This is the present I.C.R.P. value.) Of r. however, the Sr^{89} level is assessed as the amount which will produce 0.3 equivalent r. in tissue, the value obtained is 11. The M.R.C. Sub-Committee has chosen the former basis and has extended this to other bone-seeking isotopes. The U.S. Sub-Committee has taken 0.3 equivalent r. in tissue as the basis for estimating m.p.l.'s for bone-seeking isotopes. Thus there arises a difference by a factor of 5. For some of the isotopes, e.g., Y, Zr, Ce, Pr, Pm, Sm and Eu, the M.R.C. Sub-Committee has allowed a further factor of 5 for uneven distribution of the isotopes within the bone. Accordingly in some cases, there is a factor of 25 difference between the British and U.S. figures.

(b) In some cases (e.g. Y^{91} and Ru^{106}), calculations indicate that the damage to lung and to gut by temporarily retained isotopes is greater than that to the ultimate organ of storage. The British figures are based on the damage to the lung and gut, the U.S. figures on the damage to the organ of storage.

D. Programme for Washington Conference

(1) Preliminary meeting of U.K. delegates on 29th January, 1953.

The U.K. delegates, together with Dr. Katherine Williams and Dr. A. S. McLean, held a preliminary discussion of the programme on 29th January. The following is a summary of the conclusions reached.

(a) Radium.

The value of 0.1 μC as the m.p.l. for Ra. should be retained, though this probably contains a safety factor compared with the minimum damaging dose.

(b) Sr^{89}.

The value of 2.0 μC, which is accepted by all parties as the m.p.l. for Sr^{89} in the body, shall be retained.

(c) Ca^{45} and Ba^{140} (+ La^{140}).

It is felt that the distribution of Ca, Ba and Sr. in the skeleton, though not necessarily identical, are so similar that the same considerations should apply to these elements. Accordingly the delegation advocate the adoption of the British figures, which are based on the above level for Sr^{89}.

(d) Y, Ce and other bone-seeking rare earths.

The question here is as to the necessity for an additional factor of 5 for inhomogeneous distribution. The meeting was not unanimous about the policy to adopt. On the one hand, it might well be that the figure for Sr. already contains a factor (either as a safety factor or as a factor to allow for uneven distribution), which does not justify applying a further factor of 5, relative to Sr, for Y and similar isotopes. On the other hand, Hamilton and Vaughan have shown that the distribution in bone of isotopes like Y is different from Sr, and accordingly the M.R.C. Sub-Committee allowed an extra factor of 5 (PIRC/IR/33). It was, however, felt by the delegation that this procedure is quite arbitrary and that the question of applying this extra factor should be left open for discussion in Washington.

(e) Irradiation of the gut.

It was noted that there were differences of 2 or more orders of magnitude between the U.S. and British figures for the m.p.l.'s of Y and other non-absorbed elements in water. These differences could be ascribed to the fact that the U.S. Sub-Committee had assumed very low uptake figures for the rare earths and had not allowed for irradiation of the gut.

It was decided to abide by the British figures, based on 24 hours half life in the gut with a possible small relaxation for self-absorption of β rays in the contents of the gut. Dr. McLean said that the faecal excretion of Pu indicated that a 24-hr. half life was a reasonable assumption. He has offered to prepare a note for the delegation summarising the results which he has obtained.

(f) Uptake from ingestion.

Drs. Loutit and McLean said that recent observations with fission products and Pu made them doubtful of the validity of the very low gut uptake figures hitherto accepted. It was also noted that the U.S. Sub-Committee had assumed only 0.03% uptake of Po from the gut to the spleen, which they considered to be the organ of deposition. This seemed to be a low figure compared with the evidence presented in "Biological Studies with Po, Ra and Pu".

(g) M.p.i.'s for α emitters.

(i) Pu. The m.p.l. for Pu should not be altered until fresh evidence is produced.

(ii) Th, Rn, and Ac. It is desirable that new assessments be made.

(2) There is a meeting of the M.R.C. Sub-Committee on Internal Radiations on 19th February, when doubtless consideration will be given to the above matters. It is hoped that it will be possible to report upon the views of the Sub-Committee at the meeting of the Main Protection Committee which is to be held later the same day. Other problems which should receive consideration at the Tripartite Conference are:-

(a) Basic dose for X and γ rays up to 3 MeV:-

(i) whole body exposure;
(ii) partial exposure.

(b) Basic dose for X and γ rays above 3 MeV (30 erg/g.?)

(c) Permissible exposure to β rays. (Is the value of 1.5 equivalent r. too restrictive?)

(d) R.B.E. values.

(e) Neutrons:-
(i) Permissible exposure (i.e. 3 erg/g.?).
(ii) Permissible fluxes.

(f) Emergency doses.

(g) Life doses.

The U.K. delegation would welcome the advice of the Main Protection Committee on all the above items.

W. Binks
Secretary

APPENDIX 23

UK - TRI-PARTITE CONFERENCE ON PERMISSIBLE DOSES (3-30-53)

(Arden House, Harriman, N.Y., U.S.A.)
March 30th - April 1st, 1953

W. Binks 4-8-53

Present:-

U. S. DELEGATION:-

Dr. J. C. Bugher
Dr. A. W. Brues
Dr. M. Eisenbud
Professor G. Failla
Dr. J. G. Hamilton
Dr. J. W. Healy
Dr. L. Hempelmann
Dr. W. H. Langham
Dr. L. D. Marinelli
Dr. Karl Z. Morgan
Dr. H. H. Plough
Dr. Lauriston S. Taylor
Dr. Shields Warren
Dr. F. W. Western

CANADIAN DELEGATION:-

Dr. A. J. Cipriani
Dr. A. K. Longair
Dr. R. Taylor
Dr. J. D. Babbitt

U. K. DELEGATION:-

Professor J. S. Mitchell
Mr. W. Binks
Dr. J. F. Loutit
Dr. W. G. Marley

Summary of Discussions and Findings

Permissible doses for external radiation

A. General Principles

1. Units and definitions

(a) Permissible dose

The definition put forward on page 40 of the preliminary draft of the U.S. Sub-Committee on Permissible Dose from External Sources (Chairman: Prof. G. Failla) was discussed. This reads:

"A permissible weekly dose is a dose of ionising radiation accumulated in one week, of such a magnitude that, in the light of present knowledge, exposure at this weekly rate for an indefinite period of time is not expected to cause appreciable body injury to the average person at any time during his lifetime".

Major points of discussion were:-

(i) Medical and legal reactions to the definition
(ii) Interpretation of the word "average"
(iii) Reference to "maximum permissible dose" or merely "permissible dose"
(iv) Position as regards emergency doses

It was agreed that the basic principles underlying the definition were acceptable but that the actual wording might have to be settled following legal and other considerations (e.g., as to what is meant by "average" person). It was not necessary to introduce the word maximum into the generic definition, since it would appear in detailed protection rules dealing with m.p.d.s. for different tissues and different types of radiation. Emergency doses were to be considered on a separate basis later in the Conference.

(b) Units of dose

-Ergs/gramme, rontgen, rep. rem.

The Conference noted that the I.C.R.U. in 1950 recommended that the dose of any ionising radiation should be expressed in terms of the quantity of energy absorbed per unit mass (ergs per gramme) of material at the place of interest. It was also noted that, whilst I.C.R.U. did not recognise the use of special names or symbols (other than prefixes, such as kilo-, milli-, etc.) it is common practice to use a unit called the "rep", which, when tissue is the absorbing medium concerned, is the quantity of radiation such that the energy imparted to the tissue by the radiation is approximately 93 ergs/gramme. Since the value of this unit, which is derived from the rontgen, is dependent on a knowledge of (a) the energy E required to produce a pair of ions, and (b) the relative stopping powers S of air and tissue, it was felt that no attempt should be made to fix the value arbitrarily at a figure of 93, since any future alterations in the values of W and S would destroy the relationship between the rep. and the rontgen. It was considered more satisfactory to have a new unit of tissue dose (100 ergs/gramme), which would be of the same order of magnitude as the rep., but which would be independent of the rontgen and would incidentally have a value which would be more convenient for the purposes of calculation.

Although no definite recommendation was made by the Conference, it was generally agreed that there should be a new unit of tissue dose (for which, as yet, no suitable name has been thought of), which would be the dose of any ionising radiation such that the energy imparted by the radiation to the tissue at the place of interest is 100 ergs per gramme. ("Standard" tissue would have to be specified).

This suggestion would not call for any change in the I.C.R.U. (1950) recommendations that the rontgen should continue to be recognised as a unit of X-ray quantity or dose for quantum energies up to 3 MeV, but that the fundamental unit should be one in which the dose is expressed in terms of absorbed energy per unit mass (ergs/gramme) of any irradiated material at the place of interest.

There was not enough time to discuss the rem fully. Some believed that it was sufficient to multiply the numbers of reps by the appropriate r.b.e. value, and that there was no need therefore for a unit such as the rem. Others favoured a unit of this kind for simplicity of expressing results, though the name rem was not wholly satisfactory.

2. The "Standard Man".

(a) Masses of organs

The following data on the masses of organs of the adult human body were discussed:-

TABLE I

Organ	Present I.C.R.P. Value	Mass (g.)
Total body	70,000	70,000
Muscle	30,000	30,000
Skin and subcutaneous tissue	8,500	8,500
Fat	not given	8,000
Skeleton - Bone	7,000	7,000
Red Marrow	1,500	1,500
Yellow Marrow	1,500	1,500
Blood	5,000	5,400
Gastro-intestinal tract	2,000	2,300
Liver	1,700	1,700
Brain	1,500	1,400
Lungs (2)	1,000	950
Lymphoid tissue	700	700
Kidneys (2)	300	300
Heart	300	300
Spleen	150	200
Urinary Bladder	150	150
Pancreas	70	65
Salivary gland	50	50
Testes (2)	40	40
Spinal cord	30	30
Eyes (2)	30	30
Thyroid	20	15
Teeth	20	23
Prostate	20	16
Adrenal	20	14
Thymus	10	10
Other tissues and organs not separately defined	8390	-

Figures in the second column are those which appear in the current Recommendations of I.C.R.P.

In the third column are given the masses used by Dr. K. Z. Morgan, Chairman of the ICRP

Sub-Committee on Permissible Dose for Internal Radiation, in the draft which he had sent to members of his Sub-Committee. These values, it was stated, are not wholly acceptable by the Committee as there is not enough evidence in some cases.

The Conference confined its attention to those organs for which new values are suggested.

(i) Thyroid

Points raised were:-

(A) The average mass of the thyroid varies from locality to locality. The British figure is 20. The normal for the Eastern Coast of the U.S.A. is about 15, but average for whole country might be nearer 20.

(B) Some evidence from autopsy cases not typical, since there was a high degree of goitre.

(C) Deposition of iodine in the thyroid not known to a degree of accuracy suggested by a small change from 20 to 15.

(D) Constancy of the figures for "Standard Man" was one of the most important factors.

It was agreed that no change be made from the figure hitherto used.

(ii) Adrenal

Evidence considered was:-

(A) No investigator had given a value of 20 grammes
(B) On the other hand, it was believed that the data were obtained from autopsies and it appears that adrenals removed in autopsies are smaller than those removed surgically. Hence the data used may not be for normal adrenals.

It was agreed that no change be made.

(iii) Blood

Evidence submitted in support of the change from 5000 to 5400 grammes was that several experimental values were very close to 5400. It was felt, however, that new methods of estimating blood volumes should give more reliable figures and accordingly, it was agreed that the matter be given further consideration prior to the meeting of I.C.R.P. in Copenhagen in July, 1953.

(iv) Gastro-intestinal tract

Two points were raised for discussion, namely, the suggested change in the weight of the tissues involved and the need for a value for the standard content of the gut. (This was required in calculating the m.p.d.s for radioisotopes in the gut.)

It was noted that there was a great degree of variation according to the eating and excretion habits. The thickness of the wall varies, but this would not be regarded as important within the terms of the "average" man.

It was agreed that no change be made in the figure for the mass of the gastro-intestinal tract. The discussion on gut contents was postponed for lack of time.

(v) Fat

It was pointed out that the Chalk River Conference did not give a figure for fat itself. The figure was for fat and other organs. Fat is considered important when calculating the m.p.d. for C^{14}. The U.S. Sub-Committee on Internal Dose use a value of 10^4 grammes.

Dr. Wright H. Langham offered to submit further evidence to Dr. K. Z. Morgan.

(vi) Red Marrow

Dr. Shields Warren reported that he was dissatisfied with the measurements made in his own laboratory. The difficulty is that even in densely haemopoietic tissues, there is a large amount of fat.

It was agreed to retain the present value. Dr. Warren would submit new evidence prior to Copenhagen.

It was recommended that further consideration of the evidence on masses of organs be given prior to Copenhagen by the I.C.R.P. Sub-Committee on Permissible Dose for Internal Radiation. The Chairman, Dr. Morgan, said he would refer the question to the members of the Sub-Committee.

(b) Chemical Composition

(i) Average values for whole body

The values which are given in the draft of the report of the I.C.R.P. Sub-Committee on Permissible Dose for Internal Radiation are those appearing in the current Recommendations of I.C.R.P.

Reference was made to investigations in progress in Tennessee to determine the composition of elements in different organs. It was desirable to know not only the best average values for the whole body but the best for each organ.

Several delegates submitted evidence indicating that, from K^{40} measurements, the potassium content of the body appeared to be about 0.2 percent instead of the value 0.35 percent, which is used at present. The figure is important with reference to the background radiation level when trying to measure γ emitters in the body.

It was agreed to adopt the new value of 0.2 percent as the average concentration of K in the whole body. Data on other elements such as Na would be welcomed. No changes were, however, thought to be necessary for other elements.

(ii) Average values for individual organs

It was reported that investigations into the composition of individual organs were revealing surprising results, for example, a large amount of Al in liver, Cd in kidney.

The Conference felt that at present there is insufficient data on which to base any figures and advocated that further studies should be pursued.

3. Modifications of permissible dose.

(a) On age basis

The U.S. Sub-Committee on External Radiation advocated that the value of the maximum permissible dose of 300 millirems in the blood-forming organs, the gonads and the lenses of the eyes, and 600 millirems in the skin, should be doubled for persons 45 years of age or over. This would enable certain operations, which involved higher exposures, to be given to older persons.

Points raised in discussing this were:-

(i) Since genetic considerations led at one stage to a lowering of the permissible dose, it appeared justifiable to raise the level for older people, since genetic injury was then less important.

(ii) Did evidence on ovarian tumours suggest that 50 was to be preferred to 45?

Professor Failla said that the results obtained in the production of ovarian tumours in mice were not applicable to humans. If the latent period at the level concerned is 45 years, then a large dosage rate afer the age of 45 years would not influence the position, since the effects would not appear within the life span.

(iii) What evidence was there concerning leukemogenesis?
Dr. Brues stated that, for external radiation, there was no evidence of leukemia at 5r/day. The mortality rate was, however, affected.

(iv) Attention should be paid to the possible total dose which would be accumulated in a lifetime, whether, for example, this might reach a value of 1000 r. or more. It was pointed out that 1000 r. should not be regarded as a large dose when spread over a lifetime.

(v) The above led to a question about the influence of fractionation of radiation on carcinogenesis and blood-formation. Fractionation tests with internally deposited strontium indicated that 4 times as much isotope could be given if fractionated, than if delivered in a single dose. 0.5r. per day appeared to have no effect on life span of man.

(vi) Boche's work on dogs had been repeated. Dogs irradiated at 0.5 r./day for six days a week showed decreased sperm. There was an increase in abnormal sperms, which revealed itself on mating. (The exact period of irradiation was not known, but was believed to be about 1 year).

Questions were asked as to what happened at levels of 0.1 r./day. Boche's work had previously suggested changes at this level. However, it was admitted that his controls were not good. Had these changes been substantiated?

(vii) It was reported that at the Radiobiological Conference held in Stockholm in September 1951, the findings concerning the haematological effects of irradiation were, that provided radiation monitoring (both site monitoring and personnel monitoring) is carried out in all circumstances involving occupational exposure to ionising radiations, then,

(A) routine blood counts are optional in the case of workers who receive a surface dose of less than 0.1 r. per week, since for such workers the counts are of doubtful significance;

(B) blood counts are necessary in the case of workers who receive a surface dose in excess of 0.3 r. per week; and

(C) blood counts are advisable in the case of workers who receive a surface dose between 0.1 r. and 0.3 r. per week, but the interval of time between such counts should be left to the discretion of those resonsible for the health of the workers concerned.

(It was explained that, even though in the third category the effects may not be serious, the counts were required as research information.)

(viii) Dr. Langham reported haematological studies on 10 persons who were exposed at Los Alamos to X-rays and Co. γ rays for 4½ years. There were no blood counts on these persons before commencement of the exposure. Controls had therefore been obtained from other workers. Exposure at an average of 0.16 r./week showed changes in lymphocyte cells only. The average count fell by about 90 cells every 6 months. The counts were normal in all other respects and the persons appeared to suffer no ill effects.

Dr. Eisenbud presented evidence on the effects of Ra γ rays up to 1 r./week on the blood of 200 - 300 persons exposed for periods up to 7 years. There was no obvious statistical change. (The work is not yet complete and detailed results will be forwarded to U.K. later).

Other delegates referred to the slow recovery which took place in the lymphocyte level. Generally it took 6 months to 1 year for a return to normal.

(ix) Dr. Morgan raised doubts about the advisability of doubling the dose at the age of 45 and upwards. In his experience, the persons whose dose would be doubled would be those who had had a long exposure previously and therefore would be those for whom he would be most concerned. He wondered about the formation of cataract and the shortening of life span. Low doses of slow neutrons might well result in the first stages of cataract formation. For fast neutrons, doses as low as 10 reps. produced detectable changes in the lens of the eye. Whether these were real changes, he was not qualified to state.

(x) Dr. Warren, referring to the 98 Japanese cataract cases, said that it was difficult to distinguish between ordinary and radiation cataract. 84 percent of the radiation-induced cases had small granules in the lenses. In 164 controls, with no irradiation, 10 percent had small granules in the lenses. Asked whether there were any observations on older age groups in Japan, Dr. Warren stated that the general age level was low.

Dr. Failla said that, in all these cases, there was epilation. Professor Mitchell reported that he had had one case without epilation (Age 26 years at time of exposure; now 35).

(xi) Several delegates were opposed to raising the level at the age of 45, for various reasons:-

(A) Operation of general radiation - monitoring services.
(B) Reaction of the persons concerned, and inadvisability of having two levels.
(C) General practicability of working to 0.3 r./week. Therefore, unless there is pressure to increase the level for older persons, this should not be recommended.

(xii) The view of the U.K. delegates was that the proposal was unworkable in the United Kingdom. It was also perhaps unwise. Some U.S. and Canadian delegates supported this view. Accordingly, the recommendations of the U.S. Sub-Committee on External Radiation could not be endorsed. As a compromise, the following resolution was proposed by Dr. Shields Warren and seconded by Dr. Austin W. Brues:-

After consideration of the proposed report of the U.S. Sub-Committee on External Radiation, difficulties, administrative and otherwise, were envisaged; therefore the Conference adopted the following statement:-

<u>That, in older individuals in whom genetic factors are unimportant, it may be justifiable to raise</u>

the maximum permissible dose level by a factor of 2.

For: 17
Against: 4

(b) Limited regions of the body.

For local exposure, the U.S. Sub-Committee on External Radiation has proposed the following rules:-

"Rule IVA. Local exposure of the hands and forearms to any ionising radiation.

For adults of any age whose hands and forearms are exposed to ionising radiation from external sources, for an indefinite period of years, the maximum permissible total weekly dose shall be 1500 mrems. in the skin provided the respective weekly doses in mrems. in all other tissues of the hands and forearms are not in excess of those which would result from exposure to ordinary X-rays at a weekly dose of 1500 mr. in the skin."

"Rule IV-Ax. Local exposure of the hands and forearms to X-rays (γ rays) of any photon energy).

For adults of any age whose hands and forearms are exposed solely to X-rays from external sources, for an indefinite period of years, the maximum permissible total weekly dose shall be 1500 mr. in the skin".

"Rule IV.B. Local exposure of feet and ankles to any ionising radiation

Substitute 'feet and ankles' for 'hands and forearms' in Rule IVA".

"Rule IV-Bx. Local exposure of feet and ankles to X-rays (γ rays) of any photon energy.

Substitute 'feet and ankles' for 'hands and forearms' in Rule IV-Ax."

"Rule IV.G Local exposure of the head and neck to any ionising radiation.

For adults of any age whose head and neck are exposed to ionising radiation from external source, for an indefinite period of years, the maximum total weekly doses shall be 1500 mrems. in the skin and 300 mrems. in the lenses of the eyes, provided the respective weekly doses in mrems. in all the other tissues of the head and neck are not in excess of those which would result from exposure to ordinary X-rays at a weekly dose of 1500 mr. in the skin".

"Rule IV-Cx. Local exposure of head and neck to X-rays (γ rays) of any photon energy.

For adults of any age whose hands and necks are exposed solely to X-rays from external sources, for an indefinite period of years, the maximum permissible total weekly doses shall be 1500 mr. in the skin and 450 mr. in the lenses of the eyes".

Professor Mitchell asked whether the dose for the hands could be raised. It was felt that the present level was unduly restrictive. Dr. Hamilton thought the present figure was reasonable; a higher value would be risky. Dr. Cipriani mentioned that often doses of 3 r./week are recieved. Dr. Brues queried whether this referred to uniform irradiation of the hands. (It appeared that in general it referred to the dosage rate at the site receiving the highest dose, often, the finger tips).

Professor Failla was of the opinion that levels higher than 1.5 r./week might lead to skin cancer. Dr. Marley asked what evidence there was for this. Dr. Loutit, speaking on the British views, said that persons had been known in the past to receive 5 r./week and there appeared to be no damage. Since skin damage is the important effect here and this is visible, one could watch the progress of the lesion. There was therefore more control of the position than was the case with other effects. Professor Failla believed that, when damage was noted, it would be too late.

It was agreed to accept the basic principles underlying the rules cited above for hands and forearms, and feet and ankles. (It should be noted that no reference is made to the effective dose at the basal layer of the skin).

As regards irradiation of the head and neck, Dr. Lauriston Taylor expressed concern about the irradiation of the eyes. It would be difficult to administer rules involving a different figure for the eyes than for the skin of the hand and neck. Drs. Failla and Warren suggested that the rules be accompanied by general comments of the type given in the report of the U.S. Sub-Committee on External Radiation. Dr. Morgan maintained that it was necessary to specify the critical tissues implied in specifying a dose of 1500 mr. to the "skin". He would interpret this as a layer between about 1 and 3 mm. below the surface.

No decision was reached regarding the rules for head and neck exposure.

(c) Limited penetration.

For radiation of low penetrating power, the U.S. Sub-Committee on External Radiation recommends that, "for adults of any age whose entire body or major portion thereof, is exposed to ionising radiation of very low penetrating power from external source, for an indefinite period of years, the maximum permissible total weekly dose in the skin shall be 1500 mrems., provided that the total weekly dose in the lenses of the eyes does not exceed 300 mrems."

The radiation here considered has a H.V.L. of less than 1 mm. water. Accordingly the dose at a depth of 3 mm. tissue is not greater than 1/8th of the dose in rems. in the basal layer of the epidermis.

Points raised in discussion this were:-

(i) Is the proposed level safe for the cornea?
(ii) In the experimental animal, it is difficult to produce a lesion.
(iii) Doses of 3500 r. of 160 kV X-rays had been given to the cerebral cortex. No effect noted after an interval which, in some cases, was probably about 3 years.

It was agreed that the U.S. proposal be accepted, stressing that the eyes should be shielded to 300 mrem., and specifying that this proposal excluded fast neutrons.

4. Relative biological effect for various radiations and tissues.

The present I.C.R.P. recommendations for r.b.e.s. (based on the Chalk River and Buckland House Conferences) are given in table 2.

Table 2.

Radiation	r.b.e.
γ rays from Ra (filtered by 0.5 mm Pt)	1.0
X rays of energy 0.1 to 3.0 MeV	1.0
β rays	1.0
Protons	10
Fast neutrons of energy not greater than 20 MeV	10
γ rays	20

(a) Dr. Failla said that his Sub-Committee considered it better to relate r.b.e. to specific ionisation of the radiation in question, since for example, no single value of r.b.e could be assigned to protons of different energies. Accordingly, the values given in Table 3 had been recommended.

Table 3.

Type of radiation	r.b.e.
X rays electrons and positrons of any specific ionisation	1.0
Heavy particles:- Average specific ionisation (ion pairs per micron of water):-	
100 or less	1.0
100 to 200	1 to 2
200 to 650	2 to 5
650 to 1500	5 to 10
1500 to 5000	10 to 20

(b) Professor Mitchell noted that the U.S. Sub-Committee on External Radiation had taken an r.b.e. of 1.0 for ordinary X-rays,for which the average specific ionisation was taken to be 100 ion pairs per micron of water. He considered that, as the evidence of the effects of radiation had been derived mainly from exposures with 200 to 250 kV X-rays, the reference value of 1.0 should apply to such radiation; furthermore, one should specify the type of radiation and not the specific ionisation. This, of course, would lead to r.b.e.s of less than 1.0 for rays of lower specific ionisation, e.g., high-energy gamma rays. Beyond this energy level, there would appear to be little change of r.b.e. value. 30 MeV bremsstrahlung was not very different from gamma rays.

(c) Dr. Marinelli drew attentionto the difficulty of expressing specific ionisations in water.

(d) Dr. Langham reported on the results of investigations at Los Alamos, using 4 MeV γ rays and neutrons from the homogeneous reactor, and also Co gamma rays, protons from nitrogen, β rays from H^3 and Na, and α particles. He gave the values listed in Table 4. It was found that, although the specific ionisation differed in these experiments by large orders of magnitude, there was no corresponding change in r.b.e. He was unable to correlate r.b.e. with specific ionisation. For the above tests, three effects were studied, namely lethality in mice, decrease of size of spleen and thyroid and uptake of Fe^{59} by red blood cells. As regards the production of cataracts in mice by thermal neutrons, the r.b.e. appeared to be about 6. They concluded that any radiation which produced anoxia (?) does not protect against neutrons.

Table 4.

Type of radiation	r.b.e.
4 MeV γ rays	0.8
Co γrays (same value as for 250 kV X rays)	1.0
Protons from N	2.0
β rays from Na	1.4
β rays from H^3	1.3 to 1.6 depending on method
α particles	1.0

(e) Dr. Hamilton believed the r.b.e. for haematological effects arising from acute exposure to fast neutrons was about 5.

(f) Dr. Brues reported results with fission neutrons compared with cobalt gamma rays.

r.b.e. for changes in lens of eye $\sim$ 8

r.b.e. for lethal effects in mice 4

(g) Professor Failla said that his Sub-Committee had been concerned as to whether the r.b.e. is higher for chronic exposures in the range of permissible levels. He thought the value was higher, but couldn't say how much. He believed that r.b.e. values were, in general, exaggerated. The value of 20 (g contd) for α's was too high.

(h) Dr. Loutit considered that the r.b.e. for fast neutrons had a value between 5 and 10.

(i) Dr. Eisenbud indicated that if, by one approach, the m.p.d. for radium was taken to be 0.1 μC and if, by another method of approach, the m.p.d. could be regarded as 300 mrem., then an r.b.e. for αparticles could be estimated. Thus, if the 0.1 μC radium is assumed to be uniformly deposited in bone, the estimated dose was 70 mrep/week. Hence the r.b.e. for α's = $\frac{300}{70}$ = abt. 4.

Professor Mitchell said that, by a similar kind of argument he had reached the conclusion that the r.b.e. for αparticles was less than 10.

(j) Professor Failla argued that the important factor is the specific ionisation at the point of interest. He would have preferred to have taken an r.b.e. of 1.0 for radiation corresponding to the levl of minimum ionisation. However, there was no experimental data here. Accordingly, the r.b.e. had been fixed as 1.0 for 100-200 kV X-rays.

(k) Professor Mitchell preferred to relate r.b.e. to the type of radiation rather than to specific ionisation. On the other hand, Dr. Marinelli preferred the latter.

Dr. Morgan said he was not now convinced that the r.b.e. could be linked with specific ionisation. He was in favour of an r.b.e. of 1.0 for X-rays about which we had most evidence, namely 100 to 200 kV range.

Dr. Western supported this view. He felt that the attempt to relate r.b.e. to specific ionisation over-simplified the case. It depended on the system in which the measurements were conducted. He supported Dr. Morgan.

It was agreed at this stage that the type of radiation should be inserted in the table of values given by the U.S. Sub-Committee on External Radiation. In other words, column 1 should give the specific ionisation, column 2 the r.b.e. and a new column 3 the type of radiation and the specific effect of the radiation.

It was agreed also that the basic figure of 1.0 should refer to X-rays, γ rays and electrons. (In the case of electrons, all energies were implied, since the r.b.e. of 0.7 for 50 MeV electrons could be considered to be near enough to 1.0)

(1) Professor Failla expressed doubts about the dosage measurements in the Los Alamos work reported by Dr. Langham in (d) above. Dr. Langham said that the fluxes were known quite accurately, but there was difficulty in translating this to reps.

(m) Professor Mitchell proposed an r.b.e. of 10 for fast neutrons of energy not greater than 20 MeV, where chronic exposure for cataract production was considered as the basis and the reference radiation was 220 kV X-rays.

(n) Dr. Morgan suggested an r.b.e. of about 4 for α particles, and said he would like to see the r.b.e. for protons equated to that for neutrons.

Professor Mitchell suggested a value of 10 for fast protons up to 10 MeV., again taking cataract formation as the relevant effect. Dr. Marinelli thought this was reasonable.

It was agreed to retain the present I.C.R.P. value of 10 as the r.b.e. for protons up to 10 MeV.

(o) As regards α particles, Professor Mitchell proposed that tumour production for internal emitters should be used as the criterion.

Dr. Morgan thought the r.b.e. for α particles was between 4 and 5.

Dr. Brues, referring to the work of Lorenz with radon and its disintegration, said that the r.b.e. was between 2 and 2.5. He wondered whether inhomogeneity of distribution would cause differences of the order of 3.

Dr. Hamilton said that in experiments with rats and monkeys, the r.b.e. was not greater than 4.

Dr. Marley asked whether, for internal emitters, one should confine attention to carcinogenic effects only.

Dr. Brues reported that, from comparisons of the effects of Sr^{89} and Pu in producing esteogenic sarcoma, it appeared that the ratio of the quantities required to produce the same effect was 100 i 1.

From this, he deduced that the r.b.e. for α particles would be of the order of 1.

Dr. Warren referred to observationsin which 3000 to 3500 r. of X-rays was delivered in the treatment of basal cell carcinoma of the forehead. He pointed out that early radiologists had shown no bone sarcoma. Accordingly, he thought the carcinogenic effects of γ rays were small.

After further discussion, it was tentatively agreed that the r.b.e. for α particles be 5, and that the r.b.e. for fast neutrons be 10.

(The meeting was adjourned at this stage due to the lateness of the hour. It was continued next day, when delegates had had time to review the evidence and to put forward further proposals about r.b.e. values)

(p) Dr. Hamilton proposed that, if the r.b.e. for fast neutrons was taken as 10, the r.b.e. for recoil protons of the same energy would be 10 and it would then seem desirable to lower the r.b.e. for α's to 10.

Professor Mitchell advocated consideration of two problems:-

(A) r.b.e. for α's for carcinogenis, and
(B) r.b.e. for heavy recoil nuclei,

as a basis of calculation in the cataract problem.

He suggested 5 for (A), but since he was unhappy about the applicability of the same figure for heavy recoil nuclei, he suggested 20 for (B).

Professor Failla said that he agreed in principle with these views. There should be different r.b.e.s for different energies. He thought that, for cataract formation, the r.b.e. should be very much greater than 10, otherwise physicists in this field would be damaged.

Professor Mitchell then suggested that energy limits be mentioned. Thus, for α particles of energy less 10 MeV, for effects involving carcinogenesis, the r.b.e. = 5, whilst for heavy recoil nuclei for energies up to 5 MeV, referring to cataract, the r.b.e. = 20.

Professor Failla opposed reference to the energy limit for heavy recoil nuclei. Dr. Hamilton said that, as there is not enough evidence for carcinogenic effect,he hesitated to say whether r.b.e. = 5 is safe. Whilst he had no strong evidence to back his opinion, he would prefer an r.b.e. of 10 for α particles. Some delegates supported such a value, but Dr. Eisenbud asked that consideration be given to the importance of a factor of 2, both for economic and administrative reasons. He referred once more to the value of 4 which he had obtained by equating 0.1 μC Ra to 300 mr. of X-rays. Professor Failla said that this assumed that the damage in the two cases could be equated. The effects were, however, not the same. It was not possible to move from a basis of 300 mr. for blood effects to something dealing with cancer formation. The value corresponding to 0.1 μC Ra might indeed be higher than 300 mr.

Dr. Marley stated that the U.K. delegation did not accept 300 mr. as the correct approach. The basic figure should be 0.1 μC Ra. The r.b.e. derived by Dr. Eisenbud was, therefore, irrelevant.

Professor Failla suggested that some account should be taken of the different radiosensitivities of different organs. The figure of 300 mr. applied to the whole body. In general, however, we are dealing with smaller volumes.

Dr. Morgan proposed the values in Table 5. For thermal neutrons, a value could be calculated from these two basic values.

Table 5.

Radiation	r.b.e.	Effect considered
Protons, fast neutrons, α particles, heavy ions	20	Cataract formation
ditto	10	Carcinogenic effect

Professor Failla thought such a table more restrictive than the one put forward by his Sub-Committee. Since α particles, protons, etc. of different energies would have different r.b.e. values, he still preferred to use specific ionisation.

Dr. Hamilton asked whether Dr. Morgan's values applied to a limited energy region. Dr. Morgan replied that they did; for 100 MeV heavy ions, a different r.b.e. would apply.

Dr. Western expressed the view that this generalisation was again an over-simplification. Unless r.b.e.'s were intended for use in calculations, there was no point in discussing their exact values. If there is so much uncertainty as to whether an r.b.e. of 5 is correct for carcinogenesis, then we should go back to the start and find out whether 0.1 μC Ra. is correct.

Dr. Marley suggested that the r.b.e. for α particles should be derived, on an experimental basis, by comparison with 0.1 μC Ra. Otherwise an r.b.e. of 10 should be taken.

It was agreed that the Ra. figure be used as a standard of reference where applicable; that for heavy recoil particles in reference to cataract formation, the r.b.e. = 20, pending further information.

Table 6.

Summary of findings on r.b.e.'s

Radiation	r.b.e.	Biological effect
X rays, γ rays and electrons + β	1.0	Whole body irradiation (blood-forming organs)
Protons up to 10 MeV	10	Cataract formation
α Particles	Compare with 0.1 μC Ra. therwise=10	Carcinogenesis
Heavy recoil nuclei	20	Cataract formation
Fast neutrons	10	Cataract production

It should be stressed that the above values represent the best compromise which the Conference could reach and that delegates had different views about them.

5. Modifications of Permissible Dose due to Genetic Considerations and to Population Considerations.

(a) Dr. Plough reported that during the last three years, more data had been accumulated from which to derive the induced radiation mutation rate. In his work on mutation in mice, Dr. Russell found 2×10^{-6} as the frequency per gene. The frequency of radiation-induced mutation in mice was 2.5×10^{-7} per r. per gene. The spontaneous rate in man was 2×10^{-5}. It was estimated that 30 r. to 80 r. was required to double the spontaneous mutation rate in man. In general, geneticists were of the opinion that about 80 - 85 r. was a fair limit to set for the normal exposure which could be permitted.

Professor Mitchell asked whether it was desirable to consider such effects as mental effects in man. These did not enter into the mice experiments. He also asked whether the suggested figure is a maximum. Dr. Plough said that it was.

(b) Dr. Morgan expressed concern that low doses of the order of 30 r. reduced the litter size. For this reason, he was much in favour of keeping the total dose down.

Dr. Plough said that this effect was due to translocations of chromosomes.

Dr. Plough reported that Wallace had not observed a decrease in population at doses up to 300 r. Indeed there might be some possible improvement. At 2000 r. there was an effect. This may not be a population hazard but an individual hazard.

Dr. Warren said that if reduction in litter size is important, it had a bearing on the human problem. Professor Mitchell said that whilst a foetus which did not reach birth did not matter, the deleterious effects in a survivor must be considered.

(c) Dr. Loutit referred to discussions he had had with Dr. Russell and with the Edinburgh group of geneticists. There appeared to be no such thing as an absolute recessive. Attention should be paid to the question as to how much the recessives in the progeny of an individual are increased. This was an important matter for the 10^4 to 10^5 persons involved.

(d) Dr. Failla mentioned that the relevant section of the report of his Sub-Committee on External Radiation had been amended. Dr. Muller had thought 20 - 30 r. per capita a reasonable figure. On the other hand, Dr. Stern thought this too high. Joint discussions between these two members of his Sub-Committee led them to put forward a figure of 5 r. per capita. This then presented one with the problem of explaining to some workers why they could have doses of up to, say, 500 r. which is 100 times the proposed 5 r. per capita. It was now suggested that the section be omitted from the report. He had asked Stern and others what would happen to the individual who received several hundred rontgens, pointing out that what happens in a hundred generations from now is not of interest.

(e) Dr. Marinelli drew attention to the fact that in some places the dose of 5 r. per capita is received from cosmic rays alone.

(f) Dr. Brues asked whether mutagenesis is accumulative and in what cell does mutation occur.

Dr. Plough replied that they did not as yet have data on this.

(g) Professor Mitchell suggested that all the evidence we had on genetic effects pointed to the fact that the basic level must not be increased.

(h) Dr. Marley raised the question of the effects of intermarriage amongst the staff of Atomic Energy stations.

Dr. Plough said that the effect would be the same as for a consanguineous marriage.

(i) Mr. Binks reported on the resolutions passed at the Radiobiological Conference held in Stockholm in 1952:-

(i) that an assessment of the exposure to radiations of all kinds received by the population in Great Britain indicates that the average dose per head of the population at the present time is due to an overwhelming extent to natural radiations;

(ii) that, despite the small amount of available data concerning the genetic effects of radiation, it is reasonably certain that exposure to radiation other than natural radiations does not constitute a significant genetic hazard at the present time and that accordingly a figure for the dose per head of population per generation need not be stated; and

(iii) that such genetic evidence as is at present available indicates that, in circumstances in which exposure to large populations occurs, it is necessary to apply a considerable factor of safety to reduce the permissible level below that of 0.3 r. per week in tissue allowed to persons occupationally exposed".

(j) Dr. Loutit said that the decision to mention genetic effects to workers seemed to turn on national psychology. In Great Britain, it was felt that workers would not care about genetic effects, provided they themselves were not sterilised. It would appear that workers in the United States were scared about long-term consequences as well.

Dr. Bugher drew attention to two different consequences of irradiation (i) genetic effects, and (ii) sterility. He believed that workers in the U.S.A. were as indifferent as those in Great Britain about the consequences several generations from now. They were, however, deeply concerned about sterility.

Dr. Eisenbud said that the question of disturbing workers as a result of their realising the possible effects of their work had arisen in other industries in the past, for example, in fluoroscopic work and in welding. In due course, the scare died down.

Dr. Marinelli advocated that people should be instructed about other mutagens besides ionising radiations.

(k) Dr. Failla felt that the Stockholm findings evaded the issue. He proposed that his U.S. Sub-Committee on External Radiation should issue their report essentially in its present form, in which the genetic situation is ignored. There ought to be a separate report dealing with the genetic aspects. This might take 6 months to prepare.

This was agreed. Canadian and U.K. geneticists would be invited to help. It was felt, however, that the separate genetics report could not be ready in time for the Copenhagen meetings.

6. Length of time for averaging dose.

(a) The U.S. Sub-Committee on External Radiation have considered how far the weekly dose may be allowed to fluctuate from the average value represented by the basic permissible weekly dose without increasing the risk. This is a matter of considerable importance in deciding upon emergency doses. The Sub-Committee have recommended that "in exceptional circumstances in which it is necessary for a person to receive in one week more than the basic permissible weekly dose, the unit of time may be extended to 13 weeks, provided that the dose accumulated during a period of any 7 consecutive days does not exceed the appropriate basic permissible dose by more than a factor of 3 and provided further that the total dose accumulated during a period of any 13 consecutive weeks does not exceed 10 times the basic permissible weekly dose".

(b) Dr. Bugher said that occasional peaks of exposure were necessary. If the level of 0.3 rep./week was never to be exceeded, many operations would be rendered difficult. He wondered whether it was possible to allow a dose of 3.9 r. for 13 weeks, irrespective of whether the dose was received in one episode or several.

(c) Professor Mitchell preferred a value of 4 r. in 6 months. He believed the latter period to be desirable, since recovery probably took this length of time.

(d) Dr. Eisenbud said that his organisation adopted the rule advocated by Professor Failla's Sub-Committee. They found it useful.

(e) Dr. Warren said that, on the basis of the evidence of protracted dose, he could not see why the high dose could not be averaged over a period of 1 year.

(f) Professor Failla proposed that Dr. Bugher should write to the U.S. National Committee; asking approval to adopt the 3.9 r. per 13 weeks rule for a period of, say, 3 years.

(g) Dr. Warren felt that the present Conference should not deal with this matter. This was a problem for the U.S. National Committee. The reaction to this could then be noted.

This was agreed.

B. Special Considerations and Recommendations.

1. Gamma radiation and X-rays.

(a) Mr. Binks said that the Medical Research Council's Committee on Protection against Ionising Radiations had considered permissible exposure levels for x and γ rays about 3 MeV. For low-energy X-rays, the dose of 0.5 r. to the surface was equivalent to 0.3 r. or 30 ergs/g. to the critical tissues, taken to be several cm. below the surface. For high-energy X-rays, the dose at the surface is many times less than that a few cm. below the surface. Since, for high-energy X-rays, the r.b.e. appeared to be about 0.75, the maximum permissible exposure could be taken as that which produced the same energy absorption per gramme of tissue as that which is permissible for low-energy X-rays. Accordingly, it was proposed that the maximum permissible exposure for ionising radiations of quantum energy greater than 3 MeV shall be that which causes an energy absorption not greater than 30 ergs/g. in any part of the body in any one week.

(b) Professor Failla said that, in effect, all that this recommendation implied was that the r.b.e. for high-energy X-rays was 1. The proposal did not differ from that put forward by the U.S. Sub-Committee on External Radiation.

(c) Mr. Binks pointed out that there was a difference between the two proposals, in so far as the U. S. Sub-Committee advocated a permissible dose of 300 mrems in the blood-forming organs, gonads and lenses of the eyes, and 600 mrems in the skin. For high-energy X-rays this relationship between the surface dose and the dose in critical tissues did not exist. Furthermore, the value put forward by U.K. had been expressed in terms of the unit recommended by I.C.R.U.

It was agreed to accept an r.b.e. of 1.0 for all X-rays (γ rays), and a permissible exposure of 30 ergs/g./week, in critical tissues, except for low-voltage X-rays.

2. Neutrons.

(a) Mr. Binks reported upon the calculations, made by Dr. Tait, on permissible doses and fluxes for neutrons of energy greater than 0.01 MeV is due mainly to transference of energy to proton recoils. The r.b.e. for the latter was taken as 10. For lower energy neutrons, the contribution of energy absorption is due to capture of thermalized neutrons. Taking a 40-hour week as the basis, Dr. Tait had estimated the neutron fluxes corresponding to a surface dose of 0.1 r. per S hours (i.e. 0.5 r. per week) and to a dose of 0.06 r. per 8 hours (0.3 r. per week) at a depth of 2 cm. The results are given in columns 2 and 3 of Table 7. The means of the two sets of values are given in the fourth column.

Table 7.

Neutron energy	Flux giving surface dose of 0.1 r. per 8 hours	Flux giving dose of 0.06 r./8 hrs. at 2 cm.	Recommended permissible fluxes	Snyder's values of fluxes	Suggested rounded values
	$n/cm^2/sec$	$n/cm^2/sec$	$n/cm^2/sec$	$n/cm^2/sec$	$n/cm^2/sec$
10 MeV	-	-	-	26	)
5	60	44	)	26	)
4	60	44	) 50	30	) 30
3	76	48	)	35	)
2	90	64	)	42	40
1	126	94	100	58	60
0.5	160	148	150	82	80
0.1	410	530	400	220	200
10 keV	2300	1900	)	1000	1000
10 eV	7580	2380	)2000	1000	1000
0.025 eV	3300	1990	)	1800	2000

(b) Dr. Morgan quoted results obtained by Snyder. These are given in the 5th column of the table.

(c) Professor Mitchell pointed out that Tait had assumed a constant value of the cross-section for neutron-proton collisions, whereas Snyder had taken the appropriate cross-section.

(d) The U.K. Delegation suggested that the U.S. values appeared to be the more satisfactory.

After the rounding off of the figures, indicated in the last column of the table, the U. S. figures were accepted.

(e) Dr. Western asked whether it was assumed that the body of the person was present during the measurement of the flux. Professor Failla replied that the person was not present.

3. Beta radiation and electron beams.	) Not discussed because of lack of time.
4. Heavy Particles.	)
5. High Energy mesons etc.	)

PERMISSIBLE DOSAGES FROM INTERNAL RADIATION SOURCES

A. General Principles.

1. Units and Definitions.

Dr. Cipriani said that originally it had been agreed to use μc/cc. as the unit for expressing m.p.l.s of isotopes in liquids. Some now advocated μμC/litre on the grounds that the numbers involved were more convenient to deal with.

It was agreed that μc/cc. be retained.

2. Special problems presented by internally originated radiation.

Dr. Cipriani said that he interpreted this as meaning the assessment of the experimental hazards of internal radiation. He considered these problems to be the responsibility of the section of any establishment which dealt with hazard control. He suggested that the Tripartite Conferences might, in future, be converted into an organisation which could exchange information regularly on problems such as the above.

3. Particulates in Respiratory Tract.

(a) Dr. Marinelli said that, as a result of studies of 5 humans who had been exposed accidentally to radium sulphate, it had been noted that the half life in the lungs was between 30 and 180 days. This had been determined by a scanning technique. It would seem that the lung gets rid of particles from 3 days onwards after inhalation. Excretion from the lungs followed an exponential rate, ε^{-A}

Dr. Hamilton asked what fraction of the particles were absorbed from the lung into the skeleton; also what fraction goes from the G-I tract to the skeleton compared with the fraction excreted from the lung.

Dr. Marinelli gave the figures listed in Table 8.

Table 8.

Interval after inhalation	Total body burden	Lung burden
3 days	0.338	0.338
13 "	0.252	
35 "	0.282	
62 "	0.200	
102 "	0.1	
234 "	0.04	0.01

Amount left in body after 234 days = $\frac{4}{338}$ = ∿12%

Amount left in lung after 234 days = $\frac{1}{338}$ = ∿ 3%

(b) Dr. Cipriani said that every element (including Si) had some degree of solubility in the body. This was agreed.

(c) Dr. Eisenbud reported observations on the lungs of 4 uranium workers, who had been exposed to several hundred times the tolerance amount of uranium oxide. The amount of dust found in the lungs was 1% (or less) of that which had been predicted from the dog experiments at Rochester. The half life referred to by Dr. Marinelli applies only for periods of 3 days or longer. In the workers concerned, there was no abnormality in the lungs. The death of the 4 workers was not due to radiation.

(d) Dr. Bugher asked about the relationship between elimination and particle size.

Dr. Hamilton said that the figures given by Dr. Marinelli indicated that from 3 days onwards, the particles would be 5 μ or less in size. This agreed with animal evidence.

Dr. Marinelli said that the decrease in body burden was wholly accounted for as excreted.

(e) Professor Mitchell enquired whether, as a result of this evidence, the Buckland House (and I.C.R.P.) figure of 25% for permanent retention should be changed.

Dr. Morgan said that some workers assumed a figure of 12%. One investigator had found a much smaller value of 0.3%. The half life determined from the dog experiments at Rochester was 120 days.

(f) Dr. Cipriani said that present evidence indicates that the retention figures hitherto used are too high. Should the figure of 25% be reduced to 10%?

Dr. Brues asked whether this was to be based on an infinite half life. He was informed that the appropriate figure was 120 days (?)

(g) Dr. Morgan presented curves showing

(i) the varietion with time of the percentage of inhaled isotope in an organ, and
(ii) the variation with time of the dose in an organ (in reps/week).

He showed how, in the former case, his Sub-Committee on Internal Radiation had derived the fraction retained, T_a, (extrapolated to zero time) and the biological half life, T_b, whilst in the second case, retention curves plotted for several organs at the same time indicated which organ was the critical one. He added that his Sub-Committee assume that 50% is deposited in the upper respiratory tract, 25% is exhaled and 25% is retained in the lungs. If the isotope is soluble, the 25% is taken up into the body; if insoluble, 12½% is eliminated in 24 hours, and the rest remains.

In reply to a question from Dr. Marley, Dr. Morgan said that the above figures can be applied reasonably well to all isotopes.

It was agreed at this stage that the retention figure for the lungs be reduced to 10%.

(h) Dr. Eisenbud pointed out that degree of retention depends upon whether a person is a nose breather or mouth breather. He presented results from one of his publications in A.M.A. Archives of Industrial Hygiene and Occupational Medicine (Vol. 6, p. 214, Sept. 1952). For nasal breathing, the percentage deposited in the lungs (total deposition) increases with particle size from about 20% at 0.2 μ up to about 95% at 5 μ. On the other hand, the amount deposited in the alveoli rises from about 25% at 0.2 μ to about 50 - 55% at 1 μ and then falls gradually to about 25% at 5 μ. (These μ's apply to unit density material. They can be adopted to other densities).

For mouth breathers, it has been observed that both the total and alveolar depositions fall at the start with increasing particle size, reaching a minimum at about 0.5 μ. After this, deposition increases with particle size. The alveolar deposition is about 30% for particles of size 1 to 3 μ, which is the normal size encountered in industry. Dr. Eisenbud stressed that these figures referred to deposited fractions. Clearance mechanisms would then operate and would leave the retained fractions.

Dr. Eisenbud then proceeded to give the results obtained by four different investigators on nasal and mouth breathers. These are listed in Table 9.

Table 9.

		Investigators			
		1	2	3	4
Alveolar deposition	(Nasal	40%	40%	35%	-
	(Mouth	-	-	40%	-
Upper passages	(Nasal	-	35%	50%	-
	(Mouth	-	-	-	-
Exhaled	(Nasal	-	---	-	30%
	(Mouth	-	-	-	60%

Dr. Eisenbud felt that there should be no change in the present I.C.R.P. figures, namely, that 50% is deposited in the upper passages, 25% is exhaled and 25% retained.

Drs. Morgan and Eisenbud then put forward the following scheme:-

Table 10.

	Soluble Compounds	Insoluble Compounds
Exhaled	25%	25%
Deposited in upper respiratory passages	50%	50%
Deposited in lungs	25% (This is taken up into the body)	25% (Of this, 15% is eliminated in 24 hours, 10% remain-in the lungs indefinitely).

This proposal was accepted.

4. POPULATION CONSIDERATIONS

In general, these considerations are necessary when dealing with the disposal of radioactive waste.

Dr. Marley said that, in the United Kingdom, a large factor of safety (100) was allowed for populations of the order of millions.

Dr. Morgan mentioned that, in the U.S.A., a factor of safety was used which may be as large as 10.

Some delegates expressed doubt about the differentiation between plant personnel and the general public who were living in the neighbourhood of atomic energy stations. It was generally felt that it is common practice, when dealing with toxicological substances, to subject large populations to a lower concentration than small populations (e.g. plant workers). Accordingly, the following resolution was approved:-

Following accepted practice in the industrial and public health field, it is recommended, in the case of prolonged exposure of a large population, to reduce by a factor of 10, the permissible level for radioactive isotopes accepted for occupational exposures.

It is understood that such levels are additional to the natural background.

5. PERMISSIBLE LIMITS FOR LIFE FORMS OTHER THAN MAN.

(a) Dr. Marley said that two hazard problems were of concern to atomic energy stations in Great Britain:-

(i) ingestion of milk from cows grazing in an area where Sr. is released in the atmosphere, and,
(ii) consumption of meat from animals which had grazed in an area where I^{131} is released into the atmosphere.

Calculations which he had made indicated that the air tolerances would have to be reduced by a large factor. He asked whether any attempts had been made in U.S.A. to deal with problems of this nature.

(b) Dr. Healy spoke about computations which Dr. Parker had made for I^{131} in the case of sheep. Continuous administration at a level of 5 μC/day had not resulted in any damage to the sheep after a period of several years. Parker believed 0.5 μC/day was safe for an 8 kg. per day food intake. This would lead to a higher figure than the 10^{-5} μC/cc. limit* which had been used so far. As regards garden produce, they would limit the figure to 6 x 10^{-5} μC/S. (Dr. Marly mentioned a report by Parker on this subject. It is believed A.E.R.E. have seen this). Hanford practice led to a figure of 10^{-13} μC. I^{131}/cc. air. (N.B. I.C.R.P. value for radiological workers is 3 x 10^{-9} μC/cc). ┼

(c) Dr. Marley gave details of A.E.R.E. calculations for sheep. They were concerned about damage to lambs from the parents. A value of 10^{-4} μC/ g. of vegetation seemed to be reasonable. An experiment had been conducted in which I^{131} was released downwind across vegetation. A.E.R.E. had deduced a permissible level of 2 - 7 x 10^{-13} μC/cc. air.

(d) Dr. Marinelli asked what allowance had been made for the effect of rain washing the activity from vegetation into the ground. Dr. Marley said it was exceedingly difficult to remove isotopes from vegetation by washing.

(e) Dr. Warren pointed out that the figures given by Dr. Healy referred to Hanford practice. This must not be interpreted as general practice in U.S.A. The levels selected depended very much on the place. Control in other areas, for example, Brookhaven, is less restrictive than Hanford.

Later note:
* ICRP limit 3 x 10^{-5}
┼ ICRP limit 6 x 10^{-9}

B. SPECIFIC CONSIDERATIONS AND RECOMMENDATIONS OF PERMISSIBLE DOSAGES.

1. Radium

(a) Professor Mitchell presented the U.K. case, advocating that 0.1 μC., as the m.p.l. for Ra., should be retained. He also drew attention to differences between U.S. and U.K. values for m.p.l.'s. for other bone-seeking isotopes. It appeared that, whilst in the case of Sr^{89}, both countries adopted a value of 2.0 μC. (based on the observed biological effect of Sr^{89} relative to 0.1μC.Ra), the M.R.C. Committee then proceeds to equate other bone-seekers to Sr^{89}, whereas the U.S. Sub-Committee on Internal Radiation assesses the amounts as those which will produce 0.3 rep/week in tissue. This leads to a difference between the two sets of values by a factor of 5. A further difference by a factor of 5 for isotopes such as Y, Zr, Ce, Pr, Pm, Sm, and Eu, arises from the fact that the M.R.C. Committee makes some allowance for the non-uniform distribution of these isotopes within the bone. Thus some U.K. values differ from U.S. values by a factor of 25. In some cases, too, (e.g., Y^{91} and Ru^{106}) calculations indicate that the damage to lung and to gut by temporarily retained isotopes is greater than that to the ultimate organ of storage. In such instances, the U.K. figures are based on damage to lung and to gut. If these differences between U.K. and U.S. values are to be removed, agreement upon the basic principles of calculating m.p.l.s. would have to be reached.

(b) Dr. Morgan reviewed the principles adopted by his Sub-Committee. They had considered the deposition in the G.I. tract and lung but had eventually decided upon the final organ of deposition.

(c) Dr. Marinelli said that, whilst British ideas on this problem were good, it must be realised that in comparing most of the isotopes mentioned against 0.1 μC Ra, one was stepping from the effects of α particles to those of β particles. Furthermore, experimental data was confiend in the main to one animal and this was now being applied to man.

(d) Professor Mitchell asked whether Dr. Brues had any further evidence on the Ra/Sr. relationship.

Dr. Brues said that improved evidence was being accumulated. 0.1 μC. Ra appeared, from recent evidence, to have an adequate factor of safety.

(e) Professor Mitchell asked what is the minimum value at which bone tumour occurs.

Dr. Brues said it was 0.7 to 0.8 μC.

Dr. Hempelmann added that, from examination of MsTr-Ra cases, it had been concluded that 0.8 μC was the level at which damage occurred.

(f) Professor Mitchell enquired about the production of non-malignant tumours.

Dr. Brues replied that none was produced up to 2 μC.

It was agreed to retain 0.1 μC Ra as the permissible level.

2. Radon

At present there are two values of the m.p.l. of radon in air, namely, the U.S. value of 10^{-11} C/litre (10^{-8} C/cc) and the U.K. value, advocated by the British X-ray and Radium Protection Committee, of 5×10^{-11} C/litre (5×10^{-8} C/cc).

(a) Dr. Marinelli said that the U.S. value was based on observations on 2 cases of echnoid carcinoma.

(b) Professor Failla drew attention to one other piece of evidence, namely, that the observed thoron levels in gas-mantle factories which had not resulted in damage would lead one to expect that much higher values for radon than those given above could be permitted.

Mr. Binks said that measurements which he had made in a gas-mantle factory had revealed thoron concentrations up to 8.8×10^{-9} c/litre (8.8×10^{-6} C/cc) in different departments. The values were similar to those found by R.D. Evans. No clinical damage had been noted in the workers involved, and it would seem, therefore, that the radon level could be raised. Mr. Binks added that, in radium luminising departments which adopted reasonable measures to maintain low levels, it had been found difficult to get down to 2×10^{-11} C/litre.

Dr. Eisenbud reported that no damage had been discovered in 300 workers exposed to thoron. Fifty percent of those had been exposed at levels up to 130 x m.p.l. and fifty percent up to 700 x m.p.l. One individual had a 40-year exposure, whilst 5 percent had been working for 20 years.

(c) Professor Failla suggested that the m.p.l. for radon be changed to 10^{-10} C./litre (10^{-7} µC/cc).

Dr. Cipriani said that, as far as radium mines are concerned, a figure some 50 times the above is wanted, as ventilation is a most difficult problem.

Professor Mitchell supported Professor Failla. He based his assessment on the fact that the workers in the Schneerberg mines were exposed at levels of the order of 10^{-8} C/litre. A factor of 100 on this should suffice.

(d) Dr. Morgan was concerned about the adoption of a figure as high as 10^{-10} C./litre, since calculations at Rochester indicated that this would give a high dose rate to tissues.

Professor Mitchell estimated that 10^{-8} C/litre gave 1 rep/day to the tissues. If an r.b.e. of 5 was taken, he thought there was still an ample safety factor on 10^{-10} C/litre.

(e) Dr. Western enquired whether this figure for radon included the daughter products.

Some delegates were of the opinion that it did.

Dr. Morgan said that, since Dr. Hempelmann had found a factor of 8 between the dose due to radon and that due to the daughter products, he would like to retain the old value for radon.

(f) The Conference agreed to change the m.p.l. for radon and its daughter products to 10^{-10} C/litre (10^{-7} µC/cc).

3. OTHER BONE-SEEKING ISOTOPES.

(a) Actinium

Dr. Hamilton said that Ac. can be taken as representative of most bone-seeking isotopes. It was not unreasonable in this instance to use a factor of 5 for non-uniform distribution. The rate of loss of Ac. from the skeleton is quite slow. Half life is greater than 5 years. It may be 10 or 20 years. For parenteral administration, there is a high accumulation (70%) in liver for soluble Ac. forms. Actinium is potentially more dangerous than Ra, by a factor of 3. Skeletal uptake nearly cancels this out (since there is a factor of 2 in the other direction). Dr. Hamilton recommended 0.2 µC Ac. for the body burden. Asked if he would place the bone-seeking isotopes in order of importance from a practical point of view, he suggested,

(i) α emitters: All of actinide groups, including Ac (except U). Pu probably the most important.
(ii) β emitters: Sr^{90} ($\neq X^{90}$) + Y^{90}
(iii) Ce (longer lived daughter), Pr, Nd, Pm. Sm and Eu not important.

(b) Professor Mitchell asked whether, in comparing Y with Sr., it is necessary to introduce a factor of 5 for differences in distribution.

Dr. Hamilton said that a factor of 5 can be considered for discontinuous deposition, assuming Ra is uniformly distributed, whilst the latter is not actually the case, he still felt there was a difference in deposition by an order of magnitude. Dr. Hamilton then proceeded to give a list of isotopes for which there was non-uniform distribution: Sr, Ba, Ra, Y, Zr^{95}, Cb^{95}, La (short half life), Ce, Pr, Nb, Pm, Ac, Am, Cm, Zr, Th (short-lived isotope or MsTh), Pu. (U is deposited in kidney). He would apply a factor of 5 to all of the above except Sr, Ra, Ba, Ca, U and Nb. Hence, the factor of 5 would be applied relative to Sr.

(c) Professor Mitchell asked whether there was any evidence to suggest a change in the Sr^{89}/Ra. ratio of 20.

Dr. Brues said there was not. He had reviewed the data for tumour formation and considered that the ratio still held. Allowance had, of course, to be made in applying the results to man for the difference in radon exhalation from rats and man.

It was agreed that the present m.p.ls. of 2.0 µC Sr^{89} and 1.0 µC Sr^{90} remain unchanged.

(d) Dr. Brues pointed out that Ce does not fit in with Sr on a curie for curie basis.

(e) Dr. Hamilton stated that, for energetic β rays, the factor of 5 recommended by the U.K. delegation, might be wiped out. (It would seem that he was basing his earlier factor of 5 on Ac. which is an α-emitter whereas the long-ranged β rays would tend to even out the dose distribution in bone).

(f) Dr. Brues referred to an investigation on rats which had shown that spotty distribution of the isotope in bone resulted in a decreased cancerous effect.

(g) Dr. Loutit suggested the following working basis:-

(i) Ra and Sr are assumed to be uniformly distributed.
(ii) Other β and α emitters are not uniformly distributed.
(iii) For cases where there is no direct clinical evidence:

(A) for α emitters, the non-uniformity introduces a factor of 5.

(B) for β emitters, the factor might be 2 - 2½.

He pointed out that Brues' data was for soft tissue, not bone. He advocated 0.1 μC Ra as the basis, and other α emitters should have a factor of 5.

The following resolution was proposed by Dr. Bugher and seconded by Professor Failla:-

α emitters: Ra is assumed, for purposes of calculation, to be uniformly distributed in bone. Other α-emitting bone-seekers are assumed to be non-uniformly distributed by a factor of 5.

β emitters: Ba, Ca and Sr are assumed to be non-uniformly distributed. Other β-emitting bone-seekers, which are 3-, 4- and 5- valent metal ions (Ce, Zr, Nb) are assumed to be non-uniformly distributed by a factor of 2.5.

It was then moved that the figure of 2.5 for the β-emitters be changed to 1.0. This was agreed with one against and one abstainer.

(h) Dr. Langham said that experiments had been conducted comparing Ac and Pu on an acute basis. μC for μC., these isotopes produced the same effect. The factor of 5 advocated by Hamilton would in fact be 2.5.

(i) It was agreed to accept a value of 0.2 μC as the m.p.l. for Ac^{227}.

4. POLONIUM.

The present I.C.R.P. value for m.p.l. in the body is 0.005 μC.

(a) Dr. Marley said that the M.R.C. Protection Committee agreed with the U.S. Sub-Committee on Internal Radiation that the value for insoluble Po forms should be 0.02 μC. However, the British Committee was worried about the fact that the U.S. Sub-Committee had assumed only 0.03% uptake of Po from gut to the spleen, which was considered to be the organ of deposition. This value did not agree, by a factor of 10, with data in Fink's book on "Biological Studies with Po, Ra and Pu".

(b) Dr. Morgan said that his Sub-Committee had taken a value from Progress Report M-1551 on the "Metabolism of Postum", author R.W. Fink, September 21, 1944; Declass, Jan. 5, 1951.

The fact that the figures quoted by the U.S. and British Committees are both taken from Fink's data puzzled the delegates. Dr. Morgan said he would look into this matter.

5. THORIUM.

(a) Dr. Eisenbud said that studies of 300 employees exposed to Thorium, thoron, and daughter products revealed the following facts:

(i) Length of employment:

2 years - 20%
10 years - 10%
20 years - 1%
40 years - 0.3% (1 man)

(ii) There were 26 men in the 10-year exposure group. Effects completely negative.

(iii) One autopsy case. Died of coronary occlusion when still working. Not as much autopsy material available as one would have liked.

Lung gave 136 α's/min/c. metre
Liver gave 20 α's/min/c. metre

(iv) The man was exposed at a level of 140 dis./min/ c. metre of air.

Dr. Eisenbud said this is twice the figure which has been used for the permissible level.

(Binks: 70 dis/min/c. metre = 3.1×10^{-11} μC/cc.

The man was thus exposed at a level of 6.2×10^{-11} μC/cc.)

(b) Professor Mitchell enquired whether any consideration had been given to the thorotrast problem. He referred to an investigation at present in progress in a European country and said that he hoped details might be released.

(c) Mr. Binks said he was interested to observe the exposure level of 6.2×10^{-11} μC/cc, quoted by Dr. Eisenbud. Measurements which he had made in a gas-mantle factory indicated that the highest level thorium dust might be 4.3×10^{-11} μC/cc. Arrangements had been made for A.E.R.E. to repeat these tests with improved techniques and, in due course, the U.S. and Canadian delegates would be informed of the result.

(d) Dr. Eisenbud proposed that thorium be put in the same class as other α-emitters such as Ra. He advocated the following m.p.ls.

Ra^{226}	8×10^{-12} μC/cc air.
U^{nat}	$4 \times 1.7 \times 10^{-11} = 6.8 \times 10^{-11}$ μC/cc. (= 200 μg./c metre)
Pu	2×10^{-12} ref.
Th^{232}	$4 \times 1.7 \times 10^{-11} = 6.8 \times 10^{-11}$ μC/cc (= 600 μg./C.metre (about))

(The thorium figure is for thorium oxide in air. The factor of 4 which is introduced for natural U and for Th is to allow for a change of r.b.e. factor for α particles from 20 to 5.

Binks:- At a later stage during the Conference it was agreed that the r.b.e. for α particles was 10. Hence the thorium m.p.l. figures of Eisenbud would have to be reduced by 2).

The Conference agreed that, for insoluble thorium compounds, the m.p.l. in air should be 500 μg/c. metre. (This was a rounding off from Eisenbud's figure of 600 μg/c. metre. This may now have to be reduced by a factor of 2 to allow for the different r.b.e. of 10).

It was noted that the chemical toxicity of thorium is not serious.

6. THORON.

(a) Dr. Eisenbud proposed that the m.p.l. for thoron in air should be the same as that for radon, and hence should be 10^{-10} c/litre (10^{-7} μC/cc)

(b) Mr.Binks supported this view since earlier calculations by R.D. Evans had indicated that the thoron and radon figures ought to be about the same.

It was agreed that the m.p.l. for thoron in air should be 10^{-10} c./litre (10^{-7} μC/cc).

7. PLUTONIUM.

(a) Dr. Hempelmann referred to the findings on 27 cases who had been examined for Pu in the body. The body burdens ranged from 0.1 to 1.2 μC. There was a peculiar pattern of distribution in trabecular bone. It appeared, after an interval of 8 years. that everything was alright.

(b) Dr. Warren said these findings were reassuring as far as they went. However, one should realise that tumour formation occurs 12 to 20 years after the deposition of isotopes.

(c) Dr. Langham said that a check would be made on these 27 cases at intervals of 2 years.

(d) Professor Mitchell quoted from Dr. McLean's report PIRC/IR/44, which indicated that, in one case he had examined. the urinary excretion varied inconsistently from day to day by a factor of 10. The effective half life in the gut, as indicated by faecal excretion at intervals 9, 1 and 2 days, appeared to be about 24 hours, 36 hours and 24 hours respectively. On this basis, it had been estimated that the person in question had swallowed * 50 mg. The average daily urine excretion during the first week exceeded the average figure obtained 9 months later by a factor of 10^5. This did not agree with the general belief that the rate drops by a factor of about 10^3.

* There is some doubt about the mode of entry into the body.

(e) Dr. Langham presented data on 15 cases in which Pu had been injected intravenously. Tests had been conducted from time to time, in some cases for as long as 5 years.

Equations for urinary and faecal excretion were of an experimental character; $Y_{Pu} = .23 x^{0.77}$, where Y_{Pu} = total injected and x is time after injection. Typical values given in Table 11.

Table 11.

Days after injection	Percentage of body burden in urine
1 day	0.8
5 days	0.3
270 days	0.003
1260 days	0.001

(f) Dr. Morley asked whether there was any evidence for different Pu ions.

Dr. Langham said that Pu^{III} and Pu^{IV} excreted at same rate, Plutinile (?) was also about the same.

(g) Dr. Healy said that the cases at Hanford fit the same shape of curve.

Dr. Langham had found amazing consistency in the excretion rates. In studies on man and rats, the variations in excretion rate were within the limits of experimental error of counting (i.e. within a factor of 2).

Information from Dr. McLean is classified. That from Dr. Langham has current classification of "Confidential". Report IA 1151.

(h) Dr. Healy noted that Dr. Morgan's Sub-Committee had taken a figure of 0.01% as uptake from water. Experiments at Hanford indicated the uptake at the level of the m.p.l. was 0.0025%, which is less by a factor of 4. He thought it safe to adopt Dr. Morgan's value of 0.01%.

It was agreed that the m.p.l. for Pu^{239} in the body should remain unchanged at 0.04 μC.

It was also agreed that the fraction of ingested Pu absorbed from the gut be set at 0.0001. and that the m.p.l. for water be changed accordingly.

8. C^{14}.

(a) Dr. Brues thought that the value for Co_2 in air should be 30 times greater than the present value of 1 x 10^{-6} μC/cc air. Calculations based on 24 hr. exposure at 0.3 rep/week suggested a new value of 10^{-5} μC/cc.

It could be assumed that less than 10% was in exchange with C. in the environment.

(b) Dr. Hamilton asked whether the figure held for fat and bone.

Dr. Brues said that bone is a little more critical than fat. Also, equilibrium occurred in alveoli where Co_2 concentration is more or less constant.

(c) Dr. Marley asked how could isotopic dilution be applied in the case of water.

Dr. Morgan said that calculations were based on 0.3 rep/week.

Dr. Cipriani asked whether the m.p.l. for water could be ignored. Dr. Western felt it could not, since a figure was requried for C^{14} in waste disposal.

(d) Dr. Brues stated that measurements of tissue and bone carbon in animals over such a length of time that equilibrium occurs gave 10% C. in tissues and 1% C in bone. On the other hand, the specific activity in bone is higher by a factor of 10. Accordingly, there was very little difference in the levels for fat and bone.

(e) Dr. Morgan suggested that Drs. Brues and Western should consult each other in regard to a figure for C^{14} in water and should report to I.C.R.P. This was agreed.

It was also agreed that the m.p.l. for C^{14} (in the form of Co_2 in air) should be increased to 10^{-5} μC/cc.

9. H^3.

(a) Dr. Brues suggested an r.b.e. of 1.0.

(b) Dr. Langham thought the r.b.e. might be 1.3, but agreed that 1.0 is good enough.

It was agreed that the r.b.e. for H^3 should be 1.0.

(c) Dr. Western believed that the m.p.ls. for H^3 in air and water were too high by a factor of 2. Experimental work indicated that H^3 mixes with the body water soon after intake. Portions of the body contain as much as 90% water. In such tissues, the present I.C.R.P. figures would give 0.6 rep/week.

(d) Dr. Langham said that studies of the rate of turnover of water showed that this depends on uptake.

Dr. Western thought that the half-life of turnover had no bearing on the question.

However, after some discussion, it appeared that Dr. Western had over-looked the water content of food. Accordingly, he withdrew his comments.

(e) Dr. Marley asked what is the exchange rate of H^3 with H_2O in air, as for example, in the case of an escape of H^3 from a plant.

Dr. Langham thought that, until radiation chemistry effects come in, the exchange rate is exceedingly low.

It was agreed that the m.p.l. for H^3 in the body remain at 10 μC: that, however, the tolerance concentration in air be lowered by a factor of 2 to allow for skin absorption for water vapour.

This would make the m.p.l. in air 2.5×10^{-5} μC/cc. Dr. Morgan suggested this be 2×10^{-5} μC/cc. This was agreed.

10. I^{131}.

(a) Dr. Warren wondered whether this m.p.l. for I^{131} could be raised by a factor of 10. A number of youth thyroid cases have been treated with 40-70 μc I^{131} for control of cardiac decompensation. There was no damage other than a lymphocyte drop in one case. There were 20 pregnancies. All resulted in full-term children.

(b) Professor Mitchell stated that, if the value is raised by a factor of 10, some organs would receive 3 rep/week. If allowance was made for inhomogeneity as well, some parts might be getting 10 rep/week. He would be worried about effects at these levels after, say, 30 years.

(c) Dr. Warren said that he was not nearly as worried about the thyroid as about other organs.

(d) Dr. Brues felt that, since the follicles in the thyroid absorb I^{131} in turn, then over a long time this would even out inhomogeneities.

(e) Professor Mitchell said he would still be worried about late malignancies. So far, treatments had been carried out for only 10 years.

(f) Dr. Hempelmann said that from a knowledge of the effects of a high X-ray dose on thyroid, he would be prepared to go up by a factor of 2. At a later stage, it might be possible to increase the m.p.l. further.

(g) Dr. Warren was prepared to accept a factor of 2. Dr. Morgan pointed out that during the previous day, a factor of 5 had been accepted for external radiation. Drs. Mitchell and Warren did not regard this as being similar to the internal radiation problem.

(h) Dr. Hamilton said it is the small follicles which contain most I^{131}.

It was agreed that the m.p.l. for I^{131} be increased by a factor of 2.

OCCASIONAL EXPOSURE.

(a) Professor Failla presented rule V A recommended by the U.S. Sub-Committee on External Radiation. This reads:-

"Accidental or emergency exposure of the whole body of adults or parts thereof to X-rays with photon energy less than 3 MeV, from external sources, occurring only once in the lifetime of the person, under the conditions and in the respective damages below, shall be assumed to have no effect on the radiation tolerance status of that person.

(i) Exposure of the whole body. Dose measured in air.

Any adult - total dose 25r.

(ii) Local exposure - any adult. Dose measured in air and additional to whole body dose.

(A) Hands and forearms: 100r
(B) Feet and ankles: 100r."

(b) Dr. Marley asked what happens when there is a second incidence, if it is stated that a person must receive 25r. only once in a lifetime.

Professor Failla replied that such a case would have to be referred to experts for decision.

(c) Dr. Marinelli gave details about an accident involving 4 persons who received doses of fast neutrons, slow neutrons, delayed neutrons and γ rays. The values of the doses assessed by different methods are given in Table 12.

TABLE 12

Person	γ-ray dose in reps.		
A (Male)	140	136	200
B (Male)	148	127	280
C (Female)	70	60	190
D (Male)	90	9	9

(i) Neutrons/ γrays:-

Method	Percentage
Proportional Counter	10% (>0.3 Mev)
N.T.A.	3%
Carbon ion chamber	1.3%

(ii) Delayed neutrons/Fast neutrons = 30% (abt)

(iii) Slow neutrons 0.6 rep.

Dr. Brues referred to the biological effects of the above exposures. One man was sick during the night following the accident. One had a lymphocyte count of 50% at the second day. The count still held low. A, B, and D, had depressed sperm counts. (The 50% drop in lymphocyte count would correspond to 200 reps).

Dr. Hamilton asked whether Na and P activation tests had been carried out. Dr. Marinelli said they had. They indicated that the neutron estimates were out by a factor of 5.

Dr. Cipriani asked what had happend to these workers. Dr. Brues replied that they were working in the laboratories, but away from radiation hazards.

(d) Dr. Marley asked whether the 25r emergency dose produced any effect. Dr. Warren said that up to 25r, there was no evidence of damage; above 25r and up to 100r a slight amount of damage could be noted without, however, the person being seriously affected. Above 100r damage increased.

(e) Dr. Cipriani gave details about the Chalk River accident. One man received a dose of 2.1 r of external radiation during a short period when he collected a sample of water from a leak, believing this might be heavy water. Other workers engaged in various emergency jobs after the incident caught up with themselves arithmetically on dose after 6 to 8 weeks. Dr. Cipriani did not yet know what the internal hazards amounted to. He pointed out that the doses at Chalk River were much lower than those reported by Dr. Marinelli because the reactor in the former case is remote-controlled, whereas in the latter case, the workers were very near to the reactor. He added that the emergency figure of 25r was in operation at Chalk River. The idea that this did not affect the radiation status was new to him, but he agreed with it.

(f) Dr. Marley said that, administratively, this 25r limit is a dangerous conception which would handicap plant operation.

(g) Dr. Warren stressed that this figure should be regarded not as licence but as emergency. The same thing has to be faced in Civil Defence.

(h) Dr. Loutit said that, since several of the delegates were not convinced that 25r has no effect on personnel, he wondered what would be the reaction of military commanders.

Dr. Warren said that one can yield to military commanders up to a point. Then, a firm stand has to be made. Dr. Loutit agreed with this but felt that 25r was a large dose. Doses of 4-5r would be alright.

Dr. Warren stressed that the dose of 25r was to be given once in a lifetime.

Dr. Loutit asked what was the position in regard to a military person who has received 25r and goes the following week for a G.I. series.

(i) Professor Mitchell believed that the introduction of the 25r rule would lead to a breakdown in radiological safety practice. It was the thin end of the wedge. He was concerned that the persons for whom there might be genetic consequences were the best specimens.

Dr. Plough thought too that there would be concern about the genetic consequences, but Professor Failla said that two geneticists, Muller and Stern, had agreed with the terms of the report of his Sub-Committee.

(j) Dr. Marley said that the dose of 25r was acceptable. This should, however, be coupled with compensation over an appropriate period. This would then leave each country free to interpret the "appropriate period".

Dr. Warren saw no great difficulty with this.

Professor Failla agreed to consider such a proposal but said he could make no promise about introducing it into his report.

Professor Mitchell asked that this proposal should not be submitted to I.C.R.P. without further discussions taking place.

ISOTOPE EXPOSURE IN WARTIME.

(a) Dr. Marley said that for rays, Great Britain advocated the following levels:

(i) 25r would be the dose in one incident.

(ii) If the saving of life in any particular instance is necessary, the dose could be up to 75r.

(iii) If 25r is delivered in a single exposure, there should be no further exposure for ?

(iv) If 75r is given, a longer compensationperiod is necessary.

As regards isotopes, the important ones were considered to be Sr^{89} and Ba^{140}. 30 C of Sr^{89} plus 150 C of Ba^{140}, which show metabolic similarity, is taken to be the m.p.l. to which an individual should be exposed. Sr^{89} and not Sr^{90} is assumed to be the tolerance limit for exposure after bomb burst.

(b) Dr. Western said he believed A.E.R.E. had seen the U.S. calculations for ten days and 30 days after bomb burst. (The calculations for 30 days were wrong and should not have been given).

(c) Dr. Warren said these were the last official figures. He thought that Dr. Marley's figures fell within the Rochester values for safe and extreme limits.

(d) Dr. Bugher promised to send the results to A.E.R.E.

(e) Dr. Loutit asked whether there was any experimental evidence as to the important isotopes.

Dr. Bugher replied that Sr is by far the most important from all points of view, e.g., soil and water contamination.

(f) Dr. Loutit asked whether there are any studies with mixed fission products.

Dr. Hamilton remarked that it was difficult to make such studies, as the competition of the isotopes changed with time. He did not think that a single figure could be applied.

Dr. Marley asked Dr. Hamilton whether he would regard Sr as the most important isotope.

Dr. Hamilton said that, since important isotope changes occurred over a period of time, the importance of an isotope was a function of time.

(g) Professor Failla enquired about the methods of measurement which would be adopted in Great Britain. Different measuring techniques might lead to a difference by a factor of 5 and, accordingly, there was nothing to be gained by agreeing upon a particular figure for isotopes.

Dr. Marley said that the activity would be counted with G.M. tubes of the immersion type.

(h) Dr. Hamilton pointed out that the difference in the distribution of uptake in the body would introduce a factor greater than that of 5 mentioned by Professor Failla. He thought there were too many variants to enable agreement to be reached on a figure.

W. Binks, Secretary
M.R.C. Protection Committee

8th April, 1953

APPENDIX 24

U.S.-TRI-PARTITE CONFERENCE ON PERMISSIBLE DOSE (3-30-53)

Arden House, Harriman, New York

March 30, 31, and April 1, 1953

AGENDA

TRI-PARTITE CONFERENCE ON PERMISSIBLE DOSES

Arden House
Harriman, New York

March 30, 1953

Permissible Dosages from External Radiation Sources:

A. General principles of determining permissible limits

1. Units and definitions

2. The "Standard Man"

a. Masses of organs

b. Chemical composition

3. Modifications of permissible dose due to

a. Age

b. Limited regions of body

c. Limited penetration

4. Relative biological effect for various radiations and tissues

5. Modifications of permissible dose due to genetic considerations

6. Modifications of permissible dose due to population considerations

B. Specific considerations and recommendations

1. Gamma radiation and X-ray

2. Neutrons of varying energies

3. Beta radiation and electron beams

4. Heavy particles

5. High energy mesons, etc.

March 31, 1953

Permissible Dosages from Internal Radiation Sources:

A. General principles

1. Units and definitions

2. Special problems presented by internally originated radiation

3. Factors in tissue localization of radioactive materials

4. Factors influencing elimination of such materials

5. Particulates in respiratory tract

March 31, 1953 (cont)

6. Population considerations

7. Permissible limits for life forms other than man

B. Specific considerations and recommendations of permissible dosages

1. Radium (and radon)

2. Polonium

3. Actinium

4. Thorium

5. Plutonium

6. Other alpha emitters

7. $Carbon^{14}$

8. $Hydrogen^{3}$

9. $Argon^{41}$, $Xenon^{133}$, $Xenon^{135}$, Krypton

10. $Cobalt^{60}$ in water

11. Strontium

April 1, 1953

A. General problems of dosimetry

1. Gamma

2. Beta

3. Neutrons

B. Special technical considerations in radiation measurement

C. Occasional exposure

1. Accidental or emergency, with special reference to civil defense

2. Medical

D. Recapitulation of recommendations

Tripartite Conference on Permissible Doses

Arden House, Harriman, New York

March 30, 31, and April 1, 1953

Attendees:

U.S. Delegation:
Dr. John C. Bugher
Dr. Austin M. Brues
Mr. Merril Eisenbud
Dr. Gioacchino Failla
Dr. Joseph G. Hamilton
Dr. J. W. Healy
Dr. Louis Hempelmann
Dr. Wright H. Langham
Dr. L. D. Marinelli
Dr. Karl Z. Morgan
Dr. Harold H. Plough
Dr. Lauriston S. Taylor
Dr. Shields Warren
Dr. Forrest Western

U.K. Delegation:
Dr. Joseph S. Mitchell
Mr. Walter Binks
Dr. John F. Loutit
Dr. William G. Marley

Canadian Delegation:
Dr. Andre J. Cipriani
Mr. Alec K. Longair
Dr. Robert M. Taylor
Dr. John D. Babbitt

Dr. Bugher convened the first session of the Tripartite Conference; welcomed the delegates; oriented the assembly on the topics approved for discussion, the security methods under which the conference was to proceed, the clearance of news releases, and other various introductory topics; and then introduced the chairman for the first day - Dr. Mitchell.

Dr. Mitchell accepted the chair, extended greetings, and proceeded with the items on the agenda.

I. PERMISSIBLE DOSAGES FROM EXTERNAL RADIATION SOURCES

A. General Principles of Determining Permissible Limits

1. Units and Definitions

Dr. Failla presented a definition of "permissible dose" as being "a dose of ionizing radiation that in the light of present knowledge is not expected to cause appreciable bodily injury to the average person at any time during his lifetime". As used in the definition, "appreciable bodily injury" means any bodily injury or effect which the average person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well-being of the individual.

The question arose as to the use of the term "average person", and Dr. Failla explained that it was used in an effort to exclude persons who claim to be extremely sensitive or susceptible to radiation.

Another question arose as to the possible medical or legal reactions to the definition. It was, however, decided in this regard that whatever definition was accepted by this group would be regarded as having the equivalent force to law, and that any legal hassle which arose would be settled on the basis of what is technically reasonable.

A discussion also arose at this point with respect to the unit of measurement to be used. It was pointed out that the International Congress of Radiology recommended the use of "ergs per gram" in expressing doses of ionizing radiation. Dr. Failla said he would prefer to use the "rep" in this case, because it seems to better represent what is being talked about and better connote ionizing radiation. He also stated that he was submitting for national congress consideration a change in the number of ergs per gram from 93 to 100. The question here before the house, however, is to decide whether a special unit should be used for all ionizing radiation or whether the ergs per gram term should be followed.

Dr. Lauriston Taylor then stated his understanding of Dr. Failla's proposal as not suggesting the elimination of the concept "ergs per gram" but rather suggesting the use of a multiple or a unit of that for the sake of convenience. He suggested that the problem, therefore, was to agree on the multiple or a name for it...a name for one erg per gram, perhaps the number 100 because it is close to a rep.

The consensus of opinion of the group was that the term "average man" was clearly understandable, and that Dr. Failla's definition for permissible dose was excellent.

Mr. Binks, when asked to discuss the new factor of "W", said it appeared to have an energy value of around 35.

Dr. Western questioned whether the term to be used in the definition was "maximum permissible dose" or "permissible dose". After a pro and con discussion, Dr. Bugher said he believed there was implied in the definition the idea that it is a maximum value; also there was the implication that as far as amenable and practical the actual exposure being maintained be as low as feasible. It was finally agreed that the term to be used would omit the word "maximum" and merely read "permissible dose".

As for a choice between the use of the term "ergs per gram" or "rep", there was considerable discussion as to the distinction between the two, so further discussion on the subject was deferred until all the delegates might read and informally discuss the recommendation.

It was then suggested that when the minutes of this meeting were produced, the over-all report should bear its appropriate classification and each individual section should also bear its own security classification in order that unclassified portions might be discussed with uncleared persons.

2. The "Standard Man"

a. The first item under this topic was "masses of organs". Dr. Warren made the suggestion that it might be well to state as a general principle that if a value is commonly utilized and there is no very strong reason for changing it, it would be best to allow it to remain. Dr. Mitchell agreed with Dr. Warren, and proposed that the discussion under this topic be limited to any proposed changes in the previously accepted Chalk River values.

These organs for which changes were suggested were:

(i) Thyroid: The first item to arise dealt with the value to be given the thyroid. The average mass of this organ varies considerably from country to country as well as from one part of a country to another. 20 grams was the Cahlk River value, and the suggested new value is 15. The British still use 20. 25 is the normal figure used in the eastern seaboard regions of the United States. Dr. Warren said he could not rely on his autopsy evidence; it would be heavier because a number of patients had a mild degree of endemic goiter. At this point, Dr. Bugher commented that the standard man is a fictitious entity which is valuable as a constant basis of reference, and any change from the figures which have been used should be contemplated only with considerable reluctance and on the basis of real urgency because the constancy of these figures is where the value lies. It was agreed, therefore, that there would be no change from the 20 grams figure accepted at Chalk River for thyroid.

(ii) Adrenals: The presently accepted value for the adrenals is 20. The suggestion was made that the figure be changed to 14, based on a review of literature at the Argonne National Laboratory and investigators' values ranging from 6 to 12. Dr. Warren pointed out that most of the figures obtained were based on autopsy determinations - determinations that have been made on adrenal organs which have been depleted due to an acute or wasting disease and therefore are not truly representative of the normally larger sized adrenals. He therefore suggested the retention of the Chalk River value of 20.

(iii) Blood: Dr. Warren suggested a change in the total mass of the blood from 5000 grams to 5400 grams, based on the fact that more accurate methods of determining total blood vlume have been achieved since the Chalk River conference. Although it was believed that the figure of 5400 was good, it was agreed that the matter should be referred for further evidence to be brought forward at the Copenhagen conference.

(iv) Gastro-intestinal tract: The first question to be raised on this subject was whether or not the weight proposed included content. Dr. Warren said it was the substance of the walls and did not include the esophagus.

At this point the recommendation was again made that if any of these items discussed at this conference were forwarded to the Copenhagen conference they be coupled with a recommendation that as far as possible existing values be retained unless there were strong medical evidence to the contrary.

As for a proposed change in the figure for the G.I. tract from 2000 grams to 2300 grams, Dr. Warren pointed out that there is a great deal of variation in the experimental values obtained according to the eating and bowel habits of the individual; also, there would be appreciable alterations in the wall thickness and in the mass of the connective and supporting tissue. He would hesitate making a change in the present figure because, although if one went over several thousand autopsies one might find a slight shift one way or the other, within the terms of the standard man these shifts would not be significant. The value for the G.I. tract, therefore, remains unchanged.

(v) Fat: A value of 3000 was proposed for fat; in Chalk River it was defined as 8390 grams, but this figure included other tissues and organs not separately defined. Dr. Morgan said that the only occasion for needing a figure for fat would be in the determination of permissible body burden for Carbon-14. Dr. Langham suggested that he could determine rather accurately the fat figure, and would forward it to Dr. Morgan for submission to the Copenhagen conference.

(vi) Red Marrow: Dr. Warren said he was completely dissatisfied with the measurements he has attempted in his laboratory; that the great difficulty is that even in relatively dense hematopoietic areas there is a very appreciable mixture of fat. It was agreed that the present value for fat would be retained, and that Dr. Warren would submit new evidence on the subject at a later date.

All of the figures here discussed are based on a standard man with total body weight of 70 kilograms.

b. Dr. Morgan opened discussion on the second item under the topic "The Standard Man" - chemical composition - by stating that his values for the average chemical compositions were merely a listing of the Chalk River values, and that although efforts were being made to get better data on the element distribution within the particular organ, the work was still in a preliminary stage. The questions invovled in this problem are (1) to get acceptable average values for the total body, and (2) to get the best average value for each organ for use in the calculation of the distribution of radioisotopes in the body organs under equilibrium conditions.

Dr. Mitchell then mentioned some work done by the British with potassium measurements on 20 or 30 unexposed subjects which gave a body radioactivity corresponding to a potassium content of about 0.2% of the subject's weight. Drs. Langham, Binks, Hamilton and Morgan all were in agreement that preliminary work resulted in values of around 0.2% for potassium content. It was, therefore, suggested that 0.2% be adopted as a provisional value for potassium content until such time as better information is available, because it was felt that this value is important from the point of view of determining the natural background of the body. Since all of the values are provisional and have a possible error of 25 to 50%, the proposal agreed upon by the conference was that the value be changed to 0.2%.

Dr. Marinelli then suggested a sodium value might be of importance in estimating exposure over a long time. Dr. Morgan said that a number of values were amenable to better calculation, and that his subcommittee would welcome any evidence. The present value for sodium was unchanged.

Dr. Mitchell mentioned having a preliminary report on spectographic examination of eye lenses from normal humans, from which it appears there are important amounts of boron in the lens of the human eye. The British document on this work was handed over to Dr. Morgan, with the remark that further details would be published.

Dr. Mitchell then asked Dr. Morgan to speak on neutron activation analysis. Dr. Morgan said that neutron activation analysis was still in a preliminary stage, but that they have found relatively large amounts of aluminum in the liver, cadmium in the kidney, silicon and copper in the intestine, and copper, silicon, nickel, aluminum, boron, etc., in the heart. However, there is still insufficient evidence available to be sure that this represents the standard man, and further evidence must be obtained before any specific recommendations can be made.

3. Modification of Permissible Dose

a. The first portion of this discussion dealt with the modification of permissible dose due to the various factors of age.

Dr. Failla's subcommittee accepted the recommendation which distinguished between two age groups - one under 45 and the other over 45. For the over-45 age group, the permissible dose was accepted as double the permissible dose for the under-45 age group. Another recommendation was that the weekly dose rate for children be 1/10 of the permissible limit for occupational exposure.

Dr. Warren commented that he was in complete agreement with these recommendations, especially with that of going back to the original permissible dose level for persons over 45. It was the pressure of genetic considerations which changed the level originally, and that consideration is no longer a significant factor from the age of 25 on.

Dr. Loutit granted there were genetic grounds for the distinction in dose between the age groups, but wished to know if there were any clinical evidence or animal experimentation basis for it. He pointed out that there is general agreement that old animals are less sensitive than younger animals, although it is not known whether this is because the cells respond less strongly to the effect of radiation or whether it is a matter of different rates of recovery. Then again, theoretically thinking, it would seem that the young animal has better powers of recovery than the old animal, and that to permit a greater dose for the elderly was running counter to this other general principle.

Dr. Failla said that here entered the question of a latent period, and if the latent period for the production of cancer can be as long as 45 years, then the latent period for a person who receives radiation at the age of 45 and over would be beyond his life span; and since the latent period seems to vary inversely as the dose, a little larger accumulated dose can be given after a certain age because the latent period doesn't have to run as long.

Dr. Loutit then expressed concern over the statistically impaired leucocyte count in the higher energy groups. Dr. Failla said the question would be not whether there were blood changes, but rather whether the blood changes were significantly deleterious enough to lead to leukemia or anemia or whether they were just innocuous.

The question of leukemogenesis was raised, and Dr. Brues said that there was no evidence of it occurring with doses of this amount.

The question was also raised as to whether the production of ovarian tumors would suggest that is a distinction is made on the basis of age, the age of 50 was preferred to the age of 45. In reply to this question, Dr. Plough discussed the biological evidence obtained from mouse studies in which it was clear that the younger the embryo the more likely there are to be definite lethal and definitely recognizable effects of radiation. In this connection, Dr. Failla pointed out that Dr. Plough's feeling that 1000 or 1300r is high depended on the point of view - that it sounds high because the lethal dose for man man is 450 or 500r if given in one dose, but that spread over a lifetime it may not be effective enough to cause any damage. There is evidence to show that a dose of 0.5r per day has no effect on the life span of mice.

Dr. Brues was then asked to comment on the evidence of fractionation in connection with carcinogenesis and blood formation. Dr. Brues said they had been unsuccessful in producing leukemia with a dose of 5r per day, although there is a noticeable effect on the mortality rate.

Rochester experiments on carcinogenesis in dogs found that dogs which were exposed to 0.5r per day for 6 days a week showed a decrease in the total number of sperm, an increase in the numbers of abnormal sperm, and a decrease in fertility. Boche had found these effects after 18 months at a 0.1r per day level, but it was admitted that his controls were faulty and that his results had not been substantiated.

Discussion then turned to the effect of radiation on blood changes. Findings at the Stockholm conference were, roughly, that provided that radiation monitoring, both site and personnel, is carried out in all circumstances involving occupational exposure to ionizing radiation, then (a) routine blood counts are optional in the case of workers who receive a surface dose of less than 0.1r per week, since for such workers the counts are of doubtful significance; (b) blood counts are necessary in the case of workers who receive a surface dose in excess of 0.3r per week; and (c) blood counts are advisable in the case of workers who receive a surface dose between 0.1r and 0.3r per week, but the interval of time between such counts should be left to the discretion of these responsible for the health of the workers concerned. The last resolution, (c), was made not from the point of view of detecting any damage, but rather for the purpose of obtaining more information in this range.

Dr. Langham reported on 10 individuals, ranging in age from 25 to 39, who had been exposed to relatively consistent doses of about 0.16r per week gamma radiation for a period of 4-1/2 years: it was shown that there was no change other than in the lymphocyte count which dropped every nine months to the extent of about 90 per cubic millimeter. The people are still working within normal ranges, and the only thing the data showed when subjected to rigorous analysis was that these changes are significant at the 1% level. The radiation involved was essentially cobalt. This study has been followed for six 9-month periods; dose for the first four periods was 0.16r, and during the last period it dropped to 0.07r per week and the change in lymphocytes the last time was 66 cells, which is not a significant difference between the drops in the previous periods. There is no indication whatsoever that the health of these individuals has been impaired in any way.

Mr. Eisenbud reported on a homo-statistical study of a group of 200-300 individuals who have been exposed up to seven years to gamma radiation from radium up to 1r per week. During the period some of the individuals collected as much as 15 or 20r. There is no obvious or statistical change.

The question of recovery time was raised: indications were that it takes six months to a year for the lymphocyte count to return to normal.

At this point, Dr. Morgan spoke of the difficulties that are introduced by doubling the dose after age 45. His concern was over the group of people who work most with radioactive materials and who stay on the job longest after the age of 45. Many of these people would have received the maximum permissible lifetime dose of 1300r before the age of 45, and Dr. Morgan would worry about these persons who got 100 rems or a thousand or so reps of mass neutrons and the possibility of shortening their life; and also about the possibility of cataract formation.

Dr. Mitchell said it was an exceedingly difficult matter; that evidence has accumulated that detectable and statistically significant blood count changes appear at the point of the 3r per week level. There is no evidence as to the pathological significance of this, but he would suggest that in view of this evidence it would be wise not to raise the exposure levels at the present time, but rather to observe cases over the next five or ten years before doing so. He also proposed that an increase in the older age groups not be suggested. Dr. Failla said there was no pressure to make the distinction in age groups at this time.

At this point Dr. Bugher suggested that this was a good spot to move into the question of the modification of permissible dose due to genetic considerations. Dr. Plough then spoke of information with respect to genetic data:

Dr. Plough reported that as a result of the work of Russell at Oak Ridge during the past three years, the previous limits that had been set as a measure of the mutation frequency have been better defined. Dr. Russell's data gives 2×10^{-6} as frequency per gene for mutation in the mouse over the normal reproductive period. The frequency of the radiation-induced mutation for mice is approximately 2.5×10^{-7} per roentgen per gene; from that can be estimated the frequency of spontaneous mutation for man - 2×10^{-5}, which is considerably higher than even the mouse data would indicate. Using this spontaneous frequency for man and the mouse data on frequency of increase of mutation per roentgen per gene, between 30 and 80 roentgens is arrived at as being the dose needed to double mutation rate. The general guess of geneticists is that 80 or 85r might be set as a maximum limit for the normal exposure that might be allowable. Add to the frequency gotten by occupational hazard all the other hazards and the total one might assume for one individual at age 45 might be as high as from 300r to 600r.

To a question raised by Dr. Mitchell, Dr. Plough agreed that factors such as mental changes and constitutional factors that would never be noted in mice would have to be taken into account in considering genetic changes produced by radiation in man.

Dr. Mitchell then said he understood Dr. Russell was particularly concerned about first generation effects. Dr. Morgan reported a recent telephone conversation with Dr. Russell, during which Dr. Russell said that at doses down to as low as 30r he was concerned about the reduction in the leukocytes of orders of a few percent; that these doses were not sufficient to affect the pliability or mobility of these sperm. For that reason, he would suggest that persons not be encouraged or permitted to receive large accumulated doses in a lifetime. Dr. Plough said these changes are due to transmutation and appear in the first generation only and then disappear.

Mr. Eisenbud then pointed out that the Japanese population had shown practically no first generation changes.

Mr. Eisenbud then stated that he understood the geneticists had concluded that the risk of doubling mutation rate is not a risk to the individual but rather a risk to the genetic composition of the population. In this connection, Dr. Plough cited the experiments made at Harvard by Wallace in which he has kept his population going with a continuous level of chronic radiation which for the allotted times of the individuals in the population amounts to about 300r. On the other hand, when he tested this same population with a lifetime level of 2000r the population disappeared. He pointed out that this might not be a population hazard, but that it would continue to be an individual hazard.

Dr. Warren then asked if the lowering of litter size would not have an effect on the human problem. Dr. Mitchell said that more important than the possibility of miscarriage was the possibility of deleterious effects on those offspring that survive.

Dr. Loutit said that for the sake of the individual, one must consider how much one increases the recessive in his germ cell - that it might be a problem for the 10^4 or 10^5 people that would be involved.

Dr. Failla mentioned that originally Dr. Mueller had agreed to a per capita dose of 20 in the reproductive age. Later, after discussing the problem with Dr. Stern, it was suggested that the dose per capita should not be greater than 5r. It then would become necessary to explain to the people who are going to get around 300r in their reproductive age what is happening to them, because in 20 years they are going to get essentially many times more radiation than is allowed for the average person. For that reason, it was decided that no mention should be made of this section in his report - but some geneticists would be asked to prepare a separate section to the report indicating particularly what happens to people that have had 300r, what happens to their children, what is apt to happen to their children, grand-children, etc.; to point out that these things do not appear in the first generation; that they are going to appear in future generations. In this way, the individual who is going to receive 300r before his reproductive life is over will have a better concept of what this means. One hundred generations from now need be of no concern, because conditions will probably be different than they are today and other situations will arise to correct this situation if it becomes important.

Dr. Marinelli pointed out that in many cases the 5r per capita dose has already been reached, or at least 30% of it, from background radiation.

Dr. Brues asked, as a point of information, in what sort of cell mutation occurred. Dr. Plough said that in the drosophila indications were that mutations occurred in the early spermatagonia most frequently.

At this point Dr. Mitchell said that it appeared that caution should be used in considering the permissible levels, and that he would suggest that the levels not be increased for persons in the age groups were genetic effects are concerned.

The question of inbreeding arose, and Dr. Plough said that inbreeding would certainly increase the frequency of mutations in the population.

Dr. Failla then expressed concern over whether or not something should be said in his report about the per capita dose. He feared that if the subject were ignored, rumors might do more harm than good. He believed that the truth should be told as it is known at the present time.

Mr. Binks said that the British tried to assess the various types of radiation doses in diagnostic work, in occupational work, etc., and compare these with cosmic rays. The resolutions passed at the Stockholm conference were: (a) that the dose received from radiations of all kinds to the population in Great Britain indicated that the average dose per head of the population at the present time is due to an overwhelming extent to natural radiation; (b) that despite the small amount of available data concerning the genetic effects of radiation, it is reasonably certain that exposure to radiation other than natural radiation does not constitute a significant and genetic hazard at the present time and that accordingly a figure for the dose per head of population per generation need not be stated; and (c) that such genetic evidence as is at present available indicates that in circumstances in which exposure of large populations occurs, it is necessary to apply a considerable factor of safety to reduce the permissible level below that of 0.3r per week in tissue allowed in persons occupationally exposed.

Dr. Mitchell said that this year this problem of whether or not mention should be made of the per capita dose may have to be presented at the Copenhagen conference and he was anxious to be prepared. Dr. Loutit said it appeared to be a matter of national psychology; the American view is that the individual will be alarmed about this 100r dose; the British view is that the individual will not be alarmed because it won't affect him or the first generation of offspring, and he won't care about generations beyond that.

Dr. Bugher said he suspected the Americans were probably just as unconcerned as were the British toward the fifth generation, but that they were concerned about the possibility of their own sterility.

Mr. Eisenbud did not believe the atomic energy workers in America were any more concerned about sterility than workers with fluorescent lamps had been 15 years ago - and that the scare would run its course and die down now just as it had then.

As for the wisdom and desirability of issuing some statement on genetic effects, it was finally decided that Dr. Failla would issue his report without the genetic statement, and follow this up with another report dealing only with the genetic side of the situation. He said he would try, with the assistance of the British and Canadian geneticists, to get the genetic report ready in time to present at Copenhagen.

Returning to the discussion of the factor of age in the modification of permissible dose, Dr. Mitchell felt that introducing two different levels -one for the older age group and one for the younger - would be unworkable, undesirable, and unwise. It was agreed that a single standard would be preferable.

Dr. Western favored a statement to the effect that the hazard would become less with increasing age. Dr. Morgan's views, however, differed: he feels that the hazard does not decrease at the age of 45 because in his laboratories the persons over 45 are the ones that have already accumulated the large exposures; nor did he think it desirable to completely ignore the evidence of the cataract formation.

Experimental work has revealed that doses as low as 10 reps with fast neutrons appear to produce detectable changes in the lens of the eye. With the present proposal, a person at the age of 45 could have received 46.5 reps of fast neutrons, and at the age of 70, on the order of 120 reps of fast neutrons.

Dr. Warren then presented some Japanese data on cataracts. Out of 1000 persons within 1250 meters of the hypocenter, there were 98 cases of cataract. It has been impossible to differentiate clearly between radiation cataracts and spontaneous cataracts. When the eyes of these individuals were dilated and studied with the slit lamp, of 164 individuals who had received enough radiation to cause epilation, 84% had small granules in their lenses. Of 164 controls which received no radiation, 10% had small granules in their lenses. The individuals studied were almost all relatively young.

In view of the disagreement which arose over differentiating between doses for the two age groups, it was moved that a compromise statement be accepted by this group which would read:

"After consideration of the proposed report of the United States Subcommittee in External Radiation, difficulties, administrative and otherwise, were envisaged; and therefore the conference adopted the following statement:

> In older individuals in whom genetic factors are unimportant, it may be justifiable to raise the maximum permissible dose level by a factor not exceeding two."

Upon the vote being taken on this compromise statement, there were 17 ayes and 4 nays.

b. The second item under the topic "Modification of Permissible Dose" concerned the various parts of the body.

Dr. Failla opened the discussion by stating that his subcommittee has specified three regions of the body in which the dose can be higher by a factor of five: the hands and forearms; feet and ankles; head and neck. In the latter case it was specified that the dose to the lens of the eye should not exceed the usual dose of 300 millirems. The permissible total weekly dose is specified as being 1500 millirems on the skin.

The group was asked if they felt this to be a realistic figure. Dr. Hempelmann felt it could be raised somewhat; Dr. Cipriani believed 3r per week had often been received without damage.

Dr. Brues then asked if this referred to uniform exposures. Dr. Lauriston Taylor said that if they were talking about hands and forearms it would refer to the higher exposure site, the fingertips. It was pointed out that that, however, would depend on whether or not remote control devices were used or whether gloves were worn - in those cases the area of highest exposure might be the forearms.

Dr. Failla pointed out that to guard against skin cancer, he believed 1.5r per week was as high as the dose should go. Immediate damage might not be caused by higher dose levels, but after 25 years or more at a higher rate of exposure he believed skin cancer might very probably develop. He cited a case in which a man who, having worked with radium in doses of more than 1.5r per week for a period of perhaps five years, lost his hands 25 years after he stopped work.

It was finally agreed that the comments put forth by Dr. Failla's subcommittee be adopted - that the maximum permissible dose level for the skin shall be 1500 millirems provided the total weekly dose on the lens of the eye does not exceed 300 millirems.

c. The third item under the topic "Modification of Permissible Dose" dealt with the question of limited penetration. Dr. Failla's subcommittee report stated that for radiation of very low penetrating power, the maximum permissible dose shall be 1500 millirems provided the total weekly dose on the lens of the eye does not exceed 300 millirems. "For the purpose of this rule, ionizing radiation has a very low penetrating power when the tissue dose in rems decreases with depth at the rate of at least one half per millimeter absorbed tissue, so the tissue dose in rems at a depth of three millimeters is not greater than 1/8 tissue dose in rems in the basal layer of the epidermis. This is put in because the dose of the lens of the eyes essentially at a depth of three millimeters will be reduced by a factor of 8." By this statement is inferred that the radiation of the whole body with beta rays is just the same as the radiation of hands and forearms to beta rays, the difference being that one is for very superficial beta rays and the other is for penetrating rays.

Asked if the level were safe for the cornea, Dr. Failla said it was. Dr. Morgan then questioned whether it was satisfactory to permit 1500 millirems to the entire brain. Dr. Failla pointed out that having to shield the eyes from fast neutrons would make such a dose to the brain impossible of achievement. As for the brain, there are many instances of doses up to 350r in 8 days to the cortex with no injury of any sort.

It was therefore agreed that Dr. Failla's subcommittee proposal be accepted - a permissible dose level of 1500 millirems provided the lens of the eye does not get more than 300 millirems.

4. Relative Biological Effects for Various Radiations and Tissues

The first point was to determine a base line. Dr. Failla said his subcommittee had assumed

200 KV X-rays as a base line. "We have then said that for all X-rays or any ionizing particle with a specific ionization less than "x" we shall assume that the R.B.E. is 1. For any ionizing particle, irrespective of whether it is alpha, beta, protons, deuterons, or what not, for which the specific ionization is higher, we give a set of figures which run like this. This is ion pairs per micron in water:

100 or less	-	an R.B.E. of 1
100 to 200	-	an R.B.E. of 1 to 2
200 to 650	-	an R.B.E. of 2 to 5
650 to 1500	-	an R.B.E. of 5 to 10
1500 to 5000	-	an R.B.E. of 10 to 20"

Dr. Mitchell felt unhappy about taking 100 ion pairs per micron tracks in water as a base for specific ionization when most clinical evidence was based on 200-250 KV X-radiation. He felt it would be better to "Specify that we are referring to filtered 250 KV X-radiation and use the specific ionization as an intermediate without referring to it as the basic standard". He felt that "if we are going to radiate with less specific ionization, we may go to gamma rays of radium and even X-rays where the R.B.E. is less than one, because you may be needing larger amounts of radiation to give you some of the same biological effects perhaps even by factors of 1.5 or so. Our own results with the 30 MeV Brems-strahlung shows that there is very little difference in going from that up to 30 MeV."

Dr. Marinelli stated that specific ionization could not very well be defined in water.

Dr. Mitchell then asked if anyone had any new experimental evidence which might help in resolving the difficulties in interpretation of specific ionization. Dr. Langham reported that for the past three years the Los Alamos Scientific Laboratory had been trying to determine the R.B.E. of various radiations, using as a principal source the homogeneous reactor which gives a mixture in the thermal column for approximately 4 MeV gamma rays plus neutrons of approximately .025 electron volts. They determined the R.B.E. of the 4 MeV gamma rays and found it to be about 0.8; the R.B.E. of cobalt gammas was not significantly different from 250 KV X-ray; the R.B.E. of the proton occurring from slow neutron reaction with nitrogen was approximately 2; the R.B.E. of the sodium beta was rather accurately determined to be 1.4; the R.B.E. of the tritium beta was between 1.3 and 1.6 depending on the method used; and for the alpha particles, the R.B.E. was determined to be approximately 1. Although the various radiations varied in specific ionization by great orders of magnitude, they were unable to show any particular correlation between R.B.E. and specific ionization. The principal methods used for establishing the foregoing R.B.E.'s were: (1) lethality in mice; (2) decrease in the weight of the spleen of mice; (3) decrease in the weight of the thymus of mice; and (4) effect of the radiation on the rate of uptake of Iron-59 by the red blood cells. The only place where they failed to come out with something approaching an R.B.E. of 2 or less was when they used cataract in mice as a criterion - here the R.B.E. with thermal neutrons was approximately 6. Dr. Langham stated that in this latter case LASL was postulating that this could be a decrease in the sensitivity of the eye to X-ray rather than an increase in the sensitivity of the neutron because they have demonstrated that any agent which protects against X-ray by virtue of producing anexia fails to protect against neutrons. "This would mean that something like the lens of the eye, which is potentially an anexic organ because it has no blood supply, could be less sensitive to X-ray instead of more sensitive to neutrons".

Dr. Brues presented some material on fission neutrons in which the R.B.E. for killing mice was 4 or a little more, and the R.B.E. for changes of the lens was around 8.

Asked for a statement about chronic exposures with relation to acute exposures, Dr. Failla said he thought the R.B.E. in the case of the lens was considerably higher for chronic exposure than for a single dose, but he did not know how high it was. He also thought the whole principle of the R.B.E. was exaggerated.

Dr. Morgan said the cataract group thought the R.B.E. of fast neutrons increased with the distribution of dose.

Dr. Loutit said his experience with fast neutrons indicated an R.B.E. value between 5 and 10.

At this point, Mr. Eisenbud pointed out that there were two base lines being used to determine maximum permissible dose - the 0.1 microcurie of radium base, and the 300 millirem base. Using 0.1 microcuries of radium as a base, and assuming a homogeneous distribution,the dose to the bone is 10 millireps per day, or 70 per week. On this basis, converting 10 millireps per day to 300 millireps per week would result in an R.B.E. for alphas on the order of 4. Dr. Mitchell had similar calculations. However, Dr. Failla said that the trouble with this calculation is that it assumes uniform distribution of the material throughout the bone, which is known not to be the case.

Getting back to the case at hand, that of "specific ionization", Dr. Failla, when asked to prepare a table listing "type of radiation" parallel to "specific ionization" against which could be put the R.B.E. values, said that the specific ionization must be the one at the region of interest in the tissues. If that was agreeable, then the next step would be to determine the specific ionization at the region of interest, and using as a base for the R.B.E. the minimum for any ionizing particle. However, since so little is known about the biological effects in that region, a sensible compromise would be to choose the region in which the specific ionization does not vary appreciably, and call that 1. By doing this, some R.B.E.'s will have values less than 1.

Dr. Mitchell said he thought it would be best to state the radiation as a basis and then give the specific ionization.

Dr. Morgan said that a few years ago he was enthusiastic about setting R.B.E. as a function of the specific ionization, but now he isn't so sure that the specific ionization is necessarily the important factor. He personally would prefer to have the R.B.E. taken as 1 for X-rays in the 150 KV region, and then arbitrarily take it as 5 or 10 for protons and 4 or 5 for alphas with the exception of the eye.

At this point it was suggested, and agreed, that the type of radiation and specified energies be put into the table against the type of proposed R.B.E. It was also suggested that it would be helpful to state the total body radiation effects, within a factor of 2, in the table also.

Gamma rays, beta rays, and electrons were given the basic value of 1.0.

An R.B.E. of 10 was left for fast neutrons of energy not greater than 20 MeV for chronic exposure for cataract production.

Again with specific reference to cataract formation, the present value of 10 was retained as the R.B.E. for protons up to 10 MeV.

For alpha particles, it was proposed that tumer production for internal emitters be used as the criterion. Dr. Morgan said his laboratory had concluded that the R.B.E. for alpha particles was 4.

At this point Mr. Eisenbud again brought up the fact that there had to be a resolution between 300 millirems per week and 0.1 microcuries of radium. Dr. Warren then mentioned that although both 0.1 microcurie of radium and 300 millirems are amounts assumed not to do any harm, neither of them was a threshold value - they are only an assumption, and "I am quite uncertain whether they are in any sense really comparable".

Dr. Mitchell then said that he had come prepared to accept the 0.1 figure, although he was not prepared to accept the 0.3 figure because too many unknowns were involved in it.

Mr. Eisenbud then asked if they would agree that the 0.1 microcurie figure was better than the 300 millirem figure.

Dr. Marley said he wanted to hear about Dr. Langham's experiment. Dr. Langham said that since talking with Dr. Failla he was sure the experiment was bad, although results obtained at the time seemed to indicate that 1 rep of alpha particle radiation delivered to the spleen was equal to 1 rep delivered by KV X-ray.

Dr. Brues then related a radon experiment in which the R.B.E. was calculated to be between 2 and 2.5. However, Dr. Brues wondered whether the probable heterogeneous distribution of the alpha rays would not make differences of the order of 2 or 3.

Dr. Hamilton told of an experiment he made on rats and monkeys in which he used a comparison between estrogen and iodine at 600 KV X-ray. The blood count changes agree to a factor of 4 to 5, and subsequent experiments show the same factor. From the material presented for chronic exposure, Dr. Hamilton suggested the factor was 4.

At this point it seemed that the only ray of evidence that would bear on the chronic situation would be a comparison between strontium and plutonium in tumors. Dr. Brues, therefore, said that unexpectedly high activity in this comparison had led him to the conclusion that the R.B.E. is low.

Dr. Warren referred to a number of instances in which basal cell carcinomas of the forehead were treated with X-ray doses in the order of 3000 to 3500r. Among several hundred such cases, there was no incidence of bone sarcoma in the underlying bone. Dr. Failla said the same thing applied to the old radiologists who had their hands badly affected by X-rays; they never got sarcoma of the bone.

After further discussion, Dr. Hamilton proposed that the R.B.E. for alpha particles on carcinogenesis be established at 5.

II. PERMISSIBLE DOSAGES FROM INTERNAL RADIATION SOURCES

A. General Principles

1. Units and Definitions

The first item on the agenda of the March 31 session, chaired by Dr. André Cipriani, was "Units and Definitions". Discussion centered about a change in the unit in which permissible levels in air and water are expressed, the purpose being to "handle numbers that are much simpler" than the customary expression of units in millions of this or millions of that. The customary unit of measurement in the field of industrial hygiene is the "gram" or "microgram"; in toxicology units are expressed in terms of "particulates per cubic foot" or as "milligrams per cubic meter". However, the suggestion that the formerly accepted unit of measurement, "microcuries per cc", be changed to "microcuries per liter" was not accepted, and the unit of measurement remains unchanged as "microcuries per cc".

Items 2, 3, and 4 on the agenda for March 31, "Special problems presented by internally originated radiation", "Factors in tissue localization of radioactive materials", and "Factors influencing elimination of such materials", all concern the very special problems presented in determining internal hazard. Since everyone has his own ideas about the question of determining internal hazard, and since as yet there has been developed no uniform method of correlating both experimental studies and human experience, the consensus was that there is no good solution to the problem. It, therefore, was moved that discussion on the three items be deferred. The suggestion was made, however, that "...it would be a very desirable thing at some future time to take this...tolerance conference and turn it into a practical organization...which is concerned with accumulating knowledge...so we can use it for making better numbers".

5. Particulates in the Lung

The question of particulates in the lung is of great importance, for it has never been either proved or disproved that even one single insoluble radioactive particle lodged in the lung might have a reasonable chance of producing cancer. There ensued, therefore, a lengthy discussion revolving about the question: "How much of the radioactive material that one inhales is retained in the lung?" It was pointed out that the retention factor, which is an all-important aspect of inhaled particulate matter, depends on the size and solubility of the particles inhaled. To determine these two factors - particle size and solubility - several cases involving prolonged human exposure to radioactive materials were cited.

Dr. Marinelli relayed some information which had been obtained from investigations made into the case of an accidental exposure of five persons to radium sulphate. He pointed out that although the five persons had not been measured immediately after the accident and therefore the retention rate was not known, it had been ascertained, by scanning, that the half-life of the particulates concentrated in the lung ranged from a minimum of 30 days to a maximum of 180 days, with an average half-life of 120 days. Initially, all the radium in the body was accounted for in the lung; at the end of 234 days 3% remained in the lung.

Another example regarding this problem of particulates in the lung was presented by Mr. Eisenbud. He told of the examination of the lungs of a number of mill workers who had been exposed to levels of uranium oxide many times in excess of the proposed tolerance for a time sufficiently long to assume, at their deaths, that their lungs were in equilibrium with their exposure. Yet the actual concentrates found in the lung tissue were of the order of one per cent or less than what it would be predicted to be on the basis of dog experiments at the University of Rochester. He proposed that this was because lung clearances were neglected during the first few days after exposure; a time when there is very marked clearance of material from the lung. The assumption, therefore, is that the 120-day half-life spoken of by Dr. Marinelli pertains only to material in the lung for several days or longer.

From the data brought forth, it was presumed that, from three days on, the particle size was approximately five microns or smaller. As for solubility, "one gets the impression that nearly everything that gets into the lungs is soluble to some extent"; however, it was expressed that "...it is not so much the solubility as the solubility rate (which matters)"... "and the solubility rate in these cases is very high because of the enormous surface area presented and the fact that the body fluids are generally well below saturation as they are presented to the dust..."

As for the numbers, the formerly accepted retention figures, based on 100% inhalation, were: 25% immediately exhaled; 25% retained for varying lengths of time; and 50% swallowed and stopped in the upper respiratory tract. Seeking evidence for changing these numbers, it was brought out that based on Dr. Marinelli's having ascertained that the average half-life of the particulates concentrated in the lung was 120 days, the figure of 12% for the insoluble material has been used in Chicago. However, it also was noted that if the value used at Rochester based on dog experiments were used instead of 12%, it meant "...either their particles are exceedingly small or that our value of .12 doesn't apply at all in this case". It was suggested that perhaps some of this difference could be accounted for by assuming that the biological half-life was shorter than 120 days. However, Mr. Eisenbud was of the opinion that the half-life data were good data, and that he would "...not be inclined to question it so much as the concept of half-life per se when one considers that you have several mechanisms operating in the lung and the 120-day half-life pertains only to one mechanism, which presumably dominates after the material has been in the lung for an appreciable period of time." He suggested that the studies that have to be made "...will have to do with what happens in the first day or two if you have very rapid clearance for the material in that time, as I suspect you do on the basis of what we found, plus some of the animal data."

It was felt, from what had been said, that the retention figure of 25% was high and that the lung is capable of getting rid of this material in some way. It was asked, therefore, if there were sufficient evidence on which to base a reduction of this figure to 12%.

This led to a discussion on the method of calculating retention rate. Dr. Morgan pointed out that "In all of our calculations we have been working only on the equilibrium condition, and, of course, eventually we have to get around to the single intake problem". "Most of our calculations have been made on the basis of the final organ in which the material arrives...", and "...most of these isotopes, or at least a large fraction of them, deliver more dose to the lung or G.I. tract than to the final organ even under equilibrium..." "When we speak of the fraction of retention, I think it is sort of an imaginary term, because in many cases we have a very large slug going in. It doesn't stay there very long, and this 12% in this case presumably would be there." Dr. Failla pointed out, however, that it first has to be decided how much of the concentrate in the air is inhaled; and then how much of that which is inhaled is retained in the lung; and of that retained, how much is eliminated rapidly and how much remains in more or less a steady state.

As for a number on "How much is deposited in the lung?", Dr. Morgan stated that "...our committee has assumed that when you inhale insoluble dust, 50% is held up in the upper respiratory tract that has to be accounted for; 25% enters the lower respiratory tract, of which half is eliminated very shortly. Again, it may be swallowed or it may be exhaled, depending on the material." It is this latter 25% figure which it is now suggested be reduced to 12%. Since there is quite a bit of good evidence to support the theory that clearance rates of materials of low solubility appear to be identical, and since a number of human experiences indicate the 25% figure to be too high, the retention figure for the lungs was changed, by a show of hands, to 10%.

Assming 10% to be the lung retention figure, a discussion then revolved about fixing a uniform set of figures for the entire distribution of inhaled particulate material in the body. In attempting to fix a figure on how much is exhaled immediately after it is inhaled, it was pointed out that that depends on the particle size, density, and on whether the figure should apply to mouth or nose breathers. Mr. Eisenbud maintained that when a person breathes through the mouth the alveoli retention goes up with increasing particle size until at 6 microns it is almost 100%. He then presented a chart showing the differences in deposition, on the basis of mass, between mouth and nose breathers; Dr. Morgan drew a chart indicating the previously accepted values (50% in upper respiratory tract, 25% exhaled, 25% retained); and there was a discussion about the deposition of soluble and insoluble material. It was finally agreed that, where no information is available about the element involved, assuming a 100% deposit of soluble material the amount held in the upper respiratory tract (described as nose plus the ciliated bronchial epithelium) is assumed to be 50%, and 50% reaches the lower respiratory tract, of which 25% is exhaled almost immediately and 25% is retained indefinitely in the alveoli. If the material is insoluble, the figures are 50% held in the upper respiratory tract, 25% is exhaled immediately, 15% is eliminated from the lower respiratory tract in 24 hours, and 10% remains in the lungs for an indefinite period.

6. Population Considerations

This topic involves the problem of determining safe levels of disposing of waste material into water and air if discharge is made at a continuous level over a long period of time to large population groups. The recommendations made in this field are of great importance because they will not only be used in atomic energy operations but will also undoubtedly be used by private industry as a basis for discharge nearer large cities or in positions where the discharged material would go into the water supply of large cities.

Initial discussion of the problem raised the question as to a definition of the term "large populations", and it was agreed that a large population is one which is measured in millions. In determining discharge levels of radioactive material to a large population, a safety factor must be applied to conditions of plant operation. It was suggested that although this safety factor was a domestic matter which could not be agreed to on an international or national basis, agreement should at least be reached on the principle that where there is a risk to large populations a safety factor should be applied. The principle agreed to was stated as follows:

"Following accepted practice in the industrial and public health field, and in view of genetic and other considerations, it is recommended that, in the exposure to large population groups, the maximum permissible levels for radioactive isotopes accepted for occupational exposures be reduced by a reasonable factor that may be as large as ten. It is understood that such levels are in addition to the natural background."

7. Permissible Limits for Life Forms Other Than Man

Dr. Marley opened discussion on this topic by stating Britain's concern over, and requesting the United States views on, the problem of (1) the hazards to humans from drinking milk from cows which have grazed in areas where they may have assimilated strontium from the grass, and (2) the hazards to animals from the uptake of radioactive isotopes, particularly radio-iodine, from the grass. British calculations for radio-strontium and radio-iodine appear to indicate that the airborne permissible level must be reduced by "...something like a thousand to prevent injury to grazing animals as compared with the level to prevent injury to man breathing the concentrate directly".

Dr. Healy stated that experiments made at Hanford on sheep indicate that a continuous administration of 5 microcuries per day of Iodine-131 will result in no damage to the sheep. From these experiments the assumption has been drawn that 0.5 microcuries per day would be safe with a daily food intake of 8 kilograms. This amounts to a concentrate of 6 x 10^{-5} per gram on vegetation, which is higher than the previously set limit of 10^{-5}. At this point, however, Hanford ran into the problem of uptake on vegetation as compared to the breathing limit. Further experiments, however, make it appear that for vegetation at 6 x 10^{-5} microcuries per gram, an individual eating 1100 grams per day would be taking the maximum permissible amount in the thyroid. By applying the factor of 10, it has been concluded that people could eat 110 grams per day of garden produce. In view of this, a feasible limit on the vegetation of 10^{-5} microcuries per gram of iodine is proposed for man. Translating the vegetation limits to area contamination, the permissible air concentrate comes out to 10^{-13} microcuries of iodine per cubic centimeter of air. On a similar basis, the permissible limit on vegetation for cattle would be 3 x 10^{-5} microcuries per gram.

Dr. Marley pointed out that determining permissible levels for sheep was very important from the British operational point because of the risk of injury to lambs born of ewes with large concentrations of iodine in the thyroid. The British figure for sheep, arrived at by an entirely different method than that used by Hanford, is 10^{-4} microcuries per gram for vegetation, compared with the Hanford figure of 6 x 10^{-5}. Two experiments in which iodine was allowed to drift downwind across various surfaces, including grass, pointed to a deposition rate in the atmosphere of 2 x 10^{-13} and 7 x 10^{-13} microcuries per cc, compared with the Hanford figure of 10^{-13}.

It was noted that it appeared that the British and Hanford figures in this field seemed to agree (which was considered to be quite remarkable considering that local elements were the determining factor in calculations); that the Hanford practice is to control the level on vegetation to 10^{-5} and that the tolerance could be 6 x 10^{-5}; that the British figure for sheep is 10^{-4} and they have taken no account of garden produce.

As for isotopes, other than iodine, which would have to be considered, Dr. Healy reported that Hanford had had only spot difficulties with others.

It was agreed that if the acceptable criteria for human occupation in an area are met, there is no economic problem with respect to sheep.

The closing statement in the discussion of this subject was "We find it necessary, and the United States finds it necessary, to control the levels below the human level in areas where grazing animals are exposed".

B. Specific Considerations and Recommendations of Permissible Dosages

In opening the discussion on the permissible dosage levels for various radioisotopes, it was pointed out there are discrepancies between the British and American methods of calculating some of the levels due to the fact that different starting points are used. If one considers a radioactive substance which localizes in the body, one might adopt the 0.1 microcurie basis for calculation; if one considers a substance that is uniformly distributed, one might adopt the 300 milliroentgen or 0.3 rep starting point.

Dr. Mitchell stated the British viewpoint: They felt they were on safer ground in starting with the radium maximum permissible level of 0.1 microcuries and then going to the MPL for Strontium-89. If that is assessed on the basis of 0.3r/week, the tissue equivalent value is between 11 and 14. They also feel that the value of 2.0 microcuries of Strontium-89 should be retained as the MPL in the body. If one bases the original considerations on 0.3r per week for strontium, when one comes to yttrium and cerium and other bone seekers one must add a factor of 5. Then there is a further factor of 5 which must be added for inhomogeneous distribution. In connection with the radiation of the gut, there are differences of 2 or more magnitude between British and American figures. There is also a discrepancy in that the British believe the American assumption of only 3% uptake of plutonium from the gut to the spleen, considered as the organ of deposition, is low.

To recapitulate, Dr. Mitchell stated: "The International Committee on Radiation Protection proposed a maximum permissible amount of 0.1 microcurie of radium fixed in the body. In effect, this led to reducing by a factor of 5 the amount calculated to give a dose of 0.3 rep per week to the organ of concentrate. Then...we extended that principle to other elements deposited preferentially in bone, namely, yttrium, strontium, barium, cerium, and a number of others, and for yttrium and zirconium and several others this further factor of 5 allowed for uneven distribution. So that the difference between a number of the American and British values in fact includes these two factors of 5. It has a factor of 25."

It was agreed that the essential thing to do was to see if some uniformity could not be obtained in the method of calculating maximum permissible levels.

Dr. Morgan stated that in looking over the elements of the periodic table he was surprised to find that in most cases calculations show that the principal dose is received by the G.I. tract or the lungs, but that his committee had established the policy of choosing the final organ of deposition and there would have to be a meeting before any of these G.I. tract or lung phases would be changed.

Dr. Marinelli then said that although the principles expounded by the British sounded very good, it would have to be remembered that "We are doing only one class of animal, and if we assume R.B.E.'s in the human on the basis of the lower animal experience we get into contradictions. So that I would feel that the only thing we can do is if we accept the general demand both from X-rays and radium we have to say that this R.B.E. is about 5 and the two calculations become equivalent". Dr. Marley then stated that he, and the British delegates as a whole, preferred to put their trust in biological evidence.

1. Radium and Radon:

Discussion then began on establishing the MPL for radium. Dr. Brues stated that recent evidence indicated a value of 0.1 microcuries for radium as a retained dose seemed to be holding up very well. Dr. Mitchell then asked for the lowest figure which produced definite evidence of a malignant tumor. Dr. Brues believed it to be 0.7 or 0.8; Dr. Marinelli said it was 1.7; Dr. Hempelmann said they had one case of 0.8. As for non-malignant changes of deposition with smaller doses, Dr. Brues said that no individual up to 2 micrograms had sustained any serious changes.

It was unanimously agreed that 0.1 microcurie be retained as the MPL for radium.

Radon was the next element to be considered, and it was put onto the agenda because it was felt that either a choice should be made between the British value of 5 x 10^{-11} microcuries per liter and the American value of 10^{-11} microcuries per liter, or that a new value should be established.

Mr. Eisenbud stated that he believed there was no human experience on which to justify a radon tolerance - that the number of samples was inadequate, the techniques used were inadequate, and the conditions in which samples were collected lacked variety.

It was suggested that perhaps radon was not as dangerous as it was thought to be. Dr. Failla pointed out that in the old days concentrates of thorium in gas-mantle plants were much higher than 10^{-11} and no cases of cancer were detected in quite a large number of workers. Dr. Failla also said that 20-25 year veteran workers in radium dial factories had no cancer of the lung. Dr. Binks added that studies made on workers in a gas-mantle factory in London where levels of thoron were high showed no chemical evidence of damage. Mr. Eisenbud stated that a study had recently been completed of a plant employing 300 workers, 50% of whom were exposed to 150 times the thoron tolerance and 25% of whom were exposed to 700 times the tolerance. 5% of these individuals had been exposed for about 40 years; 5% for about 20 years; and 10% for ten years or longer. A careful study was made of 26 of the individuals, all of whom had 10 years or more exposure, and nothing was found to be wrong with them.

Dr. Failla then suggested a 10^{-10} microcuries per liter figure as being reasonable. It was pointed out that if this figure were being suggested for mine workers, it would be impossible to apply. However, Dr. Failla said this figure was suggested as a lifetime exposure, and that exceptions could be made for miners on the basis of a shorter exposure period (a factor of 50 was the suggested allowance for mining operations). Dr.Failla also remarked that it should be borne in mind that these recommendations were for the three countries present at the meeting and were not to be presented to the International Congress.

It was agreed that the MPL for radon, including equilibrium dust, would be changed to 10^{-10} microcuries per liter.

2. Bone Seekers:

Discussion then moved on to the topic of bone-seekers. In opening the remarks on this topic, Dr. Hamilton suggested that a discussion confined to actinium would take care of practically all of the bone seekers except strontium.

Dr. Hamilton then continued by saying that the first basic principle for estimating MPL's for bone seekers is that "...it might not be unreasonable to consider a factor of 5 as indicating the selective localization per unit of weight." The second principle is that the "...rate of loss (of actinium) from the skeleton is quite low...and (actinium) has a half life of greater than five years." Another point is that "...there is an initial high accumulation (which may be as great as 70%) in the liver following parenteral administration in a soluble state...but this half period is relatively short...on the order of 10 to 15 days and...is not as serious a problem as the continued accumulation in the skeleton." "With respect to actinium...there is the actinium daughter which has a very short life. So the loss from the skeleton is presumably very short...and the total energy released in terms of alpha particle radiation is in excess of 30 MeV, which places actinium, from that point of view, potentially more hazardous than radium by roughly the factor of 3. The lower uptake of actinium cancels this out to skeletal uptake." For "The problem of the different type of selective localization... I would put out a value of 5 in the case of actinium. In other words, the mass of the critical organ of the order of 1.4×10^3 instead of 7×10^3 grams, since it is not evenly distributed." "If one wishes to go along with these figures, it would then indicate that an upper level for Actinium-227 might be set as 0.02 microcuries for the burden of the skeleton."

When asked to enumerate what he considers the bone-seekers of importance, Dr. Hamilton said that, from a practical point of view, of the alpha emitters he would consider all of the actinide group, including actinium and excepting uranium through curium, with plutonium probably the most important. He considers strontium-90 in equilibrium with its yttrium daughter as being the next most important. Following that group, the longer half lives would be those of cerium, promethium, neodymium and praseodymium. Samarium and europium, while long-lived, are not often encountered.

Dr. Mitchell then asked Dr. Hamilton whether in comparing yttrium with strontium he felt there should be an additional factor of 5. Dr. Hamilton's reply was: "I would consider this factor of 5 for those radio-elements in which there is a high discontinuity of deposition, assuming that radium is uniformly distributed, which actually it isn't quite, and this factor of 5 is a somewhat arbitrary one." "The only factor of 5 that I would take would be the difference between being homogeneous and not being homogeneous; that is the only place where I could take a factor of 5."

On the relation between radium and strontium, Dr. Brues said that experimentally they have found no evidence on which to base a change in the figure of 10 for radon breath differences in the human being. "This factor of 10 between radon and strontium in the small animal which corresponds to the factor of 20 in the human being. The fact is that radium is twice as well retained in total in the bone."

The presently accepted British value for strontium-89, regarding the amount in the organ as 99 plus, is substantially 2.0 microcuries total body burden. The American figure for strontium-89 as compared to microcuries burden is the same as the British value - approximately 2.0. The calculated value for strontium-89, based on a tolerance of 0.3 weekly, is 11 microcuries. Applying to that a factor of 5 for non-uniformity, the value of approximately 2.0 is obtained. There seems, therefore, to be agreement between the British and Americans that the MPL for strontium-89 is 2.0 microcuries total body burden, and that for strontium-90 the 1.0 microcurie figure remains unchanged.

Following a lengthy discussion regarding the method of calculating levels for other bone seeking isotopes for which there is no biological evidence, it was finally agreed that it would be assumed that radium and strontium are uniformly distributed; that the other alpha and beta emitters are not uniformly distributed; that in the case of alpha emitters this non-uniform distribution could be called a factor of 5; and that in the case of beta emitters there is a factor of 2.5.

Re-stated for alpha emitters for which there is no biological data: "The basis is radium, with the uniform distribution. The maximum permissible amount in the body is 0.1 microcurie. In the case of the other alpha emitters which are not so uniformly distributed, we allow a factor of 5 for non-uniformity."

At this point in the discussion, the following statement was put into the form of a motion:

"Radium is assumed, for purposes of calculation, to be uniformly distributed. Other alpha emitting bone seekers are assumed to be non-uniformly distributed by a factor of 5.

"Barium, calcium, and strontium are assumed, for purposes of calculation, to be uniformly distributed. Other beta emitting bone seekers, which are trivalent, tetravalent, pentavalent metallic ions, are assumed to be non-uniformly distributed by a factor of 2.5 until more biological evidence is accumulated."

The motion was made and seconded. Dr. Marinelli voted against accepting the factor of 2.5, believing that there was not sufficient evidence to warrant accepting such a factor. It was agreed that there would be a factor involved in beta emitters, but that it would be smaller than for the alpha emitters. It was, therefore, agreed that the factor be amended from 2.5 to 1, Dr. Loutit abstaining from the vote.

3. Polonium

Discussion then turned to polonium. The accepted United Kingdom International Committee figure for polonium-210 total body burden is 0.02 microcuries. It was recommended that the figure be changed, based on biological evidence of the extreme low uptake of polonium, to 0.002 on body burden or 10^{-6} microcuries per cubic centimeter in water. The last ingestion data available on uptake of polonium from the gut was prepared by Fink in 1944. It was, therefore, decided that the data should be further examined before reaching any conclusion.

4. Thorium:

Thorium, being a newcomer, was discussed at length by Mr. Eisenbud. He pointed out that the thorium decay scheme is somewhat more complicated than the decay scheme of ordinary alpha emitters. A careful examination was made of 26 men who had worked at least 10 years in a plant engaged in the extraction of thorium nitrate and thorium oxide from sand. Results of the examinations were completely negative based on a tolerance level of 70 disintegrations per minute per cubic meter of air. Based on his findings, Mr. Eisenbud suggested that insoluble thorium oxide be put into the class of the long-life alpha emitters and be given a value of $4 \times 1.7 \times 10^{-11}$, implying that its radio-toxicity is of the same order as natural uranium. Calculating on the basis of 1 microgram per cubic meter being 1×10^{-13} microcuries per cc, the value for insoluble thorium is 500 micrograms per cubic meter and for uranium is 200 micrograms per cubic meter. This value of 500 micrograms per cubic meter was accepted as the MPL in air for insoluble thorium.

Mr. Eisenbud then proposed that the same figure be accepted for thoron as had been accepted for radon. It was agreed that the MPL for thoron in air should be 10^{-10} curies per liter, or 10^{-7} microcuries per cc.

5. Plutonium:

Plutonium-239 was the next element to be discussed. Drs. Langham and Hempelmann gave a report on studies made on 27 people who received plutonium in 1945 and whose bodies still contained amounts varying from 0.1 microgram to 1.2 micrograms with no ill effects despite an unusual type pattern of the bone. Dr. Warren pointed out that although this was reassuring from the standpoint of progress, it should be remembered that "the time to begin to worry about tumors coming up in humans is from 12 to 20 years afterwards."

Dr. Mitchell then raised the question of excretion data, and told of a case in which a man apparently swallowed (although the exact method of entry is not known) an amount of plutonium calculated to have been 50 milligrams. During the first week the average daily urine excretion exceeded the average daily urine excretion nine months later by a factor of 10^5, which made it appear "that the uptake from the gut and the proportion of the sole fraction excreted in the urine in the early stages were higher than is generally taken to be the case."

Dr. Langham then summarized by saying that "...there have been 15 cases in which plutonium has actually been injected intravenously into human subjects." From these cases have been constructed urinary and feces excretion curves through 1800 days, and equations for urine and feces excretion. The equation for determining the percent of urinary excretion per day is:

$$U \approx 0.23x^{-0.77}$$

where U = per cent of urinary excretion in per cent of injected dose per day; and x = time after examination. The curves based on this equation would indicate that the first day urinary excretion would be 0.8% of total body burden; at 5 days, 0.3%; at 270 days, 0.003%; and at 1260 days, 0.001%.

To Dr. Marley's question as to whether there are different excretion rates for a different chemical bonding or combination of the elements, Dr. Langham replied: "The only thing we have determined is that the plutonium the first day is excreted at a considerably higher rate. The plus 3 and the plus 4 are excreted essentially at the same rate, and after the first day even the plutonium which was injected as plutonium is excreted the same way as the plus 4, and we agree with Dr. Hamilton that within a few hours after gaining entrance to the body in all probability all plutonium is plus 4."

When Dr. Marley said that they had found that "urinary excretion varied inconsistently from day to day during the initial part of the event by as much as a factor of 10", Dr. Langham said that they had "never, in rats or men, observed variations from day to day other than by a factor which could be attributed to our actual errors (perhaps a factor of 2)," and that it was remarkable to him that there had been the extreme constancy of the urinary excretionary rates of plutonium.

At this point, the chairman commented that he felt "that we must turn the efforts of this committee, or a similar committee, toward the study on correlation on some of this data and uniformity...so when we get results we can really sit down and compare them, because this is the only fundamental that will ever really contribute anything to permissible exposures." In the meantime, however, he asked if anyone wanted to change the international level for plutonium.

It was finally agreed that the international tolerance MPL for plutonium-239 in the body should remain unchanged at 0.04 microcuries. It was also agreed that the fraction of ingested plutonium absorbed from the gut be set at 0.001 and that the MPL's be changed accordingly.

6. Carbon-14:

At the last meeting of the Tripartite Conference at Chalk River, the MPL set for carbon-14 was 1 x 10^{-6} microcuries per cubic centimeter for air. Dr. Brues submitted that it should be 30 times that figure. Experimental work has indicated that, based on 0.3 rep per week, and assuming a 24-hour exposure, the value should be increased by at least a factor of 10, and that exposure would have to be very extensive to hurt anyone even with the factor of 10. Thus, it was agreed that the new MPL in air for carbon-14 and CO_2 would be 10^{-5} microcuries per cc.

Considerable discussion then ensued over establishing a value for carbon-14 in water - a value which had never before been set. Dr. Brues stated that in calculating this, "one can assume less than 10% of the carbon is in exchange with the inorganic carbon of the environment." When asked if he would agree to having the value set for air and "say that the appropriate correction could hold for water", he said that "any time the assumption is based on equilibrium with the carbon, we can make the correction." Dr. Brues also stated that "the bone will turn out to be a little more critical than fat on this basis." Dr. Marley then said that he understood the method used to determine this figure "is based on the contents of the air being 0.3% and CO_2 in the air", to which Dr. Brues replied that "it is independent of the CO_2 concentrate...equilibrium takes place in the alveolar of the lung when the CO_2 concentrate is approximately constant..."

Dr. Marley also stated that he was not aware that one co[illegible] tate the amount of carbonate in any water, and Dr. Brues said: "No, but it is the amount of carbon which is taken in, turned over by the body, and the concentrate of carbonate in the blood is a relatively constant thing regardless of what is in the water." Then Dr. Marley asked if that had been taken into account in formulating the existing tolerance, and Dr. Brues' reply was: "For water, the value is calculated to give 0.3 reps per week either to the bone or to the fat, and from all this discussion I implied that this equilibrium condition would apply in either case."

At this stage of the discussion, the chairman suggested that the attempt to set a water value for carbon-14 be dropped, but Dr. Western said that such a figure was needed in waste disposal problems. However, it was agreed that the figure for air be accepted, and that Drs. Brues and Western would attempt to work out a figure for water and submit it to the conference members at a later date.

7. Tritium:

The chairman then asked if anyone had any evidence for changing the international recommendation of the R.B.E. of 1.0 for tritium. Dr. Western said that he believed the permissible concentrates for tritium in air and water were too high by a factor of 2. His reason for this belief was that experimental work shows that tritium is fairly well mixed in the body, and that assuming a large portion of the body - approximately 90% - is water, calculations based on the present international figure give about 0.6 reps per week instead of 0.3 per week.

Dr. Langham said that from a number of observations, the rate of turnover of tritium in the body water was strictly a function of water intake, and that on the basis of the "standard man" the turnover should be approximately 14 days. However, Dr. Western said the MPL value is calculated on the mean life of 10 days, which is a half-life of 7 days, but that the half-life didn't enter into the argument.

After considerable discussion on intake rates, Dr. Western remarked that he had been neglecting the fact that roughly half the water which one takes in is in the form of oxidized food; he therefore asked that his comments be withdrawn.

As regards water vapor, Dr. Langham pointed out that experiments with respect to absorption through the skin show an individual in an atmosphere of tritium water will absorb as much water through the skin as he does through his lung, and on that account the air concentrate can be changed by a factor of 2.

It was agreed that the maximum permissible level for tritium in the body be retained at 10 microcuries, but that the air tolerance concentrate be lowered by a factor of 2 to allow for skin absorption when the tritium in the air is in the form of water vapor.

The international figure for maximum concentrate, based on permissible intake of 1 microcurie complete absorption in the lungs, was 2.5×10^{-5} microcuries per cc. Dr. Morgan suggested that the figure be made into round numbers, and it was agreed that the .5 could be dropped and the new figure would be 2×10^{-5} microcuries per cc.

8. Discussion on values for argon, xenon, krypton, and cobalt-60 in water was abandoned, and the next element discussed was iodine.

9. Iodine-131:

Dr. Warren suggested raising the value for iodine-131 by a factor of 10 and then presented some sample slides on studies made in several hundred human cases with large amounts of iodine. The cases involved euthyroid individuals who had been treated for the control of cardiac decomposition. In this series there was no histologic evidence of injury at all; blood counts showed there was a relatively small effect on the blood; and of 20 pregnancies, all resulted in full-term normal children. Dr. Warren felt that from this mass of experience sufficient evidence had been gained to warrant a more liberal attitude toward iodine than had thus far been used. Dr. Mitchell, however, expressed concern that if the level were increased by a factor of 10, some organs would receive 3 reps per week; but cases of inhomogeneous distribution would result in "high spots" or areas in glands which would receive 10 reps per week, and over a period of 30 years some organs might receive as much as 15,000 reps. Dr. Warren pointed out that after 15 years of experience in treating large numbers of cases, no tumors had been produced in the thyroid gland.

A few other case histories were cited, but there was still evident concern about the relatively large doses that would ultimately accumulate. However, everyone seemed agreeable to raise the factor by 2 at this time, with the understanding that it be kept in mind that as the years go on a more liberal factor might be allowed.

Dr. Morgan then pointed out that a factor of 5 had been accepted the previous day for radiation to the head and neck. This, however, resulted in increasing the amount of external radiation from 0.3 to 1.5, and did not concern the internal and thyroid dose.

It was, therefore, agreed that the internal radiation dose for iodine-131 be increased by a factor of 2, which would change from 3 to 6×10^{-5} in water and 3 to 6×10^{-9} in air.

There then followed a "clean-up" session, a session to make a decision on two unfinished items: (1) particulates in the respiratory tract, and (2) the R.B.E. on "length of time for averaging the permissible dose".

(1) Earlier in the day it was decided that the number for the amount retained in the lung would be changed to 10%, but the misunderstanding persisted as to whether this 10% was in addition to the 50% exhaled immediately after inhalation, or whether it incorporated that. During an intermission the matter had been discussed, and two possible breakdowns of the distribution of air content of the particulate activity with insoluble and soluble materials were presented. After a lengthy discussion of differences between nose and mouth breathers, retention and deposition, solubility and insolubility, particle size, etc., the amounts shown on page 20 were adopted - i.e., for both soluble and insoluble particles, 50% is held in the upper respiratory tract for as much as 24 hours; 25% is deposited in the alveoli; and 25% is expired immediately. For soluble material, the 25% deposited in the alveoli is translocated, depending on the deposition pattern of the particular isotope. For insoluble material, 15% is eliminated within 24 hours and 105% is retained in the lungs for the half-life period of the isotope deposited.

(2) On the "length of time for averaging the permissible dose", the problem is difficult and a real one in an emergency. It is important to the Americans particularly in connection with test site operations which occasionally involve peak exposures. If the uniform rate of 0.3r per week must be adhered to and never be exceeded at any time, many test operations would be difficult, if not impossible, to perform, in spite of the fact that the total amount of radiation received over a period of time will not reach the average daily permissible level. Dr. Bugher led the discussion on this subject, and pointed out that from a genetic point of view, the total amount of radiation received is more important than the rate at which it is delivered within the range. For the immediate somatic experience, of course, the situation would be different. The Americans believe that somewhere between the maintenance of a rate never to exceed 0.3r gamma in any one week and the other extreme of building up to

the delivery of a lethal quantity there must be a practical compromise "which would enable our operations to continue without significantly increasing the hazard to the individual and at a level which is administratively and otherwise acceptable." As a temporary expedient, the American group had adopted a permissible level of 3.9r total dose over a 13-week period where the dose "is delivered in one episode or a series of episodes or continuity of exposure." It was emphasized that this concept had been adopted for test-site activities only and had not been adopted for other operations pending discussion and advice of this group.

The question before the house, therefore, is: "If we accept the idea of integration as, of course, we do...how can we extend that to several weeks...and how many is the sound space of time?"

Dr. Failla then pointed out that the dose adopted for test operations does not apply to the average radioisotope or X-ray machine user, and that in order to accept such an integrated exposure level for all conditions some reduction - perhaps a reduction of 25% in the total over the 13 weeks - must be accepted. He personally said he would be opposed "to stretching the period during which you average the dose to three months without some sort of reduction in the total". Dr. Mitchell thought the total dose should be reduced by a factor of 2.

The question of accidental exposure then arose. Dr. Failla said that for accident or emergency exposure, "if it (the dose) does not exceed 25r, then it is considered not to affect the radiation tolerance status of the individual, and, therefore, he can continue to work and can be exposed at the usual rate of 0.3r per week." In other words, in a year he could possibly get 25r plus 15r - once in a lifetime, not indefinitely.

In the event someone gets accidentally exposed, practice is to have him "stand off" from radiation work until such time as his average dose is brought down to the tolerance level of 0.3r per week.

As for Dr. Bugher's original proposition - that persons doing continuing radiation monitoring be permitted to receive the total integrated dose by quarters rather than weekly - a lengthy discussion revolved about various points raised by the proposition, but the resultant consensus of opinion seemed to be that, since this was a problem of concern primarily for atomic energy plants and did not apply to hospitals or the rest of the country and for a lifetime, and since Dr. Failla's recommendations to the National Committee on Radiation Protection seeks an extension of the integrating time only from a period of one week with an exposure of 0.3r to a period of 3-1/3 weeks with an exposure of 0.9r rather than for 13 weeks with an exposure of 3.9r, this conference would take no action on the proposal but would watch with interest the reaction of the International Committee to Dr. Failla's proposal and be guided by the general principles brought out by this discussion.

III. April 1, 1953

The April 1 session of the Tripartite Conference, chaired by Dr. Bugher, opened with the suggestion that Items A (General problems of dosimetry) and B (Special technical considerations in radiation measurement) be postponed for a not-too-distant-future conference, and that the April 1 session begin with a discussion on the Relative Biological Effect. The warning was issued that although a certain amount of factual information in this field has been developed from experimental programs, other areas involved are purely speculative and serve chiefly to orient the planning of research aimed at getting more actual data and factual information along lines which have presently been inadequately explored.

Since there had previously been very divergent opinions as to the RBE of alpha particles, Dr. Hamilton began discussion on this topic by suggesting that although evidence which had been presented at an earlier conference session indicated the value might be in the range of from 4 to 5, and that the value of 5 was finally tentatively agreed upon. In light of the RBE of 10 accepted for fast neutrons he would suggest a tentative value of 10 for alpha particles in the energy range of fast neutrons which are released from internal emitters.

Dr. Mitchell then commented that there were two separate problems for alpha particles - (1) determining the RBE for carcinogenesis, and (2) determining the RBE for heavy recoil nuclei for use in calculations in the cataract problem, and he suggested the adoption of an RBE of either 5 or 10 for alpha rays for carcinogenesis, and the retention of the RBE of 20 for heavy recoil nuclei with special reference to the cataract problem.

After considerable discussion on the 300 millirep per week vs. the 0.1 microgram of radium basis, Dr. Marley pointed out that as far as the British were concerned, the RBE for alphas was irrelevant because no alpha tolerances were calculated by this method - that although it does enable the calculations of dose in the tissue, it was not recognized as the method of estimating the permissible level for a carcinogenic agent: they rely entirely on the direct radium exponent, the amount of uptake by the skeleton.

Dr. Failla then suggested that what should be done is to assign different radio-sensitivities to different organs, because the 300 milliroentgen per week basis applies only to whole body radiation.

After a great deal of discussion, it was suggested that the discussion be summarized in this way: "For situations where we have the possibility of comparison, 0.1 microgram of radium should be the basis of reference; for heavy recoil particles in relation to cataract production, pending further information the value of 20 will be used for the RBE."

Following this, an RBE of 10 was suggested for carcinogenesis; 10 for fast neutrons for cataract production; 10 for proton recoils; and 20 for heavy ions.

The matter was left as stated, with the remark that it was not entirely satisfactory to any one person, but it pointed very clearly to the various lines of research which must be vigorously prosecuted during the next year.

A. Specific Considerations

1. Gamma radiation and X-ray:

A recommendation for gamma energies below 3 MeV was discussed earlier in the conference, but the question of values for energies above 3 MeV remains. The British recommendation, based on a suitably filtered beam, is that "the maximum permissible exposure for ionizing radiations of energies greater than 3 MeV shall be that which causes an energy absorption not greater than 30 ergs per gram in any part of the body in any one week". The RBE was believed to be somewhere about .75. Dr. Failla vigorously objected to the statement as being more restrictive than need be. Dr. Marley defended the statement by saying that "what we are doing is stating the RBE for penetrating radiation is 1.0". It was finally agreed that the conference accept an RBE of 1.0 for all X-ray energies, and 30 ergs per gram energy absorbed in the critical tissue, except for the skin and very soft radiation.

2. Neutrons of varying energies:

Both the British and Dr. Morgan's group have submitted divergent figures on this topic based on different values. The British figures took an RBE of the recoil or disintegration protons as 10 and did not allow for changes in cross-section. Despite different approaches, the British and American recommendations were very close. Dr. Mitchell proposed that the conference agree to Snyder's and Newfield's (the United States) figures, with suitable rounding off to the nearest 10. This proposal was unanimously accepted. (NOTE: The figures which were accepted are not given in the transcript.)

Since it had been urged that accidental and emergency exposure be discussed, the chairman suggested passing over the items of beta radiation and electron beams, heavy particles, and high energy mesons; in the last two cases there was insufficient information anyway, and the position on the first item was generally quite satisfactory. The suggestion was not opposed, so discussion turned to the question of occasional exposure.

B. Occasional Exposure

Dr. Failla's subcommittee envisaged certain cases in which exposure up to 25r in one episode is allowed and is assumed not to influence the radiation tolerance status of the individual; no allowances need be made later for that exposure by removing the individual from further occupational exposure at the usual rate of 0.3r per week, provided such exposure occurs only once in the lifetime of the individual. If it should happen more than one time to an individual, the case would have to be met on an individual basis, experts would have to be consulted, and the decision of the experts would be final.

At this point the chairman suggested that, in order to see how this works in practice, Dr. Marinelli give the results of the reactor incident in Chicago. The Argonne power reactor "incident" occurred at the time a cloud from a Nevada detonation passed over Chicago during a rainstorm. In this rainout there was deposited over Chicago an appreciable flood of fallout activity which was assumed by the newsmen to have emanted from the reactor incident, whereas in reality it was entirely unrelated.

As a result of the reactor incident, four persons (three male and one female) received doses of gamma rays, in reps, of 136, 127, 60 and 9 at the trunk; of 140, 148, 70 and 9 at the groin; of 200, 280, 190 and 9 at the feet. Measurements were made by three methods - the tissue chamber, carbon, and ionization. "When we used the proportional counter we got 10%; when we used the plate we got 2% if we assumed the neutron energy to be around 1 MeV." The prompt neutrons were estimated at 30%, and a reasonable estimate was that the delayed neutrons contributed a dose equal to 1% of the contribution of the fast neutrons, or 0.6 rep.

When asked about biological effects, Dr. Brues said the people involved felt reasonably well for quite a while. They did not get into the hospital until 4 hours after the accident. One of the high dose men was mildly ill during the night. Two of the people had a 50% drop in lymphocyte count. All three of the men have shown considerably depressed sperm.

When asked if sodium and phosphorus analyses were made, it was reported that they had been and that "estimates of the neutron flux are erroneous by factors of 5 or so because we didn't know the distribution very well." Of the four people involved in the accident, Dr. Brues said they were still working at the Laboratory and are presumably where they are not subject to the ordinary radiation hazards.

Asked why they were taken off the job in light of Dr. Failla's recommendation, it was stated that in the first place the people had been exposed to considerably more than 25r, and "from the purely medico-legal angle, you can justify continued exposure up to 25r: if you exceed 25r you come into a debatable zone where there is a modicum of harm that can be noticed but which probably does not seriously interfere with the total welfare of the individual until you get up to about 100r."

Dr. Cipriani then told of an accident which occurred in the reactor at Chalk River which involved two people, one of whom received an external exposure dose of 2100 milliroentgens.

Dr. Cipriani also reported that the only near case of internal exposure they had had was when a man sat on a rod for a short time and received about 4500 milliroentgens. Dr. Cipriani also said they in Chalk River had always used an emergency figure of 25r, but that "the fact that it doesn't interfere with the radiation status of the man is something new, and I am in agreement with it." They have only five or six individuals who have exceeded the average weekly dose.

Dr. Marley said that from the point of view of radiation hazard control he felt the 25r limit was a dangerous concept and that it would handicap plant operations. "The fact that we appear to take a serious view of over-exposure in the range up to 25r is a great deterrent on people, on carelessness, and and on people manipulating radioactive sources", he said. Dr. Cipriani said that biologically the 25r was acceptable to him; administratively it was another matter. Dr. Marley said he also was not disputing the biological statement, but that from the point of view of the safe conduct of atomic energy operations, it was a dangerous concept which would handicap their control considerably. Dr. Warren, however, said that it should be kept in mind that this "is not regarded as license, but that this is for an actual emergency...for example, in the civil defense field". Dr. Marley felt, however, that "it is extremely difficult to meet the different problems even if in fact there is on record the recommendation that 25r can be taken without taking any precautions about restricting exposure subsequently...in other words, it is condoned... That is the implication even if it isn't stated, and I feel we shall run into a very great problem." Dr. Warren suggested that they were talking about two different things - levels of planned emergencies such as would apply in the field of civil defense, and levels for accidents for which there can, of course, be no planning.

There was a great deal of argument on this point of administrative vs. biological effects, and it was finally suggested that if the 25r emergency dose once in a lifetime were coupled with an administrative loophole to provide for a compensatory standing off period the proposal would be more acceptable. Such a loophole would allow each individual nation to interpret the "appropriate period" as it thought best. It was felt this would make clear that exposure exceeding the permissible level is not to be treated lightly as far as the individual is concerned, and still retain the advantage of stating that a once-in-a-lifetime exposure of 25r is assumed not to influence the radiation tolerance status of the individual.

Consideration of the question of the assimilation of radioactive isotopes in wartime was then discussed. Dr. Marley led off the discussion by saying that Dr. Loutit had drawn up a table for exposure to gamma radiation indicating the biological effects for various levels of single shot exposure, and as a result had recommended that 25r be the level to which civil defense workers would operate in normal circumstances of atomic attack. If saving of life were necessary in a particular instance, up to 75r would be allowed, with a subsequent appropriate standing off period. If 25r were received in a single instance, no further exposure would be allowed for several months; and there would be a further compensating period if 75r had been given.

As for emergency tolerances for the assimilation of fission products, Dr. Marley continued, "We have computed that 30 microcuries of strontium-89 plus 150 microcuries of barium-140, which is the corresponding amount of instantaneous fission, is the maximum permissible level to which individuals should be exposed in a wartime emergency as a result of contaminated drinking water or something like that. This is body intake over the period of the episode... This figure has been used to calculate a maximum permissible tolerance for fission products in drinking water over a 10-day period." "From a normal burst, the strontium-89 would set the tolerance at that level rather than strontium-90."

The American group were asked for their computations on this topic, but since they did not have their corresponding figures with them they said they would supply them by mail. Dr. Bugher did say that experimental data seems to point very clearly to strontium to be far and away the important isotope in this system, both from the standpoint of water contamination and soil contamination.

Dr. Bugher closed the Tripartite Conference by expressing gratitude for the substantial progress made not only in a general sense but also in a specific sense. Each delegate would be given a condensation of the general discussions and a verbatim transcript of the significant actions and recommendations for his review and concurrence or correction before the minutes would be regarded as formally adopted.

* * * * *

APPENDIX 25

MISCELLANEOUS POST-CONFERENCE CORRESPONDENCE

Typical letter of invitation to participate in the conference.

Warren to Brues:

A conference to discuss radiation tolerances with United Kingdom and Canadian Representatives has been scheduled for September 29 and 30, 1939 at Chalk River, Ontario. Your presence would constitute a significant contribution to the success of the meetings. I would suggest that you be prepared to discuss fission product tolerances from the standpoint of internal emission hazard and the standard man. Naturally any material which you care to contribute on other related subjects would be most welcome.

For your information I have included a list of other invited participants and the fields for which those from the United States are being asked to assume responsibility. I urge you to make every effort to be present, since it is hoped that full participation, and full coverage of the tolerance problem, will enable us to establish a degree of agreement on working tolerance levels which will obviate, for some time at least, the need for future international conferences.

In order to facilitate the completion of arrangements, I would appreciate greatly an early indication of your availability for this conference.

Enclosure

Proposed List of Participants

Aug. 23, 1949

TOLERANCE CONFERENCE

Chalk River, Ontario

September 29 and 30, 1949

Primary Tolerance Field

G. C. Failla	-	External Radiation, Neutron
J. G. Hamilton	-	Fission products
L. Hempleman	-	Neutron, Plutonium
H. M. Parker	-	External Radiation, Fission Products
K. Z. Morgan	-	Uranium, External Radiation, Standard Man
B. S. Wolf	-	Uranium, Radon
A. Brues	-	Fission Products (Internal Emission Hazard), Standard Man
L. S. Taylor	-	External Radiation

United Kingdom Representatives

Dr. Gerard James Neary	-	Physicist in MRC Radio-biological unit unit at A.E.R.E. and Secretary of Tolerance Doses Panel of the Medical Research Council
Mr. Arthur Cyril Chamberlain	-	Senior Scientific Officer at A.E.R.E. Secretary of A.E.R.E. Tolerance Doses Committee
Dr. W. C. Marley	-	Health Physics, Harwell
Professor J. S. Mitchell		
Dr. E. F. Edson		

Tentative Agenda

August 31, 1949

A. J. Cipriani to Colonel C. A. Nelson:

I have drawn up a tentative Agenda for the Tolerance Conference to be held on September 29th and 30th, from the information received from your office and from the United Kingdom.

I feel that until all are agreed on the fundamental biological assumptions in Items 1 and 3 of this Agenda, there can be no agreement on the final points. Item 3 will not present much difficulty but Item 4 assumes the knowledge of the metabolic behaviour of a large number of elements.

I am sending this Agenda to you so that it may be passed on to your representatives for modification as they see fit.

TOLERANCE CONFERENCE

To be held at Chalk River
September 29th & 30th, 1949.

Tentative Agenda

1. Standard Man.

   a. Mass of organs.
   b. Chemical composition.
   c. Physiology.
   d. Working time.

2. Relative Biological Efficiency.

   a. Protons.
   b. Alpha particles.
   c. Fast neutrons.
   d. Slow neutrons.

3. Permissible Exposure to External Radiation
   - Fast neutrons, slow neutrons, beta-gamma.

   a. Whole body, long continued exposure.
   b. Whole body, single exposure.
   c. Hands, long continued exposure.
   d. Head, long continued exposure.

4. Internal Irradiation by:-

   Group I — Radium, Radon, Uranium, Plutonium, Thorium, Polonium.

   Group II — Fission Products.

   Group III — H^3, C^{14}, Na^{24}, P^{32}, S^{33}, A^{41}, Sr^{89}, Sr^{90}, I^{131}, Co^{60}.

   a. Amount of radioisotope permitted fixed in the body.
   b. Concentration of radioisotope in inspired air.
   c. Concentration of radioisotope in drinking water.
   d. Amount of radioisotope permitted to enter body in a single dose.

October 11, 1949

To: Subcommittee on Permissible Internal Dose (NCRP)

From: Karl Z. Morgan, Chairman

Subject: The Meeting of the Radiation Protection Committees of the United States, Great Britain and Canada, in Chalk River, Canada, September 29 and 30, 1949

I had not intended to prepare and send out any notes on the above meeting until the official minutes were distributed. However, a number of questions have arisen and in order not to delay the work of our committee I am sending out information listed in Tables I through V which bears upon the work of our committee. This information was copied somewhat casually on my part and I cannot vouch for its complete accuracy, but I think most of the values given are correct.

First of all, regarding my letter to Dr. C. H. Perry of September 28, 1949, you will note that the value agreed upon for the rate of breathing is 10×10^6 cc/8 hr. day and 20×10^6 cc/24 hr day, which values are considerably higher than those which I had recommended, and the value of 10×10^6 cc/8 hr day corresponds to the breathing rate if a man walks about 35 miles in 8 hours. This objection was pointed out at the meeting and these new values agreed upon in spite of the objection. For uniformity in calculation I would like to recommend, however, that we accept these higher values which add an additional factor of safety in our calculations. You will note further that the rate of urine excretion was agreed upon as 1,500 cc/day instead of 1,300 and that the water intake rate (exclusive of oxidation) agreed upon was the same as we suggested, namely 2,200 cc/day.

Incidentally, while referring to my letter of September 28, the equation $f_e = f_1 + f_2$ in the third paragraph on page 3, was intended to be as follows: $f_e = f_1 \times f_2$.

Most of the weights of the body organs as given in Table IV are in substantial agreement with those indicated by Dr. H. Lisco and Miss M.J. Cook; at least there is substantial agreement for the organs that we have been concerned with so far, and if organs such as the prostate and adrenals, etc. become of importance, we can contest these weights at a later date.

# # # # # # #

To: ORNL Staff and Others　　Date: October 11, 1949

From: Karl Z. Morgan

Subject: The Meeting of the Radiation Protection Committees of the United States, Great Britain and Canada, in Chalk River, Canada, September 29 and 30, 1949

I had not originally intended sending out information concerning the meeting in Chalk River on September 29 and 30, 1949, because I had hoped that the official minutes would soon be available for circulation. However, the minutes have not yet been received, and a number of persons have raised questions which I am attempting to answer by circulating the enclosed tables of data which were agreed upon at the Chalk River meeting. These data were copied down rather hurriedly while at the same time I was busy calculating and checking the various proposed values, and it is possible that some of the figures are in error or that I may have misinterpreted some of the final conclusions. In any case, I think most of the data are correct.

There was a total of twenty-two persons representing the United States, Great Britain and Canada at the meeting. Dr. Shields Warren was chairman and head of the U. S. Delegation. Dr. J. S. Mitchell was head of the British delegation, and Dr. W. B. Lewis was head of the Canadian delegation.

Of particular interest you will note the new values of exposure to ionizing radiation listed in Table I and some of the rather unreasonably low values listed in Tables II and III. In fact, some of these values are in the sub-cosmic ray region and will be difficult to measure by our present methods of instrumentation or by any new methods of which we now conceive. Nevertheless, these values have been agreed on by the majority of representatives from each of the above-named countries and for the present at least I believe we should examine carefully our own operations with the intent of realizing these radiation safety standards as nearly as possible and at the earliest possible date.

Of course, in the interest of practical operations it may be desirable to establish minor modifications of these regulations, especially where the modifications are in the direction of greater safety. For example, at Oak Ridge National Laboratory we will continue to monitor Laboratory personnel with films and pocket meters, setting the maximum permissible exposure per week at 0.5 rem irrespective of whether the radiation is received on the hands or other portions of the body. Our survey monitoring instruments will be interpreted in such a manner that the permissible exposure will be taken as 0.3 rem/week or .06 rem/8 hr day. (Note that the permissible level in free air is 0.3 rem/week and because of backscattering the permissible level for meters worn on the body was arbitrarily taken as 0.5 rem/week.

Several modifications have been made in the "standard man" which will affect our calculations somewhat, but there are no substantial changes in the masses of the body organs that are used frequently in our calculations. The breathing rate is undoubtedly high, but in the interest of uniformity in calculations I would suggest that we accept these values for the standard man at present.

When the official minutes of the meeting become available, I will send you a copy.

Enclosures (5)

cc: A. M. Weinberg
C. N. Rucker
E. J. Murphy
D. C. Bardwell
A. H. Snell
J. A. Swartout
A. M. W. (Tech. Div.)
A. Hollaender
J. H. Frye
J. S. Felton
L. B. Emlet
F. Western
C. E. Center, K-25
H. F. Henry, K-25
A. H. Holland, AEC
J. H. Roberson, AEC
M. C. Leverett, NEPA
E. G. Struxness, Y-12
F. P. Cowan, Brookhaven
L. L. German, Knolls
H. C. Hodge, Rochester
N. Garden, Berkeley
J. E. Rose, Argonne
J. P. Bradley, Dayton
E. C. Barnes, Westinghouse
W. H. Sullivan, USN
Stafford Warren, UCLA
Capt. J. A.Hilcken, USA

VALUES AGREED UPON AT A MEETING BETWEEN THE U.S., CANADIAN AND BRITISH REPRESENTATIVES OF THE RADIATION PROTECTION COMMITTEES OF THE RESPECTIVE COUNTRIES, HELD AT CHALK RIVER, CANADA, SEPT. 29-30, 1949

Table I

Maximum Permissible Tissue Dose Limits in "Reps" per Week

(does not guarantee no damage)

Based on experience in lack of damage from 200 Kv X-rays.

Type of Radiation	At Any Point Within the Body (rep)	RBE*	In the Basal Layer of the Epidermis	
			Exposure of Entire Body	Exposure of Hands Only
X-rays and Gamma Rays	0.3	1	0.5	1.5
Beta Rays	0.3	1	0.5	1.5
Protons	0.03	10	0.05	0.15
Alpha Rays	0.015	20	.025	0.075
Fast Neutrons	0.03	10	0.05	0.15
Thermal Neutrons	0.06	5	0.1	0.3

* RBE = Relative Biological Effectiveness.

For purposes of health monitoring, whole body exposure should be assumed when radiation is received to any portion of the body other than hands or forearms.

In the light of present knowledge no manifest permanent injury is to be expected from a single exposure of persons to 25 r or less with the possible exception of pregnant women.

Table II

Permissible Amounts of Radioisotopes that Become Fixed in the Body

(Values agreed on at the Chalk River Conference)

Element	Minimal Damage (Amount Continuously Present in the Body)	Maximum Permissible Amount (factor of 1/10) For Plant Personnel (Amount Continuously Present in the Body)	Maximum Permissible Amount (factor of 1/1000) For Large Centers of Population
Ra^{226}	1.0 μgm	0.1 μgm	0.001 μgm
Sr^{90} + Y^{90}	5 μc	0.5 μc (1.0 μc)*	0.005 μc
Sr^{89}	10 μc	1.0 μc (2.0 μc)	0.01 μc
U^{233}	6 μgm	0.6 μgm	0.006 μgm
Pu^{239}	1.0 μgm	0.1 μgm (0.5 μgm)	0.001 μgm
Th^{234} (UX-1)	5 μc	0.5 μc	0.005 μc
Po^{210}	0.05 μc	0.005 μc	0.00005 μc

The values in the above table are determined from the experimental evidence that the relative damage of plutonium to that of radium on the basis of microcuries in the body is:

$$\frac{Pu}{Ra} = 15$$

and the relative value for polonium is:

$$\frac{Po}{Ra} = 20$$

* Numbers parentheses, final. See memo from KZM Oct. 9, 1950.

Table III

Permissible Amounts and Concentrations of Radioisotopes that Become Fixed in the Body - as Applied to Plant Personnel*

(Values agreed on at the Chalk River Conference)

Element	Maximum Permissible Amount in Body	Maximum Permissible Concentration	
		Air	Water
H^3	10^3 μc	1×10^{-6} μc/cc	10^{-2} μc/cc
C^{14}	30 μc	10^{-6} μc/cc	-----
Na^{24}	15 μc	10^{-6} μc/cc	0.005 μc/cc
P^{32}	10 μc	2×10^{-8} μc/cc	2×10^{-4} μc/cc
S^{35}	200 μc	10^{-6} μc/cc	10^{-2} μc/cc
A^{41}	-----	10^{-6} μc/cc	-----
I^{131}	0.1 μc	10^{-9} μc/cc	10^{-5} μc/cc
Co^{60}	1 μc	2×10^{-9} μc/cc	1×10^{-5} μc/cc
Xe^{133}	-----	10^{-5} μc/cc	-----
U	-----	50 μg/m^3 3.3 c 10^{-11} μc/cc	-----
Ra^{226}	0.1 μgm	2×10^{-12} μc/cc**	4×10^{-8} μc/cc
Pu (soluble)	-----	5×10^{-12} μgm/cc	4×10^{-6} μgm/cc
Pu (insoluble)	-----	2.5×10^{-11} μgm/cc	-----
Sr^{90} - Y^{90}	-----	10^{-10} μc/cc	2×10^{-6} μc/cc
U^{233} (soluble)	-----	6×10^{-9} μgm/cc	-----
U^{233} (insoluble)	-----	2.5×10^{-11} μgm/cc	2×10^{-3} μgm/cc

*All the values in Table III are to be divided by an additional factor of safety of 100 when they are applied to large centers of population.

**Final value, 4×10^{-12} μc/cc. See memo from KZM, Oct. 9, 1950.

Table IV

Mass Distribution of the Standard Man

(Values agreed on at the Chalk River Conference)

ORGANS	PRESENT PROPOSAL (gms)	ORGANS	PRESENT PROPOSAL (gms)
Muscles	30,000	Lymphoid Tissue	700
Skeleton, Bones	7,000	Brain	1,500
Red Marrow	1,500	Spinal Cord	30
Yellow Marrow	1,500	Bladder	150
Blood	5,000	Salivary Glands	50
Gastro-Intestinal Tract	2,000	Eyes	30
Lungs	1,000	Teeth	20
Liver	1,700	Prostate	20
Kidneys	300	Adrenals	20
Spleen	150	Thymus	10
Pancreas	70	Skin and Subcutaneous Tissue	8,500
Thyroid	20		
Testes	40	Other tissues and organs not separately defined	8,390
Heart	300		

Total Body Weight 70,000 gms

Table V

Other Properties of the Standard Man

(Values agreed on at the Chalk River Conference)

WATER INTAKE PER DAY:

In food (including 300 cc water of oxidation)	1,000
As fluids	1,500
Total water	2,500
(Total water intake	2,200 cc/day)

WATER EXCRETION PER DAY:

Sweat	500
Lungs	400
Feces	100
Urine	1,500
Total	2,500 cc/day

AIR RESPIRATION:

8 hrs at work	10×10^6
16 hrs not at work	10×10^6
Total for 24 hrs	20×10^6 cc/day

RETENTION OF PARTICULATE MATTER:

Soluble - 50% stays in the lungs and 50% goes to the GI tract.

Insoluble - 25% stays in the lungs, 25% is exhaled, and 50% goes to the GI tract.

Note: For purposes of calculation the duration of life of the standard man will be assumed to be 70 years.

November 10, 1949

Langham to Morgan:

In going over a draft of the notes of the Chalk River Permissible Dose Conference, we have questioned some of the values given. Specifically, we have questioned the one given for drinking water in the case of Uranium^{233}.

Upon going back to my notes of the meeting, I find that the value I recorded is consistent with the value in the report. The report specifies that the maximum permissible amount for drinking water is 2 x 10^{-3} micrograms per cc. This calculates out to be approximately 40,000 disintegrations per minute per liter of water. This seems much higher than one would expect.

Will you please check your notes and see whether or not they are in agreement with the above value? If this value is correct, will you please tell me how they arrived at it?

# # # #

November 14, 1949

Morgan to Langham:

In reply to your letter of November 10th, 1949, I am sending you a copy of some notes I took at the Chalk River Conference, and you will see at the bottom of page three that the value 2 x 10^{-3} μgm/cc of Uranium^{233} is what I have recorded also, and is probably what was written on the board. This I believe, corresponds approximately to 2 x 10^{-5} μc/cc. If one takes the half-life of Uranium^{233}, 1.62 x 10^5 years, the equation I used for calculating the maximum permissible exposure to radioactive materials taken into the body through water is:

$$(MPC)_W = \frac{1.9 \times 10^{-3}\ W_m}{\sum(bE)rfT} \qquad \frac{1}{(1-e^{-.693\ t/t})}$$

In the equilibrium condition this gives 7.1 x 10^{-4} μc/cc calculated on the basis of damage to the kidney, or 3.1 x 10^{-3} μc/cc calculated on the basis of damage to the bone. Both of these values that I have calculated are considerably larger than the value agreed upon at Chalk River. I am assuming the half-life of Uranium in the kidney to be 5 days and in the bone to be 60 days. I am assuming further that .05% is retained by oral absorption and that 45% goes to the kidney, and 20% to the bone. I have not added any factor of safety, and am taking W in the above equation to be 0.015 reps/week, the mass, m, of the kidney as 300 grams, the mass of the bone 700 grams, and the water intake 2200 cc/day. I have assumed uniform distribution in these two body organs, and defined the rep as that amount of radiation that is absorbed in tissue to the extent of 95 ergs/gram.

It is true that the Chalk River value corresponds to about 40,000 disintegrations/minute per liter of water, but this is not considered to be serious since only a negligible fraction of this is absorbed from the G. I. tract. Therefore, I believe the Chalk River value to be on the safe side and to contain a factor of safety to take care partly of the unequal distribution of Uranium when deposited in the kidney and in the bone.

While we are discussing Uranium^{233}, I believe the value for the insoluble compounds in case of inhalation is low by a fraction of approximately 100. In other words, I believe the figure of 2.5 x 10^{-11}μgm/cc (equals approximately 2.5 x 10^{-13} μg/cc) is too low compared to the 3.3 x 10^{-11} μc/cc agreed upon for the natural Uranium. The value 3.3 x 10^{-11} μc/cc was intended to correspond to 50 μc/ cubic meter agreed upon at a meeting in Rochester on September 27th, 1949, for the soluble and for the insoluble Uranium compounds. All I can say is that this low value of 2.5 x 10^{-11} μgm/cc reflects the same policy of over-caution that was used in setting the permissible air activity for Plutonium.

I will be very glad to have you look over my notes, and if you find any errors let me know.

# # #

January 6, 1950

PERMISSIBLE LEVELS

(From Langham Files)

Recommendations of American-British-Canadian Committee, September 1949 (Langham)

Disintegrations/minute

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	2.2×10^5	-	4.4	88
Pu	1.4×10^4	1.4	0.7	(553)
Po	1.1×10^4	(12)	(35)	-
Tu	(1.3×10^4)	(6.2)	(36)	-
2% U^{234} Sol. Salt / Insol. Salt }	(1.3×10^4)	} (6.2)	(130) / (0.53)	} (4.2×10^4)
U^{233} Sol. Salt / Insol. Salt }	1.3×10^4	} (6.2)	130 / 0.53	} 4.2×10^4
T	2.2×10^9	(10^8)	2.2×10^6	2.2×10^7

*Langham's notes recorded Wolf's statement as 25 γ/cc. Probably a slip by Wolf.

January 6, 1950

PERMISSIBLE LEVELS

In use at Los Alamos

Disintegrations/minute

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	2.2×10^5	-	-	-
Pu	1.4×10^5	14	70	1400
Po	4.4×10^5	500	1400	1400
Tu	-	290	390	-
2% U^{234} Sol. Salt Insol. Salt	-	290	390	-
U^{233} Sol. Salt Insol. Salt	-	290	390	-
T	-	-	-	-

6 January 1950

PERMISSIBLE LEVELS

In use at Los Alamos

Microcuries

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	0.1	-	-	-
Pu	6.3×10^{-2}	6.3×10^{-6}	3.2×10^{-5}	6.3×10^{-4}
Po	0.2	2.3×10^{-4}	6.3×10^{-4}	6.3×10^{-4}
Tu	-	1.3×10^{-4}	1.8×10^{-4}	-
2% U^{234} Sol. Salt Insol. Salt	-	1.3×10^{-4}	1.8×10^{-4}	-
U^{233} Sol. Salt Insol. Salt	-	$(1.3 \times 10^{-4}$	(1.8×10^{-4})	-
T	-	-	-	-

# # #

6 January 1950

PERMISSIBLE LEVELS

Recommendations of American-British-Canadian Committee, September 1949 (Langham)

Microcuries

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	0.1	-	2×10^{-6}	4×10^{-5}
Pu	6.3×10^{-3}	6.3×10^{-7}	3.2×10^{-7}	2.5×10^{-4}
Po	5×10^{-3}	(5.5×10^{-6})	(1.6×10^{-5})	-
Tu	(5.7×10^{-3})	(2.8×10^{-6})	1.65×10^{-5}	-
2% U^{234} Sol. Salt } Insol. Salt	(5.7×10^{-3})	} (2.8×10^{-6})	(5.7×10^{-5}) (2.4×10^{-7})	} (1.9×10^{-2})
U^{233} Sol. Salt } Insol. Salt	5.7×10^{-3}	} (2.8×10^{-6})	6×10^{-5} 2.4×10^{-7}	} 1.9×10^{-2}
T	1000	(45)	1	10

*Langham's notes recorded Wolf's statement as 25 γ/cc. Probably a slip by Wolf

6 January 1950

PERMISSIBLE LEVELS

In use at Los Alamos

Micrograms

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	0.1	-	-	-
Pu	1.0	10^{-4}	5×10^{-4}	0.01
Po	4.4×10^{-5}	5×10^{-8}	1.4×10^{-7}	1.4×10^{-7}
Tu	-	200	270	-
2% U^{234} Sol. Salt Insol. Salt	-	.97	1.3	-
U^{234} Sol. Salt Insol. Salt	-	(1.37×10^{-2})	(1.9×10^{-2})	-
T	-	-	-	-

# # #

6 January 1950

PERMISSIBLE LEVELS

Recommendations of American-British-Canadian Committee, September 1949 (Langham)

Micrograms

Substance	Body Content	Urine (24 hr.)	Air (per m^3)	Water (per liter)
Ra	0.1	-	2×10^{-6}	4×10^{-5}
Pu	0.1	10^{-5}	5×10^{-6}	4×10^{-3}
Po	(1.1×10^{-6})	(1.2×10^{-9})	(3.5×10^{-9})	-
Tu	(8700)	(4.2)	25 *	-
2% U^{234} Sol. Salt Insol. Salt	(43)	(0.02)	(0.43) (1.8×10^{-3})	(142)
U^{233} Sol. Salt Insol. Salt	0.6	(3×10^{-4})	6×10^{-3} 2.5×10^{-5}	2
T	0.1	(4.5×10^{-3})	1×10^{-4}	1×10^{-3}

*Langham's notes recorded Wolf's statement as 25 γ/cc. Probably a slip by Wolf.

January 13, 1950

Evans to Langham:

This is in response to your letter of December 28, 1949, concerning the Chalk River Permissible Dose Conference recommendations, especially as they relate to plutonium. It is true that the only definitative quantitative data which we have on the long term effects of internal alpha emitters on humans comes from studies of chronic radium poisoning, and from a few cases of liver damage following the injection of thorotrast. You will be glad to know that the results of the last 16 years of observations of patients with radium poisoning are being written up at last. There are about 25 cases. Louis Hempelmann is now going over all of the clinical records of the patients whom Dr. Aub has seen and on whom I have made measurements, and Louie expects to have the first draft of a joint paper on these patients ready within two or three weeks. At the same time Dr. Harrison Martland is writing up all of the cases which he has seen during this period, and on which I have made radium measurements. He too hopes to have a manuscript available soon. In bold outline the results are something like this: 6 cases containing less than 1.0 μg radium are symptom free after about 25 years; 2 (?) out of 5 cases in the 1.0 to 2.0 μg domain have symptoms; 3 out of 5 patients containing 2.0 to 9 μg are symptom free after 20 to 25 years of exposure; out of 5 patients who contained more than 10 μg of radium, one who contained 18 μg of radium is dead (death certificate said leukemia), one who carried about 24 μg of radium has just died in her mid-seventies of heart disease, another who carried 10 μg of radium is alive and reasonably well, etc. Louie has all my files on these patients, and what I have just said is given from memory, and may therefore contain a few minor errors. We are all struck by the fact that the osteogenic sarcomas which Martland saw about 20 years ago are notably absent from the new series. It is presumed that this is associated with the dosages, and that the earlier patients may have contained a great deal more radium than the present survivors.

I am enclosing a reprint of the paper on "Radium Metabolism in Rats, and the Production of Osteogenic Sarcoma by Experimental Radium Poisoning" by Evans, Harris and Bunker, Am. J. Roent. 62, 353, (1944). There are some fragmentary statements on page 366 of this paper about humans, and reference 10 (Evans and Aub, to be published) refers to the clinical material which Louis Hempelmann is now working up.

It is our belief that most cases of chronic radium poisoning which are seen by physicians anywhere in the United States eventually come to the attention of Dr. Martland, or Dr. Aub, or myself, and the two series include all such cases. The number of people who carry similar quantities of radium in their skeleton but have not developed clinical symptoms is unknown. Also, the total number of people originally exposed in the luminous dial industry, by drinking radium nostrums, and by the medical administration of radium, can only be roughly estimated. Martland told me by phone yesterday that in one plant alone there were 500 to 600 workers during World War I, and that he would estimate that several thousand people had been exposed in all plants. I find that in an article on radium poisoning in the October 1933 issue of the American Journal of Public Health I said, "Due to labor turnover, probably about 800 people worked long enough to endanger their lives." Those who died in the late 1920's, and who make up the main bulk of the approximately 40 known deaths, contained large amounts of radium. The measured values at death run up to 180 μg in the body.

You asked for an estimated answer to the question "How many persons in ten thousand may be expected to be damaged by 0.1 and 1.0 μg of radium fixed in the body?" My own guess would be that none would be damaged by 0.1 μg, and that less than 10 individuals would be damaged by 1.0 μg of radium, if fixed in the body for about 30 years, which is the present limit of our actual experience. I have also asked Hempelmann and Martland to give independent estimates on your questions. Hempelmann says he "would be surprised to find more than 1 or 2" damaged out of ten thousand at 0.1 μg radium; and that he "would not be surprised to find 25 to 50 people with nonfatal, nonmalignant symptoms within 25 years" out of ten thousand at 1.0 μg radium. In making this estimate, Hempelmann presumably had in mind 1.0 μg radium content terminally, that is as seen in the series which he is now going over. As the measured half value time of radium in the human is about 45 years, this would mean that these latter individuals might have contained closer to 2 μg radium in their skeletons originally. Martland's answers to your questions are: for 0.1 μg, less than 1 case out of ten thousand exposures; and for 1.0 μg he "would be surprised to find any cases if 1.0 μg of radium was the maximum skeletal content of the individuals" out of ten thousand over a 30-year period.

You asked about rats. The enclosed reprint contains the data on these animals, and the answer to your question is that adult rats exhale 85 per cent of the radon produced by the radium contained in their skeleton.

You asked my opinion on three methods of estimating the permissible dose of plutonium. I definitely prefer methods which are based on known data from the chronic exposure of humans to internal alpha ray emitters, that is on the radium data. It is certainly necessary to include the energy delivered by the alpha rays from that portion of the radon and its decay products which are retained in the body. As you have pointed out correctly on page 2 of your letter, this definitely means that the human absorbs three times as much alpha ray energy as is represented by the radium alpha rays alone. Then if one takes the permissible radium dose as 0.1 μg radium, this corresponds energetically to 0.3 microcuries of plutonium, or 4.5 micrograms of plutonium. It is true that the details of distribution of deposited plutonium and radium differ. Robert Dudley, in our laboratory, has recently completed quantitative studies of the inhomogeneity of distribution of radium in the bones of humans who have carried several micrograms of radium chronically for several decades. The highest local concentrations which he finds correspond to ten times the local energy dissipation per gram as would be expected if the radium were absolutely uniformly distributed throughout the entire bone. I would be very much interested in comparing your data on the distribution of plutonium in human bones with the results which we have obtained on radium. Also I would think it very much worth while if you could arrange to send me a few typical bone specimens. Then we could have Dudley study these materials using exactly the same technique which he used for radium, and thus assuring strictly comparable results. I assume that this material is classified, so you will want to know that Dudley has a Q clearance, serial No. NY 5359.

I believe it is difficult or impossible to justify the use of acute toxicity experiments in attempting to estimate the relative effects of chronic exposure to radium and to plutonium. This is because the details of the over-all biological effects of the radiation may very well be quite different for acute lethal effects and for chronic effects. For example, comparing rat and man the acute whole body lethal dose of gamma radiation is nearly the same, the rat requiring about 1.5 times as much radiation. For the production of osteogenic sarcoma in chronic radium poisoning on these two species, the relative doses are dramatically different. As is shown in Table V the rat requires 150 times as much radium per kilogram of body weight as does man in order to produce similar chronic effects in a comparable fraction of the life span of the two species. The ratio would be even greater if the calculation were based on unit weight of skeleton in the two species.

Following the Research and Development Board Panel meeting at Chicago, Dr. Brues and I discussed on December 16 some aspects of the comparison of acute and chronic dosages. We did not actually discuss the plutonium problem, but I believe you will find that Dr. Brues's opinion has changed since December 15. Brues himself pointed out to the Panel that there are important but unknown differences in the biological effects of acute and chronic radiation, and that the effects of chronic radiation cannot be determined accurately from acute experiments. This point came up in connection with the report of George Sacher, who has been comparing the effects of gamma radiation on the mouse and the dog, giving both acute radiation and chronic radiation simulating RW conditions. It is found that the ratio of the acute MLD for dog to mouse is not the same as the chronic MLD when the same quality of radiation is given in the four experiments. I do not have a memorandum of the actual ratios observed in the chronic experiments, but I do recall that the results appeared compelling.

As you have pointed out, even a highly conservative calculation assuming some kind of equivalence between chronic alpha radiation, and an RBE of 20, and a whole body gamma radiation of 0.3 rep per week, leads to plutonium values of the order of 1.8 μg of plutonium. I feel that the other calculations based on the known effects for radium are much to be preferred radiobiologically. The gamma ray calculation can be used as supporting evidence if desired.

It would appear that there is a safety factor of the order of magnitude of 10 in the permissible radium value of 0.1 μg. I do not feel that in the state of our present knowledge it is justified to introduce an additional safety factor of 15 when estimating the effects of plutonium relative to radium. I do not feel that the Chalk River proposals for plutonium are "absolutely necessary to insure a sensible and reasonable protection of the personnel working with the materials in question."

In our telephone conversation you asked me to jot down some of my remarks concerning dust. A number of my earlier ideas on this subject were discussed in the colloquium on 16 April 1948 at the Sigma building. These and some supplementary calculations were written up and sent in to the H division on 30 April 1948. You may find something useful in those notes, which are unclassified, and which are headed "Chronic Radium Poisoning".

In Table I of the Chalk River Conference, there are several instances where the proposed maximum permissible amount of alpha ray emitting substances in air are even lower than the naturally occurring radioactivity. One is tempted to abandon the word "conservative", and use the word "absurd" in speaking of some of the entries in this table. To begin with, the naturally occurring radium content of ordinary rocks and soil throughout the earth's crust is 10^{-12} gms radium per gm. Simple arithmetic shows the startling but true fact that in every square mile of soil to a depth of one foot there is a total of one gram of radium, and three tons of uranium! Thorium has about three times the natural abundance of uranium in rocks and soil. Because of the longer lifetime of thorium, its contribution to the total radioactivity per gram of rock or soil is substantially equal to that of uranium. Thus in each gram of soil there are 8 alpha ray emitters of the uranium series and 6 alpha ray emitters of the thorium series, or 14 in all, and each has the specific activity of 10^{-12} curies per gram of rock.

With respect to air, I have had a long talk with Mr. Gurney of the Liberty Mutual Insurance Company, who has done a great deal of dust particle counting. Dust counts are reported in millions of particles per cubic foot of air, and all the numerical values which I refer to in the following sentences will be understood to be in these units. Under ordinary conditions of microscope illumination, magnification, etc., dust particles having a size greater than 0.8 μ are counted. About 90 per cent of all the particles usually have a mean diameter of 2 μ or less, about 10 per cent are in the range of 2 to 3 μ, and there are a very few particles on up to about 10 μ. Gurney has found that indoor air and outdoor look just about alike under the microscope, insofar as particle distribution size is concerned and also the dust found in industrial plant air is similar. Dust which is actually visible in the air, as along a country road, is ordinarily visible because of the large particles of 10 μ diameter or so, but these few large particles are accompanied by the ordinary distribution of fine particles. In respiration, the particles which are not filtered out and which actually get to the lungs are mainly those having a diameter of 2 μ or less. Normal dust counts in a city like Boston are found to be as low as 0.2 or 0.3 immediately following a rain. The counts taken on ordinary city air five stories or so above the street and on a clear, dry day, will run about 3 or 4. At the same location counts of 8 to 15 were regularly observed in Boston, even though the air looked perfectly clear to the eye, during the period of the Kansas dust storms. When dust is actually visible to the eye in the air, the particle count will be in the vicinity of 100 to well over 1,000, but the particle distribution size is substantially the same as on a clear day. The median diameter of the dust particles is about 1 μ, but because the actual volume of dust increases with the cube of the diameter of the particle, the particle size distribution is taken into account by using a diameter of 2 μ in calculating the weight of dust per unit volume of air.

Now with these data in hand we can calculate the alpha particle radioactivity of ordinary city air on a clear day. The result is that a particle count of unity (1 million dust particles per cubic foot of air) corresponds to 1 microgram of dust per liter of air. Taking the normal radioactivity of soil as given above, we come out with the figure of 10^{-14} microcuries of alpha activity per cc of air when the dust count is unity. Country air which still looks clear to the eye will have a dust count of about 10, and an alpha ray activity of 10^{-13} μc/cc, and dusty air, such as I remember so vividly at Los Alamos, will run 10^{-11} μc/cc. This is a higher value than that which is listed in Table I of the Chalk River report for plant personnel, and the Table contains a note that the maximum permissible dose for large populations is 1/100th of this amount. The tolerance proposals seem to be approaching small fractions of the alpha ray exposure which Mother Nature gives us every day. Therefore, I do not feel that these proposals are reasonable.

It should also be pointed out that the radon content of ordinary outdoor air is generally of the order of 1 to 5 x 10^{-13} curies per liter, or 10^{-10}μc Rn/cc. In addition there are the solid alpha ray decay products Ra A, Ra B, etc., which are generally deposited on dust and will augment the natural radioactive content of dust particles.

The natural radioactivity of drinking water runs in the neighborhood of 10^{-12} to 10^{-13} grams radium per gram of water. The Chalk River suggestions for the radium content of water fit for drinking by a large population is 4 x 10^{-13} grams radium per liter.

Some months ago Dr. Shields Warren was instrumental in helping me get started here a long range program on the measurement of the radium content of ordinary humans, and he has already supplied us with a number of bone samples obtained from amputations in his hospital. The National Institutes of Health have taken a great interest in this program, and we now have in addition the collaboration of Dr. Stewart, Dr. Dorn, Dr. Lorenz, and others in Washington, as well as Dr. Princi in Denver who will collect whole skeletons for us in connection with his program on environmental cancer. We look on this program as a very long range one, and hope to have some definitive numerical values, having statistical significance in, say, 3 to 5 years. I will keep you informed.

In accord with your suggestion I am sending a carbon copy of this letter to Shields Warren for his information. I would be glad to discuss these problems further with either of you at any time.

January 20, 1950

SUBJECT: RADIATION TOLERANCES PROPOSED BY THE CHALK RIVER PERMISSIBLE DOSE CONFERENCE OF SEPTEMBER 29-30, 1949

Langham to Warren:

The Technical Director of the Los Alamos Scientific Laboratory has asked the Laboratory's Health Division to prepare evidence to support the request that the tentative tolerances proposed at the Chalk River conference be carefully re-examined before any move is taken to adopt them as official AEC operating tolerance values. His request resulted from the fact that, if accepted officially, the extremely conservative tolerances proposed at the conference may have a drastic effect on the efficiency and productivity of the Los Alamos Laboratory. Their official adoption will undoubtedly force major alteration in both present and future laboratory facilities and may add millions of dollars to the cost of construction of the permanent building program now in the planning phases. In making his request for consideration of the Chalk River values, the Director stated emphatically that the operations of the Los Alamos Laboratory would be curtailed or stopped if such action were necessary to the reasonable and sensible protection of the personnel. The seriousness of this action, however, seems to be adequate reason for requesting that official adoption of the tolerances by the AEC be postponed until they have been carefully reviewed in order to make certain that the values are not unnecessarily conservative.

The tolerances which are of greatest concern to this Laboratory are those for plutonium, polonium and uranium. Los Alamos is primarily concerned with U^{235} containing 1-4 per cent of U^{234}. No tolerance was proposed at Chalk River for this material, however, if values are chosen that are consistent with those proposed for plutonium, natural uranium, and U^{233}, another very important Los Alamos operation will be seriously affected.

Since the Chalk River meeting, I have talked to and corresponded with a number of persons regarding the conference proposals and many of them agreed that re-examination of the values would seem to be highly desirable. I will try to point out in the following pages some of the reasons why reconsideration of the tolerances seems to be in order. The discussion will be confined to the body and air tolerances for those substances that are of primary concern to the Los Alamos Scientific Laboratory.

In order to emphasize the fact that the members of the Los Alamos Scientific Laboratory are not the only group who feel that values recommended at the Chalk River conference are open to question, I am including photostatic copies of letters I have received from Dr. K. Z. Morgan and Dr. Robley Evans. I have also included for your information a preliminary draft of a report covering the experiences of the Los Alamos Scientific Laboratory with the plutonium health problem.

# # #

I. Plutonium

A. Body Tolerance Dose for Plant Personnel -- The Chalk River Permissible Dose Conference tentatively proposed 0.1 μg. of plutonium as the tolerance dose for plant personnel. They arrived at this value by the following reasoning: 1.0 μg. of radium was accepted as the known or estimated fixed minimal damaging dose. The amount of plutonium equivalent to 1.0 μg. of radium was calculated merely by taking the ratio of their half lives -- $\frac{1 \times 24{,}000 \text{ years}}{1600 \text{ years}} = 15$ μg. plutonium.

Acute toxicological experiments in rats were then cited which seemed to show that plutonium on a microcurie basis was 5 to 15 times as toxic as radium. On the basis of this information, the committee chose to introduce a biological toxicity factor of 15 into the previous calculation which gave a 1 to 1 ratio between plutonium and radium (on the weight basis), resulting in an estimated fixed minimal dose of 1.0 μg. of plutonium. By continued analogy with radium, the estimated safe dose fixed in the body for plant personnel became 0.1 μg. It is the opinion of some of us that this tolerance is unnecessarily low. Some of our reasons for believing this are as follows:

1. There is little justification for introducing the biological toxicity factor of 15 since some of the prominent persons in the field believe that acute toxicity experiments have little or no relation to the establishment of a chronic tolerance dose. (See paragraph 2, page 3 of accompanying letter from Dr. Robley Evans).

2. The choice of the biological toxicity factor may be drastically dependent upon the time after injection at which one considers the results. As an example, the accompanying graph taken from the Rochester Report, UR-44, showing the relative acute toxicity of radium, plutonium and polonium shows that the relative toxicity of these various substances approach unity with increasing time. If one chooses to use the mean survival time at about twelve days after injection as a criterion of the relative biological toxicity, plutonium may be about 35 times as toxic as radium. According to this graph the relative toxicity at about 350 days should be essentially 1 to 1. In fact, the two curves

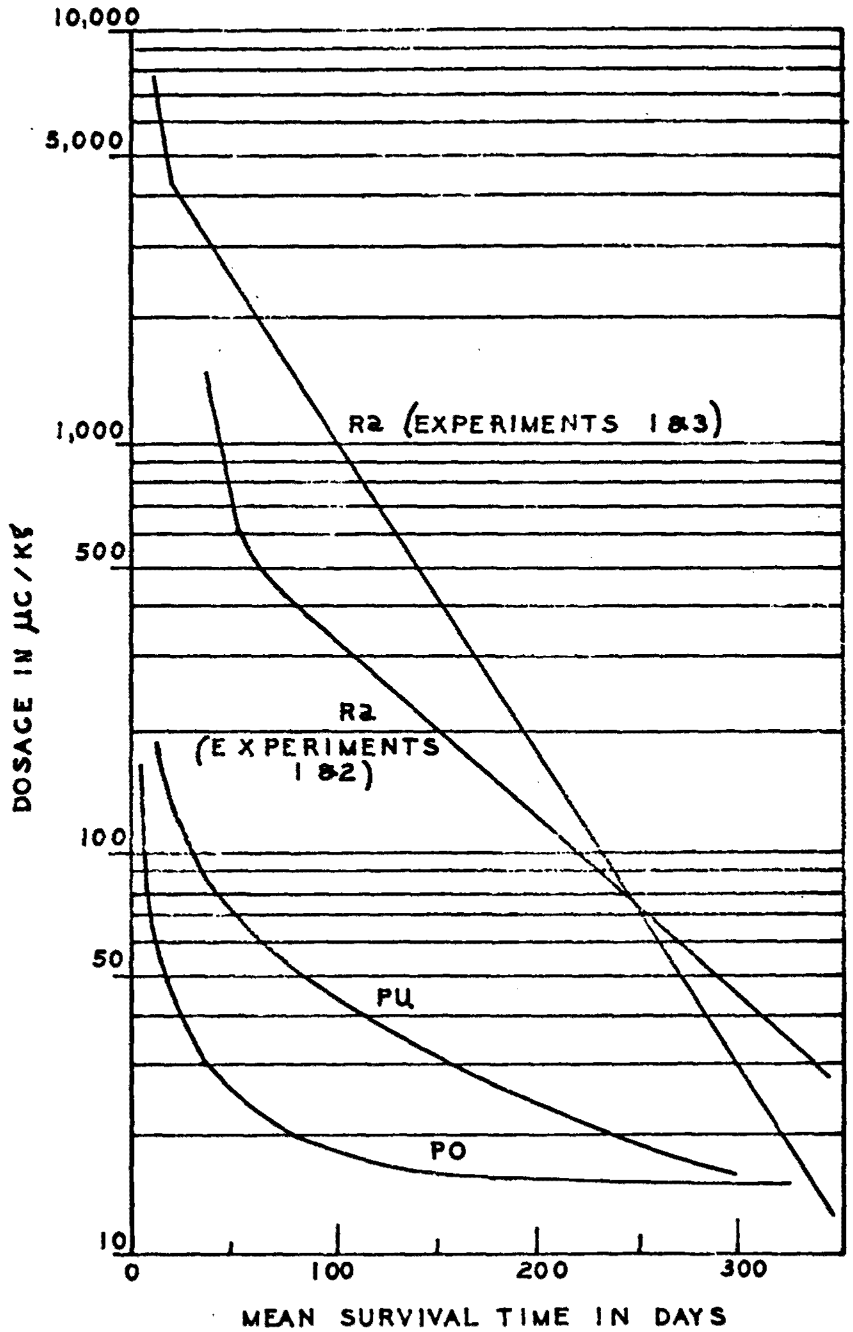

Fig. 2--From Rochester Report UR-44 by Hursh & Stannard
Survival Time of Rats vs. Microcuries of Polonium, Plutonium, and Radium Injected per Kilogram of Body Weight

may actually cross after 350 days at which time, according to this reasoning, the toxicity of plutonium may actually be less than radium. It is therefore, our belief that the biological toxicity factor of 15 has no more foundation in actual experimental observation than does any other number from 0.1 to 35 that one may care to select.

3. The method of deriving the plutonium tolerance proposed at Chalk River did not take into consideration the retention of fifty per cent of the daughter products of radium decay. This consideration will make a difference of approximately a factor of 3 in the energy ratio between radium and plutonium. The calculation should be as follows:

$$1.0\ \mu g\ Ra - \frac{2.22 \times 10^6\ d/m/\mu g}{1.4 \times 10^5\ d/m/\mu g}\left[1\left(\frac{4.8}{5.2}\right) + 0.5\left(\frac{5.5}{5.2}\right) + 0.5\left(\frac{7.7}{5.2}\right)\right] =$$

$$1.6(0.93 + 0.53 + 0.58 + 0.74) = 45\ \mu g.\ of\ plutonium$$

As can be seen from the above calculation, the relative ratios of the energy delivered to the tissues by radium and plutonium should be approximately 45 to 1 instead of 15 to 1, thereby making a difference of a factor of 3 in the calculation of an estimated fixed minimal damaging dose of plutonium from that of radium.

4. The calculation of the estimated safe dose of plutonium from other considerations gives little support to the necessity of choosing a tolerance value as low as that proposed at the Chalk River meeting. If one considers the tolerance value of plutonium from the accepted beta-gamma tolerance of 0.3 rep./wk. and the alpha-gamma RBE ratio of 20, the calculation becomes:

$$0.3\ rem/wk = \frac{0.3\ rep./wk}{20} = 10{,}000\ g. \times \frac{100}{70} \times \frac{1.54 \times 10^{-4}}{20} \times \frac{3.7 \times 10^4}{2333} = 1.8\ \mu g.pu$$

The above calculation assumes that seventy per cent of the total body content of plutonium is distributed uniformly in 10,000 grams of skeleton and that the rep. is equivalent to 93 ergs of energy per gram of tissue. An obvious objection to the above calculation is the assumption that the radiation energy is absorbed uniformly in 10,000 grams of bone. Autoradiographic studies demonstrate conclusively that this is not the case. However, Dr. Robley Evans' analyses of bone samples (see accompanying letter) from radium exposure cases demonstrate that radium is far from equally distributed in the skeletal system. In fact, he states that quantitative studies of the inhomogeneity of distribution of radium in the bones of humans who have carried several micrograms of radium chronically for several decades show that local concentrations occur which correspond to ten times that which would be expected if the radium were uniformly distributed throughout the entire bone. This inequality of the distribution of radium in the skeletal system would indicate less difference in the general pattern of deposition of radium and plutonium than has usually been considered in plutonium tolerance calculations.

Results of the analyses of nine bone samples (consisting of vertebra, sternum and rib) from persons who had received known amounts of plutonium showed an average of 0.0066% of the plutonium dose per gram of bone. On the basis of these analyses, the rep. per week delivered per gram of bone when the body contains 1 μg. of plutonium is given by the following calculation:

$$\frac{7 \times 54 \times 6.6 \times 10^{-5}\ \mu g/g \times 2333\ d/s/\mu g \times 5.15\ mev}{3.7 \times 10^4\ d/s/\mu c} = .008\ rep/wk = 0.16\ rem/wk$$

Analyses of human skeletons by Hursh, Evans and others indicate that essentially 100% of the radium content of the body is found in the bone. A calculation similar to the one above for the tolerance amount of radium (0.1 μg.) in 10,000 grams of skeleton gives the following results:

$$7. \times 54 \times 1 \times 10^{-5} \times 15 = 0.057\ rep/wk - 1.14\ rem/wk$$

According to the results obtained in the above calculation, 01 μg. of radium delivers seven times as many rem. per week per gram of bone as does 1.0 μg. of plutonium. Since radium may be unequally distributed in the bone by as much as a factor of 10, it would seem that a skeletal concentration factor of at least 70 would be necessary before 1.0 μg. of plutonium would result in a radiation intensity equal to that of radium. Experiments on rats conducted at this laboratory, comparing plutonium analyses of individual bones and portions of bones, have shown no such concentrations.

When considering the tolerance dose of plutonium it has been customary to assume that its highly selective deposition in the endosteum, periosteum and the epiphyseal junction enhances the probability of radiation damage. This may or may not be so. It is conceivable that a greater intensity of radiation to a smaller volume of tissue can be less harmful than a smaller dosage rate to a greater volume. In fact, the Chalk River group pointed out that external radiation of small areas does not seem to cause cancer and that the incidence of leukemia in mice is not significantly increased if the external radiation dosage is applied to less than one-third of the total body.

B. Air Tolerance Dose for Plant Personnel

1. "Soluble Dust" -- The value proposed at the Chalk River Conference is 3×10^{-13} μc/cc (following the conference recommendation of units) or 5×10^{-12} μgm/cc. This figure was apparently calculated as follows:

Assumptions: 0.0063 μc (= -.1 μgm) safe dose

10% retention of amount inhaled

24 hr/day, 365 day/yr exposure

30 year working exposure

No elimination

Using 20 M^3 as the daily respiration, this gives (20×10^6 cc/day x 365 day/yr x 30 yr) a total transport of 2×10^{11} cc. air through the lungs, which amount of air may contain 0.063 μc. The maximum permissible dose of 3.1×10^{-13} μc/cc is thus obtained.

It may be pointed out that the exposure time assumed in the above calculation is completely unrealistic if the result is to be applicable to the laboratory or shop. The working exposure to be used for this situation was specified by the conference to be 8 hours per day, 40 hours per week, 50 weeks per year (thus 2000 hours per year). No formal recommendation for the duration of employment was made, but it was reported to be the general opinion that twenty years was reasonable. Using these official exposure figures and the same safe dose of 0.0063 μc., we find a maximum permissible dose of 1.2×10^{-12} μc/cc air.

It is interesting to compare these figures with the natural radioactivity of air due to the dust therein. The following figures are due to Dr. R. D. Evans. Taking the radioactivity of soil as 1.3×10^{-5} μc/gm and the dust content of clear country air as 10 μg. dust per liter, we have an aerosol alpha activity of 1.3×10^{-13} μc/cc. Dusty air, as is common at Los Alamos, will run 100 times this or 10^{-11} μc/cc. In other words, the natural exposure to aerosols of alpha activity can easily exceed by a factor of thirty the Chalk River Pu^{239} tolerance.

As Dr. Evans further points out, the Rn content of ordinary air is about 10^{-10} μc/cc, in addition to the above mentioned dust activity, due to the seepage of Rn from the earth (at a rate of about 4×10^{-8} μc/cm^2 sec.). In equilibrium with this Rn will, of course, be its daughter alpha emitters which will in all probability deposit on the surface of aerial dust particles thus greatly increasing the natural aerosol activity above the value calculated in the preceding paragraph.

Measurements of the natural filterable aerosol activity of air have been made at Los Alamos by placing standard filter-type air sampling devices in Santa Fe (30 miles away) and in the mountains (10 miles away). After allowing sufficient time for the decay of any RaA and RaC' which might have been deposited on the filter by the decay of gaseous Rn, alpha activities of 3 to 300 times the proposed Chalk River tolerances were obtained. These observations of naturally occurring alpha activity in the atmosphere emphasize the extreme conservatism of the Chalk River air tolerance values. (Note also that the recommendation for large populations is 1/100 of this!)

The value of 1.2×10^{-12} μc/cc of air is calculated for a safe body dose of 0.0063 μc (0.1 μg.). If the maximum permissible dose of Pu is raised a factor of 10 (1.0 μg, 0.063 μc) as suggested previously in this letter, the calculated air tolerance becomes 1.2×10^{-11} μc/cc. At present the operating tolerance in use at the Los Alamos Laboratory is 3.2×10^{-11} μc/cc (5×10^{-10} μg/cc). During the last eight months the average air concentration of Pu in the major plutonium fabrication installation was 1.1×10^{-11} μc/cc air. This level is approximately 1/3 of our present operating tolerance but is 30 times the tolerance value proposed at Chalk River and is essentially equal to the value of 1.2×10^{-11} μc/cc calculated above on the basis of a 1 μg. body tolerance. At no time during the past eight months have the air measurements in any of the major plutonium operation areas of the Los Alamos Laboratory been below 2.3×10^{-12} μc/cc, which is a factor of 8 above the maximum permissible air level for plant personnel.

II. Uranium

A. Body Tolerance Dose for Plant Personnel --

1. Natural uranium -- Two different values for minimal damaging amounts of natural uranium were suggested at the Chalk River conference. For soluble salts, 120 μg. was proposed as the "minimal damaging dose" based on chemical toxicity to the kidney. For insoluble compounds, 150 mg. was proposed as the "minimal damaging amount" on the basis of irradiation danger to the lung. It must be assumed from the philosophy of the meeting that the maximum permissible dose of natural uranium for plant personnel

should be a factor of 10 below the above values (soluble salts, 12 μg., insoluble salts, 15 mg.).

The question immediately arises as to whether the 120 μg. value for soluble salts of natural uranium was not meant to be the maximum permissible dose for plant personnel. Howland (Ntl. Nuclear Energy Series, VI, 1 pages 993-1017) has summarized and discussed the literature on human exposure to uranium compounds. The information that was presented does not indicate the necessity of such conservatism. In fact, numerous workers were reported as excreting as much as 400 μg. per day in the urine. The body content in these cases must have been higher than 400 μg. and no symptoms of kidney damage, even of a transitory nature, were observed. Six human tracer studies conducted by Bassett, et al 'UR-37) failed to show any kidney symptoms until the dose was increased to 3910 μg. (70.9 μg/Kg body wt) of uranium as +6 acetate. Even at this dosage the symptoms were a transitory elevation in urinary protein and catalase. This dose was 33 times the minimum damaging dose proposed at Chalk River and 330 times the proposed maximum permissible limit for plant personnel. Neither do toxicological studies on animals bear out the necessity of such a low minimum damaging dose.

2. U^{233}--The maximum permissible body content of U^{233} proposed at the Chalk River conference was proposed by analogy with 0.1 μg. of Pu. The analogy is probably valid as the bone is the major site of chronic concentration and the mode and pattern of deposition of the two substances are quite similar. The proposed maximum permissible dose of U^{233} was $0.1 \times \frac{1.63 \times 10^5}{2.4 \times 10^4} =$ 0.6 μg (0.0064 μc). No consideration was made of the minor difference of 10% in energies of the alpha particles. The carrying of an additional decimal and correcting for the differences in alpha particle energy would make the value 0.73 μg.

By analogy with plutonium, the same reasoning can be used to propose a factor of 10 increase in the Chalk River value for U^{233} as was used in the case of plutonium.

3. U^{235} + 2% U^{234} -- The processing of U^{233} is not a significant operation at the Los Alamos Laboratory at the present time. The processing of U^{235} which contains approximately 2% U^{234} is, however, one of the primary operations of the Laboratory. This material has a specific activity of 1.34×10^{-4} μc/μg. By analogy with the Chalk River proposal for U^{233} the maximum body content of U^{235} + 2% U^{234} should be .0064 μc or 45 μg. This value is approximately a factor of four above the Chalk River recommendation for the maximum permissible amount of natural uranium based on damage to the kidney. By analogy with a 1.0 μg. maximum value for plutonium, the tolerance dose of U^{235} + 2% U^{234}, based on radiation hazard to the bone, would be 450 μg. The potential hazard to the bone and to the kidney created by this material seems to be of the same order of magnitude.

B. Uranium Air Tolerance

1. Natural uranium -- The maximum permissible air content of natural uranium was considerably confused in the various reports of the Chalk River Conference. The value appearing in the first and second versions gave 25 μg./cc. (1.7×10^{-11} μc/cc). Obviously one value is in error since 25 μg. of natural uranium is equivalent to 1.75×10^{-5}μc. The correct value must be 25 μg./M^3, (1.7×10^{-11} μc/cc). There is some question as to exactly how the air value for natural uranium was derived. Nothing was said regarding whether the derivation was based on the insoluble or the soluble salt body tolerance or whether it was based on the minimal damaging body dose or the maximum permissible amount for plant personnel. This matter should be cleared up before adoption of the tolerance is considered.

A value (cA) approximately that of the maximum permissible air level recommended at Chalk River may be obtained as follows:

Assume (a) 2000 working hours per year
(b) 20 year working time
(c) Respiratory exchange of 10 M^3/8 hour work day (1.25 M^3/hour)
(d) A 10% retention in the lung of all uranium in the atmosphere
(e) A lung tolerance of 150 mg. U as insoluble salts

$$1.50 \times 10^5 \ \mu g \times \frac{1}{.1} = 1.25 \ M^3/hr \times 2000 \ hr/yr \times 20 \ yr \times cA$$

$$cA = \frac{1.5 \times 10^6}{5 \times 10^4} = .3 \times 10^2 = 30 \ \mu g/M^3$$

This calculation is inconsistent, however, with the Committee's agreement to use a 25% retention figure for insoluble compounds in the lung and a maximum permissible lung content of 15 mg. of uranium.

2. U^{233} -- The maximum permissible amount of U^{233} in air for plant personnel was estimated at the conference as 6×10^{-9} μg./cc. for soluble salts and 2.5×10^{-11} μg/cc. for insoluble salts. The value for soluble salts was evidently derived by assuming a maximum permissible body content of 0.6 μg., a respiratory exchange of 10 M^3/8 hour day, an excretion half time of 60 days, and 10% absorption of the

inhaled U^{233}.

$$\frac{0.6}{0.1} = \frac{K}{\lambda} = \frac{10^7 \text{ cc/8 hr. x cA}}{\frac{0.693}{60}} = \frac{10^7 \text{ cA}}{.01}, \text{ cA} - \frac{0.06}{10^7} = 6 \times 10^{-9} \ \mu\text{g/cc.}$$

If the maximum permissible dose of plutonium can be increased by a factor of 10, then by analogy the air tolerance for soluble salts of U^{233} would become 6 x 10^{-8} μg/cc.

The proposed maximum air concentration for insoluble salts of U^{233} was derived on the basis of the amount of U^{233} required to deliver 0.3 rem/wk to 1000 grams of lung tissue assuming 25 per cent retention and no elimination, exposure of 24 hours/day and 365 days/year for a working time of twenty years. Practically every conservative step possible has been introduced into this calculation including the use of the RBE factor of 20 for alpha particles. Such conservatism seems unnecessary and can serve only to work hardship on any large scale process handing U^{233} or U^{235} + 2% U^{234}.

3. U^{235} + 2% U^{234} -- The maximum permissible air levels corresponding to the Chalk River values for U^{233} may be obtained merely by multiplying the values for the latter material by the ratios of their specific activities, as follows:

$$6 \times 10^{-9} \ \mu\text{g/cc} \times \frac{9.4 \times 10^{-3} \ \mu\text{c}/\mu\text{g}}{1.34 \times 10^{-4} \ \mu\text{c}/\mu\text{g}} = 4.2 \times 10^{-7} \ \mu\text{g/cc for soluble salts}$$

$$2.5 \times 10^{-11} \times \frac{9.4 \times 10^{-3}}{1.3 \times 10^{-4}} = 1.75 \times 10^{-9} \ \mu\text{g/cc for insoluble salts}$$

The Los Alamos Laboratory has never made any distinction between soluble and insoluble materials. The maximum permissible air level now in use is 1.3 x 10^{-6} μg/cc (1.8 x 10^{-10} μc/cc). The average of all air measurements made in all U^{235} operating areas of the laboratory during the past eight months was 3.1 x 10^{-7} μg/cc. This is a factor of about 175 times the value calculated from the Chalk River proposal for insoluble salts. The adoption of these tolerances would undoubtedly force the U^{235} metal production and fabrication operations to close down.

III. Polonium

A. Body Tolerance Dose for Plant Personnel - The maximum amount of polonium permissible in the body of plant personnel was determined at the Chalk River conference by relating polonium to radium by essentially the same reasoning as was employed in the case of plutonium.

Mention was then made of acute lethal studies in rats which compared the toxicity of radium and polonium on a microcurie basis. These studies indicated polonium was twenty times as toxic as radium, therefore, the maximum permissible dose of the latter substance was given as 0.1 μc x $\frac{1}{20}$ = 0.005 μc.

The Rochester report, UR-44 by Hursh and Stannard was mentioned, but its contents were not available or known to the Committee. The accompanying graph taken from their report emphasizes the undesirability of applying acute toxicity factors to the calculation of a chronic maximum permissible dose. As pointed out in the discussion of the plutonium body tolerance, the toxicity curves for radium and polonium approach one another rapidly with extended time of observation. If one chooses to use mean survival time at 5-10 days, the ratio of toxicity of Ra/Po may be at least 1/20. At 300-400 days, the ratio may be 1/1 and at greater times polonium may actually be much less toxic than radium. It seems that the latter ratio would be far more applicable to chronic tolerance calculations. Chronic permissible body tolerance calculations by Rose, Hursh and Stannard in which no questionable biological toxicity factors were introduced, indicate a maximum permissible body polonium content of 0.1-0.2 μc.

B. Air Tolerance Dose for Plant Personnel -- No maximum permissible polonium air tolerance for plant personnel was given in the report of the Chalk River meeting. Taking the polonium effective biological half-life value of 34 days and a body retention of 65% given by Hursh and Stannard (UR-44) and the Chalk River maximum permissible body tolerance of 0.005 μc., the maximum permissible air concentration cA, can be calculated as follows:

$$\frac{.005 \ \mu\text{c.}}{.65} = \frac{K}{\lambda} = \frac{10^7 \text{ cc air/8 hr day x cA}}{\frac{.693}{34}} = \frac{10^7 \text{ x cA}}{.0204},$$

$$\text{cA} = \frac{.005 \times .0204}{.65 \times 10^7} = 1.6 \times 10^{-11} \ \mu\text{c/cc of air}$$

If one adopts the more logical maximum permissible body tolerance of 0.1 μc., then the polonium air tolerance would be 3.2 x 10^{-10} μc/cc.

The Los Alamos Laboratory is operating at the present time with a polonium maximum permissible body tolerance of 0.2 μc. and a corresponding air tolerance of 6.3×10^{-10} μc/cc. During the past eight months the average air values in all polonium operations was 1.8×10^{-11} μc/cc. of air. On the basis of the Chalk River air tolerance the Los Alamos polonium operations would have to be closed about fifty per cent of the time.

IV. General Comments -- The preceding discussion has been for the purpose of trying to point out the possibility that a number of the tolerance values proposed at the Chalk River conferences may be unduly conservative. Special emphasis has been placed upon discussing the body and air tolerances of plutonium, natural uranium, U^{233} (and by analogy U^{235} + 2% U^{234}) and polonium. The acceptance of unnecessary conservatism in the choice of the above tolerances will definitely affect the weapons program of the Atomic Energy Commission and specifically that of the Los Alamos Scientific Laboratory. The introduction of unnecessary safety factors will also quite probably add millions of dollars to the AEC's construction of facilities and specifically to the costs of the permanent scientific laboratories being planned at Los Alamos. A sampling of the general opinion of a number of scientific personnel, both at Los Alamos and elsewhere, seems to indicate a rather widespread feeling that the tolerance values proposed at the conference are in some instances too conservative, occasionally inconsistent,, and in a few instances influenced too much by inadequate animal experimental data.

In view of these feelings it is recommended in this letter that official adoption of the Chalk River proposed values by the Atomic Energy Commission be withheld pending more careful consideration. The Chalk River conference would hardly seem to be the proper way of establishing tolerance values of such potential international significance. It was impossible to give adequate time and consideration to any one problem and in many instances much needed information was not available. It would seem more desirable to have a committee appointed to consider each radiological hazard. After adequate time for the consideration of all available information, the recommended tolerance value should then be submitted by each chairman for the approval by an international committee similar to that held at Chalk River.

Despite the large amount of animal experimentation that has been done, it seems that the most firm basis for the establishment of the tolerance values for alpha emitters is to relate them to the accepted tolerance dose for radium, introducing biological factors from animal studies only when they are well-founded on carefully performed chronic experiments. As pointed out in the accompanying photostat of a letter from Dr. Robley Evans, the maximum permissible body content of radium of 0.1 μg. is well-founded on human experiences and as more and more cases are considered, it looks more as if the tolerance value has an adequate safety factor. Dr. Evans pointed out that there was a safety factor of 10 and that everyone seemed to be struck by the fact that the osteogenic sarcomas observed a number of years ago are notably absent. This might possibly mean that the radium dosage in the earlier cases was appreciably higher than formerly surmised. He also quoted Dr. Martland as saying that the number of persons originally exposed in the luminous dial industry, etc., was probably several thousand. In view of the fact that the persons manifesting symptoms are always the ones who are called to the doctors' attention, there is little doubt that the observations of radium poisoning in humans have been made on the most susceptible individuals among the several thousand cases. This would serve to further emphasize that the maximum permissible dose of radium is a sensible and reasonably conservative basis on which to establish tolerance values for other alpha emitters.

January 25, 1950

Brues to Langham:

It was good to have a chance to discuss the question of plutonium tolerance with you in Washington yesterday.

The fact that plutonium is (per administered microcurie) approximately fifteen times as toxic as radium, appears to be borne out by the experimental facts as I outlined them yesterday, and I hope to be able to place them in a report shortly. The idea has somehow got abroad that the 15:1 ratio was based only on our acute experimental data, but this is not so, as was indicated on page 10 of the tentative Chalk River minutes (R.M.-10). Experimental data involve over 1000 rats and over 600 mice followed throughout live, plus 37 rabbits living over 400 days and 5 dogs followed up to 3-1/2 years. Data on chronic survival, radiologically determined bone damage, pathologic fractures, and bone tumors, all appear to bear out a toxicity ratio between 12 and 15. I shall therefore continue to object to the use of physical calculations to determine definitively the probability of pathologic results in our present state of ignorance as to where and through what mechanism cancer arises, not to mention our past neglect of a quantitative approach to the spatial localization of ionization in the critical tissues. These questions form a large part of our future toxicity program.

Upon thinking carefully through the derivation of human tolerance levels to plutonium, two factors appear which definitely mitigate the assumption that one microgram of fixed plutonium is equivalent to one microgram of fixed radium. 1) This ratio is based on <u>injected</u> amounts in small animals; since plutonium is about 75 percent retained and radium is about 25 percent retained; a ratio based on <u>retained</u> amounts would be improved (for plutonium) by a factor of three. 2) Since 50 percent of the radon from human deposited radium is retained for further decay and 15-20 percent of that in rodents, an additional factor of not less than two is introduced in favor of plutonium in man where the criterion is toxicity for rodents of the two respective elements. It is therefore possible to defend, on purely biologic grounds, a human tolerance for retained plutonium of 0.6 μg. This still calls for an explanation of a factor-of-ten difference between this and a physically predicted ratio. This explanation may be found in a.) the respective spatial distributions, b.) dependence of retention on time, c.) dependence of retention of dose, d.) possible impurity of radium in past clinical and experimental studies, and e.) the role of growth of decay products of radium D over a period of years, or other factors for speculation.

May I remark, parenthetically, that a human retention of 1.2 micrograms of plutonium should cause no more concern than one of 0.2 micrograms of radium, which (despite the tolerances we shoot for) is nil.

It was of great value to me to go over this material with you, and I am glad that you are going to join us in further biologic work. I hope, both personally and scientifically, that we may have ample opportunity to discuss our experimental designs.

SUBJECT: RADIATION TOLERANCES PROPOSED BY THE CHALK RIVER PERMISSIBLE DOSE CONFERENCE OF SEPTEMBER 29-30, 1949 — January 30, 1950

Langham to Warren:

As a result of the meeting Dr. Brues and I had with you and your staff in Washington on January 24, 1950, Dr. Brues has written me a letter dated January 25 in which he reaffirmed the feeling that his experimental results (even on a chronic basis) indicate a toxicity ratio between equal microcurie amounts of plutonium and radium of 12-15/1. He did, however, consider two points of significance in deriving the human maximum permissible dose of plutonium from available experimental data which were not considered at the Chalk River meeting. The two additional points were (1) the toxicity ratio was based on injected dose and not on retained dose. Therefore, a Ra/Pu retention ratio of about one-third may be introduced, and (2) the retention of approximately fifty per cent of radon by the human as compared to 15-20 per cent radon retention by the rodent would permit a factor of 2 correction in the relative alpha energy delivered from the radium chain to the human as compared to that delivered to the rodent. (i.e., for the human the energy delivered would be 4.8 + 0.5 (5.5 + 6.0 + 7.7) = 14.4 Mev. For the rodent the energy delivered would be 4.8 + 0.15 (5.5 + 6.0 + 7.7) = 7.7 Mev.) A copy of Dr. Brues' letter is appended to this memorandum for reference.

Another very significant point made by Dr. Brues is the meeting of January 24th, but not mentioned in his letter, was with regard to the air tolerance values given in the table on Page 11 of the Chalk River Report RM-10. In most cases these values were established on the basis of a thirty year working time, a 365 day year, and an exposure for twenty-four hours per day. Dr. Brues said that the notes should carry a statement that the values given were not proposed absolute working tolerances, but that actual working tolerances should be calculated therefrom to fit the various working conditions. A statement to the above effect should by all means become a part of the Chalk River Report.

If the above considerations are introduced into the calculation of the "estimated fixed minimal damaging dose" for the human in the manner proposed at Chalk River, the result is:

$$1\ \mu g\ Ra = 1 \times \frac{24{,}000}{1{,}600} \times \frac{1}{15} \times \frac{3}{1} \times \frac{2}{1} \simeq 6\ \mu g\ Pu.$$

The maximum permissible amount of retained plutonium then becomes 0.6 μg. (0.038 μc.) for the plant personnel.

After the meeting of January 24th you asked that the Los Alamos Scientific Laboratory consider their operations on the basis of a maximum permissible body content of 0.5 μg. (0.032 μc.) of plutonium. As the air and body tolerances for a number of alpha emitting substances of concern to Los Alamos were established by analogy with plutonium, it seems desirable to further consider the Los Alamos position with respect to tolerance values for other alpha emitters as well.

I. PLUTONIUM

A. Maximum Permissible Body Content for Plant Personnel -- At present the Laboratory is using a tolerance value of 1.0 μg. A tolerance exposure necessitates the quantitating of 7.0 c/m/24 hr. urine specimen assuming a urinary excretion rate of plutonium corresponding to that observed at thirty days (0.01%). A tolerance value of 0.5 μg. calls for the detection of 3.5 c/m/24 hr. sample in order to diagnose a maximum exposure. Present methods permit the detection of counts of this magnitude with about a 90 per cent confidence level. A satisfactory method of assay should, however, be able to detect considerably below the maximum permissible level in order that a worker's exposure may be assumed to be integrated over his entire employment time instead of over a thirty-day period. This point is stressed rather strongly by Dr. H. M. Parker. Present procedure at Los Alamos will not detect below 1 c/m with even a 50 per cent confidence level. Therefore, to reach a factor of 10 below the proposed tolerance of 0.5 μg. will necessitate re-equipping the assay laboratory, developing better procedures, and perhaps increasing personnel.

B. Maximum Permissible Air Level for Plant Personnel -- The maximum plutonium air level of 3×10^{-13} μc/cc (2.5×10^{-12} μg/cc) proposed at Chalk River was calculated on the basis of a 30 year working time, 365 day year, 24 hour exposure, a 10% absorption of inhaled plutonium, and a body tolerance of 0.0064 μc. (0.1 μg.).

If the calculation of the air tolerance, cA, is made on what seems to be more realistic asssumptions applicable to Los Alamos conditions, the result is as follows:

Assumptions:

(a) Maximum permissible body content, 0.032 μc. (0.5 μg.)
(b) 2000 working hours per year

(c) 20 year working time
(d) 10% absorption (although this is open to question)

The calculation is:

$$0.032 \times 10 = 2000 \text{ hours} \times 1.25 \times 10^{6} \text{ cc} \times 20 \text{ yrs} \times cA \ \mu c/cc$$

$$cA = \frac{0.32}{5 \times 10^{10}} = 6.0 \times 10^{-12} \ \mu c/cc \ (1 \times 10^{-10} \ \mu g/cc)$$

At present the operating tolerance in use at the Los Alamos Laboratory is 3.2×10^{-11} μc./cc (5×10^{-10} μc./cc.) During the last eight months the average air concentration of plutonium in the major plutonium fabrication installations was 1.1×10^{-11} μc./cc., a factor of 2 above the tolerance value calculated above (0.6×10^{-11} μc./cc.) on the basis of a plutonium body tolerance of 0.5 μg. This value could perhaps be met by instituting rigorous housekeeping and better air counting techniques. In view of Dr. Robley Evan's calculations of the alpha radioactivity of ordinary dusts, it is possible that the air values obtained at Los Alamos could be improved by installing better filtering equipment on the air intakes to the Laboratory. It is difficult, however to attach practical significance to an air tolerance value, the measurement of which requires the purification of outside air before circulating it through working areas.

In support of the argument for a less conservative air value than that proposed at Chalk River, I would like to point out the fact that even though Los Alamos has been operating with air values of the order of 10^{-11} μc./cc. (approximately 300 times that proposed at Chalk River), the urine assays of individuals working in these areas do not indicate that they are accumulating measurable amounts of plutonium.

II. <u>URANIUM</u>

A. Body Tolerance Dose for Plant Personnel

1. Natural Uranium -- As pointed out in my memorandum to you dated January 20th, the notes of the Chalk River meeting gave 120 μg. as the <u>minimal damaging dose</u> for soluble salts of natural uranium and 150 mg. as the <u>minimal damaging dose</u> for insoluble salts. Our meeting of January 24th did not clarify whether or not the former value was meant to be for the <u>maximum permissible body content</u>. I have been unable to find experimental evidence that indicates the necessity of a maximum permissible dose of 12 μg. for soluble salts of natural uranium. Consideration of the information given in UR-37, UR-82, and Vol. VI, 1, of the National Nuclear Energy series seems to indicate that 120 μg. would even be conservative as a maximum permissible dose. A dose of 3910 μg. of uranium was required to produce a transitory increase in urinary protein and catalase in a 55 kg. man. The rabbit, most sensitive of laboratory animals to uranium, required doses of 70 μg./kg. to produce similar transitory symptoms. Persons working with uranium during the war were occasionally excreting up to 400 μg. of uranium per day in the urine without any symptoms whatever of kidney damage.

The value of 15 mg. as the maximum permissible lung content of natural uranium seems to be a conservative and satisfactory value as this amount of natural uranium will deliver 0.3 rem/week to 1000 grams of lung tissue, assuming an alpha particle RBE of 20.

2. $Uranium^{233}$ -- The maximum body content of U^{233} proposed at the Chalk River conference was proposed by analogy with 0.1 μg. of plutonium. If one calculates the maximum permissible body content of U^{233} by analogy with 0.5 μg. of plutonium, the value becomes:

$$0.5 \times \frac{1.63 \times 10^{5}}{2.4 \times 10^{4}} = 3.7 \ \mu g. \ U^{233} \ (0.032 \ \mu c.)$$

3. $Uranium^{235}$ + 2% $Uranium^{234}$ -- The processing of U^{235} which contains 2% of U^{234} is one of the primary operations of the Los Alamos Laboratory. The specific activity of this material is 1.34×10^{-4} μc./μg. On the basis of analogy with the 0.5μg. (0.032 μc.) maximum permissible body tolerance for Pu (and assuming that it poses a radiological hazard to the bone instead of a chemical hazard to the kidney), the maximum permissible fixed body dose of this isotopic mixture should be 0.032 μc. or 240 μg. This value is a factor of 20 above the tolerance proposed at Chalk River for soluble salts of natural uranium provided the 120 μg. figure was meant to be an estimated fixed minimal damaging dose.

B. Uranium Air Tolerance Dose for Plant Personnel

1. Natural Uranium -- The air tolerance value of 25 μg./M^3 for natural uranium proposed at Chalk River was probably proposed by the following reasoning:

Assumptions:

(a) 24 hour exposure (20 M^3 air breathed per day)
(b) Lung tolerance concentration of 15 mg. of insoluble uranium salt based on that amount required to deliver 0.3 rem/wk. to 1000 grams of lung
(c) A 60 day biological half-time of particles in the lung
(d) A 25% deposition of all inhaled particles

The calculation then becomes:

$$15 \text{ mg.} \times \frac{1}{.25} = \frac{20\ M^3 \times cA}{\frac{0.63}{60}} = \frac{20\ M^3 \times cA,}{} \quad cA = \frac{60 \times .01}{20} = 0.03 \text{ mg}/M^3 \text{ or}$$

about 25 $\mu g/M^3$

On the basis of an eight hour working day, the value becomes 50 g./M^3 which is the air tolerance value for natural uranium presently in use at Los Alamos and elsewhere.

2. Uranium^{233} -- The maximum permissible amount of U^{233} in air for plant personnel was estimated at the Chalk River conference as 6 x 10^{-9} μg./cc. for soluble and 2.5 x 10^{-11} μg./cc. for insoluble salts. Evidently the former result was obtained by making the following assumptions:

Assumptions:

(a) Maximum permissible body content of 0.6 μg. (0.0064 μc.)
(b) Respiratory exchange of 10 M^3 per 8 hr. day
(c) An excretion half-time from the body of 60 days
(d) A 10% absorption of the inhaled U^{233} from the lung

The calculation is as follows:

$$\frac{0.6}{0.1} = \frac{10^7 \text{ cc/8hr. day} \times cA}{\frac{0.69}{60}}, \quad cA = \frac{0.06}{10^7} = 6 \times 10^{-9} \ \mu g./cc$$

The 0.6 μg. maximum permissible body content was derived by analogy with 0.1 μg. of plutonium. Therefore, to increase the maximum permissible body content of plutonium to 0.5 μg. (0.032 μc.) would result in increasing the air tolerance for U^{233} by a factor of 5, giving 3 x 10^{-8} μg./cc. There is, however, a question regarding the assumption that 10% of soluble salts of uranium are absorbed from the lung. According to Dr. Hamilton's work with the inhalation of soluble salts of plutonium, a 10% absorption rate seems to be a reasonable value. For uranium, however, the Rochester work (UR-82 and studies by Dounce) indicate that the absorption of uranyl ion from the lung may be as much as 60 to 70 per cent. The difference in absorption of the uranyl ion and the plutonyl ion may be attributed to the fact that uranium forms a soluble, stable uranyl-carbonate complex while plutonium does not. This would tend to make the air tolerance for soluble salts of uranium remain at 6 x 10^{-9} μc./cc. based on analogy with a 0.5 μg. maximum permissible body content for plutonium. What seems to be a more appropriate calculation of the air tolerance for soluble salts of Uranium^{233} is as follows:

Assumptions:

(a) Maximum permissible body content of 3.7 μg. (0.032 μc.)
(b) 66% absorption of uranyl ion from the lung
(c) 8 hours per day exposure (10 M^3 of air breathed per day)
(d) A 60 day half-time excretion from the body

The calculation is as follows:

$$3.7 \times \frac{1}{.66} = \frac{10\ M^3 \times cA}{\frac{.69}{60}} = \frac{10\ cA}{.01}, \quad cA - \frac{5.6 \times .01}{10} - .0056\ \mu g/M^3 = 5.6 \times 10^{-9}\ \mu g/cc$$

The air tolerance value for insoluble salts of U^{233} was evidently derived at the Chalk River conference on the basis of the amount of material required to deliver 0.3 rem/week to 1000 grams of lung tissue. Evidently the following assumptions were made:

(a) A 25% retention by the lung
(b) 365 days per year
(c) 24 hour exposure per day
(d) 20 year working time
(e) No chronic elimination of retained particulate matter from the lung. It should be pointed out that the last assumption is completely inconsistent with that made for the calculation of the air

tolerance for insoluble salts of natural uranium. In the latter case the biological half-time of insoluble salts in the lung was assumed to be 60 days. It would seem more logical to make the calculation for the maximum air tolerance of insoluble salts of U^{233} consistent with the calculation of the air tolerance for natural uranium. In this event the calculation would be as follows:

Assumptions:

(a) Amount of U^{233} required to deliver 0.3 rem/week to 1000 grams of lung tissue is 1.1 μg. (0.01 μc.)
(b) 25% of the inhaled particles are retained in the lung
(c) The biological half-time of particles deposited in the lungs is 60 days
(d) 8 hours exposure per day ($10M^3$ of inspired air)

The calculation is as follows:

$$1.1 \times \frac{1}{.25} = \frac{10\ M^3 \times cA}{\frac{.69}{60}},\ cA = \frac{4.4 \times .011}{10} = 0.0048\ \mu g/M^3 = 4.8 \times 10^{-9}\ \mu g/cc$$

This value seems much more reasonable than the 2.5×10^{-11} μg./cc. proposed at Chalk River. It is also consistent with the tolerance value for natural uranium and is also much more consistent with the actual working conditions.

3. $Uranium^{235}$ + 2% $Uranium^{234}$ -- The most convenient way of calculating the maximum permissible air levels for soluble and insoluble salts of U^{235} + 2% U^{234} is to multiply the corresponding values for U^{233} by the ratio of the specific activities:

$$\frac{5.6 \times 10^{-9}\ \mu g/cc \times 9.4 \times 10^{-3}\ \mu c\ of\ U^{233}/\mu g}{1.34 \times 10^{-4}\ \mu c\ of\ U^{235} + 2\%\ U^{234}/\mu g} = 4 \times 10^{-7}\ \mu g/cc \text{ for sol. salts}$$

$$\frac{4.8 \times 10^{-9} \times 9.4 \times 10^{-3}\ \mu c\ of\ U^{233}/\mu g}{1.34 \times 10^{-4}\ \mu c\ of\ U^{235} + 2\%\ U^{234}/\mu g} = 3.5 \times 10^{-7}\ g/cc \text{ for insol. salts}$$

These values correspond to 4.2×10^{-7} μg/cc. based on Chalk River proposals for soluble salts and 1.75 x 10^{-9} μg./cc. based on Chalk River proposals for insoluble salts. The Los Alamos Laboratory has never made any distinction between soluble and insoluble materials. The maximum permissible air level now in use at Los Alamos is 1.3×10^{-6} μg./cc. The average of all air measurements made in all U^{235} operating areas of the Laboratory during the past eight months was 3.1×10^{-7} μg./cc. This value is essentially equal to the tolerance values proposed by the above calculations.

III. <u>POLONIUM</u>

A. Body Tolerance Dose for Plant Personnel -- The maximum body content of polonium for plant personnel was determined at Chalk River by relating polonium to radium in essentially the same way as employed for plutonium. A biological factor of 20 was then introduced on the basis of the toxicology studies performed by Dr. Brues and associates. The maximum permissible dose, therefore, was given as follows: $0.1\ \mu c. \times \frac{1}{20} = 0.005\ \mu c.$ Po. It should be pointed out that the factor of 20 introduced into the polonium tolerance estimation at Chalk River was based on acute toxicity experiments which may have absolutely no relation to the establishment of a chronic tolerance dose.

In a telephone conversation on January 31st, Dr. Brues informed me that the results of studies of chronic toxicity of polonium should be forthcoming within a few months. It is still my feeling that theoretical considerations are as sound a basis for the establishment of a maximum permissible dose as are acute lethal studies on animals and that the maximum permissible body content of polonium should tentatively be set at 0.1 μc. If, however, we assume the acute toxicity factor of 20 between polonium and radium as valid, in extrapolating to man a factor of 2 should be allowed for the fact that animals retain 15% of the radon from radium decay, while man retains approximately 50%. The alpha energy delivered to the animal by radium decay is, therefore, 4.8 + 0.15 (5.5 + 6.0 + 7.7) = 7.7 Mev. The alpha energy delivered to man by a corresponding amount of radium would be 4.8 + 0.5 (5.5 + 6.0 + 7.7) = 14.4 Mev. This would then seem to justify changing the proposed maximum permissible body content of polonium from 0.005 μc. to 0.01 μc. This is essentially a factor of 20 below that being employed at the present time at the Los Alamos Laboratory. The adoption of 0.01 μc. as the maximum permissible dose will require the development of better methods of urine analyses for the diagnosis of exposure of personnel. The daily urinary excretion rate of polonium is approximately 0.1% of the body content (UR-44). The diagnosis of a maximum exposure of 0.01 μc. of polonium would require quantitating $\frac{0.01\ \mu c \times 2.22 \times 10^6\ d/m/\mu c}{0.001} = 22.2$ d/m/24 hour urine sample. Urine assays for polonium will have to be controlled and counted in essentially the same way as employed for plutonium.

B. Air Tolerance Dose for Plant Personnel -- no air tolerance value for polonium was proposed at the Chalk River meeting. The air concentration, cA, may be calculated, however, in the following way:

Assumptions:

(a) Maximum permissible body content, 0.01 μc.
(b) Effective biological half-life, 34 days (UR-44)
(c) Body retention of inhaled polonium, 65% (UR-44)
(d) Working time, 8 hours per day (respiratory exchange, 10 M^3)

The calculation is:

$$\frac{0.01}{0.65} = \frac{10^7 \text{ cc air/8 hr. day} \times cA}{\frac{.69}{34}}, \quad cA = 3.2 \times 10^{-11} \ \mu c./cc.$$

During the past eight months the average air values in all polonium operating areas of the Los Alamos Laboratory was 1.8×10^{-11} μc./cc., which is roughly a factor of 2 below the above calculated value.

IV. SUMMARY

In the preceding pages I have reviewed the Chalk River tolerances for alpha emitters on the basis of your agreement that the maximum plutonium content for plant personnel should be considered as 0.5 instead of 0.1 μg. I have also pointed out and tried to correct a few more inconsistencies in the Chalk River values that have come to my attention.

The information which I have presented has resulted in what seems to be reasonable and sensible tolerances for the operation of the Los Alamos Laboratory. I would, therefore, like to present for your and Mr. Bradbury's consideration the proposed tolerances given in the accompanying table as a basis for the Laboratory's health operations.

att: Table

Present and Proposed Operating Tolerances for the Los Alamos Laboratory Compared With Those Proposed at the Chalk River Meeting of September 29th - 30th, 1949

MATERIAL	MAXIMUM PERMISSIBLE BODY CONTENT, PLANT PERSONNEL			MAXIMUM PERMISSIBLE PLANT AIR LEVELS		
	L. A. Present	L.A. Proposed	C. R. Proposed	L. A. Present	L. A. Proposed	C. R. Proposed
Ra	.1 μg (.1 μc)	.1 μg (.1 μc)	.1 μg (.1 μc)	-	-	$4x10^{-12}$ μc/cc
Pu Sol.&Insol.	1 μg(.063 μc)	.5 μg(.032μc)	.1 μg(.0063μc)	$3.2x10^{-11}$ μc/cc	$6x10^{-12}$ μc/cc	$3x10^{-13}$ μc/cc
$U^{nat.}$ Sol. Salts	-	120 μg ?	12 μg	-	$2x10^{-7}$ μg/cc	[$2x10^{-8}$ μg/cc]*
Insol.Salts	15000 μg	15000 μg	15000 μg	$5x10^{-5}$ μg/cc	$5x10^{-5}$ μg/cc	$2.5x10^{-5}$ μg/cc
U^{233} Sol. Salts	-	3.7 μg(.032 μc)	.6 μg(.0063 μc)	-	$5.6x10^{-9}$ μg/cc	$6x10^{-9}$ μg/cc
Insol.Salts		1.1 μg(.011 μc)	[.2 μg(.002 μc)]*	-	$4.8x10^{-9}$ μg/cc	$2.5x10^{-11}$ μg/cc
U^{235}+ 2% U^{234} Sol. Salts	-	240 μg**	[48μg(.0063μc)]	$1.3x10^{-6}$ μg/cc	$4.x10^{-7}$ μg/cc	[$4.2x10^{-7}$ μg/cc]*
Insol.Salts	-	85 μ	[17μg(.002μc)]	$1.3x10^{-6}$ μg/cc	$3.5x10^{-7}$ μg/cc	[$1.7x10^{-9}$ μg/cc]*
Po Sol. Salts	.2 μc	.01 μc ?	.005 μc	$6.3x10^{-10}$ μc/cc	$3.2x10^{-11}$ μc/cc	[$1.6x10^{-11}$ μc/cc]*

* Results in brackets were not proposed at Chalk River but have been calculated on basis of values that were proposed for other uranium isotopes.

** Based on radiological hazard to the bone rather than chemical hazard to the kidney. If based on latter condition, value should be 120 μg.

February 4, 1950

Evans to Morgan:

This is in response to your letter of January 26 inviting me to send you copies of any written statements I had made concerning the Chalk River tables, for the use of your Subcommittee on Permissible Internal Dose. I have been in touch with Wright Langham and have his approval for sending you the enclosed copy of my letter of January 13, 1950, to him, for your use. As this is a very long letter, I would point out to you especially the consideration of the natural radioactivity of dust, on page 4 and 5, and especially paragraph 2 on page 5.

In connection with the review of all the radium poisoning cases by Hempelmann and by Martland, one very important new factor has appeared during the past week. In comparing the 24 cases which we have studied here, Hempelmann found clinical evidence which suggests a lower toxicity of radium in patients who had received injections of radium than was the case for dial painters. In fact, there seems to be no instance of injury by ingested or injected radium except when the amount retained after 20 to 30 years is above 5 micrograms of radium. The veteran dial painters, on the other hand, contain several examples of comparable bone damage, such as radiation osteitis, in persons containing about a fifth as much radium.

This stimulated a re-investigation of the amounts of mesothorium which were used in the dial paint in the early days. After about 1926, only about 20 per cent of the initial alpha activity of most of the self-luminous compounds manufactured in the United States was due to mesothorium. But prior to that time and especially between about 1916 and 1925, radium accounted for only about 20 per cent or even less of the initial alpha activity. This means that the dial painters who were exposed at that time received their principal dose from the alpha ray decay products of mesothorium, rather than radium, as was first shown many years ago by Martland. These patients now contain very little mesothorium, because of the 6.7 year half-period of this material. However, in terms of energy absorption and toxicology, mesothorium would have to be thought of as the effective agent in the dial painters from the 1916 to 1925 period. Now it was just this group of individuals who formed the basis of the decision in 1940 to fix the maximum permissible amounts of fixed radium at 0.1 microgram. It was thought that this gave a factor of safety of 10. The importance of the new information on mesothorium is that the permissible radium value of 0.1 microgram contains instead a safety factor which appears to be of the order of magnitude of 50.

Thus the data available to date suggest very strongly that there is available another factor of 5 or so in the permissible radium burden, and therefore in plutonium burden based on the human radium poisoning data.

As a result of this new information, I definitely change the estimates made in paragraph 2 of page 2 of my letter to Wright Langham to read that I would expect no injuries out of ten thousand people who initially contained a maximum of 1 microgram radium fixed in the skeleton, and who are observed thereafter over a period of 30 years.

Hempelmann is now writing up the clinical side of this radium and mesothorium study, and we are conducting here physical measurements at as rapid a pace as possible. This week Mr. Brownell has constructed apparatus for measuring the ratio of thoron to radon in the expired air. A first set of measurements have been completed using this apparatus on a veteran dial painter, who has been kind enough to come up from New Haven for this work. Although it is 25 years since her exposure, he is able to detect thoron in her exhaled breath, and in an amount which is equal to about half of the radon present in her breath. Considering the very short half-period of thoron, the fraction of thoron produced in the body which is actually successfully exhaled in the breath must be smaller than the corresponding fraction for radon. You can see that in this individual the initial mesothorium dosage must have been of the order of 10 times the initial radium dosage.

We are continuing these studies at a pace limited only by the availability of samples, and expect to study bones from deceased veteran dial painters, samples of World War I dial painters, and other surviving veteran dial painters.

October 9, 1950

Claus to Marinelli:

As I mentioned to you last week, Dr. Warren is anxious to issue a list of official AEC tolerance values based on the Chalk River and Harwell conferences, without waiting for a formal meeting of the subcommittee on internal dose. I wonder if you would kindly send me a list of your own comments on the Harwell values and minutes. In particular, have you observed any specific errors, or are there any adopted conventions which you feel are grossly out of order? I am making a similar request of Dr. Morgan, who is not altogether pleased with the results.

I would like to get this material on as firm a basis as possible and would appreciate a statement of your opinion.

October 17, 1950

Marinelli to Claus:

I am in receipt of your letter of October 9 asking me for comments on the Harwell minutes and the permissible levels discussed therein.

In answering, I am assuming that this will not prejudice in any way the deliberations of the Committee on Internal Dose of which I am a member; moreover, since the official minutes of the Harwell meeting are lacking, I must perforce limit myself to general remarks.

It is my opinion that although conferences of this type are very fruitful from the standpoint of exchange of general criteria on permissible levels, they cannot lead to acceptable proposals without much more intensive preparation. It would be most appropriate to exchange tentative values and calculations by mail before the meetings and to conciliate residual differences by means of pre-meeting discussions among the technical groups which have prepared the proposed values.

In particular I find that, both at Chalk River and Harwell, conservatism has pulled down levels several fold at every turn of the calculation. The permissible level of P^{32} in water may well illustrate the point. It is generally agreed that 1.23×10^{-3} μc of P^{32} in 1 gram of tissue results in 0.3 reps per week to that tissue. Since bone is the organ having the highest content of P^{32}, the skeleton burden is $1.23 \times 10^{-3} \times 7 \times 10^{3} = 9.6$ μc; moreover, since under equilibrium conditions the skeleton contains approximately 87.6% of the body phosphorus, the total body burden should be $9.6/.876 = 11.1$ μc. Under the conservative assumption of <u>NO</u> elimination taking place (once P^{32} is deposited in the skeleton or body), the replacement of radioactive decay alone (4.85%) will call for a daily permissible deposition of $11.1 \times .0485 = 0.534$ μc per day.

Now, we have sufficient evidence in the literature to know that, under the most careful conditions of oral administration, the retention from the G.I. track in humans is on the average 70%. A more realistic value, in my estimation, is 50% since it is unlikely that a person will continually ingest water under optimal conditions of P^{32} absorption*. This means that a permissible ingestion of $\frac{0.534}{50} \approx 1\mu$ a day is realistic enough and that for a water intake of 1.5×10^{3}cc a day the permissible concentration in water should be $1/1.5 \times 10^{3} = 6 \times 10^{-4}$ μc/cc or three times the Harwell proposed level. As you may see, an unrecognized factor of 3 has crept into the calculations although the basic assumptions are identical. I believe that no arbitrary factor of safety should be invoked because, in addition to whatever safety factor is inherent in the 0.3 rep/week figure, the assumption of no elimination from bone or soft tissues has been made.

It may be argued that P^{32} recoil nucleus may add to the hazard because of its incorporation inside living cells. This however would take place predominantly in soft tissue where the concentration would be

$$\frac{11.1 - 9.6}{7\times10^{4} - 7\times10^{3}} = \frac{1.5}{6.3 \times 10^{4}} = 2.4 \times 10^{-5} \text{ μg/gram on the average, of 1/50 the concentration in}$$

bone. Whatever incomplete evidence we have on the added biological effect of P^{32} recoil nucleus seems to be about 5 (H. Powers - paramecia) and hence insufficient to overcome the lower irradiation of soft tissues.

*Empty stomach, P^{32} deficient diet, etc.

I am inclined to believe that the task of the groups interested in internal levels would be greatly aided if some general directive were given as to the risk which may be taken in assessing permissible levels. This would have the effect of "equalizing" the conservatism which is inherent in estimates of this type.

I have attempted to calculate the risk involved in the permissible levels of Ra in a memo written to Dr. K. Z. Morgan on April 1, 1950. This memo has had wide circulation both here and in England and in recent work by Dr. Hursh (Rochester) has confirmed some aspects of the calculations. These pertained to the ratio of the concentration C_B of Ra per gram of bone to the concentration C_W of Ra in water under equilibrium conditions.

The ratio was found to be: $C_B/C_W = 280$.

Since permissible $C_B = 0.1/7000$ µgs, it follows that

$$C_W = \frac{0.1}{7000 \times 280} = 5.1 \times 10^{-8} \text{ µg/cc of water.}$$

The Harwell value based on 10% permanent retention and 10^{-4} daily elimination rate is 4×10^{-8} µg/cc. I assume, therefore, that the latter values are essentially correct. There are, however, two very important facts which have been overlooked in applying these values to water for plant personnel; namely,

1) the agreed water intake is 1.5×10^3, and

2) the employment time is 10^4 days (minutes of the meeting of Morgan's committee, 3/7/50, p. 24).

Under these conditions Q = permissible level in body = 10^{-1} µg

λ = elimination rate = 10^{-4} day^{-1}

R = permissible level per cc

t = exposure time = 10^4 days.

Since $\frac{dQ}{dt} = R - \lambda Q$ it follows that:

$$R = \frac{\lambda Q}{1.5 \times 10^3 \, (1-e^{\lambda t})} = \frac{0.1 \times 10^{-4}}{0.1 \times 1.5 \times 10^3 (1-e^{-1})} = 10^{-7} \text{ µg/cc,}$$

or 2.5 times the Harwell value.

As to the risks involved, one must note that the Harwell figure and the one above are essentially equivalent because they both limit 0.1 µg of Ra in the skeleton. One may always ask the question: what are the chances of bone damage with 0.1 µg of Ra? Professor R. D. Evans showed one case with 1 µg of Ra having osteitis of the jaw out of 27 cases examined. An assumption of 4% incidence at 1 µg is conservative because a) the case was a dial painter and hence had mesothorium, and b) because the series consisted mostly of cases with symptoms. There are theoretical grounds to believe that for small burdens the incidence goes as the square of the Ra burden; hence at 0.1 µg the incidence would decrease to .04%. Out of a laboratory population the fraction working on the average for 10^4 days of continuous exposure would indeed be small - to be conservative one will assume 10% - hence, the probability of incidence comes to 0.004% or 4:100.000. In this figure there are other factors of safety which are difficult to estimate; they are based on the fact that all radium poisoning cases have ingested radium at very high rates as compared to those considered herein and that the induction period of a lesion is a significant fraction of a lifetime. In my memo to K. Z. Morgan, I have advanced reasons which would incline one to believe that whereas in the cases of radium poisoning the deposition of Ra is spotty, it is hardly imaginable that the same occurs under the conditions of permissible exposure. With the knowledge at hand we can only say that for Ra + Mesothorium the incidence of osteitis will be less than $4:10^5$ and that for pure radium the probable incidence will be 1/100 of this [25 (due to absence of mesothorium) x 4 (to homogenous distribution)] or 4 in 10^7 which is very small indeed.

It may be well to summarize the situation as follows:

a) The permissible burden of radioelements in the body should be first agreed upon.
b) The physiological data supplied at the Chalk River Conference should form the basis for the calculation of the permissible daily ingestion (either oral or respiratory).
c) An average time of employment should be assumed and adhered to in the computations.

d) An order of magnitude of the permissible risk should be established for internal emitters.
e) An estimate of the risk involved in the 0.3 rep/week figure should be made since the permissible levels of many radioelements are based on it.
f) Intensive preparation prior to international meetings is highly desirable.

November 23, 1960

Langham to Stannard:

I had planned to be at the meeting to help you discuss the question of RBE of alpha particles and the use of the "n" factor in the calculation of maximum permissible levels. Unfortunately, the meeting conflicts with a previous commitment. Vic Bond instructed me to send my thoughts on the subject to you. At the same time I talked to him by phone, I received your letter of November 17 regarding the same subject. I had already contacted Walter Snyder by phone and asked him to send me his thoughts on the above subjects. After my decision not to attend the meeting, I talked with him again and asked him to mail his contribution to you in care of Lauriston Taylor's office.

I preparing the material given below, I have used the following basic references:

(1) Minutes of the Permissible Dose Conference held at Chalk River, Ontario (September 1949). An excerpt of the RBE portion is enclosed.

(2) Minutes of the Tripartite Conference on Permissible Doses held at Harriman, New York (March 30-April 1, 1953). An excerpt of the RBE portion is also enclosed.

(3) National Bureau of Standards Handbook 52 on "Maximum Permissible Amounts of Radioisotopes in the Human Body, etc."

(4) Recommendations of the International Commission on Radiological Protection, Brit. J. Radiol., Suppl. 6 (December 1, 1954).

(5) National Bureau of Standards Handbook 69 on "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides, etc." (June 5, 1959).

(6) Report of Committee Number Two on Permissible Dose from Internal Radiation, International Commission on Radiological Protection Report, published in the June 1960 issue of Health Physics.

First, let us take up the subject of RBE of alpha particles. It was agreed at the Chalk River Conference (see excerpt) that the RBE of alpha particles would be arbitrarily chosen as 20. Although not mentioned in the notes, I am sure Dr. Mitchell cited some information that indicated a figure as high as 35. Even at this early time, I was proposing an RBE of no greater than 5. Since inadequate information was available, an arbitrary decision was made to adopt the value of 20 largely in the interest of conservatism. This value of 20 was used in the NBS Handbook 52 and also in NBS Handbook 59, the latter dealing with permissible doses from external sources of radiation.

At the Harriman Conference, Dr. Failla introduced the concept of trying to relate RBE to ion pairs per micron of water. As you can see from the excerpt of this meeting, it was proposed that ionizing particles producing between 1500 and 5000 ion pairs per micron would be assigned arbitrarily an RBE value of 10 to 20. There was much discussion and dissatisfaction about this whole scheme, and most of the information presented indicated an RBE for alpha particles in the vicinity of 5 Mev of no greater than 5. A specific proposal was made that an RBE of 5 be adopted for alpha particles. This proposal was seemingly ignored.

The next step in the evolutionary process was the 1954 recommendations of the ICRP. Although the concept of a relationship between RBE and ion pairs per micron of water was adopted in this report, it was more or less arbitrarily assumed that one was concerned with alpha particles of approximately 5 to 7 Mev energy in which the specific ionization was nearer 1500 ion pairs per micron and the RBE, therefore, of alpha particles was used as 10 instead of 20. Recoil nuclei, however, of mass greater than 4 were assumed to have an RBE of 20. This is, in some respects, a concession thatsupports the feeling that the RBE of alpha particles was relatively somewhat lower than originally surmised. These values for the RBE of alpha particles and recoil nuclei have persisted through NBS Handbook 69 and the most recent report of the ICRP. You will find, however, that the latest ICRP report (last paragraph on page 13) makes additional concessions to the possibility of a lower RBE for alpha particles. The value of 10 is adhered to, however, on the basis of our ignorance regarding chronic effects and on the basis of incorporating a portion of the "n" factor into the concept of an average RBE. I will mention this later under the "n" factor. Incidentally, you should read rather carefully all of Section 4 of the latest ICRP report, beginning on page 11 and ending at the top of page 15. Note especially the inconsistency between the 300 millirem per week maximum permissible exposure for individual organs and the dose delivered to the bone from 0.1 μg of fixed radium. Notice also that this was elegantly discussed by

Eisenbud in the excerpt from the Harriman Conference which was held in 1953. This is one of the dirty pieces of linen that we all wish we could find a way of washing. It could be done by adopting an RBE of 5 for alpha particles. This, of course, would do damage to the maximum permissible body burden of such troublesome things as Sr-90.

The following general comment seems to be in order with regard to the philosophy of using an RBE in those cases of bone-seeking isotopes which are compared with radium. The question, of course, is why not *just use a relative potency factor and forget the idea of RBE entirely. The use of a relative potency* factor only would mean that there would be no way of deriving maximum permissible levels for radioisotopes and mixtures of isotopes (or isotope-daughter combinations) for which no relative animal toxicity experiments had been performed. This, unfortunately, is an important point since there are several cases where toxicological studies in comparison with radium just have not been made. The scheme at least does permit a summation of energies of all disintegrations and the weighting of individual radiations, be they alpha, beta, or gamma, for their respective RBE's. If this is confusing, you will find it discussed rather thoroughly on pages 12, 29, and 30 of the latest edition of the ICRP report.

So much for RBE; now let us discuss the factor "n." Austin Brues and Miriam Finkel are probably most responsible for this dilemma, although their responsibility is an indirect one. The first time it reared its head, though not actually called an "n" factor at the time, was when Austin Brues pointed out at the Chalk River Conference that on an injected dose basis plutonium was at least 15 times worse than radium. This resulted in the maximum permissible body burden of plutonium being lowered to 0.1 μg. This touched off a wave of impassioned correspondence among Austin Brues, Shields Warren, Robley Evans, K. Z. Morgan, and me. Thanks to Austin Brues' common sense, Robley Evans' wise counsel, and my youthful arrogance, the value was changed to 0.04 μc, where it still stands today. I am sure Robley Evans has a complete file on this episode, since he seems to keep complete files on everything. You might ask him if he has ever bothered to go through the material again. I found it extremely amusing.

The 1954 recommendations of the ICRP was the first time in which the "n" factor (at that time written as a "N") appeared as such. At that time it was specifically designated as "N = nonuniform distribution factor which is assumed to be 1 for X and gamma radiation and 5 for the α, β-, β+, e-, and atom recoil components of energy from radio-isotopes deposited in the bone with the exception of Ra-226 and P-32. It is taken as 1 for all body organs except bone." As you can see, it was at that time indeed a "nonuniform distribution factor." It was introduced to correct for the fact that plutonium appeared to be about 5 times as tumorogenic as radium, even when the product of the RBE and the energy imparted to bone (averaged over the entire skeleton) was the same. At this time also, there were other bits of data (e.g., Miriam Finkel's strontium work) which indicated similar abnormalities. The "n" factor has persisted *through NBS Handbook 69 and the latest report of the ICRP. The concept has undergone some modi*fication. First, it is now designated as "n" (so it will not be confused with "N" used in the expression 5 (N - 18) for accumulated dose of external radiation). Second, it is now defined as "n - relative damage factor for radionuclides deposited in bone." It is further stated "that this greater damage is attributed to several factors, some of which are (a) nonuniform distribution, (b) greater radiosensitivity of the portion of the bone in which the isotope is deposited, and (c) greater essentialness of the damaged tissue. It is introduced, therefore, to make some allowance for the greater relative effectiveness of some radionuclides as well as for the fact that many have a more heterogenous distribution in bone than radium. The relative damage factor is taken as 1 provided the parent element of the chain considered is an isotope of radium or if the energy component considered originates as X or gamma radiation. Its value is taken as 5 in all other cases, i.e., if the parent element of the chain is not an isotope of radium and if the energy component considered originates as α, β-, β+, e-, or from a recoil atom."

In general, it may be said that the "n" factor is indeed a relative potency factor, although it may be used in a somewhat more complicated sense. At the bottom of page 13 of the latest ICRP report is a statement that adds to these complications. This statement indicates that the RBE of alpha particles may well be less than 10, but since radium itself is not uniformly distributed in bone, portions of the bone in which the radium is concentrated might very well be receiving doses many times the average values. Therefore, an RBE of 10 is used to hedge against this situation. I think you can see that this is actually using the RBE to correct for something that legitimately should be contained within the "n" factor itself. Finally, I do not particularly object to using an RBE in both the denominator and numerator which subsequently cancels out in the event a pure alpha-emitting isotope is being compared with radium. This merely shows a consistency in the method of calculation between deriving maximum permissible levels for isotopes that are pure alpha emitters and those that emit a series of radiation as a result of decaying daughter products.

I don't know how helpful this material will be. I am very glad that you and not I have the job of presenting this problem to the Committee.

March 6, 1953

Failla to Colleagues:

I am enclosing herewith a copy of document sent to me by the Medical Research Council in London. (MRC 53/125 PIRC/24. See App #23) Perhaps you have received a copy of this document also but, if not, it is important that you should have a copy so that you will be acquainted with the questions raised by our British conferees before the time of the Tripartite Conference.

COMMITTEE ON PROTECTION AGAINST IONISING RADIATIONS

MRC, 53/126
PIRC/24

Programme for the U.K. Delegation to the Tripartite Conference on Permissible Levels of Radiation to be held in Washington, D.C., U.S.A., on the 30th and 31st March and 1st April, 1953

A. Previous Conferences

At the Chalk River Conference (September, 1949), the following matters were discussed:-

(1) Basic anatomical and physiological data on "Standard Man".
(2) R.B.E.s for α and β particles, fast and slow neutrons, and protons.
(3) Permissible exposures to external radiations (x and γ rays, β rays, fast and slow neutrons):-
   (a) Whole body irradiation - long continued exposure.
   (b) Whole body irradiation - single exposure.
   (c) Hands - long continued exposure.
   (d) Head - long continued exposure.

(4) Permissible exposures to internal radiations (m.p.l.'s in body, in air and in water):-

Group I - Ra^{226}, Rn^{222}, natural U, U^{233}, Pu^{239}, natural Th^{232}, $Th^{234}(UK_1)$, and Po^{210}.

Group II - Fission products.

Group III - H^3, C^{14} (as CO_2), Na^{24}, P^{32}, S^{35}, A^{41}, Co^{60}, Sr^{89}, $Sr^{90}(+ Y^{90})$, I^{131}, Xe^{133} and Xe^{135}.

At the Buckland House Conference (August, 1950) further discussions took place on many of the above items and on some new problems. In the main, these dealt with internal radiation hazards. The permissible levels for H^3, C^{14}(as CO_2), Na^{24}, P^{32}, S^{35}, A^{41}, Co^{60}, Sr^{89} (+ Y^{90}), I^{131}, Xe^{133}, Xe^{135}, Po^{210}, Ra^{226}, U^{233} (soluble and insoluble forms), and Pu^{235} were reviewed. Other items discussed were:

(1) Whether radioactivity in particulate rather than in gaseous form is likely to increase the hazard,
(2) permissible fluxes for fast and slow neutrons (fluxes expressed in neutrons per sq.cm. per sec.); and
(3) genetic factors in radiation hazards.

B. International Commission on Radiological Protection

Many of the findings of the above Tripartite Conferences were incorporated in the Recommendations of I.C.R.P. in 1950.

Since that time, there has been a Radiobiological Conference in Stockholm. A report (PIRC/18) on the Conference has previously been presented to the M.R.C. Protection Committee. It will be recalled that the main findings were:-

(1) That the basic figure of 0.3r. in any one week, recommended in 1950 by I.C.R.P. for the maximum permissible exposure of the critical tissue (blood-forming organs), remain unchanged.

(2) That, below a certain weekly exposure level, routine blood counts need not be made.

(3) That, in circumstances in which exposure of large populations occurs, it is necessary to apply a considerable factor of safety to reduce the permissible level below that of 0.3r. per week in tissue allowed to persons occupationally exposed.

C. Recent work

At the last meeting of the M.R.C. Committee on Protection against Ionizing Radiations, reports were presented by the various Sub-Committees, summarising their work in their respective fields during the past year or so.

(1) Report PIRC/15 (Amended) deals with the work on high energy radiations and heavy particles. The Sub-Committee made the following recommendations:

(a) Permissible exposure to X and γ rays above 3 MeV:-
For X or γ rays of quantum energy greater than 3 MeV, it is not possible to base the permissible whole body exposure on a measurement of surface dose. (A dose of 0.5r. to the surface for energies less than 3 MeV was based primarily on an estimated dose of 0.3r. or 30 ergs/g. to the critical tissues, taken to be be several cm. below the surface. For high energy radiation, the dose a few cm. below the surface may be many times greater than that at the surface). Accordingly the maximum permissible exposure for ionising radiations of quantum energy greater than 3 MeV shall be that which causes an energy absorption not greater than 30 erg/g, in any part of the body in any one week.

and has pointed out that many of the differences between them can be accounted for by two facts:-

(a) If the maximum permissible level of Sr^{89} is assessed on the basis of its observed biological effect relative to 0.1 μC Ra, a value of 2.0 μC is obtained. (This is the present I.C.R.P. value.) Of r. however, the Sr^{89} level is assessed as the amount which will produce 0.3 equivalent r. in tissue, the value obtained is 11. The M.R.C. Sub-Committee has chosen the former basis and has extended this to other bone-seeking isotopes. The U.S. Sub-Committee has taken 0.3 equivalent r. in tissue on the basis for estimating m.p.l.'s for bone-seeking isotopes. Thus there arises a difference by a factor of 5. For some of the isotopes, e.g., Y, Zr, Ce, Pr, Pm, Sm and Eu, the M.R.C. Sub-Committee has allowed a further factor of 5 for uneven distribution of the isotopes within the bone. Accordingly in some cases, there is a factor of 25 difference between the British and U.S. figures.

(b) In some cases (e.g. Y^{91} and Ru^{106}), calculations indicate that the damage to lung and to gut by temporarily retained isotopes is greater than that to the ultimate organ of storage. The British figures are based on the damage to the lung and gut, the U.S. figures on the damage to the organ of storage.

D. Programme for Washington Conference

(1) Preliminary meeting of U. K. delegates on 29th January, 1953.

The U. K. delegates, together with Dr. Katherine Williams and Dr. A. S. McLean, held a preliminary discussion of the programme on 29th January. The following is a summary of the conclusions reached.

(a) Radium.
The value of 0.1 μC as the m.p.l. for Ra. should be retained, though this probably contains a safety factor compared with the minimum damaging dose.

(b) Sr^{89}.
The value of 2.0 μg, which is accepted by all parties as the m.p.l. for Sr^{89} in the body, shall be retained.

(c) Ga^{45} and Ba^{140} (+ La^{140}).

It is felt that the distribution of Ga, Ba and Sr, in the skeleton, though not necessarily identical, are so similar that the same considerations should apply to these elements. Accordingly the delegation advocate the adoption of the British figures, which are based on the above level for Sr^{89}.

(d) Y, Ce and other bone-seeking rare earths.

The question here is as to the necessity for an additional factor of 5 for inhomogeneous distribution. The meeting was not unanimous about the policy to adopt. On the one hand, it might well be that the figure for Sr. already contains a factor (either as a safety factor or as a factor to allow for uneven distribution), which does not justify applying a further factor of 5, relative to Sr, for Y and similar isotopes. On the other hand, Hamilton and Vaughan have shown that the distribution in bone of isotopes like Y is different from Sr, and accordingly the M.R.C. Sub-Committee allowed an extra factor of 5 (PIRC/IR/33). It was, however, felt by the delegation that this procedure is quite arbitrary and that the question of applying this extra factor should be left open for discussion in Washington.

(e) Irradiation of the gut.

It was noted that there were differences of 2 or more orders of magnitude between the U.S. and British figures for the m.p.l.'s of Y and other non-absorbed elements in water. These differences could be ascribed to the fact that the U.S. Sub-Committee had assumed very low uptake figures for the rare earths and had not allowed for irradiation of the gut.

It was decided to abide by the British figures, based on 24 hours half life in the gut with a possible small relaxation for self-absorption of β rays in the contents of the gut. Dr. McLean said that the faecal excretion of Pu indicated that a 24-hr. half life was a reasonable assumption. He has offered to prepare a note for the delegation summarising the results which he has obtained.

(f) Uptake from ingestion.

Drs. Loutit and McLean said that recent observations with fission products and Pu made them doubtful of the validity of the very low gut uptake figures hitherto accepted. It was also noted that the U.S. Sub-Committee had assumed only 0.03% uptake of Po from the gut to the spleen, which they considered to be the organ of deposition. This seemed to be a low figure compared with the evidence presented in "Biological Studies with Po, Ra and Pu".

(g) M.P.L.'s for emitters.

(i) Pu. The m.p.l. for Pu should not be altered until fresh evidence is produced.
(ii) Th, Ra and Ac. It is desirable that new assessments be made.

(2) There is a meeting of the M.R.C. Sub-Committee on Internal Radiations on 19th February, when doubtless consideration will be given to the above matters. It is hoped that it will be possible to report upon the views of the Sub-Committee at the meeting of the Main Protection Committee which is to be held later the same day. Other problems which should receive consideration at the Tripartite Conference are:-

(a) Basic dose for X and γ rays up to 3 MeV:-
(i) whole body exposure:
(ii) partial exposure.

(b) Basic dose for X and γ rays above 3 MeV (30 erg/g.?)

(c) Permissible exposure to β rays. (Is the value of 1.5 equivalent r, too restrictive?)

(d) R.B.E. values.

(e) Neutrons:-
(i) Permissible exposure (i.e. 3 erg/g.?).
(ii) Permissible fluxes.

(f) Emergency doses.

(g) Life doses.

The U.K. delegation would welcome the advice of the Main Protection Committee on all the above items. W. Binks, Secretary

August 14, 1975

Cowper to Taylor:

Thank you for sending me a copy of Chet Richmond's paper on plutonium given at the EPA hearings. I enjoyed our brief meeting at Buffalo. I am enclosing copies of the old working papers I promised and please forgive me for the delay. Some of the pages are not the best quality copy you have seen but they are as good as the originals from which they were made.

Failla's review is perhaps the most interesting (1949) and would not require too many changes to be topical at this moment.

With all good wishes,

att:

Biomedical Effects of Plutonium on Humans

by C. R. Richmond
Oak Ridge National Laboratory
Oak Ridge, TN 37830

part of the AEC presentation at
EPA Plutonium Standards Hearings
Washington, D.C., December 10-11, 1974

INTRODUCTION

My name is Chester R. Richmond. I am the Associate Director for Biomedical and Environmental Sciences at the Oak Ridge National Laboratory. However, the views I express here are my own.

Plutonium was recognized as a potentially hazardous material soon after its discovery in early 1941. The urgency to conduct biological studies with plutonium was appreciated by several people, notably Dr. Seaborg, with the hope that the unfortunate problems experienced with radium earlier in the century would not be repeated. Within three years of the discovery of plutonium (^{238}Pu) in February, 1941, 0.5 g ^{239}Pu had been separated from the material produced by the Clinton pile and on 8 February 1944, Dr. J. G. Hamilton and coworkers at Berkeley received about 10 mg to begin experimental studies in rodents.

During late 1943 and early 1944, plutonium operations at Los Alamos consisted of research activities involving milligram quantities of material. During late 1944, gram quantities were processed in research activities directed mainly toward the production of pure plutonium metal and investigation of its physical and chemical properties. By mid-1945, kilogram quantities were processed as part of the effort to produce the nuclear components for the Alamagordo and Nagasaki weapons. Some of our most relevant data as regards exposure of humans to plutonium comes from the medical follow-up of the military personnel who worked with plutonium at Los Alamos in 1944 and 1945.

Although we have accumulated a considerable amount of information on the biological effects of plutonium on experimental animals, there is little to be said of the data on effects in humans. Obviously, we should be encouraged because of the lack of data on biological effects of plutonium in man.

DEVELOPMENT OF MAXIMUM PERMISSIBLE BODY BURDEN (MPBB) FOR Pu

Throughout 1943 and the first nine months of 1944, a maximum permissible body burden of 4-5 μg was assumed to be an acceptable guide even though no reliable method of estimating personnel exposure to plutonium had been developed. The value was derived by using bone as the critical organ and making a direct comparison with the energy deposited from 0.1 μg of ^{226}Ra fixed in the body (assuming 50% radon exhalation). Later, because of apparent differences in bone deposition patterns between Pu and Ra in rodents, a safety factor of about 5 was introduced, and the maximum permissible body burden became 1 μg. This value was used until the Tripartite Permissible Dose Conference at Chalk River, Canada, in late September 1949, at which time Dr. A. Brues presented experimental chronic toxicity data from rodents that suggested ^{239}Pu was 15 times more damaging than ^{226}Ra when both were injected in equivalent microcurie quantities. The conference recommended that the MPBB be reduced to 0.1 μg.

Subsequent reexaminations of the experimental data led to a recommendation of 0.6 μg as the MPBB for ^{239}Pu. This decision was based upon the following observations related to the assumption that 0.1 μCi of fixed ^{239}Pu was equivalent to 0.1 μCi of fixed ^{226}Ra.

(1) The Pu:Ra toxicity ratio of 15:1 was based on the injection of known amounts into rodents. Since ~ 75% of the injected Pu was retained in rodents while only ~ 25% of the Ra was retained, the ratio on the basis of retained dose could be lowered by a factor of about 3.

(2) Because radon was about 50% retained in man and only about 15-20% retained in rodents, the toxicity ratio could be lowered by another factor of at least 2 on the basis of relative energy deposited.

Thus, strictly on the basis of biological data, the MPBB for man was calculated to be:

$$(\text{MPBB})_{\text{Pu}} = 0.1 \times \frac{24,000}{1,600} \times \frac{1}{15} \times \frac{3}{1} \times \frac{2}{1} = 0.6\mu\text{g} \ (0.04\ \mu\text{Ci})$$

As a result of this information, the AEC authorized 0.5 μg (0.033 μCi) ^{239}Pu as the MPBB. In 1951, the International Commission on Radiological Protection (ICRP) at a meeting in London recommended a value of 0.04 μCi which was later endorsed at the Tripartite Conference on Permissible Dose at Harriman, New York in March 1953. In the fall of 1953, both the National Committee on Radiation Protection and Measurements (now the National Council) and the ICRP recommended a MPBB of 0.04 μCi for ^{239}Pu in their official publications; the value has remained unchanged to date although the MPBB has been discussed in more recent publications of both organizations.

MANHATTAN PROJECT EXPOSURES

Since the discovery of plutonium over three decades ago,[1] personnel exposures have been studied and reported on in varying degree, both during life and after death.[2-9] One of the most interesting groups, because of both the length of the period since exposure and the levels of exposure, is that of the Manhattan Project plutonium workers.[10]

Twenty-five male subjects, who worked with plutonium during World War II under very crude working conditions by today's standards, have been followed medically during the intervening period. Within the past several years, 21 of these men have been examined at the Los Alamos Scientific Laboratory. In addition to physical examinations and laboratory studies (complete blood count, blood chemistry profiles and urinalysis), roentgenograms were taken of the chest, pelvis, knees and teeth. Chromosomes of lymphocytes cultured from peripheral blood and pulmonary cytology were also studied. Urine specimens assayed for plutonium yielded calculated body burdens which ranged from 0.005 to 0.42 μCi. These estimates of body burden are generally higher than earlier estimates based on radioassay of urine samples collected in the past, perhaps reflecting uncertainties in the models used to estimate body burden from excretion data. Table 1 indicates the kinds of information obtained from the Manhattan Project plutonium workers. Most, but not all, of these examinations have been conducted every four to five years since the group has been studied.

This group of men in their early to mid-fifties had only the usual diseases encountered in this age zone. One man had a coronary occlusion but had recovered and was well compensated. Another of the original group died in 1959 of a coronary occlusion at age 38. Another had a benign hemotoma of the lung surgically removed without complication in 1971. A third had a melanoma of the chest wall (regional lymph nodes were negative).

APPENDIX 26

September 18, 1979

To: Those listed below.

From: Lauriston S. Taylor

Subject: Tripartite Conferences, U.K., Canada and U.S. (1949-53)

I am trying to assemble as complete a collection as possible of documents relating to the above Tripartite Conferences including those that might have been made available at the time by members of the national delegations. It is anticipated that these will soon be suitably copied and bound and made available for library retention. To achieve the most useful compilation of this material, it would be of great help if you could let me know of the existence of any other documents besides those listed below. This would include documents referred to among the papers that I have but which may or may not be critical to the Tripartite Conference discussions.

The following reports or papers are currently in my possession:

1. Report on the United Kingdom, Canadian and United States meeting on March 29 and 30, 1948 prepared by John Bowers, 5-24-48. This is only a 1¼ page summary.

2. Note on the Safe Level for Radioactive Contamination in Drinking Water by J. S. Mitchell, Cambridge, 5-31-46 (4 pages). Identification NP/P/11.

3. MRC Paper NP/P/TD/18 Research Committee on the Medical and Biological Applications of Nuclear Physics. Tolerance Doses Panel of the Protection Sub-Committee. By Dr. A. Glucksmann. 5-18-47 (5 pages).

4. MRC-NP/P/TD/71. Research Committee on the Medical and Biological Applications of Nuclear Physics. Tolerance Doses Panel of the Sub-Committee - Minutes of 14th Meeting, Sept. 17, 1948.

5. MRC-NP/P/TD/73. Research Committee on the Medical and Biological Applications of Nuclear Physics - Tolerance Doses Panel of the Protection Sub-Committee. A Consideration of the Hazard Associated with the Ingestion of Radium Together With a Reconsideration of the Derived Estimates of the Permissible Concentration of Plutonium and Strontium in Drinking Water. By L. H. Gray (No date) (6 pages).

6. MRC-NP/P/TD/76. Research Committee on the Medical and Biological Applications of Nuclear Physics - Tolerance Doses Panel of the Protection Sub-Committee. Report on Meeting of Chairman and Secretary of the Panel with Dr. G. Failla, 9-20-48 (1 page) dated Oct. 22, 1948.

7. Document NP/P/TD/81 also T. D. C. 52, also H. S. 133. The Inapplicability of Brues Law for the Incidence of Sarcoma in the Tolerance Range. By K. Fuchs, AERE Harwell, 11-25-48.

8. Document NP/P/PD/82, also T. D. C. 53, also H. S. 1534. The tolerance Amount of Radium Strontium and Plutonium in the Human Body. By K. Fuchs, AERE Harwell, 11-26-48.

9. Document NP/P/TD/83, also H. S. 4841. Extract from Letter from Professor Robley D. Evans to Dr. L. H. Gray on the Question of Human Tolerance for Radium dated Dec. 1, 1948.

10. Document NP/P/TD/85, also Sloan 5756. Letter from British Empire Cancer Campaign (W. L. Harnett) to Dr. G. J. Neary dealing with unpublished report on bone sarcoma Dec. 9, 1948.

11. Document NP/P/TD/86, from General Register Office to Dr. Neary giving table of deaths from bone sarcoma, dated Dec. 23, 1948.

12. Document NP/P/TD/94, also T. D. C. 60, also H 5670. A Note on the Maximum Permissible Flux for Past Neutrons in Relation to the induction of cataracts and a Preliminary Estimate of the Maximum Permissible Flux for Thermal Neutrons in the Region of 100 MEV by G. J. Neary (no date) (5 pages).

13. A large 3 page table not specifically identified with any of the above documents titled - Summary of Maximum Permissible Levels of Radiation Hazards Agreed by the Tolerance Dosage Panel. (no date) This gives a series of agreements apparently reached by the British Tolerance Dose Panel and giving the dates and document numbers to which these statements refer. (See page 26-4)

The following documents N/P/TD/ are referenced:

78, 61, 71, 84, 103, 21, 27, 43, 90 and 110. Of these, all but 103, 90 and 110 were issued in 1947 and 1948. The last three were issued in 1949. Taylor has the following documents: N/P/TD/71, 11, 18, 73, 76, 81, 82, 86, 83, 85 and 94. It would be very useful to have copies of the first listed documents above. Can anyone give some assistnace in knowing how this may be arranged?

The following documents relate to the Chalk River Tripartite Conference held in Sept. 1949.

14. Document No. NP/P/TD/122 on "Permissible Doses Conference" Chalk River, Sept. 29-30, 1949 (Report of the United Kingdom Delegation). Dated 12/29/49.

15. Document prepared by Canadian Delegation marked "Permissible Doses Conference held at Chalk River, Ontario, Sept. 1949." Chalk River, May, 1950.

The insert says that the report is based on the report of the U.K. Delegation, NP/P/TD/122 and it is signed by G. E. McMurtrie; the substance of this report appears to be the same as TD 122, but there is substantial abridgement of language.

16. Document on "Permissible Doses Conference held at Chalk River, Ontario, Sept., 1949." Identified only as R. M. - 14. It seems to follow fairly closely much of the material in Report TD/122 but there are some subtle differences as for example in the discussions of Radio-nuclides in group 3. The whole body of the report has not been examined for differences so it will be retained for referenece purposes. It is apparently the same as the McMurtrie Document referred to above but this is not certain.

17. Document believed of Canadian origin marked R. M. - 10 on minutes of the Permissible Doses Conference held at Chalk River, Canada, Sept. 29-30, 1949. A pencilled note on this states that this copy supersedes document RN-14. Included with it are 5 pages of notes and corrections.

18. NP/P/TD/156 on "Report on Permissible Doses Conference, Buckland House, AERE Harwell, Aug. 5-6, 1950" prepared by G. J. Neary. (This is a detailed document of some 30 pages.)

19. Preparatory document on "Tolerance Conference to be held on 4, 5, 6 August, 1950, at Buckland House near Fairingdon Berks." Attached to this are minutes of the meetings including a number of pages of personal notes by L. S. Taylor. The origin of this appears to be British but it is not certain.

20. Document marked MRC. 51/497, also PIRC/IR/5 - a Report on "Alpha Ray Dosage in Bone Containing Radium" by F. W. Spires dated 8-24-51. Included with this are several pages of appendixes marked "Appendix to PIRC 15B as amended.

21. Document (no identification no.) - "Tripartite Conference on Permissible Doses (Arden House, Harriman, New York, USA) March 30 through April 1, 1953," prepared by W. Binks, 4-8-53. This is a 34 page document on thin paper and for some unknown reason the last half of page 32 and pages 33 and 34 have been clipped off. Also as item 22 I have a poor quality photocopy of this document - origin unknown (judging by staple marks it is two or three generations later on in reproduction.) This includes the two and one half pages of missing material from document no. 21 above but parts of this are barely legible and it would be very useful to have a fairly legible clean copy of the pages.

22. Document entitled "Tripartite Conference on Permissible Doses, Arden House, Harriman, New York, March 30, 31 and April, 1953." This appears to follow Binks report (Item 21 above) but in abridged language. It was presumably prepared by someone in the US delegation. It was declassified through action by the old AEC.

Since the report above written by Binks appears to be a draft - I wonder if there is an identifiable official copy of this available.

23. Document MRC, 53/126, also PIRC/24. "Programs for the UK Delegation to the Tripartite Conference on Permissible Levels of Radiation to be held in Washington, D. C., USA on 30 - 31 March and 1 April, 1953. By W. Binks (no date).

24. Paper prepared by G. Failla, Sept. 1949 in preparation for the Chalk River Conference. "Preliminary draft of report of Sub-Committee on Permissible Dose from External Radiation" of the National Committee on Radiation Protection.

In addition to the documentary material, there are a number of letters having to do mainly with organizational matters centering around the Tripartite Conference. There appeared to be no point in reproducing these.

Mailing List

Walter Binks	A. K. Longair
Austin Brues	J. F. Loutit
D. G. Catcheside	W. G. Marley
George Cowper	J. S. Mitchell
M. Eisenbud	Karl Morgan
J. W. Healy	G. J. Neary
Louis Hempelmann	H. M. Parker
G. C. Laurence	Shields Warren
W. B. Lewis	

SUMMARY OF MAXIMUM PERMISSIBLE LEVELS OF RADIATION HAZARDS

AGREED BY THE TOLERANCE DOSES PANEL

I. External Radiation.

A. Whole body X and Gamma Radiation.

Date	Document No.	
29.10.1948	NP/P/TD/78	"The Panel is of the opinion that, in circumstances in which the whole body may be exposed over an indefinite period, to X or gamma radiation of quantum energy less than 3 MeV, the maximum permissible dose received by the surface of the body shall be 0.5 rontgen in any one week. This corresponds substantially with the American definition that the whole body dose should not exceed a value of 0.3r. of X or gamma rays measured in free air."
27.5.1948	NP/P/TD/61	"The Panel agreed that no minimum time limit should be fixed for the delivery of the dose of 0.5r. (in any one week)".
27.5.1948	NP/P/TD/61	"It was agreed that the maximum single emergency dose should be 10r."
27.5.1948	NP/P/TD/61	"The Panel ...... agreed that the maximum total dose which should be taken in emergency cases should be 13r. in any period of 6 months."
17.9.1948	NP/P/TD/71	"The Panel agreed "that the blood-forming organs should be regarded as the critical tissue."

B. Exposure of hands to X, Gamma, and Beta Radiation.

Date	Document No.	
9.12.1948	NNP/P/Td/84	It was agreed "that the maximum permissible dose be 1.5r. per week at the basal layer of the epidermis, defined for practical purposes as lying at a depth corresponding to 7 mg/cm^2, a conventional estimate agreeing with American practice."

C. Fast neutrons.

Date	Document No.	
17.9.1948	NP/P/TD/71	The relative biological efficiency factor for fast neutrons was provisionally accepted as 10, in agreement with the U.S. figure.
31.3.1949	NP/P/TD/103	The Panel adopted the following figures for maximum permissible fluxes for fast neutrons: 20 neutrons per cm^2 per sec. in the range 2 to 20 MeV) per 8 hour 40 " " " " " at 0.5 MeV.) day. These figures correspond to a biological effect equal to that of 0.1r. per 8 hour day of gamma radiation, assuming a relative biological efficiency factor for the neutron radiation of the order of 20 in the lower part of the above energy region, and a safety factor of 2.

D. Alpha rays.

Date	Document No.	
17.9.1948	NP/P/TD/71	The relative biological efficiency factor for alpha rays was provisionally accepted as 10, the figure generally accepted in the U.S.

II. Particular Isotopes

The list below represents figures agreed by the Panel reduced to a common basis of comparison. The maximum possible dose for whole body irradiation by X and gamma radiation is taken as 0.5r per week, while the anatomical and physiological data are taken from the "Standard Man" of Parker and Lisco for which the daily air and water intakes are 24 cubic metres and 3 litres respectively.

Isotope	Medium	Maximum Permissible Concentration or Amount	Date	Document Number
A^{41}	Air	1.43×10^{-12} c/cc	20.6.1947	NP/P/TD/21

Based on an external beta and gamma irradiation of approximately 0.5r/week in an infinite atmosphere, making a small allowance for the attenuation of the gamma rays in passing through the body but not for backscattering by the body.

C^{14}	Air	2.86×10^{-15}c/cc.	20.6.1947	NP/P/TD/21

Assumes that C^{14} is present as carbon dioxide, then if inhaled carbon were deposited in the elementary form in a discrete granule, the dose-rate inside would be 0.5r/week. This figure was calculated as a safe, not a maximum permissible level.

Sr^{89}	Drinking water	4.4×10^{-12} c/cc.)	2.10.1947	NP/P/TD/27
Sr^{90}	Drinking water	4.0×10^{-14} c/cc.)		

Based on maximum permissible amount of radium in skeleton = 0.1µg., and Brues' observation that a given activity of radium is equivalent to Sr^{89} of ten times the activity (see NP/P/TD/17); i.e. maximum permissible level of Sr^{89} in skeleton is 1µC or ½µC of Sr^{90} + 1µC of Y^{90}

Pu^{239}	Drinking water	1.67×10^{-15} g/cc.	29.1.1948	NP/P/TD/43

Based on maximum permissible amount of radium in skeleton = 0.1µg., and Brues' observation of the equivalence of equal masses of radium and plutonium for acute lethal effects; 100% absorption, no elimination; ingestion for 50 years.

I^{131}	Drinking water	3.34×10^{-12} c/cc.	29.1.1948	NP/P/TD/43

Based on a dose of 0.5r/week to thyroid of mass 25g. for which the gamma ray energy absorbed is one-fifth the total emitted; 100% absorption and deposition of iodine in thyroid, no elimination.

Co^{60}	Drinking water	1.7×10^{-11} c/cc.	29.10.1948	NP/P/TD/78

Based on a dose of 0.5r/week to the liver of mass 1700g. for which the gamma-ray energy absorbed is one-half the total emitted; 100% absorption and deposition of cobalt in the liver, biological half-life 20 days.

Kr^{85}	Air	4.28×10^{-12}c/cc.)		
Kr^{85}	Air	1.14×10^{-11}c/cc.)		
Kr^{87}	Air	2.21×10^{-12}c/cc.)	9.12.1948	NP/P/TD/84
Kr^{88}	Air	1.14×10^{-12}c/cc.)		
Xe^{133}	Air	1.5×10^{-11}c/cc.)		
Xe^{135}	Air	5.0×10^{-12}c/cc.)		

Based on an external beta and gamma irradiation of 0.5r/week at ground level, assuming no backscatter from the ground or the body, and no attenuation of the gamma rays in passing through the body.

Ru^{103}	Air	9.55×10^{-15}c/cc.	9.12.1948	NP/P/TD/84
Ru^{105}	Air			

Based on a dose of 0.5r/week to the lung of mass 950g., for which the gamma-ray energy absorbed is one-half the total emitted; 100% absorption and deposition of ruthenium in lung, biological half-life of 11 days. (Note: On account of the short radioactive half-life of 4.5 hrs. for Ru^{105}, the maximum permissible concentration is not determined by the biological half-life of 11 days.)

Ru^{106}	Air	1.03×10^{-15}c/cc.	9.12.1948	NP/P/TD/84

Based on a dose of 0.5r/week to the skeleton of mass 7kg. with a non-uniform distribution factor of 5; it is assumed that 100% of all inhaled activity is transferred to skeleton and retained there, leading to an equilibrium concentration determined by the radioactive decay alone.

II. Particular Isotopes (contd.)

Isotope	Medium	Maximum Permissible Concentration or Amount	Date	Document Number
I^{131}	Air	3.87×10^{-16}c/cc.)	9.12.1948	NP/P/TD/84
I^{132}	Air	1.16×10^{-14}c/cc.)		
I^{133}	Air	1.78×10^{-15}c/cc.)		
I^{135}	Air	3.56×10^{-15}c/cc.)		

Based on a dose of 0.5r/week to the thyroid of mass 25g., for which the gamma-ray energy absorbed is one-fifth the total emitted; 100% absorption and deposition of iodine in thyroid, no elimination. (Note: I^{133} and I^{135} have daughter products Xe^{133} and Xe^{135} respectively. If these isotopes also decay in the thyroid, then the maximum permissible levels should be reduced to 1.39×10^{-15} and 2.32×10^{-15}c/cc. respectively.)

Ra^{226}	Body content	0.1μg.	27.1.1949	NP/P/TD/90

This figure applies to workers under continuous medical surveillance, with three monthly checks of radium content, and is a provisional recommendation for twelve months only.

Ra^{226}	Body content	0.001μg.	27.1.1949	NP/P/TD/90

This figure applies to a large population and is intended to be the maximum permissible additional amount of radium accumulated in the body over a lifetime, i.e. one-fifth of the probable natural body content, and is a provisional recommendation for twelve months only.

Ra^{226}	Water	1.33×10^{-15}g/cc.	27.1.1949	NP/P/TD/90

Based on maximum permissible additional content of 0.001 g. of radium assuming 5 per cent of all ingested activity is deposited in the skeleton, from which it is eliminated with a half-life of 10 years. Provisional recommendation for twelve months.

Sr^{90}	Water	5.33×10^{-14}c/cc.	27.1.1949	NP/P/TD/90

Based on maximum permissible additional body content of 0.001μg. of radium, assumed equivalent to 0.01μC of Sr^{89}; .5 per cent of all ingested activity is transferred to skeleton, from which it is eliminated with a half-life of 197 days. A safety factor of 3 is introduced to allow for the fact that the Sr^{90} burden approaches equilibrium value more rapidly than the radium burden. (Note: the strontium-radium ratio of 10 to 1 applies strictly only to Sr^{89}; in the case of Sr^{90}, if the Y^{90} is also effective, the ratio should be 20 to 1). Provisional recommendation for twelve months.

Pu^{239}	Water	4×10^{-16}c/cc.	27.1.1949	NP/P/TD/90

Based on maximum permissible additional body content of 0.001μg. of radium, assumed equivalent to 0.001μg. of plutonium; 0.03% of all ingested plutonium is deposited in the skeleton from which it is eliminated with a half-life of 10 years. A safety factor of 3 is allowed for uncertainty in the plutonium radium equivalence, and a safety factor of 10 for uncertainty in the absorption of 0.03%. Provisional recommendation for twelve months.

Pu^{239}	Body content	0.1μg.	12.5.1949	NP/P/TD/110

This figure only applies to workers under continuous medical surveillance, and is a provisional recommendation for twelve months only.

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