MINUTES

of the

PERMISSIBLE DOSES CONFERENCE

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 Mr. 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 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
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:

<u>Total Water Intake</u>	- per day		
		2.5 litres	
	In food	1.0 "	(including water of oxidation)
	In fluid	1.5 "	
<u>Total Water Output</u>	- 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.

<u>Respiration</u>

The following tabulation was accepted:

<u>Total Surface Area of Respiratory Tract</u>	70 sq. metres.
Respiratory interchange area	50 sq. metres.
Non-respiratory area (upper tract, trachea, bronchioles)	20 sq. metres.

<u>Respiratory Exchange</u>

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

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

<u>Carbon Dioxide Content of Dry Air</u>

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 values 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 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 t[illegible] microcurie were retained in the lung initially but 80% appeared in the f[illegible]s in the next 48 hours. 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 a 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 1.5 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 < 20 MeV.	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 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 - 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.

Although this unit is referred to in Dr. Failla's report as the "ren", 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 o.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 was below 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 sq. cm.

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, 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 effectsof 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. The problem of tolerance for fast and slow neutrons was not discussed.

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 agreed that natural uranium be considered on the basis of chemical toxicity. (It was suggested that the best values for the minimal damaging amounts were 120 micrograms for soluble compounds, this being limited by chemical effects on the kidney and 150 milligrams for insoluble compounds, this latter value being dependent upon irradiation of the lung.

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

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		Maximum Permissible Dose ☆ Plant Personnel	
		Plant Personnel	Large Population	In Air	In Drinking Water
Radium^{226}	1 μgm☆☆	0.1 μgm	.001 μgm	4×10^{-12} μgm/cc	4×10^{-8} μgm/cc
Radon^{222}	-	-	-	-	-
Uranium (nat.)	-	-		25 ugm/cc≠≠ or 1.7×10^{-11} uc/cc	-
Uranium^{233}	6 μgm≠	0.6 μgm	0.006 μgm	Soluble salts: 6×10^{-9} ugm/cc Insoluble salts: 2.5×10^{-11} ugm/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^{210}	0.05 μc☆☆☆	0.005 uc	5×10^{-5} uc	-	-
Thorium^{234}	5 μc≠	0.5 μc	.005 μc	-	-
Strontium^{90} & Yttrium^{90}	5 mc☆☆☆	0.5 mc	.005 μc	10^{-10} μc/cc	2×10^{-6} mc/cc
Strontium^{89}	10 μc	1 uc	0.005 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 ugm/cc 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 the 8-hour exposure day.

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 $\frac{5.5}{0.8}$ x 20 x 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 $\frac{0.5}{0.8}$ x 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 populations 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 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 & 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.

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 thoses 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 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 base 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 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	Maximum Permissible Dose for Off-site Personnel (?)* In Air	In Water
$Hydrogen^{3}$	1 mc	1×10^{-6} uc/cc	1×10^{-2} uc/cc
$Carbon^{14}$	30 µc	1×10^{-6} uc/cc	--
$Sodium^{24}$	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	--
$Iodine^{131}$	0.1 µc	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^{-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.

*** 3×10^{-5} mc/cc corrected to 3/10 r/week.

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 0.14 µc/cc.

Hence, in a 70 kg. man, the total permissible amount of H^3 is approximately 70 x 0.14 = 10 mc. The alveolar air contains 50 mg. of water vapour per litre and hence the permissible concentration in inhaled air is:

$$0.14 \times 0.05 \times 10^{-3}\ \mu c/cc = 7 \times 10^{-6}\ \mu c/cc.$$

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 3.5×10^{-6} µc/cc.

Note further that possibility for isotopic dilution exists in relation to the other routes of water excretion, i.e. the concentration could be increased in proportion 2.5/o.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 = 20 day, so that concentration in inhaled air could be 25 µc. Experimentally, the half-life of tritium water is said to be 6 or 7 days.

A safety factor of 10 on the figure of 7×10^{-6} µc/cc was finally proposed leading to the figure adopted of 10^{-6} µc/cc for air , 1 mc in the body, and 10^{-2} µc/cc for drinking water.

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 uc 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 that 0.14 uc 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:

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

Hence an upper limit to the permissible concentration of C^{14} in the atmosphere is 4×10^{-6} uc/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} uc/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 uc. 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 uc. Thus, for drinking water, the maximum permissible concentration of Na^{24} is approximately 0.005 uc/cc, and for air the maximum permissible concentration is approximately 10^{-6} uc/cc.

It may be noted that the maximum permissible concentration for Na^{24} is approximately 10^{-4} uc/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.

S^{35}

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 6.4×10^{-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 0.27 MeV so that a dose of 0.3 rep/week is produced by 3×10^{-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 0.06 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 0.1 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 5×10^{-12} μgm/cc or 3×10^{-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 4×10^{-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 4×10^{-6} μg/cc or 2.4×10^{-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 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 x 10^{-11} $\mu c/cc$, whereas it should have been 1.7 x 10^{-11} $\mu c/cc$.

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 x 10^{-12} $\mu g/cc$.

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 x 10^{-8} $\mu g/cc$.

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

By analogy with radium, the maximum permissible amount of Sr^{90} in the body is taken to be 0.5 μc. The figures quoted for the levels in air and water would appear to correspond to a final retention of approximately 1%.
