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RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

and of the

INTERNATIONAL COMMISSION ON RADIOLOGICAL UNITS

1950

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U. S. Department of Commerce
National Bureau of Standards

Handbook 47

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U. S. Department of Commerce
National Bureau of Standards

Charles Sawyer, Secretary
E. U. Condon, Director

**Recommendations of the
International Commission on
Radiological Protection
and of the
International Commission on
Radiological Units
1950**



National Bureau of Standards Handbook 47
Issued June 29, 1951

**Recommendations of the
International Commission on
Radiological Protection**

Preface

This Handbook gives the recommendations agreed upon by the International Commission on Radiological Protection of the International Congress of Radiology at its recent meeting in London during the Sixth International Congress of Radiology in July 1950.

The International Congress of Radiology was organized in 1925 under the auspices of radiological and medical groups from all countries of the world. Official delegates to the Congress are named from the radiological societies and national standardization laboratories of each country. At the 1950 meetings 57 countries were represented.

The International Commission on Radiological Protection (ICRP) is one of the two permanent commissions operating under the auspices of the International Congress of Radiology. This Commission was first organized in 1928 and has been continuously active ever since. General meetings have been held during each Congress in which recommendations concerning radiological protection have been established.

Because of the rapid developments in the field of high-energy radiation and the advent of atomic energy, it has been necessary to make frequent revision of our ideas concerning radiological protection. With the development of knowledge in the biological and genetic fields, it appears that the older permissible dosage levels did not carry sufficiently large safety factors. For that reason, the permissible levels of exposure for the whole body have been lowered during the last few years.

At the same time, a new form of potential hazard has arisen because of the possibility of radioactive isotopes lodging within the body structure. While there is a great deal of uncertainty today regarding some of the factors involved when radioactive materials enter the body, it is, nevertheless, possible to lay down some tentative safety levels for ingested

isotopes. These figures will undoubtedly be revised from time to time, but the present ones will serve as a reasonable guide.

The first part of the report gives the firm recommendations of the International Commission on Radiological Protection. The Supplement does not represent firm recommendations but gives, for informational purposes, the best available data on the permissible amounts of radioisotopes in the body.

The following individuals compose the International Commission on Radiological Protection and all were present at the London meetings:

SIR ERNEST ROCK CARLING,
Chairman, Great Britain.
LAURISTON S. TAYLOR, Acting
Secretary, U. S. A.
W. BINKS, Great Britain.
E. L. CHÉRIGIÉ, France.

A. J. CIPRIANI, Canada.
R. JAEGER, Germany.
W. V. MAYNEORD, Great Britain.
R. R. NEWELL, U. S. A.
R. SIEVERT, Sweden.

The next meeting of the International Commission on Radiological Protection will be held in Copenhagen in 1953.

E. U. CONDON, *Director*.

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Recommendations of the International Commission on Radiological Protection 1950

I. Introduction

Developments in nuclear physics and their practical applications since the last International Congress have greatly increased the number and scope of potential hazards. At the same time, biological research has led to an extension of our knowledge of the dangers associated with ionizing radiations. This increase of biological knowledge has not only brought a realization of the importance of certain effects, particularly carcinogenic and genetic effects, but has also provided more information as to the permissible levels of radiation. The International Commission on Radiological Protection has therefore adopted new radiation safety standards with more rigid criteria. Such standards must, in view of the still limited experience of the effects of radiation, be kept continually under review. It appears that the effects to be considered are:

1. Superficial injuries.
2. General effects on the body, particularly the blood and blood-forming organs, e. g., production of anemia and leukemias.
3. The induction of malignant tumors.
4. Other deleterious effects including cataract, obesity, impaired fertility, and reduction of life span.
5. Genetic effects.

While it is still fundamental to express whole-body exposure in terms of a single number, it is not practicable, in general, in view of the complexity of circumstances now arising, to express the maximum permissible hazards in terms of a single parameter. It is, for example, highly desirable to derive values of maximum permissible concentrations of radioactive materials, in the air or in drinking water, taking into account the metabolism of the materials concerned, and assuming standard anatomical, physiological, and chemical data. Furthermore, the previously accepted value of 1 r/week for maximum permissible exposure to external radiation itself needs revision in the light of the

nature of the radiations to which workers are now exposed. There is the added difficulty that the roentgen is not an acceptable unit of dose for all ionizing radiations. Accordingly, the following recommendations are based on considerations of the equivalent energy absorbed in tissue, coupled with the appropriate relative biological efficiency.

While the values proposed for maximum permissible exposures are such as to involve a risk that is small compared to the other hazards of life, nevertheless in view of the unsatisfactory nature of much of the evidence on which our judgments must be based, coupled with the knowledge that certain radiation effects are irreversible and cumulative, it is strongly recommended that every effort be made to reduce exposures to all types of ionizing radiations to the lowest possible level.

II. Exposure to External Radiation

1. EXPOSURE OF INDIVIDUALS TO X, GAMMA, AND BETA RADIATION.

(a) *Whole-Body Exposure.* A careful consideration of the deleterious biological effects enumerated in the Introduction, in the light of observations on man and of the experimental data on animals, has led to the conclusion that, insofar as the well-being of the individual is concerned, the most dangerous effects of external radiation are probably those on the blood-forming organs. Although the dose delivered to these organs is regarded as a fundamental quantity, for practical reasons the maximum permissible exposure is best stated in terms of the dose per week received on the surface. The figure of 1 r/week previously adopted by the International X-ray and Radium Protection Commission seems very close to the probable threshold for adverse effects, particularly for radiations of high energy, which are more frequently encountered now than formerly. A reduction of acceptable permissible surface dose level is therefore called for. For these reasons, and for those previously outlined in the Introduction, it is recommended that:

(i) *In circumstances under 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 r in any 1 week. This dose corresponds to 0.3 r/week measured in free air.*

(ii) *In the case of high-energy beta rays, the maximum permissible exposure of the surface of the body in any 1 week shall be the energy flux of beta radiation such that the absorption*

per gram of superficial tissues is equivalent to the energy absorption from 1.5 r of hard gamma rays. For purposes of calculation, the superficial tissues concerned shall be assumed to be the basal layer of the epidermis, defined conventionally as lying at a depth corresponding to 7 mg/cm^2 .

(b) *Critical tissues.* The recommendations relating to exposure to external radiation are primarily framed in relation to exposure of the whole body. Nevertheless, a greater exposure should not be permitted for irradiation confined to a particular organ or tissue, except in the case of the hands and forearms. Measurements may be made either in air or at the surface of the body with backscatter, and it is estimated that the surface dose of 0.5 r of penetrating electromagnetic radiation would correspond roughly to 0.3 r at the critical tissue, namely, the blood-forming organs, conventionally assumed to lie at a depth of 5 cm below the surface. This figure of 0.3 r is the fundamental figure, which is thought appropriate for the irradiation of any critical tissue, with the one obvious exception of the skin.

(c) *Partial exposure.* It is recommended that:

In the case of exposure of the hands and forearms to X, gamma and beta radiation, the maximum permissible dose shall be 1.5 r (or its energy equivalent) in any one week at the basal layer of the epidermis, defined conventionally as lying at a depth corresponding to 7 mg/cm^2 .

2. WHOLE-BODY EXPOSURE OF INDIVIDUALS TO NEUTRONS.

The International Commission on Radiological Protection considers that the maximum permissible energy absorption per gram of tissues exposed to fast neutrons should not be greater than one-tenth of that permitted for high-energy quantum radiation. The Commission is presently in the process of collecting data as a basis for future numerical recommendations.

III. Exposure to Internal Radiation

3. While the Commission does not, at the moment, consider that there is sufficient information to make firm recommendations concerning maximum permissible exposures to internal radiation from radioactive isotopes, it brings to the notice of users of radioactive isotopes values which are commonly used, at the present time, in the United States of America, Canada, and Great Britain. These values will appear in a supplementary document to be prepared and circulated by the Commission. The Commission

will continually review these values as new information becomes available, and will, if necessary, circulate amended values.

IV. Working Conditions

4. The following conditions are recommended for radiation workers:

(a) The amount of radiation received by operators should be systematically checked to insure that the maximum permissible dose is not exceeded. For this purpose, photographic films or small ionization chambers should be carried on the person.

(b) In addition, radiation workers should be systematically submitted, both on entry and subsequently, to expert blood examinations every three months, and to medical and general examinations once a year, special attention being paid to the hands. These examinations will determine the acceptance, refusal, limitation or termination of occupation involving radiation exposure.

V. General X-ray and Radium Recommendations

5. All rooms should be provided with adequate ventilation. In certain climates it may be necessary to have recourse to air conditioning. For rooms of normal dimensions, say 3,000 ft³ (90 m³) in which corona-free apparatus is installed, the ventilating system should be capable of renewing the air of the room not less than six times per hour, while up to 10 times may be required when the apparatus is not corona-free. Large rooms require proportionately fewer changes of air per hour than small ones. Air inlets and outlets should be arranged to afford cross-wise ventilation of the room.

6. All rooms should preferably be decorated in light colors.

7. A working temperature of about 18° to 22° C (65° to 72° F) is desirable in X-ray rooms.

8. X-ray rooms should be large enough to permit a convenient lay-out of the equipment. A minimum floor area of 250 ft² (25 m²) is recommended for X-ray rooms, and 100 ft² (10 m²) for darkrooms. Ceilings should be not less than 11 ft (3.5 m) high.

9. High-tension generators having exposed high-tension systems should preferably be placed in a separate room from the X-ray tube.

VI. X-ray Protective Recommendations

10. An X-ray operator should on no account expose himself to a direct beam of X-rays.

11. An operator should place himself as remote as practicable from the X-ray tube. It should be borne in mind that valve tubes are capable of producing X-rays.

12. The X-ray tube should be self-protected, or otherwise surrounded as completely as possible with protective material of adequate lead equivalent.

13. Barriers of protective material against primary and secondary radiation should be erected and should be of sufficient thickness to reduce the radiation level at any point of occupancy to the permissible levels stated above.

1. Diagnostic Work

14. In the case of diagnostic work with other than completely protected tubes, the operator should be afforded additional protection from stray radiation by a screen of a minimum lead equivalent of 1 mm.

15. Screening examinations should be conducted as rapidly as possible with minimum intensities and apertures, particularly when fractures are reduced under X-rays. Palpation with the hand should be reduced to the minimum.

16. The lead glass of fluorescent screens should be of sufficient thickness to reduce the radiation to the permissible level.

17. In the case of screening stands, the fluorescent screen should, if necessary, be provided with a protective "surround", so that adequate protection against direct radiation is afforded for all positions of the screen and diaphragm.

18. Screening stands and couches should provide adequate arrangements for protecting the operator against scattered radiation from the patient.

19. Protective gloves, which should be suitably lined with fabric or other material, should have a protective value not less than $\frac{1}{8}$ -mm lead throughout both back and front (including fingers and wrist). Protective aprons should have a minimum lead value of $\frac{1}{2}$ -mm.

2. Treatment

20. In the case of X-ray treatment, the operator is best stationed completely outside the X-ray room behind a protective wall, the lead equivalent of which will depend on the circumstances. In the case of a single X-ray tube excited by voltages up to 200 kv, the protective wall should have a

minimum lead equivalent of 2 mm. This figure should be increased in the case of higher exciting voltages or of heavy tube currents so as to reduce the radiation at any point of occupancy to the agreed permissible level. In such event the remaining walls, floor, and ceiling may also be required to provide supplementary protection for adjacent occupants to an extent depending on the circumstances. Full protection should be provided in all those directions in which the direct beam can operate. Inspection windows in screens and walls should have protective lead values equivalent to that of the surrounding screen or wall.

21. In those cases in which an X-ray tube is continuously excited, and treatment periods are regulated by means of a shutter, some form of remote control should be provided for the shutter, to insure that the operator is not exposed to direct radiation while manipulating the shutter or filter.

22. Efficient safeguards should be adopted to avoid the omission of a metal filter in X-ray treatment, for example, by an interlocking device or by continuously measuring the emergent radiation. Protective screens and applicators (cones) used in treatment to define the ports of entry of X-ray beams should be sufficiently thick to reduce the dosage-rate outside the direct field of irradiation to less than 2 percent that of the direct beam.

VII. Electrical Precautions in X-ray Rooms

23. The floor-covering of the X-ray rooms should be of insulating material such as wood, rubber, or linoleum.

24. Where permanent overhead conductors are employed, they should be not less than 9 ft (3 m) from the floor. They should consist of stout metal tubing or other coronaless type of conductor. The associated connecting leads should be of coronaless wire kept taut by suitable rheophores.

25. Wherever possible, grounded guards or grounded sheaths should be provided to shield the more adjacent parts of the high-tension system. Unshielded leads to the X-ray tube should be in positions as remote as possible from the operator and the patient. The use of "shock-proof" X-ray equipment, in which the high-tension circuit is completely enclosed in earthed conductors, is recommended. In all cases, however, indiscriminate handling of X-ray tubes during operation should be forbidden. Unless there are reasons to the contrary, metal parts of the apparatus and room should be efficiently grounded.

26. Main and supply switches should be very accessible and distinctly indicated. They should not be in the prox-

imity of the high-tension system, nor should it be possible for them to close accidentally. The use of quick-acting, double-pole circuit breakers is recommended. Overpowered fuses should not be used. If more than one apparatus is operated from a common generator, suitable high-tension, multiway switches should be provided. In the case of some of the constant-potential generators, a residual charge is held by the condensers after shutting down, and a suitable discharging device should therefore be fitted. Illuminated warning devices that operate when the equipment is "alive" serve a useful purpose. The staff should be trained in the use of first-aid instructions dealing with electric shock. If foot switches are used, they should be connected in series with an ordinary switch, and should be so designed that they cannot be locked to keep the circuit "alive", and are not capable of being closed accidentally.

27. Some suitable form of kilovoltmeter should be provided to afford a measure of the voltage operating the X-ray tube.

28. Low flash-point anaesthetics should never be used in conjunction with X-rays.

VIII. Film Storage Precautions

29. The use of nonflammable X-ray films is strongly recommended. In the case of flammable films, suitable precautions should be taken as regards their use and storage. Large stocks should be kept in isolated stores, preferably in a separate building or on the roof.

IX. Radium Protective Recommendations

1. Radium Salts

30. Protection for radium workers is required from the effects of:

(a) Beta rays upon the hands.

(b) Gamma rays upon the internal organs, vascular and reproductive systems.

31. In order to protect the hands from beta rays, reliance should be placed, in the first place, on distance. The radium should be manipulated with long-handled forceps, and should be carried from place to place in long-handled boxes, lined on all sides with at least 1 cm of lead. All manipulations should be carried out as rapidly as possible.

32. Radium, when not in use, should be stored in a safe as distant as possible from the personnel. It is recommended

that the safe should be provided with a number of separate drawers individually protected. In the table below will be found the thicknesses of lead which will reduce the radiation to permissible levels at various distances from the source.

33. A separate room should be provided for the "make-up" of screened tubes and applicators, and this room should only be occupied during such work.

34. In order to protect the body from the penetrating gamma rays during handling of radium, a screen of not less than 2.5 cm of lead should be used, and proximity to the radium should only occur during actual work, and for as short a time as possible.

35. The measurement room should be a separate room, and it should preferably contain the radium only during its actual measurement.

36. Nurses and attendants should not remain in the same room as patients undergoing radium treatment with quantities exceeding $\frac{1}{2}$ g.

37. All unskilled work, or work that can be learned in a short period of time, should preferably be carried out by temporary workers, who should be engaged on such work for periods not exceeding 6 months. This applies especially to nurses and those engaged in "making-up" applicators.

38. Radium containers should be tested periodically for leakage of radon. Prejudicial quantities of radon may otherwise accumulate in radium safes, etc., containing a number of leaky containers.

39. Information regarding the quantity of radium and type of transport container, which will be accepted for transmission by land, sea, or air, should be obtained from the appropriate transport authorities in the individual countries.

2. Radon

40. In the manipulation of radon, protection against beta and gamma rays is required, and automatic or remote controls are desirable.

41. The handling of radon should be carried out, as far as possible, during its relatively inactive state.

42. Precautions should be taken against excessive gas pressures in radon plants. The escape of radon should be very carefully guarded against, and the room in which it is prepared should be provided with an exhaust fan controlled from outside the room.

43. Where radon is likely to come in direct contact with the fingers, thin rubber gloves should be worn to avoid contamination of the hands with active deposit. Otherwise,

the protective measures recommended for radium salts should be carried out.

44. The pumping room should preferably be contained in a separate building. The room should be provided with a connecting tube from the special room in which the radium is stored in solution. The radium in solution should be heavily screened to protect people working in adjacent rooms. This is preferably done by placing the radium solution in a lead-lined box, the thickness of lead recommended being according to the table below.

3. Radium-Beam Therapy

45. The risks to the operator attendant on the use of large quantities of radium in radium-beam therapy may be largely obviated if some system of remote control is adopted by which the radium is only introduced into the "bomb" after the latter has been adjusted in position on the patient. If such arrangements are not available, the importance of expeditious handling is stressed.

46. Rooms used for radium-beam therapy should provide adequate protection for adjacent wards and rooms in permanent occupancy. In the following table are given the lead thicknesses required to ensure that the maximum permissible level is not exceeded. Data may very conveniently be represented in a nomograph showing amounts of radiation through lead barriers at different distances from the source.

Quantity of radium (0.5-mm Pt screen)	Thickness of lead to give weekly maximum permissible dose at the following distances from the source				
	20 cm	50 cm	1 m	2 m	5 m
<i>g</i>	<i>cm</i>	<i>cm</i>	<i>cm</i>	<i>cm</i>	<i>cm</i>
0.1	10.0	6.0	3.5	1.0	0
.2	11.5	7.5	4.5	2.0	0
.5	13.5	9.5	6.5	4.0	0.5
1.0	15.5	11.0	8.0	5.0	1.5
2.0	16.0	12.5	9.5	6.5	3.0
5.0	18.0	14.5	11.5	8.5	4.5
10.0	19.5	16.0	13.0	10.0	6.0

Supplement on Maximum Permissible Amounts of Radioactive Isotopes

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 ICRP 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 ICRP 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 (mpl) 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 microcurie fixed in the skeleton. Accordingly, it is accepted that

(a) *The maximum permissible amount of radium fixed in the body is 0.1 microcurie.*

(b) *For radium appearing in the atmosphere as a soluble aerosol, assuming that 25 percent of the inhaled amount is absorbed and that 25 percent 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} microcurie/ml.*

(c) *If radium enters the body through liquid media, assuming 10 percent 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} microcurie/ml.

Pu²³⁹

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 Pu²³⁹ fixed in the body is 0.04 microcurie.*

For soluble compounds of plutonium in the atmosphere, it is estimated that 10 percent 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} microcurie/ml.

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/week, the corresponding concentration of the plutonium in air would be 7.5×10^{-12} microcurie/ml. 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 Pu²³⁹ in air is 2×10^{-12} microcurie/ml, for soluble and insoluble compounds.*

(c) *For Pu²³⁹ in liquid media, assuming that 0.1 percent 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} microcurie/ml.*

Sr⁸⁹ and Sr⁹⁰ (+Y⁹⁰)

On the basis of the observed relative biological effects of Sr⁸⁹ and Ra on animals, it is accepted that

(a) *The maximum permissible amount of Sr⁸⁹ in the body is 2.0 microcurie*

Since the combined disintegration energy of the Sr⁹⁰+Y⁹⁰ pair is twice that of Sr⁸⁹, the maximum amount of Sr⁹⁰ that can be permitted in the body is only one-half that of Sr⁸⁹. Accordingly,

(b) *The maximum permissible amount of Sr⁹⁰ in the body is 1.0 microcurie.* If strontium is assumed to behave like radium as regards uptake, then

(c) *For Sr⁹⁰ in air, assuming that 25 percent of the inhaled amount is absorbed and 25 percent of the absorbed amount is retained with a mean life of about 15 years, the maximum permissible concentration is 2×10^{-10} microcurie/ml.*

(d) *For Sr⁹⁰ in liquid media, assuming 10 percent of the*

ingested amount is retained with a mean life of about 15 years the maximum permissible concentration is 8×10^{-7} microcurie/ml.

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.

Po²¹⁰

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 Po²¹⁰ in the body is 0.005 microcurie.

H³

It is assumed that tritium will be encountered in chemical forms in which free exchange takes place with ordinary hydrogen in the aqueous vapour in the lungs. If the mean energy of the beta radiation is 5.5 kv, a concentration of 0.14 microcurie/g of tissue will result in the biological equivalent of 0.3 r/week. The mean life of H³ in the body is taken to be 10 days. A concentration of 0.14 microcurie/g of tissue corresponds to 10 millicuries uniformly distributed in the 70 kg of the "standard man." It is, therefore, accepted that

(a) *The maximum permissible amount of H³ in the body is 10 millicuries.*

(b) *The maximum concentration of H³ in air, based on a permissible daily intake of 1 millicurie and complete absorption in the lungs, is 5×10^{-5} microcurie/ml.*

(c) *The maximum concentration of H³ in liquid media, based on a permissible daily intake of 1 millicurie, and complete absorption in the body, is 0.4 microcurie/ml.*

C¹⁴ (as CO₂ in air)

A rate of energy absorption biologically equivalent to 0.3 r/week would be produced by 0.014 microcurie of C¹⁴ per gram of tissue. If the highest proportion of carbon in any tissue is 50 percent, then the maximum permissible concentration of C¹⁴ in carbon in the body is 0.028 microcurie/g of carbon. The postulated route of entry of C¹⁴ into the body is via the alveoli of the lungs, and the isotopic concentration in the alveolar air must therefore be limited to 0.028 microcurie/g of carbon. As alveolar air contains 5.5 percent by

volume of carbon dioxide, the maximum permissible concentration of C^{14} in the CO_2 of the alveolar air is about 1×10^{-6} microcurie/ml. Accordingly,

The maximum permissible concentration of C^{14} as carbon dioxide in air is 1×10^{-6} microcurie/ml.

Na^{24}

The energy (beta and gamma) absorbed in the body per disintegration of Na^{24} is estimated to be 2.7 Mev. As 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/week, is 15 microcuries.

As 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 8×10^{-3} microcurie/ml.*

P^{32}

Experimental and clinical data in man show that at times of the order of the mean life of P^{32} , that is, 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/week in the critical tissue (red bone marrow) is, therefore, produced by a total quantity of approximately 25 microcuries 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 microcuries.*

(b) *The maximum permissible concentration of P^{32} in liquid media, assuming that 100 percent is absorbed and that the biological excretion can be neglected in comparison to the radioactive decay, is 2×10^{-4} microcurie/ml.*

Co^{60}

Making the assumption that all the cobalt that 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/week is 1 microcurie. It is, therefore, accepted that

(a) *The maximum permissible amount of Co^{60} in the body is 1 microcurie.*

(b) *The maximum permissible concentration of Co^{60} in liquid media, assuming 100-percent absorption and a half-life in the liver of 20 days, is 1×10^{-5} microcurie/ml.*

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/week is 0.18 microcurie, which would correspond to about 0.3 microcurie in the body. It is, therefore, accepted that

(a) *The maximum permissible amount of I^{131} in the body is 0.3 microcurie.*

(b) *The maximum permissible concentration of I^{131} in air assuming that 100 percent is absorbed, that 20 percent 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 3×10^{-9} microcurie/ml.*

(c) *The maximum permissible concentration of I^{131} in liquid media, assuming that 100 percent is absorbed, that 20 percent 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 3×10^{-5} microcurie/ml.*

All the preceding permissible amounts of isotopes refer to occupational exposure, and are summarized in the following table.

Summary of permissible levels for radioactive isotopes

	Ra ²²⁶	Pu ²³⁹	Sr ⁹⁰	Sr ⁹⁰ (+Y ⁹⁰)	Po ²¹⁰	H ³	C ¹⁴ (as CO ₂ in air)	Na ²⁴	P ³²	Co ⁶⁰	I ¹³¹
Mpl in body.....microcuries	0.1	0.04	2.0	1.0	0.005	1×10 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.....microcuries	10 ⁻⁵	4×10 ⁻⁶	---	2×10 ⁻⁴	---	1×10 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)
Mpl in air.....microcurie/ml	8×10 ⁻¹²	2×10 ⁻¹²	---	2×10 ⁻¹⁰	---	5×10 ⁻³	1×10 ⁻⁶	---	---	---	3×10 ⁻⁹
Proportion retained from gut.....	0.1	0.001	---	0.1	---	1	---	1	1	1	0.2
Mpl in liquid media.....microcurie/ml	4×10 ⁻³	1.5×10 ⁻⁶	---	8×10 ⁻⁷	---	0.4	---	8×10 ⁻³	2×10 ⁻⁴	1×10 ⁻⁵	3×10 ⁻⁵

Appendix I. Standard Man

1. 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.....	70,000

2. Chemical Composition

Element	Proportion	Approximate mass in the body
	<i>Percent</i>	<i>g</i>
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.....	.25	175
Sodium.....	.15	105
Chlorine.....	.15	105
Magnesium.....	.05	35
Iron.....	.004	3
Manganese.....	.0003	0.2
Copper.....	.0002	.1
Iodine.....	.00004	.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 percent than 3 per cent.

3 Applied Physiology

Average data for normal activity in a temperate zone:

(1) Water balance:

DAILY WATER INTAKE

In food (including water of oxidation)	1. 0 liter
As fluids.....	1. 5 liters
Total.....	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 a day.

DAILY WATER OUTPUT

Sweat.....	0. 5 liter
From lungs.....	. 4 liter
In feces.....	. 1 liter
Urine.....	1. 5 liters
Total.....	2. 5 liters

(The total water content of the body is 50 liters)

(2) Respiration:

AREA OF RESPIRATORY TRACT

Respiratory interchange area.....	50m ²
Nonrespiratory area (upper tract and trachea to bronchioles).....	20m ²
Total.....	70m ²

RESPIRATORY EXCHANGE

Physical activity	Hours per day	Tidal air (liters)	Respiration per minute	Volume per 8 hours	Volume per day
At work.....	8	1. 0	20	m ³ 10	} m ³ 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%

(3) Retention of particulate matter in the lungs:

In those cases where specific data are lacking, the convention has been adopted that 50 percent 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 percent amount has been regarded as retained for 24 hours, after which only half of it, that is, 25 percent of the inhaled amount, is retained *in situ* indefinitely.

4. Duration of Exposure

(1) *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.

(2) *Duration of "lifetime" for nonoccupational exposure*

A conventional figure of 70 years has been adopted.

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 of Pt).....	1.0
X-rays of energy 0.1 to 3.0 Mev.....	
Beta rays.....	
Protons.....	
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.

**Recommendations of the
International Commission on
Radiological Units**

Preface

This Handbook gives the recommendations agreed upon by the International Commission on Radiological Units of the International Congress of Radiology at its recent meeting in London during the Sixth International Congress of Radiology in July 1950.

The International Congress of Radiology was organized in 1925 under the auspices of radiological and medical groups from all countries of the world. Official delegates to the Congress are named from the radiological societies and national standardization laboratories of each country. At the 1950 meetings 57 countries were represented.

The International Commission on Radiological Units (ICRU) is one of the two permanent commissions operating under the auspices of the International Congress of Radiology. This Commission was first organized in 1925 and has been continuously active ever since. General meetings have been held during each Congress in which recommendations concerning radiological units and standards have been established.

Because of the rapid development of the high-energy radiation field it has been necessary to make frequent revisions of our ideas concerning radiological units and standards. At the outset, the basic unit of radiation dosage was built largely around the technique employed for its measurement. Because of the rapid advances in the art this has necessitated an embarrassing number of revisions in the last 25 years. In order to minimize this possibility in the future, it was agreed at the last meeting of the Commission to attempt to utilize basic physical units for the description of radiation dosage. While it is realized that it is not practical at the present time to make direct measurements in terms of these units, it is also realized that the old unit is no longer valid, particularly in the multimillion-volt region. The

uncertainties by either method at present involve similar physical considerations. It seems a wise course, therefore, to direct our attention toward basic physical units rather than to perpetuate the difficulties that have been encountered in the use of the old units, which have been in use since 1928.

The following individuals compose the International Commission on Radiological Units, and all were present at the London meetings:

W. V. MAYNEORD, Chairman, Great Britain.	H. HOLTHUSEN, Germany. G. C. LAURENCE, Canada.
L. S. TAYLOR, Secretary, U. S. A.	R. R. NEWELL, U. S. A.
W. BINKS, Great Britain.	W. J. OOSTERKAMP, Holland.
R. COLIEZ, France.	B. RAJEWSKY, Germany.
F. ELLIS, Great Britain.	R. SIEVERT, Sweden.
G. FAILLA, U. S. A.	A. TIVOLI, Italy.

The next meeting of the International Commission on Radiological Units will be held in Copenhagen in 1953.

E. U. CONDON, *Director*.

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Recommendations of the International Commission on Radiological Units

1950

Section A. Units

1. For the correlation of the dose of any ionizing radiation with its biological or related effects the International Commission on Radiological Units (ICRU) recommends that the dose be expressed in terms of the quantity of energy absorbed ¹ per unit mass (ergs per gram) of irradiated material at the place of interest.

2. Inasmuch as calorimetric methods are not usually practicable, ionization methods are generally employed. For this purpose the quantity that must be measured is the ionization produced in a gas by the same flow of corpuscular radiation as exists in the material under consideration. The energy, E_m , imparted to unit mass of the material is then essentially related to the ionization per unit mass of gas, J_m , by the equation

$$E_m = WsJ_m,$$

where W is the average energy expended by the ionizing particles per ion pair formed in the gas, and s is the ratio of the mass stopping power of the material to that of the gas.

3. As the calculation of the dose in absolute energy units from measurements of ionization requires a knowledge of parameters W and s , as well as variables characterizing the radiation and the irradiated material, the ICRU is of the opinion that tables of the best available data should be prepared as soon as possible and held under continual revision.

4. The Commission considers that the roentgen (designated by the symbol r), in view of its long established usefulness, should continue to be recognized as the unit of X- and gamma-ray quantity or dose and that its definition remain unchanged.

¹ By "energy absorbed" is meant the energy imparted to the material by ionizing particles at the place of interest.

The roentgen shall be the quantity of X- or gamma-radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign (see Appendix, Note 1).

5. It becomes increasingly difficult to measure the dose in roentgens as the quantum energy of the X-radiation approaches very high values. The unit may, however, be used for most practical purposes for quantum energies up to 3 Mev.

6. The ICRU does not recognize the use of special names or symbols for quantities that are merely multiples of the fundamental unit. (This does not preclude the use of generally used prefixes such as kilo-, milli-, etc.).

7. The ICRU recommends that the curie be used for the measurement of radioactive materials and that the definition be as follows:

The curie is a unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10} .

This definition is in accordance with the definition of the curie adopted by the Commission on Standards, Units, and Constants of Radioactivity appointed by the International Council of Scientific Unions. The Commission notes that when the curie is defined in this way, the only point of revision that could arise would be the number of curies in 1 g of radium. It is very improbable that this number would differ from unity by an amount of clinical significance although the distinction would clearly have to be taken into account in accurate radium standardization.

8. It is suggested that the gamma-ray emission be expressed in terms of r/mc hr at 1 cm (roentgens per millicurie hour measured at 1 cm) from a point source. As this quantity is different for every isotope, the Commission will undertake the compilation of data relating to the gamma-ray emission of radioactive isotopes.

9. The ICRU requests the national standardizing laboratories to set up, interchange, and compare standards of X-rays, gamma rays, and radioactive isotopes, maintain close contact with each other, and generally by every means within their power further the improvement of methods of standardization.

Section B: Dose or the Specification of the Conditions of X-ray Treatment

After discussion, the ICRU agreed to postpone the revision of Section B, which remains as follows:

10. In the description of the conditions of X-ray treatments, distinction shall be made between the quantity of radiation measured in air and the quantity of radiation estimated to have been received by the tissue. Since the symbol r is reserved for the unit, the amount of the dose may be designated by D . The use of subscripts is suggested to distinguish dosage measurement made under different conditions; e. g., in free air, D ; at the surface of the skin (including back-scatter), D_0 , etc. (See Appendix, Note 2.)

11. The specifications of treatment conditions shall include the following:

- I. *Quantity*. The quantity of radiation (expressed in roentgens) estimated to have been received by the lesion.
- II. *Quality*.
 - (a) The spectral-energy distribution of X-radiation shall be designated by some suitable index, called quality. For most medical purposes, it is sufficient to express the quality of the X-radiation by the half-value layer in a suitable material: Up to 20 kv (peak) cellophane or cellone; 20 to 120 kv (peak) aluminum; 120 to 400 kv (peak) copper; 400 kv up (peak) tin. For a more definite specification of the quality of the radiation, the complete absorption curve in the same material is preferable.
 - (b) Material and thickness of filter, including tube walls.
 - (c) Target material.
- III. *Technique*.
 - (a) Total quantity of radiation per field (incident and emergent) received in an entire course of treatment.
 - (b) Quantity of radiation per field measured at the surface (D_0) at each individual irradiation.
 - (c) The dosage-rate, expressed in r/min , during each individual irradiation.

(d) The total time over which a course of treatments is spread.

(e) The time interval between successive doses.

(f) The target-skin distance.

(g) The number, dimensions, and location of the ports of entry.

Section C: Dose or the Specification of the Conditions of Gamma-ray Treatment

12. The specification of the conditions of gamma-ray treatment should, where possible, include statements of:

I. *Quantity*. The total quantity of radiation (expressed in roentgens) estimated to have been received by the lesion.

II. *Particulars of Radioactive Source*. (a) The total amount and nature of radioactive substance employed (expressed as equivalent milligrams of radium element).

(b) Type, number, and distribution of the containers.

(c) The material and thickness of filters and the nature of the material externally adjacent to the skin.

III. *Technique*. (a) In the case of surface applicators or "large radium units," the quantity of radiation per field at the surface.

(b) The dosage-rate during each individual irradiation.

(c) The total time over which a course of treatments is spread.

(d) The time intervals between successive irradiations.

(e) In the case of surface applicators or "large radium units," the radium-skin distance.

(f) The number, dimensions, and situations of the ports of entry.

Section D: Instruments

13. The following types of apparatus are suggested as suitable for the measurement of quantity in roentgens:

(a) *X-ray Primary Standards*. The free-air chamber shall be used for free-air measurements for all

wavelengths down to the practical limit set by the consideration that the chamber must be of such width and length that the full ionization produced by the corpuscular emission from air is measured in accordance with the definition (A, 4). An air-wall chamber which meets the requirements of the definition may be used for harder radiations.

(b) *X-ray Practical Instruments.* The air-wall chamber may be used for clinical measurements of X-ray quantity over the entire voltage range.

(c) *Gamma-ray Standards and Practical Instruments.* The air-wall chamber may be used for the measurement of primary or scattered radiation, or a combination of both.

14. Instruments used to measure radiation quantity or dosage may conveniently be called dosimeters and dosage-rate (or dose-rate) meters, respectively, and shall be calibrated in roentgens or roentgens per minute.

15. The calibration readings of dosimeters and dosage-rate meters should be independent of the wavelength within the range for which they are designed or used.

16. Dosimeters and dosage-rate meters should be provided with suitable arrangements (e. g., standard radium source, Bronson leak, or capacity sharing device) for checking the reproducibility of their readings.

17. The calibrations of dosimeters or dosage-rate meters should be tested periodically, by a recognized testing laboratory, over the range of wavelengths for which they are designed or used.

18. The national standardizing laboratories shall be invited to undertake standard measurement and the calibration of dosimeters relative to all forms of radiation therapy to which these recommendations may apply. They shall also be invited to issue joint reports from time to time thereon.

Section E: Appendix

NOTE 1. Note that 0.001293 g is the mass of 1 cm³ of dry atmospheric air at 0° C and 760 mm of mercury pressure.

NOTE 2. For example, in an hypothetical case of medium X-rays:

The dose measured in air, D , equals 300 r.

The dose measured at the surface, D_o , equals 500 r.

The dose measured at x cm depth, D_x , equals 200 r.

(D is not to be confused with the energy actually absorbed by the tissue.)

Section F: Rules Governing the Selection and Work of the International Commission on Radiological Units

19. (a) The International Commission on Radiological Units (ICRU) shall be composed of not more than twelve (12) members. The selection shall be made by the International Executive Committee from a list of nominations submitted by the national delegations and by the ICRU itself. Members of the ICRU shall be chosen on the basis of their recognized activity in the field of radiological units and standards, without regard to nationality.

(b) The ICRU shall be composed of at least three medical radiologists and three physicists.

(c) The members of the ICRU shall be selected during one International Congress to serve through the succeeding Congress. Not less than two but not more than four members of the ICRU shall be changed at any one congress. In the intervening period a vacancy caused by conditions beyond control of the International Executive Committee shall be filled on the recommendation of the ICRU.

(d) In the event of a member of the ICRU being unable to attend the ICRU meetings a substitute may be selected by the ICRU as a temporary replacement. Such a substitute member shall not have voting privileges at the meetings unless specifically authorized by the International Executive Committee.

(e) The ICRU shall be permitted to invite individuals to attend its meetings to give special technical advice. Such persons shall not have voting privileges, but may ask permission to have their opinions recorded in the minutes.

20. The continuance of the policies and records of the ICRU shall be in the hands of a Secretary of the ICRU elected by the ICRU from among its regular members and subject to the approval of the International Executive Committee.

21. The ICRU shall familiarize itself with progress in the whole field of radiation units and standards. The Secretary shall be responsible for the preparation of a program to be submitted to the Committee for discussion at its meetings. Preliminary reports shall be prepared and circularized to all members of the ICRU and other specially qualified individuals at least 6 months before the meeting of the Congress.

22. The Chairman shall be elected by the ICRU at least

6 months in advance of the Congress. The choice shall not be limited to the members of the ICRU or to the country in which the Congress is held. Such a chairman shall be a member of the ICRU, *ex officio*, but for the period of the Congress only. Meetings between Congresses shall be presided over by the Secretary or other member selected by the ICRU.

23. Decisions of the ICRU shall be decided by a majority vote, with the Chairman casting the deciding vote in case of tie. A minority opinion may be appended to the minutes of a meeting if so desired by any member and upon his submission of same in writing to the Secretary.



