SAFE DESIGN AND USE OF INDUSTRIAL BETA-RAY SOURCES

Handbook 66

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U. S. Department of Commerce • Sinclair Weeks, Secretary
National Bureau of Standards • A. V. Astin, Director

Safe Design and Use of Industrial Beta-Ray Sources

By

Subcommittee on Sealed Beta-Ray Sources of ASA Z54 Sectional Committee

Under the Sponsorship of the
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Preface

As industrial use of radioactive materials, X-rays, and particle accelerators increases, it is essential that adequate precautions be taken to protect the user and the public against excessive exposure to radiation. Sectional Committee Z54 of the American Standards Association was formed under the sponsorship of the National Bureau of Standards to formulate safety standards in this field. In 1946 the Committee issued American War Standard Z54.1, "Safety Code for the Industrial Use of X-rays," which is presently in the process of revision.

Basic standards for maximum permissible exposure to ionizing radiation are established and revised from time to time by the National Committee on Radiation Protection and Measurements, and by the International Commission on Radiological Protection. The purpose of the Z54 Committee is to formulate safety codes in which these basic standards and other appropriate data are applied to industrial radiation protection problems.

The present membership of the Z54 Sectional Committee is as follows:

Chairman: Scott W. Smith, National Bureau of Standards.
Secretary: Henry G. Lamb, American Standards Association.

American College of Radiology	G. C. Henny, R. H. Morgan, F. O. Coe*, R. R. Newell.*
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American Society of Mechanical Engineers.	N. L. Mochel.
American Society of Safety Engineers	A. N. Chapman.
American Society for Testing Materials.	C. H. Hastings.
American Welding Society	A. Gobus.
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*Alternate.

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U. S. Department of the Navy, Bureau of Ships Code 350.	C. L. Frear.
U. S. Public Health Service, Department of Health, Education, and Welfare.	P. J. 'alaer.

Members-at-large: C. B. Braestrup, G. Ferlazzo, H. Mermagen.

Nine working subcommittees have been established. The reports of the subcommittees are approved by the main committee before publication. The subcommittees and their chairmen are as follows:

1. General Provisions and Methods and Materials of Protection	C. B. Braestrup.
2. Health Provisions and Monitoring	G. C. Henny.
3. X-ray Protection for 2,000-kv Installations and Lower	D. T. O'Connor.
4. X-ray Protection for Installations Above 2,000 kv	A. L. Pace.
5. Gamma Ray Sources for Industrial Radiography	H. Blatz.
6. Electrical Protection	F. J. Euler.
7. X-ray Diffraction, Fluorescence Analysis and Microradiography	W. Parrish.
8. Sealed Beta Ray Sources	R. S. Rochlin.
9. Contamination Levels of Industrial Materials	W. A. McAdams.

*Alternate.

The present Handbook was prepared by the Subcommittee on Sealed Beta Ray Sources. Its membership is as follows:

R. S. Rochlin, Chairman.	S. E. Olson.
W. R. Clore.	H. W. Rapp.
G. B. Foster.	E. Shapiro.
L. Eggman.	R. C. Stratton.
S. J. Harris.	W. E. Swift.
S. D. Millhouse.	C. W. Wallhausen.
G. W. Morgan.	

In preparing this Handbook, the subcommittee at first attempted to formulate rigid safety rules for the manufacture and use of beta-ray sources. It was later decided that, in view of the present rapid expansion of this technology, it would be more useful to prepare a generalized discussion of the many aspects of personnel protection in connection with beta-ray sources.

Much of the material in Sections 14 and 15 of this Handbook was taken from National Bureau of Standards Handbook 54 (reference 5).

Suggestions for improvement of this Handbook will be welcome. Such suggestions should be sent to the National Bureau of Standards, Washington 25, D. C.

A. V. Astin, *Director.*

Contents

Safe Design and Use of Industrial Beta-Ray Sources

1. Scope

1.1. This Handbook has been composed to serve as a guide toward safe design, manufacture, installation, use, maintenance, and disposal of beta-ray sealed sources for industrial applications (see section 2.28).

1.2. It is hoped that the information contained herein will help the reader to comply with the radiation protection regulations issued by the United States Atomic Energy Commission and other Federal and State agencies. However, these governmental regulations may be changed from time to time and may differ in detail from the recommendations herein. A list of such regulations is given in appendix A.

2. Definitions

Terms in this Handbook will be used in accordance with the following brief definitions. For a more complete glossary, see references 21, 39, and 46.[1]

2.1. **Absorbed dose.** The absorbed dose of any ionizing radiation is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It is expressed in rads. (Note: Without the qualifying word "absorbed", dose can have several meanings. See section I of reference 48, and sections 2.13, 2.21, 2.22, and 4.8 of reference 6.)

2.2. **Activity.** A synonym for curiage.

2.3. **Background radiation.** Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be additional background radiation due to the presence of sources of radiation in other parts of the building. (See also definition, reference 21.)

2.4. **Beta rays** (or Beta particles). Electrons (either negative or positive) emitted during radioactive disintegration.

2.5. **Container.** In connection with a sealed source, the container means the sealed enclosure which surrounds the radioactive material.

[1] References are given in section 16 on page 23.

2.6. **Contamination** (radioactive). Deposition or presence of radioactive material in any place where it is not desired, and particularly in any place where its presence can be harmful. The harm may be in vitiating the validity of an experiment or a procedure, or in being a source of danger to persons.

2.7. **Curiage.** The number of curies.

2.8. **Curie.** The quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

2.9. **Daughter.** A nuclide formed by the decay of a radioactive nuclide. The daughter may be either radioactive or stable.

2.10. **Dose.** See "Absorbed Dose."

2.11. **Gamma rays.** Electromagnetic radiation of short wavelength and correspondingly high frequency, emitted by nuclei in the course of radioactive decay.

2.12. **Half-life.** The time in which the curiage of a particular radioactive nuclide has decayed to half its initial value.

2.13. **Isotope.** One of several nuclides having the same number of protons in their nuclei, and hence belonging to the same element, but differing in the number of neutrons, and therefore differing in mass. For example, strontium-88 and strontium-90 are isotopes.

2.14. **Microcurie** (μc). One-millionth of a curie (3.700×10^4 disintegrations per second).

2.15. **Millicurie** (mc). One-thousandth of a curie (3.700×10^7 disintegrations per second).

2.16. **Millirad** (mrad). One-thousandth of a rad.

2.17. **Millirem** (mrem). One-thousandth of a rem.

2.18. **Milliroentgen** (mr). One-thousandth of a roentgen.

2.19. **Nuclide.** A species of atom characterized by the constitution of its nucleus, i. e., by the number of protons, number of neutrons, and energy content.

2.20. **Prototype** source. A source used for type tests of new designs.

2.21. **Rad.** The rad is a unit of absorbed radiation dose and is equal to 100 ergs per gram.

2.22. **Radioactive material.** Material which is undergoing spontaneous nuclear disintegration, resulting in the emission of corpuscular or electromagnetic radiation, such as alpha, beta, gamma, or X-rays.

2.23. **Radioactivity.** Spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiations.

2.24. **Radioisotope.** A radioactive isotope of an element.

2.25. **Rem.** The quantity of any ionizing radiation such that the energy imparted to a biological system (cell, tissue, organ, or organism) per gram of living matter by the ionizing radiation present in the region of interest has the same biological effectiveness as an absorbed dose of 1 rad from lightly filtered X-rays generated at potentials of 200 to 300 kilovolts. For radiation protection purposes, 1 rem may be taken as equivalent to 1 rad for beta rays and gamma rays. (See sections 4.8 and 5.2 (c) of reference 6.)

2.26. **Rep.** An obsolete unit of absorbed dose, equal to 93 ergs per gram. Replaced by the rad.

2.27. **Roentgen.** The quantity of X- or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. (A unit of exposure dose.)

2.28. **Sealed source.** Radioactive material that is encased in, and is to be used in, a container in a manner intended to prevent leakage of the radioactive material. Unless stated otherwise, the term "sealed source" in this Handbook is understood to refer only to sources containing radioactive material that emits beta rays (whether or not it also emits alpha, gamma, or other radiation, and whether or not the beta rays are totally shielded by the container).

2.29. **Weekly dose.** The dose received in any period of 7 consecutive days. See "Absorbed Dose."

3. Radiation Exposure

3.1. *Range of Hazards.* There is a wide variety of types and strengths of sealed beta-ray sources used in many different industrial applications. There is a correspondingly wide range in the degree of associated hazards, both during the manufacture of these sources and in their use. The information on radiation protection and emergency procedures given in this standard, particularly in sections 3. 14, and 15, is intended as a general guide and will be applicable to a greater or lesser degree depending upon the particular sources and application. The degree of potential hazard depends upon the number and strength of the sources, how they are mounted and shielded, the design of the containers with regard to preventing leakage, and other factors. (See also section 6.1).

3.2. *Nature of Hazards.* The potential hazards to health from radiation may be classified under two headings:

(a) Radiation originating outside the body.

(b) Radiation originating from radioactive material inside the body.

For sealed beta-ray sources in normal use, protection is required against the first type of hazard. If a sealed source should leak, the radioactive material thus released may be

454779°—58——2

taken into the body through the mouth, nose, or broken or intact skin, giving rise to the second type of hazard.

3.3. *External and Internal Dose Limits.* Maximum permissible dose limits for external radiation and maximum permissible intake limits for radioactive materials are recommended by the National Committee on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection. These recommendations are revised from time to time as new knowledge becomes available regarding the various effects of radiation on the human body and the metabolism of various radioisotopes. Because these exposure limits are subject to change, specific values are omitted from the body of this Handbook. For a summary of current recommendations, see appendix B.

3.4. *Beta-Ray Dosimetry.* Accurate measurement of external beta radiation is more complicated than X-ray or gamma-ray measurements, and requires the services of a qualified expert to select proper instruments, calibrate them, and properly interpret their readings in terms of surface dose and depth dose in tissue. In general, such measurements can be made with a properly designed ionization chamber, which has a window thin enough to admit a substantial fraction of the beta particles. Such a chamber can be calibrated with a standard source of similar beta-ray energy distribution, preserving similar geometrical conditions. Precise measurement of beta radiation from a surface is best done with an extrapolation chamber. See references 3, 27, 28, 29, 30, 32, 35, and 36.

The outermost layer of skin is considered to be a dead cornified layer, which acts as a filter, and the beta-ray dose should be measured for the zone immediately below this. This dead layer is often taken to have an average value of 7 mg/cm^2. For the eye, however, it is zero, and for the palm of the hand, 40 mg/cm^2 is often used.

3.5. *Penetrating Radiation.* In addition to measuring the beta radiation from beta-ray sources, attention should be given to the secondary X-radiation (bremsstrahlung) produced by beta rays in shielding materials, and to the fact that many beta-emitting radioisotopes also emit some gamma radiation. Shielding which completely stops the beta radiation may be inadequate protection against the more penetrating bremsstrahlung and gamma radiation.

4. Selection of Radioactive Materials

4.1. *Selection of Radioisotope.* In those cases where more than one radioisotope will satisfy the functional requirements of a particular application, preference should be given to the

one of lowest toxicity. Table 1 of reference 39 or appendix B of reference 47 may be used as a guide in comparing the relative radiotoxicity of radioisotopes. Reference 25 contains a convenient table for selecting beta emitters according to energy and half-life.

4.2. *Selection of Form of Radioisotope.* The chemical and physical form of the radioisotopes contained in sealed sources should be so chosen as to:

(a) Minimize chemical or radiation damage which may cause the sealed source to leak radioactive material. (For example, nitrates and organic compounds are usually unacceptable. See section 5.1.)

(b) Minimize the likelihood of intake into the body and of retention in the body.

(c) Minimize dispersion of the radioactive material if the container should leak, or be damaged in an accident or fire. Liquids, powders, or readily decomposed solids are usually undesirable. Radioactive gases may be acceptable if any leakage would be certain to diffuse so quickly that no one could inhale an excessive quantity.

Following are a few examples of preferred forms for radioactive material in sealed sources:

(a) Radioactive metal foil or plating (see reference 37).

(b) Radioactive powder bound inside a thin gold ribbon by a powder-metallurgy technique.

(c) A fused glass or ceramic, of which the radioisotope is one constituent. A type of glass should be chosen that is resistant to radiation damage.

(d) Radioactive powder bonded to a ceramic base with cement that is resistant to radiation damage.

5. Design of Sources

5.1. *General.* The design of a sealed source should be such as to minimize the probability of leakage of the radioactive material, both in normal shipment and use and under such abnormal conditions as can be foreseen. Careful consideration should be given to possible eventual damage to the container or its seal by any of the following factors:

(a) Radiation from the source itself, including both direct radiation damage, and secondary effects, such as production of ozone in the air in the source, thereby accelerating possible corrosion (see section 6.5).

(b) Attack by chemicals inside the container.

(c) Attack by corrosive fumes, solvents or other chemicals to which the source may be exposed (see section 6.4).

(d) Buildup of gas pressure inside the container by the action of radiation from the source upon the container or its contents, or by heating, such as in a fire.

(e) Breakdown due to discharge of high electrical potentials built up by the transmission of beta particles through insulating material.

(f) Vibration, shock, or other mechanical injury (see section 6.3).

(g) Stresses set up by differences in thermal expansion of container parts.

(h) Deterioration inherent in the materials used for the container (e. g., loss of solvents or plasticizers from plastics).

(i) Damage by high or low temperatures, humidity, low pressure experienced in shipment by air, or any other unfavorable environmental conditions that can be foreseen (see section 6.2).

5.2 *Assembly.* The design of the sealed container should be such as to make disassembly difficult. (Examples: welding, riveting, crimping, soldering, peening, covering screw heads with solder.)

5.3 *Internal Utilization Sources.* In many beta-ray sources, the beta rays need not emerge from the sealed container to perform their desired function. Examples of such sources are nuclear batteries; and self-luminous markers, which consist of radioactive material mixed with a phosphor. Such sources should normally be designed with a thick enough container to prevent emergence of any beta rays. (See sections 11.2 and 3.5.)

5.4 *High-Curiage Sources.* Sources containing more than a few curies of radioactive material give rise to special design problems which are beyond the scope of this Handbook.

6. Prototype Testing

6.1. *General.* Because many of the design factors listed in section 5 are difficult to evaluate thoroughly, it is strongly recommended that tests be made on prototypes of each new source design before sources of such design are put into industrial use. How extensive the prototype testing should be depends upon the following factors:

(a) Radiotoxicity of the radioisotope.

(b) Chemical and physical form of the radioisotope (likelihood of accidental dispersal, etc.).

(c) Number of millicuries in each source.

(d) Number of sources to be made.

(e) Degree to which similar designs have proved to be leak-tight for long periods of time under similar conditions of use.

For example, since a 10-millicurie strontium-90 source contains more than 1,000 times the maximum permissible

single intake quantity, very thorough prototype testing of such a source would be advisable.

In general, a prototype test consists of subjecting a prototype source to chemical attack, extremes of temperature, pressure, shock, vibration, etc., at least as severe as such sources might be expected to receive in use, shipment or storage, and then inspecting the prototype source for leakage of radioactive material. In order to pass these tests the source should show no detectable leakage. (For methods of measuring surface contamination and leakage, see section 6.7.)

When a source window or seal has very small fissures, radioactive material sometimes leaks out quite slowly. It is therefore advisable to make two leakage tests at least one week apart before concluding that a source does not leak.

6.2. *Temperature and Pressure Extremes.* Except for sources intended for special applications, the extremes of temperature and pressure are likely to be encountered in shipment rather than in use. Outdoor temperatures in the United States vary from about −54° C (−65° F) to 57° C (135° F) in the shade.[2] A source shipped by air at 35,000 feet in an unpressurized, unheated baggage compartment will experience an absolute pressure of about 7 inches of mercury (0.23 atmosphere) and may experience temperatures as low as −60° C (−76° F).

6.3. *Shock.*

6.3.1. *Shock in Shipment.* The following test is suggested to simulate the shocks a source may encounter during shipment. The source is placed in a capped metal pipe 3 feet long, with a diameter at least twice the maximum dimension of the source. The pipe is rotated about its midpoint at such a speed that the source will approximate a free fall from one end of the pipe to the other. Since the way in which the source falls may be critical, this test should be repeated for at least 100 falls. The source is then removed and tested for leakage. The interior of the pipe should also be examined for radioactive contamination. A thin removable liner for the pipe will facilitate this, and will also simplify decontamination of the pipe.

6.3.2. *Shock in Mill Accidents.* A more severe shock test than the above may be desirable if the sources are intended for applications in plants where heavy impact may be expected from mill accidents (e. g., steel mill thickness gages).

6.4. *Corrosion.* Sealed beta-ray sources for industrial use are especially vulnerable to leakage due to corrosion because

[2] In enclosures, the shipment may be subjected to even higher temperatures.

of (a) the thin windows required to permit the beta rays to emerge, and (b) the large variety of corrosive fumes and chemicals found in industrial establishments. The prototype source should be subjected to attack by those chemicals that may reasonably be expected in industrial environments. Where possible, accelerated life tests should be made to determine the effect of many years exposure to small concentrations of corrosive agents.

Even sources carefully protected from spills of corrosive liquids are subject to condensation of water droplets which combine with gases commonly present in industrial atmospheres, such as hydrogen chloride and sulfur dioxide, to form corrosive acids. According to page 154 of reference 8, a 0.002-inch thickness of type 304 stainless steel will be penetrated in about 12 days by a 10 percent hydrochloric acid solution at room temperature. Plating stainless steel with a noble metal such as rhodium is usually not advisable, since accelerated corrosion is liable to occur by galvanic action at microscopic imperfections in the plating.

Corrosion resistance is a complex subject (see references 8 and 9), and the brief comments above are intended merely to indicate the need for careful attention to potential corrosion in the design and use of sealed beta-ray sources.

6.5. *Radiation Damage.* The physical properties of many materials are changed when subjected to radiation. In general, metals are least affected by beta radiation, while organic materials are among those most susceptible to radiation damage (see references 10 through 16).

Beta radiation can, over a period of time, cause a sealed source to leak by various different modes of action, such as,

(a) Decomposition of the thin window,

(b) Decomposition of cements, binders or glues, used to seal parts of the container together,

(c) Decomposition of water, solder flux, or other material inside the sealed container, giving rise to internal gas pressure which ruptures the container.

It is usually undesirable to use any organic material in the design of sources which contain more than a few microcuries of radioactive material.

One way to determine the "safe life" of a prototype source is to give it a radiation damage life test; that is, to wait until the prototype source suffers leakage because of the radiation damage from its own radiation. In most cases this would take too long to be practicable.

Another way is to make an accelerated life test, by preparing a special test source similar to the prototype but containing, say, 100 times as much activity. If it is feasible to

design the special source in such a way that the actual absorbed dose in the critical materials is 100 times greater than in the prototype, and if one were to assume time reciprocity, the prototype would be expected to last 100 times as long as the special test source before leaking. Since there is considerable uncertainty as to how far the time reciprocity principle may be extrapolated, an appropriate safety factor should be used.

An accelerated life test can also be made by bombarding a prototype source with beta rays from a large external radioactive source or with an electron beam from a high-energy accelerator. If such machines are used, extreme care must be taken in interpreting the test results, since the differences in energy spectra and in bombardment geometry may give rise to large variations in absorbed dose in the critical materials.

Since gamma rays and beta rays cause similar radiation damage for equal absorbed doses, a high gamma flux facility can also be used for radiation damage tests. For example, a dose rate of 2×10^7 roentgens per hour is available from the discharged fuel elements of the Idaho Falls Materials Testing Reactor (see reference 19).

If accurate radiation damage data are available for all the components of a new source design, it may not be necessary to test the complete prototype assembly to determine the safe life. Here again, however, conservative safety factors should be employed.

6.6. *Dispersal Test.* Under special circumstances, where the source is expected to be used in such a way that the source window may be accidentally torn or punctured, it is advisable to test the prototype to determine how readily the radioactive material will disperse from a damaged source. To make such a test, the source may be placed in a small enclosure so designed as to facilitate the following steps:

(a) The thin window of the source is punctured or torn while in the enclosure.

(b) The source, still in the enclosure, is subjected for at least 24 hours to such air currents and vibration as would be likely to occur in normal use.

(c) The source is transferred to a second enclosure.

(d) The inside surfaces of the first enclosure are checked to determine how much radioactive material has left the source.

The use of a gloved box or similar device is recommended to protect the operator against contamination and external radiation hazards during this test. It may be preferable to make this test with a special source, scaled down to, say, 1 percent of the curiage of the prototype.

6.7. *Surface Contamination Test Methods.* The test methods described below are intended merely as examples of acceptable methods. Other test methods may also be acceptable. These tests should be made only by persons who are qualified to cope with the attendant hazards, including those arising from leaking sources as well as from the external radiation.

6.7.1. *Wipe Test.* All external surfaces of the source container are wiped thoroughly with a piece of moist absorbent paper. The paper is then placed a measured distance from a Geiger counter or other suitable device which has walls thin enough to admit beta rays from the radioisotope involved, and the activity on the paper is measured. (For measurement techniques, see references 3, 18, and 20.) A calibration for this test consists of placing a small known amount of the radioiostope in question (say 0.05 microcurie) on a surface similar to the source container and performing the wipe tests.

Sometimes, a more sensitive test may be obtained by using a suitable complexing agent such as Versene, rather than water, to moisten the absorbent paper.

6.7.2. *Immersion-Scrub Test.* In some cases a small leak can be found more quickly by immersing the source in water (or a solution of a complexing agent) and scrubbing the surface with a brush. The source is then removed, the solution is evaporated to dryness, and the activity of the residue is measured.

This immersion-scrub method can be readily adapted to testing the source's susceptibility to corrosion by various liquids.

6.7.3. In determining whether a source leaks under shock, vibration, and extremes of temperature and pressure, care must be taken in each case to insure that any radioactive material which leaks out of the source remains confined in some enclosure suitable for measuring its activity.

7. Instruction Manuals

7.1. Instruction manuals for sealed sources and for equipment containing sealed sources should include information on the following subjects, as appropriate:

(a) Recommended procedures during installation, normal use, shutdown and storage to protect personnel from excessive radiation. (See sections 11, 12, 13, and 14.) In particular, the recommended frequency and method of leakage tests by the user should be specified.

(b) Recommended procedures in case of accident, fire,

or flood to minimize radiation hazards and radioactive contamination hazards to personnel. (See section 15.)

(c) A statement of the tested "safe life" of the source from the standpoint of radiation damage (see section 6.5). It should be clearly recommended that the source be disposed of before the end of said safe life, including recommendations for or references on safe disposal. (See section 13.2.)

(d) A statement of the temperature extremes, pressure extremes, shock and vibration under which the prototype source passed the leakage test. (See sections 6.1, 6.2, and 6.3.)

(e) Information on the resistance of the source to attack by corrosive fumes, solvents, or other chemicals. This should include both:

(1) A description of the source construction, including the materials used and the thickness of the thinnest portion of the sealed container, and

(2) A listing of typical chemicals to which the source container may be safely exposed and chemicals to which it should not be exposed. The list of chemicals to which the source may be safely exposed should be based on actual tests on the materials of which the source is constructed, and shall include data on concentrations used, temperature, and duration of exposure. (See section 6.4.)

8. Labels

8.1. *Caution Labels.* The presence of sealed beta-ray sources during normal use or storage should be made known by one or more suitable labels on the source or on devices containing the source, or by signs in the area where the source is located. Such labels or signs should be durable and conspicuous, should display the standard radiation symbol (see fig. 2, p. 23), and should bear, where applicable, wording substantially as follows:

(a) **CAUTION—RADIOACTIVE MATERIAL.** Unauthorized persons stay at least ____________ feet away.

(b) This equipment contains not more than __________ millicuries of (name of radioisotope).

(c) In case of emergency call ________________________ (Name), ____________ (Phone) or ____________________________ (Name), ___________ (Phone).

(d) Do not operate before reading instruction manual.

454779°—58——3

8.2. *Identification Labels.*

8.2.1. Every sealed source container should bear, if feasible and practicable, a durable identification label or labels which should include the following information:

(a) The word "radioactive."
(b) Name or symbol of radioisotope(s) and approximate curiage.
(c) Year of sealing.
(d) Identification of manufacturer.
(e) Serial number.

Example: Radioactive Source No. 497
10 mc. Tl–204
Doe Mfg. Co., 1954

8.2.2. If it is not feasible or practicable to put all of the information listed in section 8.2.1 on the source container itself, this information should be shown on a durable label so located as to minimize the probability of the source becoming separated from the identification label. In the case of small sources manufactured in large quantities, a type number may be used instead of a serial number.

9. Manufacture of Sources

9.1. *Production Testing.* Every sealed source should be tested for leakage before being shipped by the manufacturer. For suggested test methods, see section 6.7.

9.2. *Production Safety.* Detailed instructions for safe procedures during source manufacture are beyond the scope of this Handbook. (See references 1 and 2.) Unsealed radioactive materials should be handled only under the supervision of a qualified radiation safety expert.

9.3. *Manufacturing Records.* The manufacturer should keep complete records of all sealed sources produced. These records should include the following information for each source:

(a) Serial number, if any (otherwise type number).

(b) The specific radioisotope(s) contained in the source, and the chemical forms of said radioisotopes.

(c) Date of sealing.

(d) Source strength (curiage), and the method or a reference to the method of determining it.

(e) The dates and results of all tests performed on the source.

(f) A description or a reference to the description of the design and method of manufacture.

(h) The date of shipment or transfer.

(i) The name and address of the transferee.

10. Shipment of Sources

10.1. Radioactive material should be shipped in conformance with all pertinent regulations of the Interstate Commerce Commission or other government agency having jurisdiction. See appendix A.

11. Installation of Sources

11.1 *General Precautions.* The location and use of sealed sources and of equipment containing sealed sources should be such that:

(a) The sources are so mounted as to minimize the exposure of persons to external radiation during the use or maintenance of the sources, and to limit the exposure of others to doses that are negligible with respect to maximum permissible dose limits.

(b) Opportunity for tampering by unqualified personnel is minimized (e. g., use of a padlock).

(c) The possibility of damage to the source from fire, flood, storm, industrial accidents, cold, shock, vibration, corrosive fumes, etc., is minimized.

(d) In the event of damage to a source, likelihood of dispersal of radioactive material and consequent hazard to personnel is minimized. For example, transport of sealed sources by blasts of compressed air increases the probability of rupture and of subsequent wide dispersal.

11.2. *Shielding.* The thickness of material needed to stop beta rays may be obtained from figure 1 (p. 22). Since the values of beta-ray range shown are measured along the crooked paths of the beta particles, a shield of corresponding thickness will provide a factor of safety. In terms of milligrams per square centimeter, most materials have similar stopping powers for beta rays. Values read from the lead curve will be adequate for lighter materials. The data for figure 1 were taken from reference 34 which contains tables of reciprocal stopping power (RSP) ranges for many other elements and compounds. See also figure 12 of reference 38. Light materials are preferred for beta-ray shielding because they produce less of the penetrating secondary X-radiation (bremsstrahlung) (see section 3.5). Metals are preferred over plastics because they are more resistant to radiation damage (see section 6.5). In designing beta-ray shields, consideration should be given to the reflection or scattering of beta radiation by the shields or other objects.

11.3. *Instruction Manuals.* Every installation of equipment containing a sealed source should be provided with an instruction manual containing the information listed in section 7.

11.4. *Safety Program.* At the time of installation, the user of a source should set up an adequate safety program covering the matters listed in sections 7, 12, 13, 14, and 15.

12. Inspection by User for Leakage

12.1. *Frequency.* Sources in industrial use which contain enough radioactive material so that leakage thereof would be a hazard to personnel, should be inspected periodically for leakage at least as often as is recommended in the instruction manual (section 7). The recommended frequency of such leakage tests will differ for different sources, depending upon such factors as:

(1) Number of years of favorable experience with sources of similar design under similar conditions of use.
(b) Curiage of the source.
(c) Radiotoxicity of the radioisotope.
(d) Chemical and physical form of the radioisotope (likelihood of accidental dispersal, etc.).

For the majority of sealed sources presently in use, leakage testing at least every 6 months is recommended. Leakage tests should also be made after mill accidents, after shipment to a new location, and at such other times as environmental conditions may cause damage to the source seal. Any source found to have a leak should be removed from use and disposed of or repaired (see section 13.2).

12.2. *Notification of Leakage.* Information on the discovery of leakage and on the probable cause thereof should be sent both to the manufacturer and to the Isotopes Branch, Atomic Energy Commission, Washington 25, D. C., in order to provide data that may be helpful in designing safer sources.

12.3. *Test Methods.* The test methods described in section 6.7 may be used, provided that such tests are made by a person qualified to perform them safely and interpret the results properly.

The following special leakage test method is suggested for those cases where the source is mounted in a device which has an opening through which high-energy beta radiation emerges (e. g., a thickness gage). This opening is kept covered at all times with a piece of thin adhesive cellulose tape. At regular intervals (e. g., once each week) the tape is removed carefully and replaced with a new piece. The

removed piece is folded in two, with the sticky sides together, to seal in any radioactive contamination which may have adhered to it. The activity on the tape is then measured, to indicate whether the source has leaked. This method has the advantage of interposing an additional barrier to the spread of contamination in case a source does leak.

13. Storage and Disposal of Sources

13.1. Storage of a sealed source when not in use should be such as to minimize the probability of tampering or handling by unqualified persons or the probability of excessive exposure of personnel to radiation. If a source is stored for more than 6 months, it should be tested for leakage before it is put into use.

13.2. Sources that require disposal should be either returned to the manufacturer or disposed of in some other manner approved by the U. S. Atomic Energy Commission or other appropriate government agency. Detailed information on disposal of radioactive sources is beyond the scope of this Handbook. See references 23, 24, and 31.

14. Working Conditions

14.1. *General.* Before a person is allowed to handle radioactive sources he shall be informed of the hazards involved and how to guard against them.

14.2. *Personnel Monitoring.* Personnel monitoring should be employed where radiation safety depends upon proper operating procedures. A film badge may be used. Various types of wrist badges or rings incorporating films are available for monitoring local exposure to the hands. If a particular operation is routine or repetitive and the hazard is slight, the local exposure may be established without the necessity of wearing such devices continuously. See references 3, 30, and 33.

14.3. *Radiation Protection Officer.* In every plant handling radioactive sources that constitute a potential hazard to personnel, some responsible employee should be designated as radiation protection officer. The radiation protection officer should be responsible for the establishment of satisfactory working conditions according to current standards, including those recommended in this Handbook. He should have authority, as well as responsibility, to investigate and advise on all phases of the work in matters of radiation protection. His recommendations should take precedence over the work requirements in order to safeguard life, health, property, the public, and the reputation and responsibility of the installation.

14.3.1. The specific responsibilities of the radiation protection officer or his deputy should include the following duties:

(a) Assure that every worker selected to handle radioactive sources has suitable physical and mental requirements to qualify him for the work to be performed.

(b) Be responsible for the instruction of personnel regarding safe working practices, the consequences which may result from overexposure to radiation, and proper procedures in emergencies.

(c) Establish and maintain operational procedures so that the radiation exposure of each worker is kept as far below the maximum permissible as is practicable.

(d) Assure that under normal conditions no one receives more than the maximum permissible dose.

(e) Investigate each case of excessive or abnormal exposure to determine the cause and take steps to prevent its recurrence.

(f) Assure that personnel monitoring devices are used where needed and keep permanent records of the results of such monitoring.

(g) Assure that suitable caution labels or signs are in place when and where required (section 8.1).

(h) Keep records of all sources including their locations.

(i) Conduct radiation surveys and periodic leakage tests and keep records of them (section 12).

(j) Assure that all shields, containers, and handling equipment are maintained in satisfactory condition.

(k) Plan and post in advance adequate procedures for coping with accidents, fire, flood, source leakage, etc., which might result in external overexposure of personnel or intake of radioactive materials. This should include maintaining and posting a list of local physicians who have familiarized themselves in advance with diagnosis and treatment of radiation injuries and radioisotope intake. (See section 15.)

14.3.2. Since the ultimate responsibility for adequate radiation protection rests with top management, steps should be taken to insure that the protection program described above is initiated as written company policy and is not permitted to deteriorate over the years due to changes in personnel, vacations, pressure of other affairs, etc. Such steps might well include an arrangement whereby the radiation protection officer is appointed by and directly responsible to the plant manager or a company executive, and is required to submit to him periodic reports on the status of the radiation protection program.

14.4. *Physical Examinations.* No special examinations other than those considered good medical or industrial practice should be required. Preemployment physical examination is always advisable in order to reveal any physical conditions that later may be attributed to radiation exposure. The preemployment examination should include: (a) medical history, (b) radiation exposure history, (c) physical examination, and (d) blood count. If there is any possibility of accidental overexposure of any person, a normal blood-count series for any such individual may be useful as a later reference to indicate the presence or absence of significant radiation damage.

15. Accidents Entailing Radiation Hazards

15.1. *Introduction.* Radiation overexposure may involve external radiation only, or it may include intake of radioactive material into the body from a leaking source. In the event that only external radiation exposure in excess of the permissible limits is involved, the cause of the overexposure should be investigated, and corrective measures should be taken. A distinction should be made between technical overexposure only slightly in excess of permissible limits, and overexposure having the connotation of injury. When the total overexposure exceeds 25 rems, or if actual overexposure in this range is suspected, a physician should be consulted, preferably from the list referred to in section 14.3.1 (k).

In the case of leaking sources, spills, or similar accidents, in which there is any possibility of ingestion, inhalation of radioactive material or severe body contamination, a physician should be consulted immediately. The information below may be initially useful to the physician in charge, as well as to persons awaiting the physician's arrival. See also section VI–4 (page 20) of reference 2, and reference 22.

The hazards resulting from contamination of humans and the entry of radioactive substances into the body vary greatly with various isotopes, depending on their physical and chemical properties and forms. Because the metabolism of these isotopes in humans is often not well understood, rather detailed study procedures are described in order to provide helpful information for any future accident that may occur as well as to aid the exposed individuals.

The procedures listed below may be abridged appropriately for accidents involving sources of very low curiage. As a guide for such abridgement, see section 3.3. The procedures may also be modified when it can be immediately ascertained that contamination is confined to a small known area.

15.2. *Source Leakage*

15.2.1. If there is reason to suspect that leakage of a potentially hazardous amount of radioactive material has occurred, the following emergency measures should be taken at once:

(a) No immediate attempt should be made to clean up the spill.

(b) All windows should be closed, fans and air-conditioner should be shut off, and everyone should leave the room.

(c) All doors should be closed and locked.

(d) If powdered sources are involved, the door and all other openings leading into the room should be sealed with wide masking tape or adhesive tape and heavy wrapping paper.

(e) Every person who might have been contaminated should be tested for radioactivity, and, if contaminated, should remove his clothes and be decontaminated. If no means are available for testing, it should be assumed that the person is contaminated. See section 15.3.

(f) Entrance to the contaminated area should be prohibited until a consultant experienced in radiation hazards can be called in and his advice followed.

(g) Special problems associated with the spillage of liquid sources are covered in reference 2.

15.2.2. Under no circumstances should any untrained person attempt to examine or clean up any spilled radioactive material. The cleanup technique should be planned with the same care as is used in quantitative chemical analysis or in bacteriological handling of virulent organisms. Fans or ventilating apparatus should not be turned on in an attempt to blow away the radioisotope, except possibly in special cases involving gaseous sources (see section 15.2.3). Such a maneuver will only disseminate the radioactive material throughout the area. If the radioisotope is blown out of a building, air currents may carry the finely divided material into nearby windows or air-intake ducts. Proper precautions taken immediately will protect human life and minimize financial losses.

15.2.3. If the leaking radioisotope is in the form of a gas, it may be safer to blow it outdoors than to allow it to diffuse throughout a building through cracks around doors, etc. The proper emergency procedure for each such installation should be planned in advance and posted. (See section 14.3.1 (k).)

15.3. *Emergency Care for Possibly Contaminated Persons.*

15.3.1 All suspected persons should be surveyed for radioactive contamination. (See reference 2 for suggested permissible levels.)

15.3.2. If no monitoring instrument is available, all possibly exposed persons should be regarded as contaminated. Wipes from various parts of the bodies of these persons and their clothing should be made with some type of disposable tissue, filter paper, or blotting paper, and the samples placed in separate labeled envelopes for future study.

15.3.3. Contaminated persons should remove all significantly contaminated clothing carefully and place it in some type of disposable container or bag. If such a container is not available, clothing should be put on paper to prevent contamination of floor and furniture. The clothing can be monitored later to determine the possibility of decontamination or the need for disposal.

15.3.4. Contaminated persons should then be covered with some type of emergency clothing and taken to a shower area for bathing.

15.3.5. Bathing should be done under showers, and commercially available detergents and soaps can be used. Several separate washings should be performed. Highly alkaline soaps, abrasives, organic solvents, or cleaners that tend to increase permeability of the skin should not be used. Special emphasis should be given to cleaning of fingernails, toenails, nostrils, scalp, ears, and body folds.

15.3.6. Scrub brushes should be used, but care should be taken that the skin surfaces do not become abraded.

15.3.7. After the body is well washed, the person should be surveyed with a suitable monitoring instrument and additional smears taken with disposable tissues, cotton-tipped applicators, or filter paper. The ear canals and nostrils should be swabbed for contamination. Smear tests are especially important if alpha contamination may be possible, since alpha survey instruments may not be able to detect body contamination in recessed areas. Fresh clothing should be put on.

15.3.8. Small cuts and other breaks in the skin surface should be sought for carefully, since absorption of isotopes can occur by this route. Such lesions should be decontaminated after the above washes by repeated 5-minute scrubs. Removal of scabs and crusts to eliminate underlying contamination should be under the direction of a physician.

15.3.9. A physician should be called immediately, preferably from the list referred to in section 14.3.1 (k). He should carry out appropriate medical studies on contaminated persons, such as the following:

(a) In the case of ingestion, inhalation, or wound contamination by "bone-seekers", such as strontium-90, prompt injection or local application of certain drugs can markedly reduce subsequent deposition in the bones (see references 40 through 45). The physician can obtain up-to-date information on such treatment promptly by telephone from the Director, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington, D. C., or from the medical director of one of the large Atomic Energy Commission installations, such as Hanford Atomic Products Operation, Richland, Wash., or Los Alamos Scientific Laboratory, Los Alamos, N. Mex.

(b) A complete medical history should be taken with special emphasis on previous occupational history and possible exposure to radiation.

(c) A thorough physical examination, with standard urinalysis may be indicated. If exposure in the range of 25 rems is suspected, a complete red, white, and differential blood count may need to be made. Such blood counts should normally be repeated daily for at least 7 days.

(d) Quantitative collection of urine should be made for the first 72 hours for assay of the isotope. A small sample (approximately 100 ml) of urine should be collected between 1 and 3 hours after the accident, and should be kept in a separate container. Each day's specimen should be put in a separate container. These specimens may be collected in bottles containing 10 ml of dilute nitric acid (approximately 10 ml of concentrated nitric acid per liter of water) for each 24-hour specimen. An additional 10 ml of concentrated nitric acid should be added to the specimen after the collection is complete. A preservative such as formaldehyde may also be added to the specimen, if refrigeration is not available. Care must be taken to prevent contamination of these samples.

(e) Feces collection for the first 72 hours for determination of radioactivity. Each day's specimen should be put in a separate container. These can be collected in round, 1-quart cardboard ice-cream containers. Care must be taken to prevent contamination of these samples.

(f) Arrangement should be made for surveys of the total body gamma radiation with a sensitive measuring device, if such facilities are available.

(g) Within 72 hours, blood should be taken in 20-ml samples for determination of radioactivity. One blood sample should be taken between 1 and 3 hours after the accident, if feasible, to provide early diagnostic information. Care must be taken to prevent contamination of these samples.

(h) The specimens of urine, feces, and blood should be refrigerated and kept until arrangements can be made for radioactivity analysis at a qualified laboratory. Proper collection and storage of these samples will be of great value in prescribing treatment for the contaminated persons and also in obtaining further data concerning the metabolism of the isotope involved.

15.4. *Decontamination*. The following recommendations will facilitate the cleanup of a radioactive isotope, especially when it is in the form of a powder. This work should be done only under the direct supervision of a qualified radiation safety expert. For additional guidance and for data on maximum permissible levels of residual contamination in areas to be reoccupied, see reference 2.

(a) A traffic-control program should be instituted immediately to minimize spread of contamination on shoes to other areas.

(b) The following equipment should be available: Respirators, coveralls, shoe covers, vacuum cleaner, and steel drums for refuse.

(c) Inexpensive latex or plastic overshoes can be used. Ordinary paper bags may be used as shoe covers in an emergency.

(d) Periodic surveys with appropriate radiation detection instruments should be performed and the readings recorded on an area map.

(e) Vacuum cleaning should be performed before wet mopping or scrubbing. By vacuum cleaning first, the contamination will be reduced significantly and less radioactive material will become lodged in the flooring. A filter which is efficient for particles down to 0.2 micron in diameter should be in the intake line of the vacuum cleaner.[3] The operator should wear a suitable respirator and helmet.

(f) After dry vacuum cleaning or if a suitable vacuum cleaner with filter is not available, damp mopping with a detergent and chelating agent will help to remove radioactive contamination. Care must be taken in disposing of the contaminated mop and water.

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[3] Firms which are reported as able to supply such special filter media include Cambridge Filter Corp., 738 Erie Blvd., East Syracuse 3, N. Y.; Flanders Mill, Riverhead, N. Y.; and Mine Safety Appliances Co., 230 N. Braddock Ave., Pittsburgh 8, Pa.

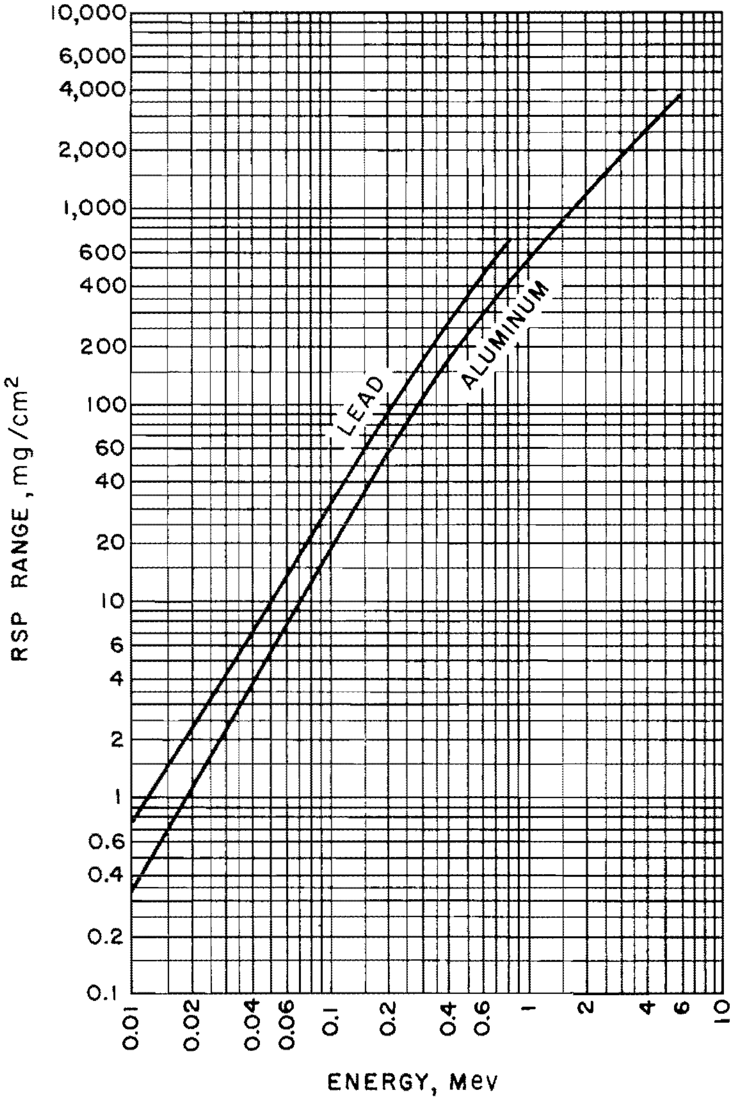

FIGURE 1. *Beta-ray shielding thicknesses.*

See text, section 11.2.

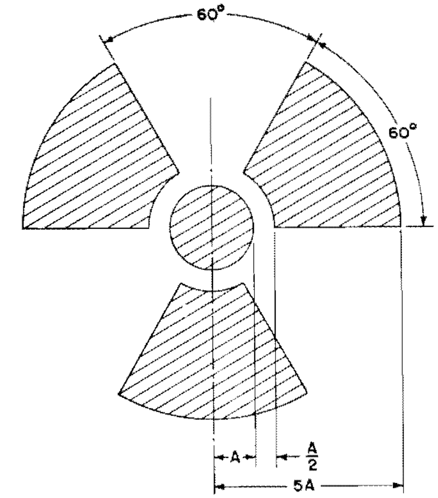

FIGURE 2. *Standard radiation symbol.*

Cross-hatched areas are purple, background is yellow. See reference 17 for detailed color specifications.

16. References

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Appendix A. Listing of Pertinent Laws and Regulations

1. *Regulations of the United States Atomic Energy Commission*, as published from time to time in the Federal Register, may be obtained from the Isotopes Branch, U. S. Atomic Energy Commission, Washington 25, D. C. Parts pertinent to sealed beta-ray sources include:

Part 20. "Standards for Protection Against Radiation." Published in Federal Register, Tuesday, January 29, 1957.

Part 30. "Licensing of Byproduct Material." Present revision published in Federal Register, January 11, 1956.

Part 31. "Radiological Protection Standards for Sealed Sources." Publication of proposed draft pending.

2. *Regulations for Shipping Radioactive Material.* Summarized in "Handbook of Federal Regulations Applying to the Transportation of Radioactive Materials," published July 1955 by the U. S. Atomic Energy Commission, Division of Construction and Supply, Traffic Management Section, Washington 25, D. C. (48 pages). (This Handbook does not include ICC shipping container specifications.) Full official texts and latest revisions of shipping regulations may be obtained as follows:

(a) *Interstate Commerce Commission Regulations.* Published as Title 49, Parts 71 to 78, of the Code of Federal Regulations. Amendments are published in the Federal Register. Both may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Alternatively, the ICC regulations may be purchased from the Bureau of Explosives, Association of American Railroads, 30 Vesey Street, New York 7, N. Y. (current price $3.50). The shipping labels required by the ICC can also be obtained from the Bureau of Explosives.

(b) *Civil Aeronautics Board Regulations.* Published as Title 14, Part 49, of the Code of Federal Regulations. May be purchased separately for $0.10 from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., under the title, "Civil Air Regulations, Part 49: Transportation of Explosives and Other Dangerous Articles." Page 9 of this publication provides instructions for obtaining amendments issued since the last printing.

(c) *U. S. Postal Regulations.* Chapter IV, Article 37, "Radioactive Materials," and any revisions thereto may be obtained from the Bureau of Transportation, Post Office Department, Washington 25, D. C.

(d) *U. S. Coast Guard Regulations*, covering transportation of radioactive materials by water, appear in Title 46, Part 146, of the Code of Federal Regulations as amended. See Federal Register July 17, 1952, and December 31, 1952. These may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

3. *Regulations, if any, issued by the State or municipality* or both, in which beta-ray sources are manufactured or used. Information on any such radiation protection regulations can usually be obtained from the State or municipal Department of Health.

Appendix B. Maximum Permissible Exposure Limits

The problem of establishing basic formulas for maximum permissible exposure limits that involve an acceptable degree of risk for persons occupationally exposed to ionizing radiations and provide adequate protection for others in the environs of radiation sources without unduly hampering progress in this field, has been the subject of much careful study over many years by both national and international groups. The National Committee on Radiation Protection and Measurements (NCRP) in the United States and the International Commission on Radiological Protection (ICRP) have pioneered in this field and have issued various statements of their conclusions. Those of the NCRP have been published as National Bureau of Standards Handbooks and of particular interest in connection with the present document are NBS Handbook 59, "Permissible Dose From External Sources of Ionizing Radiation" (reference 6) and NBS Handbook 52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water" (see table 1 and reference 4). These handbooks are at present under revision, but these revisions probably will be available soon after publication of the present Handbook on Sealed Beta-Ray Sources.

Table 1. *Maximum permissible amount of radionuclides related to internal dose limits* [a, b]

Radionuclide	MPC [c]-Water	MPC-Air	MPBB [d]
	$\mu c/ml$	$\mu c/ml$	μc
Carbon-14	8.2×10^{-3}	1.2×10^{-6}	260
Cobalt-60	4.9×10^{-4}	1.1×10^{-7}	13
Cerium-144+daughters	1.2×10^{-4}	3.3×10^{-9}	4.6
Cesium-137+Ba^{137m}	1.5×10^{-4}	2.2×10^{-8}	33
Hydrogen-3 (HTO or T_2O)	0.034	5.0×10^{-6}	1.3×10^{3}
Krypton-85 [e]	----------	----------	----------
Plutonium-239	----------	4.8×10^{-13}	----------
Promethium-147+Sm^{147}	2.2×10^{-3}	2.2×10^{-8}	60
Radium-226+30% daughters	1.2×10^{-6}	1.0×10^{-10}	[f] 0.1
Ruthenium-106+Rh^{106}	1.2×10^{-4}	2.6×10^{-8}	2.8
Strontium-90+Y^{90}	3.1×10^{-6}	2.6×10^{-10}	[f] 1
Sulfur-35	6.3×10^{-4}	9.3×10^{-8}	91
Thallium-204	1.1×10^{-3}	2.1×10^{-7}	14
Thulium-170+Yb^{170m}	4.6×10^{-4}	1.2×10^{-8}	9.3
Unidentified β and γ emitters [e]	----------	----------	----------
Unidentified α emitters [e]	----------	----------	----------

[a] For controlled areas.

[b] These values have been taken from the most recent considerations by the NCRP and ICRP and should be considered as tentative. It is expected that the NCRP will publish new data on maximum permissible concentrations at an early date.

[c] Maximum Permissible Concentration.

[d] Maximum Permissible Body Burden.

[e] Data not yet available.

[f] Values from ICRP (1955).

Present recommendations for *occupational exposure* are expressed in terms of "controlled areas." A *controlled area* is one in which the occupational exposure of personnel to radiation or radioactive material is under the supervision of a *radiation safety officer*. (This implies that a controlled area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.)

Recommendations for Maximum Permissible Dose (MPD) for persons outside controlled areas, but within the same general environs, is one-tenth that specified for controlled areas, integrated over periods up to 1 year and with proper consideration for workload, use factor and occupancy factor. Table 2 is given below as a convenient summary of the present basic recommendations for MPD; however, Handbook 59 should be consulted for a more complete treatment of the basic factors.

TABLE 2. *Recommended limits on exposure to radiation*

Part of body exposed	Requirements inside controlled areas	Notations
Critical Organs: Includes whole body, head and trunk, blood-forming organs and gonads.	(a) Accumulated dose (external exposure) = 5 (N−18) rems. (b) Dose in any 13 consecutive weeks is not to exceed 3 rems.	N is the age and is greater than 18. The 12 rems annual limit applies only where adequate records exist to show that the age-prorated accumulated dose is not exceeded.
Other Organs:		
Skin of whole body	(a) Accumulated dose = 10 (N−18) rems. (b) Dose in any 13 consecutive weeks is not to exceed 6 rems.	N is the age and is greater than 18. Applies to radiation of low penetrating power.
Lens of the eyes	Dose limited by dose to head and trunk.	
Hands, feet, and forearms.	(a) MPD = 75 rems/year (b) Dose in any 13 consecutive weeks is not to exceed 25 rems.	MPD = Maximum Permissible Dose.
Internal Organs:	Accumulated dose from internal emitters based on:	
Most individual organs.	MPD = 15 rems/year	Maximum permissible concentrations of radionuclides in air and in water are determined by various factors, including nature of organ, type and energy of radiation, biological half life, radioactive half life, etc.
Thyroid or skin	MPD = 30 rems/year	
Bone	MPD = body burden equivalent to that of 0.1 μg Ra^{226} plus daughters.	
Gonads or whole body	MPD = 5 rems/year	
Whole Body	Accidental or emergency dose of 25 rems *once in lifetime*.	Need not be included in the radiation exposure status of the person.
Any Part of Body	Medical dose from necessary medical and dental procedures.	Need not be included in the radiation exposure status of the person.

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