NCRP REPORT No. 41

SPECIFICATION OF GAMMA-RAY BRACHYTHERAPY SOURCES

NCRP

National Council on Radiation Protection and Measurements

SPECIFICATION OF GAMMA-RAY BRACHYTHERAPY SOURCES

Recommendations of the
NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

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Preface

This report of the National Council on Radiation Protection and Measurements (NCRP), successor to the National Committee on Radiation Protection and Measurements, is concerned with the specification of sealed sources of nuclides which emit gamma rays—sources useful in brachytherapy. The report resulted from the Council's belief that a single well-defined method for specifying the radionuclide in an encapsulated source would be advantageous for both the users and the suppliers of such sources. Presently, encapsulated radionuclides are being specified in terms of the activity of the radionuclide, in terms of the equivalent mass of radium, or in terms of the exposure rate at a specified distance from the source. This report examines each of these methods of specification and, on the basis of this examination, develops recommendations on the method of specification considered to be appropriate. Although the subject matter presented in this report is related to that found in NCRP Report No. 40, *Protection Against Radiation From Brachytherapy Sources,* this report's content is limited to the characteristics of the sources themselves rather than to a discussion of the way in which they may and should be used.

The present report was prepared by the Council's Scientific Committee 27 on Specification of Radium Substitutes. Serving on the Committee during the preparation of this report were:

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The Council wishes to express its appreciation to the members and the consultants of the Committee for the time and effort devoted to the preparation of this report.

LAURISTON S. TAYLOR
President, NCRP

Washington, D.C.
December 15, 1973

Contents

1. Introduction

Various encapsulated radionuclides that emit gamma rays (see Appendix A) are used in the same manner as, and frequently as substitutes for, radium sources in brachytherapy [1].[1] Except for radionuclides that emit low-energy gamma photons (approximately 0.1 MeV or less), the relative distribution of absorbed dose around such substitutes is frequently given with an accuracy sufficient for clinical purposes when the dose[2] distribution is calculated from available radium dosage tables [2, 3, 4, 5]. This is true for photons of energies greater than approximately 0.1 MeV because the inverse square relation rather than the attenuation of the radiation in tissue is the primary reason for dose rate reduction with distance. The dose distribution near the ends of the sources is uncertain for all radionuclides including radium. Because radium dosage tables have been available and used for many years, many radiation therapists wish to retain them to determine relative dose distribution produced by other radionuclides, provided this results in acceptable accuracy. However, calculation of absolute doses requires an appropriate quantitative specification of the particular brachytherapy source.

Suppliers of encapsulated radionuclides have used several methods to specify gamma-ray brachytherapy sources. The meaning, usefulness, and accuracy of the specification have not always been clear. A single well-defined method for specifying the sources would be advantageous for both the user and the supplier.

[1] Numbers in brackets indicate literature references listed on page 11.

[2] In this report the word "dose" is used as a synonym for the term "absorbed dose". Terms used in this report are defined in Appendix B.

2. Present Methods of Specification

Encapsulated gamma-ray therapy sources are being specified now in terms of activity of the radionuclide (usually in millicuries), in terms of the equivalent mass of radium (usually in milligrams), or in terms of the exposure rate at a specified distance in air from the source (usually in roentgens per hour at one meter).

2.1 Specification in Terms of the Activity of the Radionuclide

It often has been assumed that the exposure rate at any point in the vicinity of an encapsulated gamma-ray-emitting radionuclide, including radium, is proportional to the activity of the radionuclide and its specific gamma-ray constant.[3] Although specification of gamma-ray brachytherapy sources in terms of activity has been and is being used, there are some problems associated with, and objections to, its use.

(1) The exposure rate may be reduced considerably because of self-attenuation in the radionuclide and attenuation in the wall of the container. These effects are taken into account when the mass of radium in a capsule is determined and in the selection of the numerical value of the specific gamma-ray constant for radium; also, they were taken into account when some radium dosage tables were calculated. Whether or

[3] The International Commission on Radiation Units and Measurements has defined a new quantity, *exposure rate constant*, to replace *specific gamma-ray constant* [6]. The exposure rate constant includes the exposure rates from photons (of energies greater than a specified minimum) of the characteristic x rays and internal bremsstrahlung, in addition to the exposure rate from the gamma rays. The specific gamma-ray constant includes only the latter. For encapsulated radionuclides the exposure rates from all three of these radiations will be modified by self-attenuation and by attenuation in the wall of the capsule; also, some low energy photons not included in the exposure rate constant may be important in dosage considerations. Hence, neither quantity may be entirely applicable to brachytherapy sources.

not these effects were taken into account when the activity of substituted radionuclides was determined has not always been specified. The filtration effect of the wall depends on the energies of the photons and the material and thickness of the wall of the capsule.

The exposure rate at a distance from the source may vary because the attenuation of the gamma rays in tissue from all radionuclides may not be the same due to differences in the energies of the photons.

Errors caused by these differences in attenuation are considered by some to be within acceptable limits for clinical purposes for a number of radionuclides [2, 3, 4, 5], but not by others [2, 7, 8].

(2) There may be no standard source available for determining the activity of some radionuclides that may be used. The accuracy of the determination of the activity of such radionuclides may vary substantially from one supplier to another.

(3) The activity of an encapsulated source can be determined by comparing the ionization produced by it with that from a standard source if the two sources are similarly encapsulated. If they are not similarly encapsulated, corrections will have to be made for the differences in self-attenuation and attenuation in the walls of the containers.

(4) For clinical purposes the value of the exposure rate constant or the specific gamma-ray constant may not be entirely applicable or may not be known to a sufficient degree of accuracy for all radionuclides that may be used.

2.2 Specification in Terms of the Equivalent Mass of Radium

This method of specifying a radionuclide in a tube or needle would enable a therapist to use radium dosage tables. There are several reasons why this specification may not be satisfactory.

(1) If the equivalent mass of radium of the substituted radionuclide is determined from the activity of the radionuclide and the ratio of the exposure rate constants or the specific gamma-ray constants of radium and the substituted radionuclide, the uncertainties discussed in Section 2.1 apply.

(2) Occasionally the equivalent mass of radium has been determined with the same lead-walled ionization chamber used for radium comparisons. If the energies of the photons from the radium source and the substituted source are not the same, the chamber will respond differently to the two sources. Thus a one-milligram radium equivalent of the sub-

stituted source would not deliver the same dose in tissue as a one milligram source of radium.

2.3 Specification in Terms of the Exposure Rate at a Specified Distance

The International Commission on Radiation Units and Measurements recommends that high-activity gamma-beam sources, such as are used for gamma-beam therapy, be specified on the basis of an exposure rate at a stated reference point, defined as a point one meter from the front face of the source capsule [9]. A similar method would seem to be logical for specifying all encapsulated gamma-ray-emitting radionuclides used in therapy. Several attributes of the method are worthy of note.

(1) The user is interested not in the activity of the encapsulated radionuclide but in the available exposure rates at distances of interest from the source. Such rates can be computed from the known exposure rate at a specified distance.

(2) Methods of measuring exposure rates are well established [10]; such measurements can be made with an accuracy of about three percent and a precision of one percent or better.

(3) The activity that a source appears to have, a specification which may be required by some regulatory agencies, can be determined by dividing the exposure rate at a specified distance from the source by that for a unit of activity of the radionuclide with the same filtration and at the same distance.

(4) If it is desired to know an "effective" equivalent mass of radium (encapsulated in a container with a specified wall thickness) for a radionuclide in a source, it can be determined by dividing the exposure rate at a specified distance from the capsule by the exposure rate at the same distance from a unit mass of radium (in a capsule with the specified wall thickness). Such an "effective" equivalent mass of radium can be used to calculate dose around the capsule by the use of standard radium dosage tables, if such calculated dose is sufficiently accurate for clinical purposes.

3. Discussion

The determination of the exposure rate at a specified distance from the source is most appropriately made with an air-equivalent ionization chamber; the material and thickness of the wall of the chamber would have to be appropriate for the energy of the gamma rays emitted by the particular radionuclide. If the ionization chamber is calibrated with a gamma-ray source such as radium or cobalt-60, with a known exposure rate at a specified distance, a correction factor may be required for gamma rays of other energies. (The correction factor depends on such parameters as the gamma-ray attenuation in the wall, the ratio of the electron stopping power of the wall of the ionization chamber to that of air, and the ratio of mass-energy-attenuation coefficients of the wall and of the center electrode to that of air.) Usually the variation of this correction factor with photon energies of interest will not exceed two or three percent. An apparatus for determining the exposure rate for gamma-beam therapy sources has been recommended by the International Commission on Radiation Units and Measurements [9]; this apparatus might be adapted for measurements of exposure rates for gamma-ray brachytherapy sources.

4. Recommendations

The specification of gamma-ray brachytherapy sources *should*[4] be in terms of the exposure rate at one meter from, and perpendicular to, the long axis of the source at its center. This exposure rate may be computed from a measurement made at any convenient distance meeting the requirements of item 2 of the enumeration set out below. The units in which a source strength is specified then become R m^2 h^{-1}, or any suitable multiple of this unit. It is recommended that the source be measured with an ionization chamber which has been calibrated over the energy range of the gamma photons to be measured. This calibration may be made either by use of a suitable gamma-ray standard, or by having the ionization chamber itself calibrated in suitable beams. These calibrations *should* be directly traceable to the exposure standards maintained by the National Bureau of Standards[5].

The supplier *shall* furnish a certificate which gives, for each source, the half-life and purity of the radionuclide, the dimensions of the source, the composition and thickness of the encapsulating material, the conditions of the measurement, and other information that may be needed by the user.

The exposure rate *shall* be determined thus:

(1) By the use of an ionization chamber
  a. with air equivalent response (or if not air equivalent, a proper correction *shall* be made); and
  b. with walls of proper thickness to establish electronic equilibrium.

(2) The distance between the source and the ionization chamber *shall* be great enough that the source can be considered to be a point source and the chamber a point detector; this distance *shall* be stated in the certificate.

[4] NCRP recommendations are expressed in terms of "shall" and "should". *Shall* indicates a recommendation that is necessary or essential to meet current accepted standards. *Should* indicates an advisory recommendation that is to be applied when practicable.

[5] In this context, "directly traceable" means that there should be not more than one intermediate step between the calibration of the working instrument and the calibration at the National Bureau of Standards.

(3) If the attenuation of the radiation in air is greater than one percent, a correction for attenuation *shall* be made and this correction *shall* be described in the certificate.
(4) The measurement *shall not* include radiation scattered from the surroundings.
(5) The accuracy of the measurement *should* be within ± 3 percent and *shall* be within ± 5 percent (with 95 percent confidence limits).
(6) The precision of the measurement *should* be within ± 1 percent and *shall* be within ± 2 percent (with 95 percent confidence limits).
(7) The time and date of the measurement *shall* be stated in the certificate.

APPENDIX A

Data for Selected Gamma-Ray Sources[a]

Radionuclide	Half-Life	Gamma Photons	Specific Gamma-Ray Constant[b]	Exposure Rate Constant[b]
		MeV	$R\ cm^2\ h^{-1}\ m\ Ci^{-1}$	$R\ m^2\ h^{-1}\ Ci^{-1}$
Cesium-137	30.0 years	0.6616	3.226	0.3275
Chromium-51	27.72 days	0.3200	0.1842	0.01842
Cobalt-60	5.26 years	1.173–1.322[c]	13.07	1.307
Gold-198	2.698 days	0.4118–1.088[c]	2.327	0.2376
Iodine-125	60.25 days	0.03548	0.04228	0.1326
Iridium-192	74.2 days	0.1363–1.062[c]	3.948	0.4002
Radium-226 with daughters	1604.0 years	0.0465–2.440[c]	9.068[d]	1.015
Tantalum-182	115.0 days	0.0427–1.453[c]	7.692	0.7815

[a] Reference 11.

[b] The specific gamma-ray constants and exposure rate constants were calculated from the latest decay-scheme data by L. T. Dillman. Contributions to these values from gamma photons and x rays of energies less than 11.3 keV have not been included. Dr. Dillman is a member of NCRP Scientific Committee 33 from which this information had been requested.

[c] Minimum and maximum values of gamma photons included in the calculation of specific gamma-ray constant and exposure rate constant.

[d] This value differs from the currently accepted value of 8.25 for radium because the value of 9.068 was calculated for no filtration. The value of 8.25 is for a filter of 0.5 mm platinum and includes such secondary radiations as may be generated in the platinum filter.

APPENDIX B

Definitions

absorbed dose: The mean energy imparted by ionizing radi...ti..., to matter per unit of mass of irradiated material at the place of interest. See rad.

absorbed dose rate: Absorbed dose per unit time.

accuracy: The degree of correctness with which a method of measuring yields the "true" value of a measured quantity [12].

activity: The number of spontaneous nuclear transformations occurring in a given quantity of a radionuclide per unit time. See curie.

attenuation: The reduction of exposure rate resulting from the interposition of matter.

air equivalent response: The response of an ionization chamber to photons is said to be "air equivalent" over some stipulated energy interval if the calibration factor for the chamber can be considered to be constant.

brachytherapy: A method of radiation therapy in which an encapsulated source or a group of such sources is utilized to deliver gamma or beta radiation at a distance up to a few centimeters either by surface, intracavitary, or interstitial application.

curie (Ci): The special unit of activity equal to a nuclear transformation rate of 3.7×10^{10} per second (exactly).

dose: See absorbed dose.

dose rate: See absorbed dose rate.

electronic equilibrium: Electronic equilibrium exists when the total ionization in a volume is equal to the total ionization that would be produced by the corpuscular emission originating in that volume.

encapsulated source: A radionuclide sealed in a container such as a tube or needle for use in brachytherapy, or in a container for use in a teletherapy machine.

exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all of the ions of one sign produced in air, when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. See roentgen.

exposure rate: The exposure per unit time.

exposure rate constant: This quantity is similar to "specific gamma-ray constant", but includes the exposure rates from photons (of energies greater than a specified minimum) of the characteristic x rays and internal bremsstrahlung, in addition to the exposure rate from the gamma rays. A specific unit of exposure rate constant is $R\ m^2\ h^{-1}\ Ci^{-1}$ or any convenient multiple of this.

million electron volts (MeV): Energy equal to that acquired by a particle with one electronic charge in passing through a potential difference of one million volts (one MV).

millicurie (mCi): One-thousandth of a curie.

nuclide: A species of atom having specified numbers of neutrons and protons in its nucleus [6].

precision: The degree of reproducibility among several independent measurements of a quantity.

radionuclide: A nuclide which is radioactive.

rad: The special unit of absorbed dose, equal to 0.01 joule per kilogram.

roentgen (R): The special unit of exposure, equal to 2.58×10^{-4} coulomb per kilogram (exactly).

shall: *Shall* indicates a recommendation that is necessary or essential to meet current accepted standards.

should: *Should* indicates an advisory recommendation that is to be applied when practicable.

specific gamma-ray constant: The exposure rate produced by the unfiltered gamma rays from a point source of a defined activity of a radionuclide at a defined distance. A common form of specific gamma-ray constant is the exposure per millicurie-hour at one centimeter, which has the units R cm^2 h^{-1} mCi^{-1}. (The value for radium, 8.25 R per mg h at 1 cm, is obtained with a filter of 0.5 millimeter of platinum.)

stopping power: The stopping power of a material for a charged particle of specific energy is the energy loss per unit length of path.

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2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units, and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations;
3. Develop basic concepts about radiation quantities, units, and measurements, about the application of these concepts, and about radiation protection;
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The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee.

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American Radium Society
American Roentgen Ray Society
American Society of Radiologic Technologists
American Veterinary Medical Association
Association of University Radiologists
Atomic Industrial Forum
Defense Civil Preparedness Agency
Genetics Society of America
Health Physics Society
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The Council's activities are made possible by the voluntary contribution of the time and effort of its members and participants and the generous support of the following organizations:

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Society of Nuclear Medicine
United States Atomic Energy Commission
United States Public Health Service

To all of these organizations the Council expresses its profound appreciation for their support.

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The NCRP seeks to promulgate information and recommendations based on leading scientific judgment on matters of radiation protection and measurement and to foster cooperation among organizations concerned with these matters. These efforts are intended to serve the public interest and the Council welcomes comments and suggestions on its reports or activities from those interested in its work.

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57 *Instrumentation and Monitoring Methods for Radiation Protection* (1978)

58 *A Handbook of Radioactivity Measurements Procedures* (1978)

59 *Operational Radiation Safety Program* (1978)

60 *Physical, Chemical, and Biological Properties of Radiocerium Relevant to Radiation Protection Guidelines* (1978)

61 *Radiation Safety Training Criteria for Industrial Radiography* (1978)

62 *Tritium in the Environment* (1979)

63 *Tritium and Other Radionuclide Labeled Organic Compounds Incorporated in Genetic Material* (1979)

64 *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980)

65 *Management of Persons Accidentally Contaminated with Radionuclides* (1980)

66 *Mammography* (1980)

67 *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements* (1981)

68 *Radiation Protection in Pediatric Radiology* (1981)

69 *Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV* (1981)

70 *Nuclear Medicine-Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy* (1982)

71 *Operational Radiation Safety—Training* (1983)

72 *Radiation Protection and Measurement for Low Voltage Neutron Generators* (1983)

73 *Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children* (1983)

74 *Biological Effects of Ultrasound: Mechanisms and Clinical Implications* (1983)

75 *Iodine-129: Evaluation of Releases from Nuclear Power Generation* (1983)

76 *Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment* (1984)

77 *Exposures from the Uranium Series with Emphasis on Radon and its Daughters* (1984)

78 *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States* (1984)

79 *Neutron Contamination from Medical Electron Accelerators* (1984)

80 *Induction of Thyroid Cancer by Ionizing Radiation* (1985)

Other Documents

The following documents of the NCRP were published outside of the NCRP Reports series:

"Blood Counts, Statement of the National Committee on Radiation Protection," Radiology 63, 428 (1954)

"Statements on Maximum Permissible Dose from Television Receivers and Maximum Permissible Dose to the Skin of the Whole Body," Am. J. Roentgenol., Radium Ther. and Nucl. Med. 84, 152 (1960) and Radiology 75, 122 (1960)

X-Ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements (National Council on Radiation Protection and Measurements, Washington, 1968)

Specification of Units of Natural Uranium and Natural Thorium (National Council on Radiation Protection and Measurements, Washington, 1973)

NCRP Statement on Dose Limit for Neutrons (National Council on Radiation Protection and Measurements, Washington, 1980)

Krypton-85 in the Atmosphere—With Specific Reference to the Public Health Significance of the Proposed Controlled Release at Three Mile Island (National Council on Radiation Protection and Measurements, Washington, 1980)

Preliminary Evaluation of Criteria For the Disposal of Transuranic Contaminated Waste (National Council on Radiation Protection and Measurements, Bethesda, Md, 1982)

Control of Air Emissions of Radionuclides (National Council on Radiation Protection and Measurements, Bethesda, Md, 1984)

Copies of the statements published in journals may be consulted in libraries. A limited number of copies of the remaining documents listed above are available for distribution by NCRP Publications.

INDEX