ICRU REPORT 18

# Specification of High Activity Gamma-Ray Sources

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

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INTERNATIONAL COMMISSION ON RADIATION
UNITS AND MEASUREMENTS
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see page 23)

# Preface

## Scope of ICRU Activities

The International Commission on Radiation Units and Measurements (ICRU), since its inception in 1925, has had as its principal objective the development of internationally acceptable recommendations regarding:

(1) Quantities and units of radiation and radioactivity,

(2) Procedures suitable for the measurement and application of these quantities in clinical radiology and radiobiology,

(3) Physical data needed in the application of these procedures, the use of which tends to assure uniformity in reporting.

The Commission also considers and makes recommendations in the field of radiation protection. In this connection, its work is carried out in close cooperation with the International Commission on Radiological Protection (ICRP).

## Policy

The ICRU endeavors to collect and evaluate the latest data and information pertinent to the problems of radiation measurement and dosimetry and to recommend the most acceptable values for current use.

The Commission's recommendations are kept under continual review in order to keep abreast of the rapidly expanding uses of radiation.

The ICRU feels it is the responsibility of national organizations to introduce their own detailed technical procedures for the development and maintenance of standards. However, it urges that all countries adhere as closely as possible to the internationally recommended basic concepts of radiation quantities and units.

The Commission feels its responsibility lies in developing a system of quantities and units having the widest possible range of applicability. Situations may arise from time to time when an expedient solution of a current problem may seem advisable. Generally speaking, however, the Commission feels that action based on expediency is inadvisable from a long-term viewpoint; it endeavors to base its decisions on the long-range advantages to be expected.

The ICRU invites and welcomes constructive comments and suggestions regarding its recommendations and reports. These may be transmitted to the Chairman.

## Current Program

In 1962 the Commission laid the basis for the development of the ICRU program over the next several years. At that time it defined three broad areas of concern to the Commission:

I. The Measurement of Radioactivity
II. The Measurement of Radiation
III. Problems of Joint Interest to the ICRU and the International Commission on Radiological Protection (ICRP)

The Commission divided these three areas into nine subareas with which it expected to be primarily concerned during the next decade. The division of work agreed upon is as follows:

I. Radioactivity
   - A. Fundamental Physical Parameters and Measurement Techniques
   - B. Medical and Biological Applications

II. Radiation
   - A. Fundamental Physical Parameters
   - B. X Rays, Gamma Rays and Electrons
   - C. Heavy Particles
   - D. Medical and Biological Applications (Therapy)
   - E. Medical and Biological Applications (Diagnosis)
   - F. Neutron Fluence and Kerma

III. Problems of Joint Interest to the ICRU and the ICRP
   - A. Radiation Protection Instrumentation and its Application

The Commission established a separate planning board to guide ICRU activities in each of the subareas. The planning boards, after examining the needs of their respective technical areas with some care, recommended, and the Commission subsequently approved, the constitution of task groups to initiate the preparation of reports. The substructure which resulted from these actions is given below.

- Planning Board I.A. Radioactivity—Fundamental Physical Parameters and Measurement Techniques
  - Task Group 1. Measurement of Low-Level Radioactivity
  - Task Group 2. Specification of Accuracy in Certificates of Activity of Sources for Calibration Purposes
  - Task Group 3. Specification of High Activity Gamma-Ray Sources (Joint with P.B. II.B)
- Planning Board I.B. Radioactivity—Medical and Biological Applications
  - Task Group 1. In Vivo Measurements of Radioactivity
  - Task Group 2. Scanning
  - Task Group 3. Tracer Kinetics
  - Task Group 4. Methods of Assessment of Dose in Tracer Investigations
- Planning Board II.A. Radiation—Fundamental Physical Parameters
- Planning Board II.B. Radiation—X Rays, Gamma Rays and Electrons
  - Task Group 1. Radiation Dosimetry; X Rays from 5 to 150 kV
  - Task Group 2. Radiation Dosimetry; X and Gamma Rays from 0.6 to 100 MV
  - Task Group 3. Electron Beam Dosimetry
- Planning Board II.C. Radiation—Heavy Particles
  - Task Group 1. Dose As a Function of LET
  - Task Group 2. High Energy and Space Radiation Dosimetry
- Planning Board II.D. Radiation—Medical and Biological Applications (Therapy)
  - Task Group 1. Measurement of Absorbed Dose at a Point in a Standard Phantom (Absorbed Dose Determination)
  - Task Group 2. Methods of Arriving at the Absorbed Dose at any Point in a Patient (In Vivo Dosimetry)
  - Task Group 3. Methods of Compensating for Body Shape and Inhomogeneity and of Beam Modification for Special Purposes (Beam Modification)
  - Task Group 4. Statement of the Dose Achieved (Dosage Specification)
- Planning Board II.E. Radiation—Medical and Biological Applications (Diagnosis)
  - Task Group 1. Photographic Materials and Screens
  - Task Group 2. Image Intensifier Radiography
  - Task Group 3. TV Systems
- Planning Board II.F. Radiation—Neutron Fluence and Kerma
  - Task Group 1. Neutron Fluence, Energy Fluence, Neutron Spectra and Kerma
- Planning Board III.A. Radiation Protection Instrumentation and its Application
  - Task Group 1. Radiation Protection Instrumentation Handbook—Part I
  - Task Group 2. Neutron Instrumentation and its Application to Radiation Protection

Because the Commission's basic recommendations on radiation quantities and units relate to the work of all of the planning boards, the Commission decided to establish a separate committee with membership drawn largely from the Commission itself to initiate the revision of ICRU Report 10a, *Radiation Quantities and Units*. Thus, the Committee on Fundamental Quantities and Units was added to the above substructure.

In 1962 the Commission decided to abandon its past practice of holding a meeting together with all of its sub-units every three years. Instead it was decided that the Commission would receive reports from the subgroups at the time of their completion rather than at fixed deadlines. Meetings of the Commission and of the subgroups are held as needed.

The adoption of the new substructure and mode of operation was intended to alleviate some of the problems associated with the expanded program required in recent years. In the past, the Commission's attempt to administer and review the work of each of the working groups imposed a very considerable burden on the Commission itself. The need to concern itself with each detail, which was inherent in such a scheme of operation, when coupled with the procedure of completing all reports at one time, subjected the Commission members to an intolerable work load if rigorous standards were to be maintained. The new substructure and mode of operation is now beginning to produce results in the form of reports drafted by the task groups and reviewed by the planning boards. Present evidence indicates that the substructure and mode of operation, while not perfect, has to a substantial extent succeeded in alleviating the problems previously experienced. Recently, however, the commission has begun the examination of further modification of the substructure.

### ICRU Reports

In 1962 the ICRU, in recognition of the fact that its triennial reports were becoming too extensive and in some cases too specialized to justify single-volume publication, initiated the publication of a series of reports, each dealing with a limited range of topics. This series was initiated with the publication of six reports:

ICRU Report 10a, *Radiation Quantities and Units*
ICRU Report 10b, *Physical Aspects of Irradiation*
ICRU Report 10c, *Radioactivity*
ICRU Report 10d, *Clinical Dosimetry*
ICRU Report 10e, *Radiobiological Dosimetry*
ICRU Report 10f, *Methods of Evaluating Radiological Equipment and Materials*

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These reports were published, as had been many of the previous reports of the Commission, by the United States Government Printing Office as Handbooks of the National Bureau of Standards.

In 1967 the Commission determined that in the future the recommendations formulated by the ICRU would be published by the Commission itself. This report is published by the ICRU pursuant to this policy. With the exception of ICRU Report 10a, which was superseded by ICRU Report 11, the other reports of the "10" series have continuing validity and, since none of the reports now in preparation are designed to specifically supersede them, will remain available until the material is essentially obsolete. All future reports of the Commission, however, will be published under the ICRU's own auspices. Information about the availability of ICRU Reports is given on page 23.

### ICRU's Relationships With Other Organizations

One of the features of ICRU activity during the last few years has been the development of relationships with other organizations interested in the problems of radiation quantities, units, and measurements. In addition to its close relationship with the International Commission on Radiological Protection and its financial relationships with the International Society of Radiology, the World Health Organization, and the International Atomic Energy Agency, the ICRU has also developed relationships of varying intensity with several other organizations. Since 1955, the ICRU has had an official relationship with the World Health Organization (WHO) whereby the ICRU is looked to for primary guidance in matters of radiation units and measurements, and in turn, the WHO assists in the worldwide dissemination of the Commission's recommendations. In 1960 the ICRU entered into consultative status with the International Atomic Energy Agency. The Commission has a formal relationship with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), whereby ICRU observers are invited to attend UNSCEAR meetings. The Commission and the International Organization for Standardization (ISO) informally exchange notifications of meetings and the ICRU is formally designated for liaison with two of the ISO Technical Committees. The ICRU also corresponds and exchanges final reports with the following organizations:

Bureau International des Poids et Mesures
Council for International Organizations of Medical Sciences
Food and Agriculture Organization
International Council of Scientific Unions
International Electrotechnical Commission
International Labor Office
International Union of Pure and Applied Physics
United Nations Educational, Scientific and Cultural Organization

Relations with these other international bodies do not affect the basic affiliation of the ICRU with the International Society of Radiology. The Commission has found its relationship with all of these organizations fruitful and of substantial benefit to the ICRU program.

### Operating Funds

Throughout most of its existence, the ICRU has operated essentially on a voluntary basis, with the travel and operating costs being borne by the parent organizations of the participants. (Only token assistance was originally available from the International Society of Radiology.) Recognizing the impracticability of continuing this mode of operation on an indefinite basis, operating funds were sought from various sources in addition to those supplied by the International Society of Radiology.

Prior to 1959, the principal financial assistance to the ICRU had been provided by the Rockefeller Foundation which supplied some $11,000 to make possible various meetings. In 1959 the International Society of Radiology increased its contribution to the Commission providing $3,000 for the period 1959–1962. For the periods 1962–1965 and 1965–1969 the Society's contributions were $5,000 and $7,500, respectively. In 1960 the Rockefeller Foundation supplied an additional sum of some $4,000 making possible a meeting of the Quantity and Units Committee in 1960.

In 1960 and 1961 the World Health Organization made available the sum of $3,000 each year. This was increased to $4,000 per year in 1962 and $6,000 per year in 1969. It is expected that this sum will be allocated annually, at least for the next several years.

In connection with the Commission's Joint Studies with the ICRP, the United Nations allocated the sum of $10,000 for the joint use of the two Commissions.

The most substantial contribution to the work of the ICRU has come from the Ford Foundation. In December 1960, the Ford Foundation made available to the Commission the sum of $37,000 per year for a period of five years. This grant was to provide for such items as travel expenses to meetings, for secretarial services and other operating expenses. In 1965 the Foundation agreed to a time extension of this grant making available for the period 1966–1970 the unused portion of the original grant. To a large extent, it is because of this grant that the Commission has been able to move forward actively with its program.

In 1963 the International Atomic Energy Agency allocated the sum of $6,000 per year for use by the ICRU. This was increased to $9,000 in 1967. It is expected that this sum will be allocated annually at least for the next several years.

From 1934 through 1964 valuable indirect contributions were made by the U.S. National Bureau of Standards where the Secretariat resided. The Bureau provided substantial secretarial services, publication services and travel costs in the amount of several thousands of dollars.

The Commission wishes to express its deep appreciation to all of these and other organizations that have contributed so importantly to its work.

## Composition of the ICRU

It is of interest to note that the membership of the Commission and its subgroups totals 140 persons drawn from 16 countries. This gives some indication of the extent to which the ICRU has achieved international breadth of membership within its basic selection requirement of high technical competence of individual participants.

The membership of the Commission during the preparation of this report was as follows:

Lauriston S. Taylor, *Chairman*
M. Tubiana, *Vice Chairman*
H. O. Wyckoff, *Secretary*
A. Allisy
J. W. Boag (1965–1966)
R. H. Chamberlain
F. P. Cowan
F. Ellis (1965)
J. F. Fowler
H. Fränz (1965)
F. Gauwerky
J. R. Greening
H. E. Johns (1965–1966)
K. Lidén
R. H. Morgan
V. A. Petrov
H. H. Rossi
A. Tsuya

The current membership of the Commission is as follows:

H. O. Wyckoff, *Chairman*
A. Allisy, *Vice Chairman*
K. Lidén, *Secretary*
F. P. Cowan
F. Gauwerky
J. R. Greening
A. M. Kellerer
R. H. Morgan
H. H. Rossi
W. K. Sinclair
F. W. Spiers
A. Tsuya
A. Wambersie

## Composition of ICRU Subgroups Responsible for the Initial Drafting of this Report

Serving on the Task Group on Specification of High Activity Gamma-Ray Sources during the preparation of this report were:

R. G. Wood, *Chairman*
J. H. Aitken
M. J. Berger
M. Cohen
R. F. Errington
C. M. LaLanne

L. A. W. Kemp and C. B. G. Taylor served as consultants to the Task Group.

Serving on the Planning Board on Radioactivity—Fundamental Physical Parameters and Measurement Techniques during the preparation of this report were:

F. W. Spiers, *Chairman*
H. Houtermans
W. B. Mann
J. K. Miettinen

K. Lidén served as the Commission Sponsor for the Planning Board.

Throughout the preparation of the report there was consultation with the Planning Board on Radiation—X Rays, Gamma Rays and Electrons which consisted of:

W. Pohlit, *Chairman*
D. V. Cormack
C. Garrett (1965–1966)
A. Somerwil

A. Allisy and J. R. Greening served as Commission Sponsors for that Planning Board.

The Commission wishes to express its appreciation to the individuals involved in the preparation of this report for the time and effort they devoted to this task.

Harold O. Wyckoff
*Chairman, ICRU*

Washington, D.C.
June 15, 1970

# Contents

# Specification of High Activity Gamma-Ray Sources

## 1. Introduction

Increase in the availability and use of high activity gamma-ray sources has been accompanied by a corresponding development in the number of source types and of source housings and associated equipment. At the same time there is diversity in the methods used to describe such sources and consequently a need to formulate an agreed basis for their specification. Other attempts to suggest satisfactory methods of specification for teletherapy sources (IAEA, 1962) were limited by lack of information on the extent to which they would be affected by scattered gamma radiation. New experimental data, as well as new theoretical calculations, relevant to the problem of gamma-ray scattering, have made it possible to put forward practical recommendations for the specification of the various high activity gamma-ray sources now in use.

A complete specification of a radioactive source must include its physical, chemical, mechanical and geometrical properties as well as its radiation characteristics. Such a specification is needed by the user for several reasons: (i) to enable him to select, in general terms, the type of source most suitable for his requirements and, within this general category, a particular source with satisfactory physical and other properties; (ii) to give him as complete an understanding as possible of the quantity, quality and distribution of the radiation which will be provided by the source in the environment in which he plans to use it; and (iii) to enable him to compare sources and equipment offered by different suppliers (Kemp, 1961).

The present report is concerned only with gamma-ray sources and only with those aspects of the specification of such sources which relate to the quantity of radioactive material and the radiation emitted. Data on radionuclides and their decay schemes can be found in compilations by Lederer, Hollander and Perlman (1967), by Blichert-Toft (1968) and in NCRP Report No. 28 (NCRP, 1961). It is presumed that the gamma-ray source contains one radionuclide only. If, however, an appreciable fraction of the photon emission is due to other radionuclides, their presence should be stated. The other items of a full specification, including dimensions, mechanical construction and test requirements (e.g., mechanical stability of the source contents, freedom from surface radioactive contamination and from leakage) are dealt with in a series of reports now being prepared by the International Organization for Standardization (ISO, 1968). Reference should also be made to a report by the British Standards Institution (BSI, 1962). The adherence of suppliers to the recommendations of these reports and to those of the present report will contribute substantially to the better selection and more effective use of sources, particularly by those users who do not have the facilities to carry out independent investigations of source characteristics.

The sources with which this report is concerned are sealed sources, primarily those used in teletherapy, and to a lesser extent those used in industrial radiography and in irradiation units for industry and research. These types are usually considered as "high activity" sources, but a numerical definition of this term cannot be given since the practical lower limit of activity of the sources considered varies according to their type and purpose. In general, the relevant activities are tens of curies and above. Furthermore, the sources discussed have physical dimensions such that internal absorption and scattering cannot be regarded as negligible. It is assumed that the capsule in which the source is contained effectively absorbs any alpha or beta radiation.

The characteristics of sources for teletherapy, radiography, research and industrial irradiation are different, as are their requirements for specification. General aspects of the specification of sources are discussed in Section 3, followed by separate sections on each type of source.

## 2. Explanation of Terms

For the purposes of this report, it is necessary to classify sources and irradiators in relation to their nature or their application. The following terms are used to distinguish different types. The descriptions are not intended to be rigid definitions.

### 2.1 Sealed Source

A sealed source consists of radioactive and inert material designed to be used in such a way that the active material does not enter into immediate contact with the source surroundings. It is comprised of one or more units such as discs, pellets or rods, or sometimes fine grains, incorporating radioactive and inactive materials, sealed in an envelope or capsule of sufficient strength to prevent, under normal conditions of use, any dispersion of radioactive substances.

In the remainder of this report the word source will normally be understood to refer to a sealed source.

### 2.2 Multiple Source

A multiple source is comprised of two or more sealed sources securely incorporated in a housing or equipment so as to give rise to a radiation field suitable for special purposes. In practice, a multiple source may also be referred to as a *source array* or a *source assembly* and the individual sources therein as *source elements*.

### 2.3 Teletherapy Source

A teletherapy source is a sealed source of small dimensions designed for use in teletherapy.

### 2.4 Radiography Source

A radiography source is a sealed source of small dimensions designed for use in industrial or medical radiography.

### 2.5 Research Irradiator

A research irradiator is comprised of either a single sealed source or an array of sealed sources designed to irradiate various materials at specified exposure rates within specified limits of uniformity.

### 2.6 Industrial Irradiator

An industrial irradiator is comprised of an array of sealed sources, often of extended dimensions, together with shielding and suitable product-conveying equipment, designed to irradiate a large quantity of material to a specified absorbed dose within specified limits of uniformity during passage through the irradiator.

## 3. Methods of Specifying Gamma-ray Sources

A gamma-ray source may be specified in terms of (i) the mass of the relevant radionuclide contained within the source; (ii) the number of nuclear transformations per time interval, i.e. the *activity* of the radionuclide contained in the source; (iii) the rate of *total energy release* within the source; or (iv) a suitable measure of the *photon radiation emitted* from the source, e.g., exposure rate or absorbed dose rate at a stated point. These various methods of specification cannot be applied with equal convenience to radioactive sources of any type, size or form, and special considerations of a restrictive nature apply to solid sources of high activity of the type considered in this report. Several possible methods will be considered in turn.

### 3.1 Mass of Radionuclide

Specification in terms of mass has a firm historical precedent in the natural radioelements such as radium. There is no possibility, however, of determining directly the mass of an artificially produced radionuclide unless it is separated from other isotopes, whether stable or radioactive.

### 3.2 Activity of the Source

There are practical difficulties in determining the activity in high activity sources either by calculation or by measurement.

#### 3.2.1 Calculation

For radionuclides produced by neutron irradiation in a reactor the calculation is based on the neutron fluence rate at the appropriate position in the reactor, the activation cross-section of the material concerned, the half-life of the radioactive product and the time of irradiation. However, some factors involved, such as fluence rate depression and self-shielding, are often not known with precision and the calculated activity is an approximate value only. For radionuclides produced as fission products any such calculation would be still less precise.

#### 3.2.2 Measurement

A method of measurement applicable to any radionuclide is to count the number of particles and/or photons emitted per time interval and hence to deduce the disintegration rate. If this is to be done on an absolute basis, it is usually necessary for the activity to be restricted to a few microcuries. Application of this method to sources in the curie or kilocurie range involves the measurement of a series of related aliquots from which the activity of the whole can be calculated. The process is lengthy and the errors may be considerable so that the method cannot be recommended for high activity sources.

### 3.3 Rate of Total Energy Release

The principle here is to place the source within a calorimeter which measures the total amount of energy released per time interval. If the rate of energy release is to be converted to activity, accurate knowledge of the radionuclidic composition of the source and of the disintegration schemes of the individual components is required.

### 3.4 Measurement of Photon Radiation

#### 3.4.1 Exposure Rate

Measurement of exposure rate at a specified point under suitable conditions may be made the basis of a method of source specification. The measured exposure rate will depend, however, not only on the source activity and on the dimensions and geometry of the source, but also on the nature and geometry of the material surrounding the source and in its vicinity.

#### 3.4.2 Absorbed Dose Rate

Some consideration has been given to the possibility of specifying teletherapy sources in terms of a measurement of absorbed dose rate at a point in a standard phantom. Indeed, ICRU (1962b) recommends that calibration for depth dose purposes be made at 5 cm (or other suitable depth) in a homogeneous phantom rather than in air. This method, if applied to the present purpose, would have the advantage of providing conditions of measurement closely related to those of actual use in teletherapy. This advantage, however, would be offset by the complication involved in specifying the conditions of the measurement. Furthermore, the measurement of absorbed dose rate for therapeutic purposes should be made with the source in its teletherapy housing, according to the principles laid down in other ICRU recommendations (ICRU, 1970).

## 4. Recommended Basis for Source Specification

The user's requirement, common to all the sources discussed in this report, is some measure of the gamma radiation at a defined point outside the source. Of the methods considered in Section 3, measurement of exposure rate at a specified point provides the best basis for source specification. With the exception of measurement of absorbed dose rate, the other methods determine quantities less directly related to the uses to which the gamma-ray sources are put; neither measurement of mass nor measurement of activity of the radionuclide in a high activity source is practicable; measurements of rate of energy release and of absorbed dose rate, though practicable, do not provide the most relevant information.

It is recommended that the specification of high activity gamma-ray sources be made on the basis of an exposure rate measurement. The record of such a measurement should always include a statement of the time and date of measurement and the half-life of the radionuclide.

It is necessary, however, to consider the contributions to the exposure rate that arise both from scattering in the source itself and from scattering from the source housing. Scattered radiation from the source is in-

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evitably included in the measurement of exposure rate. The contributions to be expected from sources of different dimensions, however, have been calculated by Monte Carlo methods, and examples are given in Appendix B; they are in agreement with such spectrometric measurements as have been made in a limited number of cases. Contributions to the exposure rate from radiation scattered by the source housing are less easily calculated but, as will be discussed later, can usually be measured for actual conditions of use.

The exact methods of measurement to be adopted depend therefore on the type of source and its application. For teletherapy sources, two measurements are required, one which determines the exposure rate from the source alone and one which includes the scatter from the source housing. For radiographic, research and industrial sources, the requirements are less stringent and measurement of exposure rate under some defined conditions is usually sufficient. Also it is sometimes convenient, but less desirable, to convert exposure rate into an "exposure-rate equivalent activity".[1] If this conversion is made, the value of the specific gamma-ray constant on which it is based must be stated, and the geometry of the source must be taken into account (see Section 7.2).

Detailed recommendations of methods for the specification of different types of source are discussed in the following sections.

# 5. Teletherapy Sources

## 5.1 Principles of Specification

Teletherapy sources are intended to give a relatively narrow, well collimated beam of radiation at considerable distances (usually 20–100 cm) from the source. The dimensions of the source are small compared with the distance of use yet not small enough to allow it to be regarded as a point source for all purposes. The nuclides most commonly used for teletherapy sources are cobalt-60 and caesium-137 (with barium-137m).

In order to estimate the performance of a given source in any given equipment in which it may be used, the two measurements referred to in Section 4 should be made under the following conditions:

A. The exposure rate measured at a stated reference point, defined as a point 1 m from the front face of the source capsule and on the source axis. The conditions of measurement must be such that the measuring instrument receives primary and scattered radiation which comes directly from the source (including its capsule), but as far as possible, does not receive radiation scattered by the surroundings.

B. The exposure rate measured at 1 m from the front face of the source capsule and on the source axis when the source is in the complete associated housing.

The housing will add some scattered radiation, for example in a typical arrangement having a cobalt-60 source in a teletherapy shield, radiation scattered by material outside the source may contribute about 10 per cent to the measured exposure rate (Aitken and Henry, 1964; Henry and Garrett, 1964) (see Appendix B). The housing may also attenuate the emerging radiation if absorbing material is present in the beam. In practice the geometry of the housing is variable and a given equipment is subject to variation according, for example, to the setting of the collimator (see Appendix C). The effect of the housing may be represented by an "equipment conversion ratio" defined as:

$$\text{equipment conversion ratio} = \frac{\text{measurement B}}{\text{measurement A}}.$$

It is suggested that the most useful service the manufacturers of the radiation apparatus can give, besides item A, is the determination of a series of equipment conversion ratios using sources of each type suitable for their equipment in each type of equipment manufactured, for the full range of collimator apertures. Such information would be valuable for potential as well as actual users of the particular equipment, constituting important indices of the scattering and absorption characteristics of individual designs of treatment heads and collimating systems.[2]

It should be pointed out that a high equipment conversion ratio is indicative of circumstances in which the radiation emerging from the source is degraded by scatter; a low conversion ratio means that there is beam absorption as well as scatter. The extent of the degradation of the emerging radiation thus depends on the detailed design of the equipment.

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[1] Exposure-rate equivalent activity is given as the activity of a point source of the same radionuclide which would give the same exposure rate at the same distance from the center of the source (ICRU, 1962a, Section 3.4).

[2] Examples of measured equipment conversion ratios are given in Appendix C.

It must be emphasized that measurement of exposure rate and/or absorbed dose rate for *treatment purposes* should be made locally by the user himself. The statement of equipment conversion ratio by the manufacturer should not be regarded as a substitute for this. It must also be emphasized that the equipment conversion ratio refers to a distance of 1 m from the front face of the source and is not applicable to any other distance which might be chosen as a treatment distance.

## 5.2 Low-Scatter Measuring Cell

A measurement of type A provides a unique and unambiguous specification of the source for both scientific and commercial purposes. It entails the setting up of special measurement conditions in which external scatter must be reduced to a minimum. Minor and inevitable variations in an adopted geometry then become less serious in their effect on the measurement.

The principles of a typical arrangement of source, collimator and detector intended to minimize the scattered radiation reaching the detector from the surroundings of the source are shown in Fig. 1. The source, S, is supported and located by a holder which is as light as possible consistent with requirements for rigidity and accurate positioning by remote handling. It is supported in a cavity ABB′A′ surrounded by sufficient absorbing material to give adequate protection outside the cell. The diameter of the cavity and the diameter of the collimator aperture must ideally be so related that no scatter from the side walls AB, A′B′ can pass into the upper cavity without being scattered again from the walls of the collimator. Furthermore, in order to restrict the "field of view" of the ionization chamber as much as possible while including the whole of the source, collimator inserts of various apertures may be required to suit sources and chambers of different dimensions.

The distance between the front face of the source capsule and the centre of the ionization chamber should be 1.000 ± 0.001 m and the collimator should be located half way between them in order to minimize scatter reaching the chamber from the collimator itself (see Appendix A, Section A.3). The thickness of the collimator should preferably be sufficient to ensure that the transmitted radiation is not more than about 0.1% of the incident radiation. For cobalt-60 radiation this will require a thickness of at least 12 cm of lead (NCRP, 1960) or 9 cm of tungsten alloy. Comparatively light shielding will then be adequate for the upper cavity.

The measurements described in Appendix A, Section A.2 show that the back of the source capsule may approach as closely as 0.3 cm to a lead surface without significant increase in exposure rate due to scatter, but

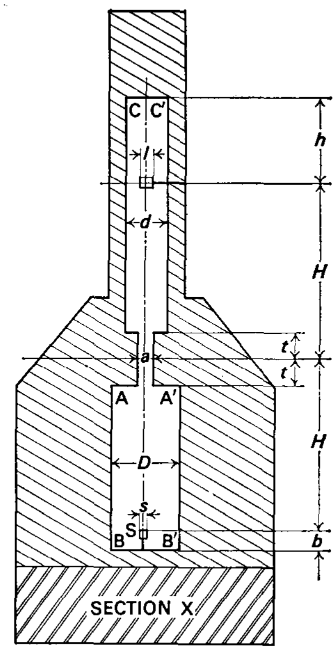


**Fig. 1.** Typical low-scatter measuring cell.

that the scatter from a steel surface may be appreciable. The immediate surroundings of the source should therefore be of lead. The separation between the back of the source capsule and the back wall is then not critical. The diameter of the cavity containing the ionization chamber should be such that no part of the side walls is visible from the source through the largest aperture of the collimator.

It is recommended that the user of the source shall be provided with a drawing of the measuring arrangement to enable him to consider to what extent scatter has been minimized. It is estimated in Appendix A that the percentage of scattered radiation contributed to the measurement by a measuring cell designed on the above lines should be less than 1% for cobalt-60 radiation. Data for radiation of other energies are not available, but the scatter contribution should still be small.

If the activity of a cobalt or caesium teletherapy source is required, it may be estimated from a measurement of exposure rate in this low-scatter cell by using the tables in Appendix B to calculate the effects of scatter and self-absorption in the source itself and by applying known specific gamma-ray constants.

## 5.3 Measuring Instrument

The radiation measuring instrument should satisfy the conditions laid down by the ICRU (ICRU, 1962b, Sections IV and IX.A).

# 6. Radiographic Sources

Radiographic sources are usually smaller than teletherapy sources and approximate more closely to point sources. In some cases, cobalt-60 is used in teletherapy-type shields in which the direction of the useful beam is along the principal axis of the source, but often a useful beam may be taken from a single source in several different directions. Many industrial radiographic sources consist of iridium-192, thulium-170 or caesium-137 of much lower activity than teletherapy sources. Thulium-170 and iodine-125 sources have also been used for medical or dental radiography. Such sources are often used in an arrangement in which the contribution of scattered radiation is not an important consideration.

If accurate specification in terms of exposure rate should be required, measurements may be made in the low-scatter measuring cell described above, due account being taken of the necessity to increase the sensitivity of the measuring instrument. In practice, however, accuracy of this order may not be required or may not be economically justifiable. It is suggested that specification might then be achieved in a less elaborate manner. For example, measurements might be made in the open air, or in a large shielded room in which approximate corrections for the scatter contribution are applied as described in Section 7.2. The result is often conveniently expressed in terms of "exposure-rate equivalent activity" (see Section 4). Details of the method of measurement and any assumed value of specific gamma-ray constant should be supplied to the user.

# 7. Research and Industrial Irradiation Sources

## 7.1 General Considerations

Sources considered under this heading are usually of extended physical dimensions and are used for the irradiation of large volumes of material and/or for irradiating material to very high dose levels. Conditions of use are so variable and different from those of teletherapy and radiographic sources that considerations appropriate to the latter no longer apply and a full specification falls outside the scope of this report. Some limited recommendations are made, however, to assist manufacturers and users.

The principal radionuclides now used are cobalt-60 and caesium-137, the complete source assembly usually being made up of a number of source elements in the form of rods or flat strips. In an industrial irradiator a considerable number of these elements may be combined to make up a multiple source in the form of a large plaque, cylinder or other configuration, and the product to be irradiated is moved within the radiation field in such a way that each unit of material receives approximately the same total absorbed dose, whilst the radiation field as a whole is utilised to the maximum degree. Research irradiators are often self-contained semi-portable units in which the experimental material can be placed in a radiation field of specified uniformity.

Suppliers of self-contained irradiation equipment should provide data on the radiation exposure rate and distribution within the irradiation chamber. In industrial irradiators the design of the conveyor which moves the product through the radiation field has a very important bearing on the overall performance, and the user should therefore seek full details not only of the spatial distribution of the exposure rate provided by the source configuration, but also of the ability of the conveying equipment to take advantage of this distribution and hence of the radiation available.

## 7.2 Specification of Source Elements

It is not possible to express in a single number a specification for a source element which allows it to be compared in a fully satisfactory way with a source element of a different size or shape. For example, two similar source arrays of the same total activity but composed of different source elements (e.g., rods or flat strips) could deliver significantly different absorbed doses to the same extended target in the same time of irradiation. Even if a complex specification is given, a true comparison can only be made in the context of the complete irradiator design and the function to be performed. In these circumstances it is suggested that the "exposure-rate equivalent activity" of a source element should be specified by measuring the exposure rate at a point on a perpendicular bisector of its long axis at a distance at least 5 times its length in a "hot cell" whose internal dimensions are several metres in each direction. The contribution of scattered radiation from the walls of the cell can be estimated by shielding the detector from direct radiation from the source by lead absorbers. This procedure is of a lower accuracy than that recommended for teletherapy sources (Section 5.2) since "exposure-rate equivalent activity" is not a constant for a given extended source, but depends on the measurement distance, and furthermore, allowance for the scatter contribution from the cell may be approximate. However, it may be regarded as adequate for the purposes envisaged in this section. If the activity of the source is required as a specification, it can be calculated from the exposure rate provided the self-absorption corrections are known, e.g., from Monte Carlo calculations of the type given in Appendix B, Section B.3; appropriate data on industrial sources are becoming increasingly available.

In practice, the extent of the specification of individual source elements must be left to the supplier in consultation with the user, depending on the circumstances in any particular case. For example, when a very large number of individual source elements is involved, it may suffice to divide the complete batch into small groups and to measure the total activity of each group. In a large irradiator the user would then be in a position to replace the lowest activity groups with new groups of higher activity when he is replenishing his source. On the other hand, a user buying a small number of elements and designing his own irradiator may specify that each one be measured.

Alternatively, when many source elements of the same nominal activity are to be assembled in one array, it may be sufficient to give an estimate of the mean activity of the sources or source groups together with an estimate of the standard deviation. If, however, several sources or groups of intentionally different activities are used, the individual activities of each may be required.

Typical charts giving the distribution of exposure rate in air around each standard type of source element or group of elements in the array should be made available to the user.

### 7.3 Specification of Source Arrays

#### 7.3.1 Research Irradiators

In addition to the specification discussed in Section 7.2, suppliers should provide data on the exposure rate in air at a reference point in the irradiation field; for example, in hollow cylindrical arrays this will normally be the geometrical centre of the assembled array. In addition, suppliers should provide charts showing the exposure rate, relative to that at the reference point, at any point in the irradiation volume with an accuracy of $\pm 10\%$. These measurements are usually made in air and the user must realize that any target being irradiated will alter the field distribution by an amount which is a function of its dimensions, absorption and scattering properties, and location within the irradiated volume. Information on the spectral distribution of the radiation within the irradiated volume is also useful if available.

#### 7.3.2 Industrial Irradiators

In present practice, industrial irradiators are usually specified by the total activity of the source array. A criterion of effectiveness of an industrial irradiator is then the mass of material irradiated to a given absorbed dose level (with a given uniformity) per curie-hour. In addition to this information, the specifications discussed in Section 7.2 should also be provided by suppliers of irradiation plants. In this case, it must be made clear how the total activity in the irradiator has been estimated and on what measurements the estimate is based.

It should be noted that it may be misleading to express the efficiency of an irradiator solely in terms of the ratio between the radiation absorbed in the product and the total radiation emitted by the source, as all parts of the product may not be irradiated to the same extent. Any absorbed dose in excess of that prescribed is wasted and should not be included in this ratio.

## 8. Summary of Recommendations

### 8.1 Teletherapy Sources

**8.1.1** It is recommended that the specification of high activity gamma-ray sources be made in terms of the exposure rate under standard conditions at 1 m from the front face of the source capsule (Section 5.2).

**8.1.2** It is recommended that these measurements be made in a low-scatter measuring cell having the essential features illustrated in Fig. 1 (Section 5.2 and Appendix A). A drawing of the actual measuring cell used should be supplied.

**8.1.3** It is also recommended that manufacturers of teletherapy equipment should measure exposure rate at a specified point at 1 m from the front face of the source capsule using sources of each type suitable for their equipment, in each type of equipment manufactured. This measurement should be carried out for the full range of collimator apertures, and the results expressed as "equipment conversion ratios" (Section 5.1).

## 8.2 Radiographic Sources

In most cases a specification in terms of "exposure-rate equivalent activity", based on measurements made either in the open air or in a simple cell, is adequate. If more precise specification is needed for special reasons, the method recommended for teletherapy sources may be adopted (Sections 4 and 6).

## 8.3 Research and Industrial Irradiation Sources

The limited recommendations which follow are not intended to represent a full specification.

**8.3.1** The activity of a single source element is often specified in terms of its "exposure-rate equivalent activity" (Sections 4 and 7.2).

A chart should be provided showing the exposure-rate distribution around each standard type of source (Section 7.2).

**8.3.2** When large numbers of source elements are involved, the activities of groups of elements may be given, the number of groups to be measured depending on the user's requirements. When the number of elements is small and the performance of the irradiator is critically dependent on the individual activities of the elements, it may be necessary to specify each element individually (Section 7.2).

**8.3.3** For research irradiators, a measured exposure rate at a specified point in the irradiation field should be given, together with a chart giving the distribution of exposure rate within the irradiated volume (Section 7.3.1).

**8.3.4** For industrial irradiators, much depends on the conveyor system. If the information given to the user is the mass of material irradiated to a given absorbed dose level (with a given uniformity) per curie-hour, it must be made clear how the activities of the sources have been defined and determined (Section 7.3.2).

## APPENDIX A

# Practical Considerations in the Design of a Low-Scatter Cell

### A.1 Geometrical Relationships in an Ideal Cell

The following symbols refer to the dimensions of the low-scatter measuring cell illustrated in Fig. 1:

$2H$ = distance between front face of source and axis of ionization chamber
$D$ = diameter of source cell
$d$ = diameter of cell containing ionization chamber
$a$ = diameter of collimator aperture
$2t$ = thickness of collimator
$l$ = length of ionization chamber
$s$ = diameter of source
$b$ = distance from front face of source to end wall of source cell
$h$ = distance from axis of ionization chamber to end wall.

In an ideal cell the following conditions should be satisfied:

(i) To ensure that no scatter from the side wall AB of the source cell shall pass through the collimator aperture without being first scattered from the collimator:

$$D \geqslant a(H + b)/t \qquad (1.1)$$

(ii) To ensure that the side wall of the source cell is invisible from any part of the ionization chamber:

$$D \geqslant [a(2H + b) + l(H + b - t)]/(H + t) \qquad (1.2)$$

(iii) To ensure that the whole of the source and no more is visible from the ionization chamber:

$$a = [H(l + s) + t|l - s|]/2H \qquad (1.3)$$

(iv) To ensure that there shall be no direct irradiation of the side wall of the cell containing the ionization chamber:

$$d \geqslant [a(2H + h) + s(H + h - t)]/(H + t) \qquad (1.4)$$

### A.2 Scatter Measurements

#### A.2.1 Region Around the Source

Measurements have been made to determine the effect of scatter from material near a cobalt-60 teletherapy source on the exposure rate at 1 m distance (Rice, McGuire and Maloney, 1969). The experimental arrangement represented in Fig. 2 was set up in a room having dimensions 5.18 m in the direction of the beam, 3.21 m high and 6.56 m horizontally perpendicular to the beam. The detector was a 0.6 $cm^3$ Baldwin Ionex chamber with a 4.5 mm thick equilibrium cap and it viewed the front of the source through a 3.6 cm diameter lead aperture midway between the source and the detector. Two teletherapy sources, of diameters 1.25 cm and 2.5 cm were used. Each was of a thickness equivalent to about 16 $g/cm^2$ of cobalt. They were supported from below by a V-stand made of 0.64 mm stainless steel. The scattering mass was a disc of lead 6.7 cm thick by 37.5 cm diameter, suspended behind the source and moved by remote control.

The exposure rates from both sources were measured as the source-to-scatterer distance was increased from 0.3 cm to 145 cm and then on complete removal. No decrease greater than 0.4% was found. However, a 0.6 cm thick steel plate placed on the face of the lead disc increased the measured exposure rate by about 0.5%.

In further measurements, the 1.25 cm diameter source was placed axially within a lead cylinder of internal diameter 9.6 cm in such a way that the detector did not view the internal side walls by direct line-of-sight. No change in exposure rate greater than 0.4% was observed. However, a tungsten sleeve of wall thickness 0.596 cm surrounding the source increased the measured exposure rate of the bare source by about 5%.

A flat lead block brought within 0.3 cm of the side



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