Radiation Quantities and Units

International Commission on Radiological Units and Measurements (ICRU)

Report 10a

1962

Handbook 84

United States Department of Commerce
National Bureau of Standards

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* In preparation.

UNITED STATES DEPARTMENT OF COMMERCE • Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

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Foreword

The reports of The International Commission on Radiological Units and Measurements for a number of years have been published by the National Bureau of Standards in the Handbook series. In the past, each of the triennial reports of the ICRU represented a complete restatement of the recommendations of the Commission. Because of the increasing scope of its activities, however, the Commission in 1962 decided to modify the previous practice. It will issue a series of reports presenting the current recommendations of the Commission. Each report will cover a particular portion of the area of interest to the ICRU. This procedure will facilitate revision of ICRU recommendations and also spread out in time the workload of the Commission. This Handbook is one of the new series presenting the recommendations of the Commission on one aspect of the field with which the Commission is concerned. It presents recommendations agreed upon at the meeting of the Commission held in Montreux, Switzerland, in April 1962.

The National Bureau of Standards is pleased with its continuing opportunity of increasing the usefulness of these important reports by providing the publication outlet.

A. V. ASTIN, *Director.*

Contents

Preface

A. Scope

The International Commission on Radiological 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 on radiation quantities, units and measurements in the field of radiation protection. In this connection, its work is carried out in close cooperation with the International Commission on Radiological Protection.

B. 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.

Recognizing the confusion that exists in the evaluation of different radiological equipment and materials, the ICRU is studying standard methods of determination of characteristic data for the equipment and materials used in diagnostic and therapeutic radiology. This activity is confined to methods of measurement and does not include the standardization of radiological equipment or parts thereof.

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 wishes to encourage radiologists to use the quantity "absorbed dose" more widely, since this is the physical quantity which can be most closely correlated with biological effects.

For x and gamma radiation it is convenient to retain the quantity which was called in the 1956 report "exposure dose". At that time the term "exposure" was preferred by the ICRU but the word "dose" was included at the request of ICRP. This request stemmed from the fact that many legal radiation protection documents contained the word dose together with the unit roentgen. In the 1956 report the term "exposure dose" was introduced for this purpose in spite of the possibility of confusion with the term absorbed dose. As the principal reason for the inclusion of dose in the name seems to have disappeared, the ICRU returns to its 1956 preference, exposure, as the name for the quantity of which the roentgen is the unit. The Commission having reviewed the whole question of quantities and units now recommends that the word dose be eliminated and the term "exposure" be used alone to designate the quantity of which the roentgen is the unit. (See following sub-section 4.D.(13)).

In this report the ICRU recommends with considerable reluctance and some misgivings, the use of the symbol *R* instead of *r* for roentgen. Several recognized international groups working in the field of symbols and nomenclature including the International Council of Scientific Unions have agreed upon the convention that the first letter of abbreviations of units named after individuals should be capitalized. At least one country has already officially adopted the symbol *R* for roentgen. There are many indications that, however unnecessary, this trend will continue and hence the Commission has acceded to the pressure for change. As far as medical radiology is concerned, this change will result more in annoyance than confusion.

Hitherto the definitions and recommendations of the ICRU have been made with little explanation of the philosophy on which they were based. It is recognized that this neglect has given rise to confusion in the past. In the present report the ICRU has tried to repair this omission while continuing to develop the necessary technical information to facilitate the interpretation and application of the recommendations. These sections of the 1962 reports represent a further enlargement over the 1959 report.

The aim of much of the work of the ICRU is to improve the accuracy of the evaluation of absorbed dose in all places of interest in a patient or other objects. For comparisons of biological effects, the absorbed dose should be known as accurately as possible and the limits of accuracy should be estimated.

In 1955 the Commission entered into an official relationship with the World Health Organization (WHO). In this relationship, the ICRU will be looked to for primary guidance in matters of radiation units and measurements, and in turn WHO will undertake the worldwide dissemination of the Commission's recommendations. In 1960 the ICRU entered into consultative status with the International Atomic Energy Agency (IAEA).

The above relations with other international bodies do not affect the basic affiliation of the Commission with the International Society of Radiology.

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

C. Current Program

A two week meeting of the ICRU was held in Montreux, Switzerland, April 2nd to April 14th 1962. This meeting included the Main Commission and all the Committees that had reports prepared for final approval. Some 70 persons attended. An additional meeting of the Commission and Committee Officers was held in Ottawa from August 21 to August 23, 1962 for the principal purposes of the preparation of the status report for the Xth International Congress of Radiology and the outlining of program objectives for the next several years.

The 1956 report called attention to some basic problems in the establishment of radiation quantities and units. These were the subject of major discussions during and following the 1958 meetings. One of the difficulties is in reconciling the differences between radiation quantities and units as they have evolved over the past thirty years, and the system of quantities and units as used in the physical and engineering sciences. There are obvious divergencies between the two sets. It appeared possible that a complete resolution of this difficulty might necessitate abandonment of the quantities and units as used by the medical profession. This would accomplish a reconciliation between the two systems but it did not appear that it would introduce any substantial improvement in the understanding and utilization of the quantities by the medical profession. Naturally there was considerable hesitancy about taking such a step.

As indicated in the 1959 report, an *ad hoc* committee was set up for the purpose of examining the whole problem of radiation quantities and units. This committee has met three times (Munich, 1959; Geneva, 1960; Copenhagen, 1961). The study represented a moderate amount of compromise of viewpoints but it is believed that the final report now provides a consistent and satisfactory set of definitions for use in the field of radiation measurements. The report as approved by the Main Commission makes up the body of this document.

A meeting of Committee III–B (Clinical Dosimetry) was jointly sponsored and financed by the ICRU, WHO, and the IAEA in Geneva in April 1961. For this meeting a number of additional consultants were invited to attend. Following the general meetings, a closed meeting of the committee membership was held for a period of two days to prepare a draft report.

In addition there were meetings of various tasks groups of the committee on Standards and Measurement of Radiological Exposure in Paris in January 1961 and in London in April and September 1961. The committee on Radiological Dosimetry also held a meeting in April 1961. The ICRU was also represented at a meeting of the Consultative Committee on Ionizing Radiation of the International Committee of Weights and Measures at Sèvres in October 1961.

As noted in the last report, two joint committees had been established between the ICRU and the ICRP. The Joint Committee on RBE has met twice with ICRU participation. The Committee on Methods and Instruments for Radiation Protection has not met.

Upon the request from the United Nations Scientific Committee on the Effects of Atomic Radiations, the ICRU and the ICRP agreed to undertake a second study dealing with the Medical and Physical Parameters in Clinical Dosimetry. This committee met in New York for one week in September 1959 and for a week in Stockholm in June 1960. A report of this study entitled "Exposure of Man to Ionizing Radiation Arising from Medical Procedures with Special Reference to Radiation Induced Diseases, An Inquiry into Methods of Evaluation", was published in Physics in Medicine and Biology, **6,** No. 2, 199 (Taylor and Francis, Ltd., London, England, Oct. 1961)

Reports and recommendations of the ICRU originally designed for medical applications, have come into common use in other fields of science, particularly where "dosimetric" considerations are involved. For this reason the committees have included in their membership some scientists having competence outside of the medical radiology field. Material in the reports is designed to meet physical, biological, and medical requirements wherever possible.

This has introduced a small problem in terminology. The name of the Commission includes the term "radiological". In many European countries the term "radiological" is taken as inclusive of both the physical and biological sciences. In other countries, the United States, for example, "radiological" appears to carry the primary connotation of relationship to medicine. It therefore may be desirable to change the name of the Commission from "Radiological" to "Radiation". It is believed that this would be properly understood by all concerned. The question has been debated by the Commission, but final action is being delayed for future consideration.

D. The Current Series of Reports

Hitherto, the triennial reports of the ICRU have been published in single volumes. However the reports are now becoming too extensive, and in some cases too specialized, to make a single publication practicable. Beginning with this 1962 series, the ICRU reports will be issued in smaller entities, each dealing with a limited range of topics. The 1962 series supersedes the 1959 report. Revisions of the 1962 series will be undertaken individually as circumstances warrant. A full listing of ICRU recommendations, including the present series, is given on page iii of the cover of this report.

The current report series includes revisions of much of the material that appeared in the 1959 report in addition to a number of new topics. The following summary indicates some of the highlights of the current report series.

Radiation Quantities and Units (Report 10a)—One of the most important changes is the revision of the section on quantities and units. This revision resulted from the thorough study by the *Ad Hoc* Committee on Quantities and Units mentioned above. It includes new names for certain quantities and clarified definitions for others. It presents a system of concepts and a set of definitions which is internally consistent and yet of sufficient generality to cover present requirements and such future requirements as can be foreseen.

Physical Aspects of Irradiation (Report 10b)—This report deals broadly with the physical aspects of irradiation with a considerable amount of new material added since the 1959 report. It includes an extensive discussion of the various techniques for the measurement of absorbed dose as well as exposure. Characteristics of radiation instrumentation are covered in some detail including the more sophisticated work on standards. The section on spectra has been up-dated and a new section added on neutron measurements and standards. Available data for stopping power ratios and the average energy (W) required to produce an ion pair in a gas have been reviewed. On the basis of this review it has been necessary to modify the previous ICRU tables for these factors. This modification amounts to about 1 or 2 percent change in stopping power ratios and up to 1 percent in W.

Radioactivity (Report 10c)—The portions of the report dealing with direct and relative measurements of radioactivity and the availability and requirements for radioactivity standards, and the parts dealing with the techniques and measurements of radioactivity in hospitals and biological laboratories are revisions of the 1959 report, embracing a review of the developments that have occurred since that report and bringing up to date the material included. In addition, a new section on low level radioactivity in materials as related to the problems of radiological measurements has been added. This topic is important because of the problems arising from the contamination, or possible contamination, in the last decade of a great many of the materials used in the construction of counting equipment, shields, and in the reagent chemicals employed in radioactivity measurements.

Clinical Dosimetry (Report 10d)—Much of the Commission's work on clinical dosimetry is brought together in this report. Included is an extensive discussion of practical calibration procedures and the determination of dose along the central ray. Depth dose data relative to stationary and moving-field therapy have been extended as have the conversion data necessary to relate ionization measurements to absorbed dose.

The principal effort has been toward the definition of nomenclature and the indication of methods. While some examples are given and data are provided for these, in general the reader is referred to other published data. The report considers ways of increasing the accuracy and comparability in clinical dosimetry. The discussion includes not only the physical aspects of dose measurement but also the wider subject of planning treatment in such a way as to deliver the prescribed absorbed dose to a defined "target volume". It also includes comments upon the common sources of error in clinical dosimetry and discusses the information which should be recorded during treatment and that which should be reported about any new treatment technique. Appendices to this report include pertinent material taken from other reports in this series.

Radiobiological Dosimetry (Report 10e)—This report deals primarily with radiobiological dosimetry, and considers methods of improving the accuracy and intercomparability of absorbed dose measurements in radiobiology. It is in effect a handbook for the experimental radiobiologist. It emphasizes the great importance of planning the experimental work in a way which makes the dosimetry easier and more accurate and it illustrates how this can be done.

Methods of Evaluating Radiological Equipment and Materials (Report 10f)—This is the first of a new group of ICRU reports dealing with methods of evaluating radiological equipment and materials. It includes a revised discussion on the measurement of focal spots and new sections on grids, image intensifiers and body section equipment.

E. 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 available from the ISR.) Recognizing the impracticality 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 to $3,000 to cover the period until the Xth Congress. 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 contributed the sum of $3,000 each year to the Commission for carrying forward its work. This was increased to $4,000 in 1962. It is expected that this sum will be allocated annually, at least for the next several years. In addition the WHO has provided substantial assistance to the Commission in providing meeting space, secretarial services, etc., for the meetings held in Geneva and Montreux.

In connection with the Commission's Joint Study with the ICRP, the United Nations allocated the sum of $10,000 for the joint use of the two Commissions for the purpose of carrying out their second study. This fund has been administered by the ICRP.

The most substantial contribution to the work of the ICRU has come from the Ford Foundation through the particular efforts of Dr. Paul Pearson. Effective 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 money is to be used for such items as travel expenses to meetings, for secretarial services and other operating expenses. To a large extent, it is because of this grant that the Commission has been able to hold the several meetings considered to be necessary to move forward actively with its program.

The International Atomic Energy Agency has allocated the sum of $6,000 per year for use by the ICRU. It is expected that this sum will be allocated annually at least for the next several years.

A valuable indirect contribution has been made by the U.S. National Bureau of Standards where the Secretariat has resided. The Bureau has provided substantial secretarial services, reproduction 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.

F. Rules

The International Commission on Radiological Units and Measurements (ICRU) functions under the auspices of the International Congress of Radiology. The Commission was established in 1925 by the First International Congress to define the physical units required in the field of radiology and to make recommendations on the standards required to realize proper measurements in terms of the units defined.

The following rules, amended in 1956, govern the selection and work of the ICRU.

1. (a) The International Commission on Radiological Units and Measurements (ICRU) shall be composed of a chairman and not more than 12 other members. The selection of the members shall be made by the ICRU from nominations submitted to it by the National Delegations to the International Congress of Radiology and by the ICRU itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRU shall be chosen on the basis of their recognized activity in the field of radiological units, standards, and measurements, without regard to nationality.

(b) The ICRU shall include at least three medical radiologists and three physicists.

(c) The members of the ICRU shall be approved during each International Congress to serve through the succeeding Congress. Not less than 2 but not more than 4 membership changes shall be made for any one Congress. In the intervening period a vacancy may be filled by the ICRU.

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

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

2. The Chairman shall be elected by the ICRU from among its regular members to serve for a term corresponding to the interval between Congresses. The choice shall not be limited to the country in which it is proposed to hold the succeeding Congress. The Chairman shall be responsible for reporting the proceedings and recommendations of the ICRU at the next Congress.

3. The ICRU may elect from among its members a Vice-chairman who will serve in the capacity of chairman in the event that the Chairman is unable to perform his duties.

4. Minutes of meetings and records of the ICRU shall be made by a technical secretary selected by the Chairman of the ICRU subject to the approval of its regular members. The technical secretary need not be a regular member of the ICRU. The records of the ICRU shall be passed on to the succeeding secretary.

5. The Chairman, in consultation with the Vice-chairman, shall prepare a program to be submitted to the Commission for discussion at its meetings. Proposals to be considered shall be submitted to the Chairman and circularized to all members of the ICRU and other specially qualified individuals at least two months before any meeting of the ICRU.

6. Decisions of the ICRU shall be made by a majority vote of the members. A minority opinion may be appended to the minutes of a meeting if so desired by any member and upon his submission of same in writing to the secretary.

7. The ICRU may establish such committees as it may deem necessary to perform its functions.

G. Organization of the ICRU Committees

In line with the Commission's policy of rotation of members and Chairmen of Committees whenever feasible, a number of changes have been introduced for the period 1959 to 1962.

H. Composition of the ICRU

(a) It is of interest to note that the membership of the Commission and its committees for the period 1959–62 totals 139 persons drawn from 18 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 members.

(b) The membership of the Main Commission during the preparation of this report was as follows:

Lauriston S. Taylor, Chairman	United States.
L. H. Gray, Vice-chairman	United Kingdom.
H. O. Wyckoff, Secretary	United States.
K. K. Aglintzev	U.S.S.R.
A. Allisy	France.
R. H. Chamberlain	United States.
F. Ellis	United Kingdom.
H. Fränz	Federal Republic of Germany.
H. E. Johns	Canada.
W. J. Oosterkamp	Netherlands.
B. Rajewsky	Federal Republic of Germany.
H. H. Rossi	United States.
M. Tubiana	France.

I. Composition of Committee Preparing Initial Draft of Present Report

H. O. Wyckoff, Chairman
A. Allisy
J. W. Boag
H. Fränz
W. C. Roesch
H. H. Rossi
M. Tubiana

Radiation Quantities and Units

International Commission on Radiological Units and Measurements (ICRU) Report 10a 1962

1. Introduction

There has recently been much discussion of the fundamental concepts and quantities employed in radiation dosimetry. This has arisen partly from the rapid increase in the number of individuals using these concepts in the expanding field of nuclear science and technology, partly because of the need for extending the concepts so that they would be of use at higher photon energies and for particulate as well as for photon radiation, but chiefly because of certain obscurities in the existing formulation of the quantities and units themselves.

The roentgen, for example, was originally defined to provide the best quantitative measure of exposure to medium energy x radiation which the measuring techniques of that day (1928) permitted. The choice of air as a standard substance was not only convenient but, also appropriate for a physical quantity which was to be correlated with the biological effect of x rays, since the effective atomic number of air is not very different from that of tissue. Thus a given biological response could be reproduced approximately by an equal exposure in roentgens for x-ray energies available at that time. Since 1928 the definition of the roentgen has been changed several times, and this has reflected some feeling of dissatisfaction with the clarity of the concept.

The most serious source of confusion was the failure to define adequately the radiation quantity of which the roentgen was said to be the unit.[1] As a consequence of this omission the roentgen had gradually acquired a double role. The use of this name for the unit had become recognized as a way of specifying not only the magnitude but also the nature of the quantity measured. This practice conflicts with the general usage in physics, which permits, within the same field, the use of a particular unit for all quantities having the same dimensions.

Even before this, the need for accurate dosimetry of neutrons and of charged particles from accelerators or from radionuclides had compelled the International Commission on Radiological Units and Measurements (ICRU) to extend the number of concepts. It was also desired to introduce a new quantity which could be more directly correlated with the local biological and chemical effects of radiation. This quantity, *absorbed dose*, has a generality and simplicity which greatly facilitated its acceptance, and in a very few years it has become widely used in every branch of radiation dosimetry.

The introduction of absorbed dose into the medical and biological field was further assisted by defining a special unit—the *rad*. One rad is approximately equal to the absorbed dose delivered when soft tissue is exposed to one roentgen of medium voltage x radiation. Thus in many situations of interest to medical radiology, but not in all, the numbers of roentgens and rads associated with a particular medical or biological effect are approximately equal and experience with the earlier unit could be readily transferred to the new one. Although the *rad* is merely a convenient multiple of the fundamental unit, erg/g, it has already acquired, at least in some circles, the additional connotation that the only quantity which can be measured in rads is absorbed dose. On the other hand, the rad has been used by some authors as a unit for a quantity called by them *first collision dose;* this practice is deprecated by the Commission.

Being aware of the need for preventing the emergence of different interpretations of the same quantity, or the introduction of undesirable, unrelated quantities or units in this or similar fields of measurement, the ICRU set up, during its meeting in Geneva in September 1958, an *Ad Hoc* Committee. The task of this committee was to review the fundamental concepts, quantities, and units which are required in radiation dosimetry and to recommend a system of concepts and a set of definitions which would be, as far as possible, internally consistent and of sufficient generality to cover present requirements and such future requirements as can be foreseen. The committee was instructed to pay more attention to consistency and rigor than to the historical development of the subject and was authorized to reject any existing quantities or units which seemed to hinder a consistent and unified formulation of the concepts.

[1] Fränz, H. and Hübner, W. Concepts and Measurement of Dose, Proceedings of Second International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958, P/971 **21**, 101, United Nations, Geneva (1958).

Bertrand Russell[2] in commenting on the use and abuse of the concept of infinitesimals by mathematicians, remarks: "But mathematicians did not at first pay heed to (these) warnings. They went ahead and developed their science, and it is well that they should have done so. It is a peculiar fact about the genesis and growth of new disciplines that too much rigor too early imposed stifles the imagination and stultifies invention. A certain freedom from the strictures of sustained formality tends to promote the development of a subject in its early stages, even if this means the risk of a certain amount of error. Nonetheless, there comes a time in the development of any field when standards of rigor have to be tightened."

The purpose of the present reexamination of the concepts to be employed in radiation dosimetry was primarily "to tighten standards of rigor". If, in the process, some increased formality is required in the definitions in order to eliminate any foreseeable ambiguities, this must be accepted.

2. General Considerations

The development of the more unified presentations of quantities and units which is here proposed was stimulated and greatly assisted by mathematical models of the dosimetric field which had been proposed by some members of the committee in an effort to clarify the concepts. It appeared, however, that the essential features of the mathematical models had been incorporated into the definitions and hence the need for their exposition in this report largely disappeared. The mathematical approach is published elsewhere.[3]

As far as possible, the definitions of the various fundamental quantities given here conform to a common pattern. Complex quantities are defined in terms of the simpler quantities of which they are comprised.

The passage to a "macroscopic limit" which has to be used in defining point quantities in other fields of physics can be adapted to radiation quantities and a special discussion of this is included in the section headed "limiting procedures".

The general pattern adopted is to give a short definition and to indicate the precise meaning of any special phrase or term used by means of an explanatory note following the definition. There has been no attempt to make the list of quantities which are defined here comprehensive. Rather, the Commission has striven to clarify the fundamental dosimetric quantities and a few others (such as activity) which were specifically referred to it for discussion.

It is recognized that certain terms for which definitions are proposed here are of interest in other fields of science and that they are already variously defined elsewhere. The precise wording of the definition and even the name and symbol given to any such quantity, may at some future date require alteration if discussions with representatives of the other interested groups of scientists should lead to agreement on a common definition or symbol. Although the definitions presented here represent some degree of compromise, they are believed to meet the requirements in the field of radiation dosimetry.

3. Quantities, Units, and Their Names

The Commission is of the opinion that the definition of concepts and quantities is a fundamental matter and that the choice of units is of less importance. Ambiguity can best be avoided if the defined quantity which is being measured is specified. Nevertheless, the special units do exist in this as in many other fields. For example, the hertz is restricted, by established convention, to the measurement of vibrational frequency, and the curie, in the present recommendations, to the measurement of the activity of a quantity of a nuclide. One does not measure activity in hertz nor frequency in curies although these quantities have the same dimensions.

It was necessary to decide whether or not to extend the use of the special dosimetric units to other more recently defined quantities having the same dimensions, to retain the existing restriction on their use to one quantity each, or to abandon the special units altogether. The Commission considers that the addition of further special units in the field of radiation dosimetry is undesirable, but continues to recognize the existing special units. It sees no objection, however, to the expression of any defined quantity in the appropriate units of a coherent physical system. Thus, to express absorbed dose in ergs per gram or joules per kilogram, exposure in coulombs per kilogram or activity in reciprocal seconds, are entirely acceptable alternatives to the use of the special units which, for historical reasons, are usually associated with these quantities.

The ICRU recommends that the use of each special unit be restricted to one quantity as follows:

The rad—solely for absorbed dose
The roentgen—solely for exposure
The curie—solely for activity.

It recommends further that those who prefer to express quantities such as absorbed dose and kerma (see below) in the same units should use units of an internationally agreed coherent system.

Several new names are proposed in the present report. When the absorbed dose concept was adopted in 1953, the Commission recognized the need for a term to distinguish it from the quantity of which the roentgen is the unit. In 1956 the Commission proposed the term *exposure* for this latter quantity. To meet objections by the ICRP, a compromise term, "exposure dose" was agreed upon.[4] While this term has come into some use

[2] Russell, B., Wisdom of the West, p. 280 (Doubleday and Co., Inc., New York, 1959).
[3] Rossi, H. H. and Roesch, W. C., Field Equations in Dosimetry, Radiation Res. **16**, 783 (1962).

[4] For details see ICRU, 1956 Report, NBS Handb. 62, p. 2 (1957).

since then, it has never been considered as completely satisfactory. In the meantime, the basic cause of the ICRP objection has largely disappeared since most legal codes use either the units rad or rem.

Since in this report the whole system of radiological quantities and units has come under critical review, it seemed appropriate to reconsider the 1956 decision. Numerous names were examined as a replacement for exposure dose, but there were serious objections to any which included the word dose. There appeared to be a minimum of objection to the name *exposure* and hence this term has been adopted by the Commission with the hope that the question has been permanently settled. It involves a minimum change from the older name exposure dose. Furthermore, the elimination of the term "dose" accomplishes the long-felt desire of the Commission to retain the term dose for one quantity only—the absorbed dose.

The term "*RBE* dose" has in past publications of the Commission not been included in the list of definitions but was merely presented as a "recognized symbol." In its 1959 report the Commission also expressed misgivings over the utilization of the same term, "*RBE*", in both radiobiology and radiation protection. It now recommends that the term *RBE* be used in radiobiology only and that another name be used for the linear-energy-transfer-dependent factor by which absorbed doses are to be multiplied to obtain for purposes of radiation protection a quantity that expresses on a common scale for all ionizing radiations the irradiation incurred by exposed persons. The name recommended for this factor is the *quality factor*, (*QF*). Provisions for other factors are also made. Thus a *distribution factor*, (*DF*), may be used to express the modification of biological effect due to non-uniform distribution of internally deposited isotopes. The product of absorbed dose and modifying factors is termed the *dose equivalent*, (*DE*). As a result of discussions between ICRU and ICRP the following formulation has been agreed upon:

The Dose Equivalent

1. For protection purposes it is useful to define a quantity which will be termed the "dose equivalent", (*DE*).
2. (*DE*) is defined as the product of absorbed dose, *D*, quality factor, (*QF*), dose distribution factor, (*DF*), and other necessary modifying factors.

$$(DE)=D\,(QF)\,(DF)\ldots.$$

3. The unit of dose equivalent is the "rem". The dose equivalent is numerically equal to the dose in rads multiplied by the appropriate modifying factors.

Although this statement does not cover a number of theoretical aspects (in particular the physical dimensions of some of the quantities) it fulfills the immediate requirement for an unequivocal specification of a scale that may be used for numerical expression in radiation protection.

Another new name is that for the quantity which represents the kinetic energy transferred to charged particles by the uncharged particles per unit mass of the irradiated medium. This is the same as one of the common interpretations of a concept "first collision dose," that has proved to be of great value in the dosimetry of fast neutrons. The concept is also closely related to the energy equivalent of exposure in an x-ray beam. The name proposed, *kerma*, is based on the initials of *k*inetic *e*nergy *r*eleased in *ma*terial.

Still another new name is the *energy fluence* which is here attached to the quantity in the 1953 ICRU report called *quantity of radiation*. The latter term was dropped in the 1956 ICRU report but the concept—time integral of intensity—remains a useful one and the proposed term appears to be acceptable in other languages as well as English. A related quantity, *particle fluence*, which is equivalent to the quantity *nvt* used in neutron physics, is included to round out the system of radiation quantities.

The quantity for which the curie is the unit was referred to the committee for a name and definition. Hitherto the curie has been defined as a *quantity of the radioactive nuclide* such that 3.7×10^{10} disintegrations per second occur in it. However, it has never been specified what was meant by quantity of a nuclide, whether it be a number, mass, volume, etc. Meanwhile the custom has grown of identifying the number of curies of a radionuclide with its transformation rate. Because of the vagueness of the original concept, because of the custom of identifying curies with transformation rate and because it appeared not to interfere with any other use of the curie, the Commission recommends that the term *activity* be used for the transformation rate, and that the curie be made its unit. It is recognized that the definition of the curie is of interest to other bodies in addition to the ICRU, but by this report we recommend that steps be taken to redefine it as $3.7\times10^{10}s^{-1}$, i.e., as a unit of activity and not of quantity of a nuclide.

It is also recommended that the term *specific gamma ray constant* be used instead of *specific gamma ray emission* for the quotient of the exposure rate at a given distance by the activity. The former term focuses attention on the *constancy* of this quotient for a given nuclide rather than the *emission* of the source.

4. Detailed Considerations

A. Limiting Procedures

Except in the case of a uniform distribution of sources throughout a large region, radiation fields are in general non-uniform in space. They may also be variable in time. Many of the quantities defined in this report have to be specified as functions of space or time, and in principle they must therefore be determined for sufficiently small regions of space or intervals of time by some limiting procedure. There are conceptual difficulties in taking such limits for quantities which depend upon the discrete interactions between radiations and atoms. Similar difficulties arise with other macroscopic physical quantities such as density or temperature and they must be overcome by means of an appropriate averaging procedure.

To illustrate this procedure we may consider the measurement of the macroscopic quantity "absorbed dose" in a non-uniform radiation field. In measuring this dose the quotient of energy by mass must be taken in an elementary volume in the medium which on the one hand is so small that a further reduction in its size would not appreciably change the measured value of the quotient energy by mass and on the other hand is still large enough to contain many interactions and be traversed by many particles.[5] If it is impossible to find a mass such that both these conditions are met, the dose cannot be established directly in a single measurement. It can only be deduced from multiple measurements that involve extrapolation or averaging procedures. Similar considerations apply to some of the other concepts defined below. The symbol Δ precedes the symbols for quantities that may be concerned in such averaging procedures.

In the measurement of certain material constants such as stopping power, absorption coefficient, etc., the limiting procedure can be specified more rigorously. Such constants can be determined for a given material with any desired accuracy without difficulties from statistical fluctuations. In these cases the formulae quoted in the definitions are presented as differential quotients.

B. Spectral Distributions and Mean Values

In practice many of the quantities defined below to characterize a radiation field and its interaction with matter are used for radiations having a complex energy spectrum. An important general concept in this connection is the *spectral concentration* of one quantity with respect to another. The spectral concentration is the ordinate of the distribution function of the first quantity with respect to the second. The independent quantity need not always be energy or frequency; one can speak of the spectral concentration of flux density with respect to quantum energy or of the absorbed dose with respect to linear energy transfer. The interaction constants (such as μ, S and W) referred to in this report are often mean values taken over the appropriate spectral distributions of the corresponding quantities.

C. Units

For any of the quantities defined below the appropriate unit of an internationally agreed coherent system can be used. In addition certain special units are reserved for special quantities:

the rad for absorbed dose
the roentgen for exposure
the curie for activity.

D. Definitions

(1) *Directly ionizing particles* are charged particles (electrons, protons, α-particles, etc.) having sufficient kinetic energy to produce ionization by collision.

(2) *Indirectly ionizing particles* are uncharged particles (neutrons, photons, etc.) which can liberate directly ionizing particles or can initiate a nuclear transformation.

(3) *Ionizing radiation* is any radiation consisting of directly or indirectly ionizing particles or a mixture of both.

(4) The *energy imparted* by ionizing radiation to the matter in a volume is the difference between the sum of the energies of all the directly and indirectly ionizing particles which have entered the volume and the sum of the energies of all those which have left it, minus the energy equivalent of any increase in rest mass that took place in nuclear or elementary particle reactions within the volume.

NOTES: (a) The above definition is intended to be exactly equivalent to the previous meanings given by the ICRU to "energy retained by matter and made locally available" or "energy which appears as ionization, excitation, or changes of chemical bond energies". The present formulation specifies what energy is to be included without requiring a lengthy, and possibly incomplete, catalogue of the different types of energy transfer.

(b) Ultimately, most of the energy imparted will be degraded and appear as heat. Some of it, however, may appear as a change in interatomic bond energies. Moreover, during the degradation process the energy will diffuse and the distribution of heat produced may be different from the distribution of imparted energy. For these reasons the energy imparted cannot always be equated with the heat produced.

(c) The quantity *energy imparted to matter* in a given volume is identical with the quantity often called *integral absorbed dose* in that volume.

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[5] In interpreting radiation effects the macroscopic concept of absorbed dose may not be sufficient. Whenever the statistical fluctuations around the mean value are important, additional parameters describing the distribution of absorbed energy on a microscopic scale are necessary.

(5) The *absorbed dose* (D) is the quotient of ΔE_D by Δm, where ΔE_D is the energy imparted by ionizing radiation to the matter in a volume element, Δm is the mass of the matter in that volume element and Δ has the meaning indicated in section 4.A.

$$D=\frac{\Delta E_D}{\Delta m}$$

The special unit of absorbed dose is the *rad*.

$$1 \text{ rad}=100 \text{ erg}/g=\frac{1}{100} \text{ J}/kg$$

NOTE: J is the abbreviation for Joule

(6) The *absorbed dose rate* is the quotient of ΔD by Δt, where ΔD is the increment in absorbed dose in time Δt and Δ has the meaning indicated in section 4.A.

$$\text{Absorbed dose rate}=\frac{\Delta D}{\Delta t}$$

A special unit of absorbed dose rate is any quotient of the rad by a suitable unit of time (rad/d, rad/min, rad/h, etc.).

(7) The *particle fluence*[6] or *fluence* (Φ) of particles is the quotient of ΔN by Δa, where ΔN is the number of particles which enter a sphere[7] of cross-sectional area Δa and Δ has the meaning indicated in section 4.A.

$$\Phi=\frac{\Delta N}{\Delta a}$$

(8) The *particle flux density* or *flux density* (φ) of particles is the quotient of $\Delta\Phi$ by Δt where $\Delta\Phi$ is the particle fluence in time Δt and Δ has the meaning indicated in section 4.A.

$$\varphi=\frac{\Delta\Phi}{\Delta t}$$

NOTE: This quantity may also be referred to as particle fluence rate.

(9) The *energy fluence* (F) of particles is the quotient of ΔE_F by Δa, where ΔE_F is the sum of the energies, exclusive of rest energies, of all the particles which enter a sphere[8] of cross-sectional area Δa and Δ has the meaning indicated in section 4.A.

$$F=\frac{\Delta E_F}{\Delta a}$$

(10) The *energy flux density* or *intensity* (I) is the quotient of ΔF by Δt where ΔF is the energy fluence in the time Δt and Δ has the meaning indicated in section 4.A.

$$I=\frac{\Delta F}{\Delta t}$$

NOTE: This quantity may also be referred to as energy fluence rate.

(11) The *kerma*[9] (K) is the quotient of ΔE_K by Δm, where ΔE_K is the sum of the initial kinetic energies of all the charged particles liberated by indirectly ionizing particles in a volume element of the specified material, Δm is the mass of the matter in that volume element and Δ has the meaning indicated in section 4.A.

$$K=\frac{\Delta E_K}{\Delta m}$$

NOTES: (a) Since ΔE_K is the sum of the initial kinetic energies of the charged particles liberated by the indirectly ionizing particles, it includes not only the kinetic energy these charged particles expend in collisions but also the energy they radiate in bremsstrahlung. The energy of any charged particles is also included when these are produced in secondary processes occurring within the volume element. Thus the energy of Auger electrons is part of ΔE_K.

(b) In actual measurements Δm should be so small that its introduction does not appreciably disturb the radiation field. This is particularly necessary if the medium for which kerma is determined is different from the ambient medium; if the disturbance is appreciable an appropriate correction must be applied.

(c) It may often be convenient to refer to a value of kerma or of kerma rate for a specified material in free space or at a point inside a different material. In such a case the value will be that which would be obtained if a small quantity of the specified material were placed at the point of interest. It is, however, permissible to make a statement such as: "The kerma for air at the point P inside a water phantom is . . ." recognizing that this is a shorthand version of the fuller description given above.

(d) A fundamental physical description of a radiation field is the intensity (energy flux density) at all relevant points. For the purpose of dosimetry, however, it may be convenient to describe the field of indirectly ionizing particles in terms of the kerma rate for a specified material. A suitable material would be air for electromagnetic radiation of moderate energies, tissue for all radiations in medicine or biology, or any relevant material for studies of radiation effects.

[6] This quantity is the same as the quantity, *nvt*, commonly used in neutron physics.

[7] This quantity is sometimes defined with reference to a plane of area Δa, instead of a sphere of cross-sectional area Δa. The plane quantity is less useful for the present purposes and it will not be defined. The two quantities are equal for a unidirectional beam of particles perpendicularly incident upon the plane area.

[8] See footnote 7.

[9] Various other methods of specifying a radiation field have been used, e.g., for a neutron source the "first collision dose" in a standard material at a specified point (see Introduction).

Kerma can also be a useful quantity in dosimetry when charged particle equilibrium exists at the position and in the material of interest, and bremsstrahlung losses are negligible. It is then equal to the absorbed dose at that point. In beams of x or gamma rays or neutrons, whose energies are moderately high, transient charged-particle equilibrium can occur; in this condition the kerma is just slightly less than the absorbed dose. At very high energies the difference becomes appreciable. In general, if the range of directly ionizing particles becomes comparable with the mean free path of the indirectly ionizing particles, no equilibrium will exist.

(12) The *kerma rate* is the quotient of ΔK by Δt, where ΔK is the increment in kerma in time Δt and Δ has the meaning indicated in section 4.A.

(13) The *exposure* (X) is the quotient of ΔQ by Δm, where ΔQ is the sum of the electrical charges on all the ions of one sign produced in air when all the electrons (negatrons and positrons), liberated by photons in a volume element of air whose mass is Δm, are completely stopped in air and Δ has the meaning indicated in section 4.A.

$$X = \frac{\Delta Q}{\Delta m}$$

The special unit of exposure is the roentgen (R).

$$1R = 2.58 \times 10^{-4} C/kg$$ [10]

NOTES: (a) The words "charges on all the ions of one sign" should be interpreted in the mathematically absolute sense.

(b) The ionization arising from the absorption of bremsstrahlung emitted by the secondary electrons is not to be included in ΔQ. Except for this small difference, significant only at high energies, the exposure as defined above is the ionization equivalent of the kerma in air.

(c) With present techniques it is difficult to measure exposure when the photon energies involved lie above a few Mev or below a few kev.

(d) As in the case of kerma (4D(11), note (c)), it may often be convenient to refer to a value of exposure or of exposure rate in free space or at a point inside a material different from air. In such a case the value will be that which would be determined for a small quantity of air placed at the point of interest. It is, however, permissible to make a statement such as: "The exposure at the point P inside a water phantom is . . . ."

(14) The *exposure rate* is the quotient of ΔX by Δt, where ΔX is the increment in exposure in time Δt and Δ has the meaning indicated in section 4.A,

$$\text{Exposure rate} = \frac{\Delta X}{\Delta t}$$

[10] This unit is numerically identical with the old one defined as 1 e.s.u. of charge per .001293 gram of air. C is the abbreviation for coulomb.

A special unit of exposure rate is any quotient of the roentgen by a suitable unit of time (R/s, R/min, R/h, etc.).

(15) The *mass attenuation coefficient* $\left(\frac{\mu}{\rho}\right)$ of a material for indirectly ionizing particles is the quotient of dN by the product of ρ, N, and dl where N is the number of particles incident normally upon a layer of thickness dl and density ρ, and dN is the number of particles that experience interactions in this layer.

$$\frac{\mu}{\rho} = \frac{1}{\rho N} \frac{dN}{dl}$$

NOTES: (a) The term "interactions" refers to processes whereby the energy or direction of the indirectly ionizing particles is altered.

(b) For x or gamma radiations

$$\frac{\mu}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho} + \frac{\sigma_{coh}}{\rho} + \frac{\kappa}{\rho}$$

where $\frac{\tau}{\rho}$ is the mass photoelectric attenuation coefficient, $\frac{\sigma}{\rho}$ is the total Compton mass attenuation coefficient, $\frac{\sigma_{coh}}{\rho}$ is the mass attenuation coefficient for coherent scattering, and $\frac{\kappa}{\rho}$ is the pair-production mass attenuation coefficient.

(16) The *mass energy transfer coefficient* $\left(\frac{\mu_K}{\rho}\right)$ of a material for indirectly ionizing particles is the quotient of dE_K by the product of E, ρ and dl where E is the sum of the energies (excluding rest energies) of the indirectly ionizing particles incident normally upon a layer of thickness dl and density ρ, and dE_K is the sum of the kinetic energies of all the charged particles liberated in this layer.

$$\frac{\mu_K}{\rho} = \frac{1}{E\rho} \frac{dE_K}{dl}$$

NOTES: (a) The relation between fluence and kerma may be written as

$$K = F \frac{\mu_K}{\rho}$$

(b) For x or gamma rays of energy $h\nu$

$$\frac{\mu_K}{\rho} = \frac{\tau_a}{\rho} + \frac{\sigma_a}{\rho} + \frac{\kappa}{\rho}$$

where

$$\frac{\tau_a}{\rho} = \frac{\tau}{\rho}\left(1 - \frac{\delta}{h\nu}\right)$$

$\left(\frac{\tau}{\rho}=\right.$the photoelectric mass attenuation coefficient, δ=average energy emitted as fluorescent radiation per photon absorbed.$\left.\right)$

and
$$\frac{\sigma_e}{\rho}=\frac{\sigma}{\rho}\frac{E_e}{h\nu}$$

$\left(\frac{\sigma}{\rho}=\right.$total Compton mass attenuation coefficient, E_e=average energy of the Compton electrons per scattered photon.$\left.\right)$

and
$$\frac{\kappa_a}{\rho}=\frac{\kappa}{\rho}\left(1-\frac{2mc^2}{h\nu}\right)$$

$\left(\frac{\kappa}{\rho}=\right.$mass attenuation coefficient for pair production, mc^2=rest energy of the electron.$\left.\right)$

(17) The *mass energy-absorption coefficient* $\left(\frac{\mu_{en}}{\rho}\right)$ of a material for indirectly ionizing particles is $\frac{\mu_K}{\rho}$ $(1-G)$ where G is the proportion of the energy of secondary charged particles that is lost to bremsstrahlung in the material.

NOTES: (a) When the material is air, $\frac{\mu_{en}}{\rho}$ is proportional to the quotient of exposure by fluence.

(b) $\frac{\mu_K}{\rho}$ and $\frac{\mu_{en}}{\rho}$ do not differ appreciably unless the kinetic energies of the secondary particles are comparable with or larger than their rest energy.

(18) The *mass stopping power* $\left(\frac{S}{\rho}\right)$ of a material for charged particles is the quotient of dE_s by the product of dl and ρ, where dE_s is the average energy lost by a charged particle of specified energy in traversing a path length dl, and ρ is the density of the medium.

$$\frac{S}{\rho}=\frac{1}{\rho}\frac{dE_s}{dl}$$

NOTE: dE_s denotes energy lost due to ionization, electronic excitation and radiation. For some purposes it is desirable to consider stopping power with the exclusion of bremsstrahlung losses. In this case $\frac{S}{\rho}$ must be multiplied by an appropriate factor that is less than unity.

(19) The *linear energy transfer* (L) of charged particles in a medium is the quotient of dE_L by dl where dE_L is the average energy locally imparted to the medium by a charged particle of specified energy in traversing a distance of dl.

$$L=\frac{dE_L}{dl}$$

NOTES: (a) The term "locally imparted" may refer either to a maximum distance from the track or to a maximum value of discrete energy loss by the particle beyond which losses are no longer considered as local. In either case the limits chosen should be specified.

(b) The concept of linear energy transfer is different from that of stopping power. The former refers to energy imparted within a limited volume, the latter to loss of energy regardless of where this energy is absorbed.

(20) The *average energy* (W) *expended in a gas per ion pair formed* is the quotient of E by N_W, where N_W is the average number of ion pairs formed when a charged particle of initial energy E is completely stopped by the gas.

$$W=\frac{E}{N_W}$$

NOTES: (a) The ions arising from the absorption of bremsstrahlung emitted by the charged particles are not to be counted in N_W.

(b) In certain cases it may be necessary to consider the variation in W along the path of the particle, and a differential concept is then required, but is not specifically defined here.

(21) A *nuclide* is a species of atom having specified numbers of neutrons and protons in its nucleus.

(22) The *activity* (A) of a quantity of a radioactive nuclide is the quotient of ΔN by Δt where ΔN is the number of nuclear transformations which occur in this quantity in time Δt and Δ has the meaning indicated in section 4.A.

$$A=\frac{\Delta N}{\Delta t}$$

The special unit of activity is the curie (c).

$$1c=3.7\times10^{10}s^{-1} \text{ (exactly)}$$

NOTE: In accordance with the former definition of the curie as a unit of quantity of a radioactive nuclide, it was customary and correct to say: "Y curies of P–32 were administered . . . . ." It is still permissible to make such statements rather than use the longer form which is now correct: "A quantity of P–32 was administered whose activity was Y curies."

(23) The *specific gamma ray constant* (Γ) of a gamma-emitting nuclide is the quotient of $l^2 \frac{\Delta X}{\Delta t}$ by A, where $\frac{\Delta X}{\Delta t}$ is the exposure rate at a distance l from a point source of this nuclide having an activity A and Δ has the meaning indicated in section 4.A.

$$\Gamma=\frac{l^2\Delta X}{A\Delta t}$$

Special units of specific gamma ray constant are $Rm^2h^{-1}c^{-1}$ or any convenient multiple of this.

NOTE: It is assumed that the attenuation in the source and along l is negligible. However, in the case of radium the value of Γ is determined for a filter thickness of 0.5 mm of platinum and in this case the special units are $Rm^2h^{-1}g^{-1}$ or any convenient multiple of this.

TABLE 4.1. *Table of quantities and units*

No.	Name	Symbol	Dimensions [a]	Units		
				MKSA	cgs	Special
4	Energy imparted (integral absorbed dose).	......	E	J	erg	g. rad.
5	Absorbed dose	D	EM^{-1}	J kg^{-1}	erg g^{-1}	rad.
6	Absorbed dose rate.	......	$EM^{-1}T^{-1}$	J kg^{-1}s^{-1}	erg g^{-1}s^{-1}	rad s^{-1} etc.
7	Particle fluence or fluence.	Φ	L^{-2}	m^{-2}	cm^{-2}	
8	Particle flux density.	φ	$L^{-2}T^{-1}$	m^{-2}s^{-1}	cm^{-2}s^{-1}	
9	Energy fluence	F	EL^{-2}	J m^{-2}	erg cm^{-2}	
10	Energy flux density or intensity.	I	$EL^{-2}T^{-1}$	J m^{-2}s^{-1}	erg cm^{-2}s^{-1}	
11	Kerma	K	EM^{-1}	J kg^{-1}	erg g^{-1}	
12	Kerma rate	......	$EM^{-1}T^{-1}$	J kg^{-1}s^{-1}	erg g^{-1}s^{-1}	
13	Exposure	X	QM^{-1}	C kg^{-1}	esu g^{-1}	R (roentgen).
14	Exposure rate	......	$QM^{-1}T^{-1}$	C kg^{-1}s^{-1}	esu g^{-1}s^{-1}	Rs^{-1} etc
15	Mass attenuation coefficient.	$\frac{\mu}{\rho}$	L^2M^{-1}	m^{2}kg^{-1}	cm^{2}g^{-1}	
16	Mass energy transfer coefficient.	$\frac{\mu_K}{\rho}$	L^2M^{-1}	m^{2}kg^{-1}	cm^{2}g^{-1}	
17	Mass energy absorption coefficient.	$\frac{\mu_{en}}{\rho}$	L^2M^{-1}	m^{2}kg^{-1}	cm^{2}g^{-1}	
18	Mass stopping power.	$\frac{S}{\rho}$	EL^2M^{-1}	J m^{2}kg^{-1}	erg cm^{2}g^{-1}	
19	Linear energy transfer.	L	EL^{-1}	J m^{-1}	erg cm^{-1}	kev(μm)$^{-1}$.
20	Average energy per ion pair.	W	E	J	erg	ev.
22	Activity	A	T^{-1}	s^{-1}	s^{-1}	c(curie).
23	Specific gamma-ray constant.	Γ	QL^2M^{-1}	Cm^{2}kg^{-1}	esu cm^{2}g^{-1}	Rm^{2}h^{-1}c^{-1} etc.
	Dose equivalent	DE	....	....	....	rem

[a] It was desired to present only one set of dimensions for each quantity, a set that would be suitable in both the MKSA and electrostatic-cgs systems. To do this it was necessary to use a dimension Q, for the electrical charge, that is not a fundamental dimension in either system. In the MKSA system (fundamental dimensions M, L, T, I) Q represents the product IT; in the electrostatic-cgs system (M, L, T) it represents $M^{1/2}L^{3/2}T^{-1}$.

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Recommendations[a] of International Commission on Radiological Units and Measurements (ICRU)

Report Number	Reference[b]
1	Discussion on International Units and Standards for X-ray Work Brit. J. Radiol. **23**, 64 (1927)
2	International X-ray Unit of Intensity Brit. J. Radiol. (new series) **1**, 363 (1928)
3	Report of Committee on Standardization of X-ray Measurements Radiology **22**, 289 (1934)
4	Recommendations of the International Committee for Radiological Units Radiology **23**, 580 (1934)
5	Recommendations of the International Committee for Radiological Units Radiology **29**, 634 (1937)
6	Report of International Commission on Radiological Protection and International Commission on Radiological Units National Bureau of Standards Handbook 47, Washington, D.C. (1951)
7	Recommendations of the International Commission for Radiological Units Radiology **62**, 106 (1954)
8	Report of International Commission on Radiological Units and Measurements (ICRU) 1956 National Bureau of Standards Handbook 62, Washington, D.C. (1957)
9	Report of International Commission on Radiological Units and Measurements (ICRU) 1959 National Bureau of Standards Handbook 78, Washington, D.C. (1961)
10a	Radiation Quantities and Units National Bureau of Standards Handbook 84, Washington, D.C. (1962)
10b	Physical Aspects of Irradiation National Bureau of Standards Handbook 85, Washington, D.C. ([c])
10c	Radioactivity National Bureau of Standards Handbook 86, Washington, D.C. ([c])
10d	Clinical Dosimetry National Bureau of Standards Handbook 87, Washington, D.C. ([c])
10e	Radiobiological Dosimetry National Bureau of Standards Handbook 88, Washington, D.C. ([c])
10f	Methods of Evaluating Radiological Equipment and Materials National Bureau of Standards Handbook 89, Washington, D.C. ([c])

[a] Current recommendations are included.
[b] References given are in English. Many of them were also published in other languages.
[c] In preparation.

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