THE INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

ICRU NEWS

1
90

ICRU

ICRU NEWS

Publisher:
International Commission on Radiation Units and Measurements (ICRU)

7910 Woodmont Avenue, Suite 800
Bethesda, MD 20814-3095, USA
Tel.: (301) 657-2652,
Fax: (301) 907-8768

Editorial Board:
A. Allisy (Chairman), R. S. Caswell, A. M. Kellerer, W. R. Ney, A. Wambersie, H. O. Wyckoff

Managing Editor:
H. G. Ebert

The Commission wishes to thank the individuals involved in the preparation of this issue of ICRU NEWS for the time and effort they devoted to this task and to express its appreciation to the organizations with which they are affiliated.

Printed in
the Federal Republic of Germany,
Druckerei Emhart, Aachen.

Table of Contents — June 1990

Table of Contents 2

ICRU Committees

Announcements

Information on ICRU Reports

Advertisers

Insert

Order Card for free future issues of ICRU NEWS

Current ICRU Objectives

André Allisy
BIPM
92310 Sèvres, France

The major principles on which the work of ICRU is based, are the establishment of concepts, quantities, units and measurement techniques important to all users of ionizing radiations, in order to allow them to express their results in a way which permits an easy and unambiguous understanding and comparison. The work necessary to achieve this goal can be subdivided into the following categories

- Radiation quantities and units
- Measurement methods and related data
- Specific measurement techniques
  - Radiotherapy
  - Imaging systems
  - Radiation protection
- Protocols for reporting therapy.

The work on **radiation quantities and units** is so fundamental that it justifies the existence of the only standing committee of the Commission. This Committee has produced definitions of quantities in accordance with the general rules used in physical science which constitute the foundation of effective communication among scientists. The results of its efforts have been published in the report on "Radiation Quantities and Units" (ICRU Report 33) which is now under revision. (ICRU NEWS 89-2).

In the field of **measurement methods**, a report on "Fundamentals of particle counting applied to radioactivity measurements" is in preparation. It will contain some of the main results obtained in the field of activity measurements in the past two decades (ICRU NEWS 89-2). Recently, the Commission decided to create a report committee on hyperthermia. The quantities clinically meaningful in this field are still to be discussed and the current project is presented in this issue of ICRU NEWS. In the related field of **physical data**, the ICRU programme on stopping powers is completed for electrons and positrons (ICRU Report 37), will be shortly reviewed by the Commission for protons and alpha particles (ICRU NEWS 89-1) and is in preparation for heavy ions (ICRU NEWS 90-1). New work on secondary electron spectra resulting from charged particle interactions is in its initial phase (ICRU NEWS 90-1). An extensive programme on tissue substitutes in radiation dosimetry and measurement was started a few years ago. The first report is published (ICRU Report 44); the second has been accepted by the Commission, and as a natural progression, a report on phantoms in therapy, diagnosis and protection has been initiated (ICRU NEWS 89-1).

The ICRU has developed reports on **specific measurement techniques** for a long time and has improved them as required for new applications. This is true in particular in the field of **radiotherapy**, where new radiation sources are steadily brought into use. Work on clinical neutron dosimetry has been divided into two parts: Part I, dealing with the "Determination of absorbed dose in a patient treated by external beams of fast neutrons", is published (ICRU Report 45). Part II which will deal with the specification of beam quality is in its initial phase. Finally, the Commission has initiated a project on proton beam dosimetry for therapy.

The introduction of new **imaging systems** in radiology has been spectacular during the past two decades. Today digital systems are commonly used where the acquired data are stored and sometimes processed prior to display. In such complex devices it becomes important to assess the quality of the image. The Commission has decided to expand its efforts in this area and it is hoped that a general treatment of that subject can be later used in various specific imaging modalities (ICRU NEWS 89-2 and 90-1).

The current ICRU programme in **radiation protection measurement** is influenced by the introduction of the new operational quantities: ambient, directional and individual dose equivalents. Part 2 of the report "Determination of dose equivalents from external radiation sources" is already published (ICRU Report 43). It gives the data on which the operational quantities are based. Part 3, dealing with instrumentation, is under consideration by the Commission. An effort in the field of *in situ* gamma spectrometry in the environment is to begin soon.

A common language is vital in the dose prescription and specification in radiotherapy by means of **protocols** widely accepted by a majority of scientists. The ICRU has been for a long time aware of the importance of that task directly related to the health of mankind. The evolution of the technical tools used in radiotherapy is very fast and as a result, the treatment techniques are becoming more and more complex. It is therefore necessary to adapt the older reports to the new situation. This led the Commission to undertake a revision of Report 29 on "Dose specification for reporting external beam therapy with photons and electrons" (ICRU NEWS 90-1). A new report dealing with the dose specification for reporting interstitial therapy is in preparation.

This brief overview of the ICRU objectives shows the coherence of the ICRU programme; it also evidences the important role played by the ICRU NEWS as a means of keeping the scientific community informed of our efforts.

More than 12 000 copies of each of the first three issues of the ICRU NEWS have been distributed. The ICRU will, however, not be in a position to continue to send such a large number of complimentary copies. **Therefore, it is essential that all those interested in receiving future issues of ICRU NEWS return now the Survey Card enclosed in this issue, if they have not already sent in the forms from either issue no. 1 or no. 2 asking to receive future issues.**

80 Years of Quantities and Units Personal Reminiscences

Part II: From the "International X-Ray Unit Committee" to the "International Commission on Radiation Units and Measurements (ICRU)"

Lauriston S. Taylor
ICRU
Bethesda, MD 20814-3095

Introduction

Part i of this report gave a very condensed story of the development of the philosophy and science of the measurement of ionizing radiation as applied by the medical profession. Over the period of roughly 1910-1925, a number of proposals were developed for the quantities and units to be applied in the use of, first x rays, and then the gamma rays from radium. Most of the measurements were described as being made "free in air" thus involving some form of the large free-air ionization chamber as the standard. The unit of measurement was the **roentgen** which was variously defined until action was taken by the International Committee for Radiological Units in 1928.

By 1931, international comparison of national laboratory standards had led to the acceptance of the name, the principles of measurement and the clinical application of calibrated instruments. The change of the organization's name from "Committee" to "Commission" took place in 1950 but throughout its history the organization was referred to as the ICRU.

The Period 1934-1950

At the 1931 meeting of the ICRU, a small working Subcommittee was constituted (made up of individuals from those countries having national standards laboratories), to further study the problems associated with radiation measurements. No records have been found of any correspondence or meetings by the Subcommittee. However, there were two actions of note. The first was at least informal recognition that the French standard, while moderately satisfactory for use within the country, did not fit into the international scheme of things. At the suggestion of the Committee at its Paris meeting, it was agreed that the National Bureau of Standards in the United States would supply France with an exact copy of the small guarded field ionization chamber which had been used for the transfer measurements. This was done within the following year and, when I visited the Laboratory in 1934, the instrument was present but had not yet been set up for use. It is not known whether this ever was done but it may be noted that in the middle 1950's, after Allisy had established a free air standard at his laboratory in Paris, he had never heard of the existence of the guarded field chamber sent to France.

The other item of note, that came from the 1931 discussions, was the published agreement between the national laboratories of U. S., U. K., Germany and France. This was in response to the role specified by the Units Committee to be carried out by the Subcommittee (1). These actions on the part of the laboratories went forward largely under their own initiative and followed long established procedures for dealing with standards problems between national laboratories. Results were reported to the Units Committee and the laboratories were appreciative of the action by that Committee in encouraging interlaboratory collaboration.

By the time the four laboratories had reached agreement, there had also been further opportunity for analyzing and fine tuning the results of the standards comparison in 1931. The final table of results was expressed in terms of the number of units (r), for units measured with the NBS full size parallel plate ionization chamber. They were as follows:

Large NBS Chamber	1.0005
NPL	0.9886 to 1.001
PTR	1.0035
Solomon (110 kV)	2.10
(110-190 kVp)	2.29

I am surprised at my having taken part in the publishing of a paper carrying so many significant figures when I am reasonably certain now that plus or minus a couple of percent would have been more realistic.

Seven specific recommendations were agreed upon by the laboratories participating in the comparisons, largely centering around some points of chamber design and current measurement systems (1). Also, Solomon (France) announced his acceptance of the open air ionization chamber as his fundamental standard while, at the same time, recognizing the secondary calibration with radium as theretofore used by him (1).

X-ray technology moved forward rapidly during the period between the 1931 and 1934 International Congresses of Radiology. X-ray tubes classified in the 1920's as having 200 kV ratings could hardly be called satisfactory in terms of their operating lifetime. This was changed by the introduction of thick walled tubes, tubes having metal centers, oil immersion and so on. Not only had radiology passed through the 200 kV range but by now was up to 400 kV clinical equipment and there were indications that it would be going higher.

Coolidge had developed a three-stage tube that could operate at around 900 kV. Lauritsen developed a multi-stage tube that would operate at 1,000 kV and a couple of the commercial organizations in the U.S. and abroad had developed various tubes operating at from 600 to 1,000 kVp. It seemed fairly obvious that this new technology would soon find its applications in radiation therapy and so the national laboratories, especially the NBS and NPL, felt the necessity for remaining abreast of the demands for radiation dosimetry at these higher energies.

In that period there were essentially three classes of ionization chambers. One of these was the free-air standard ionization chamber defined according to the recommendations of the ICRU. There were no limitations included in those recommendations specifying any upper limit as to the radiation energy to which such a chamber should be applied. The second class of ionization chamber included the thimble- or cavity-type made of wall materials such as to yield a uniform response to radiations at all qualities and energies when compared with a free air ionization chamber. A third class included various types of chambers, usually of a multi-plate transmission type, which were used primarily in a radiation beam for output control purposes and not being required to be independent over a wide energy range. The problem was that at energies of 400 kV and higher there was no positive assurance, at that period, as to what the thimble chamber response would be to energies above 200 kVp. Accordingly, the NBS and the NPL each started, independently, to develop ionization chambers of large dimensions suitable for measuring radiation up to 600 kV and 1 MeV, respectively. In addition, both laboratories had included in the program, the measurement of a beam of radiation from radium.

Because of the large dimensions that were calculated to be necessary for such a chamber, the NBS chose to reduce its size by operating under a pressure of approximately 10 atmospheres. A guarded-field parallel-plate ionization chamber designed to operate at various plate separations was contained in a suitable cylindrical tank. Its maximum plate separation of 40 cm at 10 atmospheres would be roughly equivalent at 4 meters at one atmosphere.

Earlier studies made in the NBS laboratory of the ionization of liquids by x rays and gamma rays, provided experience with the problem of ionization recombination in liquids. It had been found possible to make a correction for the loss of ionization in liquids and, as a result of some preliminary experiments, it was found that the same principle could be applied to corrections for losses in air under moderately high pressures.

Binks (NPL) chose to remain with the free-air method at atmospheric pressure. For this he constructed an ionization chamber of some 4 meters plate separation and used the guarded field principle for avoiding field distortion. Fortunately, there was suitable space in which such an ionization chamber could be set up, using the radiation from radium since, at that time, a high voltage generator was not available. It might be noted that with the NBS system, it was also possible to measure a beam of radiation from a suitable source of radium. In fact, the assurance of the validity of such measurements with a pressure ionization chamber was to be demonstrated by a measure of the emission constant of radium, which had been done by other laboratories using small cavity ionization chambers. It may well be said that the basic purpose of both of these laboratories was to prove or disprove that radiations in the very high energy region could be measured in strict accordance with the existing definition of the roentgen. Once this was demonstrated, it was expected that the calibration of instruments in the national laboratories would probably be by comparison against a cavity type ionization chamber for which the readings had both been calculated and compared with the high energy pressure chamber.

An excellent review article, "Some background information on the development of dose units", was written by H. M. Parker in November 1955 as a report to be submitted to the Commission on Radiological Units, Standards and Protection, of the American College of Radiology. In this (3) comment was made that "in the United States there was perhaps more reluctance to accept the Bragg-Gray methodology. Taylor *et al.* are clearly dubious of the thimble chamber until they have proved its results against new free air chambers built to be suitable for high voltage radiation. This is perhaps understandable in view of the excellence of the free air developments at the U.S. Bureau of Standards." An implication here is that Gray's work was not being recognized in the U.S. and this was certainly not the case. The Bragg-Gray theory, really developed for dosimetric purposes by Gray, was put forward by him in 1929 and was known about in general terms. However, Gray's initial interest had been in connection with cosmic ray studies and it was not until his paper in 1936 that the real applicability of his work in radiology became appreciated (3). Also, somewhere in the interim, Gray essentially moved from the cosmic ray research community to the radiological physics community and, hence, by the mid '30s there was increasing confidence in the acceptance of his work. However, both the NBS and the NPL programs noted above had been started in the early '30s before the time at which Gray's cavity ionization theories had become recognized and accepted. Until then, it was felt essential that standards for dose should be in close compliance with the definition of the roentgen.

This also points up a problem that was beginning to evidence itself in the discussions centering around dose measurement in the radiation community. The definition of the roentgen as a quantity, was also a definition of the unit and it was not to be for another decade or two that the ICRU fully sorted out this problem.

The concluding recommendation of the 1931 meeting of the Committee was, "the International Committee shall henceforth be called the 'International Committee for Radioligical Units.'" It was not until 1950 that the name was officially modified again, changing from Committee to Commission in line with the name that had already been selected by the ICRP. The last name change was in 1968 when "radiological" was changed to "radiation", to indicate a broader future base of interests.

The Period 1931-1934

The technical changes in the recommendations of the ICRU at its 1934 meeting in Zurich were of a relatively minor nature, in spite of an endeavor, in recognition of earlier problems, to go further into the rationale that was being developed for radiological dosimetry. The various problems will be touched upon only briefly but they are, nevertheless, important because of the influence their solution had on future operations of the Commission.

The first problem, and one already noted, was the sheer size of the group meeting in the name of the Committee. In accordance with the Congress rules which allowed attendance by two individuals from each country participating in the International Congress of Radiology, there had been 40 such attendees in 1928, 39 in 1931 and 33 in 1934. Also it was customary to have an honorary chairman from the host country preside over the meeting and this usually had worked out satisfactorily because the chairman was selected from among the radiological community. However, at the meeting in Zurich in 1934, two honorary chairmen, Professor P. Scherrer and Dr. H. König were presented, neither of whom had any close ties with the medical applications of radiation. The second and even more important problem was the fact that of this large number of persons on the Committee, not more than a small handful were really active in the field of radiological measurements and, hence, the large majority of the attendees could contribute essentially nothing to the discussions.

Primarily because of this, and another problem which will be mentioned below, the Committee decided that it was only practical to set up some kind of a working group made up of individuals active in the measurement field. For this reason an Executive Subcommittee was established, subject to needed adjustment as the Committee met in the future. The first members were as follows: I. Solomon, Chairman; L. S. Taylor, Secretary; H. Behnken, E. A. Owen, R. Sievert and E. Pugno Vanoni.

This meant that in the future, the Executive Subcommittee, which presumably would be working between the Congresses, would reach agreement on a program of recommendations which would be placed before the Committee. The Executive Committee would elect its own chairman and secretary from among its members and would be expected to report on the progress of dosage measurements and prepare its program to be submitted to the main Committee at least six months before its meeting at a Congress. Unfortunately, this Executive Committee arrangement had only a single opportunity to function and that occurred at the 1937 meeting of the Committee.

The possibility of the formation of such a committee had been contemplated between Congresses but no formal action taken. In the meantime the Standardization Committee of the Radiological Society of North America (RSNA) had been intensively studying the problem of radiation quantities and units and had been receiving input from individuals outside of the Committee structure. These discussions culminated in the preparation of a report in 1933, five months ahead of the next meeting of the Committee. The report was signed off in September 1933 but not published until March 1934 (Radiology 22, page 289-294, March 1934). This was clearly in preparation for the upcoming 1934 meeting of the Committee. Copies had been sent to all members of the Committee. Based on replies and informal discussions, a program was prepared in advance of the Congress which was agreeable to France, Germany, Italy, Sweden and the United States. England replied that their members did not wish to reveal their views until just before the Congress. The proposed program was adopted unanimously by an *ad hoc* committee set up for this purpose under the chairmanship of E. A. Owen. However, when Owen presented the report to the Whole Committee, he attacked the *ad hoc* Committee's own conclusions, thus, reversing its stand. This created the impression that the other countries were opposed to the report rather than its being just an expression of the British position only. The principal point of contention was a rewording of the definition of a unit in accordance with the RSNA 1933 proposals which had been acceptable to the countries cited above. This resulted in an enormous amount of discussion and it was what led to the subsequent election of the Executive Subcommittee discussed above. The change eliminated much of the nationalism which had dominated the last three meetings of the Committee and materially strengthened the benefits of its decisions.

It might be noted that there were frequent comments about measurements, about energy absorbed or energy deposited or energy left behind in the region of interest, but there is no mention in the record, nor is there any in my own recollection, that Gray's cavity ionization theory had taken hold seriously even as late as 1937, at which time the last pre-war meeting of the Committee took place. I suspect that most of the comments, referred to as energy considerations, were to be considered as casual rather than towards proposing direct consideration of the question by the Committee.

Between 1934 and 1937, there was considerable action of record on the broad subject of radiation dosimetry. Two groups, in particular, were active, namely the British Committee on Radiological Units and the American Standardization Committee of the RSNA. The only records available are those of the latter group and these are included in the treatment, "X ray Measurements and Protection 1913-1964", (2) pages 60 to 68. Much of the attention here had developed over some concepts and proposals developed by C. C. Lauritsen and were primarily brought about because of his special interest in the so-called supervoltage radiation therapy. Actually, he was, in essence, proposing two new quantities and units for that but since these were never adopted they will not be dealt with here. On the other hand, the material in his correspondence and the replies he received raised interesting points of issue. Some of this was brought before the International Committee at its meeting in Chicago in 1937.

The meeting of the Committee in 1937 was the first one for which a program, including a draft report, had been prepared and reviewed in advance by the Executive Subcommit-

tee. For the first time, the Committee broadened its consideration of clinical dosimetric problems, and extended its range of radiation energies up to 400 kV for x rays and the gamma rays for radium.

The final report of the Committee included four main technical parts, plus an appendix and a set of operating rules for the Committee. These are highlighted below.

Section A. **Units.** The principal change from the earlier recommendations was the redefinition of the ions collected in a free-air standard ionization chamber. Specification of the ions collected was changed from a volume to a mass consideration defined as 0.001293 grams of air and reference to the total corpuscular emission therefrom.

Section B. **Dose or the specification of the conditions of x-ray treatment.** This was divided into three subsections: **Quantity, Quality** and **Techniques.**

Section C. **Dose or specification of the conditions of gamma-ray treatments.** It was also divided into three parts: **Quantity, Particulars of the Radium source** and **Techniques.**

Section D. **Instruments.** This covered both free-air standard ionization chambers as well as the clinically practical air-wall chambers and their calibration.

Section E. **Appendix.** This dealt with the symbols used for dose measured in air, on skin surface and at depths.

Section F. **Rules governing the selections and work by the International Committee on Radiological Measurements.** Among other things it introduced and used the acronym ICRU which will be used hereinafter.

The outbreak of war in Europe put a temporary end to the work of the ICRU and Taylor, as Secretary of the Executive Subcommittee held on to the pieces. He had already been asked to serve in the same capacity for the International Commission on Radiological Protection (ICRP).

In 1948 Taylor began to renew contacts with his European colleagues who had survived the war years – in particular Walter Binks, formerly at the National Physical Laboratory and W. V. Mayneord, both of whom had been very active in the area of radiation measurements and radiation quantities and units. In May 1948, Mayneord had sent Taylor advance copies of a study made by the British Committee for Radiological Units (BCRU) entitled "Memorandum on a measurement of ionizing radiations for medical and biological purposes" (BCRU/13, May 1948). Also, Dr. G. Failla had visited with the British Committee which further strengthened the liaison between the Committees from the two countries; it was unfortunate that at this period Germany, France, and Italy were all too concerned with the ravages of war to be thinking about these matters.

Unfortunately, the BCRU request for prompt reactions came at the very time that the Standardization Committee in the U. S. was being reorganized and shifted to the American College of Radiology. Thus, the real effort on studying the British Proposals fell to the National Bureau of Standards and to the members of the old Standardization Committee of the Radiological Society of North America, although they were not yet officially organized as a committee of the College.

The BCRU/13 document was six pages long (see NBS-625, pages 81-86) (4).

Without knowledge of the study underway by the BCRU, the *ad hoc* NBS group was conducting much the same sort of a study and in June 1948 prepared a paper entitled, "The roentgen and other physical units of radiation therapy." This group was made up of K. Corrigan, G. Failla, G. C. Laurence, H. M. Parker and L. S. Taylor (NBS-625, pages 87-90) (2). Again, without going into detail, it was obvious that this group was strongly of the opinion that it was necessary to move to energy per mass as the quantity of interest for basic measurements, but that certainly, for the time being, it would be necessary to have some quantity and unit that was familiar to the medical profession and at least could be carried on for the near future.

Preparation for the Next International Congress of Radiology: London, 1950.

It might be noted, although having only secondary interest to the technical dosimetric questions, that Mayneord and Taylor, who were to be involved in further discussions of radiation quantities and units, met in the United States in July 1948 to discuss plans for the upcoming International Congress of Radiology to be held in London in 1950. They had been asked to make plans, recommendations and arrangements for reconstitution of the ICRU and the ICRP. As it turned out, Taylor was the surviving secretary of the ICRU and had also been named acting secretary of the ICRP in a communication from Kaye in 1939 (Taylor, 1979, 7–205) (5).

There was considerable activity in both countries dealing with radiation standards and protection and the discussions between them are carefully documented in correspondence starting in 1948 and continuing right up to the verge of the Congress Meeting in July 1950. The differences between the British and American views were basically minor although there were a number of secondary points which had to be sorted out. All of this is covered in NBS-625, pages 73–107 (2) and need not be dealt with in any detail here.

It should be noted that during the Spring of 1949, L.H. Gray, who is credited with the practical philosophy of cavity ionizations, spent some time in the United States including some days at the NBS. As a result of this, a new memorandum was prepared by Fano and Taylor expressing their views together with those of Gray, Wyckoff and Taylor (6). The memorandum was forwarded to Mayneord and later to members of the newly reestablished ICRU.

The basic agreement and recommendation of this memo were briefly as follows: 1. The use of the roentgen as the unit of x and gamma ray quantity should be continued within those limits of radiation quality where it is practicable to meet the present definition, 2. for correlations of the dose of any ionizing radiation with the biological or other effects which it produces the fundamental principle shall be to express the dose in terms of the quantity of energy absorbed

per unit mass (erg/g) of the material irradiated at the place concerned, and 3. a series of notes needs to be provided indicating the kinds of further information that will be required to translate ionization measurements to measurements of ergs/g.

Final summaries of the discussion that had been taking place over the previous two or three years were set out in memos from Gray to the BCRU which included a memo from Fano outlining his comments on the errors in the determination of energy absorption from x rays. Copies of this exchange were sent to all of the individuals expecting to participate in the forthcoming meetings of the ICRU.

Final correspondence included a memo from Failla calling attention to the possibility that the stopping power of a substance might be different in the gaseous or solid or liquid phase. If this proved to be true, the Bragg-Gray relation would become untenable. Final documentation included Gray's more detailed response to Failla's point and to Fano's memorandum of May 1949. The discussions essentially closed with a note that during this period of discussion, the paper by Fano and Taylor, "Dosage units for high energy radiation", was published (6).

This essentially brings us up to the meeting of the new ICRU at the 6th International Congress of Radiology in London, July 1950. From this point on, reliance may be placed in the records of the Commission Meetings. For the first time, they will have been kept in substantial detail and reported to the members. In general it may be said that the published reports of the commission for the most part, constitute adequate records of their proceedings.

The London Meeting, 1950

We turn now to the ICRU Meeting in 1950. Operating temporarily under the old rules, the Commission meeting in London was under the chairmanship of the host country from which W.V. Mayneord was chosen. Taylor continued as secretary.

As could be reasonably expected, by this time, the ICRU in its 1950 report made it clear that all efforts were to be aimed in the future toward the development and acceptance of a system of radiation dosimetry based on energy absorbed per unit mass of irradiated material at the place of interest. It was obviously impossible in the course of a one-day meeting of a newly organized ICRU to be more specific. Basically, the 1950 report was a complete revision of Section A of the 1937 report and the temporary retention of Sections B through E of the old report (7).

Important changes were made in Section F covering the rules governing the selection and work of the ICRU. Among these it was specified that the new Commission would be composed of not more than 12 members and a chairman, the members being chosen on the basis of their recognized activity in the field of radiological units and standards, without regard to nationality. With the smaller and more compact committee, there was no further need for the Executive Subcommittee. The remaining rules were much the same as had been adopted in 1937.

The 1953 Meeting of the ICRU

The next meeting of the ICRU took place in Copenhagen during the week preceding the opening of the 1953 Congress. This was a useful innovation that was shared in by the ICRP. Each group met for a period of three days, thus permitting ample time and opportunity for thorough discussions of the problems before it.

With the preparation that had taken place, as evidenced by the discussions from 1948 through the Congress in 1950, it was clear that the ICRU was prepared and ready to make the definitive change from the quantity of radiation as measured by the roentgen, to absorbed dose as the amount of energy imparted to matter per unit mass of material for which the new unit would be the **rad.**

The term rad was simply suggested as a word by itself. Since then it has frequently been improperly referred to as an abbreviation for "radiation absorbed dose". This is simply incorrect.

As before, the Commission completely redid what had been Section A of its report, making it into a new Section I on definitions and units. The remainder of the earlier report contained minor changes which are not of significance as far as the philosophy of dose measurement was concerned.

Section I of the 1953 report is reproduced below.

There was a further innovation in the 1953 meeting of the ICRU and this was the introduction of a full day's session for the presentation of invited papers dealing with questions under discussion by the Commission. Those presented at the Copenhagen meeting have been published as Supplement 117 of the Acta Radiologica and deal with roentgen ray standards, radioactivity standards and basic information needed for the measurement of absorbed dose.

Conclusion and Outlook

We thus have gone from the earliest attempts at radiation dosimetry beginning as far back as 1900 and traced the rather tortuous path (as seen in hindsight) that was followed before reaching what was obviously the most logical conclusion, namely the expression of radiation dose in fundamental units. However, we should not be too critical of ourselves. If one studies the various papers, particularly those prepared by organized groups working in this field, over the past 80-odd years, it will be recognized that there was repeated reference directly or indirectly, to the concept of energy transfer or energy measurement. The normal scientist would certainly direct his attention along those lines to an extent compatible with our capability for making the necessary measurements. Obviously this capability did not exist in the early days. The nearest approach might have been some of the efforts to make calorimetric measurements of x-ray beams. However, only the most powerful beams could produce any effect that could be measured calorimetrically even under the most highly sophisticated laboratory techniques. The whole process of energy transfer, ionization and so on have been steadily evolving and while we no doubt think ourselves quite smart as of today, I have no doubt that important evolutionary changes may be looked for in the future.

RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL UNITS

REVISED AT THE SEVENTH INTERNATIONAL CONGRESS OF RADIOLOGY, COPENHAGEN, DENMARK, JULY, 1953

I. DEFINITIONS AND UNITS

1. *Intensity of radiation* is the energy flowing through unit area perpendicular to the beam per unit time. It is expressed in ergs per square centimeter per second or watts per square centimeter.

2. *Quantity of radiation* is the time integral of intensity. It is the total energy which has passed through unit area perpendicular to the beam and is expressed in ergs per square centimeter or watt-seconds per square centimeter.

3. *Absorbed dose* of any ionizing radiation is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It shall be expressed in *rads*.

4. The *rad* is the unit of absorbed dose and is 100 ergs per gram.

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

$$E_m = W S J_m$$

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

6. Since the calculation of the absorbed dose from measurements of ionization requires a knowledge of the parameters W and S as well as variables characterizing the radiation and the irradiated material, it is recommended that tables of the best available data be prepared and held under continual review.*

7. The roentgen (r) remains the unit of X- and γ-ray dose and its definition remains unchanged as below:

> *The roentgen* shall be the quantity of X- or γ-radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign.

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

9 *Integral absorbed dose* is the integration of the energy absorbed throughout a given region of interest. The unit is the *gram-rad*. 1 gram-rad = 100 ergs.

10. Amounts of radioactive material shall be expressed in curies. The accepted definition of the curie is:

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

With this definition the curie is independent of the disintegration rate of radium.

11. It is suggested that the γ-ray emission be expressed in terms of roentgens per millicurie-hour at 1 cm. from a point source. This quantity is different for every isotope. Preliminary data have been compiled relating to a number of radioactive isotopes and will be supplemented from time to time.*

12. The International Commission on Radiological Units requests the national standardizing laboratories to set up, interchange and compare standards of X-rays, γ-rays and radioactive isotopes, maintain close contact with each other, and generally by every means within their power further the improvement of methods of standardization.

* Preliminary reports on this subject were presented to the Commission and it is hoped will be published in the near future.

Fig. 1 Section I of the 1953 ICRU Report

References

1. Taylor, L.S. (1932). International Comparison of X-ray Standards. Radiology, **18**, 99.

2. Taylor, L.S. (1981). X-ray Measurements and Protection No. 625.

3. Parker, H.M. in Taylor (1981), pgs. 283–287.

4. See Taylor (1981), pgs. 81–86.

5. Taylor, L.S., (1979). Organization for Radiation Protection, 7–205, Nat. Tech. Info. Serv. Springfield, VA 22161.

6. Fano, U. and Taylor, L.S. (1950). Dosage Units for high-energy radiation. Radiology, **55**, 743.

7. Taylor, L.S. (1951). Recommandations of the International Commission on Radiological Units (London, 1950). Am. J. Roentg. and Radium Therapy, LXV, 99.

Image Perception: The Problem as Perceived by the Radiologist*

Ian Isherwood
University of Manchester
Department of Diagnostic Radiology
Manchester M13 9PT, U.K.

The process of radiological diagnosis is a complex one; it begins with the patient, and is completed by a management decision. The process traditionally has relied on a combination of educated observation, experience, and logical analysis. Radiological images, whatever their derivation, still rely heavily for their interpretation on clinical judgement and interpretation of morphological features. The ability to locate disease before structural change becomes apparent, to stage disease accurately, to detect early response and end points in treatment, and to identify relapse during apparent clinical remission, would be major advances.

The radiologist of today is a clinician concerned with all aspects of investigative imaging, from conventional radiographs to the exploration of cellular metabolic processes, and with interventional procedures. No longer is it necessary or even appropriate in some circumstances for biological events to be recorded pictorially. The display may be entirely numerical, graphic or spectral. Increasingly, the analog image is derived from digital data. As Stephen Daedalus in Ulysses says "Signatures of all things I am here to read". The construction of diagnostic strategies from an increasing range of imaging and interventional methods; the selection of optimal display formats and the translation of visual information into language are equally important factors in the radiologist's perception of the image.

The basic challenge for the radiologist has always been to represent a three-dimensional patient on a two-dimensional surface. The problem of course is not new. Many artists, have used interposition, perspective and shadow to great effect, and in doing so illustrated the limitations of the x-ray shadowgram and the underlying paradox of flat retinal images as representations of reality. The image is part of our world of objects and yet simultaneously represents the three-dimensional objects it portrays. The radiologist needs to understand both the properties of the object (the patient) and the imaging method.

In normal vision the eye perceives areas and spatial frequencies which neurones code for brightness and edges from the retina through to the visual cortex. Indeed much of the information used by the eye can be contained in edges. Uncontoured border contrast, on the other hand, can often be detected by the Mach effect. The pointillism of Seurat also provides such a linear contour illusion. By emphasising the appropriate spatial frequencies the same effect can be seen in radiological images. Even when the retinal image is constant perception can be ambiguous. The Epinal pictures created by Pellerin in 1756 conceal a facial contour in the edge of a vase. In a contour image of the barium filled stomach can one be sure that an ulcer crater is projecting from the wall or embedded in it?

Some image features are recognised very quickly, largely on the basis of having seen them before. Others require a more complex inductive reasoning process, testing clinical and scientific hypotheses until an acceptable result is achieved. The first, a cognitive approach, assumes a global response based on memory and immediate recognition of salient boundaries or colours within the duration of one eye fixation, about 200 milliseconds, followed by a scanning routine where the mental spotlight is moved from one location to another. A number of studies have examined the eye movement patterns of radiologists and untrained observers, but it remains unclear whether eye movements lead or follow perception. The alternative complex inductive approach is much more to do with information processing.

Some prominent image features are immediately discarded by a trained radiologist as benign, safe and irrelevant. Others, though apparently trivial, command great significance, for example, microcalcification in the breast as a feature of malignancy. The ability to recognise and interpret such features is of importance, not only to the patient but also to the effectiveness of population screening programmes where negative biopsy rates need to be low. Features can be camouflaged but eventual recognition instantly alters perception. Once recognised diagnostic features are then usually perceived correctly.

Ultrasound does not use ionising radiation, is relatively inexpensive, highly mobile, but operator dependent. Real time ultrasound is an excellent screening method for abdominal disease and of great value in guiding biopsy needles and drainage tubes. Intraluminal and peroperative probes are already available. Doppler signals with colour coding are now providing quantitative information about blood flow.

Nuclear Medicine is concerned with functional imaging. Anatomical detail is a secondary issue. Radionuclides of ever widening pharmaceutical range can be administered to the patient by almost any route and their activity recorded from relevant functioning pathways. The identification of osteoblastic activity and the assessment of regional cerebral blood flow are examples. PET is a powerful extension of the

*The following paper was presented at the ICRU Symposium on Image Perception at the International Congress of Radiology 1989. The Symposium was chained by Professors Mallard and Isherwood, and opened by Professor Isherwood with this general introduction of the problem of image perception as perceived by the radiologist.

technique, capable of providing quantitative clinical imaging of detailed cellular biochemistry. Current exploration of neuroreceptors in psychiatric disorders holds promise for more precise structural and functional correlations.

Perhaps the most significant paradigm shift in radiology occurred as a consequence of the introduction of Computed Tomography in 1973. CT, providing quantitative information about uniformly thin slices of tissue and at the same time offering a wide dynamic range, introduced the concepts of digital data acquisition, interactive displays and powerful image processing systems to in vivo biological activities. Kelvinistic metrics had hitherto been confined to the laboratory. A variety of analytical approaches, based on the attenuation properties of small volumes of tissue, have been explored to enhance clinical and radiological judgements. Attempts to characterise tissue histologically have had limited success, though the ability to measure bone mineral, particularly with dual energy techniques in both axial and appendicular skeleton, has been of significant value. Multiplanar reconstructions of numerical data in alternative planes are routinely exploited. Three-dimensional imaging has offered new opportunities to analyse complex thin section data, particularly with rapid low dose techniques and the use of intravenous contrast media to outline intracranial vascular structures.

Temporal and energy subtraction are currently used to exploit the differences in attenuation properties between iodine and surrounding tissue in digital vascular imaging. Both have limitations, the one by movement and the other by the availability of photon flux and the polychromatic nature of the x-ray beam. Synchrotron radiation may provide a new source of monochromatic x rays, the energy of which can be finely tuned to the K edge of iodine. The challenge would be to reduce high energy storage rings to hospital proportions.

Nuclear Magnetic Resonance as a means of observing the magnetic properties of selected atomic nuclei has been of scientific interest for over fifty years. Magnetic Resonance Imaging of proton distribution has the advantage of multiplanar representation and an absence of ionising radiation. Variations in contrast and tissue discrimination can be achieved by exploiting the wide range of tissue parameters, including proton density, relaxation times, chemical shift, flow, diffusion, perfusion and magnetic susceptibility, with a variety of radiofrequency pulse sequences. Conspicuity of disease can also be influenced by the use of contrast agents, including the paramagnetic Gadolinium-DTPA which acts by reducing T_1 and T_2 at target sites. Relaxation time measurements have been used to explore tissue structure in defined regions of interest with some success. Recently more sophisticated analytical methods based on texture of T_1 maps have significantly improved the discriminatory ability of these measurements.

Magnetic Resonance Spectroscopy of other nuclei, though presently limited by problems of localisation and resolution, nevertheless holds promise as a sensitive analytical measure of biochemical and metabolic activity.

The radiological paradox now seems to lie in the relationship between the pictorial image and the wealth of digital, biochemical and metabolic information contained within it. The quantity and complexity of information available poses real problems of selection, perception, transmission and storage. It seems clear that we have to explore in much greater depth the interface between the human observer and intelligent knowledge-based systems if we are to optimise the clinical effectiveness of the imaging methods now at our disposal. In the meanwhile the quest for improved precision and accuracy is complicated by the opportunities which non-invasive methods offer to investigate both the sick and the healthy, raising new ambiguities about the perception of normality.

"Everything possible to be believed is an image of the truth", said William Blake, but perhaps Pasternak perceived our real problem.

"What is laid down, ordered, and factual, is never enough to embrace the whole truth. Life always spills over the rim of every cup."

Hyperthermia: The Problem of Clinically Meaningful Dose

George M. Hahn
Stanford University, School of Medicine
Department of Radiation Oncology
Stanford, CA 94305-5468, U. S. A.

Introduction

The concept that increasing body temperature has healing powers is hardly novel. Roman and Greek physicians, and probably others before them, commented on the association of fever with the healing process. This has led to a hypothesis, one that persists and perhaps has found some verification in modern times, namely that fevers are beneficial and have a role to play in permitting the body to conquer disease. While even today only a few studies exist that really support such a concept, we are quite sure that very high fevers (> 42°C) can have dire and even fatal consequences, illustrating the limited temperature range that is consistent with the survival of complex organisms such as man.

The application of elevated temperatures to treat cancers also goes back many years. Illustrations exist dating from the Middle Ages that show attempts to treat localized tumors by the application of extremely hot metallic objects - red-hot swords, in fact. It is not clear whether physicians applying these devices were truly concerned with benefitting their patients, and certainly dose concepts (time and temperature of application) were not uppermost in their minds.

Today, of course, we are in a quantitative age. Furthermore, the rational basis for the use of hyperthermia in the clinic rests not only on anecdotal tales but on results from precise studies performed on cells and on experimental tumors. The clinical data available today indicate quite strongly that the combination of heat and radiation therapy is superior to radiation therapy alone in those tumors that can be heated. What constitutes adequate heating, and the associated problem of quantifying the biological effect caused by the heating, is one of the major areas of controversy in hyperthermia. While physical quantities such as temperature and time of treatment are readily measured, their relationship to biological result is very complicated. Yet it is clear that if protocols for hyperthermia treatments are to be standardized so that intercomparisons of clinical data from different institutions are to be accomplished, a unified dose concept that relates measured quantities to clinical outcome appears to be essential. Yet to date, no generally accepted unit of dose has been established (1). In my short and abbreviated discussion, I will indicate some of the biological effects of hyperthermia, concentrating on those that demonstrate the difficulty of defining a biologically and clinically relevant unit of hyperthermic dose.

Cell Survival at Elevated Temperatures

All current cancer treatments concentrate on eliminating as many malignant cells as possible without excessively impairing vital normal tissue. Hyperthermia is no exception; it also kills cells. For localized heating, it is the response of the normal tissue within the heated volume that limits the temperature and/or duration of treatment. In whole body heating, obviously it is the most heat-sensitive organ that constitutes the treatment-limiting normal tissue. Because of variable normal tissue tolerances, localized heating can often be carried out at temperatures that may reach as high as 50°C in parts of some tumors. Whole body hyperthermia, on the other hand, is limited to temperatures somewhat below 42°C.

Parametric Studies of Variables that Influence Cell Survival In Vitro

Most survival curves of cells in tissue culture are obtained under what might be called standard conditions: Cells are supplied with sufficient nutrients and oxygen, growth temperature is at 37°C and pH approximates that of most normal tissue (7.4). These are not, however, the conditions that prevail in the interiors of many tumors. There, nutrient and oxygen exist only in limited supply, and pH is frequently well below that of normal tissue. The combination of these factors makes cells more heat sensitive. Even the growth temperature may vary, depending upon the location of the tumor and its available blood supply. All these variables can modify appreciably the survival kinetics of mammalian cells (2).

Even under standard conditions, however, considerable variability is encountered. This is illustrated by the survival of cells from one murine (RIF-1) and one human (HT 1080) fibrosarcoma exposed to temperatures in the clinical hyperthermic range. For both these lines, little cell killing is achieved at temperatures below 43°C; for the mouse cells, the survival curves become steep at 43°C and moderately steeper at higher temperatures. This behaviour, *i. e.*, a "break" or transition point at about 43°C is typical for all rodent cell lines that have been examined. In the human cell line, the general pattern is qualitatively similar, but the cells are more heat resistant at all temperatures and the change in survival kinetics occurs at 44°C or perhaps even higher. It is now beginning to be recognized that most human tumor (and normal) cells tend to be more resistant in culture than are mouse cell lines, and that the transition point may differ from cell line to cell line. For example, in a series of human cell lines examined in three laboratories, the transition temperature for thermal survival varied between 42 and 44.5°C (3). I am dwelling on this point because a proposed "biological dose" is based on this behavior (see "43°C equivalent minutes") (1). The survival picture is further complicated by the observation that for a given cell line, both the absolute sensitivity and the pattern of the transition temperature depends upon the cells' past history. This is illustrated in Table 1, where I've shown survival results for Chinese hamster cells treated by two protocols. These differ only in the order of treatments (1 h at 41°C and 15 min at 45°C). For comparison, Table 1 also includes the theorethical survival that would be expected if the two treatments were independent. Clearly that is not the case. Treatment at 41°C followed by 45°C leads to protection ("thermotolerance"), while the opposite protocol leads to sensitization ("stepdown heating"). These protocols are not really indicative of what happens in actual treatment; they were designed to illustrate the overwhelming effects that thermal history may have (3).

Table 1

Cell Survival

	Theoretical	20 min at 45°C followed immediately by 1 h at 41.5°C	1 h at 41.5°C followed immediately by 20 min at 45°C
1 cycle	5×10^{-2}	3×10^{-4}	5×10^{-1}
2 cycles	2.5×10^{-3}	$\sim 10^{-6}$	2×10^{-1}
3 cycles	1.25×10^{-4}	$\ll 10^{-6}$	8×10^{-2}

Column 1 shows the calculated survival that would be expected if survival were independent of thermal history; columns 2 and 3 show measured survival. Column 2 indicates the sensitizing effect of step-down heating; column 3, the protective effect of thermotolerance. Note that the physical dose (absorbed energy) is the same for columns 2 and 3 (G.M. Hahn, unpublished data).

Combination of Hyperthermia with X Rays or with Chemotherapeutic Agents

Hyperthermia enhances the effectiveness of many anticancer agents (1). Perhaps of greatest interest is the more than additive cell killing resulting from the combination of x rays and heat. To demonstrate such an interaction, the two treatments need to closely follow each other. For example, the cytotoxicity of x rays becomes appreciably increased if the cells are heated at 43°C for 1 h either immediately before or after irradiation. The dose modifying factor in this case is about 1.4. Heat can also enhance the antitumor effect of many drugs. Enhancement of drug cytotoxicity tends to follow two patterns. For some drugs even modest increases of temperature appreciably enhance the cytotoxic effects of the drug. This is true for the drugs such as BCNU and cisplatinum, and for other alkylating agents. For other drugs, there appears to be a threshold in sensitization. An example of this is the glycoprotein bleomycin. Between 37 and 41°C, there is only very modest enhancement of cytotoxicity; at 43°C and above, this drug suddenly becomes much more effective in killing Chinese hamster cells. The effectiveness of some other drugs, such as methotrexate and most other analogs, is not enhanced at hyperthermic temperatures; thermotolerance actually protects cells against adriamycin, actinomycin D and some other agents. It is important to note that the pattern of heat-induced sensitization does not necessarily mirror that of cells killing. This further complicates the definition of heat dose.

Heating Modalities

Heating of localized human tumors is carried out either by introducing the heating device directly into the tumor (interstitial heating) or by having one or more radiators or electrodes placed externally to the body or inserted into a body orifice (external heating). Interstitial heating can be achieved either with electromagnetic techniques, either at microwave or lower frequencies, or by conduction or by a combination of the two. External heating can also be done utilizing electromagnetic techniques, but ultrasound offers an alternative. The physics involved in equipment development can, at times, be quite complicated. Each of the techniques has its advantages and disadvantages, and I don't propose to discuss these in detail. There is now commercial equipment available in all the categories mentioned. None of these devices can adequately heat all tumors by external means. This is even true for superficially located lesions, particularly if these exceed a few cubic centimeters in volume. Heating is nonuniform even under the best of circumstances. A major problem is blood flow. Blood is a highly efficient coolant: near major blood vessels, the tumor temperature tends to approach that of the incoming blood, rather than that of the heated tissue. Because blood flow is nonuniform and, with current techniques cannot be mapped, it is impossible by treatment planning to compensate for blood flow variations. While feedback techniques can be used to some extent to overcome localized temperature changes, limited control over deposition of energy as well as our current inability to measure temperature with noninvasive techniques limits the usefulness of feedback techniques.

Whole body heating is achieved in a variety of ways that range from extra-corporeal heating of blood, to conduction, to use of various electromagnetic techniques.

What is an Appropriate "Dose" for Hyperthermic Treatments?

Several types of dose have been considered for hyperthermia. These are based either on physical or biological concepts. The former are of more interest to the engineer or physicist; the latter for the clinician.

Physical Dose

Electrical (or Acoustical) Characteristics of Radiation Devices

The most obvious characterization of a device would be to determine the spatial distribution of electromagnetic (or acoustical) intensities measured either in free space for electromagnetic devices or in a water tank for ultrasound. Such characterization is not useful for hyperthermia. The reason is that absorption of energy by tissue considerably modifies free space or water tank patterns. Further, such absorption is highly frequency-dependent, both for radio EM and US waves, and to a lesser degree, varies from tissue to tissue. Therefore, free space data or water tank data have only limited usefulness.

Specific Absorption Ratio (SAR)

If tissue is to be elevated in temperature, then energy must be absorbed in (or near) that tissue in order to effect the temperature rise. Therefore, it seems reasonable to use absorbed energy per unit volume of tissue as dose. Such a dose description would be similar to the dose unit used in radiation therapy, *i. e.*, the gray, which is of course also defined in terms of absorbed energy. SARs can be measured in a tissue phantom whose electrical or acoustical characters match those of specific tissue. Indeed, from the point of view of equipment design, the characterization of an antenna or ultrasound transducer in terms of SAR is probably the best method of doing so. Changes of SAR with tissue depth are of particular interest since these determine the depth to which tissue can be heated without overheating the tissue surface areas.

"Biological Dose"

Unfortunately, biological responses are not determined by SARs, but by the ultimate temperature distribution resulting from energy deposition, from conduction of heat within the tissue, and from convective cooling owing to blood flow. In addition to spatial variations, blood flow frequently changes during treatment, thereby introducing temporal changes. This means that even if the SARs are known precisely over the tumor volume and its surroundings, temperature distributions are not necessarily predictable. These must therefore be measured continually during treatment. This is done via the insertion of multiple measuring devices, usually thermocouples.

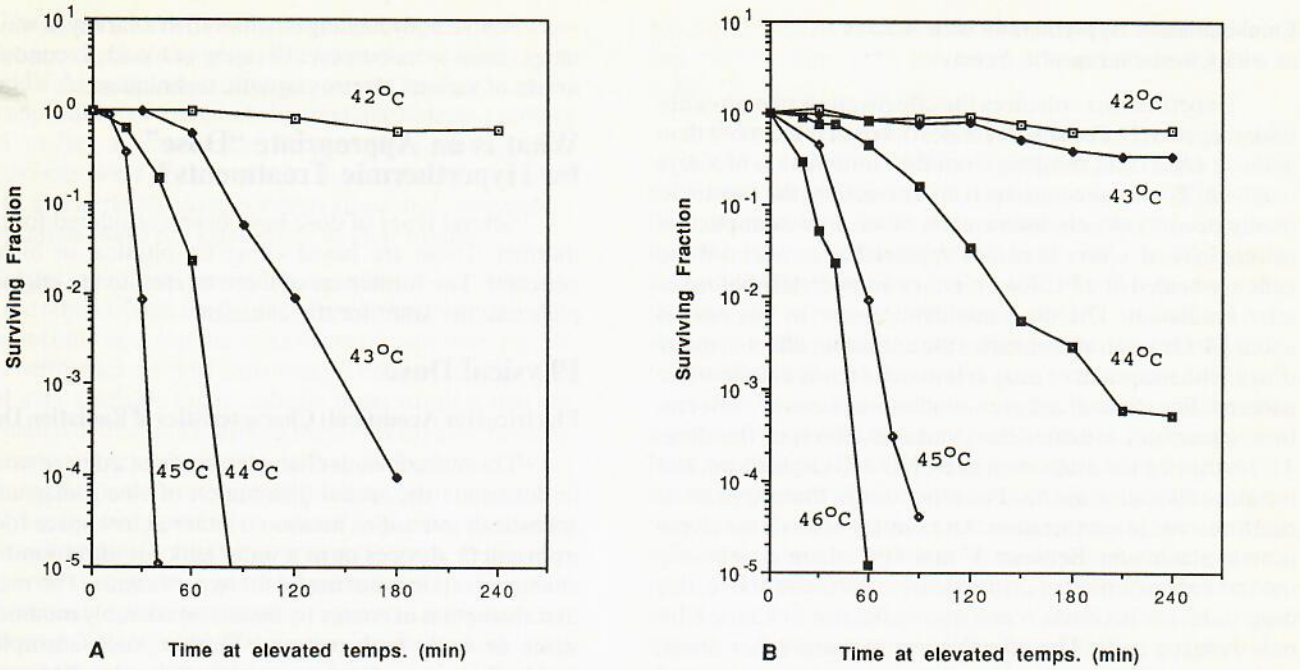

Fig. 1 Survival of cells from a mouse and a human fibrosarcoma. Panel A: mouse RIF-1 cells. Panel B: human HT 1080 cells. Note the greater heat resistance of the human cells at all temperatures and the difference in transition temperatures (approx. 42.5°C for RIF-1 and 44°C for HT 1080).

If cell killing or heat-induced radiosensitization were linear with temperature (or with rise in temperature), then a map of time-averaged temperature would give a good description of the efficacy of the treatment. However, as we have discussed earlier, neither cell killing by heat nor radiosensitization is linearly related to temperature. As a result, time averaging of temperature without introducing appropriate weighting to compensate for nonlinearities yields a quantity that may bear no relationship to biological effect. Similarly, a temperature map is not necessarily a linear measure or indicator of biological effect. For this reason, time-temperature products (or products of time and temperature differentials) are not necessarily units of dose. They can be used as treatment descriptors but may be quite misleading if considered as dose indicators.

"43°C Equivalent Minutes"

A very interesting attempt to define dose exclusively in units of time is based on data such as the survival curves of Fig. 1 (and on other data that quantify biological effects as a function of temperature) (6). The idea is to eliminate temperatures as a key variable. This is done by expressing the effects of treatment at an arbitrary temperature in terms of the time required to achive an iso-effect at a reference temperature.

An examination of Fig. 1 shows that above the transition temperature a simple relationship holds: for each increase of temperature by 1°C, the treatment time needs to be reduced by a factor of 2 in order to achieve an iso-effect of cell killing. This leads to the simple relationship $t_1 = t_2 R^{(T_1-T_2)}$, where t_1 and t_2 are two treatment times to achieve iso-effects at temperatures T_1 and T_2 respectively. If we take T_1 as a reference, then the equivalent number of "reference minutes" to convent t minutes at temperature T to t_{REF} is $t_{REF} = tR^{(T_{REF}-T)}$. In addition, if T is time dependent, then $t_{REF} = \int_0^t R^{(T_{REF}-T)}dt$. This formulation works very well for tissue culture cells. For previously unheated murine cells, R = 0.5 above 43°C, and 0.15–0.25 above 43°C. 43°C is usually used as reference temperature, hence the term "43°C equivalent minutes". Problems arise when one tries to apply this concept to the treatment of human tumors. Although the values of R are still more or less appropriate, the transition temperature varies from tumor to tumor; for some human tumor cells, it is as high as 44.5°C. Therefore, it is not known what reference temperature to use; also, the value of R for treatment below the transition temperature is not clearly established and development of thermotolerance or step-down heating may change both the transition temperature and the value of R. The temperature regions where this situation may cause the most difficulty (*i. e.*, the uncertainty in equivalent minutes be greatest) is between 42–44°C, precisely the range in which most hyperthermia treatments are carried out.

I have only discussed cell killing by heat. Even less is known about an appropriate "dose" for heat-inducted radiosensitization for human tumors; essentially nothing is known about thermal heat "dose" for thermochemotherapy. It is extremely unlikely that 43°C equivalent minutes would be useful for drug-heat treatments.

Conclusions

Hyperthermia is progressing in an ad hoc manner as a useful clinical modality in the treatment of cancer, particularly in conjunction with radiation therapy. As additional centers offer hyperthermia to their patients, it becomes more and more important to standardize treatments. Yet, as my short article has indicated, such standardization is far from easy. Current dose concepts are only initial steps towards developing descriptors that have direct clinical meaning. Accurate statistical comparison of various treatment parameters will only be possible once these descriptors have been found. At the current time, it is probably wisest to specify the time-temperature distributions, both spatial and temporal, within tumors. While these are not necessarily a direct measure to biological effect, they are sound physical parameters, and they do not provide what may be a false sense of security based upon single parameters, such as 43°C equivalent minutes.

References

1. Overgaard, J. (1987). Int. J. Hyperthermia **3**, 326–336.

2. Hahn, G.M. (1982). Hyperthermia and Cancer, Plenum Press.

3. Raaphorst, P., Li, G.C. and Hahn, G.M. Letter to Editor, Int. J. Hyperthermia (in press).

4. Hahn, G.M. unpublished.

5. Sapareto, S. (1987). Int. J. Hyperthermia **3**, 297–305.

6. Sapareto, S. and Dewey, W. (1984). Int. J. Radiat. Oncol. Biol. Physics **10**, 787–800.

Spectra of Secondary Electrons from Electron and Proton Collisions

M. Eugene Rudd
University of Nebraska
Dept. of Physics and Astronomy
Lincoln, NE 68588-0111, U. S. A.

When energetic charged particles traverse matter, several processes such as ionization, excitation, and charge transfer occur which contribute to the energy loss of the primary and to energy deposition in the target. At medium and high energies, the most important of these mechanisms of energy transfer is that of ionization, *i. e.*, the ejection of electrons from the atoms or molecules of the target. Furthermore, if these secondary electrons have enough energy, they may, in turn, cause further ionization. In order to make a detailed model of the energy deposition by fast particles, it is necessary to have a knowledge of the energy spectrum of the secondary electrons from such collisions. Progress, both experimental and theoretical, has been made over the past 25 years in this area and in the last six years several semi-empirical models have been developed. Therefore, we are at the point where reliable electron spectra can be calculated for most of the simple atomic and molecular targets such as the rare gases, the atmospheric gases including water vapor, some of the hydrocarbon molecules, and a few other targets. The spectra are generally presented in the form of differential cross sections. These are proportional to the probability per unit energy range for ejecting an electron of a given energy.

In the case of electron impact, the measured spectrum of electrons results from both secondary electrons and the scattered primary electrons which have lost energy. If T is the primary energy and I the binding energy of electrons in the target, the spectrum of electrons involved in ionization extends only up to an energy T-I and, for a single-shell target, it must be symmetric about the energy $(T\text{-}I)/2$. This is because for each electron ejected with an energy W, there must be a primary of energy T-W-I. Figure 1 shows a somewhat idealized version of the observed spectra from hydrogen gas for several different primary energies.

If the target atom or molecule has electrons of more than one binding energy, *i. e.* different shells, then there is a contribution from each shell with its own high energy cutoff. When added together the result is no longer symmetric but has a discontinuity for each inner shell as shown in the example of Fig. 2.

For proton impact, the secondary electrons follow a continuous fall-off which changes smoothly from a $(W+I)^{-3}$ to a $(W+I)^{-2}$ dependence up to a cutoff energy at approximately $W_C = 4T-2(IT)^{1/2}$ where now $T = m_e v^2/2$, with m_e the electron mass and v the proton velocity. Above W_C the spectrum falls off approximately exponentially. Examples of electron spectra from hydrogen are shown in Fig. 3. As the primary energy decreases, the cutoff comes at a lower energy, becomes less pronounced and eventually the exponential section above the cutoff dominates the entire spectrum. This is shown in Fig. 4. In Fig. 5 one may see how the contributions of the various shells combine to make the total spectrum for the case of proton collisions with argon atoms. While the weakly bound outer shells contribute most of the cross section at the lower secondary energies, the inner-shell contribution becomes dominant at high energies.

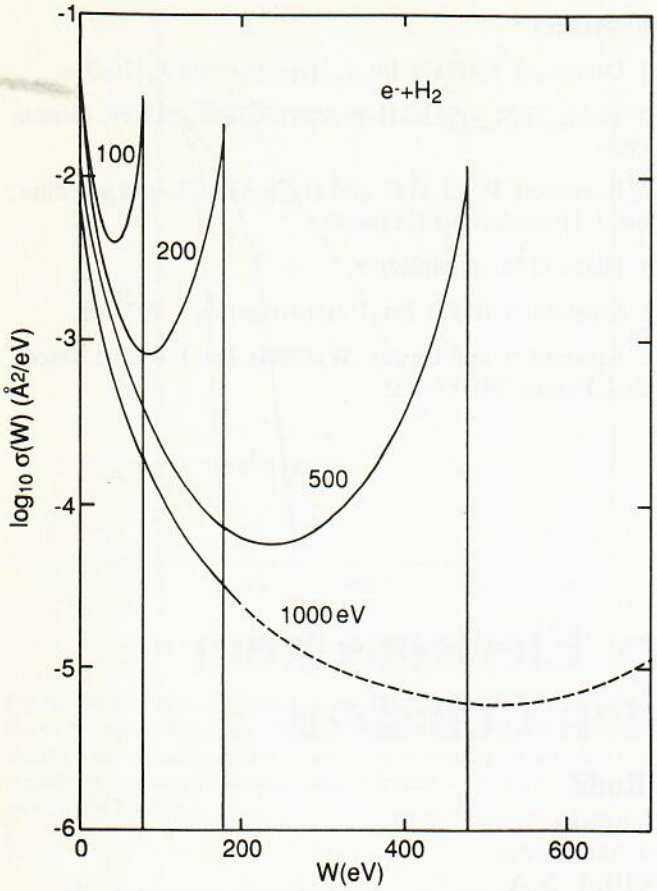

Fig. 1 Spectra of electrons from collisions of electrons of various primary energies with hydrogen gas. *W* is the energy of the detected electron.

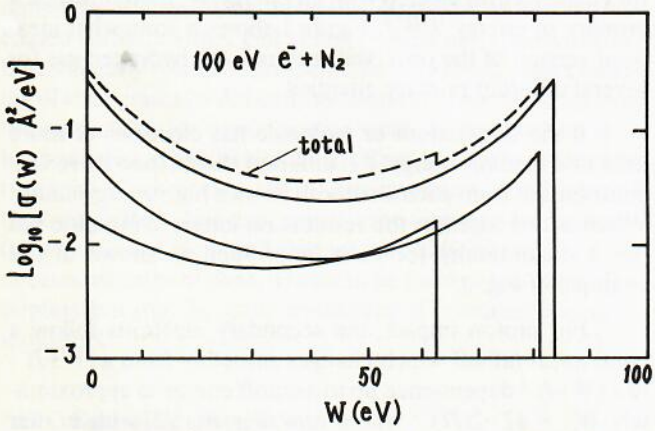

Fig. 2 Spectrum of electrons from 100 eV electron collisions with nitrogen. Contributions from three shells are shown as solid lines and the total shown as a dashed line.

The most advanced and accurate theoretical treatment of such collisions is quantum mechanics, usually using the Born approximation. Unfortunately, this method requires accurate knowledge of initial- and final-state wave functions, information which is available only for the simplest atomic systems. Furthermore, this method involves a rather extensive calculation to obtain the cross section for even a single combination of primary and secondary energies. To make matters worse, it is accurate only for velocities of the primary particle which are considerably greater than the orbital velocity of the tarrget electrons. This restricts its usefulness to primary energies above about 200 keV for protons and 100 eV for electrons.

Fortunately, there are alternatives for investigators needing such cross section data as input for energy loss and similar calculations. This is the use of semi-empirical models. One such model was developed by John Miller and co-workers (1)-(5) at Battelle Pacific NW Laboratories in Richland, Washington. In this approach, use is made of the fact that a separation may be made into soft- and hard-collision contributions to the cross section. Through the application of the Bethe expansion of the Born approximation, a relationship can be established between the soft-collision portion and the differential optical oscillator strength for that particular target. Since accurate values of such oscillator strengths have been measured for many targets, that data may be used to compute the major portion of the cross section. The hard-collision component is obtained by a combination of experimental data and a classical calculation. Miller has used this model for both proton and electron collisions but, again, it is useful only at high energies.

Another model, developed by the present author for proton impact, Rudd (6), (7), makes use of the fact that to a good approximation the cross section per electron depends only on the primary energy, the secondary energy, and the binding energy of the electron. The binding energies of electrons in various shells have been determined by spectroscopic and x-ray methods and are available for many targets. By combining two treatments, one for high and the other for low energy collisions, a single simple expression was obtained which gives the secondary electron spectrum at any primary energy in terms of three parameters in addition to the binding energy. One of these parameters turns out to be a constant, independent of the primary energy. The other two parameters can be expressed as analytical functions of the primary proton energy. The parameters of these expressions have been determined from experimental data for about 10 of the common target gases. A very simple computer program then suffices to give the entire spectrum of secondary energies for any given primary energy from a relatively small number of target parameters. This model yields results which are within 10-20% of the average experimental values for all primary energies for which data are available. This is generally the range of 5 keV to 5 MeV. It has also proven to be accurate for impact of bare ions as heavy as neon at 5 MeV/u.

A review paper on differential cross sections for proton impact by M. E. Rudd, Y.-K. Kim, D. H. Madison, and T. Gay, which is in preparation, will supplement an earlier paper (8) on total ionization cross sections. This paper will review all of the known experimental data, discuss experimental and theoretical techniques, give semi-empirical models, and present recommended values for the cross sections by listing the parameters in the model mentioned above. A somewhat more ambitious review of secondary electron spectra has recently been commissioned by the ICRU which will include all atomic projectiles and, to the extent that data are available, will cover solid targets as well as gaseous ones. Additionally, the

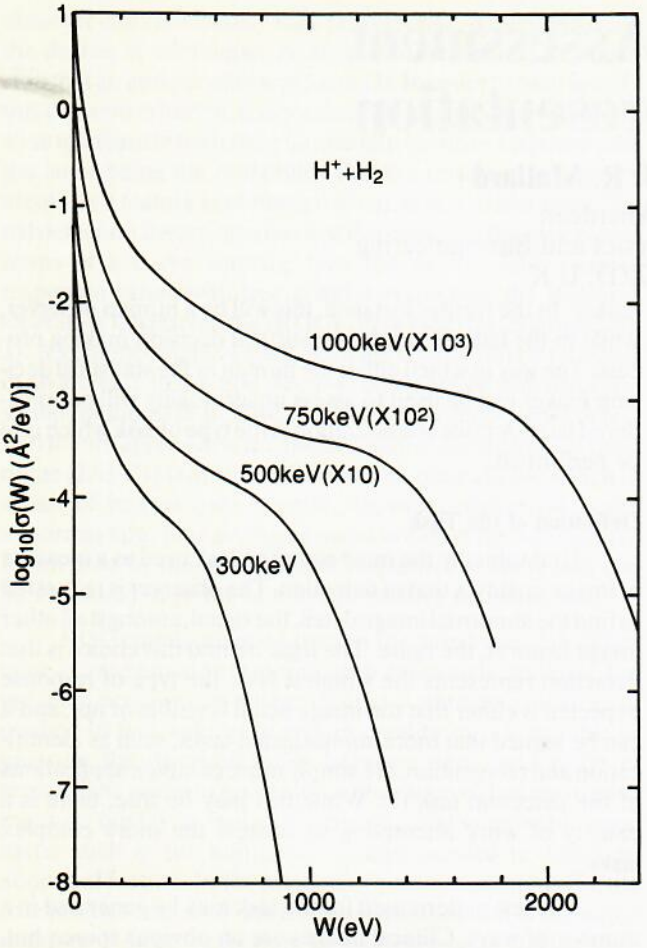

Fig. 3 Spectra of electrons from hydrogen gas bombarded by protons of 300-1000 keV primary energies.

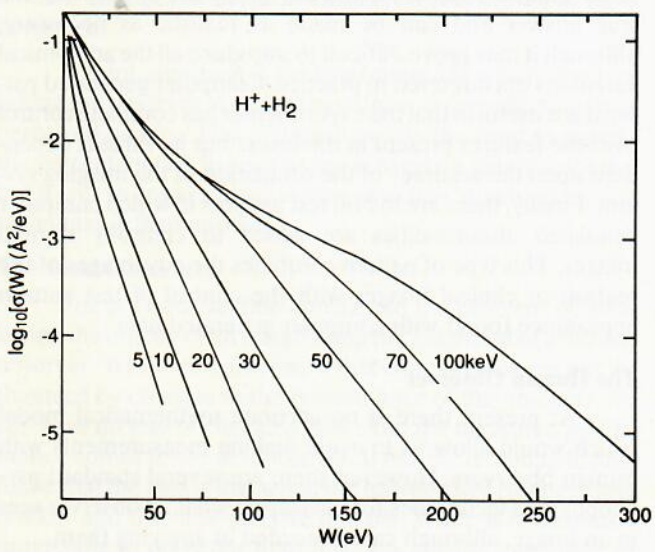

Fig. 4 Same as Fig. 3 but for 5-100 keV primary energies.

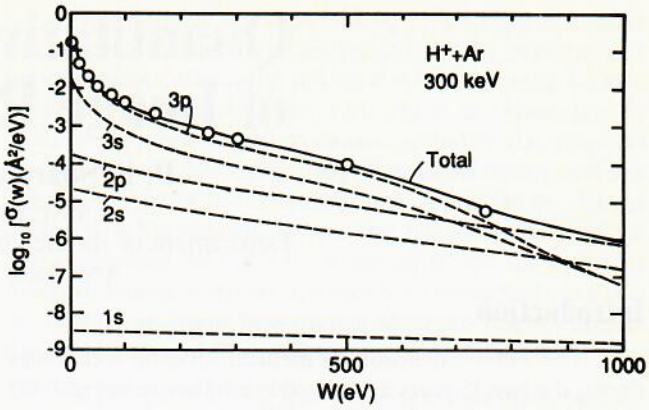

Fig. 5 Spectra of electrons from 300 keV proton collisions with argon. Contributions from the various subshells are shown as dashed lines and the total as a solid line. The points are experimental values.

angular distributions of secondary electrons, important for such applications as the calculation of radial distributions of energy deposition around tracks, will be considered. The committee which will work on this project consists of M. E. Rudd, Chairman, L. H. Toburen, N. Stolterfoht, Y.-K. Kim, T. Märk, and J. Schou. The Commission members who are sponsors of the report are M. Inokuti and H. Paretzke.

References

1. Miller, J.H., Toburen, L.H. and Manson, St. T. (1983). Phys. Rev. A **27**, 1337-1344.

2. Miller, H. and Manson, St. T. (1984). Phys. Rev. A **29**, 2435-2439.

3. Wilson, W.E., Miller, J.H. and Toburen, L.H. (1984). J. Chem. Phys. **80**, 5631-5638.

4. Miller, J.H., Wilson, W.E., Manson, S.T. and Rudd, M.E. (1987). J. Chem. Phys. **86**, 157-162.

5. Hollman, K.W., Kerby III, G.W., Rudd, M.E., Miller, J.H. and Manson, S.T. (1988). Phys. Rev. A **38**, 3299-3302.

6. Rudd, M.E. (1987). Rad. Res. 109, 1-11.

7. Rudd, M.E. (1988). Phys. Rev. A **38**, 6129-6137.

8. Rudd, M.E., Kim Y.-K., Madison, D.H. and Gallagher, J.W. (1985). Rev. Mod. Phys. **57**, 965-994.

Quantitative Assessment of Image Representation

P. F. Sharp and J. R. Mallard
University of Aberdeen
Department of Biomedical Physics and Bioengineering
Aberdeen AB9 2ZD, U.K.

Introduction

The rapid expansion in medical imaging technology during the past 15 years has served to emphasize our inability to measure, quantitatively, the performance of these instruments. This is not to belittle the very large amount of work which has been done in measuring specific aspects of instrument performance, such as spatial resolution and sensitivity, but rather it is a criticism of our failure to combine these elements into a measure of overall device performance. It is only when such a holistic approach has been taken that we will be able to make comparisons of the performance of different techniques.

One reaction to this criticism might be that such measurements are already provided by clinical trials. It is the performance of instruments at clinical tasks which is the ultimate measure of their utility. One cannot disagree with this assertion and clinical trials will always provide the final test of the value of a clinical technique, but they have several limitations; for example, they are often so time consuming that the technology may have changed significantly by the time that the trial has been completed, they are difficult to design and provide no guarantee that the imaging device is being operated in a technically optimal fashion. It is, therefore, desirable to develop alternative ways of measuring performance other than by embarking on such trials.

In the most general sense, the problem is one of measuring image quality and it is the remit of the ICRU Report Committee to devise a framework within which such measurements can best be made.

Image Quality

In very general terms, image quality can be defined as a measure of the effectiveness with which an image can be used for its intended task.

Two points emerge from this definition. Firstly, image quality is task dependent. While the measurement of certain aspects of an imaging device's performance, such as spatial linearity, may provide information about the *appearance* of the image, image quality can only be judged by considering what information it is hoped to extract from the image. While for some tasks the appearance and quality of an image may coincide, this is not necessarily always the case.

The second point is that the term "image" may refer either to the displayed data or the raw data as acquired by the imaging device prior to reconstruction into a visible image. In both cases, the performance of the task requires a decision-maker. In the former instance, this will be a human observer, while in the latter it can be a statistical decision making process. The way in which either the human or the statistical decision maker can be used to assess image quality will be considered later. A prior consideration is the type of task which is to be performed.

Definition of the Task

Undoubtedly the most common task used as a measure of image quality is that of detection. The observer is requested to find the abnormal image detail, the signal, amongst all other image features, the noise. The logic behind this choice is that detection represents the simplest task, the type of response expected is either that the image detail is visible or not, and it can be argued that more sophisticated tasks, such as identification and recognition, are simply more complex applications of the detection task (1). While this may be true, there is a paucity of work attempting to address the more complex tasks.

The test pattern used for the task may be generated in a number of ways. Clinical images are an obvious source but, even when specific cases have been selected, they have many of the drawbacks associated with a clinical trial. Images generated using a phantom avoid any problems of knowing the true answer and can be made as realistic as necessary, although it may prove difficult to introduce all the anatomical variations encountered in practice. Computer generated patterns are useful in that the experimenter has complete control over the features present in the image but its value is dependent upon the accuracy of the simulation of the imaging system. Finally, there are hybrid test patterns in which computer simulated abnormalities are added to clinically normal images. This type of pattern combines the advantages of the realism of clinical images with the control of test pattern appearance found with computer generated data.

The Human Observer

At present there is no accurate mathematical model which would allow us to avoid making measurements with human observers. However, there are several standard psychophysical techniques for measuring what an observer sees in an image, although care is needed in applying them.

The major problem encountered in performing such tests is to define the visual task. It may appear that, for example, in a simple detection type of experiment all that it is necessary is to ask the observer whether or not he sees a particular abnormal feature. While this is all too often the way in which such tests are carried out, it overlooks the fact that the

observer can consciously vary his response, depending upon the degree of confidence he needs before coming to a decision that an abnormality is present (2). In order to fully specify this decision criterion, it is necessary to design the experiment so as to measure both the true and false positive response rate, the latter being the probability that the observer mistakenly identifies a feature as abnormal when, in fact, it is normal. Signal detection theory measures performance of the observer in terms of a curve showing how the rate of false positive responses varies with true positive responses, the Receiver Operating Characteristic (ROC) curve (see, for example, ref. 3). A genuine improvement in image quality will be reflected in an increase in the true positive response rate with no corresponding increase in false positives. A second signal detection theory approach is the two alternative forced choice technique (2AFC) (4) in which the observer must choose which of a pair of images (one normal, the other abnormal) is the abnormal one. This avoids the need to define the decision criterion used by the observer and performance at the task can be measured in terms of the true positive response rate.

ROC curves are often used to show that there is a difference in image quality resulting from different techniques, but are often perceived as not providing a quantitative measure of quality. In fact, subject to certain conditions it is possible to measure the discriminability between signal and noise in terms of the signal to noise ratio. Other approaches are used to measure quality in terms of some physically realisable parameter such as the minimum contrast needed to detect an abnormal feature. In the method of constant stimulus (5), the true positive response rate is plotted as a function of the signal intensity. However care must be taken to ensure that the decision criterion does not vary by measuring the false positive response rate. There is, however, no way of correcting the data for changes in decision criterion if this proves to have happened.

A third approach is ranking/rating (5) which involves asking the observer to rank images in an order reflecting their perceived quality. This approach avoids the need to specify the perceptual task in such a way as to give a binary response but it fails to answer the question as to how much better one technique is than another.

The Ideal Observer

The previous section considered the problem of measuring the quality of an image using the judgment of a human observer. While we can ensure that comparisons are not influenced by changes in the performance of the observer, we still have no way of checking how close the measured performance comes to the best possible. It may be tempting to postulate that the best is that when the true positive response rate is 100% and the false positive one 0%. While it is obviously impossible to do better than this, it is equally unrealistic to expect performance to approach this in the presence of noise. Instead, what is needed is a measure of the response rates which can be achieved by a decision maker which uses the available information about the signal and noise in the most efficient way. This is provided by the "ideal observer" or "maximum likelihood detector" (6).

The statistical decision making process has the major advantage of providing a "gold standard" for performance measurements, albeit with the proviso that one must be able to specify the characteristics of the signal and noise. It is, in addition, no longer necessary to assume that the data needs to be constructed into a visible image; one of the strengths of this approach is that it can be equally well applied to the data as captured by the imaging device. This has led to the proposal that it provides the basis for a unified theory for analysing medical imaging systems (1). It should be noted that it can also be used for analysing how human observers might interpret displayed data and how well they perform this task (7).

At present there are limitations as to how to mathematically represent the signal and noise for more complex situations; for example, if the imaging system is non-linear where spatial resolution varies across the image and when noise is non-stationary. There are also problems to be resolved when the "perceptual task" is not simply one of detection.

Conclusions

Statistical decision theory provides a framework for examining the performance of medical imaging systems. At one level, signal detection theory allows the performance of the imaging system to be studied independently of the performance of the human observer, while the concept of the ideal observer provides a way of measuring performance on an absolute scale.

References

1. Wagner, R. F. and Brown, D. G. (1985). Unified SNR analysis of medical imaging systems. Phys. Med. Biol. **30**, 489-518.

2. Tanner, W. P. and Swets, J. A. (1954). A decision making theory of visual detection. Psychol. Rev. **61**, 401-409.

3. Metz, C. E. (1986). ROC methodology in radiologic imaging. Invest. Radiol. **21**, 720-733.

4. Green, D. M. and Swets, J. A. (1966). Signal detection theory and psychophysics. (John Wiley and Sons, New York).

5. Sharp, P. F. (1987). Image perception. IEE Procs. **134**, Pt. A, 211-224.

6. Peterson, W. W., Birdsall, T. G. and Fox, W. C. (1954). The theory of signal detectability. IRE Trans. PGIT-4, 171-212.

7. Burgess, A. E., Jennings, R. J. and Wagner, R. F. (1982). Statistical efficiency: a measure of human visual signal-detection performance. J. Appl. Photog. Engin. **8**, 76-78.

Stopping Powers of Heavy Ions

P. Sigmund
Odense University
Physics Institute
Odense, Denmark

Efforts have been made recently to solve the fundamental problem underlying all work on heavy-ion stopping, *i. e.*, the absence of a comprehensive theory that would allow scaling of stopping powers in a way similar to what has been done for light particles like electrons, positrons, and light ions.

It is well documented that the range of validity of Bethe's theory of particle stopping is limited to higher and higher energies with increasing projectile charge.

At energies of several MeV/u and below, corrections occur that go as successive powers of the charge number Z of the ion. A promising way to scale stopping powers of not too heavy ions is to find reliable estimates of the Z^3 and Z^4 corrections and to include them in Bethe scaling.

During the past year, much progress has been achieved with regard to the Z^3 correction. Experimental work of two groups at CERN, comparing the stopping power of antiprotons with that of protons, has reinforced the very existence of the Z^3 effect and has provided quantitative data on its magnitude for specific cases. Theoretical work at Odense University has provided the first rigorous evaluation of the Z^3 correction for the harmonic oscillator, and theoretical work by two groups at Argonne National Laboratory has a similar scope but addresses the electron gas and atomic hydrogen, respectively. All this work was presented at the International Conference on Atomic Collisions in Solids at Aarhus, Denmark, in August 1989.

For heavier ions, the Z^4 correction has similar magnitude as the Z^3 one. Theoretical work at Odense University has addressed this correction, much along the same line as the Z^3 work. This project aims at testing the accuracy of Bloch's (1933) correction to the Bethe formula, and it includes polarization effects of the type that make up the Z^3 correction which were neglected in Bloch's treatment. The first quantitative results are emerging right now.

It is not known at this point to what extent these corrections saturate for higher charge numbers. In order to investigate this question, a straight numerical effort has been made to rigorously solve the stopping problem for a model system (harmonic oscillator). This work is being done jointly at the Universities of Copenhagen and Odense.

For the highest charge numbers, the above approaches are hardly applicable, while a purely classical trajectory calculation is presumably the best available starting point. The main complication here is the very high significance of multiple excitation and ionization in single ion-atom/molecule collisions. I plan to establish a contact to provide access to classical-trajectory data for the ICRU Report Committee.

It follows from the above that there has been a very important and rapid development of the physical basis underlying all work on heavy-ion stopping. For this reason, I found it interesting to present here this development at the beginning of the actual committee work.

ICRU Report Committee Activities

W. R. Ney
ICRU
Bethesda, MD 20814-3095, U.S.A.

Introduction

The International Commission on Radiation Units and Measurements (ICRU) utilizes report committees made up of experts in a particular field to draft ICRU reports. When the drafting work is completed, the draft documents undergo a rigorous process of review and modification prior to release.

Currently, eighteen report committees are engaged in the development of ICRU reports. These efforts are in different stages of completion, with some just getting underway and others nearing entry into the review process. The scopes of six of these efforts are summarized below, while more detailed progress reports or outlines of the work of others appear in other parts of ICRU NEWS.

It should be emphasized that the information on this work in progress is, indeed, tentative in character. The report committees modify the planned presentation as the work progresses and further modifications are introduced during the review process. It is hoped, however, that the information provided will give the reader an appreciation of the questions being addressed in the report committee efforts.

Absorbed Dose Standards for Photon Irradiation and their Dissemination

In the past, standards for measurements of absorbed dose carried out in the clinic or laboratory have been in terms of quantities other than absorbed dose and this has meant that

many conversion factors had to be employed in the calibration process. Now, primary standards can be provided in terms of absorbed dose to water in a water phantom. This eliminates the many uncertainties associated with the use of conversion factors. Also, our knowledge of the interaction coefficients and dosimetric data (stopping power ratios, mass energy absorption coefficients, W values, and radiation chemical yields) involved in the direct determination of absorbed dose has improved. The report being prepared capitalizes on these facts. The report is to treat interaction of photon beams with matter, covering such subjects as interaction data, photon fluence distribution, secondary particles, radiation quality specification and determination, and determination of data via experiment and calculations. In treating standards for absorbed dose and their uncertainties, the report will cover calorimetric, chemical, and ionization absorbed dose standards and intercomparison of absorbed dose determination by means of different methods. Dissemination of the unit of absorbed dose is also being treated with attention focused on the formalism involved, absorbed dose determined under reference conditions, and the transfer of absorbed dose to another center. Finally, the report will provide details on correction factors, displacement factors and perturbation factors.

Clinical Dosimetry for Neutrons: Specification of Beam Quality

With the completion of the work that resulted in ICRU Report 45, *Clinical Neutron Dosimetry - Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons,* work on this related project is being initiated. ICRU Report 45 focuses on standardization of the dosimetry procedures used in support of the clinical applications of fast neutrons. This work will address biological problems, such as the dependence of relative biological effectiveness on the neutron energy spectrum and the relative contribution of gamma rays to the absorbed dose.

Dose Specification for Reporting Interstitial Therapy

Previously published reports of the ICRU have treated dose specification for reporting external beam therapy with photons and electrons (ICRU Report 29) and intracavitary therapy in gynecology (ICRU Report 38). The Commission determined to expand its work in this area to treat dose specification for reporting interstitial therapy.

This work seeks to develop a common language for reporting the results of the different systems used in interstitial therapy. The report being prepared is to provide definitions of terms and concepts for basic dosimetry, source definition, dose distributions and time factors. Recommendations for reporting will be covered including description of the technique used; total reference air kerma and implanted volume; reporting (1) dose in the central plane, (2) the mean central dose, (3) minimum doses and high dose regions, and (4) for the special cases of a single source and surface applicators. The report will treat quality assurance and also cover the time-dose pattern.

Dose Specification for Reporting Therapy with Photons and Electrons

In 1978, the ICRU published ICRU Report 29, *Dose Specification for Reporting External Beam Therapy with Photons and Electrons.* The report met the need for a common language for reporting the results of external beam therapy and has been widely used. In the more than ten years since the release of ICRU Report 29, many new ideas and approaches relevant to reporting external beam therapy have evolved. As a result, the Commission determined to prepare a new report to supersede ICRU Report 29. The new document will repeat many of the features of ICRU Report 29, but, in the case of a number of definitions and recommendations, radical revision is expected. As an example, in discussing volumes, the new report will stress tumor volumes, enumerating the reasons for the requirement that demonstrated tumor volume be specified. This is a change from the previous emphasis on target volume, which will be treated in a more general way and not related to the specific technique being utilized. Another example of the new approach is the use of the planning volume, which avoids the problems inherent in the fact that, with the old recommendations, a change in technique required a change in specification of the target volume. The new report will also stress the three dimensional characteristic of the absorbed dose pattern.

Measurement of Dose Equivalent

ICRU recommendations relating to determination of dose equivalents resulting from exposure to sources external to the body will ultimately be contained in three reports. ICRU Report 39, *Determination of Dose Equivalents Resulting from External Radiation Sources,* states definitions of quantities to be employed in radiological protection monitoring, including the ambient dose equivalent, the directional dose equivalent, the individual dose equivalent penetrating, and the individual dose equivalent superficial. ICRU Report 43, *Determination of Dose Equivalents from External Radiation Sources - Part II,* provides the grounds for the Commission's selection of these quantities and the basis for their definition, including extensive compilations of the physical data supporting the selection of those quantities. The third report, now in preparation, provides guidance on design criteria, calibration and use of instruments required to implement the recommended systems of operational quantities, conversion factors between opertional quantities and quantities realized by primary standards, and information on progress in the field of instrumentation and new techniques. The report will cover the basis of measurements, characteristics of instruments, calibrations, and the impact of the new operational quantities on the design of future instrumentation.

Quality Assurance in External Beam Therapy

Quality assurance in medical care covers a very broad range of subjects from orgnizational structure through qualifications and number of staff to the physical facilities employed. Quality assurance in external beam therapy, however, is focused on the procedures involved in the delivery of

therapeutic doses, from clinical evaluation through treatment planning and treatment to follow-up evaluation. The report being prepared on this subject addresses the accuracy of the absorbed dose delivered throughout the target volume and the surrounding tissue and the methodology required to assure this accuracy at each stage of the process. For each component in the process, two aspects will be addressed: (1) the quality assurance of operational procedures, and (2) quality control of machine or equipment related parameters. General matters such as accuracy in radiation therapy and acquistion of dosimetry data will also be addressed from the point of view of quality assurance. Specifics of acquisition of patient data, treatment planning, treatment simulation, treatment accessories, patient treatment, documentation for outcome analysis and organization will be provided.

The summary of ICRU report committee activities provided above gives an indication of the breath of the Commission's program. It needs to be emphasized again that the information provided is preliminary in character, in that each committee can be ecxpected to modify the report plans as the work progresses and, further, the subsequent review process will certainly introduce additional changes. While it has not been possible to provide detailed information on all aspects of each report committee effort, it is hoped that the information given provides a sense of the scope of each effort.

Announcements

The Röntgen-Plakette for A. Wambersie

The city of Remscheid (Germany) which is the birth place of Wilhelm Conrad RÖNTGEN in 1845 (Remscheid-Lennep) has awarded the Röntgen-Plakette for 1990 to Prof. STENDER and Prof. WAMBERSIE.

André WAMBERSIE has been a member of the ICRU since 1969. He directs at the University Clinics St-Luc (Brussels) the Radiotherapy and Radiobiology Departments and is conducting a neutron therapy and proton beam therapy program at the UCL cyclotron in Louvain-la-Neuve (Belgium).

Two other present members of the ICRU Commission have received this award:
A. M. KELLERER (1985) and G. E. ADAMS (1989).
Three previous members of the Commission were also among the 68 winners of the Röntgen-Plakette:
H. HOLTHUSEN (1954), B. RAJEWSKY (1958) and R. H. MORGAN (1979).

In the ICRU NEWS of December 1990, the activities of André WAMBERSIE at the Radiotherapy and Radiobiology Departments and at the Cyclotron Unit will be presented.

The 1990 Meeting of the Commission

The ICRU has accepted the gracious invitation of the Gesellschaft für Strahlen- und Umweltforschung (GSF), Neuherberg, to hold the 1990 meeting of the Commission at Schloss Elmau in Bavaria. The meeting will be held during the period 9-15 September. It will provide the opportunity for the Commission

- to act on draft reports submitted for review,
- to examine the current status of efforts underway in ICRU subgroups,
- to consider the immediate future course of the Commission's program
- and to act on various other matters related to Commission operations.

An important part of the meeting will be detailed review and resulting modification of three draft reports submitted for action:

- Measurement of Dose Equivalents from External Radiation Sources
- Stopping Powers for Protons and Alpha Particles
- Phantoms and Geometric Models in Radiation Dosimetry and Measurement

Plans for completion of the first phase of the work on performance assessment in the digital representation of images will also be carefully examined. The meeting will include a number of seminars and presentations on topics of interest to the Commission, including several related to potential new activities.

List of Available ICRU Reports

No. Title

10b *Physical Aspects of Irradiation (1964)*
10c *Radioactivity (1963)*
10f *Methods of Evaluating Radiological Equipment and Materials (1963)*
12 *Certification of Standardized Radioactive Sources (1968)*
13 *Neutron Fluence, Neutron Spectra and Kerma (1969)*
14 *Radiation Dosimetry: X Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV (1969)*
15 *Cameras for Image Intensifier Fluorography (1969)*
16 *Linear Energy Transfer (1970)*
17 *Radiation Dosimetry: X Rays Generated at Potentials of 5 to 150 kV (1970)*
18 *Specification of High Activity Gamma-Ray Sources (1970)*
20 *Radiation Protection Instrumentation and Its Application (1971)*
22 *Measurement of Low-Level Radioactivity (1972)*
23 *Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays (1973)*
24 *Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures (1976)*
25 *Conceptual Basis for the Determination of Dose Equivalent (1976)*
26 *Neutron Dosimetry for Biology and Medicine (1977)*
27 *An International Neutron Dosimetry Intercomparison (1978)*
28 *Basic Aspects of High Energy Particle Interactions and Radiation Dosimetry (1978)*
29 *Dose Specification for Reporting External Beam Therapy with Photons and Electrons (1978)*
30 *Quantitative Concepts and Dosimetry in Radiobiology (1979)*
31 *Average Energy Required to produce an Ion Pair (1979)*
32 *Methods of Assessment of Absorbed Dose in Clinical Use of Radionuclides (1979)*
33 *Radiation Quantities and Units (1980)*
34 *The Dosimetry of Pulsed Radiation (1982)*
35 *Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV (1984)*
36 *Microdosimetry (1983)*
37 *Stopping Powers for Electrons and Positrons (1984)*
38 *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecology (1985)*
39 *Determination of Dose Equivalents Resulting from External Radiation Sources (1985)*
40 *The Quality Factor in Radiation Protection (1986)*
41 *Modulation Transfer Function of Screen-Film Systems (1986)*
42 *Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photons and Electrons (1987)*
43 *Determination of Dose Equivalents from External Radiation Sources – Part 2 (1988)*
44 *Tissue Substitutes in Radiation Dosimetry and Measurement (1989)*
45 *Clinical Neutron Dosimetry – Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons (1989)*

Binders for ICRU Reports are available. Each binder will accommodate from six to eight reports. The binders carry the identification, "ICRU Reports", and come with label holders which permit the user to attach labels showing the Reports contained in each binder.

The following bound sets of ICRU Reports are also available:

Volume I. ICRU Reports 10b, 10c, 10f
Volume II. ICRU Reports 12, 13, 14, 15, 16, 17, 18, 20
Volume III. ICRU Reports 22, 23, 24, 25, 26
Volume IV. ICRU Reports 27, 28, 29, 30, 31, 32
Volume V. ICRU Reports 33, 34, 35, 36
Volume VI. ICRU Reports 37, 38, 39, 40, 41
Volume VII. ICRU Reports 42, 43, 44

ICRU Reports are distributed by the ICRU Publications' office:

ICRU Publications
7910 Woodmont Avenue, Suite 800
Bethesda, Maryland 20814-3095, U.S.A.
Phone (301) 657-2652, Fax (301) 907-8768

ICRU Reports are also distributed by:

Prof. G. E. Adams
Medical Research Council
Radiobiology Unit
Chilton, Oxon OX11 0RD, U.K.
Phone (0) 235-834-393

Prof. André Wambersie
UCL-Cliniques St. Luc
Avenue Hippocrate, 54.69
B-1200 Brussels, Belgium
Phone (02) 764.54.68

Mrs. Brigitte Harder
Konrad-Adenauer-Straße 26
D-3400 Göttingen
Federal Republic of Germany
Phone (0551)2 26 12

Order Form

Please send me the following ICRU Reports (Prices valid until 1 December 1990):

No.	Short Title	Price	Copies	Total
10b	Physical Aspects	7.00 $	_____	_____ $
10c	Radioactivity	6.00 $	_____	_____ $
10f	Equipment & Materials	5.00 $	_____	_____ $
12	Radioactive Sources	5.00 $	_____	_____ $
13	Neutron Fluence	9.00 $	_____	_____ $
14	X Rays and Gamma Rays	8.00 $	_____	_____ $
15	Cameras for Fluorography	8.00 $	_____	_____ $
16	LET	10.00 $	_____	_____ $
17	X Rays	9.00 $	_____	_____ $
18	Gamma-Ray Sources	9.00 $	_____	_____ $
20	Instrumentation	12.00 $	_____	_____ $
22	Low Level Radioactivity	12.00 $	_____	_____ $
23	Absorbed Dose in a Phantom	11.00 $	_____	_____ $
24	Absorbed Dose in a Patient	11.00 $	_____	_____ $
25	Dose Equivalent	10.00 $	_____	_____ $
26	Neutron Dosimetry	13.00 $	_____	_____ $
27	Intercomparison	14.00 $	_____	_____ $
28	Particle Interactions	14.00 $	_____	_____ $
29	Reporting	13.00 $	_____	_____ $
30	Dosimetry in Radiobiology	13.00 $	_____	_____ $
31	Ion Pair	13.00 $	_____	_____ $
32	Clinical Use of Radionuclides	14.00 $	_____	_____ $
33	Quantities and Units	11.00 $	_____	_____ $
34	Pulsed Radiation	16.00 $	_____	_____ $
35	Electron Beams	23.00 $	_____	_____ $
36	Microdosimetry	18.00 $	_____	_____ $
37	Stopping Powers	24.00 $	_____	_____ $
38	Intracavitary Therapy	14.00 $	_____	_____ $
39	Dose Equivalents	10.00 $	_____	_____ $
40	Quality Factor	15.00 $	_____	_____ $
41	Screen-Film Systems	16.00 $	_____	_____ $
42	External Beam Radiotherapy	19.00 $	_____	_____ $
43	Dose Equivalents 2	17.00 $	_____	_____ $
44	Tissue Substitutes	22.00 $	_____	_____ $
45	Clinical Neutron Dosimetry 1	18.00 $	_____	_____ $

Bound Copies	Price	Copies	Total
Volume I	27.00 $	_____	_____ $
Volume II	80.00 $	_____	_____ $
Volume III	67.00 $	_____	_____ $
Volume IV	90.00 $	_____	_____ $
Volume V	78.00 $	_____	_____ $
Volume VI	90.00 $	_____	_____ $
Volume VII	68.00 $	_____	_____ $
Volumes I-VII	470.00 $	_____	_____ $
Binders for Reports	9.00 $	_____	_____ $
TOTAL			_____ $

Please send all invoices to:

Name _____

_____

Address _____

_____

_____

Please send reports to:

Name _____

_____

Address _____

_____

_____

Payment (to be enclosed for orders under 20 $):

Cheque enclosed _____ ☐

Credit Card _____ ☐ VISA ☐ MC ☐ CHOICE

No. ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ Exp. date __ /__

It is possible to receive the ICRU Reports automatically via the Standing Order List, please place my name on your Standing Order List _____ ☐

Number of copies _____

Return to:
ICRU Publications
7910 Woodmont Avenue · Suite 800
Bethesda · MD 20814-3095 · U.S.A.

Operating Funds

ICRU has operated since its inception more than 60 years ago as a non-profit and non-governmental organization.

The Commission utilizes the freely volunteered services of physicians, scientists and engineers who participate in its program through service on the Commission or on working groups engaged in the development of guidance and recommendations.

Financial support has been gratefully received recently from the following organizations:

ADAC Laboratories
Agfa-Gevaert, N.V.
American Society for
Therapeutic Radiology and Oncology
Atomic Energy Control Board
Bayer AG
Central Electricity Generating Board
CGR Medical Corporation
Commissariat à l'Energie Atomique, CEA
Commission
of the European Communities
Dutch Society for Radiodiagnostics
Eastman Kodak Company
Ebara Corporation
EDF Electricité de France
E.I. Du Pont de Nemours and Company
Elscint
General Electric Company
Gilbert X-ray Company
Hitachi, Ltd.
International Atomic Energy Agency
International Radiation Protection Association
International Society of Radiology
Italian Radiological Association
Japan Industries Association
of Radiation Apparatus
National Cancer Institute
of the U.S. Department
of Health and Human Services
National Electrical Manufacturers Association
National Institute of Radiological
Sciences of Japan
Nederlandse Philips Bedrijven, B.V.
Philips Medical Systems, Inc.
Pyne Corporation
Radiation Research Society
Scanditronix AB
Shimadzu Corporation
Siemens AG
Society of Nuclear Medicine
Sumitomo Heavy Industries, Ltd.
Toshiba Corporation
University Hospital Lund
Xerox Corporation

In addition to the direct monetary support provided by these organizations, many organizations provide indirect support for the Commission's program. This support is provided in many forms, including among others, subsidies for (1) the time of individuals participating in ICRU activities, (2) travel costs involved in ICRU meetings, and (3) meeting facilities and services.

In recognition of the fact that its work is made possible by the generous support provided by all of the organizations supporting its program, the Commission expresses its deep appreciation.


LOUIS
HAROLD
GRAY
1905
1965