THE INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

ICRU NEWS

1
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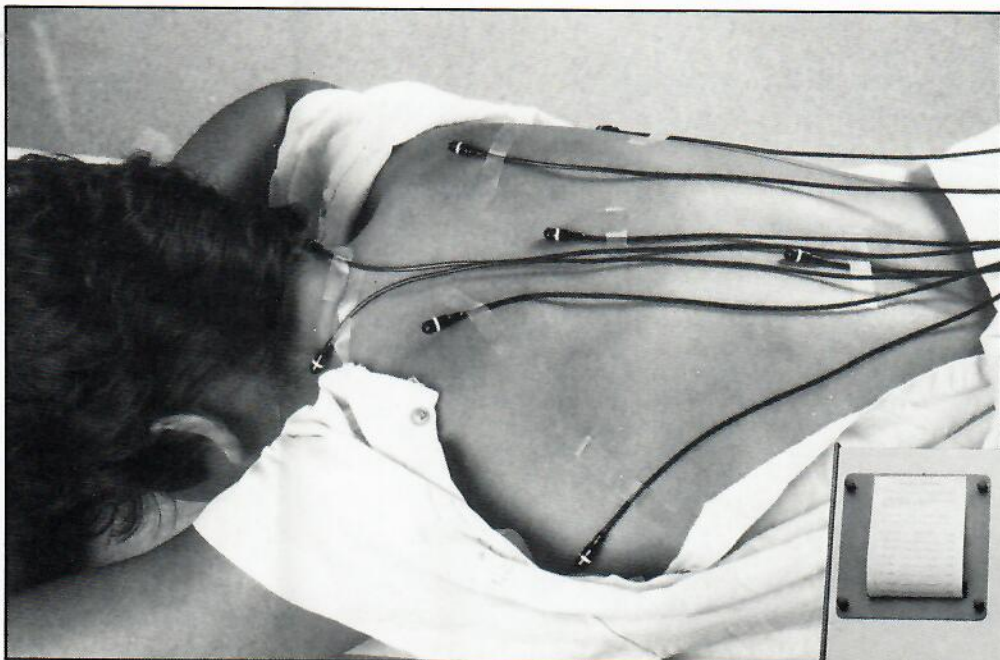

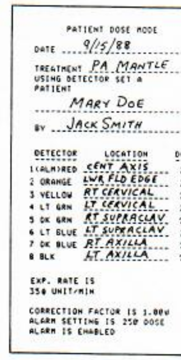

PATIENT DOSE MODE
DATE 9/15/88
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PATIENT
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BY JACK SMITH

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2 ORANGE	LWR FLD EDGE	204
3 YELLOW	RT CERVICAL	212
4 LT GRN	LT CERVICAL	213
5 DK GRN	RT SUPRACLAV	219
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7 DK BLUE	RT AXILLA	214
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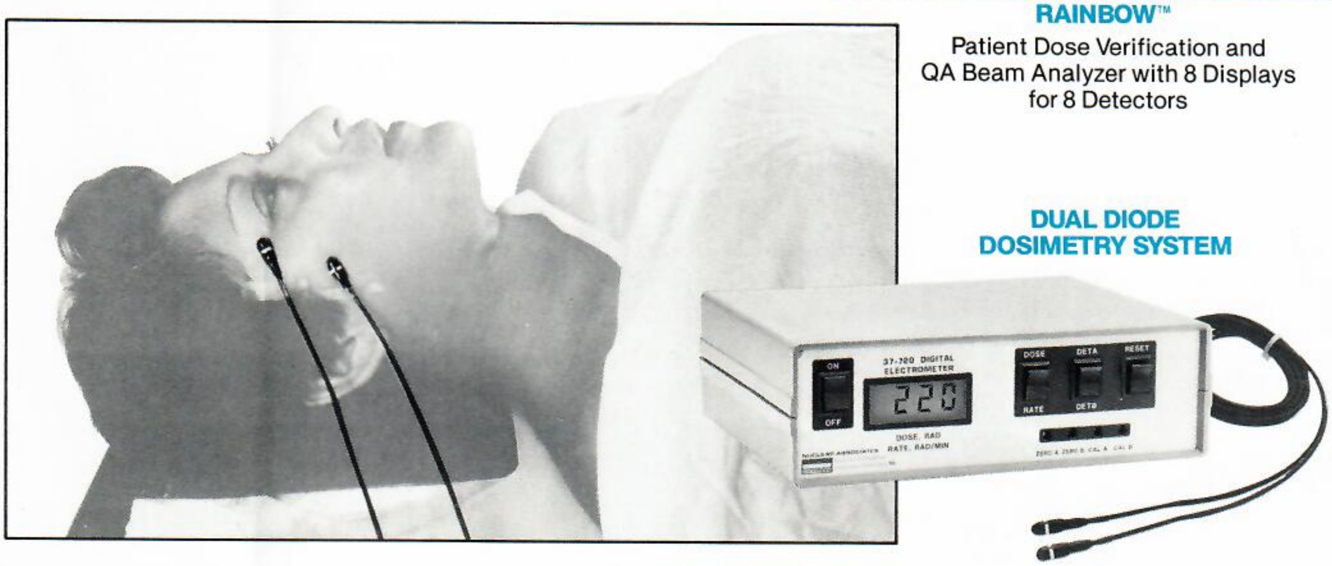

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Table of Contents 1/89 — June 1989

The Chairman's Page

A. Allisy
Why New "ICRU NEWS"? 3

The L. H. Gray Medal Award

G. E. Adams and M. Inokuti
Professor Dr. Dietrich Schulte-Frohlinde, the Sixth ICRU-Gray Medalist 4

The ICRU-Gray Medal 5

Article

L. S. Taylor
80 Years of Radiation Quantities and Units – Personal Reminiscences
Part 1: From a Variety of Radiation Units to the International Standards 6

Reports on ICRU Seminars

P. F. Sharp
Image Perception and Performance Assessment in Digital Imaging 14

T. S. Tenforde
Applications, Dosimetry and Biological Interactions of Static and Time-varying Magnetic Fields 17

Work in Progress

M. J. Berger
ICRU Report on Stopping Power for Protons and Alpha Particles 20

D. R. White
Phantoms in Therapy, Diagnosis and Protection 21

New ICRU Efforts

D. R. White
Tissue Substitutes in Radiation Dosimetry and Measurement 22

Reports on ICRU and ICRU Sponsored Meetings

W. R. Ney
The 1988 Meeting of the Commission 23

T. E. Burlin and J. R. Harvey
Seminar on the Implementation of Dose-Equivalent Operational Quantities into Radiation Protection Practice 24

Announcements

A. Allisy
The ICRU at the 17th International Congress of Radiology (ICR) 25

A. Wambersie
ICRU Symposium on Energy Deposition, Specification of Radiation Quality, and Shape of the Dose Response Curves in Radiation Protection and Therapy, Brussels, 11-16 Sept. 1989 26

Information on ICRU Reports

New: ICRU Report 44
Tissue Substitutes in Radiation Dosimetry and Measurement 27

New: ICRU Report 45
Clinical Dosimetry for Neutrons, Part 1: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons 27

W. R. Ney
ICRU Reports Related to Radiology 28

List of Available ICRU Reports 30

Order Form for ICRU NEWS and ICRU Reports 31

Reader Survey Form 32

Advertisers

NUCLEAR ASSOCIATES (p. C2) · PANASONIC INDUSTRIAL COMPANY (p. 7)
THOMSON & NIELSEN ELECTRONICS Ltd. (p. C3)

Why New "ICRU NEWS"?

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In science, real progress is usually achieved by novel ways of looking at things or by taking advantage of new technical possibilities. As a consequence, pioneers first penetrating in a new field often not only have to work out their own measuring methods, but also to form new concepts which allow them to describe their findings and to transmit them to the scientific community. New applications, techniques and interpretations may subsequently be proposed. However, there can be no doubt that well-chosen concepts, together with a concise and clear language, always bring along the benefit of an important economy in scientific thinking provided that they are generally accepted and used. Such a language can only be worked out on an international level, and preferably at a focal point of information. There one has to search with rigor for the best consensus and to develop clear recommendations which are acceptable for a vast majority of scientists.

The International Commission on Radiation Units and Measurements (ICRU) has endeavored, since its inception in 1925, to serve as such a focal point for the field of ionizing radiation. It has published over 50 reports which lay down the bases of this particular branch of science, informing regularly the users on the best physical data and the most reliable experimental techniques. The preparation of an ICRU report involves the treatment of a vast amount of scientific information, starting with seminars intended to inform the Commission on the needs of the scientific community, going on to the work of a report committee formed of the leading specialists in the particular field covered by the report, and ending with the discussion and final approval by the Commission.

Needless to say, communication between the ICRU and the scientific world is essential at every step of such a process. Taking into account the increasing number of scientists interested in ICRU reports, and considering the mutual benefit which would result from a better interaction between them and the ICRU, the Commission has decided to publish regularly, twice a year, this ICRU NEWS.

In the past, the ICRU NEWS has not been issued at regular intervals, but primarily when a new ICRU report was published. In the future, the reader will find in the "new" ICRU NEWS:

- articles related to scientific matters of interest to the ICRU and, in particular, the Gray Lectures,
- reports on ICRU Seminars,
- information on work in progress and on new ICRU activities,
- reports on meetings organized or sponsored by ICRU.

As with any ICRU publication, the ICRU NEWS will be prepared with great care. However, the ideas expressed in this new publication do not necessarily reflect an ICRU consensus, as do its reports. The selected texts appearing in the NEWS are published under the name of the author(s) and it is felt that this procedure will be advantageous for the exchange of ideas.

We hope that the reader will realize the scope of the ICRU and appreciate its deep historical roots. We are proud, indeed, to evidence these via publication in this first issue of Lauriston Taylor's personal reminiscences. Laurie attended the first ICRU meeting in 1928 and is still our Honorary Chairman and Member Emeritus. Many readers will enjoy once more his vivid writing and we, at ICRU, will try to make the best possible use of his experience, remembering that history always repeats itself.

Professor Dr. Dietrich Schulte-Frohlinde Sixth ICRU-Gray Medalist

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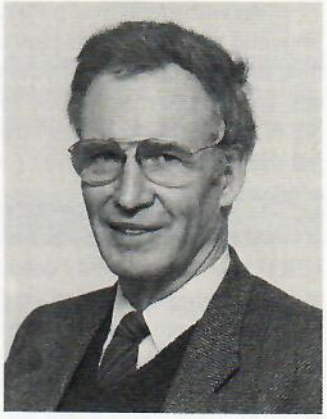
The International Commission on Radiation Units and Measurements is pleased to announce that the L. H. Gray medal for 1989 will be presented to Professor Dr. Dietrich Schulte-Frohlinde at the ICRU Symposium to be held during the Congress of Radiology in Paris, 1-8 July 1989.



Professor Schulte-Frohlinde was born in Munich, Germany in 1924 and received his Diploma in physical chemistry from the University in Heidelberg in 1952. His post-graduate work was carried out under R. Kuhn and he received his Ph. D. degree in 1956. After a further three years at Heidelberg as a research assistant, Prof. Schulte-Frohlinde moved to Karlsruhe as Leader of the Radiation Chemistry Group and, in 1965, became Director of the Institut für Strahlenchemie at the Kernforschungszentrum. In 1969, he took over as Director of the Radiation Chemistry Department at the Max-Planck-Institut für Kohlenforschung in Mülheim, later to become the Max-Planck-Institut für Strahlenchemie, where he remains to the present day.

In his earlier years, Prof. Schulte-Frohlinde was particularly active in photochemistry and made numerous important and novel contributions concerning mechanisms of cis-trans isomerization and energy transfer in organic systems. His work with Eiben, on irradiated frozen alkaline aqueous solutions signalled a major entry into radiation chemistry. They correctly assigned the blue colour produced by γ-irradiation to the spectrum of the thermal electron trapped by solvation in the frozen matrix. This work was carried out independently of parallel pulse radiolysis studies of Boag, Hart and Keene that characterised the electron spectrum in liquid water.

The discovery of the hydrated electron heralded a huge expansion of interest world-wide in free radical radiation chemistry involving many applications of the new technique of pulse radiolysis. Prof. Schulte-Frohlinde participated fully in this "explosion" and made many unique and valuable contributions to it, particularly in the field of chemical reactions initiated by hydroxyl radicals and other short-lived reactive species.

However, even in the Karlsruhe period, Prof. Schulte-Frohlinde was already becoming more and more intrigued by problems posed in molecular radiation biology. He was also attracted into the DNA field, partly by his own curiosity and partly by the fact that Karl Zimmer, also at Karlsruhe, believed very much in the importance of chemical processes in the mechanisms of radiation damage to cells. For over twenty years, he has devoted the major part of his research to the study of radiation-induced free radical reactions in DNA and its model compounds. Many and varied studies enabled Prof. Schulte-Frohlinde and his co-workers, particularly Clemens von Sonntag, to track down and characterise many of the free-radical reactions involved in the extraordinarily complex mechanisms of DNA radiolysis. Classification of abstraction, addition, transfer, migration, and other types of free radical reaction in DNA and its constituent bases, sugars and phosphate esters enabled him and his team to propose, investigate and eventually verify, a detailed mechanism of DNA strand breakage which included all the separate, but inter-linked, steps from the initial chemical damage through to the final products. Other studies brought together into a comprehensive mechanism, the methods whereby peroxyl radical reactions were involved in, and contributed to, oxygen-mediated enhancement of DNA strand breakage.

Prof. Schulte-Frohlinde is also an accomplished experimentalist and brought together in the work of his group various techniques, including product analysis, electron-spin resonance and pulse radiolysis involving both optical and conductiometric methods of following fast chemical reactions.

During his career, Prof. Schulte-Frohlinde has published over 230 papers, books or monographs and has established himself as an international figure in radiation chemistry, particularly in areas related to mechanisms in radiation biology. He is the first chemist to receive the Gray Medal and the ICRU is honoured to include him in the list of distinguished recipients.

The ICRU-Gray Medal

In 1967, the ICRU established a medal honoring the late Louis Harold Gray, a former member and Vice Chairman of the ICRU, who is well known for both his contributions to measurement of ionizing radiation and his radiobiological research. The medal may be awarded once every four years to the author of a particularly outstanding scientific contribution in one of the fields of science which are of special interest to the ICRU. On the occasion of the awarding of the Medal, the Medalist is invited to give a scientific lecture to the ICRU and its guests. The lecture is published in the scientific literature.

The first ICRU-Gray Medal was awarded to Dr. Lewis V. Spencer on the basis of his contributions to the theory of charged particle and photon penetration in material and his extension of Gray's theory of cavity ionization chambers. During the XIIth International Congress of Radiology in Tokyo (1969), Dr. Spencer presented a lecture, "Remarks on the Theory of Energy Deposition in Cavities", and received the Medal from Dr. K. Tsukamoto, the President of the Congress. The lecture was later (1971) published in Acta Radiologica.

The second ICRU-Gray Medal was awarded to Dr. John W. Boag for his work on the theory of recombination, his observations of the spectra of the hydrated electron and lifetimes of transient species during pulse radiolysis. During the XIIIth International Congress of Radiology at Madrid (1973), Dr. Boag presented a lecture, "Quanta, Quantities, Radicals and Cells", and received the Medal from Dr. J. Gomez-Lopez, the President of the Congress.

The third medal was awarded to Dr. Mortimer M. Elkind for his contribution to our understanding of cellular radiobiology and, in particular, to the identification of repair in cells. During the XIVth International Congress of Radiology at Rio de Janeiro (1977), Dr. Elkind presented a lecture entitled "Molecular and Cellular Radiobiology of Damage-Repair Processes in Mammalian Cells", and received the Medal from Dr. N. Caminha, the President of the Congress.

The fourth award was to Professor Maurice Tubiana in 1981 for his work on the use of radioactive isotopes and high energy radiation in medicine. Professor Tubiana presented his lecture, "Cell Kinetics and Radiation Oncology", at an ICRU Symposium at the XVth International Congress of Radiology in Brussels. The Lecture was subsequently published in the International Journal of Radiation Oncology, Biology and Physics. The Medal was presented by Prof. Louis Jeanmart, the President of the Congress.

Dr. Harald H. Rossi was the fifth recipient, in 1985, for his pioneering work in radiobiology and microdosimetry. The Medal was presented at the XVIth International Congress of Radiology in Hawaii, by the President, Dr. Robert D. Moseley, Jr. Dr. Rossi's Lecture, "Radiation Quality", was published in Radiation Research.

80 Years of Quantities and Units Personal Reminiscences Part I: From a Variety of Radiation Units to the International Standards

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1. A Spate of Measurements

When x rays were discovered by Röntgen in 1895, world interest and experimentation spread like wildfire. Because of the widespread and ready availability of gas discharge tubes and associated equipment, there was rapid discovery of many effects, all of which were ready to be exploited for possible radiation measurement purposes. Of course the photographic effect, which was first noted by Röntgen, was the initial effect to be studied, and it was quickly found that the blackening of photographic emulsions bore a consistent relationship to the amount of exposure.

Then there was the ionization effect. In early 1896 Thompson and Perrin, working independently in England and France, discovered that electrified bodies lost their charges under the action of roentgen rays and, hence, they were among the first to distinguish between the ionization produced in a gas surrounding a charged body, and the photoelectric effect due to the impinging radiation on the body itself (S. R., p. 125). It was soon extended to ionization in air. The first application of this to radiation measurement was in the form of the customary gold leaf electroscope in an enclosure of some sort, which, when exposed to ionizing radiation, made an acceptable ionization measurement device.

Chemical effects of ionizing radiation were also recognized very early. Holzknecht, in 1902, observed that some chemicals changed color in a systematic manner upon exposure to x rays in varying quantities (Hirsch, p. 196). Using pastilles made up of barium-platino cyanide that were radiosensitive, he devised a quantitative system for determining the x-ray dosage on the basis of the degree of color change. The device was used for many years. A similar, but more quantitatively useful pastille, was developed by Sabouraud and Noiré in 1904 and apparently both methods remained in use at least into the '30s according to a report by Eric Smith on early work of the National Physical Laboratory (NPL) (Smith, 1973, pgs. 18, 43).

Effects in the form of photoluminescence, including fluorescence and phosphorescence of various materials, provided a mechanism suitable for radiation measurement and scintillation was especially useful for detection of low levels of radiation and alpha particles (It became the base for some highly sophisticated radiation measuring devices in the 1950s). Then there were also other effects, as for example, the photo-voltaic effect in selenium, which was developed into a practical instrument by Furstenau in 1905 (Hirsch, p. 95).

On the biological side, primarily because of what was early recognized as the needs of the medical profession for some quantitative and reliable radiation control devices, experiments in all of these directions were proceeding at the same time and without any kind of coordination or central point of interest.

There was also the early observation that exposure of a person to x rays could produce a reddening of the skin (erythema) at moderate doses, and severe ulceration at higher doses. It was scarcely seen to be a technique for measuring x rays but, indeed, turned out to be so. The evaluation of the exposure necessary to produce an erythema on a person became a consistent method for dosage control in radiation therapy early in the century. It was, in effect, a kind of calibration of an x-ray beam. As late as the 1930s, Francis Carter Wood, in New York, was successfully using the killing rate in drosophila as his means of therapeutic dosage control (another type of calibration of a source). He used to contend that he could measure the dosage by that method as accurately as could be done using the then-prevalent ionization chambers.

While, as already noted, some of these systems continued in use for two or three decades, others were gradually pushed aside by the steady increase in understanding and advances in technology centered around the use of ionization methods. For that reason, most of the emphasis below will be on ionization rather than the other techniques noted above.

2. Early Ionization Measurements

Important to an understanding of the ionization phenomena were such early studies as those by Rutherford in 1900, at which time he determined the energy required to produce a pair of ions by air ionization. In 1905, Duane, while measuring

radon, noted scattering from the walls of his ionization chamber caused additional ionizations. This led to his introduction of the large parallel-plate ionization chamber in which the beam would not strike any walls (Duane, 1905), (S. R., p. 126).

One of the more important advances in the ionization techniques was that of Villard in 1908. He defined the unit of a quantity of radiation as "that which liberates by ionization, one electrostatic unit of electricity per cubic centimeter of air under normal conditions of temperature and pressure" (S. R., p. 125). This was essentially the definition of the international unit of dose that was subsequently adopted in 1928. It had been proposed by Villard but remained unused from 1908 to 1928. This is probably a good example of the need for some kind of a central point of interest, or body of concern, that would become aware of such advances and be in a position to either promote or reject them.

The next pertinent step was made by Duane in 1914, at which time he defined a unit of intensity as "that intensity of radiation which produces under saturation conditions one electrostatic unit of current per cubic centimeter of air under normal pressure and temperature". "The unit of intensity", he designated as E. The unit of dose was the electrostatic unit second, written as ES (S. R., p. 126). This could have meant the product of charge and time, but he did not say so. In fact, he spoke of current only and there is no need now to puzzle as to his intention. His method for reproducing this measurement was by using a large parallel-plate air ionization chamber so constructed that the radiation passing through it struck no solid material whatsoever. The ionization current was measured by means of a galvanometer which, in spite of being of the "high sensitivity" type, was inadequate for the very small ionization currents. Because of this, some errors were built into his measurements.

In 1918, Krönig and Friedrich published their extensive study on x-ray measurements using the unit of dose that was originally defined by Villard, which they designated as e (S. R., p. 126), (Krönig and Friedrich, 1918). In 1921, Solomon, in Paris, proposed a unit based on the constancy of gamma radiation from radium (Solomon, 1921). He called his unit R and defined it as "the intensity of a roentgen radiation producing the same ionization per second as one gram of radium placed two centimeters from the ionization chamber and filtered with 5 mm platinum". It should be noted that terms such as "intensity", "dose" and "exposure" appearing in this early literature are defined vaguely, if at all. We should not be unduly concerned as to hidden significances. Many usages have been refined and more sharply limited in current technical styles. The difficulty with Solomon's system was that it was entirely dependent upon a specific piece of apparatus, a thimble ionization chamber and a gold leaf electroscope located in a hospital laboratory in Paris (1st ICR, p. 66).

In 1922-23, Duane carried further his earlier experiments centered around the ionization quantity and unit which he had proposed earlier. At about the same time, Küstner, in Germany, had developed a cylindrical type free air ionization chamber centered about the Villard type of definition and a "free air" ionization chamber. It is interesting that this chamber has continued in use until this day since it was promoted by the World Health Organization two or three decades ago because of its capability of producing repeatable measurements and its transportability. My own measurements with it, in about 1930, indicated that it seemed to be fairly satisfactory for x-ray energies up to a little over 100 kV, but above that it was clearly too small to avoid wall effects. If calibrated against suitable free-air standards, it could be used at higher energies.

An important development that had occurred some ten years earlier, played a major role in the direction in which radiology would move in the future. This was the development of the Coolidge hot-cathode x-ray tube for both diagnostic and therapeutic purposes. Here was a new tube which could operate continuously, steadily and reliably with large tube currents and hence high radiation output. In therapy, such tubes were beginning to be made to operate at the order of 200,000 volts, thus, opening up a whole new era in deep therapy radiation treatments. Such treatments could be carried out safely and quantitatively only if there were good systematic and reliable systems of dosimetry available to the radiologists. Any clinical radiation measurements must be capable of standardization and there must be some central point in which clinical instruments in and between countries can be calibrated so that each institution knows exactly what another institution is talking about.

3. The First International Congress of Radiology, London, 1925

In the field of radiation protection, up to this point, all of the so called protection standards or recommendations were essentially in terms of thickness of material, time of exposure, distance from the source and so on. Protection procedures were pure cookbook patterns without reliable means of measuring and describing the condition against which protection was sought. It was thus essential that before one could proceed with therapeutic medical applications of radiation and with protection against radiation, there be a reliable system of standards for which there is a well understood and consistent system of quantities and units.

Its is not surprising, therefore, that the First International Congress of Radiology, in 1925, should concentrate a great deal of its attention on the questions, first of measurements and then of protection. It was out of this that in July 1925 the International X-Ray Unit Committee was born and the International Commission on Radiological Protection was conceived.

The whole first day of the Congress was devoted to discussions on international units and standards for x-ray work. The discussions are of enough interest to warrant further discussion here. After the introductions, the session opened with the 8th Sylvanus Thompson Memorial Lecture given by Duc de Broglie from Paris, who talked about the absorption and scattering of x and gamma radiation. (My personal interest in this today, is sparked by the fact that I gave the Sylvanus

Thompson Lecture just twenty-five years later in London.) This was followed by the reports on x-ray standards and dosimetry, chemical action of x rays, radiation protection and so on, with discussions that lasted throughout the day under the chairmanship of Sir William Bragg (1st ICR, pgs. 64-199).

Since the standard proposed by the French was in his own laboratory, it is not unnatural that Antoine Béclère was building up a case for it. He pointed out that the erythema dose of that period varied widely in terms of any measurements made with ionization chambers. Reference was made to the inquiry by Grebe and Martius about the different values of the biological unit known as the Hauteinheitsdosis, abbreviated HED (unit skin dose) (1st ICR, p. 68). Béclère cited their study of the different number of roentgens for, presumably, the same HED measured in 14 institutes. The values ranged from 285 to 1,120 roentgens, a range of almost four times. It is interesting that the measurements made in German Röntgen were translated to the French R-units using a constant ratio of 2.25 French R per one German R. (Grebe and Martius, 1927). It was not realized, as the knowledge about wall effects developed later, that there was a substantial energy dependence factor between the French and German units. Béclère closed:

> I call on the radiotherapists of all countries asking them first to admit the necessity of standardization for dosage measure and to elect an international committee for the study of this very important question.
>
> The international committee ought to be composed of both physicians and physicists, the former needing certainly the help of the latter, but the physician's point of view will not be necessarily that of the physicist.
>
> Physicists are never satisfied with the precision of their measures and always try to improve it. They are right in developing their capability to measure heat to a thousandth of a degree but physicians are not wrong when they are satisfied with taking the temperature of a patient to only a tenth of a degree.

The German unit of x radiation was described by Behnken from the Physikalisch-Technische Reichsanstalt (PTR). At the outset, he said that in examining more closely the meaning of the word "dose", it is found that with pharmacological medication the dose is the mass of the substances administered and, therefore, is determinable by its weight. X rays, however, do not represent a mass but an energy, and he carried the point further to reach the conclusion that "the dose is the roentgen energy absorbed by a unit of the bulk of the tissue". He related to this an ionization measurement made in free air in accordance with the definition discussed above. This was clearly the first obvious mention of the energy-per-unit-mass concept that was ultimately treated quantitatively by Gray in the mid 1930's and finally by the ICRU in 1950 (1st ICR, p. 73).

The ionization chamber used by the PTR was of special interest. It was of a cylindrical type with the beam passing axially through the center. To ensure that electrons from the scattered beam did not reach the side walls, the chamber was filled with air at a pressure of approximately six atmospheres, thus reducing the required dimensions of the chamber at atmospheric pressure by a factor of about six; it also increased the available current by a substantial factor. This device was in place by about 1922 or 1923 and I saw it there when I visited the laboratory in 1928. When I visited the laboratory a second time in 1931, the pressure chamber had been replaced with a larger chamber of similar basic design but operating at atmospheric pressure and then about 30 cm in diameter and 75 cm long. Behnken's paper was followed by a report on "Röntgen Ray Measurements in Absolute Units and Ray Doses Necessary for Skin Erythema" by Grebe and Martius from Bonn, discounting the Solomon unit and pointing out, correctly, that this was clearly not an absolute measure (1st ICR, p. 78). In addition, the penetrating radiation from radium would exert its influence not only upon the ionization chamber but upon the rest of the electrometer even though it was protected by a considerable amount of lead.

They had made their own further studies then to check on the validity of the Behnken method at the PTR (Grebe and Martius, 1927). In these they made comparisons between their own pressure chamber and some free air chambers of the open-air cylindrical type such as was attributed then to Holthusen. Two chambers were made having diameters of 10 and 25 cm and, according to their measurements, they found that the 10 cm chamber gave the same charge per unit mass of air as that of the larger diameter. From this they concluded that it is not necessary for practical dosimetry to use the special arrangements of a pressure chamber.

Recalling, from above, that Küstner's standard chamber was, with the beam passing within about 2-3 cm from an electrode, only the order of 10 cm in diameter, it must be said in hindsight that their findings were probably largely conditioned by the fact that in that early period x-ray tubes did not operate very satisfactorily above some 140 kV, for which energy a smaller chamber might, indeed, be suitable. Studies many years later by Kemp and by Wyckoff and Attix indicated that the dimensions cited by Grebe and Martius are clearly much too small (Kemp and Hall, 1954), (Wyckoff and Attix, 1957).

Early authors called attention to the wide variations between the dose in roentgens required to produce an erythema dose. Grebe and Martius had made their own measurements, arriving at a figure of 600 R and these were to be compared with Duane's figure of 1800 R and the 1400 R found by Fricke and Glasser. They mentioned that the two American values (1400 and 1800 R) could be considered to be in agreement within the limit of biological uncertainty – roughly 20%.

Dauvillier, from Duc de Broglie's laboratory in Paris, described his own brand of cylindrical-shaped free-air ionization chamber. Because of the geometry of the electrodes, it could be anticipated that there would be severe field distortion within the chamber with probable loss of ions which should otherwise have been measured. It was never heard from further. He also brought up the importance of understanding the quality of the radiation which had to be measured (Dauvillier, 1927). Dauvillier said that in connection with half value layer measurements, the use of media such as aluminum or water was not sensitive enough to yield meaningful and useful values for the quality. The ideal method would evidently be spectrometric but he admitted that this carried too many experimental difficulties to be practical.

Duane (AJR, page 167, March 1922) had recognized the quality problem and proposed that it be expressed in terms of the thickness of aluminum giving the same transmission as a constant thickness of copper (1st ICR, p. 126), (Duane, 1923). The principle here was that by reason of the rapid variation of the selective absorption of heavy metals and of the constancy of scattering by the light elements, the ratio of absorption varies very much as a function of the wavelength. Thus, the quality could be expressed in terms of an "effective wavelength" that was derived from an experimentally determined aluminum transmission. The method was reasonable up to a point but was impractical from a clinical point of view and never came into use.

Quality expression by means of half value layer measurements in various materials has remained adequately useful and is easy to apply in practice. Later proposals were made for quality measurements by Mutscheller and by Taylor and will be noted later. Neither suggestion was particularly well adapted to clinical practice.

At the close of the discussions during that first day of the 1925 Congress, a resolution was passed to appoint an international committee to study the question of measurement. The International Commission on Radiation Units and Measurements was thus born as the "International X-Ray Unit Committee". The following were nominated: Sir William Bragg, F. U. Hopwood, E. A. Owen, C. E. S. Phillips, A. W. Porter, and Sydney Russ, who later named a very effective committee of 24 members of demonstrated competence and reputation from some 16 countries (1st ICR, p. 101). It might be noted in passing that the Congress also designated a small committee, headed by G. W. C. Kaye from England, to select a similar body for the study of radiation protection problems – later to become the International Commission on Radiological Protection. The two groups followed quite different organizational patterns, but worked closely together at the start, as they do today.

4. Efforts in Standardization

Its is interesting to note that up until approximately this time, there was no national laboratory in any country which was directly involved in radiation measurement standards. The first national laboratory to move in this direction was the PTR in Berlin, with Behnken, working in collaboration with the Deutsche Röntgen Gesellschaft.

Following the appointment of the International X-Ray Unit Committee at the end of the 1925 International Congress of Radiology, there was considerable effort in several countries devoted to the development of suitable x-ray standards. While no formal agreement had been attempted, it appeared to be fairly obvious after the London meetings that the standard would be based on a measurement of ions produced by the radiation, free-in-air without wall effects, and would embody the essential principles previously outlined by Villard, Behnken, Friedrich, Duane and others. At that time, the only x-ray standard ionization chamber in place was the pressure chamber at the PTR.

In Germany, the Deutsche Röntgen Gesellschaft had a committee dealing with the question of x-ray standards. A similar committee had been started in the United States by the Radiological Society of North America, and in England, the British Institute of Radiology had established its British Committee on Standards and Units (BCRU). Sometime in that period, the exact time is not clear, the British National Physical Laboratory (NPL) constructed a parallel plate ionization chamber for the purpose of measuring x rays in terms of the new unit. It was contained in a box 20 cm long and 10 cm in cross section with a plate separation on the order of 5 cm. It was intended for use with x rays generated at potentials only up to 100 kVp. On the basis of today's knowledge, this plate separation would have been barely adequate for even 100 kVp. They recognized the shortcoming of this design and sometime soon after the 1928 Congress, constructed a chamber with 12 cm plate separation and a length of 40 cm (Smith, 1973).

In France, the Solomon thimble-chamber standard, calibrated against radium, remained as their primary standard until at least into the middle 1930's.

Because of the 1925 action by the International Congress, considerable pressure was developed in the United States to have its National Bureau of Standards organize an x-ray standards program and this was accomplished beginning in the summer of 1927. In the meantime, numerous activities were underway in the private sector. In 1926, Glasser and Meyer checked a number of instruments imported from Germany that had been calibrated at the PTR; they reported that there was considerable discrepancy between the German Röntgen and the unit, as determined by Duane (S. R., p. 127). In the fall of 1927 Behnken brought a specially calibrated secondary chamber of the thimble type to the United States for a comparison with the standards here. Agreement between Duane and Behnken was reported, but since there were no known changes in either the German or U. S. standards, this disagreement with the Glasser results is unclear (S. R., p. 127).

In late 1928, by which time the National Bureau of Standards (NBS) had a free-air standard ionization chamber in place (Taylor, 1929), intercomparisons by means of a secondary thimble type chamber were made between the free air ionization chambers of Glasser, Failla and Duane (not published). There was adequate agreement with Failla and Glasser but the Duane standard read considerably lower. It was obvious that there was something basically amiss, at least as far as the United States' standards were concerned. It was this situation which led Taylor to consider the design of some type of ionization chamber which was better suited to a transfer of measurements between various standards laboratories, especially those in Europe.

When the U. S. Congress appropriated funds, specifically for an x-ray standards program at the NBS, the work was originally expected to be done by a member of the staff who had been a graduate student of Duane's. However, for personal reasons, he decided to leave the Bureau and it was at that point that I was brought in from the outside to organize the program. In the meantime, Duane had supplied the Bureau with one of his free-air standard ionization chambers and it was anticipated that when I arrived there, I would simply set it up and the Bureau would be in business. However, before doing anything, I spent two or three months reviewing all of the background literature in the field and visiting several laboratories in the U. S. The conclusion of this was that the Duane chamber, as supplied to the Bureau, couldn't possibly be suitable. The ionization chamber plates, approximately 15 cm square, were at a fixed separation of 5 cm. The diaphragm was 1 x 5 cm (Hirsch, p. 177 and fig. 18 c). It would undoubtedly read low by some uncertain amount, possibly as much as 10 or 15%.

Because of this, a new design study was carried out. The final free- air chamber, as used by the NBS, had a plate system approximately 50 cm long, and spaced 12 cm apart. It was contained in a lead box about 80 cm long and 30 x 40 cm in cross section – obviously larger than any others then in being.

Checks were made between the new NBS standard and the standards of Glasser, Failla and Duane using this standard. There was good agreement between Failla and Glasser but when the discrepancy with the Duane standard was reported informally, Duane was furious, complained to the Director of the NBS and recommended that I be dismissed. I wasn't.

5. The International X-Ray Unit Committee – Alias ICRU

The newly appointed International X-Ray Unit Committee held its first meeting of one day during the Stockholm meeting of the Second International Congress of Radiology in 1928.

At that time, under the organization rules of the Congress, a committee or a commission was entitled to include two representatives from each country participating in the affairs of the Congress. Fortunately, not every country took advantage of the opportunity to be represented on the Committee but, nevertheless, the group meeting in Stockholm, consisted of three officers and twenty-one participating members. I was not a member at that time because I had entered the field, now known as radiological physics, only one year previously. However, I was permitted to attend and take part in the meeting. At the close of the Congress, I was selected by the U. S. to take the place of Duane.

Until the Committee became a Commission and was reorganized in 1950, it was customary that its chairman for a meeting be selected from the country in which the Congress was being held. In this case, it was Siegbahn from Upsala, an eminent radiation physicist who was, however, without any particular experience in the radiological physics area. The only continuing officer for the Committee was an honorary secretary, in this case Owen, who had formerly been with the NPL in Great Britain. A second honorary secretary, named by the host country in 1928, was Holthusen, a radiologist from Germany and an individual who continued his close association with the Commission for many years. The listing of the twenty-one members of the Committee made a veritable 1928 "Who's Who in Radiological Physics", and most of them were active in the field through the 1930s.

The principal topic of discussion at the meeting was, of course, the adoption of the unit in which to express the quantity that was being measured with the free-air ionization chamber. The only record of the meeting is the eight point set of recommendations proposed by the Committee and adopted by the Congress on July 27, 1928:

Recommendations of the International X-Ray Unit Committee

1. That an international unit of X-radiation be adopted.

2. That this international unit be the quantity of X-radiation which when the secondary electrons are fully utilized and the wall of the chamber is avoided, produces in one cubic centimeter of atmospheric air at zero degrees C, and 76 centimeters of mercury pressure, such a degree of conductivitity that one electrostatic unit of charge is measured as saturation current.

3. That the international unit of X-radiation be called the Röntgen and that it be designated by the letter small "r".

4. That various standard methods be employed to establish the unit.

5. That for all comparative purposes it is advisable to employ ionization chambers which have been calibrated in terms of a standard chamber for X-radiation of the various qualities employed. It is also advisable to make the wall effects of these chambers as small as possible.

6. That the practical instrument used to measure X-ray output be called a dosage meter (Dosismesser, or dosimètre).

7. That the constancy of the indications of the dosage meter be tested by means of gamma radiation emitted from a definite quantity of radium element, the measurement being always carried out under the same conditions.

8. That any specification of dosage is incomplete without specifying the quality as well as the quantity of irradiation. The quality of X-radiation used for practical purposes is very varied and it would be impractical to give a complete specification of it; but much information can be obtained from a knowledge of degree of

absorption of the radiation in standard materials, the peak voltage applied to the tube together with the filter employed, and the general character of the high tension apparatus.

For practical purposes the quality may be expressed by stating the half value layer in a suitable material, or by stating the effective wavelength as determined by the percentage amount of radiation transmitted through a given thickness of a suitable material (copper or aluminium).

In view of the fact that rapid progress is being made in methods of X-ray measurements and in our knowledge of X-ray phenomena, the Committee feels that the above recommendations should be regarded as being of a provisional character.

M. Siegbahn Sweden Chairman	E. A. Owen Gr. Britain Hon. Secretaries	H. Holthusen Germany
F. Sluys Belgium	V. Posejpal Czechoslovakia	K. Gawalowski Czechoslovakia
H. M. Hansen Denmark	L. Arntzen Denmark	N. S. Finzi Gr. Britain
A. Dauviller France	L. Solomon France	H. Behnken Germany
M. Ponzio Italy	E. Pugno-Vanoni Italy	M. Nakaidzumi Japan
S. A. Heyerdahl Norway	N. Nemenow S.S.S.R.	J. Grau Casas Spain
R. Torres Carreras Spain	R. M. Sievert Sweden	R. Gilbert Switzerland
H. R. Schinz Switzerland	W. Duane U.S.A.	E. C. Ernst U.S.A.

Imperfect as this report would now appear, it was nevertheless of critical importance at the time and certainly was compatible with the general understanding of the overall problems of measuring ionizing radiation at that period. It satisfied the initial needs of x-ray dosimetry for radiation therapy. It defined a reproducible method for measuring x rays and was the first step leading to the replacement of a variety of other measurement techniques and systems of quantities and units. Again, in hindsight, it is interesting today to realize the naivete of some of our early thinking in that period.

The definition of the Röntgen, as agreed upon in 1928, was really the definition of a quantity and also of the unit in which that quantity was to be expressed. In addition, it defined the geometry of the standard. An examination of the minutes and reports of the ICRU meetings over the next decade would make clear some of the confusion during this early period. Much of this was not to be straightened out until sometime beginning around the middle 1950s, by which time a great deal of new knowledge had been developed about ionizing radiation and there were available many more individuals having experience in the ionizing radiation field.

6. International Comparisons

However, the obvious and immediate problem following the 1928 Congress was to establish acceptable free air x-ray standards in national laboratories of those countries that had such laboratories. Actually, there were less than half a dozen of these, including U.S., U.K., Germany, France and Sweden, the latter two being of relatively limited scope.

Because of the confusing situation in connection with the relationship between European and American standards, as noted above, it appeared to Taylor and collaborators in NPL and in PTR that a more effective intercomparison of standards must be carried out as soon as possible. This, in turn, led to the development of a more compact free-air ionization chamber using a guard-wire system to provide a uniform field in which the ionization would be collected.

By the spring of 1931, large free-air ionization chambers were in place in England, Germany and the United States and, in addition, there was a small guarded-field ionization chamber which the Bureau of Standards regarded as a transfer standard. Direct comparisons, using the transfer standard were made with the existing standards in the laboratories of each of the countries during a period of 6 or 7 weeks, immediately preceding the 1931 Congress in Paris and the second meeting of the International X-Ray Unit Committee. In this connection, it should be recalled that at this time the NBS standard had shown agreement with Glasser and Failla and that the measurements with the Duane standard were low, that is, there was a loss of measured ionization somewhere.

Comparing the 1928 and 1931 visits at the NPL, it was noted that they now had a new ionization chamber having a 12 cm plate separation, a total length of about 40 cm, and about 35 cm from the diaphragm to the center of the collector electrode, thus, better assuring an adequate field correction. Comparison measurements were made at 110 and 143 kV constant potential. The initial measurements indicated a difference of slightly over 6% between the U.S. and the U.K. measurements. However, this was found to be due to differences in the diaphragms used to define the beam entering the ionization chamber. When the same diaphragm was used on either chamber, the disagreement was reduced to less than 3% which, at the time, was considered satisfactory.

Arriving at the PTR in Berlin in 1931 there was surprise at finding that the small pressure chamber which Behnken had had in place on the first visit in 1928, had been replaced with a larger cylindrical chamber following the design ascribed to Holthusen, with a distance of about 40 cm between diaphragm and collector electrode and operating at atmospheric pressure. Measurements were made at 150 and 180 kVp and the average error between the various measurements was a little less than 1% (Taylor, 1932). It developed that all three national laboratories had introduced new standards since 1928.

Recalling that earlier there had been agreement between Duane and Behnken in 1927 but both had been shown to be low compared to the NBS standard and Glasser, this change in ionization chambers is significant. This was to be found out some years later (1940) when the NBS carried out studies with ionization chambers operating in air pressures up to about 10 atmospheres, where one must apply rather sophisticated corrections to overcome the loss of ionization by ion recombination (Taylor *et al.*, 1939). Thus, it would seem that the picture which had developed as a result of the 1927 disagreement between measurements in the U.S. and Germany were now largely explained.

Comparisons were also made with the only French standard then in existence, namely the Solomon standard which operated at the Hôpital St. Antoine in Paris. The chamber which they referred to as the standard was also used in the hospital for routine calibration of their own equipment. Indeed, the comparison measurements were made in one of the therapy rooms at voltages of 110, 150 and 190 kVp. Direct numerical comparison between the French and other standards could not be made because of the basically different principles upon which they operated. The final results showed that one r, international, equalled 2.29 R, Solomon. This compared with a value of 2.25 R reported earlier by Solomon for the same chamber and which could be considered as very good agreement. Actually the agreement could not be as good as the second decimal place.

The presentation of the results of these comparisons to the ICRU, at its meeting in Paris, resulted in considerable satisfaction as to the status of the measurement problem. Following the introduction of this report, a move was made to adopt the compact U.S. standard as an international transfer standard but this was opposed and no action was taken.

The one-day meeting of the International X-Ray Unit Committee in 1931, was attended by 30 participants from a number of countries and it is recalled that it was an almost unmanageable congregation. It is not surprising, therefore, that there were no fundamental considerations regarding the quantities and units question. (A new minor recommendation called for the measurement of "intensity" of irradiation to be expressed in r per second. This was apparently pretty much ignored subsequently). Some further recommendations were made as follows (Radiol **22,** 294, Mar 1934):

1. The experimental methods of establishing a standard for the determination of the International X-Ray Unit shall be entrusted to a subcommittee consisting of the following members of the Unit Committee: M. de Broglie (France), W. Friedrich (Germany), E. A. Owen (Great Britain), R. Sievert (Sweden), I. Solomon (France), E. Pugno-Vanoni (Italy), L.S. Taylor (U.S.A.). (Honorary Secretary of the Committee, E. A. Owen). This subcommittee shall invite the collaboration of the various existing national bureaus for standard measurements in existence and also those about to be instituted.

2. The Committee shall consider: (a) methods for controlling the constancy of dosage meters; (b) the correlation of X-ray and gamma-ray dosage; (c) the establishment of a gamma-ray unit of intensity.

3. The progress of the work done by the Subcommittee shall be reported once a year to the members of the International X-Ray Unit Committee.

4. Each country shall be requested immediately to elect its two representatives on the International X-Ray Unit Committee; until new representatives are elected, the present members shall serve.

5. The International Committee shall henceforth be called the International Committee for Radiological Units.

From the discussion above, it is clear that the major preoccupation of the Committee in 1931 was the matter of measurement and measurement techniques and there is no question but that this had to be agreed upon as quickly as possible on some basis. It may be recalled that at the close of the 1928 meeting, the Committee had noted that its recommendations should be regarded as being of a provisional character. While not so specified at the end of the 1931 Paris meeting, it can probably be said that the Committee continued to hold to its concept that the recommendations remain provisional. In any case, it was to be considered as a successful overall conference.

7. Conclusion

During the period from Röntgen's discovery of x rays in 1895 until 1931, the world of quantitative radiation measurement had moved forward. Slowly at first, but with greater urgency and effort to meet growing demands by the medical profession, it moved from the qualitative methods of detection or indication to more scientifically comprehended understandings of the basic phenomena. These advances were accompanied by the development of more sophisticated systems of measurements embodying broad agreement among workers and the national laboratories of several countries.

The ICRU became the keystone in the first big step in 1928, and has remained in that critical role, since.

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Image Perception and Performance Assessment in Digital Imaging

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Image Quality

The quality of an image can be defined in two ways. The more conventional approach is to compare it with the object; measures such as image fidelity (Linfoot, 1964), have been introduced to measure quantitatively the similarity between object and image. The main drawback with the technique is that it gives equal weight to both relevant and irrelevant features, those pertinent to the interpretation of the data and those which are not.

If we confine this discussion to medical images, then we are primarily interested in those features which aid in making the correct diagnosis. An imaging modality or processing technique which emphasises these features at the expense of others may give an image which, while not resembling the object with any great accuracy, will be more effective at achieving the aim of the imaging process, a correct clinical diagnosis. Our second measure of image quality can, therefore, be defined as "the effectiveness with which the image can be used for its intended task" (Sharp, 1984).

The most general approach to assessing image quality utilises the so-called "signal to noise ratio" (De Vries, 1943; Rose, 1942, 1948). This parameter assesses the degree of discrimination between relevant (signal) and irrelevant information (noise) in the image. Note that, in the sense we are using it here, noise is not simply limited to random fluctuations in image intensity but refers to all detail which distracts from the detection of the signal.

The term "detection of the signal" must also be considered in a little more detail at this stage. Image quality may depend critically upon the level of diagnostic information required from the imaging technique. Signal discriminability can be regarded as taking place at two levels. The first of these, simple detection, involves the realisation that the image detail differs from that which would be regarded as normal, this may be abnormal pathology, for example. The second level involves the ability to extract additional information from the abnormal signal which then permits the type of abnormality to be identified, i. e., a choice to be made from several possibilities (e. g., Wagner and Brown, 1985). The distinction is thus between the degree of information which can be extracted from the image.

Any assessment of image quality must, therefore, address this fundamental problem of defining the objective of the imaging technique. In the context of a medical imaging modality, this must, in the final reckoning, be the amount of diagnostic information provided. Any framework to study the performance of digital imaging must be able to encompass this objective, although, as this may be difficult to achieve, more conventional measures of quality must be incorporated into the chain of assessment.

To evolve a performance assessment it is first necessary to consider a general imaging system (see Figure 1). Then each element can be examined to identify the areas in which quality may be significantly degraded.

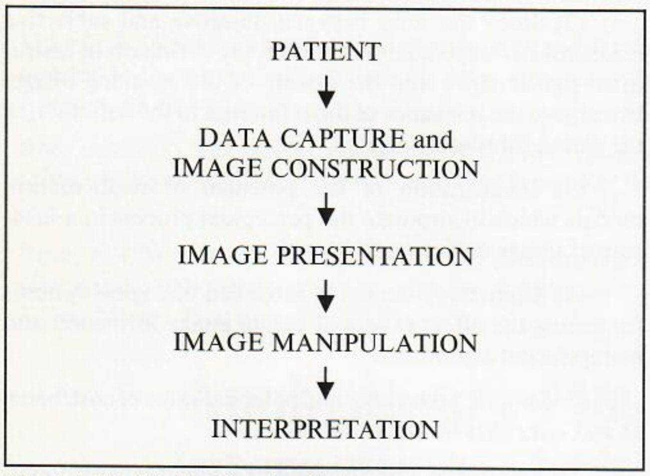

Figure 1. The Medical Imaging System.

Patient

At this stage, image quality is degraded by what can be termed as physiological noise. This covers several factors such as variations in normal anatomy of an organ, the distortion caused by organ motion, artefacts created by blood flow and effects caused by the surrounding tissue such as signal attenuation. All of these are peculiar to the patient and while the actual effect of the different sources of degradation produced depends upon the imaging process, it is largely out of the control of the operator.

Data Capture and Image Construction

Data capture refers to the first part of the imaging process, that in which the signal from the patient is received. No matter how accurately the imaging device can reproduce the received signal, if this signal has been distorted, then image quality will be degraded. An example of this effect would be the failure of the imaging device to reject those x or gamma-rays which have been scattered by patient tissue.

After this signal has been detected by the imaging device, it is necessary to manipulate the detected signal to create an image from it. Image quality depends upon both the construction of the device and the accuracy of the algorithms used to construct the image, such as tomographic routines, spin warp, etc. The instrument may also introduce spatial non-linearities or poor resolution.

Presentation

Before it can be interpreted by a clinician, the data must be presented in a form which will allow it to be analysed visually. The efficacy of a display system can be considered in two parts. Firstly, how accurately the data presented to the display represents the image and, secondly, how effectively this information is then conveyed to the observer. The first problem can be analysed mainly in mathematical terms, e. g., the adequacy of the sampling of the data, while the latter requires an understanding of the behaviour of the visual system.

Image Manipulation

Noise in the image can be further reduced by manipulation of the data. Several techniques have been used; for example, maximum entropy techniques (Kemp, 1981) aim to make the image more closely resemble the original, while principal component analysis (Barber, 1976) reduces the image to only its abnormal features, and functional imaging (Goris, 1987) completely alters the form of the image data.

Interpretation

The final step is the decision making process where the information present in the image is used to make a clinical decision. One of the major sources of error at this stage, and one which is rarely recognised, is the failure to appreciate the limitations inherent in the imaging technique and the precise nature of the information that is being provided.

Current Approaches to Measuring Image Quality

Faced with the noise originating from a number of sources, assessment of image quality has developed along several different lines.

Specifications of Imaging Device Behaviour

The performance of the imaging instrument itself is measured in terms of spatial resolution, temporal resolution, homogeneity of detector response, etc. The choice of parameters has been largely dictated by the need to produce quantitative measures both to facilitate intercomparison of the performance of different models of the same type of imaging device and for quality assurance testing.

To achieve this, the performance indices have often been chosen to measure specific aspects of the performance of the imaging device, such as sensitivity and spatial resolution, with the result that interrelationships and trade-off between one aspect of performance and another has been difficult to achieve. Also, there has been little effort to relate measures made on one type of imaging device to another type. Finally, there is a problem in determining the action thresholds for these indices, i. e., the value which indicates that remedial action is necessary. The choice of this threshold is clearly linked to the effect of changes in these indices on image quality.

Measurement of the Quality of Images

This deals mainly with the effectiveness of the link between the final data, usually in the form of an image, and the observer. Two main approaches have been made to this problem. The first is the use of standard psychometric techniques to assess quantitatively the perceived quality of the image. Signal detection theory (Green and Swets, 1966), the method of constant stimulus (Corso, 1967) and ranking/rating techniques (Sharp, 1987) have all been utilised with various degrees of success.

The second approach has been to develop mathematical models, usually incorporating some model of the perceptual process, to predict the quality of the image (for example, Rose, 1946; Morgan, 1965; Schade, 1956; Sharp and Mallard, 1974; Burgess *et al.* 1982; Wagner, 1983). Recently, there has been considerable progress in producing a model, based on the concept of the ideal observer, which would be applicable to predicting the performance of a variety of digital imaging devices (Wagner and Brown, 1985).

Effectiveness of Algorithms

One of the major advantages of a digital imaging technique is that it facilitates the use of mathematical algorithms in the image formation process. These algorithms may contribute directly to the image formation process, as in various tomographic imaging procedures, or they may be used to enhance the image by further processing of the acquired data, for example, image filtering and functional analysis. Such techniques can be tested using computer simulated data but the main problem encountered in such simulations is to produce data with noise resembling that found in the clinical images.

Clinical Effectiveness of the Imaging Technique

Ultimately, the effectiveness of an imaging device is measured by the value of clinical information which can be obtained form it. Full clinical trials are lengthy and difficult to perform and have several major drawbacks. For example, to influence the development and acceptability of a new technique they need to be performed in the early phase after its introduction, yet this is just when the technology is changing most rapidly. A second problem is that the contribution made by a new technique towards a particular diagnosis must be assessed in conjunction with the information provided by existing techniques which, themselves, may not have been fully evaluated. Finally, the results of these trials must be incorporated into a form of cost/benefit or cost/effectiveness assessment. A fuller discussion of these problems of technology assessment can be found in Fineberg (1985).

Structure of Proposed ICRU Study*

The prime aim of this study is the production of a framework within which the performance of digital imaging technology can be linked to the effectiveness of the technique. There are several strands which, at least initially, can be pursued separately.

(1) Definition of the basic aims of the different forms of digital imaging modalities, i. e., radionuclide imaging, MRI, US, digital radiology. Assess the accuracy with which these aims can be achieved with existing technology. Identify the limitations of current and future technology.

(2) Study the links between objective and subjective measures of image quality, between the definition of instrument performance and the quality of the resulting image. Investigate the relevance of these findings to the definition of the action threshold.

(3) Investigation of the potential of mathematical models which incorporate the perceptual process in a measure of image device performance.

(4) Study the potential of modelled biological systems for testing the effectiveness of digital image formation and manipulation algorithms.

(5) Study the relevance and potential value of cost/benefit and cost/effectiveness studies.

This particular study is planned at a particularly opportune moment. There is a strong practical and theoretical framework for studying image quality, and there has been a considerable amount of work in some, but not all, of the digital imaging modalities on how to measure the performance of imaging devices. What is now required is the ability to combine these different approaches into a single framework which will ultimately also include a measure of clinical efficacy of the technique.

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Applications, Dosimetry and Biological Interactions of Static and Time-varying Magnetic Fields

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The primary topics of this presentation include: (1) the applications of magnetic fields in research, industry, and medical technologies; (2) mechanisms of interaction of static and time-varying magnetic fields with living systems; (3) human health effects of exposure to static and time-varying magnetic fields in occupational, medical, and residential settings; and (4) recent advances in the dosimetry of extremely-low-frequency electromagnetic fields. The discussion of these topics is centered about two issues of considerable contemporary interest: (1) potential health effects of the fields used in magnetic resonance imaging and in vivo spectroscopy, and (2) the controversial issue of whether exposure to extremely-low-frequency (ELF) electromagnetic fields in the home and workplace leads to an elevated risk of cancer.

Magnetic Resonance Imaging and In Vivo Spectroscopy

The application of nuclear magnetic resonance (NMR) techniques for medical imaging and in vivo spectroscopy involves the exposure of humans to static magnetic fields, time-varying magnetic fields, and radiofrequency (RF) fields. Nearly all of the NMR imaging devices currently being used throughout the world employ static magnetic fields with flux densities less than 2.5 tesla. The time-variation of the flux density in these devices is less than 3 T/s, and the RF fields produce whole-body specific absorption rates that are less than 0.4 watts per kilogram (W/kg.) The potential health effects of these fields has been reviewed recently by Tenforde and Budinger[1].

The primary mechanisms of interaction of static magnetic fields with living systems are: (1) electrodynamic interactions with moving electrolytes such as the ions flowing in the circulatory system; (2) magneto-mechanical effects, which include the translation of paramagnetic and ferromagnetic materials in strong magnetic field gradients, and the orientation of diamagnetically anisotropic molecular assemblies in strong uniform fields (e.g., retinal rod disk membranes); and (3) effects on electronic spin states of radical-mediated charge transfer processes. Only the first of these mechanisms of interaction has been demonstrated in laboratory studies to produce a measurable effect in animals, namely, the magnetic induction of electrical potentials in the central circulatory system. These potentials reach a level exceeding one millivolt in large animal species exposed to a 2 tesla field. However, there are no measurable hemodynamic alterations associated with the mechanical volume forces resulting from these magnetically-induced electrical potentials. At the very high field levels of 5 to 10 tesla proposed for future use in NMR spectroscopy with human subjects, small magnetohydrodynamic effects on blood flow are predicted to occur.

Time-varying magnetic fields with ELF frequencies result from the rapid switching within an NMR imaging volume of the magnetic field spatial gradients that are used to localize signals from protons or other nuclei. Based on numerous laboratory studies and limited studies with human subjects, the biological effects of ELF magnetic fields can be related to the current density induced within specific tissues. Fields inducing current densities in the range of 1 to 10 milliamperes per square meter (mA/m^2) have been found to produce various reversible effects that do not lead to quantifiable health risks. One example is the production of a flickering illumination within the visual field, a phenomenon first discovered by d'Arsonval in 1896 and known as magnetophosphenes. At higher induced current densities of 10 to 100 mA/m^2, a variety of irreversible tissue effects have been reported to occur in response to ELF magnetic field exposure. These effects include the acceleration of bone fracture healing, apparently in response to the stimulation of osteoblast proliferation and an increase in collagen production as a consequence of the magnetically-induced electrical current established within the fracture region. At induced current density levels exceeding 100 mA/m^2, direct effects on nerve tissue electrical activity and neuromuscular stimulatory effects have been reported. When the induced current density exceeds 1 A/m^2, there is a risk of severe effects on electrically active tissues such as the heart.

The RF fields used in NMR imaging and in vivo spectroscopy interact with tissue primarily through the deposition of thermal energy. The specific absorption rate of the RF fields is proportional to the electrical conductivity and the square of the electric field intensity in tissue. When the deposited energy exceeds approximately 4 W/kg, the thermoregulatory capactiy of the body is exceeded and significant elevations in tissue temperature occur. Extensive laboratory research has demonstrated that the prolonged heating of tissue by RF fields can produce adverse effects on neuroendocrine and nervous tissue functions, on sensory function and animal behavior, the circulatory system, the hematologic and immunologic systems, and on reproduction and fetal development. In general, the specific absorption rates that produce significant effects on living tissues are not exceeded in the present generation of NMR imaging devices.

A number of laboratory and epidemiological studies have been carried out to assess the effects of exposure to static and time-varying fields on human health. In general, exposure to high-intensity fields for the brief periods typical of NMR imaging and in vivo spectroscopy procedures have not been found to alter physiological functions or lead to an elevated incidence of disease. There are, however, a number of physical hazards that can result from high-intensity static magnetic fields and time-varying fields. These hazards include: (1) forces and torques exerted on ferromagnetic materials such as aneurysm clips and prosthetic devices; (2) heating of large prosthetic devices exposed to RF fields; and (3) pacemaker malfunctions associated with closure of the reed relay switch by static magnetic fields, and the introduction of electromagnetic interference by time-varying fields.

Cancer Risk in Relation to ELF Field Exposure

A second major health issue discussed in this lecture is the recent set of epidemiological observations which indicate that chronic exposure to ELF electromagnetic fields may lead to an elevated risk of cancer, primarily leukemia and nervous system tumors. Since 1979, a total of 27 publications have appeared on the topic of a possible relationship between residential and/or occupational exposure to power-frequency fields and the risk of cancer. The initial publication by Wertheimer and Leeper[2] reported an apparent correlation between the incidence of cancer and exposure of children to the 60-Hz magnetic fields from high-current primary and secondary wiring configurations in the vicinity of their residences. This conclusion was based on a case/control epidemiological survey of death records for children in the Denver, Colorado area during the period 1950-1973. The authors speculated that the larger 60-Hz magnetic fields in the homes of subjects living near high-current distribution lines may be a causal factor underlying their elevated cancer risk. A later epidemiological survey by Tomenius[3] on childhood cancer incidence in Stockholm, Sweden, produced results that were consistent with the Wertheimer and Leeper study. A second epidemiological study by Wertheimer and Leeper[4] on cancer deaths among adults living in the Denver area led to results that were similar to those obtained in the earlier study on children from the same geographic area.

In contrast to these three studies, five other independent epidemiological surveys have shown no clear relationship between childhood or adult cancer incidence and residential exposure to the 60-Hz magnetic fields from electric power distribution lines.[5-9] The most noteworthy of these studies was carried out by Savitz *et al.,*[9] who attempted a replication of the original Wertheimer/Leeper study on childhood cancer in the Denver area. These investigators used a case/control epidemiological study design similar to that of Wertheimer and Leeper. However, in addition to estimating exposure of the subjects to residential 60-Hz fields based on the high-current or low-current configuration of power distribution lines, point-intime measurements were made of the 60-Hz electric and magnetic fields present in the residences of the cases and controls. Based on these direct field measurements, there was no statistically significant correlation between 60-Hz field exposure and the incidence of childhood cancer. In contrast, the cancer risk was found to be correlated with the estimated exposure levels based on power line configurations, which was interpreted by the investigators as being supportive of Wertheimer and Leeper's original observations. It is important to note, however, that the assocation found by Savitz *et* *al.*[9] between presumed exposure based on power-line configuration and cancer incidence was marginally significant, whereas the earlier findings of Wertheimer and Leeper[2] were robust with relative cancer risk factors approaching a factor of 2.

The possible association between exposure to power-frequency fields and cancer risk was extended to include occupational exposure with the 1982 publication by Milham[10] of a study in which he observed a higher incidence of leukemia among workers in various electrical occupations. This report was followed in the subsequent 5 years by 18 publications on the topic of occupational exposure to ELF fields and cancer risk. Of these studies, a total of 13 reported a statistically significant increase in cancer, primarily leukemia and nervous system tumors, among workers in various electrical occupations. The results of any individual study, however, were seldom unambiguous insofar as workers in some electrical occupations exhibited an elevated cancer incidence, whereas those in other electrical occupations did not. There was little consistency between studies in regard to which electrical occupations are associated with an elevated risk of leukemia or other forms of cancer.

In an effort to reconcile the discrepancies between these independent studies, Savitz and Calle[11] carried out a comprehensive evaluation of 11 sets of epidemiological data in which the cancer risk could be expressed in terms of a relative risk factor. They found that few electrical occupations could be uniquely associated with an elevated risk of leukemia. However, when the pooled data from 12 occupational categories was analyzed, the relative risk factors for acute leukemias and acute myelogenous leukemias were found to be 1.4 and 1.5, respectively. Both of these relative risk factors were statistically significant, thereby supporting the original hypothesis of Milham[10] that occupational exposure to power-frequency fields is associated with an elevated risk of leukemia.

Overall, the results of 16 of 27 epidemiological surveys published since 1979 indicate an apparent association between cancer incidence and residential or occupational exposure to power-frequency electromagnetic fields. However, there were a number of methodological deficiencies in these studies that limit the soundness of their conclusions. Several specific problems are the following: (1) In nearly all of the studies thus far reported, the magnetic field dosimetry was at the best qualitative. In studies of residential ELF magnetic fields, the neglect of local fields from applicances may have led to incorrect conclusions regarding the peak and average exposure of individuals to 60-Hz fields and the harmonic frequencies that emanate from various electrical devices used within the home. (2) The sample populations in many of the epidemiological studies were small, and the reported increases in cancer incidence by a factor of 2 or less could occur on the basis of chance alone. In these studies, it would have been informative if the authors had presented data on several nonexposed occupational groups in which the sample size was comparable to that of the exposed groups. (3) Control groups were frequently chosen in a nonblind manner involving subjective criteria, and the control population was often not matched with the exposed group on the basis of age, sex, race, socioeconomic class, or urban/rural residential status. (4) Several of the studies used weak statistical methods such as the calculation of proportionate mortality ratios, which can lead to incorrect conclusions for population subgroups in which the overall incidence of disease is low with the exception of one disease class such as cancer (or some specific form of cancer such as leukemia). (5) The existence of confounding factors such as smoking habits and exposure to industrial pollutants of known carcinogenic potential (e. g., aryl hydrocarbons) was ignored in nearly all of the epidemiological studies that have attempted to relate ELF field exposure and cancer risk. Seven new epidemiological studies that have been designed to overcome many of these deficiencies are being undertaken in North America and Europe at the present time.

An important aspect of future epidemiological studies related to ELF field exposure and cancer risk is the use of miniature personal dosimeters. Since 1984, a total of 8 personal dosimeters have been fabricated and tested at various laboratories in the United States, Canada, and Europe. These devices contain microprocessors and random-access memories that record exposure to 50-Hz and 60-Hz electric fields, magnetic fields, or both. Several of these units hold promise as cost-effective devices that can be mass-produced for monitoring ELF field exposures in significant populations of electrical workers or individuals in household environments. In addition, seven new models of portable or stationary survey meters have been developed for the long-term (days to weeks) monitoring of ELF fields at specific locations in residences and industrial environments.

The issue of whether exposure to power-frequency fields in residential and occupational settings elevates the risk of cancer has led to a rapid expansion of research on the biological effects of nonionizing radiation during the past two years. At the present time, the major sponsors of research in this area in North America are the Electric Power Research Institute (Environmental Division/Radiation Studies Program), the U.S. Department of Energy (Office of Energy Storage and Distribution), the U.S. Office of Naval Research, Ontario Hydro and Hydro Quebec, and the Canada Health and Welfare Department in Toronto. In Europe, active research programs are funded by the Swedish National Institute of Occupational Health, the Central Electricity Research Laboratories of England, Électricité de France, and the Ente Nazionale per l'Energia Elettrica in Italy.

Two comprehensive reviews prepared by the Non-ionizing Radiation Committee of the International Radiation Protection Association on the biological effects of ELF fields have recently been published as Environmental Health Criteria (EHC) documents by the World Health Organization: "Extremely Low Frequency (ELF) Fields" (EHC No. 35) and "Magnetic Fields" (EHC No. 69). Both documents are very comprehensive, and the EHC document number 69 contains an extensive discussion of the literature on cancer risk in relation to ELF field exposure.

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ICRU Report on Stopping Power for Protons and Alpha Particles

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Work is in progress on a tabulation of stopping powers for protons and alpha particles at energies from 1 keV to 1000 MeV in 73 elements and compounds of interest in radiation dosimetry. The list of materials included is the same as that in ICRU Report 37 (1984) on electron stopping powers. The new tables include electronic stopping powers (due to inelastic interactions with atomic electrons), nuclear stopping power (due to elastic collisions with atomic nuclei), and total stopping powers. Also included are continuous-slowing-down approximation (csda) ranges, and detour factors which are the ratios of projected ranges to csda ranges.

The tabulations were done differently in the high- and low-energy regions, with the energy boundary at approximately 0.5 MeV for protons and 2 MeV for alpha particles. In the high-energy region, use was made of Bethe's stopping power theory, with an empirically determined mean excitation energy, and with semi-empirical shell corrections, Barkas corrections and Bloch corrections, and, in the case of protons, density-effect corrections. The values of the mean excitation energy (a key parameter in Bethe's stopping power formula) were taken from ICRU Report 37, because an examination of the recent literature indicated little need for changes. The shell corrections and the Barkas corrections for elements with atomic numbers less than 64 were also the same as those used in ICRU Report 37. Those for elements with larger atomic numbers were obtained from a new data analysis by Bichsel (1988).

In the low energy region, stopping powers for elements were obtained from empirical data fits of Andersen and Ziegler (1977) for protons, and of Ziegler (1977) and Watt (1988) for alpha particles. In addition, more recent experimental data were used to adjust these fits wherever possible. For protons in compounds, use was made of direct experimental stopping powers where possible; for alpha particles such information was obtained mainly from a report prepared for the committee by Powers (1978). When direct information was lacking, the stopping powers for compounds were obtained through the combination of stopping powers for elements, assuming Bragg additivity.

The curves of stopping power vs. energy in the high- and low-energy regions were merged through a splining procedure (controlled by visual graphical inspection for each case) applied to the product of particle energy times stopping power, plotted vs. the logarithm of the energy (Fano plot).

The nuclear stopping powers, and the detour factors, were derived from the elastic scattering cross sections. The latter were calculated by a classical method (and for protons at high energies also a quantum mechanical method), using a screened Coulomb potential. For protons, Molière's approximation to the Thomas-Fermi potential was used; for alpha particles, an atom-atom potential given by Ziegler, Biersack and Littmark (1985) was used.

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Phantoms in Therapy, Diagnosis and Protection

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Following the completion of the ICRU Report entitled, "Tissue Substitutes in Radiation Dosimetry and Measurement", and its subsequent acceptance by the Commission for publication as ICRU Report 44, a new Report Committee was formed to investigate the specification of phantoms. This new initiative which is considering "Phantoms in Therapy, Diagnosis and Protection", was seen as a natural progression from the Report on tissue substitutes.

The new Report Committee has Professor A. Wambersie and Professor H. Rossi as Sponsors and a membership of seven, including theoretical and experimental physical scientists, an anatomist/anthropologist and a mathematician [D. White (Chairman), C. Buckland-Wright, R. Griffith, L. Rothenberg, G. Williams, I. Wilson and M. Zankl]. Consultants advising the Committee include recognised world authorities on body tissue composition and on the design and use of specialised phantoms [J. Dickerson, G. Drexler, I. Nikl, E. Widdowson, H. Woodard and J. Zoetelief].

The Committee had its first meeting in Munich during October, 1987 and its second in Brussels during June/July, 1988. At the second meeting, a draft of some 50% of the expected final text was discussed in detail. The Report has major sections on human anatomy, selection requirements for phantoms, phantoms in radiotherapy, diagnostic procedures, radiation protection and radiobiology, geometric models and quality assurance.

Reliable data on *human anatomy* is essential when body (anthropomorphic) phantoms are being designed. The internal and external geometry of the human body and its organs, from fetus to adult is being considered, together with the associated physical dimensions and tissue compositions. Variations due to ethnic origins are also being assessed. Close liaison with the committee of the International Commission on Radiological Protection that is concerned with the Reference Man and groups involved with establishing Reference Chinese and Reference Japanese is being maintained.

The section on *selection requirements for phantoms* sets out clearly the requirements of all types of phantoms intended to represent the human body. Dosimetric, calibration, imaging and body phantoms are included in the analysis.

Four separate sections deal with *phantoms in radiotherapy, diagnostic procedures, radiation protection and radiobiology*. The special requirements of each specialty are discussed. Over 60 phantoms have been identified for inclusion in the Report.

A generalized approach to mathematical models *(geometric models)* has been developed. The main paediatric and adult models used in theoretical studies are discussed in detail.

Quality assurance programmes that users of phantoms can adopt for long-term checks on their phantoms will be outlined.

Extensive *Appendices* are being prepared for this Report. These include human anatomical data and full specifications of each of the cited phantoms and geometric models.

Tissue Substitutes in Radiation Dosimetry and Measurement

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In ICRU Report 44, the elemental compositions of 24 healthy, adult body tissues were given. These were selected from a tabulation for 56 body tissues, produced during a reassessment of tissue composition initiated by the ICRU Report Committee responsible for the preparation of ICRU Report 44. The compositions of average soft tissues were also included in the Report. The ICRU Report Committee on Phantoms in Therapy, Diagnosis and Protection has recently extended these studies to include fetal and pediatric tissues.

The consequence of this work is that there are now approximately 100 tissue compositions available, covering soft and skeletal tissues in the age interval from fetus to adult. As a result, the ICRU authorized the preparation of a supplement to ICRU Report 44.

Calculated interaction data for photons, electrons, protons and neutrons were produced for ICRU Report 44, using the computational methods developed at the National Bureau of Standards, Washington. The same system will be used in the Supplement to generate interaction data for the complete set of tissue compositions.

The Supplement will start with a short introduction to the tabulations of radiation interaction data. The computational methods adopted will be outlined and the elemental compositions of the selected body tissues listed.

The body tissues will be considered in three groups, namely, soft tissues, skeletal tissues/calculi and average tissues. All the major soft tissues will be covered, including adipose tissue, brain, kidney, liver, lung, muscle (skeletal), skin, spleen and thyroid. Skeletal tissues/calculi will include osseous tissue, red marrow, yellow marrow, cartilage, gallstones, urinary stones and breast calcifications. Average tissues will cover the whole body, soft tissue, whole bones and whole breast. For each body tissue or group of tissues, the compositions appropriate to fetal, infant, child and adult subjects will be used, if they were not included in ICRU Report 44. Any differences in the compositions of average whole body and average soft tissue because of ethnic origins will be identified. A small selection of diseased soft and skeletal tissues will also be considered. Any additional tissue compositions cited in the ICRP Reference Man Revision will be included.

The 1988 Meeting of the Commission

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The International Commission on Radiation Units and Measurements (ICRU) met in Helsinki 15-19 August 1988 on invitation of the Centre for Radiation and Nuclear Safety of Finland. The meeting was planned to permit the Commission to (1) examine the current status of efforts underway in ICRU subgroups, (2) consider the immediate future course of the Commission's program, and (3) act on various other matters related to Commission operations.

At the meeting Dr. Schulte-Frohlinde was selected as the Sixth Gray Medalist. The Medal, which honors the late Louis Harold Gray, a former member and Vice Chairman of the Commission, will be presented at the XVIIth International Congress of Radiology to be held in Paris 1-8 July 1989. Dr. Schulte-Frohlinde will present the ICRU Gray Medal Lecture at the Congress.

No report committee drafts had been submitted for review by the Commission at the 1988 meeting, and thus the Commission had the opportunity to devote considerable attention to examination of the work currently underway, plans for new efforts and potential new activities.

As part of its examination of the current status of efforts presently underway, the Commission noted the status of the following recently completed efforts:

Published:

ICRU Report 42, *Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photons and Electrons*

In press:

ICRU Report 43, *Determination of Dose Equivalents from External Radiation Sources - Part 2* (now published)

ICRU Report 44, *Tissue Substitutes in Radiation Dosimetry and Measurement* (now published)

Preparing printer's manuscript:

ICRU Report 45, *Clinical Neutron Dosimetry - Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons*

The Commission also received reports on the activities underway in the following subgroups of the ICRU:

- Absorbed Dose Standards for Photon Irradiation and Their Dissemination
- Clinical Dosimetry for Neutrons (Dose Specification for Reporting)
- Fundamental Quantities and Units
- Measurement of Dose Equivalent
- Fundamentals of Particle Counting
- Stopping Powers for Protons and Alpha Particles

A review of the activities of these subgroups indicated that the drafting work on the reports being prepared is making good progress.

The Commission devoted considerable attention to plans for recently initiated report committee activities, receiving detailed information on efforts devoted to the following topics:

- Dose Specification for Reporting Interstitial Therapy
- Performance Assessment in Digital Representation of Images
- Phantoms for Therapy, Diagnosis and Protection
- Quality Assurance in External Beam Therapy

As a result of its examination of the work underway and the plans for future work, the Commission determined to reorganize the efforts of the report committees working on chemical dosimetry and specification of imaging instruments in nuclear medicine.

Continuing the policy initiated at the 1986 meeting, the Commission utilized seminars given by invited speakers to gather information and understanding of scientific fields of interest to the Commission. The 1988 meeting included the following seminars:

Relating to recently initiated activities:

- Dose Specification for Reporting Therapy with Photons and Electrons - Dr. T. Landberg
- Stopping Powers for Heavy Ions - Dr. P. Sigmund

Relating to potential new activities:

- Concepts and Quantities in Microelectronic Damage - Dr. J.C. Ritter
- Hyperthermia - Dr. T. Landberg (based on written material developed by Dr. B. Persson)
- Magnetic Fields - Dr. T.S. Tenforde
- Radon Quantities, Units and Measurements - Dr. J. Harley

The Commission has found the seminars valuable to the development of its program, particularly with a view to identification of areas where new ICRU work can make an important contribution.

The Commission received from Dr. L. Feinendegen a briefing on "The Question of Dose Definition for Exposure to Ionizing Radiation in the Very Low Dose Region" and this stimulated a lively discussion of this important topic and work that might be done by the Commission in this area.

During the course of the 1988 meeting, the Commission directed attention to a number of proposed new activities with the result that three new report committees were constituted:

- Calculated Photon, Electron, Proton and Neutron Interaction Data for Body Tissues
- Proton Therapy
- Secondary-Electron Spectra

The Commission determined that further study should be devoted to the need for an ICRU effort concerned with hyperthermia and for an additional effort related to dosimetry at high doses.

The Commission has long recognized the interest in its work of all of those concerned with radiation quantities, units and measurement and has explored means of disseminating more widely information on activities and plans of the ICRU. Commission consideration of this matter at the 1988 meeting culminated in the decision to initiate the publication of the ICRU NEWS as a new periodical.

At the Helsinki 1988 meeting, the ICRU decided to accept the invitation of the Bureau International des Poids et Mesures to hold the 1989 meeting of the Commission in Paris. To be included in the program for the 1989 meeting are seminars on the following topics:

- Charged Particle Tracks and Semiconductors
- Chemical Dosimeters
- Dosimetry for Radiation Processing
- ICRU Work in the Area of Hyperthermia
- Radiological Measurements following a Nuclear Accident

Seminar on the Implementation of Dose-Equivalent Operational Quantities into Radiation Protection Practice

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A seminar on the "Implementation of Dose-Equivalent Operational Quantities into Radiation Protection Practice" was held in June 1988 at the PTB, Braunschweig. It was organized by the Commission of the European Communities, but ICRU, ICRP, US DOE and EURADOS helped to set the stage. In some ways, the event suffered from the absence of Hamlet – ICRU Report 43 was to play the leading part, but it had not met the publication date. Its absence was compensated by a comprehensive overview of the bases for the selection of operational protection quantities, which highlighted the contents of ICRU Report 43. A second survey outlined current work of the ICRU towards a report on the design, calibration and use of instruments for the implementation of the recommended system of dose-equivalent quantities.

Subsequent discussions were centered on a number of main topics:

- Consequences of impending changes of the value of Q on operational dose-equivalent quantities. Will it be possible to retain the existing energy dependencies of the operational quantities and hence to apply a constant factor for all energies?
- The characteristics of a range of current or novel survey instruments (e.g., Rossi-counters) in terms of the new operational quantities. Some existing instruments seemed more suitable to measure the new ICRU 39 quantities – particularly at photon energies below 100 keV – than the quantities which were formerly employed.
- The importance of the definition of the individual dose-equivalent quantities for satisfying needs of legal rigour and for application to all body sites, including extremities.
- The energy and angular response of a number of existing individual dosimeters and the effect of different detectors, containers, and filters. Several intercomparisons of dosimeters had been undertaken and it was felt that the individual dosimeters with the highest energy dependence, such as film-based dosimeters, gave the least satisfactory performance in terms of the new operational quantities.
- Calibration procedures for the dosimeters used to measure (penetrating and superficial) individual dose-equivalents. The use of the directional dose-equivalent, i.e., the employment of the ICRU sphere, was advocated for type testing of the individual dosimeters.
- The relationship of calibrations performed with the ICRU sphere to calibrations with phantoms of other

shapes or materials. Correction factors between different phantoms were presented for various angles of incidence.

- Conversion factors between the operational dose-equivalent quantities and primary quantities, such as fluence. The importance of the proper utilization of all available data was stressed and different methods were proposed to achieve a synthesis of the information.

The discussion of the various technical issues was complemented by reports on the approaches of some national and international organizations towards the introduction of the dose-equivalent operational quantities.

The seminar concluded with a discussion session. It was clear that there were fewer problems with the environmental monitoring quantities than with the individual monitoring quantities. Nevertheless, there was some critical discussion of the environmental quantities. It was suggested that some environmental measurements had the primary function of ascertaining that radiation fields remain unchanged over long periods of time, and it was argued that such measurements have no direct relevance to radiation risks and could, therefore, be made in terms of a simple quantity, such a air kerma. The opposite extreme, calibration in terms of effective dose-equivalent, found only a small minority of adherents.

The choice of conversion factors between primary standard quantities and operational quantities was also discussed. Some favoured the relation proposed by Wagner and colleagues, if only because of the convenience of the analytical expression. Others looked to the ICRU to provide definitive guidance. The continued uncertainty in the values of Q was much regretted.

The discussion moved to the individual monitoring quantities which engendered lively discussion. Various speakers argued for measurements in terms of H_p (10), H' (10), H_E and an unspecified isotropic quantity similar to exposure.

Some metrologists were perturbed by the fact that the value of H_p (10), being the dose equivalent in a person, depended on size and shape of the individual and not solely on the radiation field. A number of speakers discussed the desirability of having a dosimeter which measures H_p (10) be "Phantom independent". The argument was that if a dosimeter measures the dose equivalent at 10 mm depth in a range of phantoms (in the simplest case a sphere and a slab) then it will measure H_p (10) in the individual's trunk, since the geometry of the trunk is intermediate between sphere and slab.

The previous PTB Seminar in 1985 saw the emergence of the ICRU 39 quantities. Now, 3 years later, the second seminar has confirmed their broad acceptance, and particularly the general acceptance of the environmental quantities. The concepts of expansion and alignment are widely familiar, although it was commented that they were not as yet sufficiently understood at the operational health physics level.

The seminar was generally considered to be useful and it has provided valuable input for the members of the current ICRU committee on the measurement of dose equivalent.

The ICRU at the 17th International Congress of Radiology Paris, 1-8 July 1989

A. Allisy
BIPM
92310 Sèvres

The ICRU organizes or sponsors three major contributions for its parent organization, the International Congress of Radiology.

- A Round Table is sponsored by the ICRU on Dose Specification for Reporting Interstitial Therapy, chaired by A. Dutreix and D. Ash, 4 July 1989, 14 h 30, Palais des Congrès, Porte Maillot.
- The sixth recipient of the Gray Medal, Prof. Dr. Dietrich Schulte-Frohlinde, will present the Gray Lecture entitled Irradiation of DNA in Cells and in Aqueous Solution: Comparison of Chemical Reactions and Biological Consequences, 4 July 1989, 17 h 30, Palais des Congrès, Porte Maillot.
- An ICRU Symposium on Image Perception will be chaired by I. Isherwood and J. Mallard, 6 July 1989, 14 h 30, Parc des Exposition, Porte de Versailles.
  The following topics will be covered:
  General Introduction: The problem as perceived by the radiologist - I. Isherwood
  An overview of image perception - P. F. Sharp
  Image display in two and three dimensions - D. Barber
  Radiological image processing: Automated image analysis - C. J. Taylor
  Evaluation of diagnostic performance - C. Metz
  A unified analysis of medical imaging systems - R. Wagner

ICRU Symposium on Energy Deposition – Specification of Radiation Quality – Shape of Dose Response Curves in Radiation Protection and Therapy

A. Wambersie
UCL
1200 Brussels

The ICRU will sponsor a symposium at the 22nd Meeting of the European Society for Radiation Biology in Brussels, 11-16 September 1989. The symposium will deal with the understanding and specification of radiation quality in terms of the patterns of radiation energy deposition in biological material, with the relationship of these energy deposition patterns to microdosimetric quantities and absorbed dose, and with their use in radiation biology and radiation therapy. The connecting link between the five presentations in the symposium is "radiation quality", its scaling in terms of physical quantities, its efficiency in terms of biological response and its biological consequences in terms of different radiation mechanisms which are still a matter of investigation. The speakers at the ICRU Symposium will be in the order of the programme, Drs. Kellerer, Feinendegen, Booz, Menzel and Barendsen.

Dr. Kellerer will first review in his talk, "From the pattern of energy deposition to absorbed dose", the already classical specifications of stochastic quantities and their relation to absorbed dose and LET, and then treat the development of new intermediate dosimetric quantities aimed at a new quantification of radiation quality.

Dr. Feinendegen will treat "Specification of radiation quality for low dose effects". He will cover the adaptive responses of cells *in vivo* to low-LET absorbed doses (in the order of 0.01 Gy) and the relation of these responses to physical and chemical impacts such as pre-radiation doses, magnetic fields and chemical drugs. These results show that low-LET, low dose effects are not necessarily additive and can be interpreted as effects of radicals on cellular membranes. This leads to the working hypothesis that effects from low-LET radiations are unspecific responses of cells to the formation and effect of radicals in the cell or cell nucleus as a whole.

Dr. Booz will address "The use of microdosimetric quantities and functions for the evaluation of biological response", dealing with the problem of how to obtain a non-parametric, i.e., unbiased, description of low-dose effects as a function of radiation quality. This "response function" is the relation between single events of energy imparted to a biological site and the response of that individual site. Dr. Booz will discuss the possibilities and problems connected with this approach, showing in particular its application to the end point of double strand-break formation.

The problem of specifying and accounting for radiation quality in a situation of practical relevance is to be discussed by Dr. Menzel. The neutron beams for radiation treatment of tumors used by various therapy centres are of widely differing energies. Correspondingly, differences of up to 50% in the relative biological effectiveness (RBE) between different beams have been found in radiobiological experiments. Moreover, at some facilities, RBE variations have been observed with increasing depth in a phantom. A pragmatic and empirical solution for the specification of radiation quality for fast neutron therapy is proposed. It is based on empirical RBE versus lineal energy response or weighting functions.

Dr. Barendsen will discuss mechanisms of cell reproductive death and the consequences for the shapes of cell survival curves, in relation to differences in energy deposition patterns associated with the linear energy transfer of ionizing particles. For LET values in excess of 30 keV/μm, the initial parts of survival curves of mammalian cells between surviving fractions of 1.0 and 0.3, can be described by $S(D)/S(0) = \exp - a_1 D$. The value of a_1 increases steeply between 30 and 100 keV/μm. Consideration of the derived cross sections for inactivation as a function of LET indicate that cell reproductive death by single particles is most efficiently produced by energy depositions of several hundred eV in sites of the order of 10 nm. The hypothesis will be advanced that two DNA double strand breaks (DSB), produced sufficiently close together, constitute the composite effective lesions responsible for cell reproductive death induced by single tracks of ionizing particles. Potentially lethal damage is assumed to be associated with somewhat larger distances between two DSB's. For low-LET radiations, survival curves between surviving fractions of 1 and 0.2 can be represented by: $S(D)/S(0) = \exp - (a_1 D + a_2 D^2)$. It will be shown that the lesions associated with the quadratic term are induced with little dependence on LET. These lesions might be simple DSB's.

New Report

Tissue Substitutes in Radiation Dosimetry and Measurement

ICRU Report 44, *Tissue Substitutes in Radiation Dosimetry and Measurement,* was prepared in recognition of the fact that the measurement of absorbed doses within and around the irradiated body tissues necessitates the use of carefully selected materials from which phantoms and radiation detectors can be constructed. The use of such materials permits determination of absorbed doses when information on the energy and nature of the charged particles at the point of interest is incomplete or fragmentary. To make an appropriate selection of material for such purposes, it is necessary to have information on the characteristics of tissue substitutes that affect radiation interaction and the report provides these. Since the required degree of agreement between the measured and "actual" absorbed doses depends upon the intended application of the data, the individual specialties employing tissue substitutes are surveyed in the report, including phantom and detector materials used in radiotherapy, radiodiagnosis, radiation protection and radiobiology.

ICRU Report 44 initially gives the physical quantities that should be considered when tissue substitutes are selected for dosimetric studies and other measurements involving photons, electrons, neutrons and heavy charged particles. Next, important human body tissues requiring simulation are discussed and their elemental compositions, mass densities and electron densities are tabulated. Comparative interaction and depth-dose data for selected tissue substitutes are presented. The report concludes with recommendations on the use of tissue substitutes. Detailed tabulations of the elemental compositions and physical characteristics of the sixty-two tissue substitutes treated in the report are provided. Interaction data for all the body tissues and tissue substitutes are also tabulated. An outline of the formulation and fabrication techniques used in the production of tissue substitute materials is presented in an appendix of the report.

New Report

Clinical Neutron Dosimetry, Part 1: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons

ICRU Report 45, *Clinical Neutron Dosimetry – Part: I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons,* is the first of two new reports addressed to clinical neutron dosimetry. The report focuses on standardization of the dosimetry procedures used in support of the clinical applications of fast neutrons. It has been recognized that the comparison of the clinical results of fast neutron therapy at different institutions is compromised by difficulties in comparing the technical irradiation conditions. This is true even though institutions use the methods for determining the absorbed dose and kerma of fast neutrons recommended in ICRU Report 26, *Neutron Dosimetry for Biology and Medicine.* As a result, the new report provides guidance on the values of parameters and experimental techniques to be employed with the aim of standardization of the dosimetry procedures. Since radiation quality is important, a major section of the report treats experimental methodology and results of energy spectrum measurements of clinical neutron beams that yield information necessary for the characterization of the radiation quality. This is followed by a review of the dosimetric methods available for clinical neutron dosimetry. Beam characteristics are treated next, with coverage of such matters as output, dose build-up, depth dose and penumbra. A treatment of experimental and theoretical methods for determination of absorbed dose distributions concludes the report. 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, are to be treated in the second report of the series which is now in preparation.

ICRU Reports Related to Radiology

W. R. Ney
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With the roots of the International Commission on Radiation Units and Measurements (ICRU) firmly embedded in radiology, via its founding by the First International Congress of Radiology in 1925, it is not surprising that the initial reports of the Commission were directed at problems in radiology. What may not be widely recognized, however, is that in spite of the subsequent tremendous expansion of ICRU activities into fields other than radiology, a very major portion of the Commissions's work still addresses problems encountered in radiological diagnosis and therapy. This is evidenced by the ICRU reports highlighted below.

Therapy

ICRU Reports 23, 24 and 29 recommend procedures for the determination of absorbed dose in radiation therapy, beginning with the dose in a phantom and carrying this through the dose in the patient, to the specification of dose for reporting purposes.

ICRU Report 23, *Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays,* treats three of the four steps involved in the determination of the absorbed dose at any point in a patient – determination of the radiation at the calibration point, deduction of the peak absorbed dose rate (or, for low energies, the surface absorbed dose rate) and, establishment of the absorbed dose rate at any point of interest in relation to the peak or surface absorbed dose rate. The fourth step, the assessment of modifications attributable to the shape, size and composition of the patient, is treated in ICRU Report 24, *Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures.* Report 24 covers the basic data derived from water phantom measurements, patient data, combination of basic data and patient data, combinations of single beams, planning and delivery of radiation therapy and errors in clinical dosimetry. ICRU Report 29, *Dose Specification for Reporting External Beam Therapy with Photons and Electrons,* defines important volumes, areas and absorbed dose patterns, and recommends methods of specifying the absorbed dose in reports of treatment with external radiation beams.

ICRU Report 35, *Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV,* provides comparable recommendations for electron beam therapy. Treated in the report are interaction of electron beams with matter, characteristics of clinical electron beams, determination of absorbed dose, absorbed dose measurement techniques, absorbed dose in a phantom irradiated by an electron beam, determination of absorbed dose distribution in a patient, electron beam monitors, tests of constancy of performance parameters, and radiobiological aspects.

ICRU Report 42, *Use of Computers in External Beam Radiotherapy Procedures with High Energy Photons and Electrons,* carries the series of reports dealing with dosimetric problems in external beam therapy forward into the area of computer applications. The report covers treatment planning and recording and documentation procedures using computers. Treated are acquisition of beam data, utilization of patient data, and computation of absorbed dose distribution in the patient. Practical aspects of treatment planning by computer are also covered as is quality assurance of the computer system.

ICRU Report 26, *Neutron Dosimetry for Biology and Medicine,* recommends procedures for determining absorbed dose and kerma of fast neutrons employed in radiobiological and medical applications. Basic concepts and definitions are covered in the report, as are the principles of experimental techniques employed. The report describes methods and instrumentation, covers techniques for monitoring the radiation conditions during dosimetry measurements or irradiations, treats specific features of different neutron sources, and addresses specific problems of neutron dosimetry in radiobiology and radiotherapy.

ICRU Report 38, *Dose and Volume Specification for Reporting Intracavitary Therapy in Gynecolgy,* while focused on gynecological applications of intracavitary therapy, develops concepts which are generally applicable to intracavitary applications. The report defines terms and concepts, and specifies reporting requirements for description of the techniques used, specification of the total reference kerma, description of the reference volume, specification of absorbed dose at reference points, and specification of the time-dose pattern.

Nuclear Medicine

While many of the basic recommendations of the ICRU relate to the sources and metrology involved in nuclear medicine, ICRU Report 32, *Methods of Assessment of Absorbed Dose in Clinical Use of Radionuclides,* deals specifically with dosimetric problems in the utilization of radiopharmaceuticals. The report presents basic concepts and formulae relevant to determining the absorbed dose received by tissues of patients administered radiopharmaceuticals for diagnostic purposes and then addresses the methods used in obtaining the biological data needed for calculation of the absorbed dose. The procedures recommended for the calculations are summarized and their limitations and the difficulties involved in their use are highlighted. Appendices provide sources of information on the characteristics of radionuclides, a survey of the published work on absorbed fractions for gamma rays, examples of calculations of absorbed dose, information on problems raised in the dosimetry of radionuclides and information on sources of biological data.

Diagnosis

While many of the basic recommendations of the Commission also relate to various aspects of diagnostic applications, ICRU Report 41, *Modulation Transfer Function of Screen – Film Systems,* addresses specifically the analysis of the physical aspects of radiographic image quality for screen – film systems used in diagnostic radiology. The concepts used are described generally, however, to facilitate their application to other radiographic imaging modalities. In treating radiographic image quality, the report covers resolution, noise, and contrast. The treatment of transfer function analysis encompasses linearity and shift invariance, point spread function, line spread function, convolution, modulation transfer function (MTF) and the Fourier spectrum. Various methods for the measurement of MTFs of screen-film systems and factors affecting MFTs, such as crossover exposure and x-ray beam quality, are also treated. Appendices to the report provide mathematical derivations and a glossary.

Basic Recommendations

Many ICRU reports, other than those cited above, provide information, guidance and data relevant to various radiological practices and techniques (see list set out elsewhere in this publication). Fundamental to all applications of radiation, however, are the definitions of the quantities and units specified by the Commission. These are given in ICRU Report 33, *Radiation Quantities and Units.* The report provides definitions for quantities and units intended for general use as well as those intended for use in radiation protection. In the first category are such quantities as absorbed dose, kerma, exposure, activity, particle fluence, energy fluence, mass attenuation coefficient and linear energy transfer. The radiation protection category includes such terms as dose equivalent, absorbed dose index, dose equivalent index, shallow dose equivalent index and deep dose equivalent index. (These are now supplemented by the quantities defined in ICRU Report 39, *Determination of Dose Equivalents Resulting from External Radiation Sources.)* ICRU Report 33, in addition to providing definitions of quantities and units, also provides didactic material on general considerations, stochastic quantities, and nonstochastic quantities. It represents the latest in a continuing series of ICRU reports providing definitions for fundamental radiation quantities and units.

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