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 Furstuenau 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, Kröning 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), (Kröning 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 electrometer 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 Bécélaire 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 Hautenichtsosis, abbreviated HED (unit skin dose) (1st ICR, p. 68). Bécélaire 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. Bécélaire 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 Frick 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 Committee 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

It 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 Volland, 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 conductivity 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.

**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 Faila 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

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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 comparision 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 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.

General References


From “Quantity of Radiation” and “Dose” to “Exposure” and “Absorbed Dose” – An Historical Review, H.O. Wyckoff, NCRP Lecture No. 4., National Council on Radiation Protection and Measurements, Bethesda, 1980.

**Individual References**


