From: Izmeritel'naya Tekhnika, No. 1, pp. 20-23, 1956

DEFINITION OF THE ROENTGEN IN CONNECTION WITH THIS UNIT'S APPLICATION FOR ALL IONIZING RADIATIONS

By

I. V. Poroikov

The timely article by M. F. Yudin, "Comments on the Problem of the New Definition for the Units of X and Gamma Radiations and Radioactivity" (Izmeritel'naya Tekhnika, No. 1, 1955), has attracted long overdue attention to the shortcomings contained in the recommendations of the International Commission on Radiological Units of 1953.[1]

The questions raised by M. F. Yudin appear to be particularly opportune in view of the publication in our metrological literature of materials which illuminate erroneously the subject matter of discussion.[2]

Furthermore, during the last ten years in connection with the successful utilization of radioactive isotopes as internal emitters, a change was made in the definition of the roentgen and this unit was given broad application not only in expressing doses of X and gamma radiations but also those of other ionizing radiations.

Thus the need for a revision of the All-Union State Standard for this unit has become quite pressing.

To obtain a clearer perception of the deficiencies of the 1953 ICRU recommendations, the problem of the roentgen definition should be reviewed in its historical aspect.

The ICRU recommendations established the roentgen[3] as a unit of X-radiation defining it as the "quantity of X-rays which...in a cubic centimeter of atmospheric air...produces such conductivity...that the charge measured at current saturation is equal to one electrostatic unit."

As it may be seen, this definition was concerned only with X-radiation and specifically with that quantity of X-rays which produces the work of gas ionization. In other words, it dealt with the absorbed energy of X-radiation related to the unit volume of the absorbed medium (air). This is precisely what is stated in the definition of the roentgen which is given in the All-Union Standard (OST) 7623 with specification of the dimensionality of this unit ($L^{-1} MT^{-2}$), meaning: energy related to the unit volume.

Meanwhile, in the work referred to above[2], published in 1954, it is alleged (page 68) that: "a departure can be detected from the universally adopted views concerning the physical quantities and units--as it is explained hereafter--in the concept of the roentgen as stipulated in OST 7623." Yet, the explanations prove to be not only peculiar and subjective but also entirely inconclusive. First of all, for instance, for some obscure reasons, the admissibility is being questioned to consider the volume density of the absorbed energy of radiation as an independent physical quantity, although the author--as one would like to believe--knows well that the absorbed energy of radiation is not in a stochastic but in a functional relation to the irradiated volume as well as to the mass of the exposed substance. After a futile operation (page 69) with an erroneously written expression referring to the absorbed energy of radiation, an allegation is made to the effect that the volume derivative of the absorbed radiant energy "actually is a derivative of the energy irradiation with respect to the course of energy propagation and gives an idea of the change (decrease) of the irradiation in depth of the medium". The deficiency of this allegation can be easily gathered from the fact that the dimensionality of the derivative of absorbed energy with respect to volume ($L^{-1} MT^{-2}$) is other than the dimensionality of the derivative of energy irradiation (page 68) with respect to the course ($L^{-1} MT^{-3}$).

There obviously is little sense in comparing quantities of different dimensionality.

The analysis of these misunderstandings is essential because the work[2] bears the stamp of the Mendeleyeff All-Union Scientific-Research Institute; and in the foreward signed by the "responsible editor", the wish is expressed in the name of the Learned Council of MAUSRI for a general discussion of the debatable positions of the author.

In the ICRU recommendations of 1937, the application of the roentgen was extended to cover the field of gamma radiations with the retention of the physical meaning of the unit. At the same time the text of the definition contained this statement: "unit of quantity or dose of X and gamma radiations".

Thus, in this definition the term "quantity of radiations" is identified with the term "dose".

The 1950 recommendations of ICRU introduced an essential new element with regard to the roentgen, viz: they changed the physical meaning of this unit, having left its name and size unchanged. It was proposed to correlate the radiant energy not to the irradiated volume but to the irradiated mass of air (0.001293 g. of air).

This change was suggested in view of the fact that in utilizing the distributed internal emitters it is difficult to outline the limits of the irradiated volume of the material and it is easier to determine the mass of the material subjected to irradiation. The new definition changed the dimensionality of the roentgen. It became a unit of a different physical quantity, which, nevertheless, preserved the designation of dose regardless of the fact that the volume density of the absorbed energy was replaced by specific absorbed energy.

The ICRU recommendations of 1953 did not contribute anything new to the definition of the roentgen, but they introduced a new terminology and new units of measurement which brought about the previously mentioned elements of confusion and the ensuing misunderstandings.

In the ICRU recommendations of 1953, the concepts of "quantity of radiation" and "dose" are separated. The quantity of radiation is termed as the "time intergral of intensity" (point 2), and the dose--which is emphatically designated as "absorbed dose"--is defined (point 3) as: "the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material".

Yet, reference to point 7 of the same recommendations, which is confined to the definition of the roentgen, will clearly show that it treats as synonymous "the dose of radiation" and the "quantity of radiation such that the associated corpuscular emission...".

At the same time it remains unclear whether the stipulated term, "dose of radiation", coincides with the concept contained in point 3. Also vague is the question whether the words used in the definition "quantity of radiation such that the associated..." have the same meaning as the term "quantity of radiation" from point 2, or is this supposed to mean the radiant energy transformed in the substance by means of corpuscular emission.

The presence of these elements of confusion in the text of the 1953 ICRU recommendations explains the misunderstandings which have sprung up as a result of different interpretations of the significative content of the roentgen unit.

It should be noted that point 5 of the same recommendations provides a mathematical expression indicating the method of determining the "absorbed dose" value on the basis of "ionization produced in gas".

The text of the recommendations reads: "The energy E_m imparted to the unit mass of the material is then essentially related to the ionization per unit mass of gas I_m by the equation:

$$E_m = W \cdot S_m I_m$$

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

Whatever are the units used to express E_m, it will be--according to point 2--the "absorbed dose", or--according to the definition--the energy related to the unit mass, i.e., a quantity whose dimensionality is $(L^2 T^2)$.

In the given expression S_m is the magnitude of zero dimensions, whereas W, according to the definition, is the magnitude of the amount of energy or work, hence I_m must have the magnitude of (M^{-1}) which in fact corresponds to the physical meaning of the term "ionization per unit mass of gas".

Thus, in the mathematical expression contained in the ICRU recommendations of 1953, no magnitude can be found which could be taken as a quantitative characteristic of the "surface density of radiant energy", as the author[2] wishes it to be. Furthermore, it ensues from the recorded expression that in measuring ionization in air and in determining E_m in air, we obtain $S_m = 1$ whereupon the energy of radiation absorbed per unit mass is:

$$E_m = W_s I_m$$

Since W_s--for the entire range of X and gamma radiations--may on the average be assumed to be a constant quantity of equal to 33 ± 3 electronvolts, it becomes evident that the measured quantity of ionization per unit mass of air is a quantity which is proportional to the radiant energy absorbed in air and related to unit mass of air or to the absorbed dose.

Hence, according to the ICRU recommendations and in spite of the author's[2] opinion, the roentgen is a unit of absorbed and not of incident radiant energy.

The fact that these recommendations assign another unit for the absorbed dose, namely the rad (X-ray absorbed dose), is to be explained by different considerations. Ionization in air is being measured by means of roentgenmeters and the air dose values, expressed in roentgens, are frequently mistaken for tissue doses--a matter against which warnings were always made in the recommendations.

Attempts were made in the 1953 recommendations of ICRU to eliminate errors through introduction of a special designation for the unit of dose in materials with a mechanical equivalent value given as 100 $\frac{ergs}{g}$. It would be an oversight not to mention here that this operation proved to become the source of new misunderstandings.

Indeed air is also a material, and a dose of 1 roentgen it seems should have been equal to an air dose of 1 rad. However, 85 $\frac{\text{ergs}}{\text{g}}$ (mechanical equivalent of roentgen) are not equal to 100 $\frac{\text{ergs}}{\text{g}}$; and, consequently, the roentgen and the rad prove to be two different units of dose even in air.

The above analysis of contradictions contained in the ICRU recommendations of 1953 shows that these recommendations cannot be accepted without essential amendments for the formulation of the new definitions of the All-Union State Standard for units of X and gamma radiation and radioactivity.

This situation, in our opinion, is mainly due to the fact that the Metrological Institute of the Soviet Union is not represented at ICRU.

As to the wording of the roentgen definition for the projected new All-Union State Standard, one should remark that a satisfactory formulation of this definition is impossible as long as no coordination is achieved in the interpretation of the meaning and the field of application of the roentgen.

There are three points of view in M. F. Yudin's article which deal with the question of the quantity of which the roentgen should be the unit. The first version, treating the roentgen as a unit of surface density of X ray energy, is to be discarded since this is a result of an obvious misunderstanding duly referred to above.

The second version, which describes the roentgen as a unit of specific absorbed radiant energy in any material (with its size determined by its mechanical equivalent, i.e., 85 $\frac{\text{ergs}}{\text{g}}$), results from the acknowledgement of the constancy of the energy imput required to produce an ion pair in air throughout the entire spectral region of radiations to which the roentgen is applicable as a unit. However, this region at the present time has expanded to such an extent (up to quantum energy radiation of 3 MeV) that no sufficiently conclusive data are available any longer to permit considering the quantity W as constant for the entire region of X and gamma radiations.

In this case it would really become necessary to recalculate the values of medical therapeutic doses. This presents a certain inconvenience.

The third version is unsuitable and should be rejected because the unit of physical dose adequate for one material (air) cannot be considered inappropriate to express the amount of the same physical quantity when applied to any other material.

The dose unit in the sense of points 3 and 5 of the ICRU 1953 recommendations is equally applicable to all materials including air.

It ensues from the aforesaid that none of the versions of the roentgen interpretation reviewed in M. F. Yudin's article could satisfy the requirements of clarity, practical need, and convenience.

In practice the situation becomes even more complicated because the roentgen is being used as a universal unit of dose for all ionizing radiations with a qualifying reference as to the roentgen equivalence of the dose made either on the basis of the ionizing process in air (roentgen-equivalent-physical-rep), or on the basis of the biological effect in tissues (rem). As already mentioned earlier, still another new unit was now added to these by the ICRU recommendations of 1953, namely, the unit of absorbed dose, rad = $100 \frac{ergs}{g}$.

In our opinion, a radical solution of the problem resulting from the definition of the roentgen--which as a unit has received broad application in radiological practices exceeding by far the framework of X and gamma radiation measurement--could be found only at the cost of rejection of any significative association of the roentgen with any energy characteristics of radiation.

The roentgen should neither be defined as a dose of radiation, nor as the quantity of radiation. It should--in strict conformity with the specific features which determine the magnitude of this unit--be considered as a unit of "ionization". With such a modification of the meaning of the roentgen many metrological advantages will be achieved. First of all, there no longer would be any need to explain of what quantity the roentgen is a unit. Secondly, the definition of the roentgen could be made more precise, much shorter, and generally more convenient in the sense of its relation to the adopted units of other quantities. Thirdly, the need would disappear for the use of artificial units such as rep and rad. Fourthly, the contradictions contained in the ICRU recommendations of 1953 would be removed. Fifthly, the universally adopted units of energy for all energy quantities relative to ionizing radiations of any type could be preserved and recommended.

On the basis of the above, the following wording of the roentgen definition could be advanced:

"The unit of ionization--roentgen (rg. R)-- is the ionization originating in matter under the influence of radiation, at which 1.61×10^{12} ion pairs are being formed by radiation per one gram of irradiated matter."

Note:

1. For X rays generated at potentials of 100-200 kV, ionization in air of 1 roentgen corresponds to the specific energy of radiation absorbed by air or to the dose of radiation in air of 85 $\frac{ergs}{g}$.

2. For the calculation of the specific absorbed energy, or the dose of any ionizing radiation in a given material, it is necessary to multiply the ionization in air, measured in roentgens, by the value of work done to form one roentgen in air for the considered radiation and by the ratio of the mass stopping power of the material to that of the air.

In conformity with the above, the roentgen per second should be given a new term--"increment of ionization" to replace the old designation of "dose rate".

The above-mentioned radical decisions can be reached, however, only at the cost of great sacrifices. A habit has taken root in application practices of ionizing radiations to consider the roentgen as a dose of radiation in air, and it will not be easy to give up this routine and to begin expressing the dose in erg/g instead of the customary roentgens. However, this is just what the 1953 recommendations of ICRU are anyway already leading to; and should it be considered opportune to refer the proposed new definition of the roentgen to this organization, it would hardly seem possible that considerations of "habit" could develop into an obstacle barring the implementation of the afore-cited useful and progressive measures.

BIBLIOGRAPHY

1. British Journal of Radiology, Vol. XXVII, No. 316, 1954

2. P. M. Tikhodeyev, MAUSRI - "Ocherki ob iskhodnikh izmereniyakh," (Studies on Initial Measurements), Mashgiz, pp. 65-70, 1954

3. I. V. Poroikov - Spravochnik po rentgenometriyi (Roentgen Metrology Manual), Standartgiz, p. 70, 1936