MATHEWS

Editorial

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On the Definition of Sievert and Its SI Unit

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ABSTRACT

The sievert (symbol: Sv) is the special name for the International System of Units (SI) of equivalent dose, which is defined as 1 Sv = 1 J kg^{-1}. Depending on the radiation type, however, an inconsistency occurs in which the same energy imparted per unit mass (e.g., 1 J kg^{-1}) will result in different equivalent doses (e.g., 1 Sv for x-rays and 20 Sv for alpha particles). This short communication discusses the definition of equivalent dose and suggests to redefine sievert as a measure of the equivalent biological effect produced by 1 J kg^{-1} of absorbed dose.

According to the International System of Units (SI), the sievert (symbol: Sv) is a derived SI unit of ionizing radiation dose, which is named after Rolf Maximilian Sievert, a Swedish medical physicist renowned for work on radiation dose measurement and research into the biological effects of radiation (ICRP 1977). The sievert has been used for a number of radiobiological dose quantities, e.g., equivalent dose and effective dose, which are part of the international radiological protection system devised and defined by the ICRP (2007) and ICRU (2011).

The absorbed dose is a fundamental radiation dose quantity that relates all biologic effects to radiation exposures. Absorbed dose is expressed in units of joules per kilogram (J kg^{-1}) and is given the special name gray (Gy). For radiation protection applications, the equivalent dose $H_{T,R}$ is defined as the product of w_R and $D_{T,R}$, i.e.,

$$H_{T,R} = w_R \cdot D_{T,R}, \qquad (1)$$

where $D_{T,R}$ is the absorbed dose (averaged over a tissue or organ T) due to radiations of type R and w_R is a radiation weighting factor (ICRP 2007). Since wR is dimensionless, the SI unit for the equivalent dose is the same as for absorbed dose, i.e., both the sievert (Sv) and gray (Gy) equal to the joule per kilogram (J kg^{-1}).

The value of w_R is different based on the radiation type. For example, w_R is 1 for x-rays, gamma rays, electrons and 20 for alpha particles, fission fragments and heavy nuclei (ICRP 2007). It is a paradox that for the same absorbed dose of 1 J kg^{-1}, the equivalent dose can be either 1 J kg^{-1} for x-rays or 20 J kg^{-1} for alpha particles, as calculated using Eq. (1). One might argue that here 20 J kg-1 implies an equivalent dose from x-rays. However, the definition of 1 Sv = 1 J kg^{-1} does not explicitly say so; one has to derive such a concept based on his/her own understanding (Ma 2010). To

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avoid this confusion it has been suggested to use the special name (Sv) rather than the SI unit (J kg^{-1}) for equivalent dose, effective dose or operational dose quantities (BIPM 2006).

The problem remains as these biologically equivalent radiation dose quantities are expressed in terms of the same SI units (i.e., J kg^{-1} or m^2 s^{-2}) as that for absorbed dose, which is a fundamental physical quantity. Although ICRP (2007) assigned the unit of equivalent dose the special name sievert (with physical dimensions in joules per kilogram), equivalent dose is not a physical quantity; rather, it is a mathematical concept as expressed by Eq. (1), i.e., the product of two entities: (1) a physical quantity (absorbed dose) and (2) a construct of relative biological effectiveness by radiation type (the radiation weighting factor). By nature, equivalent dose represents a biological effect produced by radiation, e.g., carcinogenesis and hereditary effects as defined by ICRP (2007). Therefore, the unit of equivalent dose, sievert (Sv), should be defined in terms of the amount of radiobiological effect produced per unit of absorbed dose, not the amount of radiation required to produce it. Accordingly, the sievert should not be expressed by the SI unit of J kg^{-1}.

One of the benefits of redefining these radiobiological radiation dose quantities such as equivalent dose, effective dose, etc. and their unit, i.e., sievert, is to prevent conceptual misunderstanding and misuse of these quantities. For example, the International Committee for Weights and Measures (CIPM) strongly recommend the use of gray (Gy) and sievert (Sv) for absorbed dose and other biologically equivalent dose quantities, respectively, because of the dangers to human health that might arise from mistakes involving the unit J kg^{-1}, in case it is incorrectly taken to identify the different quantities involved (BIPM 2006). The quantities and units used in radiation science and radiation protection caused considerable communication problems and confusion. One example is the use of the same unit for the quantities equivalent dose of an organ and effective dose without specifying the quantity (Gonzalez et al. 2013). The fundamental problem is that these radiobiological dose quantities represent different biological effects and are not interchangeable although they have the same physical units. This problem can be solved by redefining the SI unit serviet (Sv) and abandoning its physical dimensions in joules per kilogram and m^2 s^{-2} for these biologically equivalent dose quantities.

Furthermore, the precise definition of the biological effect for a radiobiological dose quantity also ensures its proper application. For example, effective dose is the weighted sum of tissue-equivalent dose; therefore, both quantities need to have the same unit, which is J/kg. In communications of radiation exposure assessments, this has caused confusion and misunderstanding, particularly if the exposure predominantly affects one or a few organs (e.g. exposure of the thyroid from iodine, for which the equivalent dose for the organ is substantially higher than the effective dose). Confusion has occurred in the practical application of these radiobiological dose quantities, e.g., in the communication of dose information to non-experts (Gonzalez et al. 2013) and in the use of effective dose to predict cancer risk among exposed persons (Martin 2007, Balonov and Shrimpton 2012, Harrison and Ortiz-Lopez 2015, Fisher and Fahey 2017). Dietze et al. (2009) believed that confusion between quantities is an inevitable consequence of specifying only units without also referring to the quantity being used. The concept of effective dose has been criticized and an alternative to effective dose, focusing on estimates of cancer incidence from radiation and called ‘effective risk’, ‘risk index’ or “lifetime attributable risk”, has been proposed (Brenner 2008, 2012, Li et al. 2011, Andersson et al. 2017). This new radiobiological quantity is not expressed in physical units as the dimensionless weighting factors are replaced by risk coefficients (risks per unit dose), which are actually conversion coefficients between the radiobiological quantity and the physical dose.

Finally, the precise definition of the units and reference conditions for biologically equivalent dose quantities ensures the accurate determination of these quantities. It is important to realize that these radiobiological quantities are not physical quantities and they represent different biological effects. The specific biological effect of interest for a radiobiological quantity can be defined together with its unit and the reference conditions to determine its numerical value (Sgouros et al. 2009, Ma 2010). The precise amount of radiation to produce the same biological effect will depend on many factors including the biological system, end-point, radiation quality, dose rate, fractionation, overall time, irradiation condition such as oxygenation or temperature, etc. This will allow researchers to establish the relationship between a radiobiological quantity and the fundamental physical quantity absorbed dose, and improve the accuracy of corresponding conversion coefficients between these quantities.

REFERENCES

1. Andersson M, Eckerman K, and Mattsson S. (2017). Lifetime attributable risk as an alternative to effective

dose to describe the risk of cancer for patients in diagnostic and therapeutic nuclear medicine. Phys Med Biol. 62(24):9177–9188.

2. Balonov MI, Shrimpton PC. (2012). Effective dose and risks from medical x-ray procedures. Ann ICRP. 41(3/4):129–141.
3. BIPM. (2006). International Bureau of Weights and Measures/Bureau International des Poids et Mesures. The International System of Units (SI) (8th Ed.), ISBN 92-822-2213-6.
4. Brenner DJ. (2008). Effective dose: a flawed concept that could and should be replaced. Br J Radiol. 81:521–523.
5. Brenner DJ. (2012). We can do better than effective dose for estimating or comparing low dose radiation risks. Ann ICRP. 41(3/4), 124–128.
6. Dietze G, Harrison JD, Menzel HG. (2009). Comments on the paper of DJ Brenner 'Effective dose: a flawed concept that could and should be replaced'. Br J Radiol. 82:348–351.
7. Gonzalez AJ, Akashi M, Boice JD, et al. (2013). Radiological protection issues arising during and after the Fukushima nuclear reactor accident. J Radiol Prot. 33:497–571.
8. Harrison JD, Ortiz-Lopez PO. (2015). Use of effective dose in medicine. Ann ICRP. 44(1S):221–228.
9. Fisher DR and Fahey FH (2017). Appropriate use of effective dose in radiation protection and risk assessment. Health Phys. 113(2): 102–109. DOI:10.1097/HP.0000000000000674.
10. ICRP. (1977). Recommendations of the International Commission on Radiological Protection. ICRP publication 26. Ann ICRP. 1(3).
11. ICRP. (2007). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP. 37:1–332.
12. International Commission on Radiation Units and Measurements. (2011). Fundamental quantities and units for ionizing radiation. J ICRU. 11(1) ICRU Report 85a-revised.
13. Li X, Samei E, Segars WP, Sturgeon GM, Colsher JG, and Frush DP. (2011). Patient-specific radiation dose and cancer risk for pediatric chest CT Radiology. 259:862–74
14. Ma C-M. (2010). On the definition of biologically equivalent radiation dose quantities. Med Phys. 37(5):2394-2395.
15. Martin CJ. (2007). Effective dose: how should it be applied to medical exposures? Br J Radiol. 80:639–647.
16. Sgouros G, Howell RW, Bolch WE, Fisher DR. (2009). MIRD commentary: proposed name for a dosimetry unit applicable to deterministic biological effects-the barendsen (Bd). J Nucl Med. 50:485–487.