Kvantifikace zasažení osob a jeho monitorování v případě ozáření z radioaktivních odpadů

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Souhrn

Při nakládání s radioaktivními odpady je nutno zajistit adekvátní ochranu osob a minimalizovat dopad těchto odpadů na okolní životní prostředí. V referátu je diskutován přehled veličin a jednotek pro tyto účely, včetně možnosti jejich monitorování a identifikace přítomných radionuklidů. Tyto veličiny reflektují nejenom fyzikální vlastnosti radionuklidů a jimi emitovaného ionizujícího záření, ale také biologické účinky tohoto záření na lidský organismus. V případě charakteristiky radionuklidů je hlavní pozornost věnována zejména takovým veličinám, jakými jsou emise zdroje, aktivita, měrná aktivita, fluence částic a fluence energie. Na druhé straně, referát podrobně popisuje definice veličin a jejich interpretaci určených pro kvantifikaci ozáření osob, kde hlavní roli hrají expozice, kerma, dávka, dávkový ekvivalent, efektivní dávka, jakož i řada operačních veličin určených pro praktické použití k odhadu zdravotních účinků ozáření osob. Je přitom poukázáno i na některé problémy v této oblasti související s velkým počtem veličin a jenom 2–3 jednotkami, které vyvolávají v praxi nejednotnost v posouzení skutečného radiačního rizika, protože není vždy jasné, ke které veličině se příslušná jednotka váže.

Klíčová slova: *Kvantifikace ozáření, veličiny a jednotky, inkonsistence definic, monitorování záření, radioaktivní odpad.*

Quantification of personal exposure and its monitoring in the case of radiation from radioactive wastes

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Abstract

When dealing with radioactive waste, it is necessary to ensure adequate protection for people and minimise its impact on the surrounding environment. The paper provides an overview of quantities and units for these purposes, including the possibility of monitoring and identifying the radionuclides present. These quantities reflect not only the physical properties of radionuclides and the ionising radiation they emit, but also the biological effects of this radiation on the human body. In the case of radionuclide characteristics, the focus is on variables such as source emission, activity, specific activity, particle fluence, and energy fluence. On the other hand, the paper describes in detail the definitions of variables and their interpretation intended for the quantification of human exposure, where the main role is played by exposure, kerma, dose, dose equivalent, effective dose, as well as a number of operational quantities intended for practical use to estimate the health effects of human exposure. At the same time, some problems in this area stem from the large number of quantities and only 2-3 units available, which, in practice, lead to inconsistencies in assessing actual radiation risk because it is not always clear to which quantity individual units are related.

Keywords: *Quantification of exposure, quantities and units, inconsistencies in definitions, radiation monitoring, radioactive waste.*

1. Introduction

The persons who may be affected by ionising radiation (IR) emitted by radionuclides present in radioactive waste may include workers handling and in contact with the waste, and, to a certain extent, members of the public. This may happen under normal, controlled conditions and in emergencies where radioactive waste is not fully under control.

If all safety requirements based on the national radiation protection standards are met, workers' exposure remains below certain limits, beyond which they may be affected only at levels corresponding to stochastic health effects. Such low exposures are achieved because workers are qualified and know how to protect themselves against radiation exposure. Moreover, in their work areas, radiation levels are strictly monitored, and, if necessary, workers may use appropriate personal protective equipment to minimise their exposure.

Public exposure is kept at much lower levels under normal circumstances. However, in such emergency situations, such as accidents or terrorist attacks, exposures to both workers and the public may reach quite high levels, resulting in the uncontrollable release of radioactive materials from waste packages and containers. In this case, all efforts should be made to reduce exposure as much as possible and return the situation to normal conditions.

To keep personal exposure and possible radioactive contamination from radioactive waste under adequate control, the situation should be monitored using relevant radiation detectors and monitors, and the results reported in relevant quantities and units.

2. Quantities and units in radiation protection

The determination of quantities relevant to radiation protection often involves significant uncertainties. In addition, a variety of approximations must be used for relating physical measurements to biological effects caused by radiation. Although a comparatively wide margin may be admissible in radiation protection, it is essential that the quantities employed be unambiguously defined and that the approximations be clearly identified. The bases for radiation protection quantities are physical quantities which, after applying appropriate weighting factors reflecting biological effects, can be converted into the radiation protection quantities (Fig. 1).

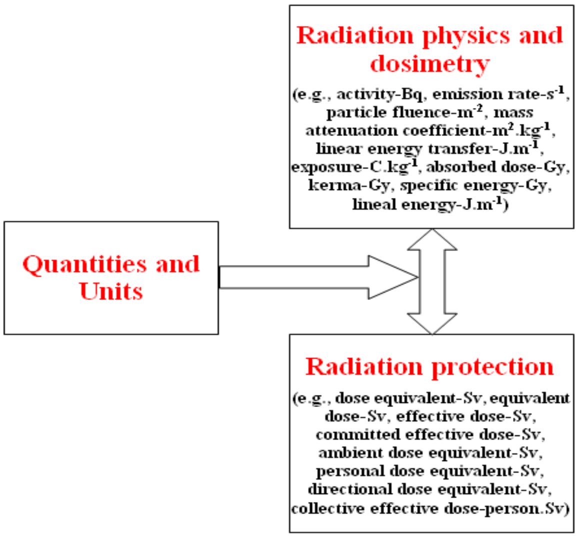

Fig. 1. Main quantities and units used in radiation protection dosimetry and protection.

Since radiation is emitted by a radioactive source, the source parameters should first be quantified using appropriate radiation quantities and units. This is, in most cases, done by the quantity *activity*, which is defined as the number of disintegrations occurring in the source per second. The SI unit of activity is the becquerel (Bq), defined as one decay per second, i.e., 1 Bq = 1 s^{-1}. An alternative quantity often used for a similar purpose in radiation dosimetry is the *emission rate*, defined as the number of particles or photons emitted by a radioactive source per 1 s (s^{-1}).

The radiation dose (or dose) is related to the damage inflicted on the body and can be expressed as the absorbed dose, the equivalent dose, the effective dose or the collective dose. The dose rate is the dose per unit of time. It is a determinant of the deterministic effect and may affect the probability of a stochastic effect occurring.

The absorbed dose is the primary physical quantity of radiation dosimetry. It is defined as the radiation energy absorbed per unit mass of an organ or tissue and is used in studies of the damage to a particular organ or tissue. The unit is J kg^{-1}, and the special name is the gray, which is equal to 1 J kg^{-1}.

An overview of the radiation protection quantities, essentially derived from physical quantities, is in Fig. 2. Radiation protection quantities (effective dose, equivalent dose) reflect health risks but cannot be measured directly. Operational quantities (ambient, directional, and personal dose equivalents) serve as measurable surrogates that conservatively estimate protection quantities for external radiation, enabling practical, calibrated monitoring to ensure safety limits are met.

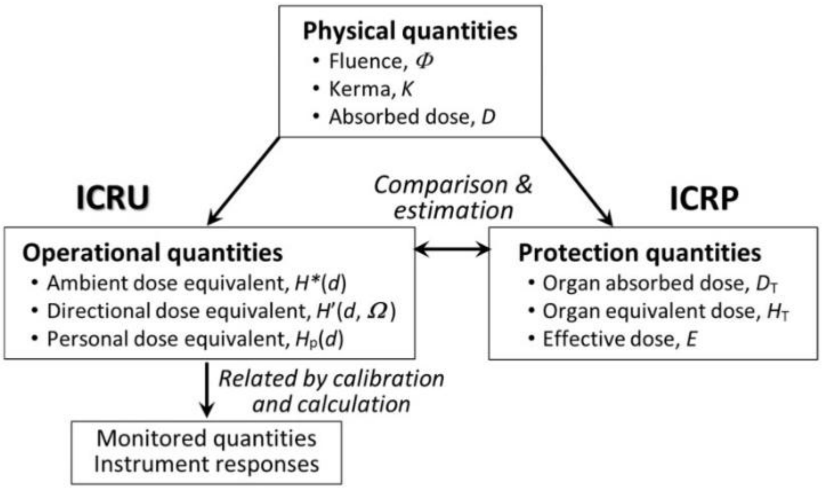

Fig. 2. Relationship between the basic physical, protection and operational quantities suggested by ICRU [1] and ICRP [2].

The protection quantities are defined based on the mean absorbed dose, $D_{T,R}$, in the volume of a specified tissue or organ, T, due to radiation of type R. The equivalent dose in a tissue or organ, H_T, is then defined as

$$H_{\mathrm{T}} = \sum_{\mathrm{R}} w_{\mathrm{R}} D_{\mathrm{T,R}}$$

where w_R is the radiation weighting factor for radiation R. The w_R values are chosen to account for the relative effectiveness of different radiation types in terms of stochastic effects.

On the other hand, one of the main radiation protection quantities, the effective dose, *E*, is introduced by the expression

$$E = \sum_{\mathrm{T}} w_{\mathrm{T}} H_{\mathrm{T}} = \sum_{\mathrm{T}} w_{\mathrm{T}} \sum_{\mathrm{R}} w_{\mathrm{R}} D_{\mathrm{T,R}}$$

where wT is the tissue weighting factor for tissue T, and P wT ¼ 1. The wT values are chosen to represent the contributions of individual tissues and organs to the overall radiation detriment due to stochastic effects. The unit of equivalent dose and effective dose is J/kg, and its special name is the sievert (Sv).

The above definitions are related only to external radiation exposure. Moreover, they can be used only up to about 500-600 mSv, since exposure above this level initiates deterministic effects, for which the committed dose equivalent is used, an assessment that is rather complicated.

Another problem concerning radiation protection quantities and units is that there are too many quantities currently in use, which complicate assessment and interpretation of monitoring results, since there are essentially only two units for more than 10 quantities, namely Gy and Sv. In many cases, the value is given in one of these units, but it is not always mentioned to which quantity they belong [3,4].

3. Monitoring of radiation emitted by radioactive sources

Monitoring of radioactive waste involves the continuous or periodic measurement of radiation and contamination to ensure the safety of people and the environment. It is a critical component of the waste management lifecycle, from the initial generation of radioactive or nuclear materials at facilities where these substances are used to long-term storage or geological disposal.

This monitoring includes measurements of specific quantities that identify and quantify radioactive sources (activity, emission rate, etc.), and especially the parameters of the radiation field around them, from which personal exposure can be assessed. Radiation monitoring involves using specialised detectors—primarily Geiger-Müller counters, ionisation chambers, semiconductor and scintillation detectors—to measure dose rates and detect contamination. Key safety measures include using personal dosimeters, surveying work areas, and maintaining shielding (lead, concrete) to avoid exposure from radioactive sources [5].

We must distinguish between area or field monitoring instruments (Fig. 1) and personal dosimeters (Fig. 2) aimed at personal dose measurement

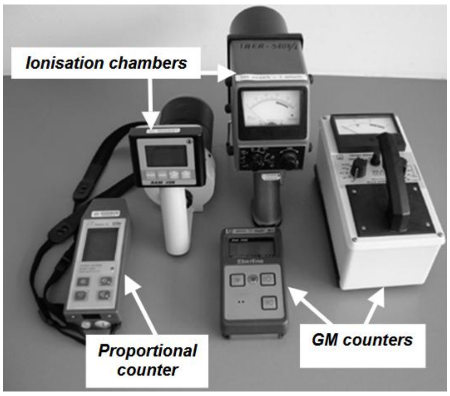

Fig. 2. Some typical radiation monitors for measuring the level of the radiation field and assessing personal exposure around radioactive sources.

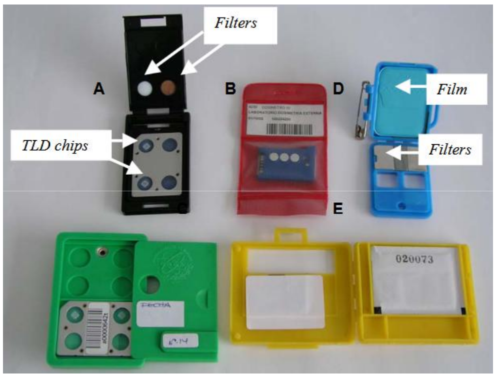

Fig. 3. Various types of personal dosimeters for monitoring personal exposure.

In many cases, national laws demand that nuclear waste be kept in repository chambers located deep underground. These are often carved out from dense, geologically stable rock. To eliminate any risk of contamination, these chambers must be far out of reach from natural groundwater systems and from the biosphere. The geological repositories are to be used for spent nuclear fuel and high-level radioactive waste (radioactive waste) that will remain in interim storage for many years before being placed in a deep geological repository. Low and intermediate-level radioactive waste are stored in surface or subsurface storage sites, and these kinds of waste are the most abundant.

Even when it is safely stored, this material must be intensively *monitored*. Whatever its origin, the waste ends up in special drums that must be placed in short- or medium-term repositories, where they are periodically inspected by operators. A few specific radiation detectors placed inside the repository are then used to monitor the local environment.

The main requirement for the monitoring system is to ensure that the risk of hazardous events is reduced to an acceptable level at minimal cost for its creation and operation. A two-level structure of the monitoring system is proposed, including a basic system that provides control of radiation dose rate, transmission, storage of information, assessment of changes, risk determination, decision-making on the need for preventive measures, and an additional system that provides information necessary for continuous adjustment of the remediation process and monitoring of the state of the territories at the request of the basic system.

The exponential decay law of radioactivity, contrary to chemical waste, will decrease the dangerousness of radioactive waste if stored for a long enough time. With comprehensive radiation monitoring, radioactive waste can be stored safely. However, the general population doesn't always share this trust. This is why one needs to communicate the risk associated with radioactive waste to the public in a way that they understand the real impact of the wastes kept under control and monitoring.

Fortunately, not all kinds of waste require special attention. This is needed only for high-level waste, which accounts for about 3% of total waste (Fig. 4).

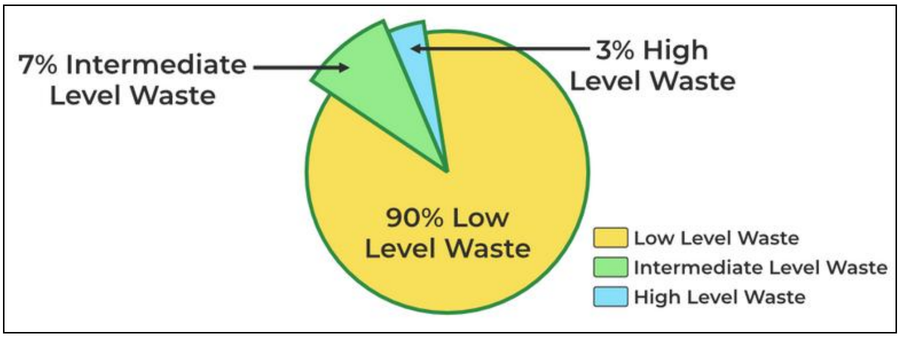

Fig. 4. Radioactive waste volume in percentages.

4. Conclusion

Radioactive waste poses severe, long-term risks to human health and the environment, including cancer, DNA damage, and ecosystem contamination, as it remains hazardous for thousands of years. Major problems include safe long-term disposal, managing high-level waste from nuclear energy and weapons, and preventing contamination of water and soil.

With the ever-increasing public health problem posed by radiation, there has been renewed interest in studying the rising levels of radioactivity and their probable effects on human health. Radionuclides are used in various fields, which may lead to environmental contamination and require strict control and monitoring. This is also the case for used radioactive sources in waste, which must be kept safe under special conditions to prevent radioactive contamination of the environment and thus expose the affected population.

The current approach to radioactive waste (RAW) safety is based on a well-established international consensus. It relies on a multi-barrier system using deep geological repositories for high-level waste, while proven near-surface facilities are used for low- and intermediate-level waste. Safety standards, largely guided by the IAEA, stress that radioactive waste management must avoid placing unnecessary burdens on future generations.

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