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UCID--19117

DE82 006180

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STATUS OF MEASUREMENTS FOR RADIATION PROTECTION

GUY A. ARMANTROUT

December 4, 1981

Lawrence
Livermore
Laboratory

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This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

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ABSTRACT

The Dose Equivalent Index (DEI) has been proposed as a dosimetric standard. We have considered the impact of the change on health physics instrumentation measurements and have evaluated the probable errors of representative instruments for measuring the DEI. Little change is found from earlier slab standards.

A more important consideration is the appropriateness of the use of the DEI as a dosimetric standard. The DEI may be satisfactory from a conservative viewpoint, but is not necessarily proportional to the true radiological risks involved. An alternate parameter (such as the 1 cm depth dose equivalent for an isotropically irradiated 30 cm sphere as suggested by Kramer) may be more appropriate.

INTRODUCTION

LLNL is currently investigating the ability of health physics instrumentation to measure the dose equivalent index for NRC. This report briefly reviews the current status of the radiation protection problem, the standards which are being considered as indicators of dose, and the status of instrumentation for making such measurements.

MEASUREMENT STANDARDS

The primary objective of radiation protection is to reduce health risks to individuals to an acceptable level. The role of measurements in supporting this objective are to: 1) provide a measurement of absorbed dose in an individual which has a direct relationship to the risk incurred by that individual, and 2) provide a measurement of radiation fields such that effective dose estimates can be made which are directly related to the risks which may be incurred by an individual if exposed in that field.

Earlier standards for dose estimates were based on the maximum effective dose rate in a 30 cm tissue equivalent slab. Instruments, which were usually calibrated to exposure in air, gave readings which could be readily converted to dose provided the approximate energy spectrum was known. Neutron instruments were usually calibrated directly in terms of dose.

Such a standard had difficulty in handling non-undirectional sources. In order to provide a more universal standard, a 30 cm tissue sphere was chosen by the ICRU in 1976 and the Dose Equivalent Index (DEI) was defined as the maximum dose rate at any point in the sphere². Significant problems in energy additivity and the angular distribution of the source remain and will be discussed in more detail later.

CURRENT STATUS

We have been tasked to determine the ability of health physics instrumentation to measure the DEI. The first step is to determine the flux

to dose conversion curve for the DEI. Several groups (Dimbylow at Harwell, Kramer at Munich, and Chilton at the University of Illinois)³⁻⁵ are performing such calculations. We have also performed such calculations as a check on their work.

Figure 1 shows the flux to dose conversion factor versus energy for the unidirectional DEI as calculated at LLNL. Shown for comparison are the flux to dose conversion curves for air and for the 30 cm tissue slab. At higher energies, all three curves are seen to converge. The shape of the curves remains essentially the same at lower energies, though the values do differ by up to 50%. In general, the unidirectional DEI is not significantly different from the slab curve as might be expected. We have not calculated the isotropic case yet since we are waiting for specific data from Kramer and Dimbylow.

For comparison purposes, we have calculated the maximum dose to the brain as a function of energy as also shown in Fig. 1. The brain was chosen due to its higher content of high atomic number elements which significantly increases its absorption coefficient at lower energies. This effect can be noticed by the enhancement in dose between 35 and 200 KeV. The apparent significance of such a hazard is reduced by the relative insensitivity of the brain to radiation exposure.

Art Chilton's calculations for neutrons have been summarized in Fig. 2 and compared to the 30 cm slab. As can be seen, there is little difference between the slab and the unidirectional DEI for neutrons. The greater difference occurs for the isotropic source incident on the 30 cm sphere where the DEI is significantly less. A similar effect will be evident for the γ -ray DEI curve, with an effect of up to a factor of four times less at lower energies expected.

INSTRUMENT RESPONSE

Given the similar flux to dose conversion curves for the unidirectional DEI and the 30 cm slab for both γ -rays and neutrons, we would expect similar instrument response characteristics. We have evaluated the instrument response for the unidirectional γ -ray DEI for a number of the more common health physics instruments as follows.

FIG. 1.

DOSE PER UNIT FLUX vs ENERGY

FIG. 2.

NEUTRON FLUX TO FLUENCE CONVERSION FACTOR

Since such instruments are normally calibrated in terms of air exposure (Roentgens), it was necessary to first calculate the exposure to dose curve shown in Fig. 3. Using this curve and the published measured response of these instruments to air exposure⁶, we calculated the instrument reading to unidirectional DEI conversion curves for specific instruments as shown in Figs. 4 and 5. As can be seen, most instruments approach the expected value of 0.876 for energies greater than 100 KeV. For energies less than 100 KeV, significant variations can be found depending on the detector type and wall thickness.

While Figs. 4 and 5 can be used as a direct estimate of accuracy for measuring monoenergetic sources, most real-world radiation hazards are due to distributed photon spectra. The ability of these instruments to measure the unidirectional DEI under these conditions was also evaluated. Three representative sources were chosen as standard spectra for this evaluation as shown in Fig. 6. The spectrum marked "background" is representative of a normal environmental background composed primarily of potassium, uranium, thorium, and their daughters and is representative of a distributed high energy source. The ²³⁹Pu spectrum is more characteristic of a medium energy radionuclide in a heavily scattering medium. The ¹³³Xe cloud was taken from data obtained following the TMI accident and represents a distributed low energy spectrum⁷. The low energy cutoff on all three spectra is due to atmospheric attenuation.

The relative response of three of these instruments to these three source spectra are shown in Fig. 7. All three instruments are reasonably accurate for the background and ²³⁹Pu source. A significantly greater error is seen for the ¹³³Xe cloud due to the poorer accuracy of the instruments at energies <100 KeV. Even at this energy, however, the V-440 ion chamber was within 25% of the unidirectional DEI value. The E-120G GM detector system showed a significant over-response (225%) for this source.

Similar comparisons were made for the brain dose measurement accuracy for these three instruments using the brain dose curve in Fig. 1. The results are shown in Fig. 8. For the higher energy sources, the readings are relatively accurate. However, for the ¹³³Xe cloud significant error is encountered due to the relatively increased dose rate to the brain over this energy range.

FIG. 3.

AIR IONIZATION IN RADS vs ENERGY

FIG. 4.

CALIBRATION CURVES FOR ROENTGENS TO REMS FOR SELECTED SURVEY METERS

FIG. 5.

CALIBRATION CURVES FOR ROENTGENS TO REMS FOR SELECTED SURVEY METERS

FIG. 6.

STANDARD TEST SPECTRA

FIG. 7.

SURVEY METER ACCURACY FOR MEASURING THE DOSE EQUIVALENT INDEX AS A FUNCTION OF SOURCE

FIG. 8.

SURVEY METER ACCURACY FOR MEASURING THE DOSE EQUIVALENT (MAX) TO THE BRAIN AS A FUNCTION OF SOURCE

DISCUSSION

Relatively simple instruments (e.g., the ion chambers) can result in relatively accurate readings ($\pm 20\%$) for a wide range of γ -ray spectral inputs. Certain classes of instruments (primarily the photon counters) would be expected to have a poorer response at higher energies where dose build-up is more critical.

In the case of neutron remmeters, existing meters have been designed to mimic the flux to dose conversion curve shown in Fig. 2 and do so reasonably well, though there is still some concern about over-response at lower energies⁸. No significant changes in this situation are expected for dose measurements based on the unidirectional DEI.

The central issue in radiation protection, however, is not how well instruments can measure the dose equivalent index. Rather, the central issue is how well we can determine the health risk level for an individual exposed to a given radiation field. Significant concern exists over whether the DEI is the proper measurement and evaluation parameter for health risk effects. The problem stems from several factors which include different DEI values for different spatial source distributions and the fact that the DEI values for different energy sources are not additive. Errors of up to a factor of 5 can result. The definition is such that the unidirectional DEI gives the most conservative estimate and will tend to over estimate dose to the 30 cm tissue sphere for most real-world exposure conditions.

An effective dose limit has been proposed by the ICRP which considers the average dose received by each organ and then multiplies that dose by a factor which takes into account the relative organ size and the radiobiological risk of that organ.⁹ This effective dose limit, H_e , is determined by

$$H_e \approx \sum_{i=1}^n W_i H_i$$

where H_i is the average individual organ dose and W_i is the weighting factor. If the values of W_i are appropriate and the values of H_i are accurately determined, then H_e would represent a dose level which is directly related to risk. Unfortunately, there is no free field way to determine H_i . In fact, such measurements on a phantom (or an individual undergoing radiotherapy) are difficult and time consuming and still have the possibility of significant measurement error. Such problems formed the incentive for establishing a standard based on the 30 cm DEI.

From a regulatory point of view, the question arises as to whether the conservative DEI represents the proper parameter for regulatory control or whether a parameter based on a better approximation of true dose should be sought. The argument for the latter approach is based on the fact that the radiation risks being considered are stochastic in nature and most likely are not subject to a threshold level of radiation. As such, it would seem appropriate to choose a protection parameter which is proportional to the most probable dose risk level as defined by $H_e = \sum W_i H_i$. As a specific example, the DEI for isotropic exposure is considerably less than for the unidirectional case. However, the isotropic DEI is also more likely to be representative of the averaging effects of an individual who is moving within a single or multi-point radiation field. Table I considers some possible pros and cons of taking either a conservative or a probabilistic regulatory stance on the measurement parameter.

Kramer is currently considering the problem of identifying a more reasonable dose parameter for radiation protection.¹⁰ Based on the effective dose expression $H_e = \sum W_i H_i$, he has made calculations of flux to dose versus energy for his MIRD phantom model. These calculations more closely approximate the risk an individual may expect upon exposure to an arbitrary radiation field. In comparing his MIRD calculations to his various calculations on the 30 cm sphere, he has found the best agreement as a function energy exists between the MIRD calculations and the isotropic 1 cm deep dose equivalent for the 30 cm tissue sphere and has recommended this as a possible dose standard.

We feel that his work has merit in terms of better relating a measureable quantity to the actual health risks of radiation exposure. It is very

TABLE 1. Comparison of measurement approaches.

CONSERVATIVE	PROBABILISTIC
<u>Advantages</u>	<u>Advantages</u>
Minimal public criticism Easily determined protection levels (e.g., DEI) Utilizes current instrumentation approaches	Better correlation of risks with measured dose Reduces expense and restrictions in meeting a given protection level
<u>Disadvantages</u>	<u>Disadvantages</u>
Excessive restrictions on nuclear facilities Poor correlation of estimated exposure with actual risk probability	No currently accepted parameter for measurement Does not correlate with current instrumentation calibration/response Potential public concern

important to agree upon such a representative health risk standard prior to evaluating the capability of instrumentation to provide the needed dose measurements.

In the meantime, measurements of instruments relative to air ionization would appear to be the most prudent route since such measurements can be converted by means of calibration curves in the future.

Eventually a standard measurement approach will be defined. When this occurs, instruments which give readings in direct proportion to the health risks encountered should be developed.

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LLNL* 1981/12