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Chief, Rules and Directives Branch
Division of Administrative Services
Office of Administration
U. S. Nuclear Regulatory Commission
Mail Stop T6-D59
Washington, DC 20555-0001

SUBJECT: **Comments on Proposed Generic Communication; Method for Estimating Effective Dose Equivalent From External Radiation Sources Using Two Dosimeters – 68 FR 43769**

Reference:

1. Federal Register Notice, Vol. 68, No. 142, July 24, 2003, pp. 43769 – 43771.
2. Entergy letter to NRC regarding request for exemption to 10 CFR 20.1003, July 20, 2001
3. Entergy letter to NRC regarding response to request for additional information regarding 10 CFR 20.1003 exemption request, June 13, 2002.
4. NRC exemption from the requirements of 10 CFR Part 20.1003, definition of total effective dose equivalent, 67 FR 58826, September 18, 2002.
5. Federal Register Notice, Vol. 68, No. 177. Friday, September 12, 2003, pp. 53755 – 53758.

Dear Sir or Madam;

Entergy, as the operator of ten nuclear power plants (Arkansas Nuclear One - Units 1 and 2, Indian Point Units 2 and 3, Pilgrim, River Bend, James A. FitzPatrick, Grand Gulf, Waterford 3, and Vermont Yankee), takes this opportunity to comment on the proposed generic communication, "Method for Estimating Effective Dose Equivalent From External Radiation Sources Using Two Dosimeters," published in the July 24, 2003 Federal Register (Reference 1).

E-RIDS = ADM-03

Template = ADM-013

Add = C. Petrone (CDP)
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The proposed generic communication provides guidance on the application of a two-dosimeter monitoring method for estimating effective dose equivalent (EDE) from external radiation exposures. This method is useful in estimating EDE and can be used instead of the deep dose equivalent (DDE) in complying with NRC regulatory requirements. The RIS describes several limitations on the use of this method. Specifically, it does not permit this method to be used in exposure situations where the sources of radiation are nearer than 12 inches (30 cm) from the surface of the body. This limitation severely restricts the application of this methodology and effectively renders it impractical for use in nuclear power plants.

New analyses have been performed since Entergy submitted it's exemption request over two years ago (References 2, 3 and 4). This analysis evaluates sources at distances between 1 and 4 cm. The conclusion is that this limitation is unnecessary, and that the two-dosimeter method results in conservative EDE estimates for sources closer than 12 inches. A report, summarizing these new analyses is attached (Attachment 1). Also attached is a copy of a presentation on this topic recently given at the annual 2003 Health Physics Society meeting (Attachment 2). The same individual involved in the original development of the two-dosimeter method performed these analyses.

Entergy believes that this method is an important tool for NRC licensees for estimating personal radiation exposures. Besides Entergy, other licensees have recognized the value of this method and have been granted an exemption by the NRC to use it (Reference 5). Entergy believes that the method can be made more valuable and the method applied to a broader range of radiation exposure situations, if the staff considers new developments in this generic communication. The NRC should review the attached report and revise the proposed generic communication to permit the use of this method closer than 12-inches from potential radiation sources.

There are no new commitments made in this letter. If you have any questions, please contact Ms. Charlene Faison at 914-272-3378.

Very truly yours,

Michael J. Colomb
Vice President
Operations Support, Acting

Attachment:

1. Project Report, "Additional EDE Data for Point Gamma Sources Near the Body," August 2003, prepared by Dr. George Xu, Associate Professor, Rensselaer Polytechnic Institute (9 sheets)
2. Slide presentation, Health Physics Society 48th Annual Meeting, July 21, 2003, "Implementation of the Use of Effective Dose Equivalent in External Dose Assessments" (15 sheets)

cc: Next page.

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Additional EDE Data for Point Gamma Sources Near the Body

Project Report

August 2003

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Report Summary

Due to NRC's concern about the lack of EDE data for point sources within 33-cm of the body, implementation of EPRI Two-dosimeter Algorithm is not currently approved. This project was initiated to provide the necessary data for NRC's further evaluation and hopefully rule-making. The project first defined 35 locations at about 11 cm from the surface of the body in the front and back, as well as near the side and overhead. MCNP code and the MIRD mathematical phantom were then used to calculate effective dose equivalent and dosimeter responses. Processed EDE and dosimeter responses are summarized in a table and a graph. The results show that, for point sources located in the front and back of the body at 11 cm away, the average ratio of 22 positions is about 1.6. This suggests that the proposed EPRI Two-dosimeter Algorithm #3 still yields conservative EDE estimate.

1. INTRODUCTION

In the past ten years, Entergy has been the driving force in nuclear industry's efforts to develop and to implement the so-called EPRI Two-Dosimeter Algorithm. On February 13, 2003, NRC issued a Regulatory Issue Summary (RIS) on EDE [1]. In this RIS, NRC decided to ".....permit the use of effective dose equivalent for external exposure in place of the DDE." NRC also stated: "....10CFR20.1201 (c) does not apply, because the DDE is no longer used in the definition of TEDE." However, in this RIS, the above statements apply only to "computational EDE," and NRC explicitly excluded "dosimeter measurements." NRC further stated: "In personnel monitoring situations for which this use of DDE measured at the location of highest exposure may not be desirable, NRC will grant approval for other methods of dose monitoring, on a case-by-case basis, if the proposed methods can be shown to be technically adequate for the intended use." This last statement was clearly an indication that Entergy's request was being considered by NRC.

Although the RIS 2/13/2003 opened door for general adoption of EDE, Entergy's effort in implementing EDE is hindered by NRC's concern about a lack of data on EDE and dosimeter response for point sources located within a foot to the surface of the body. In a U.S. NRC Federal Register Notice dated July 24, 2003 [2], it is stated that "This method of estimating EDE from two dosimeter readings is not applicable to exposure situations where the sources of radiation are nearer than 12 inches (30 cm) from the surface of the body. This is the closest distance that the two-dosimeter algorithm has been demonstrated to provide conservative results for discrete point sources." Indeed, the original work on EDE by EPRI [3] limited the investigation of the two dosimeter algorithm (as shown in Table 9 of Reference 3) to parallel beams and point sources at 44 cm from the center of the body (at Z=41cm and Z=6 cm). The original scope of the EPRI project performed 10 years ago was to cover most common parallel beam exposures in nuclear power plants and point sources within one foot from the body were not addressed. At the time NRC issued the above statement, hot particle (point gamma sources in contact with the body) issue was also being considered at NRC. Therefore, NRC's concern can also be interpreted as an effort to separate the EPRI Dosimeter Algorithm and the hot particle issue.

The purpose of this project is to calculate the effective dose equivalent and dosimeter responses from point-like gamma sources located within a foot of (but nor in contact with) the body. Algorithm #3 defined in the report on EPRI EDE algorithm [3] will then be calculated using these newly calculated EDE and dosimeter data. A photon energy of 0.08 MeV is used to represent a conservative scenario. The source locations are chosen to complement the locations already studied in the prior EPRI work [3].

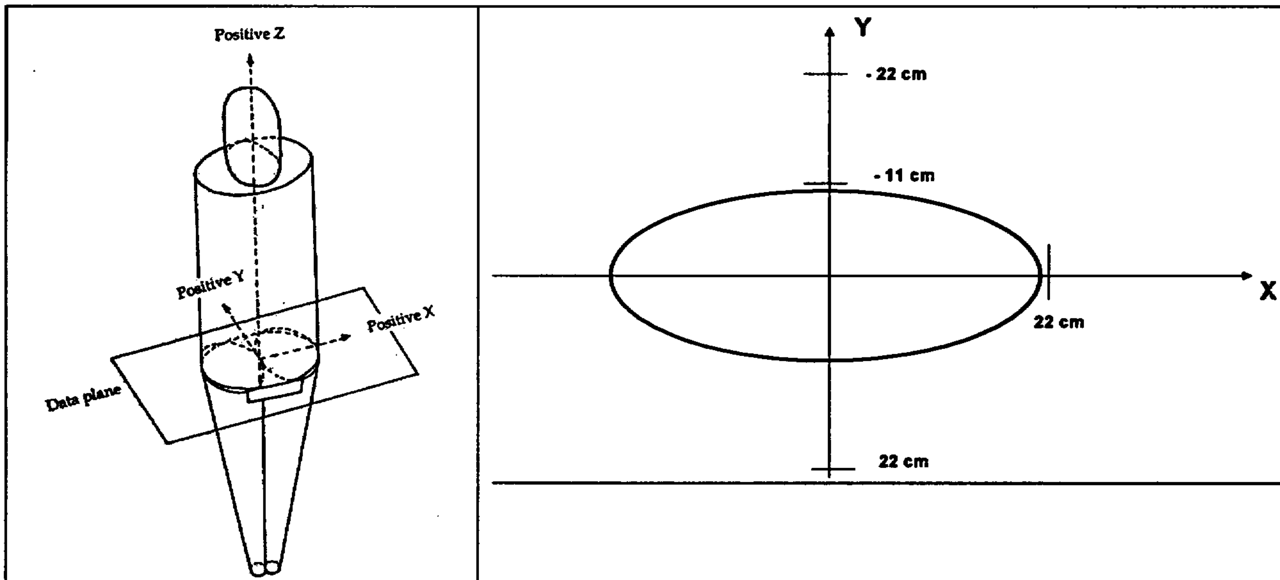
2. METHOD

Computational method is the same as those used in previous EPRI projects [3]. The following sub-sections discuss the selection of energy and locations of the source.

2.1. Source Definition

The Algorithm #3 is based the ratio of the dosimeter response and the corresponding EDE. When a gamma point source is located near the body surface, the relationship between response of a chest-worn (or back-worn) dosimeter and effective dose equivalent becomes highly dependent on the specific location of the source. Because the radiation flux of a point source follows the "$1/(\text{distance})^2$" rule, the distances from the source to the dosimeter and to an organ,

respectively, play important roles. The major concern is that, when the source moves towards the body, the algorithm will become less conservative and then break down eventually in some extreme cases. Obviously, the lower the gamma energy, the earlier the breakdown might occur because the weak penetrating gamma rays will reduce the dosimeter responses. For this reason, we decided to use very conservative gamma energy of 0.08 MeV in our test, although nuclear power plants usually encounter much higher gamma energies from activation and fission products. Within the source to body surface distance of 30 cm, we decided to consider three locations for each height on the body. These points are located at 22cm from the center of the body, as shown in the Fig. 1. Because the front surface of the body is 11 cm from the center of the body, the source is actually about 11 cm from the body surface. The side surface is 21 cm from the body center, leaving the source to be 1 cm off the body surface from the side.



a b

Figure 1. (a) Schematic of the phantom coordinate system; (b) Cross section view of the source locations on the data plane at each height Z on the phantom.

2.2 Computational Phantom

The most widely used models of the workers in radiation protection dosimetry were originally developed for the MIRD Committee of The Society of Nuclear Medicine in 1960's [4,5]. Fig. 2 illustrates the exterior and cut-away views of the original MIRD stylized adult male model. These models were analytically defined in three principal sections: an elliptical cylinder resenting the arm, torso, and hips; a truncated elliptical cone representing the legs and feet; and an elliptical cylinder representing the head and neck. A total of 41 organs and tissues have been defined. The mathematical descriptions of the organs were formulated based on descriptive and schematic materials from general anatomy references. The goal was to make the mathematical equations simple, thus minimizing computing time. Later improvements at Oak Ridge National Laboratory led to a series of "family" stylized models, which include both genders at several ages [6,7]. There are only three media with distinct densities: bone, soft tissue, and lung. For thirty years, these simplified models have been used practically as the "standard" mathematical representations of the Reference Man [8] in radiation protection, nuclear medicine, and medical imaging.

Two dosimeters were simulated using air-filled spheres, each with a radius of 1 cm, located at the chest and back at height Z=41 cm in contact with the phantom, respectively.

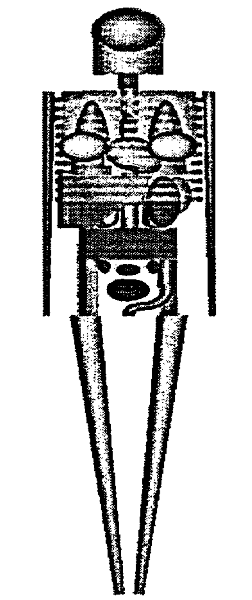


Figure 2. MIRD stylized model

2.3 Monte Carlo Method

Analytical calculations for the transport of the radiation through media can be performed only in very simple geometries and under severe approximations. Monte Carlo method, which is based on the first principles, provides the only practical way of performing accurate calculations of 3-D dose distributions from particle interactions in a complex target such as the human body. The earliest use of a Monte Carlo simulation technique was around 1873 [9]. The real development and application of the technique, however, stemmed from work on the atomic bomb during World War II by von Neumann, Ulam, and Fermi. Neumann coined the term "Monte Carlo" to reflect the idea that a conceptual roulette wheel could be employed to select the random nuclear processes. Today, a computer-generated random number between 0 and 1 is used for this purpose. The random number determines which interaction will occur by comparing probabilities (i.e., cross sections) of each interaction. The process is repeated and a particle is tracked in the target until it deposits all its energy or escapes. When a large number of particles (usually several millions) are studied this way, the results accurately predict the physical processes (such as dose) that may be experimentally determined. Validation of a code must be done before the code may be used for calculations. Among several most widely used codes is MCNP, originated from Los Alamos National Laboratory. MCNP has the capbility to transport photons, neutrons, and, in the recent Versions of 4B and 4C, also the electrons [10]. MCNP has a generalized input capability allowing a user to model a variety of source and detector conditions without having to modify the source code itself. The ENDF/B cross section libraries are used. MCNP4C represents the state-of-the-art in terms of the radiation physics, cross-section data and physical models involving photons, electrons, neutrons, and protons. Because MCNP has been validated through extensive experiments, results from MCNP are often considered to be extremely accurate and precise, provided that the geometry and source definitions are correctly done.

2.4. EDE Calculational Procedure

The mean absorbed dose in an organ or tissue (D_T) are calculated by MCNP4C code using energy deposition tally as the total energy deposited in organ T per unit mass. The equivalent dose (H_T) in T is calculated by multiplying the mean absorbed dose by the radiation weighting factor, w_R, which is always unity for photons and electrons. Since the same dose equivalent value can cause different risk in different organs or tissues, a tissue weighting factor (w_T), has to be applied to yield the total risk, in terms of effective dose equivalent using Equation 1 [11],

$$E = \sum_T w_T H_T \qquad \text{(Eq. 1)}$$

The tissue weighting factors were first recommended by ICRP in its ICRP Report 26 [11]. Later, the weighting factors were revised and new organs were added in its ICRP Report 60 [12]. However, NRC has so far only adopted the ICRP-26 weighting factors [13]. Table 1 lists critical organs/tissues and their weighting factors explicitly recommended by ICRP-26 and ICRP-60. Because MIRD phantom does not have the "bone surface," the dose will be substituted with the dose to bone, as in all such calculations. The "remainder" organ includes about ten inexplicit organs that share a total tissue weighting factor of 0.3 (or 0.05 in ICRP-60). Upper large intestine was combined to the critical organ, colon. Interestingly, ICRP-60, but no ICRP-26, considers the skin as part of the whole-body exposure. Since, NRC will have to adopt some of the newer tissue weighting factors, as did all other countries, it is prudent to use both sets of weighting factors in our calculations for EDE.

Table 1. ICRP Weighting Factors.

Tissue	W_T, ICRP 26	W_T, ICRP 60
Gonads	0.25	0.20
Bone marrow (red)	0.12	1.12
Colon	Not given	0.12
Lung	0.12	0.12
Stomach	Not given	0.12
Bladder	Not given	0.05
Breast	0.15	0.05
Liver	Not given	0.05
Esophagus	Not given	0.05
Thyroid	0.03	0.05
Skin	Not given	0.01
Bone surface	0.03	0.01
Remainder	0.3	0.05

2.5. Computational Procedures

A Monte Carlo calculation took approximately one hour for each energy and location. These resulted in statistical uncertainties that are less than three percent (3%) for majority of the organs and less than ten percent (10%) for a few very small organs. These are very satisfactory results and the confidence level about the data presented here is high. Once a Monte Carlo calculation is done, a code developed for this project is applied to extract organ doses into a one-page summary and to compute EDE using Eq. 1 and Table 1.

3. RESULTS AND DISCUSSION

Table 2 summaries the name of the one-page data, the location of each source in terms of X, Y, and Z axes, responses of dosimeters worn on the chest and back, EDE, EDE for male and female. Three EPRI algorithms were used for the calculation [3], although here we only discuss the Algorithm #3:

$$H'_E = [\mathrm{Max}(R_{front}, R_{back}) + \mathrm{Avg}(R_{front}, R_{back})]/2 \qquad \text{Eq. 2}$$

where H'_E is the estimated EDE from dosimeter readings. Table 2 also lists the ratio of the H'_E using these three algorithms to the true H_E calculated from Monte Carlo phantom, which is a measure of how conservative the algorithm is:

$$Ratio = \frac{H'_E}{H_E}. \qquad \text{Eq. 3}$$

The ratios are listed under #1, #2, and #3 in Table 2, respectively. When a ratio is greater than one, the algorithm is conservative. The last column is results for ED using ICRP-60 weighting factors. The complete one-page post-processed original data for all 35 locations are not enclosed in this report but are available upon request.

Table 2. Results.

Name	X (cm)	Y (cm)	Z (cm)	Front (Gy)	Back (Gy)	EDE (Sv)	Male (Sv)	Female (Sv)	#1	#2	#3	ED (Sv)
P50o	0	0	105	4.58E-20	4.56E-20	1.28E-17	1.27E-17	1.29E-17	0.004	0.004	0.004	4.53E-18
P51o	0	-22	105	8.80E-18	2.07E-19	8.16E-18	6.11E-18	1.02E-17	1.078	0.552	0.815	4.57E-18
P52o	0	22	105	2.27E-19	8.55E-18	5.89E-18	5.69E-18	6.10E-18	0.038	0.744	1.097	3.64E-18
P53o	22	0	105	4.09E-19	3.67E-19	7.48E-18	6.76E-18	8.19E-18	0.055	0.052	0.053	4.44E-18
P54o	0	0	95.2	6.15E-20	3.96E-20	3.12E-17	3.11E-17	3.14E-17	0.002	0.002	0.002	1.08E-17
P55o	0	-22	86.85	1.46E-17	3.81E-19	1.56E-17	1.16E-17	1.95E-17	0.937	0.481	0.709	9.97E-18
P56o	0	22	86.85	4.99E-19	1.43E-17	1.11E-17	1.06E-17	1.15E-17	0.045	0.667	0.978	7.86E-18
P57o	22	0	86.85	5.57E-19	4.74E-19	1.14E-17	1.03E-17	1.24E-17	0.049	0.045	0.047	7.66E-18
P58o	0	-22	61	6.67E-17	2.71E-18	4.75E-17	3.08E-17	6.43E-17	1.403	0.730	1.066	2.59E-17
P59o	0	22	61	2.99E-18	6.55E-17	2.72E-17	2.54E-17	2.91E-17	0.110	1.258	1.832	2.22E-17
P60o	22	0	61	2.79E-18	2.51E-18	1.80E-17	1.44E-17	2.17E-17	0.155	0.147	0.151	1.26E-17
P61o	0	-22	41	2.70E-16	4.92E-18	4.88E-17	3.38E-17	6.38E-17	5.525	2.813	4.169	3.41E-17
P62o	0	22	41	5.41E-18	2.66E-16	4.04E-17	3.75E-17	4.33E-17	0.134	3.365	4.980	2.61E-17
P63o	22	0	41	7.00E-18	6.35E-18	2.93E-17	2.60E-17	3.26E-17	0.239	0.228	0.233	1.77E-17
P64o	0	-22	21	6.64E-17	2.46E-18	4.11E-17	3.61E-17	4.62E-17	1.615	0.838	1.226	3.52E-17
P65o	0	22	21	2.83E-18	6.45E-17	3.26E-17	2.74E-17	3.78E-17	0.087	1.033	1.506	2.52E-17
P66o	22	0	21	1.88E-18	1.62E-18	1.84E-17	1.48E-17	2.20E-17	0.102	0.095	0.098	1.58E-17
P67o	0	-22	6	2.50E-17	7.19E-19	4.72E-17	5.78E-17	3.66E-17	0.530	0.273	0.401	3.76E-17
P68o	0	22	6	9.63E-19	2.42E-17	2.30E-17	1.93E-17	2.67E-17	0.042	0.547	0.800	1.89E-17
P69o	22	0	6	3.80E-19	3.48E-19	1.38E-17	1.21E-17	1.56E-17	0.027	0.026	0.027	1.21E-17
P70o	0	-22	-6	1.41E-17	3.28E-19	3.78E-17	5.72E-17	1.85E-17	0.372	0.190	0.281	3.07E-17
P71o	0	22	-6	4.20E-19	1.37E-17	1.36E-17	1.36E-17	1.35E-17	0.031	0.519	0.763	1.19E-17
P72o	22	0	-6	1.54E-19	1.53E-19	5.56E-18	6.32E-18	4.80E-18	0.028	0.028	0.028	5.74E-18
P73o	0	-22	-21	7.83E-18	1.21E-19	1.46E-17	2.24E-17	6.86E-18	0.535	0.272	0.403	1.24E-17
P74o	0	22	-21	1.30E-19	7.73E-18	5.78E-18	6.46E-18	5.11E-18	0.023	0.679	1.007	5.60E-18
P75o	22	0	-21	8.32E-20	7.34E-20	1.40E-18	1.91E-18	8.80E-19	0.060	0.056	0.058	2.02E-18
P76o	0	-22	-41	4.51E-18	4.39E-20	4.74E-18	6.98E-18	2.49E-18	0.951	0.480	0.716	4.30E-18
P77o	0	22	-41	5.42E-20	4.25E-18	1.70E-18	1.90E-18	1.50E-18	0.032	1.268	1.886	2.02E-18
P78o	22	0	-41	2.31E-20	5.16E-20	2.84E-19	3.76E-19	1.92E-19	0.081	0.132	0.157	7.43E-19
P79o	0	-22	-61	2.85E-18	2.22E-20	2.14E-18	3.04E-18	1.25E-18	1.331	0.670	1.000	1.98E-18
P80o	0	22	-61	2.55E-20	2.72E-18	6.03E-19	6.50E-19	5.56E-19	0.042	2.275	3.391	8.62E-19
P81o	22	0	-61	5.18E-20	3.54E-20	1.09E-19	1.27E-19	9.10E-20	0.475	0.400	0.437	3.49E-19
P82o	0	-22	-81	1.79E-18	2.17E-20	1.19E-18	1.63E-18	7.46E-19	1.502	0.760	1.131	1.03E-18
P83o	0	22	-81	1.75E-20	1.82E-18	2.69E-19	2.73E-19	2.66E-19	0.065	3.418	5.094	3.87E-19
P84o	22	0	-81	2.22E-20	3.54E-20	6.21E-20	6.35E-20	6.07E-20	0.358	0.464	0.517	1.57E-19

Among these results, locations in front of and behind the phantom are the most useful because these are locations that a point sources are likely to be encountered by a worker. Because the phantom in MCNP is necessarily and unrealistically stationary related to the source, the overhead location (X=0, Y=0, Z=105cm) and locations on the side of the body (X=22cm) for the point sources are found to be unrealistic, underestimating the dosimeter responses as a result of body self-shielding. In reality, a worker must move around, significantly reducing the self-shielding effects.

To visualize the results for locations in front and behind the phantom, Figure 3 plots the ratio (#3 in the Table 2) for Algorithm #3, where the results are placed in a 2-D coordinate system with the phantom facing to the right side.

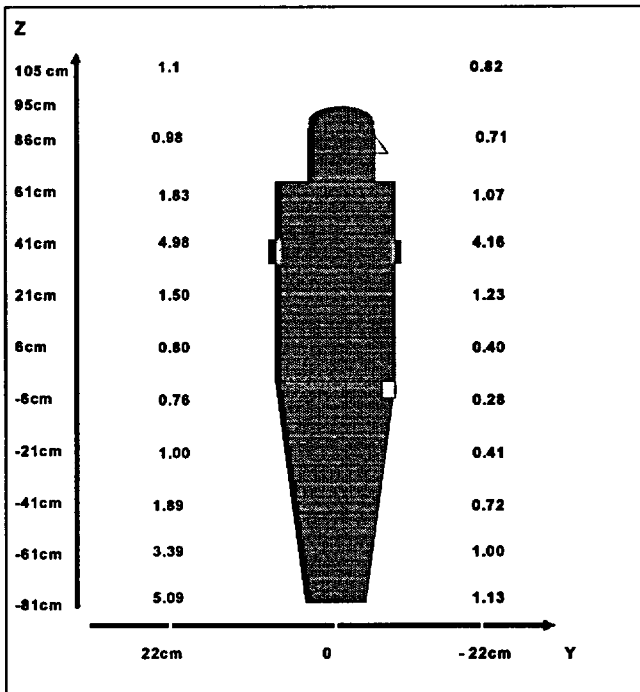


Fig. 3. Ratio of the estimated EDE to true EDE

From Table 2 and Figure 3, we make the following observation:

1) Overhead and side locations give very small dosimeter readings (dosimeters are shielded by the body), leading to small ratios. As discussed earlier, these results are not realistic because a worker will move around in reality.

2) Chest height locations (Z=41 cm) give very high dosimeter readings and high EDE, leading to very conservative ratios (4.16 for the front and 4.98 for the back))

3) Point sources located in the back give high dosimeter reading and low EDE (most organs are shielded), leading to generally high ratios than the locations in the front. Front ones are worse than back ones because most critical organs are situated in the upper/front of the phantom.

4) Point sources at heights near Z=6cm or -6cm give high EDE (gonadal doses) and median dosimeter readings, leading to less-than-one ratios (0.28 for the front and 0.76 for the back).

5) Near ground locations (Z=-81 cm) are far away from the critical organs and the dosimeters. The compounding effects lead to small EDE and small dosimeter readings, but greater-than-one ratios.

6) The simple average of these 22 front and back ratios (excluding the locations in the right side of the phantom and the overheard) yield a conservative ratio of 1.6. This is a result for 0.08 MeV sources. Photons at 0.3 MeV and 1.0 MeV will likely to result in even more conservative results.

In summary, this set of new data are based a limiting case of very low energy photons. They show that, for point sources located in the front and back of the body at 11-cm away from the surface, the proposed EPRI Two-dosimeter Algorithm #3 still yields conservative EDE estimate.

4. REFERENCE CITED

1. US NRC. NRC Regulatory Issue Summary 2003-04: Use if the Effective dose equivalent in place of the deep dose equivalent in dose assessment. February 13, 2003.
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Implementation of the Use of Effective Dose Equivalent in External Dose Assessments

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HPS 48th Annual Meeting
San Diego, CA July 21, 2003

Overview

- Current Practice for Measuring and Reporting
- Changes in Technical and Regulatory Guidance
- Industry Activities to Address Changed Guidance
- Entergy Implementation

▪Current Practice for Dosimetry

- Methodology Based on ICRU Guidance
- Conservative Measurement of Shallow Dose DDE Reported as TEDE w/o Internal Dose(10CFR20.1003)
- Reported Dose 10 to 50 Percent Higher than Actual TEDE
- Present Methods Meet Regulatory Requirements

Change in Guidance

- ICRP 26 - 1977
- EPRI Research Initiated - 1988
- Draft 10CFR20 Change - 1991
- EPRI Reports Issued – 1993 & 1995
- Change to 10CFR20 - 1994
- Peer Reviewed Journal Articles - 1995+
- NCRP Report 122 – 1995
- EPRI EDE Implementation Guide - 1998

▪Industry Activities to Address Changed Guidance

- NEI Request to NRC-1996
- Entergy Exemption Request-5/1/01
- NRC Completeness Review-5/29/01
- NRC Meeting-6/18/01

▪Industry Activities to Address Changed Guidance

- Entergy Revised Exemption Request-7/20/01
- NRC RAI Response-6/13/02
- NRC Exemption Issued-9/12/02
- NRC SECY-02-0214 Approved 1/20/03
- NRC RIS 2003-04, 2/13/03 Allows Use of EDE in Place of DDE for Personnel Dosimetry by All Licensees with Prior Approval
- Research to Address Constraints in Exemption and RIS

Research

- Exemption Limited Use of the Method to Sources at Least 12 inches (30 cm) from the Body
- Limitation Made the Exemption Impractical for Use in Power Plants
- Additional Monte Carlo Calculations for Sources Closer to the Body Performed to Validate Method for these Conditions

Concept of Effective Dose (Equivalent)

1. **Effective dose equivalent, H_E**

   - ICRP-26 (1977) and 10CFR20 (1994)

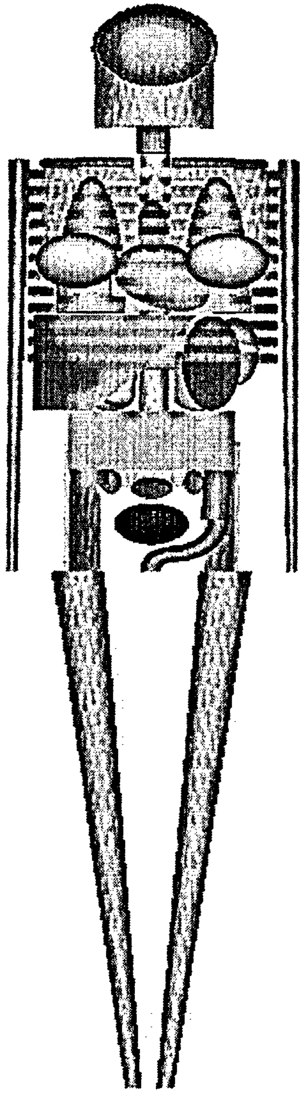
   $$H_E = \Sigma_T w_T H_T$$

2. **Effective dose, E**

   - ICRP-60 (1991)

Organ	w_T(ICRP-26)	w_T(ICRP-60)
Gonads	0.25	0.20
Bone marrow (red)	0.12	0.12
Colon	Not given	0.12
Lung	0.12	0.12
Stomach	Not given	0.12
Bladder	Not given	0.05
Breast	0.15	0.05
Liver	Not given	0.05
Esophagus	Not given	0.05
Thyroid	0.03	0.05
Skin	Not given	0.01
Bone surface	0.03	0.01
Remainder	0.30	0.05

Computational Approach



1. MCNP Code (4C) originated from Los Alamos National Lab

2. MIRD adult male and female phantoms originated from Oak Ridge National Lab for Society of Nuclear Medicine (1987)
   - *50 organs and tissues*
   - *Soft tissue (1.04 g/cm3)*
   - *Skeleton (1.4 g/cm3)*
   - *Lung (0.296 g/cm3)*

EPRI Two-dosimeter Algorithm

EPRI Algorithm #3

$$H'_E = [Max(R_{front}, R_{back}) + Avg(R_{front}, R_{back})]/2$$

$$Ratio = \frac{H'_E}{H_E}$$

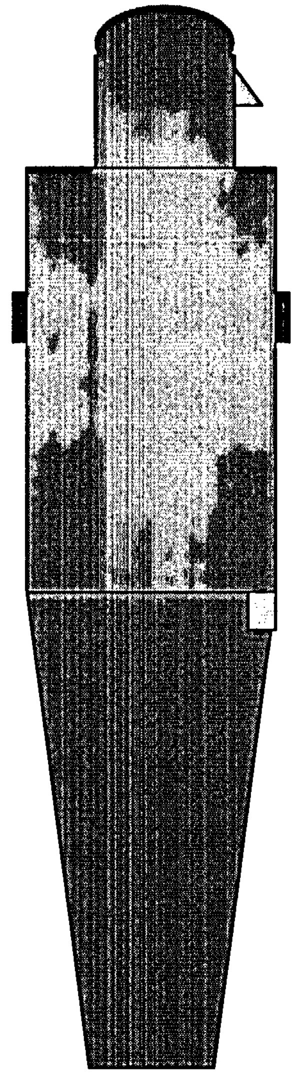
Where H'_E is the estimated EDE;

H_E is the EDE from Monte Carlo calculations

R is the dosimeter reading

Results

-0.08 MeV Photons
-Point sources 22 cm in front or back from the body centerline



Ratio as Function of Distance

Z= +41		Z=+6	
Y	Ratio	Y	Ratio
-44	1.58	-44	0.87
-22	4.16	-22	0.40
+44	1.41	+44	1.24
+22	4.98	+22	0.80

Use of EPRI Method at <30 cm

- Calculation for .08 MeV Photon Point Source a Conservative Limiting Case
- Power Plant Environment-Extended Sources with Energies an Order of Magnitude Greater

Use of EPRI Method at <30 cm

- Source at 10 cm from phantom Provides Conservative Measure of Dose Except for Point Source in Vicinity of Male Gonads and Near Lens of Eye in Front of Phantom

Conclusion

- Calculations at 22cm from Phantom Centerline(10cm from Surface) Demonstrate Validity of EPRI/TEDE Methodology at this Distance
- Earlier EPRI Work Demonstrated Validity at Greater Distances
- Method is Valid for Use in Power Plants Environments at Any Distance in Compliance With Other Exemption Requirements