

Latest Data on Effective Dose Equivalent

Database of EDE for gamma-emitting hot particles
(Sponsored by EPRI)

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Background

12/1999

NCRP 130 recommends “The dose to skin at a depth of 70 μm from hot particles on skin, hair, or clothing be limited to no more than 0.5 Gy (i.e. 50 rad) averaged over the most highly exposed 10-cm² of the skin” per particle.

1/2002

NRC I.N. 2002-03 about Susquehanna Station reiterated that DDE at 1-cm deep under the exposed skin should be calculated for hot particles. Per 10CFR20.1201C, DDE is added to obtain TEDE.

4/2002

NRC adopted NCRP 130, stating that NCRP “established a more risk-informed limit.”

6/2002

NRC approved TEDE exemption request from Entergy (two-dosimeter algorithms for parallel beam exposures).

2/13/2003

NRC issued a Regulatory Issue Summary (RIS) on EDE. In this RIS, NRC started to “.....permit the use of effective dose equivalent for external exposure in place of the DDE.”

The Issue Facing the Licensees

NRC I.N. 2002-03 states:

“The issue emphasized in this notice is that highly radioactive (hot) particles represent a radiological hazard not just shallow dose to the skin or extremity but also a deep or whole-body dose.”

As a result:

- A licensee must determine DDE at 1-cm deep under the exposed skin for gamma-emitting hot particles, because 10CFR20.1201C requires that DDE be assessed for the part of body receiving the highest exposure**
- However, DDE at 1-cm deep over-estimates the true stochastic risk to an exposed worker**

Project Objective

Systematically assess effective dose equivalent (EDE) from gamma-emitting hot particles, in support of future rulemaking to allow for reporting EDE in place of DDE from hot particles.

Dosimetric Issues of Hot Particles (Beta vs. Gamma and Skin vs. Whole Body)

Beta Emitters

- Beta dose to skin dominates (assuming no clothing and self-absorption)
- Clothing and self-absorption can reduce beta dose significantly
- Always irradiate locally over a small region (not entire surface of the body)
- Skin dose (local) must be averaged over 10-cm²

Gamma Emitters

- Gamma dose to skin is generally small due to a lack of CPE
- CPE profile (up to 1-cm) for isotropic point sources not well established
- Gamma dose to skin (local) dominates when clothing and self-absorption exist
- Skin dose (local) must be averaged over 10-cm²
- Can irradiate whole-body (DDE at 1-cm vs. EDE)
- Skin (entire body surface) is defined as a critical organ in Eff Dose (not in EDE)

Concept of Effective Dose (Equivalent)

1. Effective dose equivalent, H_E

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

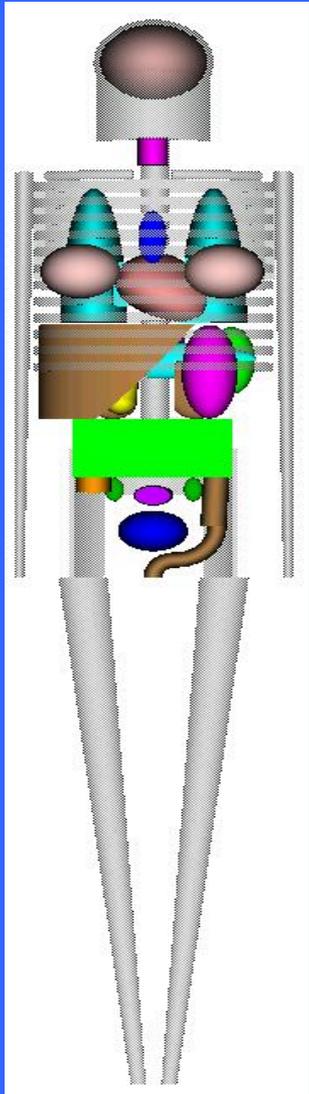
$$H_E = \sum_T w_T H_T$$

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

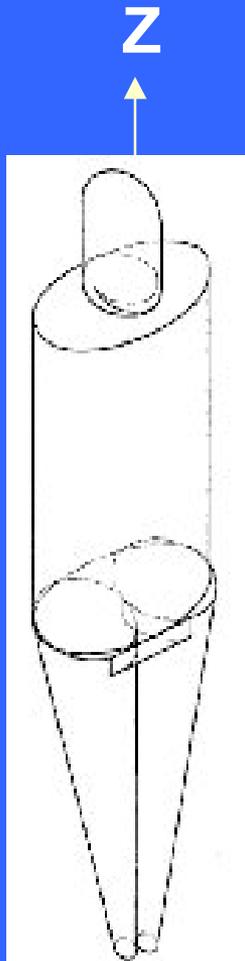
Computational Approach



- MCNP Code (version 4C) originated from Los Alamos National Lab
- MIRD adult male and female phantoms originated from Oak Ridge National Lab for Society of Nuclear Medicine (1987)
 - 50 organs and tissues
 - Various densities
 - Various tallies
- Skin is modeled as a 2-mm thick layer covering the entire body surface

Gamma Source Energies and Locations

- The entire surface of the body is divided into more than 60 zones
- Dosimeters are defined in the front and back at chest level
- Isotropic and mono-energetic gamma sources at defined
- Photon energies of 0.1, 0.2, 0.4, 0.6, 0.662, 0.8, 1.0, 1.25, 1.5, and 2.0 MeV.

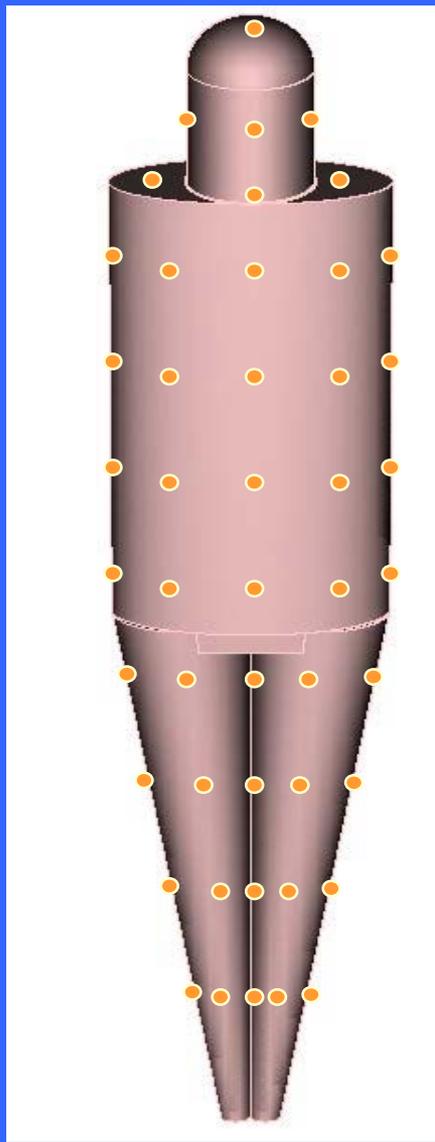


Height	Zone Names	# of Zones	# of calculations
Head and shoulder	Top, front, left, right, back, left shoulder, front neck, right shoulder, back neck	9	7
Z=61 (upper chest)	Left, front, right, back, upper left arm, upper right arm	6	4
Z=41 (lower chest)	Left, front, right, back, left elbow, right elbow	6	4
Z=21 (abdomen)	left, front, right, back, left lower arm, right lower arm	6	4
Z=6 (lower waist)	left, front, right, back, left hand, right hand	6	4
Z= -6 (upper thigh)	Left, front (2), between, right, back (2)	7	4
Z= -21 (lower thigh)	Left, front (2), between, right, back (2)	7	4
Z= -41 (knee)	Left, front (2), between, right, back (2)	7	4
Z= -61 (middle leg)	Left, front (2), between, right, back (2)	7	4
DDE at 10-mm depth of tissue		1	1
Energies		10	
Total Number of Calculations		$(39+1) \times 10 = 400$	

Results For Co-60

(Other results
Are being
reported to
EPRI)

X (cm)	Y (cm)	Z (cm)	EDE ($\mu\text{Rem} / (\text{h} \cdot \mu\text{Ci})$)
0	11.2	61	10.20
10.1	9.83	61	8.85
21.2	0	61	5.28
10.1	-9.83	61	15.69
0	-11.2	61	23.89
0	11.2	41	18.21
10.1	9.83	41	17.58
21.2	0	41	8.28
10.1	-9.83	41	18.48
0	-11.2	41	17.43
0	11.2	21	12.85
10.1	9.83	21	10.51
21.2	0	21	5.58
10.1	-9.83	21	12.55
0	-11.2	21	14.52
0	11.2	6	8.53
10.1	9.83	6	7.87
21.2	0	6	4.39
10.1	-9.83	6	12.38
0	-11.2	6	22.67
0	0	95.2	6.22
0	11.2	86.85	5.60
9.2	0	86.85	7.10
0	-11.2	86.85	6.58
0	11.2	70	7.56
0	-11.2	70	11.56
14.2	0	71	6.42
20.2	0	-6	2.55
9.6	10.7	-6	3.28
9.6	-10.7	-6	9.21
0	1.94	-6	9.86
0	-1.94	-6	19.03
16.2	0	-21	0.96
8	8.2	-21	1.16
8	-8.2	-21	2.72
0	1.78	-21	1.94
0	-1.78	-21	3.11
12.2	0	-41	0.19
6	6.2	-41	0.25
6	-6.2	-41	0.72
0	1.54	-41	0.32
0	-1.54	-41	0.74
8.19	0	-61	0.04
4	4.19	-61	0.07
4	-4.19	-61	0.29
0	1.25	-61	0.08
0	-1.25	-61	0.28



Note:
Average Co-60 energy of 1.25 MeV is used. The phantom facing negative Y axis.

Results on EDE from Co-60

- From the table for Co-60, EDE for the front chest location is $17 \text{ microRem}/(\text{h} * \text{microCi})$. NRC I.N. 2002-03 about Susquehanna Station reported Co-60 hot particles of up to 75 mCi. Such a source would have exposed the worker from the chest to exceed the annual limit of 5 Rem in about 4 hours. This is a much longer time than the 2-minutes stated in NRC I.N. 2002-03
- These results confirm that the NRC approach in using DDE is indeed overly conservative

Summary of Project

- **A comprehensive database on EDE at more than 60 locations and ten energies is now available**
- **Guidelines are being developed for reporting EDE for the gamma-emitting hot particles**
- **User-friendly software has been demonstrated**
- **Development of commercial software to easily report EDE for hot particles is proposed**