

Application of EDE Methodology To Hot Particles

Dr. X. George Xu

Associate Professor

Nuclear Engineering and Health Physics Programs

Rensselaer Polytechnic Institute

Troy, New York

Phone: 518-276-4014

E-mail: xug2@rpi.edu



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).

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**
- DDE at 1-cm deep over-estimates the true stochastic risk to an exposed worker**

Proposed new method:

Change from DDE at 1-cm deep under the exposed skin to EDE for the whole-body involving the organs listed in 10CFR20.

Project Objective

Systematically assess effective dose equivalent (EDE) from gamma-emitting hot particles

Tasks:

- 1) Evaluate existing data**
- 2) Consider format of new data**
- 3) Develop calculational strategy**
- 4) Obtain Monte Carlo simulation results**
- 5) Publish data at HPS meetings and journals**
- 6) Assist in rulemaking**

Physics of Hot Particles

- Activation products or fuel fragments that have a size between 10 and 250 microns
- Also called “fleas” “specks” or “discrete radioactive particles”
- Hot particles emit beta and gamma radiation
- Mostly ^{60}Co containing tiny sections of metals
 - wear-resistant alloys (stable cobalt) from valve seats, reactor coolant pumps
 - $^{59}\text{Co} (n, \gamma) ^{60}\text{Co}$.
- Electrically charged and mobile

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

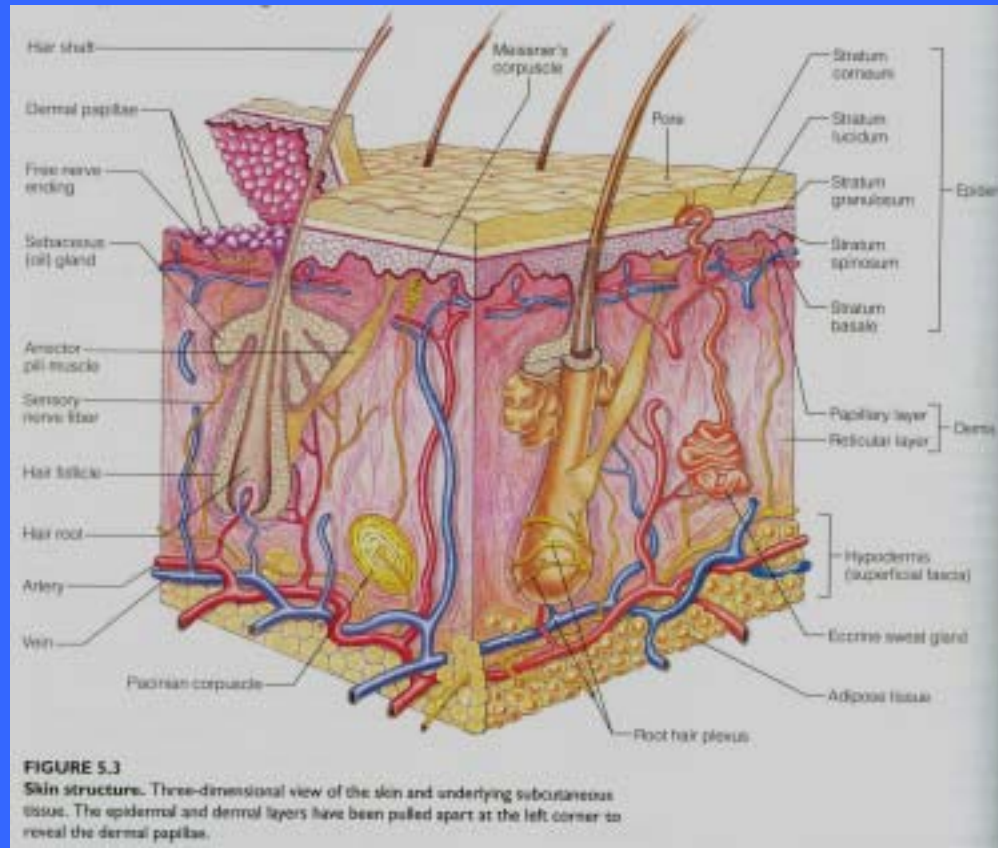
Skin dose (local) must be averaged over 10-cm²

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)

Skin Thickness For Different Body Sites

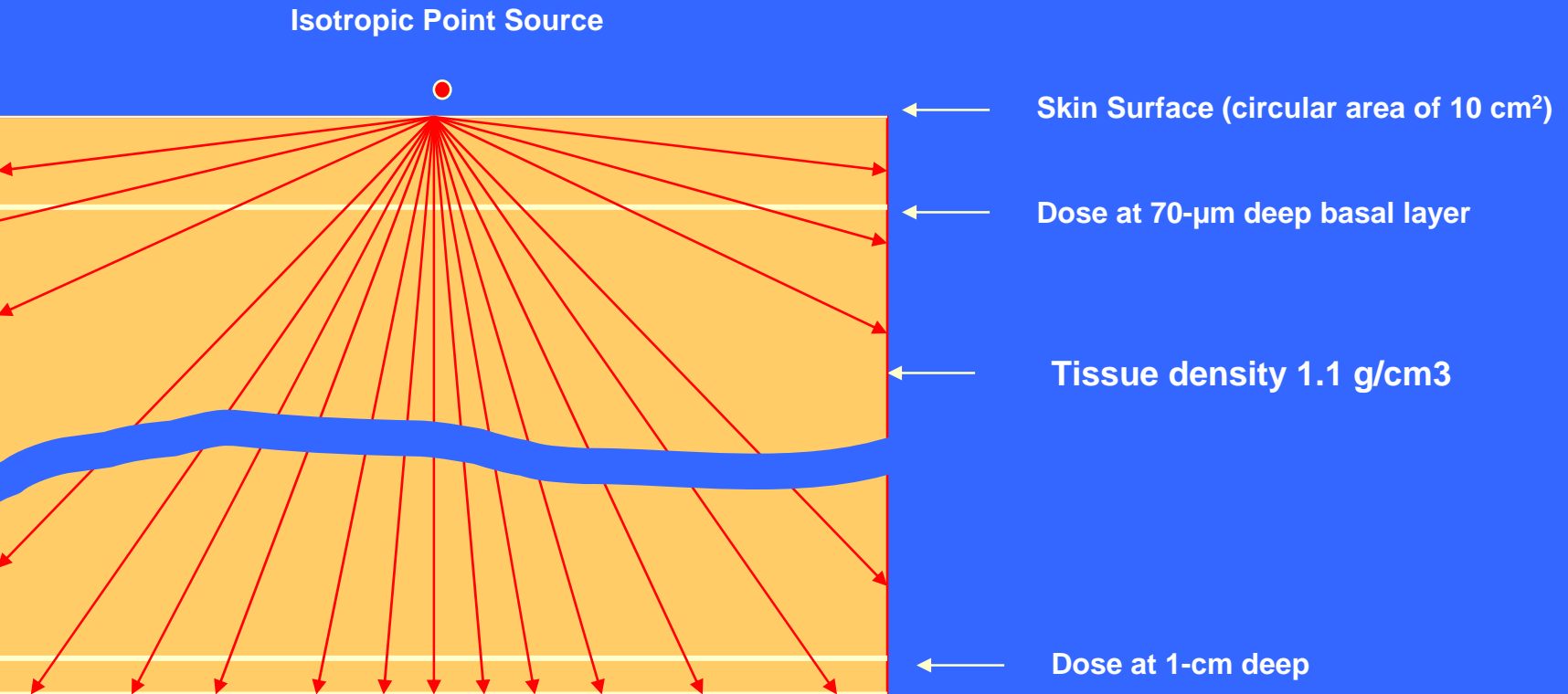
Skin Site	Epidermis (μm) ^a		Epidermis+ Dermis (mm) ^b
	Males	Females	
Thigh:			
medial	50-71	18-55	0.99±0.08
lateral	39-78	45-63	1.32±0.16
Forearm:			
back	49-65	53-55	1.29±0.08
front	34-65	39-61	1.11±0.05
Leg:			
medial	38-55	35-113	1.11±0.05
lateral	55-78	39-56	1.32±0.16
Back	49-92	45-61	2.50±0.15



Data adopted from NCRP 130 (1999)

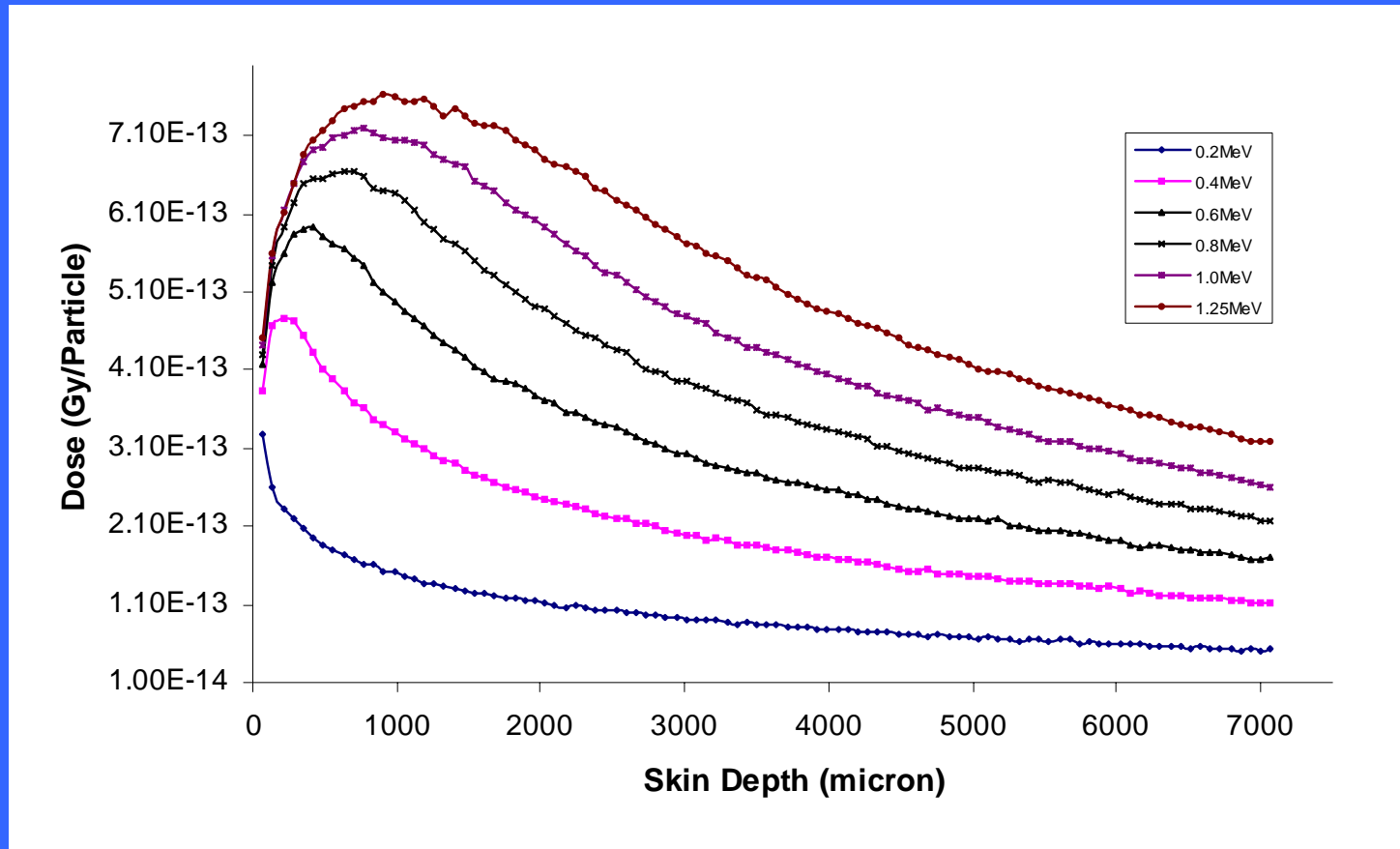
What should be the depth at which the skin dose is determined?

Monte Carlo Calculation of Dose Depth Profile



- The behaviors of parallel beams are understood
- An isotropic point source achieves CPE under 10-cm² area at a shallower depth

Preliminary Monte Carlo Study of Dose Depth Profile



Not Published Data

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

Selected Past EDE Work Related to Hot Particles

1. Reece et al. (1993-1997)

- For two-dosimeter study**
- Parallel photon beams at 0.08, 0.3 and 1.0 MeV**
- Point sources at selected positions in contact and near skin**
- Not enough energy/location**

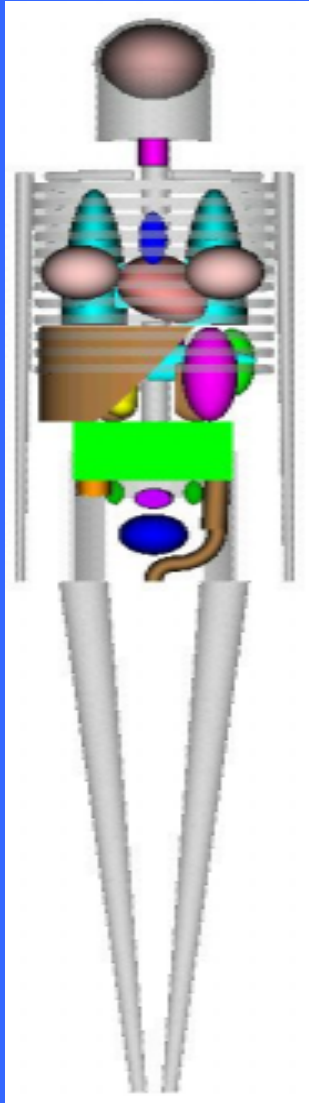
2. Kim et al. (1999)

- For environmental study**
- Point and disc sources away from the body**
- Not on the skin**

3. Walters et al. (1999)

- Point sources at four locations (head, chest, upper leg, lower leg)**
- 0.5, 0.662, 1.25 and 2.0 MeV**
- Not enough locations on the skin**
- EDE algorithms questionable**

Computational Approach

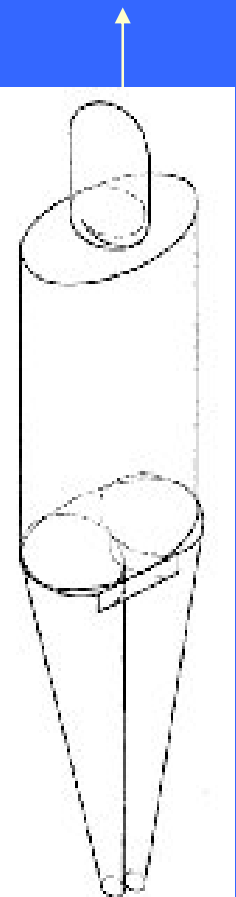


- MCNP Code (4C) originated from Los Alamos National Lab
- MIRD adult male and female phantoms originated from Oak Ridge National Lab for Society of Nuclear Medicine (1987)
 - 50 organs and tissues
 - Various densities
 - Various tallies
- Skin is modeled as a 2-mm thick layer covering the entire body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

Gamma Source Energies and Locations

1. The entire surface of the body is divided into 61 zones
2. Isotropic and mono-energetic sources
3. 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

Z



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		$(39+1) \times 10 = 400$	

Consideration for Final EDE Data

- **Look-up table based on averaged EDE data for the zones and energies discussed above**
- **Guidelines are developed for implementing a change from DDE at 1-cm deep under the exposed skin to EDE for the whole-body involving the organs listed in 10CFR20**

Schedule of EDE Work for Hot Particles

1. Sept 1 to Dec 31, 2002

- EPRI Workshop
- Literature review
- Development of strategy
- Verification of model and MCNP code

2. Jan 1 to Aug 31, 2003.

- Depth dose profile
- EDE calculations and data processing
- Publications

Summary

- **Strategies need to be agreed by all**
- **Skin depth dose profiles for isotropic point gamma sources will be determined**
- **EDE from gamma-emitting hot particles will be systematically assessed**
- **Data will be reviewed and disseminated**