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June 14, 2005  
Contract NRC-02-02-012  
Account No. 20.06002.01.352

U.S. Nuclear Regulatory Commission  
ATTN: Mrs. Deborah A. DeMarco  
Division of High-Level Waste Repository Safety  
Office of Nuclear Material Safety and Safeguards  
Mail Stop 8A-23  
Washington, DC 20555

Subject: Programmatic Review of Presentation Titled "Adding Radionuclides to the  
Varskin 3 Library Correctly"

Dear Mrs. DeMarco:

The subject presentation is being submitted for programmatic review. This presentation will be given by James Durham at a meeting of the Health Physics Society in Spokane, Washington, July 10-14, 2005. The work discussed in this presentation was originally performed by Dr. Durham prior to his employment at CNWRA; the work was performed on behalf of the NRC Office of Nuclear Regulatory Research. Although this work was not originally performed as part of CNWRA support of the NRC Division of High-Level Waste Repository Safety (HLWRS), we believe the subject matter of the presentation (e.g., approaches for correctly including radionuclides in dose assessment) is directly relevant to the Biosphere Characteristics integrated subissue and the Methodology and Overall System Performance components of the HLWRS program.

Dr. Durham's presentation focuses on the correct method for adding radionuclides to the Varskin 3 radionuclide library. Varskin 3 is a recently-released update to a code that calculates dose from skin contamination. One of the biggest improvements in the code is the ability for the user to create a custom radionuclide library. The library contains only the radionuclides chosen by the user and adding a radionuclide to the library does not require knowledge of basic nuclear physics. For each radionuclide added to the library, the user must choose the cutoff energy and yield (% emitted per disintegration); decay paths for the chosen radionuclide that fail to exceed both criteria will not be included in the library file for that radionuclide. Simply choosing the default values for the minimum photon energy and yield can result in incorrect values because the minimum energy for a dose calculation at one skin depth may not be appropriate at another skin depth.

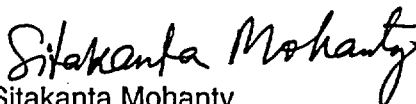


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June 10, 2005  
Mrs. Debbie DeMarco  
Page Two

Please advise me of the results of your programmatic review. If you have any questions regarding this presentation, please contact me at 210-522-5185. Your cooperation in this matter is appreciated.

Sincerely,

  
Sitakanta Mohanty  
Assistant Director, Engineering and  
Systems Assessment

JW/rm  
Enclosures: Presentation  
NRC Form 390A

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# **Adding Radionuclides to the Varskin 3 Library Correctly**

**Dr. Jim Durham**  
**Center for Nuclear Waste Regulatory**  
**Analyses**  
**Southwest Research Institute**  
**San Antonio, TX**



# Purpose

- **Discuss Recent Changes in Varskin 3**
  - ◆ Redesign Interface in Version 3.0
  - ◆ Correct errors identified in Version 2.2
- **Discuss the Correct Method of Adding Radionuclides to the Library**
  - ◆ New Options in Version 3.0
  - ◆ Photon Minimum Energy

# Varskin 3

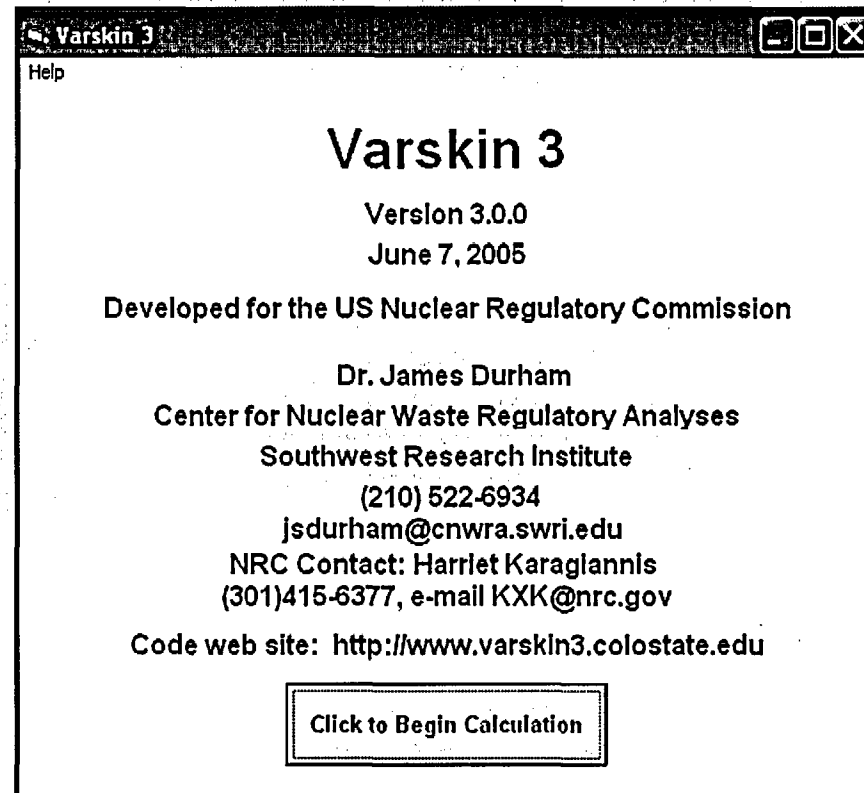
- **Calculates dose to skin from contamination on skin or on a cover material**
- **Uses the Berger Point Kernel:**

$$\text{Dose}(\mathbf{x}) = \frac{AYkE_{\text{avg}} F_{\beta}(\mathbf{x} / X_{90})}{4\pi\rho\mathbf{x}^2 X_{90}}$$

- **GUI written in Visual Basic**
- **Calculation engines written in Fortran**

# Revised Opening Screen

- **Reflects new contact information for the author**



# Revised User Interface

The screenshot displays the 'Source Geometry' software window with the following sections:

- Source Geometry:** Radio buttons for Point, Sphere, 2-D Disk, Slab (selected), 3-D Cylinder, and Syringe.
- Special Options:** Checkboxes for 'Include Photon Dose', 'Perform Volume Averaging', and 'Offset Particle Model' (checked). An 'Offset value' field is set to 1 cm.
- Skin Averaging Area:** A field set to 10 cm².
- Exposure Time:** A field set to 60 min.
- Radionuclide Library:** A list of radionuclides (Ac-227, Ac-228, Ag-111, Al-28, Am-245, As-76, At-217, Au-198, Ba-128, Ba-137m) with 'Select', 'Add', and 'Remove' buttons. A 'Use Distributed Source' checkbox is present.
- Selected Radionuclides:** An empty list box with 'Edit', 'Remove', and 'Clear' buttons below it.
- Slab Source Irradiation Geometry:** Fields for Skin Thickness or Skin Density (7 mg/cm²), Air Gap Thickness (0 mm), Clothing or Cover Thickness (0 mm), Clothing or Cover Density (0.00E+00 g/cm³), X-Side Length (1 μm), Y-Side Length (1 mm), Source Thickness (1 μm), and Source Density (1 g/cm³). Includes a 'Multiple Cover Calculator' button.
- File Operations:** Buttons for 'Open File', 'Save File', and 'Save File As'.
- Bottom Buttons:** 'Calculate Doses' and 'End'.

- Selected units are more obvious
- Default values and units have not changed

# Revised User Interface

The screenshot displays the 'Source Geometry' software window. It features a menu bar with 'File', 'Edit', 'View', and 'Help'. The main interface is divided into several sections:

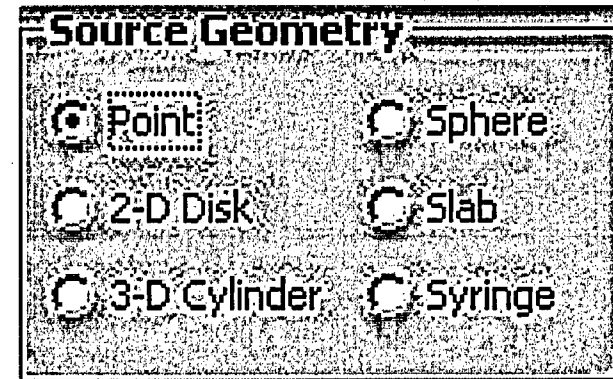
- Source Geometry:** Contains radio buttons for 'Point', '2-D Disk', '3-D Cylinder', 'Sphere', 'Slab', and 'Syringe'. The 'Slab' option is currently selected.
- Special Options:** Includes checkboxes for 'Include Photon Dose' (checked), 'Perform Volume Averaging', and 'Offset Particle Model'.
- Skin Averaging Area:** A numeric input field set to '10' with units of 'mm²' and 'cm²'.
- Exposure Time:** A numeric input field set to '60' with units of 'sec' and 'min'.
- Radionuclide Library:** Lists 'Co-60', 'Cs-137', 'Sr-90', and 'Y-90'. It includes 'Activity Units' (mCi, mCi) and buttons for 'Select', 'Add', and 'Remove'. A checkbox for 'Use Distributed Source' is also present.
- Selected Radionuclides:** An empty list box with 'Edit', 'Remove', and 'Clear' buttons at the bottom.
- Slab Source Irradiation Geometry:** Contains input fields for 'Skin Thickness or Skin Density' (7 mg/cm², µm), 'Air Gap Thickness' (0 µm, mm), 'Cover Thickness' (0 µm, mm), and 'Cover Density' (0 mg/cm³, g/cm³). It also includes fields for 'X-Side Length' (1 µm, mm), 'Y-Side Length' (1 µm, mm), 'Source Thickness' (1 µm, mm), and 'Source Density' (1 mg/cm³, g/cm³). A 'Multiple Cover Calculator' button is located at the bottom of this section.
- File Operations:** Includes buttons for 'Open File', 'Save File', and 'Save File As'.
- Calculate Doses:** A large button at the bottom right.
- End:** A button at the bottom right.

- Selected units are more obvious
- Default values and units have not changed

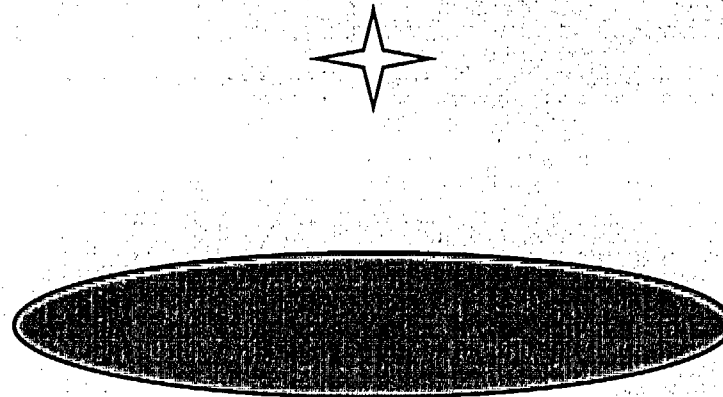


# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry

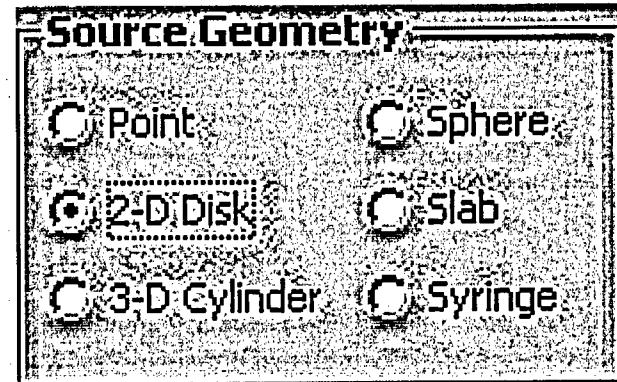


- Point source

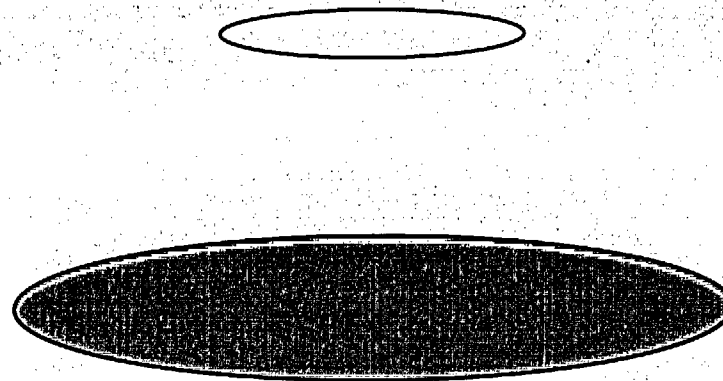


# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry

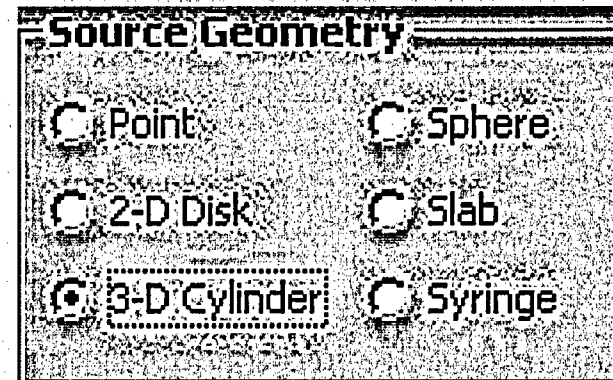


- 2-D disk source

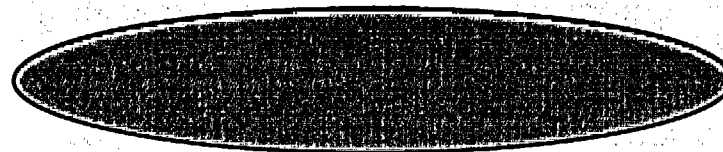


# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry

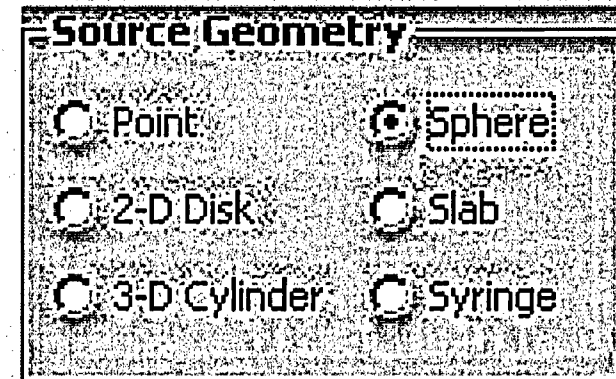


- 3-D cylinder source

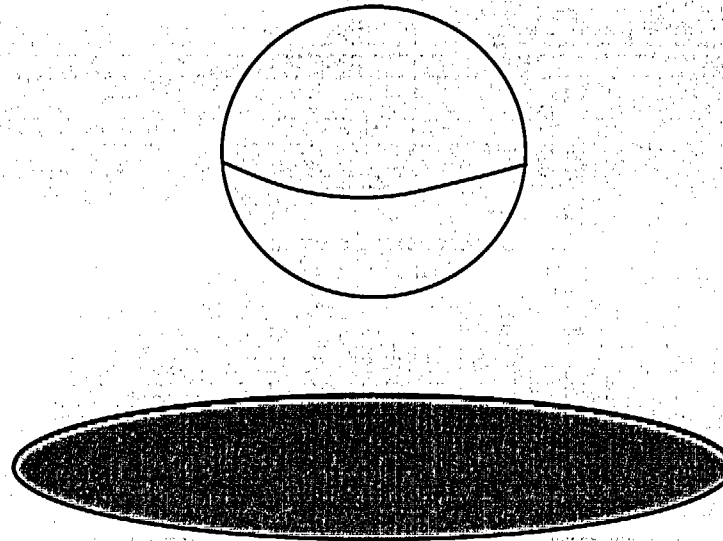


# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry

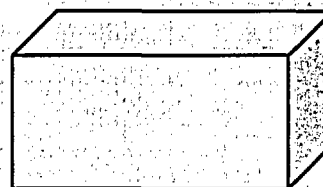
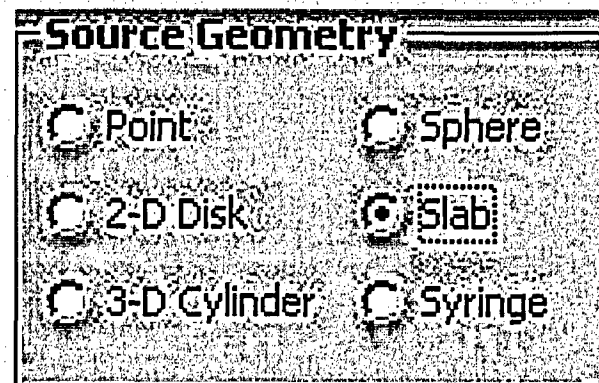


- Sphere source



# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry

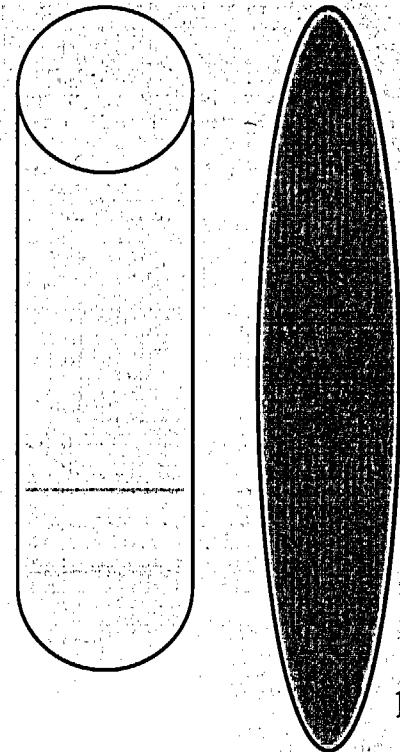
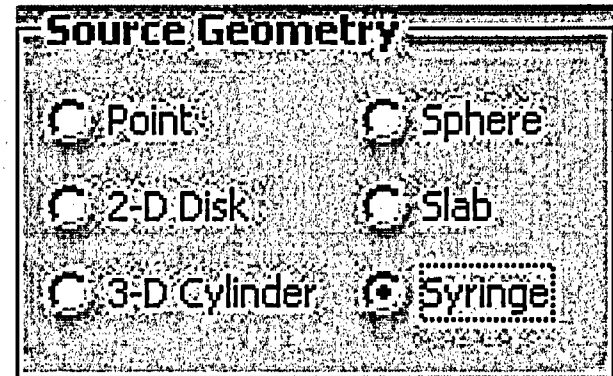


- Slab source



# Source Geometry Options

- Choose from six source geometry models
- Input screen adjusts for data entry
- Syringe source



# Radionuclide Library

- Library is built using “Add” button

**Radionuclide Library**

Co-60	Activity Units
Cs-137	µCi
Sr-90	mCi
Y-90	

Select

Add

Remove

☐ Use Distributed Source

# Revised “Add Radionuclide” Screen

**Add Radionuclide to Library**

Help

**Radionuclides Available to Add**

Ac-223	Ag-108m	Am-242	As-72	Au-195	Ba-135m	Bi-206	E
Ac-224	Ag-109m	Am-242m	As-73	Au-195m	Ba-137m	Bi-207	E
Ac-225	Ag-110	Am-243	As-74	Au-198	Ba-139	Bi-210	E
Ac-226	Ag-110m	Am-244	As-76	Au-198m	Ba-140	Bi-210m	E
Ac-227	Ag-111	Am-244m	As-77	Au-199	Ba-141	Bi-211	E
Ac-228	Ag-112	Am-245	As-78	Au-200	Ba-142	Bi-212	E
Ag-102	Ag-115	Am-246	At-207	Au-200m	Be-10	Bi-213	E
Ag-103	Al-26	Am-246m	At-211	Au-201	Be-7	Bi-214	E
Ag-104	Al-28	Ar-37	At-215	Ba-126	Bi-200	Bk-245	E
Ag-104m	Am-237	Ar-39	At-216	Ba-128	Bi-201	Bk-246	C
Ag-105	Am-238	Ar-41	At-217	Ba-131	Bi-202	Bk-247	C
Ag-106	Am-239	As-69	At-218	Ba-131m	Bi-203	Bk-249	C
Ag-106m	Am-240	As-70	Au-193	Ba-133	Bi-204	Bk-250	C
Ag-108	Am-241	As-71	Au-194	Ba-133m	Bi-205	Br-74	C

Electron and Photon Minimum Energy (keV) **Add Radionuclide** Electron and Photon Minimum Yield (%)

2 Cancel 1.0



# Revised “Add Radionuclide” Screen

**Add Radionuclide to Library**

Help

**Radionuclides Available to Add**

Ac-223	Ag-108m	Am-242	As-72	Au-195	Ba-135m	Bi-206	E
Ac-224	Ag-109m	Am-242m	As-73	Au-195m	Ba-137m	Bi-207	E
Ac-225	Ag-110	Am-243	As-74	Au-198	Ba-139	Bi-210	E
Ac-226	Ag-110m	Am-244	As-76	Au-198m	Ba-140	Bi-210m	E
Ac-227	Ag-111	Am-244m	As-77	Au-199	Ba-141	Bi-211	E
Ac-228	Ag-112	Am-245	As-78	Au-200	Ba-142	Bi-212	E
Ag-102	Ag-115	Am-246	At-207	Au-200m	Be-10	Bi-213	E
Ag-103	Al-26	Am-246m	At-211	Au-201	Be-7	Bi-214	E
Ag-104	Al-28	Ar-37	At-215	Ba-126	Bi-200	Bk-245	E
Ag-104m	Am-237	Ar-39	At-216	Ba-128	Bi-201	Bk-246	C
Ag-105	Am-238	Ar-41	At-217	Ba-131	Bi-202	Bk-247	C
Ag-106	Am-239	As-69	At-218	Ba-131m	Bi-203	Bk-249	C
Ag-106m	Am-240	As-70	Au-193	Ba-133	Bi-204	Bk-250	C
Ag-108	Am-241	As-71	Au-194	Ba-133m	Bi-205	Br-74	C

Photon Minimum Energy (keV):

**Add Radionuclide**

Cancel

Photon Minimum Yield (%):

- Minimum energy and yield is chosen for photon dose only

# How Varskin 3 Calculates Photon Dose

- **Specific Photon Dose Constant (rad-cm<sup>2</sup>-mCi<sup>-1</sup>-h<sup>-1</sup>)**

$$\Gamma = 1938 \left[ \sum_{i=1}^n P_i E_i \left( \frac{\mu_{en}}{\rho} \right)_{E_i, \text{tissue}} \right]$$

- ◆  $P_i$  is the probability of emission of a photon having an energy  $E_i$  (MeV)
- ◆  $(\mu_{en}/\rho)_{E_i, \text{tissue}}$  is the mass energy absorption coefficient in tissue (m<sup>2</sup>/kg)
- ◆  $n$  is the number of photons emitted

# Specific Photon Dose Constant

- ◆ Assumes the photon source is a point source



Point Source



# How Varskin 3 Calculates Photon Dose

- **Average Energy (MeV)**

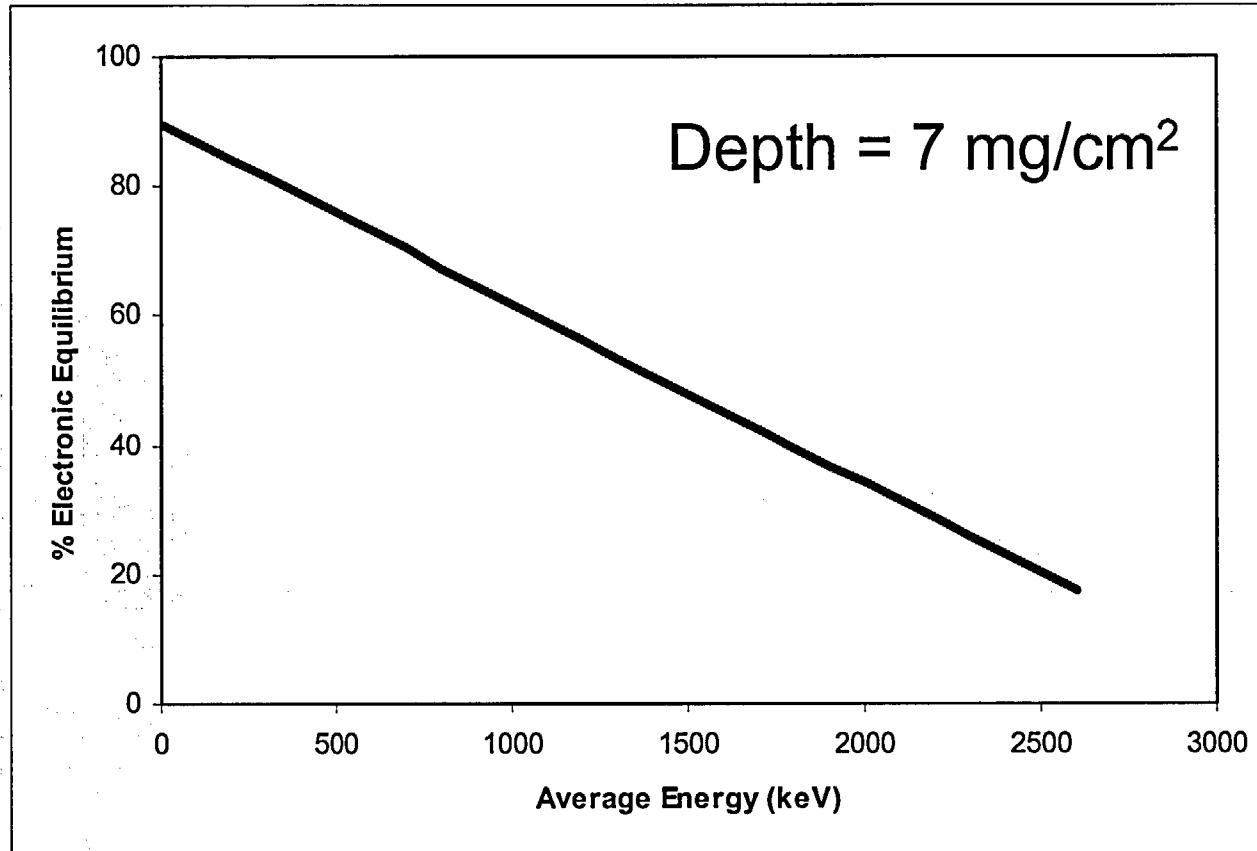
$$E_{\text{avg}} = \frac{\sum_i P_i E_i}{\sum_i P_i}.$$

- ◆ **Determines to what extent electronic equilibrium is established**

# **Problems with the Minimum Energy**

- **Choosing a low value of the cutoff energy may include the dose contribution from photons that do not contribute to dose at that depth**
- **Including photons that do not contribute to dose at a chosen depth has two effects**
  - ◆ **The average energy is decreased**
  - ◆ **The specific photon dose constant is overestimated**

# Electronic Equilibrium



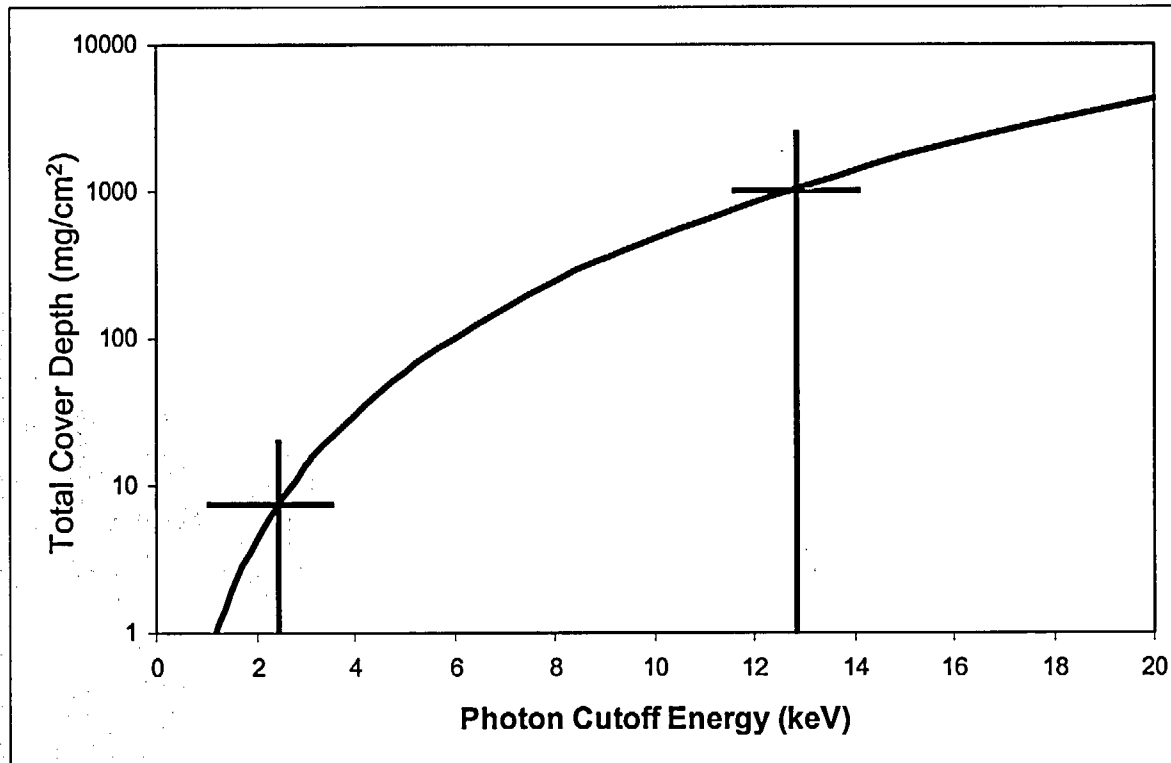
- **Calculated dose is multiplied by the fraction that electronic equilibrium is established**

# Example: Photon Minimum Energy

Specific Photon Dose Constant, $\Gamma$ , as a Function of Minimum Energy for $^{57}\text{Co}$	
Minimum Energy (keV)	$\Gamma$ (rad-cm <sup>2</sup> -mCi <sup>-1</sup> -h <sup>-1</sup> )
2	14.98
10	1.00
20	0.556
100	0.556
Published Value	0.9

- **Published value from Radiological Health Handbook**

# Minimum Energy vs. Depth



- Depth includes any cover materials plus skin density thickness
- Includes any photon that contributes 10% to dose
- Shallow dose minimum energy: 2 keV
- Deep dose minimum energy: 13 keV



# **Limitations Imposed on Photon Dose Model**

- **Maximum source dimension: 1 mm**
- **Maximum air gap: 5 cm**
- **No photon dose for syringe model**

# **Additional Changes to Varskin 3**

- **Printout error corrected**
- **Offset particle model activated**
- **Average  $\beta$  energy no longer includes IC and Auger electrons**
- **NUREG document and Help file updated**

# **Acknowledgements**

- **Harriet Karagiannis, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission**
- **Sami Sherbini, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission**
- **Mike Lantz, Arizona Public Service**

# **Disclaimer**

**The activities presented here were performed on behalf of the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research. The work was pursued while the staff author was at Colorado State University. This presentation does not necessarily reflect the view or regulatory position of the NRC.**