Chapter 6

- Effective Dose Equivalent (EDE) for External Radiation Exposure
- Submersion Dose
- Skin Dose

EFFECTIVE DOSE EQUIVALENT (EDE) FOR EXTERNAL RADIATION EXPOSURE

Objectives

- State the 10 CFR Part 20 definition and reporting requirements for external dose
- State the default weighting factor for external irradiation as given in 10 CFR 20.1003 and discuss the use of other weighting factors by licensees (given that they have NRC approval)

Objectives

- Discuss the use of effective dose equivalent (EDE) calculation methods by licensees for assessing external exposure
- Given various exposure scenarios and multibadging results, estimate effective dose equivalent and determine the correct dose to report to NRC

10 CFR Part 20 is a Risk-Based System of Radiation Protection

- NRC based new Part 20 on ICRP 26 recommendations
- Risk is proportional to amount of body tissue exposed (partial vs whole-body exposure)
- In 2006, NRC revised the definition of TEDE in Part 20 to allow use of EDE in place of DDE – Reference: 71 FR 55382, 9/22/2006

Precedent for NRC Granting Approvals to Use EDE

- Prior to 2002, all NRC licensees were required to use DDE measurements to report external dose.
- The NRC identified a discrepancy with medical licensees who were exposed to radiation from licensed material AND from state regulated fluoroscopy devices.
- RIS 2002-006 allowed EDE to be used for medical personnel wearing protective aprons during radiology procedures

Precedent for NRC Granting Approvals to Use EDE

- RIS 2003-04 was issued by NRC February 13, 2003
- It encouraged licensees to use EDE methodology in place of DDE where doses are calculated (i.e. do not involve direct monitoring of external exposures using personnel dosimetry)
- No prior NRC approval was required when using the EDE from external exposure in place of DDE in such situations

Precedent for NRC Granting Approvals to Use EDE

- An exemption from 10 CFR Part 20 was granted to Entergy to use a weighted two-dosimeter (EPRI) method for estimating EDE at their sites in around the time that RIS 2003-04 was published
- The NRC issued a generic approval for all of its licensees to use the EPRI weighted method in 2004 (RIS 2004-01, dated February 17, 2004)

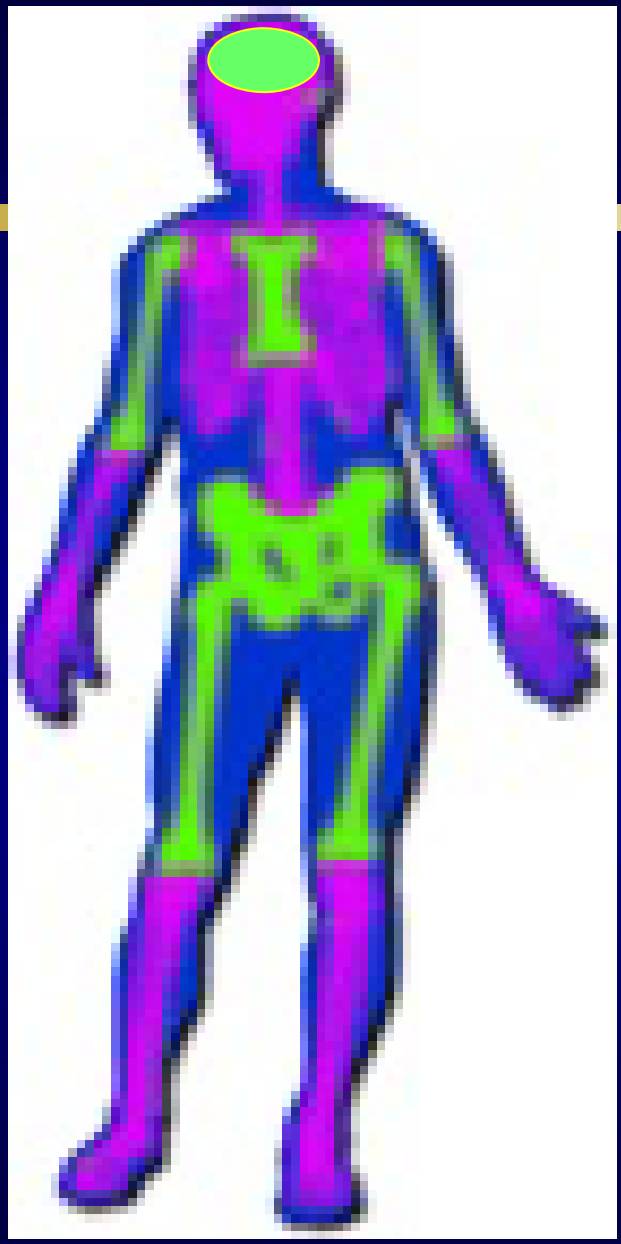
Precedent for NRC Granting Approvals to Use EDE

- RIS 2003-04 did not allow use of EDE for situations in which individual doses from external radiation fields were measured using personnel dosimetry
- In personnel monitoring situations, NRC would grant approval for other methods of dose monitoring, on a case-by-case basis

Precedent for NRC Granting Approvals to Use EDE

- In 2005, the NRC approved a request from Southern California Edison to use a compartmental method (ANSI/HPS N13.41-1997) to determine EDE
- The NRC issued RIS 2009-09 last year that gave generic approval for all licensees to use the ANSI compartmental method for determining EDE

Whole Body contains most of the red marrow (shown in green)



TEDE Definitions

OLD NRC APPROACH

TEDE = DDE + CEDE

ICRP 26 APPROACH NOW USED BY NRC

TEDE = EDE + CEDE

or

TEDE = H_E + CEDE

External Dose Definitions from 10CFR20

- 10 CFR Part 20.1003 states that deep-dose equivalent (H_d) applies to external whole-body exposure, and "is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2)."
- It also defines the effective dose equivalent (H_E) as "the sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors (w_T) applicable to each of the body organs or tissues that are irradiated."
- It further defines the total effective dose equivalent (TEDE) as "the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures)."

EDE

- ***Effective dose equivalent*** **(H_E) is the sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated ($H_E = \Sigma W_T H_T$).**
- **EDEX – effective dose equivalent for external radiation exposures**

ICRP 26 EDE Summation

$$H_E = \sum w_T H_T$$

10 CFR Part 20
Weighting Factors

Organ or Tissue	w_T
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surface	0.03
Remainder	0.30[1]
Whole Body	1.00[2]

[1] 0.30 results from 0.06 for each of 5 remainder organs (excluding the skin and the lens of the eye) that receive the highest doses.

[2] For the purpose of weighting the external whole body dose (for adding it to the internal dose), a single weighting factor, $w_T = 1.0$, has been specified. The use of other weighting factors for external exposure will be approved on a case-by-case basis until such time as specific guidance is issued.

External Dose Limits - 10 CFR 20.1201 (c)

- When the external exposure is determined by measurement with an external personal monitoring device, the deep-dose equivalent must be used in place of the effective dose equivalent, unless the effective dose equivalent is determined by a dosimetry method approved by the NRC.

  In addition, the assigned deep-dose equivalent and shallow-dose equivalent (averaged over 10 cm^2) must be for the part of the body receiving the highest exposure.

Comparison of Approaches To External Radiation Measurement

DDE Method

- DDE is simple to measure and report
- DDE is conservative
- DDE may overestimate risk in certain exposure situations (e.g. partial body/non-uniform radiation fields)

EDE Method

- EDE can be less straightforward to determine
- In some cases, EDE would more accurately reflect true radiation risk (partial body/non-uniform radiation fields)

Comparison of TEDE Using DDE vs. EDE

Suppose only a worker's thyroid is exposed to a collimated beam of gamma rays (no internal exposure). Calculate the TEDE for the worker using both the DDE and EDE methods.

Given:
Thyroid weighting factor, $w_T = 0.03$
Worker was wearing a dosimeter near the neck.
The dosimeter result = 1 rem

By the two methods:

TEDE = DDE = 1 rem (Default weighting factor = 1)

TEDE = EDE = 1 rem x 0.03 = 0.03 rem or 30 mrem (dose of 1 rem to thyroid has same risk as a dose of 30 mrem to whole body)

Regulatory Guide 8.41

- Regulatory Guide 8.40, "Methods for Estimating Effective Dose Equivalent from External Exposure" was published in July 2010

- The guidance summarizes three approaches that NRC licensees may use for assessing EDE from external sources.

Approved EDE Methods – RG 8.40

1. EPRI weighted two-dosimeter method
2. ANSI multiple dosimeter/compartmental method
3. NCRP two-dosimeter method for medical personnel

EPRI Method

Allows estimation of EDE using two dosimeters:

$$EDE = \tfrac{1}{2}\,(HIGH + \tfrac{1}{2}(R_{front} + R_{back}))$$

where:

R_{front} = dosimeter reading on the front of the body

R_{back} = dosimetry reading on the back of the body

HIGH is the greater value of the two dosimeter readings

EPRI Method

- Approved EPRI method is not applicable to exposure situations where the sources of radiation are nearer than 12 inches (30 cm) from the surface of the body
- In particular, it will not apply to doses from point sources (i.e. hot particles) on or near the surface of the body
- Not valid for exposure situations in which the individual is surrounded or immersed in a shielding material

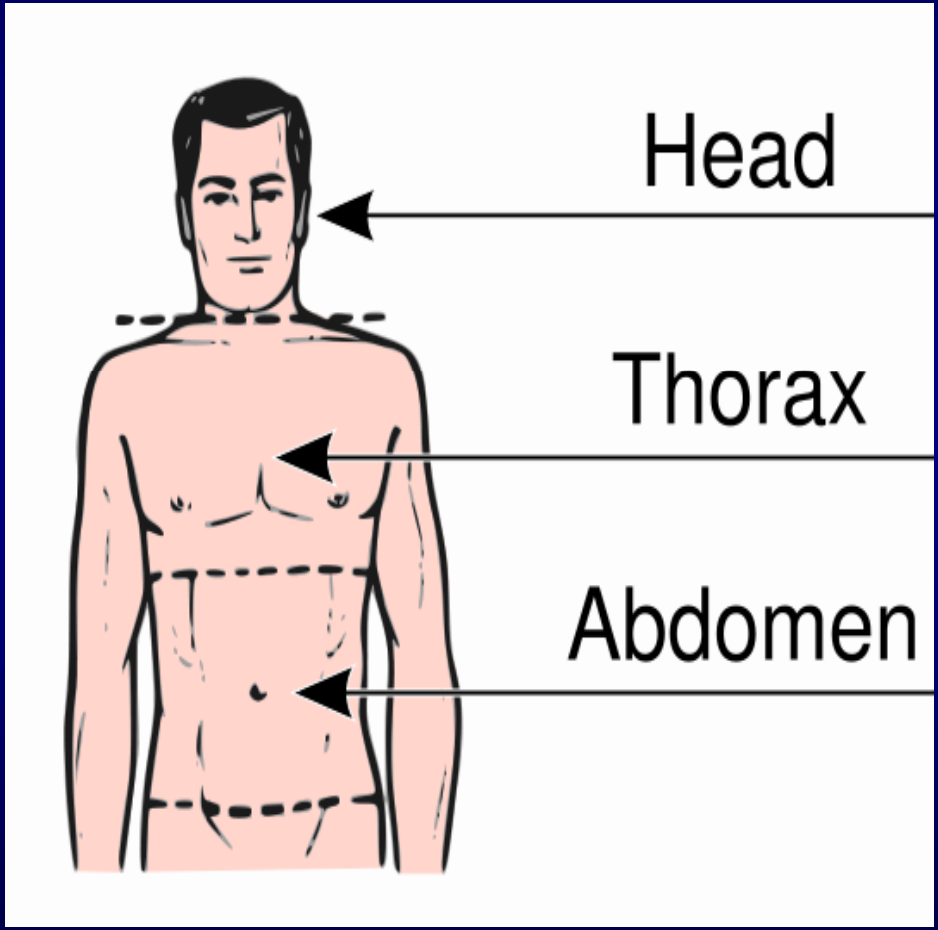
ANSI Method

Another approach to EDE is contained in ANSI/HPS N13.41-1997 (published by the Health Physics Society), entitled "Criteria for Performing Multiple Dosimetry."

The ANSI method separates the body into different compartments, and defines compartmental weighting factors that are applied to dosimeters placed in the compartments.

Turn to MISC-58

ANSI COMPARTMENTS



- Head/Neck
- Thorax, above diaphragm
- Abdomen, including pelvis
- Proximal Extremities (4)

ANSI EDE Compartments

Compartment Name	Associated Organs and Tissues	ICRP-26 Stochastic Risk Weighting Factor, w_T	Fraction of w_T Assigned to Compartment	Resulting w_T for Compartment
Head/Neck	Thyroid	0.03	1.0	0.03
	Bone Surfaces	0.03	0.33	0.01
	Red Bone Marrow	0.12	0.165	0.02
	Remainder: Esophagus	0.06	0.6	0.04
TOTAL FOR COMPARTMENT				0.1

ANSI EDE Compartments

Compartment Name	Associated Organs and Tissues	ICRP-26 Stochastic Risk Weighting Factor, w_T	Fraction of w_T Assigned to Compartment	Resulting w_T for Compartment
Thorax	Breast	0.15	1.0	0.15
	Lung	0.12	1.0	0.12
	Red Bone Marrow	0.12	0.33	0.04
	Bone Surfaces	0.03	0.33	0.01
	Remainder:			
	Esophagus	0.06	0.4	0.02
	Stomach	0.06	0.4	0.02
	Liver	0.06	0.4	0.02
TOTAL FOR COMPARTMENT				0.38

ANSI EDE Compartments

Compartment Name	Associated Organs and Tissues	ICRP-26 Stochastic Risk Weighting Factor, w_T	Fraction of w_T Assigned to Compartment	Resulting w_T for Compartment
Abdomen	Gonads	0.25	1.0	0.25
	Red Bone Marrow	0.12	0.33	0.04
	Bone Surfaces	0.03	0.33	0.01
	Remainder:			
	Liver	.06	0.6	0.04
	Stomach	0.06	0.6	0.04
	Other GI Tissue	0.12	1.0	0.12
TOTAL FOR COMPARTMENT				0.5
Proximal Extremity	Red Bone Marrow	0.12	0.04	0.005

ANSI Method

- Allows the combination of adjacent compartments into a composite compartment
- Each compartment should be measured by locating the dosimeter at the highest exposed portion of the respective compartment
- Licensees using this approach must also use ICRP 26 weighting factors for their other dosimetry methods

NCRP 122 Method

The NRC also allows medical personnel to use the following method, published in NCRP Report 122:

$$EDE = 0.04C + 1.5W$$

where:

C = unshielded collar dosimeter reading

W = shielded dosimeter reading (worn on waist under a protective lead apron)

Complexities of EDE Methods

- selection of method to use
- number of dosimeters
- placement of dosimeters
- use of body compartment weighting factors
- use of tissue weighting factors

Problem

A medical worker wears two dosimeters. One is located on the worker's collar and is unshielded. The other dosimeter is worn on the worker's waist, and is located under a lead apron that covers his upper body down to his knees.

Given:
Unshielded Collar Dosimeter Reading = 5000 mrem
Shielded Waist Dosimeter Reading = 500 mrem

1. Calculate the workers' EDE using the NCRP 122 method

2. Calculate the worker's EDE using the ANSI method

END OF EFFECTIVE DOSE EQUIVALENT (EDE) FOR EXTERNAL RADIATION EXPOSURE

SUBMERSION DOSE

Objectives

- Explain the basis for the derivation of the air concentration limits for noble gases for workers and for members of the public
- State one noble gas whose limiting air concentration is not based on external submersion dose
- Given various concentrations of airborne radioactivity, calculate dose to workers and members of the public

EPA Federal Guidance Report (FGR) No. 11

- Will cover FGR-11 in more detail next week when we discuss internal dose calculations
- The FGR-11 methodology and Dose Conversion Factors (DCFs) are endorsed by NRC
- Submersion dose conversion factors were used to derive limiting air concentrations of noble gases for workers and the public (see EPA DCF/S-1)

Submersion Limits

Occupational

- Derived Air Concentration, DAC (μCi/mL)
- Most limiting pathway for whole body, lens of eye, organ and skin (5 rem, 15 rem, or 50 rem)
- Exposure period is 2,000 hrs/year
- Internal dose not considered

Member of Public

- Effluent Concentration Limit (μCi/mL) = (DAC/219)
- 100 mrem/yr TEDE
- (non-stochastic effects are not considered)
- 8760 hrs/year
- Internal dose not considered

Derived Air Concentration (DAC)

- The derived air concentration (DAC) is the concentration in air which, if breathed in or immersed in over a working year, will result in a dose equal to the applicable annual limit.

  Note: One working year is considered to be 40 hours per week and 50 weeks per year (2000 total hours).

- DACs are based on either the stochastic dose limit (5 rem effective dose equivalent to the whole body) or the deterministic dose limit (50 rem to the skin or 15 rem to lens of the eye)

Sample Radionuclides Producing a Submersion Dose

Radionuclide	DAC (μCi/mL)	Limiting DCF
^{3}H*	5E-01	Effective †
^{37}Ar	1E+00	Effective †
^{83m}Kr	1E-02	Lens
^{85m}Kr	2E-05	Effective
^{85}Kr	1E-04	Skin
^{87}Kr	5E-06	Effective
^{131m}Xe	4E-04	Skin
^{133}Xe	1E-04	Effective
^{135}Xe	1E-05	Effective

* Elemental

† See Lung DCF on EPA DCF/S-1

DAC-hours (Stochastic)

2,000 hours @ 1 DAC = 2,000 DAC-hours

Then for stochastic-based DACS:

2000 DAC-hours = 5,000 mrem

DAC-hours (Deterministic)

2,000 hours @ 1 DAC = 2,000 DAC-hours

Then for deterministic-based DACS:

2000 DAC-hours = 50,000 mrem (skin)

2000 DAC-hours = 15,000 mrem (lens of the eye)

Submersion Dose for Public

- To limit dose to the public, Effluent Concentrations are used rather than DACs.
- Effluent Concentrations are derived by dividing the DAC value by a factor of 219

$$219 = \frac{(5{,}000\ \text{mrem/yr})}{(100\ \text{mrem/yr})} \times \frac{(8{,}760\ \text{hr/yr})}{(2{,}000\ \text{hr/yr})}$$

$$219 = 50 \times 4.38$$

See 10CFR20; Appendix B-3

Bases for Submersion Limits

- Original calculations carried out for the ICRP in the 1970's and published in ICRP 30
- For beta radiation, tissue depths of 7 mg/cm^2 and 300 mg/cm^2 were used for skin and lens of eye, respectively
- Radiations of H-3 and Ar-37 (Isotopes-4 and 28) are too weak to penetrate dead skin layer, but they do deliver dose to the epithelial lining of the lung

Tritium Dose

- Low energy betas from H-3 are too weak to be an external hazard, thus submersion is based on inhalation and lung dose. Note: footnote to EPA table says "elemental"

- However, H-3 in the form of tritiated water vapor (HTO) passes readily through the skin when a person is submerged in H-3 and thus it becomes an internal whole body hazard. NRC DAC in Appendix B to 10 CFR Part 20 takes this into account.

Submersion Dose Summary

- For submersion radionuclides for which whole body (effective dose) is limiting (e.g. Xe-133 and Xe-135), 2,000 DAC-hrs = 5 rem TEDE
- For submersion radionuclides for which skin (SDE) is limiting (e.g. Kr-85), 2,000 DAC-hrs = 50 rem SDE
- For submersion radionuclides for which lens of eye (LDE) is limiting (e.g. Kr-83m), 2,000 DAC-hrs = 15 rem LDE

Problem

A worker is performing a job inside of a large tank that has an airborne concentration of the noble gas Xe-133 equal to 8×10^6 Bq/m^3. What is the worker's external EDE from submersion in the noble gas if he remains in the tank for four hours?

Problem

For the previous problem, what percentage of a DAC is the worker exposed to?

Calculate his EDE using DAC-hrs.

END OF SUBMERSION DOSE

BETA/GAMMA SKIN DOSE

Objectives

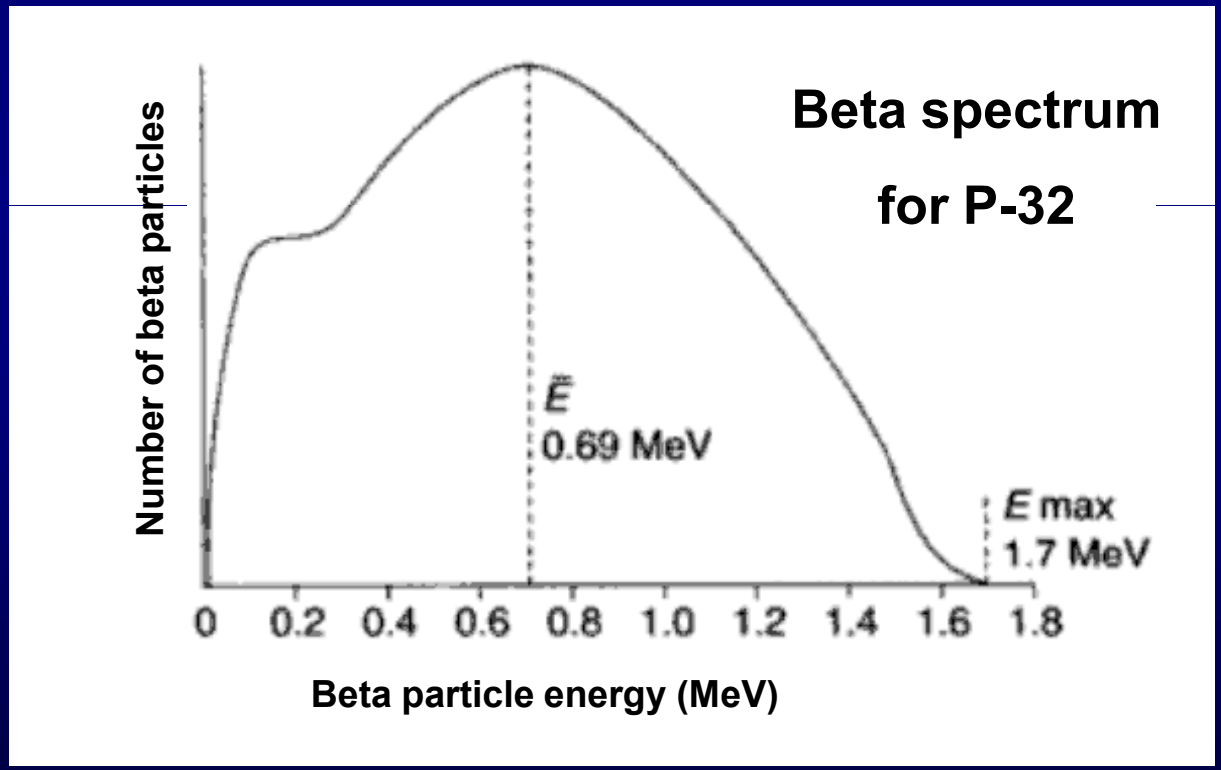
- Identify the tissue depth for the SDE
- Describe the exposure limit and rationale used for hot particle exposures
- Determine the dose from a hot particle from beta and gamma radiation

Charged Particle Interactions

- Charged particles lose energy through collisions as they travel through matter.
- The rate of energy loss per unit distance traveled is called the stopping power, S (MeV/cm)
- The stopping power divided by the density of the material is called the mass stopping power: $MeV/cm/g/cm^3 = MeV \cdot cm^2/g$
- The mass stopping power provides a means to calculate dose from charged particles.

Beta Decay and Average Beta Energy

$$n \rightarrow p^{+} + \beta^{-} + \overline{\nu}$$



$$E_{avg} = \frac{1}{3} E_{max}$$

Skin Dose

- To determine the dose to the skin we need to determine the amount of energy deposited.

- Factors which influence the amount of energy deposited are the: activity, the radionuclide(s), the duration that the activity was on the skin, any attenuation between the activity and the skin (e.g. clothing, “air gap”), and the geometry of the source to the skin.

Skin Dose Calculations

$$D = (dE/\rho dX)(\Phi)(k)$$

where,

$(dE/\rho dX)$ is the mass stopping power,

Φ is the number of beta particles impacting the skin,

k is an effective conversion factor.

Example Skin Dose Calculation

An individual has 2 microcuries of P-32 on his arm. The activity is determined to be over an area of 4 cm^2 and was present for 1.5 hours. What is the skin dose?

P-32 has a 0.7 MeV (average) beta with 100% yield (see Isotopes-48 vs. MISC-41 has 1.7 MeV for E_{max})

From MISC-16, the total stopping power is 1.9 MeV-cm^2/g

Example Skin Dose Calculation

D = (Activity/cm^2) x (Time) x (Stopping Power) x (Conversion Factors) x (Yield) x (Geometry)

D = (2 μCi/10 cm^2) x (1.5 h) x (1.9 MeV-cm^2/g) x (3.7E4 dis/s/μCi) x (3600 s/h) x (1.6E-6 erg/MeV) x (1 rad/100 erg/g) x (100%) x (50%)

D = 0.6 rad

NOTE: 10 cm^2 is used here for the averaging area in accordance with the guidance in RIS 2002-10

Skin Dose - Photons

- Dose = (Activity) x (Time) x (Geometry) x Σ[(Yield) x (Energy per Photon) x (Mass Energy-Absorption Coefficient)] x (Conversion Factors)
- Dose = (dis/s/cm^2) x (s) x (1/2)
  x Σ[(Y) x (MeV/d) x (cm^2/g)]
  x (1.6E-6 erg/MeV) x (1 rad/100 erg/g)
- Dose = (K)(A)(t)(G)Σ [(Y)(E/γ)(μ_{en}/ρ)]

Photon Skin Dose Example

What is the gamma dose from a 1 μCi Co-60 particle that is on the skin for 1 hour?

$$\text{Dose} = (K)(A)(t)(G)\Sigma\,[(Y)(E/\gamma)(\mu_{en}/\rho)]$$

To find μ_{en}/ρ for 1.17 MeV:

(1.17-1)/(X-0.0306) = (1.5-1)/(0.0280-0.0306) or X = 0.0297

To find μ_{en}/ρ for 1.33 MeV:

(1.33-1)/(X-0.0308) = (1.5-1)/(0.0280-0.0306) or X= 0.0289

Photon Skin Dose Example

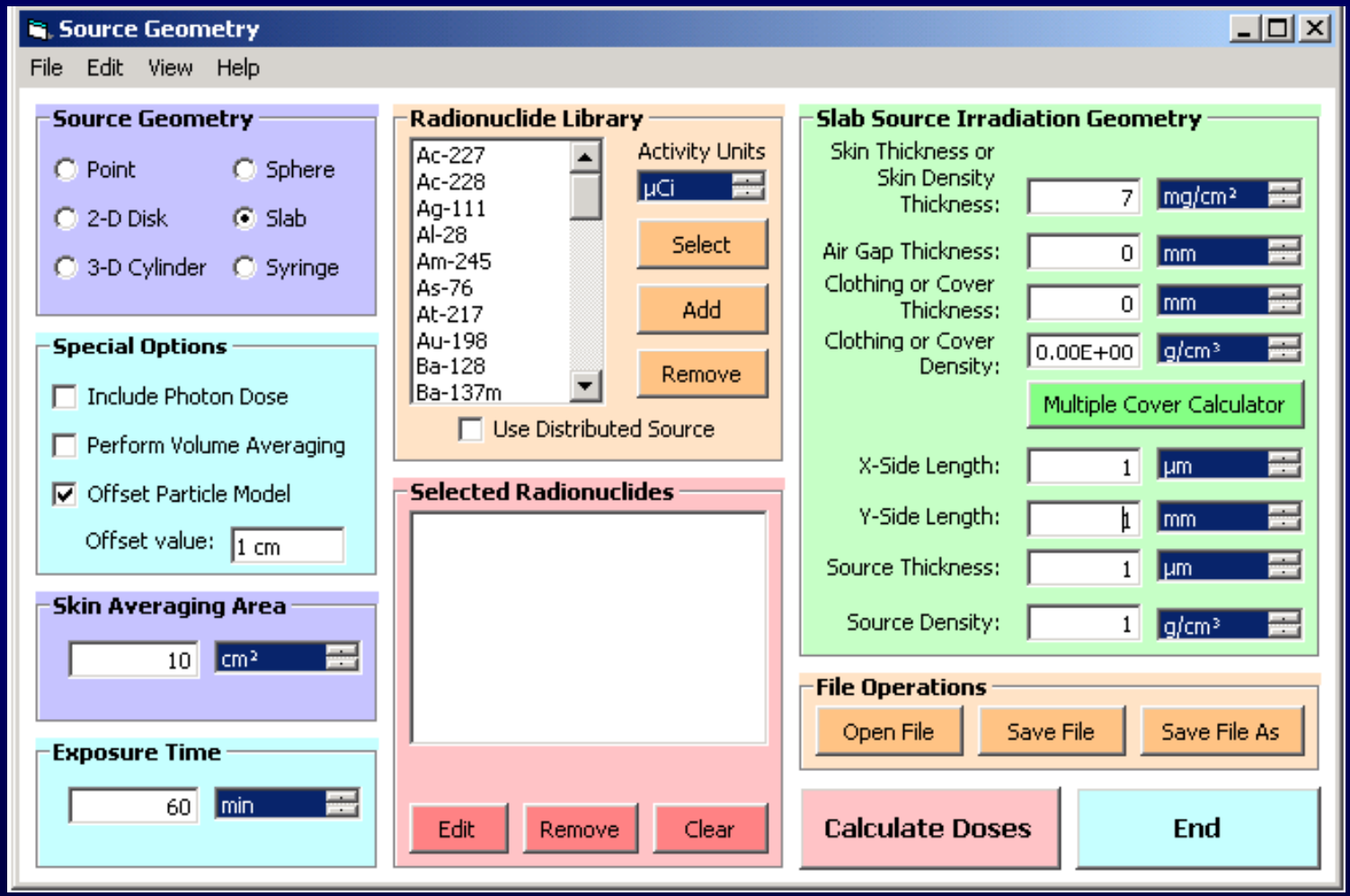
Dose = (1 μCi/10cm^2) x (3.7E4 dis/s/μCi) x (3600 s) x (1.6E-6 erg/MeV) x (1 rad/100 erg/g) x (1/2) x [(1.17 MeV/dis) x (100%) x (0.0297 cm^2/g) + (1.33 MeV/dis) x (100%) x (0.0289 cm^2/g)]

= 8 mrem

VARSKIN-3

- VARSKIN was developed to calculate the dose from radioactive material on the skin
- It was developed for uniform activity
- A revision to the code was made to calculate the dose from discrete particles
- VARSKIN-2 allowed different source geometries as well as the ability to account for attenuation of the source due to clothing, air gaps, and other factors
- Initially the code did not account for photon dose; a revision to the program included photon dose
- VARSKIN-3 included the revision for averaging the dose over 10 cm^2.

VARSKIN-3


Source Geometry
File Edit View Help
Source Geometry
Point
Sphere
2-D Disk
Slab
3-D Cylinder
Syringe
Special Options
Include Photon Dose
Perform Volume Averaging
Offset Particle Model
Offset value: 1 cm
Skin Averaging Area
10
cm²
Exposure Time
60
min
Radionuclide Library
Ac-227
Ac-228
Ag-111
Al-28
Am-245
As-76
At-217
Au-198
Ba-128
Ba-137m
Activity Units
µCi
Select
Add
Remove
Use Distributed Source
Selected Radionuclides
Edit
Remove
Clear
Slab Source Irradiation Geometry
Skin Thickness or Skin Density Thickness:
7
mg/cm²
Air Gap Thickness:
0
mm
Clothing or Cover Thickness:
0
mm
Clothing or Cover Density:
0.00E+00
g/cm³
Multiple Cover Calculator
X-Side Length:
1
µm
Y-Side Length:
1
mm
Source Thickness:
1
µm
Source Density:
1
g/cm³
File Operations
Open File
Save File
Save File As
Calculate Doses
End

VARSKIN-3 Dose Factors

Nuclide	Dose Factor	Nuclide	Dose Factor	Nuclide	Dose Factor
C-11	0.671	P-32	0.663	Sc-47	0.509
C-14	0.111	S-35	0.121	Sc-49	0.677
N-13	0.677	Cl-36	0.562	Mn-52	0.273
O-15	0.694	Cl-38	0.769	Fe-59	0.417
F-18	0.655	K-40	0.58	Co-56	0.207
Na-22	0.605	K-42	0.743	Co-58	0.136
Na-24	0.693	Ca-45	0.312	Co-60	0419.
Mg-28	0.533	Ca-47	0.588	Cu-64	0.333
Al-28	0.75	Ca-49	0.724	Zn-65	0.037

Dose Factors are in rem/hr/microcurie/10 sq. cm.

VARSKIN-3 Dose Factors

Nuclide	Dose Factor	Nuclide	Dose Factor	Nuclide	Dose Factor
Ga-68	0.633	Y-88	0.0535	Cd-109	0.027
As-76	0.702	Y-90	0.6832	Ag-111	0.603
Br-82	0.512	Y-91	0.636	Sb-124	0.548
Kr-79	0.0647	Zr-95	0.43	Sb-125	0.258
Kr-85	0.571	Nb-95	0.101	I-125	0.0247
Rb-86	0.645	Tc-99m	0.00235	I-124	0.183
Sr-89	0.634	Mo-99	0.588	I-132	0.643
Sr-90	0.547	Tc-99	0.415	I-133	0.598
Y-87	0.018	Ru-103	0.215	Ir-192	0.559

Dose Factors are in rem/hr/microcurie/10 sq. cm.

VARSKIN-3 Dose Factors

Nuclide	Dose Factor	Nuclide	Dose Factor	Nuclide	Dose Factor
Cs-134	0.42	Sm-153	0.567	Bi-214	0.661
Cs-137	0.511	Hg-203	0.324	Ac-228	0.658
Ba-140	0.571	Pb-210	0.005	Th-231	0.324
La-140	0.664	Tl-204	0.527	Pa-234m	0.669
Ce-141	0.594	Tl-208	0.719	Th-234	0.117
Ce-144	0.328	Pb-212	0.693	Ni-63	0
Pr-144	0.716	Pb-214	0.722		
Pm-147	0.221	Bi-210	0.602		
Au-198	0.611	Bi-212	0.415		

Dose Factors are in rem/hr/microcurie/10 sq. cm.

END OF BETA/GAMMA SKIN DOSE

END OF CHAPTER 6