SHLDUTIL: A Code for Useful Shielding Data

by

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SHLDUTIL is a collection of modules that yield much useful data for use in shielding analyses. These modules have been collected by us over the years and slowly incorporated into a single self-contained program. Much of the data and the details of how calculations are done can be found in one or the other of our texts (1) *Radiation Shielding*, ISBN 0-89448-456-7, American Nuclear Society, La Grange Park, IL (2000) or (2) Radiological Assessment: Sources and Doses, ISBN 0-89448-455-9, American Nuclear Society, La Grange Park, IL (1999).

Throughout this summary document there are numerous references to sections and appendices of our books where the formulas and details can be found. In such references "RS" stands for *Radiation Shielding* and "RA" for *Radiological Assessment*. The primary sources for the data bases used can be found by going to these references. In this document, we briefly summarize the capabilities of SHLDUTIL.

SHLDUTIL is started by simply double-clicking the file SHLDUTIL.EXE. A DOS window will open and the MAIN MENU appears from which you selected what information you seek by entering the number of the option.

```
------------ MAIN MENU -------------
Select Type of Information:
   1  photon (mu/rho) values
   2  photon response functions
   3  neutron response functions
   4  photon buildup factors
   5  coeff. for buildup factors
   6  photon albedos
   7  neutron & sec. gamma albedos
   8  proton/electron ranges
   9  fission product decay power
  10  th. neutron capture gammas
  11  special functions
   0  to EXIT
------------------------------------
Enter value ====>
```

Upon selection of an option, the top menu for the option appears and various suboptions can be selected. Depending on the suboption selected, you will be asked to enter various values, until what you seek appears in a RESULTS table. In the sections below, the information available for each of the MAIN MENU options is outlined.

1 Photon μ/ρ Values

The total (less coherent) (μ/ρ) and the energy absorption (μ_{en}/ρ) mass interaction coefficients can be obtained for air, water, concrete, iron and lead for any photon energy between 0.01 and 15 MeV. Although these data (and more) are tabulated in [RS Ap. C], this routine avoids the need for interpolating the tabular data.

2 Photon Response Functions

This MAIN MENU option allows you to obtain a variety of photon response functions, i.e., fluence-to-dose conversion factors, for photon energies between 0.01 and 10 MeV. These response functions are from [RA Sec. 2.14; RS Ap. D]. The response functions available are

1. exposure (air)
2. the kerma absorbed dose in air, water, concrete, iron and lead
3. the ANSI (1977) prescribed dose equivalent
4. ICRP (1987) dose indices and ambient dose equivalents H^*(10mm) and H^*(.07mm)
5. ICRP (1996) dose indices and ambient dose equivalents H^*(10mm) and H^*(.07mm)
6. ICRP (1987) anthropomorphic phantom (AP, PA, LAT, ROT, ISO): effective dose equivalent
7. ICRP (1996) anthropomorphic phantom (AP, PA, LAT, ROT, ISO): effective dose equivalent

3 Neutron Response Functions

This MAIN MENU option allows you to obtain a variety of neutron response functions, i.e., fluence-to-dose conversion factors, for neutron energies between thermal and 10 MeV. These response functions are from [RA Sec. 2.14; RS Ap. D]. The response functions available are

1. the ANSI (1977) prescribed dose equivalent (NCRP 1971)
2. ICRP (1987) dose indices and ambient dose equivalents H^*(10mm) and H^*(.07mm)
3. ICRP (1996) dose indices and ambient dose equivalents H^*(10mm) and H^*(.07mm)
4. ICRP (1987) anthropomorphic phantom (AP, PA, LAT, ROT): effective dose equivalent
5. ICRP (1996) anthropomorphic phantom (AP, PA, LAT, ROT): effective dose equivalent
6. the tissue kerma in the ICRU four-element approximation of tissue

4 Dose Buildup Factors for Photons

SHLDUTIL uses three approximations for the photon buildup factor:
(1) Taylor's form

$$B(E_o, \mu r) \simeq A_1 e^{-\alpha_1 r} + (1 - A_1)e^{-\alpha_2 r},$$

with parameters A_1, α_1, and α_2,
(2) Berger's form

$$B(E_o, \mu r) \simeq 1 + a\mu r b^{b\mu r},$$

with parameters a and b, and

(3) the ANSI/ANS (1991) standard Geometric Progression (GP) form

$$B(E_o, \mu r) \simeq \begin{cases} 1 + (b-1)(K^{\mu r} - 1)/(K-1), & K \neq 1 \\ 1 + (b-1)\mu r, & K = 1, \end{cases}$$

where

$$K(\mu r) = c(\mu r)^a + d\frac{\tanh(\mu r/\xi - 2) - \tanh(-2)}{1 - \tanh(-2)},$$

with parameters a, b, c, d, and ξ.

Data are available, generally, for air, water, concrete, iron and lead [RS Ap. E]. Buildup factors can be for a single shield material or can be for a multilayered shield composed of up to ten different layers. For the multilayered shield, based on extensions to the method of Broder [RS Sec. 7.2.2].

5 Coefficients for Buildup Factor Formulas

The coefficients needed for the Berger and Taylor buildup-factor approximation can be extracted for air, water, concrete, iron and lead for a specified photon energy.

6 Photon Albedos

The differential photon dose albedo $\alpha_D(E_o, \theta_o; \theta, \psi)$ [RS Sec. 7.4.6] is computed for water, concrete, iron or lead using
(1) the two-parameter Chilton-Huddleston approximation

$$\alpha_D(E_o, \vartheta_o; \vartheta, \psi) \approx \frac{C(E_o) \times 10^{26}[\sigma_{ce}(E_o, \vartheta_s)/Z] + C'(E_o)}{1 + \cos\vartheta_o/\cos\vartheta},$$

in which $C(E_o)$ and $C'(E_o)$ are empirical parameters, and
(2) the 7-parameter Chilton approximation

$$\alpha_D(E_o, \vartheta_o; \vartheta, \psi) = F(E_o, \vartheta_o; \vartheta, \psi)\frac{C(E_o) \times 10^{26}[\sigma_{ce}(E_o, \vartheta_s)/Z] + C'(E_o)}{1 + (\cos\vartheta_o/\cos\vartheta)(1 + 2E_o \operatorname{vers}\vartheta_s)^{1/2}},$$

in which the factor F is a purely empirical multiplier, given by

$$\begin{aligned} F(E_o, \vartheta_o; \vartheta, \psi) = {} & A_1(E_o) + A_2(E_o)\operatorname{vers}^2\vartheta_o + A_3(E_o)\operatorname{vers}^2\vartheta \\ & + A_4(E_o)\operatorname{vers}^2\vartheta_o \operatorname{vers}^2\vartheta + A_5(E_o)\operatorname{vers}\vartheta_o \operatorname{vers}\vartheta \operatorname{vers}\psi, \end{aligned}$$

in which $\text{vers}\theta = 1 - \cos\theta$.

7 Neutron Albedos

The differential neutron dose albedo $\alpha_D(\Delta E, \theta_o; \theta, \psi)$ is computed for water, concrete, iron or lead using a new 24-parameter approximation by Brockhoff that is within 10% of the MCNP calculated albedos.[1] Albedos are available for 10 contiguous energy groups between 0.1 and 10 MeV, for ^{252}Cf fission neutrons, for 14-MeV neutrons, and for thermal neutrons. Dose units for the neutron albedo are (1) ICRP anthropomorphic phantom effective dose equivalent (AP), (2) the ambient dose equivalent, and (3) the Henderson (tissue-kerma) response function. The 24-paramter albedo approximation is

$$\alpha_D(\Delta E_o, \theta_o; \theta, \psi) \simeq \frac{H(\kappa_1, \cos\theta_o)H(\kappa_2, \cos\theta)}{1 + K_1(E_o, \theta_o; \theta)/\cos\theta} \sum_{i=0}^{12} B_i P_i(\cos\theta_s),$$

[1]R.C. Brockhoff, *Calculation of Albedos for Neutrons and Photons*, PhD Dissertation, Kansas State University, Manhattan, KS 2003. Also R.C. Brockhoff and J.K. Shultis, "A New Approximation for the Neutron Albedo," *Nucl. Sci. Eng.*, submitted.

where

$$K_1(E_o,\theta_o;\theta) = \sum_{i=0}^{2} \cos^i\theta \sum_{j=0}^{2} A_{ij}\cos\theta_o^j.$$

The 24 parameters are κ_1, κ_2, the 9 A_{ij}, and the 13 B_i, and $P_i(\cos\theta)$ is the ith order Legendre polynomial.

Also calculated by this program option is the secondary-photon albedo using a 5-parameter approximation, introduced in 1966 by Maerker and Muckernthaler, using new parameters derived by Brockhoff.

$$\alpha_{D_2}^{(n,\gamma)}(\theta_o,\theta) = \cos^{A_1}(\theta)[A_2 + A_3\cos(\theta_o) + A_4\cos^2(\theta_o)]A_5.$$

with parameters A_1, A_2, A_3, A_4, and A_5. Dose units available for the secondary-photon are the effective dose equivalent (AP) and the ambient dose equivalent.

8 Ranges for Electrons and Protons

The range Λ of electrons and protons from 0.01 to 100 MeV in aluminum, iron, gold, air, waster, tissue, and bone can be provided by this MAIN MENU option. Results are based on the approximation [RS Sec. 3.6.3]

$$\rho\Lambda = 10^{a+bx+cx^2} \qquad \text{g cm}^{-2},$$

where $x = \log_{10} E_o$ and the particle energy E_o is in Mev. The parameters a, b, and c were obtained by Berger using the ESTAR code.

9 Fission Product Decay Power

The energy release rate from the decay of fission products can be calculated by SHLDUTIL for (a) arbitrary operation time (at constant fission rate) (b) an infinite operation time (equilibrium case), and (c) a burst of fissions at $t = 0$. All scenarios can be followed by an arbitrary cooling time, after which the gamma-energy release rate by gamma-ray energy group is calculated as well as the beta-energy release rate. [RS Sec. 4.2.3]

10 Thermal-Neutron Capture-Gamma Spectrum and Doses

The rate at which capture gamma rays are emitted by any one of 35 elements irradiated by a specified flux of thermal neutrons is provided as (1) the number of photons emitted by energy group $\text{s}^{-1}\text{g}^{-1}$, as well as the dose-rate at a unit distance from the source. [RS Sec. 4.2.4]

11 Special Shielding Functions

The following functions can be evaluated by SHLDUTIL [RS Ap. B]:
(1) the Sievert (secant) integral

$$F(\vartheta,b) = \int_0^{\vartheta} dx\, e^{b\sec x},$$

where $b \geq 0$ and $0 \leq \vartheta \leq \pi/2$,
(2) the exponential integral function $E_n(x)$,

$$E_n(x) = x^{n-1}\int_x^{\infty} dt\,\frac{e^{-t}}{t^n} = \int_1^{\infty} du\,\frac{e^{-ux}}{u^n} = \int_0^1 dv\, v^{n-2}\, e^{-x/v},$$

(3) the function $Ei(x)$,

$$Ei(x) = -\mathcal{P}\int_{-x}^{\infty} dt\,\frac{e^{-t}}{t}$$

where $\mathcal{P}$ denotes the principal value of the integral, and
(4) Chandrasekhar's H-function $H(\cos\theta)$, which is the solution of the nonlinear integral equation

$$\frac{1}{H(\kappa, \cos\theta)} = \sqrt{1-\kappa} + \frac{\kappa}{2}\int_0^1 du\, \frac{uH(\kappa, u)}{u + \cos\theta}.$$