Scientific Notebook 833E Ali A. Simpkins

Development of Biosphere dose model for performance assessment

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10/5/06 AAS

Given concentrations in groundwater, air or underground tank for various radionuclides, the model will predict the dose to various adult receptors for different scenarios. Soil concentration will also be an allowing input, but if entered, it will override the computed soil concentration. The following scenarios will be considered: resident farmer, resident gardener, recreationist, chronic intruder and acute intruder. The source term used for the first three will be the ground water concentration and the air concentration and these will now be referred to as ground water dependent scenarios for discussion purposes. For the chronic and acute intruder, the source term will be the inventory of the underground tank and hence will be referred to as tank inventory dependent scenarios. Table 1 shows the pathways that will be considered for each scenario and Table 2 shows the radionuclides that will be considered and their associate chains.

Table 1.

Pathways	**Resident Farmer**	**Resident Gardener (subset of Farmer)**	**Recreationist**		**Intruder Acute**	**Intruder Chronic**
Ingestion						
Ingestion of Drinking Water	X	X				X
Ingestion of Veg	X	X				X
Ingestion of Milk	X					X
Ingestion of Beef	X					X
Ingestion of Game			X			
Ingestion of Fish	X	X	X			X
Ingestion of Soil	X	X	X		X	X
Inhalation	X	X	X		X	X
External						
Surface	X	X	X		X	X
Submersion in Air	X	X	X		X	X
Submersion in Water			X			

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Ground Water Dependent Scenarios

All information is taken from GENII manual 2004 (PNNL-14584) unless otherwise noted. The first scenario discussed will focus on the resident farmer since a majority of the pathways are utilized by this scenario. The irrigation deposition rate for each radionuclide on the surface of the ground is given as follows:

$$ID_{it} = C_{wi}(t) \times IR \times 1000$$

ID_{it}=irrigation deposition rate of radionuclide I for year t ($Bq/m^2/y$)

$C_{wi}(t)$= concentration of radionuclide I in water used for irrigation (Bq/L)
(This needs to represent the entered concentration decayed to the year in question - can this be handling by the RT model?)

IR = irrigation rate (m/yr)

$$AD_{it} = \chi * v_{di}$$

AD_{it}= air deposition rate of radionuclide I for year t ($Bq/m^2/y$)

χ= air concentration (Bq/m^3)

v_{di}= radionuclide specific deposition velocity (m/s)

Wet depostion will not be included at this time since it typically is insignificant at most site.

The average soil concentration present at the start of the year can then be calculated as follows:

$$C_{soil} = \{C_{soili} + \frac{AD_{it} + ID_{it}}{\lambda_i T}[T - \frac{1 - e^{-\lambda T}}{\lambda}]\} / \rho_x d_s$$

C_{soil} = average soil concentration (Bq/kg)

C_{soili}= average soil concentration at start of year (Bq/kg)

AD_{it}= air deposition rate of radionuclide I from air for year t (Bq/m^2y)

ID_{it}= irrigation deposition rate of radionuclide I from air for year t (Bq/m^2y)

T = one year

d_s= thickness of soil

ρ_s= density of soil

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DOSE EQUATIONS

Dose from Ingestion of food type f. This is applicable to ingestion of water, vegetables, meat, milk, fish, soil.

$$D_f = C_f I_f DCF_{ing}$$

f = ingestion pathway

D_f= dose from pathway f (Sv)

C_f= concentration in ground water (Bq/L or Bq/kg))

I_f= Ingestion rate(L/yr of kg/yr)

DCF_{ing} = Dose conversion factor for Ingestion (Sv/Bq)

Dose from Inhalation

$$D_f = C_a I_a DCF_{inh}$$

D_f= dose from pathway f (Sv)

C_a= concentration in air (Bq/m^3)

I_a= Inhalation rate (m^3/yr)

DCF_{ing} = Dose conversion factor for Ingestion (Sv/Bq)

Dose from Surface Exposure

$$D_g = C_{air} SF \times DCF_{gs} 1yrCF$$

C_{soil}= concentration in soil (Bq/kg) over time period T

SF = shielding factor

DCF_{gs}= dose coefficient for exposure to contaminated ground surface (Sv/Bq s m^{-2})

1 yr = exposure time

CF seconds to years

Dose from Air Submersion

$$D_g = C_{sw} \times DCF_{subwater} T_{swim} CF + C_{sw} \times DCF_{subwater} T_{boat} CF / 2$$

C_{air}= concentration in air (Bq/m^3) over time period T

SF = shielding factor

DCF_{gs}= dose coefficient for exposure submersion in air (Sv/Bq s m^{-3})

1 yr = exposure time

CF seconds to years

Dose from Water Submersion (recreation dose)

$$D_g = C_{soil} SF \times DCF_{gs} 1yr \rho_s d_x CF$$

C_{sw}=concentration in surface water (Bq/L)

$DC_{subwater}$=dose coefficient for submersion in water (Svm^3/Bq s)

T_{swim} = time swimming (hrs/yr)

T_{boat} = time boating (hrs/yr)

Email from P. Laplant 11/10/06 on internal DC

Attached is a complete set of FGR11 and ICRP 72 max dose coefficients for the radionuclide list you provided. For efficiency, most of these were culled from prior TPA code data that has been checked and verified umpteen times in the past (so I'm 99.99% sure they are correct max values) but we can include verification of the data "by the book" for validation testing later down the road. If you really really really want verification by the book sooner then I can do that but presently I don't have time to do that now. I think spreadsheet files of data can be read directly into Goldsim so this should work (extra words may need to be clipped off).

Maximum Value Ingestion and Inhalation Adult Dose Coefficients from Federal Guidance 11 and ICRP 72 (Sv/Bq)
PAL 11/10/06

	Adult72	Adult72	AdultFG11	AdultFG11	
Nuclide	^---ing---	^---inh---	^---ing---	^---inh---	
start_da					
H3	1.80E-11	2.60E-10	1.73E-11	1.73E-11	
C 14	5.80E-10	5.80E-09	5.64E-10	5.64E-10	
NI59	6.30E-11	4.40E-10	5.67E-11	7.31E-10	
CO60	3.40E-09	3.10E-08	7.28E-09	5.91E-08	
NI63	1.50E-10	1.30E-09	1.56E-10	1.70E-09	
SE79	2.90E-09	6.80E-09	2.35E-09	2.66E-09	
SR90	2.80E-08	1.60E-07	3.85E-08	3.51E-07	
Y 90	2.70E-09	1.50E-09	2.91E-09	2.28E-09	
NB94	1.70E-09	4.90E-08	1.93E-09	1.12E-07	
TC99	6.40E-10	1.30E-08	3.95E-10	2.25E-09	
I 129	1.10E-07	3.60E-08	7.46E-08	4.69E-08	
CS137	1.30E-08	3.90E-08	1.35E-08	8.63E-09	
BA137M	none	none	none	none	Ba126, 128, 131, 131m, 133, 133m, 135m, 139, 140, 141, 142 available
PB210	6.90E-07	5.60E-06	1.45E-06	3.67E-06	
RN222	0.00E+00	0.00E+00	0.00E+00	0.00E+00	No DC avail for Rn in either source (also NRC does not regulate Radon)
RA226	2.80E-07	9.50E-06	3.58E-07	2.32E-06	

AC227	1.10E-06	5.50E-04	3.80E-06	1.81E-03
RA228	6.90E-07	1.60E-05	3.88E-07	1.29E-06
TH228	7.20E-08	4.00E-05	1.07E-07	9.23E-05
TH229	4.90E-07	2.40E-04	9.54E-07	5.80E-04
TH230	2.10E-07	1.00E-04	1.48E-07	8.80E-05
PA231	7.10E-07	1.40E-04	2.86E-06	3.47E-04
U 232	3.30E-07	3.70E-05	3.54E-07	1.78E-04
TH232	2.30E-07	1.10E-04	7.38E-07	4.43E-04
U 233	5.10E-08	9.60E-06	7.81E-08	3.66E-05
U 234	4.90E-08	9.40E-06	7.66E-08	3.58E-05
U 235	4.70E-08	8.50E-06	7.19E-08	3.32E-05
U 236	4.70E-08	8.70E-06	7.26E-08	3.39E-05
NP237	1.10E-07	5.00E-05	1.20E-06	1.46E-04
U 238	4.50E-08	8.00E-06	6.88E-08	3.20E-05
PU238	2.30E-07	1.10E-04	8.65E-07	1.06E-04
PU239	2.50E-07	1.20E-04	9.56E-07	1.16E-04
PU240	2.50E-07	1.20E-04	9.56E-07	1.16E-04
PU241	4.80E-09	2.30E-06	1.85E-08	2.23E-06
AM241	2.00E-07	9.60E-05	9.84E-07	1.20E-04
CM242	1.20E-08	5.90E-06	3.10E-08	4.67E-06
PU242	2.40E-07	1.10E-04	9.08E-07	1.11E-04
CM244	1.20E-07	5.70E-05	5.45E-07	6.70E-05

Email from P. Laplante 11/10/06 on External DC

Attached is a data file for external dose coefficients from FGR12 for Air Submersion, Water Submersion, and Ground Surface. For efficiency I leveraged an available TPA input table which was in annual units (converted from tabulated values in sec to year). They could be converted back to sec for ease of verifying but for now I wanted to give you what I have available. Let me know if you have any questions. There is no comparable ICRP 72 document with external dose coefficients and that should be fine w/ NRC. I know DOE has actually recalculated values for ICRP 72 or obtained comparable values from ICRP for the HLW program but that appears to be "going too far" as far as I'm concerned (i.e., NRC likes to use the values that are tabulated in published reports, guidance etc).

External Dose Coefficients from Federal Guidance 12 (Sv-n/Bq-yr)
PAL 11/10/06
(note: units converted from source doc sec to yr for this table)

n=units	FGR12 Air ubmersion m^3	Water Immerse m^3	GR12 Soil Surface m^2
H3	1.04E-11	0.00E+00	0.00E+00
C 14	7.06E-12	1.38E-14	5.08E-13
NI59	0.00E+00	0.00E+00	0.00E+00
CO60	3.97E-06	8.64E-09	7.41E-08
NI63	0.00E+00	0.00E+00	0.00E+00
SE79	9.56E-12	1.87E-14	6.53E-13
SR90	2.38E-10	4.60E-13	8.96E-12
Y 90	6.00E-09	1.14E-11	1.68E-10
NB94	2.43E-06	5.27E-09	4.83E-08
TC99	5.11E-11	9.90E-14	2.46E-12
I 129	1.20E-08	2.81E-11	8.14E-10
CS137	2.44E-10	4.70E-13	8.99E-12
BA137M	9.08E-07	1.97E-09	1.85E-08
PB210	1.78E-09	4.13E-12	7.83E-11
RN222	6.02E-10	1.31E-12	1.25E-11
RA226	9.94E-09	2.19E-11	2.03E-10
AC227	1.84E-10	4.10E-13	4.95E-12
RA228	0.00E+00	0.00E+00	0.00E+00
TH228	2.90E-09	6.46E-12	7.42E-11
TH229	1.21E-07	2.70E-10	2.70E-09
TH230	5.49E-10	1.24E-12	2.37E-11
PA231	5.43E-08	1.19E-10	1.28E-09
U 232	4.48E-10	1.02E-12	3.19E-11
TH232	2.75E-10	6.28E-13	1.74E-11
U 233	5.14E-10	1.15E-12	2.26E-11
U 234	2.41E-10	5.52E-13	2.36E-11
U 235	2.27E-07	5.01E-10	4.67E-09
U 236	1.58E-10	3.66E-13	2.05E-11
NP237	3.25E-08	7.32E-11	9.06E-10
U 238	1.08E-10	2.51E-13	1.74E-11
PU238	1.54E-10	3.60E-13	2.64E-11
PU239	1.34E-10	3.03E-13	1.16E-11
PU240	1.50E-10	3.50E-13	2.53E-11
PU241	2.29E-12	5.11E-15	6.09E-14
AM241	2.58E-08	5.93E-11	8.68E-10
CM242	1.80E-10	4.19E-13	3.02E-11
PU242	1.27E-10	2.95E-13	2.10E-11

CM244	1.55E-10	3.63E-13	2.77E-11

11/13/06 AAS

Concentration if vegetation equals the sum contribution from deposition on plant surface and uptake from the root uptake. Deposition on plant surface can occur from the air and from the irrigated water. The plant types will include at least leafy, other, fruit and grain. The concentration in plant type p equals the following:

$$C_p(t) = [C_{gw}(t) IR_p \frac{12}{M} r_{ip} + C_{air}(t) v_d r_{dp} + C_{soil} RF v_{di}] \frac{T_{pi}}{B_p} \left[\frac{1 - e^{-(\lambda_w + \lambda_i) T_{gp}}}{\lambda_w + \lambda_i} \right]$$

where

$C_{gw}(t)$ = concentration in groundwater at time t

IR = irrigation rate (m/yr)

M = months per year irrigation occurs

r_{ip}=irrigation interception fraction for plant type p

$C_{air}(t)$ = concentration in air at time t (Bq/m^3)

vd = deposition velocity (radionuclide dependent) (m/s)

r_{dp}=deposition interception fraction for plant type p

$C_{soil}(t)$= concentration in soil at time t (Bq/kg)

RF =resuspension factor (1/m)

T_{pi}= soil to plant transfer factor for plant type t and radionuclide (element)i

B_p= biomass for plant type p (kg/m^2)

λ_w=weathering constant (typically 18.07 1/yr)

T_{gp}= growing period for plant type p

11/14/06 AAS

Concentration in Beef (and Game) is estimated by the following equation as taken from GENII

(2004), p. 151.

$$C_{beef}(t) = F_b\left[C_{gw}(t)f_{bw}U_{bw} + C_{soil}(t)f_{bs}U_{bs} + \sum C_p(t)f_{bp}U_{bp}\right]$$

where

$C_{beef}(t)$ — Concentration in beef at time t (Bq/kg)

F_b — transfer factor for beef (d/kg)

$C_{gw}(t)$ — Concentration in groundwater at time t (Bq/L)

f_{bw} — fraction of water consumed that is contaminated by beef cows

U_{bw} — Daily beef cow water consumption rates (kg/d)

$C_{soil}(t)$ — concentration in soil at time t (Bq/kg)

f_{sw} — fraction of soil consumed that is contaminated by beef cows

U_{sw} — Daily beef cow soil consumption rates (kg/d)

$C_p(t)$ — concentration in plant type p at time t (Bq/kg)

f_{pw} — fraction of plant type p consumed that is contaminated by beef cows

U_{pw} — Daily beef cow soil consumption rates (kg/d)

Currently the three plant types to be considered for ingestion by cows is forage, grain, and stored hay. The equation for milk cows would be very similar except all the subscripts would be 'm' for milk instead of 'b' for beef. Also the units on the first term F_m would be d/L for the milk cow.

Concentrations in game should be similar but likely water source will be surface water and the only type of plant ingestion type will be forage, but will need further review to ensure this is true.

11/15/06 AAS

Concentration in the soil can be estimated using the following equations as taken from GENII (2004)

$$C_{soil}(t) = C_{gw}(t)IR\left[\frac{1-e^{-(\lambda_i+\lambda_l+\lambda_e)t}}{\lambda_i+\lambda_{li}+\lambda_e}\right]$$

where

$C_{gw}(t)$ — Concentration in ground water at time t (Bq/L)

IR — irrigation rate (m/yr)

λ_i — radionuclide decay constant (1/yr)

λ_{li} — radionuclide-specific leaching loss rate -see below (1/yr)

λ_e — erosion loss rate - see below (1/yr)

$$\lambda_{li} = \frac{OW}{d\theta\left[1+\frac{\rho}{\theta}kd_i\right]}$$

where

OW — overwatering rate (m/yr)

d — depth of soil

θ — volumetric water content of soil (unitless)
ρ — density of the soil (kg/m^3)

kd_i — soil-liquid partition coefficient (m^3 liquid/kg solid)

$$\lambda_e = \frac{ER}{d\rho}$$

ER — erosion rate (kg/m^2yr)

12/7/06 AAS

The drilling scenario includes both acute and chronic exposure. The acute exposure is intended to include exposure of a person directly involved in the drilling activities. The chronic intruder then farms on the area with drill cuttings spread over it.

The amount of waste that is exhumed to the surface would be calculated as follows.

$$W_v = \pi(d/2)^2 * W_t$$

where

W_v volume of waste in m^3

d diameter of drill (m)

W_t thickness of the waste (m)

This volume is assumed to be spread over lot size that is entered by the user and mixing depth that is entered by the user. The exposure time for the intruder should also be a user input.

Using DOE/NE-ID-11226 as a basis the intruder is assumed to inadvertently drill into the contents of the tank or vault. The drill cuttings are assumed to be spread over 2200 m^2 which corresponds to about 0.5 acres. The mixing depth is assumed to be 0.6 m. The intruder exposure time is 160 hours.

For the chronic exposure the person then farms and grows livestock on the contaminated area. Intake of contaminated forage will be have to be adjusted to account for feeding on noncontaminated ground.

Surface Water

User's should enter a ground water flux (bq/s) and be given the option of a pond or stream/river. Regardless of which is selected, simple dilution will be used. (GENII, p. 4.54)

For the stream/ river the concentration in the water is estimated by

$$C_{sw} = \frac{GW}{FR}$$

C_{sw} Concentration in the surface water (Bq/L)

GW ground water flux (Bq/s)

FR flow rate (L/s)

12/13/06 AAS

Concentration in the fish

$$C_f = C_w * BF_f$$

C_f concentration in the fish muscle (Bq/kg)

C_w concentration in water fish is in (stream/river or pond) (Bq/L)

BF_f Bioaccumulation factor for fish for radionuclide I (L/kg)

1/9/07 AAS

Implementation of H-3 and C-14 model

H-3 (tritium oxide - HTO) concentration in the plant water is directly proportional to the concentration HTO in water in the air and is often referred to as a specific activity model.

$$C_{p-trit} = \frac{C_{air-trit} F_{p-trit} RF_{tritp}}{H}$$

C_{p-trit} — concentration of tritium in the plant (Bq/kg)

$C_{air-trit}$ – concentration of tritium in the air(Bq/m^3)

F_{hp} — fraction of plant type p that is fresh matter

RF_{tritp} — reduction factor for plant type p

H — annual average absolute humidity (kg/m^3) - use 0.008 to start

The concentration of tritium in the animal product m is

$$C_{hm}(t) = f_{hm} \left[\frac{C_{wh}(t) U_{wm} d_{wm} + \sum_{f=1}^{N} C_{hp}(t) U_{ap} d_{ap}}{U_{wm} + \sum_{f=1}^{N} f_{hp} U_{p}} \right]$$

where

$C_{hm}(t)$ — tritium concentration in animal product m at time t (Bq/kg or Bq/L)

f_{hm} fraction hydrogen in animal product m

$C_{wh}(t)$	tritium concentration in water (Bq/l)
U_{wm}	usage amount water for animal m (kg/yr)
d_{wm}	fraction of water from contaminated source (unitless)
N	number of different types of crops consumed for animal m
$C_{hp}(t)$	tritium concentration in plant type p at time t (Bq/kg)
U_{ap}	usage amount of plant type p from animal m (kg/yr)
d_{ap}	fraction of plant type p from contaminated source (unitless)
f_{hp}	fraction of plant that is fresh matter

Values taken from GENII 2004 page 163

usage and fraction contaminated same as before

name	Leafy veg	fruit	Root and other veg	grain	pasture
RF_{tritp}	0.9	0.8	0.8	0.8	0.9
f_{hp}	0.906	0.853	0.824	0.117	0.8

C-14 models

The C-14 model is similar to the H-3 model. The concentration in the vegetation is the combined effect on the irrigation contribution and the air contribution.

Then concentration from the irrigation is

$$C_{cwp}(t) = C_{soil}(t) + \frac{0.1 f_c C_w(t) IR}{0.01P}\left[\frac{1 - e^{-\lambda_{ec} t_{gp}}}{\lambda_{ec}}\right]$$

C_{cp} carbon concentration in plant type p from irrigation (Bq/kg)

f_{cp} fraction of plant type p that is carbon

λ_{ec} effective removal rate for carbon in soil
all other terms previously defined.

The concentration in plants due to atmospheric contamination would be

$$C_{cap}(t) = \frac{C_{ac}(t) f_{cp}}{CC_a}$$

$C_{cap}(t)$ concentration of carbon in plant type p from atmosphere (Bq/kg)

$C_{ac}(t)$ concentration of carbon in the air (Bq/m^3)

C_{ca} concentration of carbon in the air (kg/m^3)

The concentration of C-14 in animal products would then be

$$C_{cm}(t) = f_{cm} \frac{C_{cp}(t) U_{mp} + C_{wp}(t) U_{w}}{U_{mp} f_{cp} + U_{w} f_{cw}}$$

where

f_{cm} fraction of carbon in animal product m

f_{cp} fraction of carbon in plant type p

f_{cw} fraction of carbon in water

food	Carbon fraction (wet)
fresh fruit vegie, grass	0.09
grain and stored feed	0.4
eggs	0.15
milk	0.07
beef	0.24
poultry	0.2
water	2E-5 kg/L convert to fraction

7/3/07 AAS

Modifications to drilling scenario to include dilution

The waste will be diluted by potentially two methods: with clean volume exhumed to surface during well drilling and with clean soil that is plowed.

The waste concentration is needed in units of activity/m^2 to be propagated in the chronic intruder scenario.

The dilution factor for the borehole would be

$$D_{drill} = \frac{\pi(d/2)^2 W_t}{\pi(d/2)^2 D_b}$$

where

d diameter of the borehole

W_t thickness of the waste

D_b depth of the borehole

If the depth of the borehole is entered to be less than the thickness of the waste, the program will be terminated with an error message.

The second dilution could occur with the plowing of the contaminated drill cuttings into the clean soil.

If the thickness of the contaminated drill cuttings is greater than the plow depth, then no dilution occurs. However, if the thickness of the contaminated drill cuttings is less than the plow depth then the contamination is diluted by the following dilution factor

$$D_{plow} = \left\{ \begin{array}{ll} \frac{\pi (d/2)^2 D_b}{A} \geq d_p & 1 \\ \frac{\pi (d/2)^2 D_b}{A} \leq d_p & \frac{A d_p}{\pi (d/2)^2 D_b} \end{array} \right\}$$

D_{plow}	dilution due to plowing
d	diameter of the borehole {n}
D_b	depth of the borehole [m]
A	spread area [m^2]
d_p	plow depth [m]

10/24/07 AAS

Scientific Notebook Closed.