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Verification of EPA's "Preliminary Remediation Goals for Radionuclides" (PRG) electronic calculator

Introduction

The U.S. Environmental Protection Agency (EPA) requested an external, independent verification study of their "Preliminary Remediation Goals for Radionuclides" (PRG) electronic calculator. The calculator provides information on establishing PRGs for radionuclides at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites with radioactive contamination (Verification Study Charge, Background). These risk-based PRGs set concentration limits using carcinogenic toxicity values under specific exposure conditions (PRG User's Guide, Section 1). The purpose of this verification study is to ascertain that the computer codes has no inherit numerical problems with obtaining solutions as well as to ensure that the equations are programmed correctly. To verify the calculator, all equations for each receptor type (resident, construction worker, outdoor and indoor worker, recreator, farmer and composite worker) were hand calculated using the default parameters. The same eleven radionuclides (Am-241, Bi-212, Bi-214, Co-60, H-3, Pb-212, Pb-214, Po-218, Pu-238, Rn-220, and Rn-222) were used for each calculation to keep consistency throughout.

Concerns

There were a number of problems found in the latest updates of the PRG calculator. Each issue will be addressed by receptor type.

Resident

All calculations using the default parameters for the resident receptor type were correct; the problems found with this receptor came from using the manual parameter option for the Tapwater calculations. The λ_i value given in the PRG outputs were not the same as the values calculated, affecting the λ_B and λ_E values as well (Table 1). Only when the manually inputted TR value (2.00E-03) was replaced with the default TR value (1.00E-06) in the hand calculation did the λ_i better match PRG (Table 2).

Another issue in this set of calculations was the calculated Irr_{res} values were approximately 17% less than PRG's output after the λ values were altered to match PRG (Table 2). A reason for this was not determined.

Farmer

The farmer calculations were performed through the manual parameter option in order to use the newly added goat and sheep calculations, but all other values were left as the default values. Starting with the direct consumption of agricultural products calculations, the ingestion rates for poultry, eggs, beef, milk, swine and fish were different values in the PRG input than were on the equation and variable sheets (Figure 1). After changing these values to match PRG, all of the consumption values matched.

However, in the direct consumption back calculated to water calculations, the $PRG_{far\text{-}beef\text{-}ing}$ value for H-3 used by PRG (7.32E+00) is not the value calculated in direct consumption (3.31E+00). Another issue found was the $PRG_{wat\text{-}far\text{-}tot}$ calculation does not calculate correctly. It was found that to equal the PRG output, the calculation could only use ingestion, fruits and vegetables, beef and milk, but this does not include Pb-212 and Pb-214 (Table 3 & Table 4). The calculation for the totals of these two radionuclides has not been found. The final issue found in this set of calculations was the values for Sheep Milk and Goat Milk not calculating correctly and the reasons have not been determined (Table 5).

In the direct consumption back calculated to soil and water calculations, PRG uses a y-intercept for H-3 (4.10E-01) that is not the direct consumption calculated value (1.86E-01). The PRG output contains a duplicate Sheep slope column in place of the Sheep Milk slope column and because of this, the values from the hand calculations and the PRG calculations cannot be compared. Also, the Sheep Milk y-intercept and x-intercept are switched (Figure 2).

Conclusions

After running through all the calculations, EPA's PRG electronic calculator appears to be mathematically correct in most scenarios using the default parameters; however, the calculator is displaying many issues with correctly calculating scenarios using manually input parameters.

References:
PRG User's Guide. Section 1 "Introduction"

EPA's PRG Verification Study Charge.

cc: J. J. Mayer, 999W-322
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Table 1. For resident, tapwater calculations, the λ_i, λ_B, and λ_E values calculated using the manually inputted TR value (2.00E-03) were approximately 5% different from PRG for Bi-212.

Bi-212			
	Calculated	PRG	% Differ.
Ingestion	7.49E+04	7.49E+04	0.1%
Inhalation	N/A	N/A	N/A
Immersion	3.44E+08	3.44E+08	-0.1%
Lambda i	1.73E+01	1.65E+01	4.9%
Lambda B	1.73E+01	1.65E+01	4.9%
Lambda E	1.74E+01	1.65E+01	5.2%
Irr(res)	7.05E-07	8.80E-07	-22.0%
Irr(dep)	4.24E-02	4.45E-02	-4.9%
F & V	1.45E+06	1.38E+06	5.2%
Total	7.13E+04	7.11E+04	0.2%

Table 2. For resident, tapwater calculations, the λ_i, λ_B, and λ_E values calculated using the default TR value (1.00E-06) were approximately 0.2% different from PRG for Bi-212.

Bi-212			
	Calculated	PRG	% Differ.
Ingestion	7.49E+04	7.49E+04	0.1%
Inhalation	N/A	N/A	N/A
Immersion	3.44E+08	3.44E+08	-0.1%
Lambda i	1.65E+01	1.65E+01	0.1%
Lambda B	1.65E+01	1.65E+01	0.1%
Lambda E	1.65E+01	1.65E+01	0.3%
Irr(res)	7.41E-07	8.80E-07	-17.2%
Irr(dep)	4.45E-02	4.45E-02	0.0%
F & V	1.39E+06	1.38E+06	0.4%
Total	7.11E+04	7.11E+04	0.0%

Figure 1. For farmer, direct consumption of agricultural products calculations, the ingestion rates provided on EPA's PRG website for poultry, eggs, beef, milk, swine and fish do not match the input values used by PRG (provided in the output sheets).

$$PRG_{far\text{-}poultry\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFP_{far\text{-}adj}\,(1{,}318{,}100\ g)\ \times CF_{far\text{-}poultry}\,(1)}$$

where:

$$IFP_{far\text{-}adj}\,(1{,}318{,}100\ g) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRP_{far\text{-}c}\left(\frac{23.6\ g}{day}\right)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRP_{far\text{-}a}\left(\frac{106.6\ g}{day}\right)\right)\end{array}\right)$$

16	$IRP_{far\text{-}a}$ (poultry ingestion rate - farmer adult) g/day	107.4
17	$IRP_{far\text{-}c}$ (poultry ingestion rate - farmer child) g/day	46.9
18	$IFP_{far\text{-}adj}$ (age-adjusted poultry ingestion factor) g	1376550

$$PRG_{far\text{-}egg\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFE_{far\text{-}adj}\,(658{,}455\ g)\ \times CF_{far\text{-}egg}\,(1)}$$

where:

$$IFE_{far\text{-}adj}\,(658{,}455\ g) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRE_{far\text{-}c}\left(\frac{10.95\ g}{day}\right)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRE_{far\text{-}a}\left(\frac{53.4\ g}{day}\right)\right)\end{array}\right)$$

19	$IRE_{far\text{-}a}$ (egg ingestion rate - farmer adult) g/day	59.6
20	$IRE_{far\text{-}c}$ (egg ingestion rate - farmer child) g/day	31.7
21	$IFE_{far\text{-}adj}$ (age-adjusted egg ingestion factor) g	775810

$$PRG_{far\text{-}beef\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFB_{far\text{-}adj}\,(2{,}202{,}410\ g)\ \times CF_{far\text{-}beef}\,(1)}$$

where:

$$IFB_{far\text{-}adj}\,(2{,}202{,}410\ g) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRB_{far\text{-}c}\left(\frac{40.1\ g}{day}\right)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRB_{far\text{-}a}\left(\frac{178.0\ g}{day}\right)\right)\end{array}\right)$$

22	$IRB_{far\text{-}a}$ (beef ingestion rate - farmer adult) g/day	165.3
23	$IRB_{far\text{-}c}$ (beef ingestion rate - farmer child) g/day	62.8
24	$IFB_{far\text{-}adj}$ (age-adjusted beef ingestion factor) g	2098950

$$PRG_{far\text{-}dairy\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFD_{far\text{-}adj}\,(6{,}036{,}590\ g)\ \times CF_{far\text{-}dairy}\,(1)}$$

where:

$$IFD_{far\text{-}adj}\,(6{,}036{,}590\ g) = \left(\begin{array}{l}\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRD_{far\text{-}c}\left(\frac{349.5\ g}{day}\right)\right)+\\ \left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRD_{far\text{-}a}\left(\frac{445.6\ g}{day}\right)\right)\end{array}\right)$$

25	$IRD_{far\text{-}a}$ (dairy ingestion rate - farmer adult) g/day	676.4
26	$IRD_{far\text{-}c}$ (dairy ingestion rate - farmer child) g/day	994.7
27	$IFD_{far\text{-}adj}$ (age-adjusted dairy ingestion factor) g	10138030

$$PRG_{far\text{-}swine\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFSW_{far\text{-}adj}\,(1{,}203{,}860\ g)\ \times CF_{far\text{-}swine}\,(1)}$$

where:

$$IFSW_{far\text{-}adj}\,(1{,}203{,}860\ g) = \left(\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRSW_{far\text{-}c}\left(\frac{18.5\ g}{day}\right)\right)+\left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRSW_{far\text{-}a}\left(\frac{97.9\ g}{day}\right)\right)\right)$$

28	$IRSW_{far\text{-}a}$ (swine ingestion rate - farmer adult) g/day	92.5
29	$IRSW_{far\text{-}c}$ (swine ingestion rate - farmer child) g/day	33.7
30	$IFSW_{far\text{-}adj}$ (age-adjusted swine ingestion factor) g	1171520

$$PRG_{far\text{-}fish\text{-}ing}\,(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IFFI_{far\text{-}adj}\,(10{,}078{,}180\ g)\ \times CF_{far\text{-}fish}\,(1)}$$

where:

$$IFFI_{far\text{-}adj}\,(10{,}078{,}180\ g) = \left(\left(EF_{far\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}c}\,(6\ years)\times IRFI_{far\text{-}c}\left(\frac{85.6\ g}{day}\right)\right)+\left(EF_{far\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{far\text{-}a}\,(34\ years)\times IRFI_{far\text{-}a}\left(\frac{831.8\ g}{day}\right)\right)\right)$$

43	$IRFI_{far\text{-}a}$ (fish ingestion rate - farmer adult) g/day	831.8
44	$IRFI_{far\text{-}c}$ (fish ingestion rate - farmer child) g/day	57.4
45	$IFFI_{far\text{-}adj}$ (age-adjusted fish ingestion factor) g	10018960

Table 3. For direct consumption back calculated to water calculations, the total for most of the radionuclides (except H-3, Po-218, Rn-220, Rn-222) were over 100% different from the PRG value.

	Calculated	PRG	% Differ.
Am-241	2.98E-03	7.75E-02	**-185.2%**
Bi-212	5.69E+00	4.18E+01	**-152.1%**
Bi-214	2.17E+01	1.57E+02	**-151.5%**
Co-60	5.17E-02	4.23E-01	**-156.5%**
H-3	4.41E+00	4.41E+00	**0.0%**
Pb-212	1.02E-01	1.07E+00	**-165.3%**
Pb-214	7.54E+00	8.51E+01	**-167.5%**
Po-218	1.81E+13	1.81E+13	**-0.2%**
Pu-238	2.81E-05	6.12E-02	**-199.8%**
Rn-220	6.71E+00	6.71E+00	**0.1%**
Rn-222	3.39E+00	3.39E+00	**-0.1%**

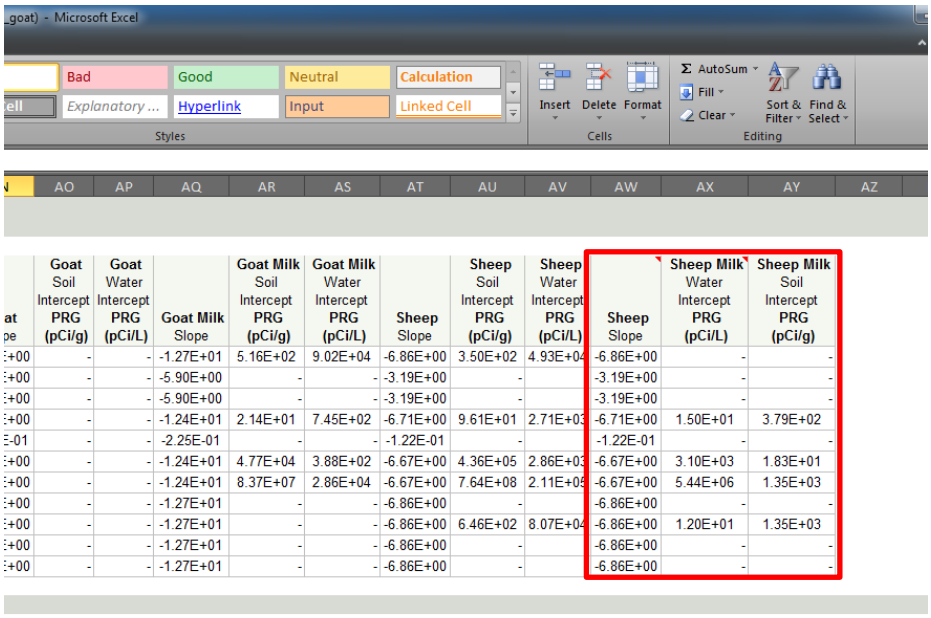
Table 4. For direct consumption back calculated to water calculations, only using the ingestion, fruits and vegetables, beef and milk totals in the final total for each radionuclide; the difference moved closer to 0% (except for Pb-212 and Pb-214).

	Calculated	PRG	% Differ.
Am-241	7.73E-02	7.75E-02	**-0.3%**
Bi-212	4.18E+01	4.18E+01	**0.1%**
Bi-214	1.58E+02	1.57E+02	**0.4%**
Co-60	4.26E-01	4.23E-01	**0.7%**
H-3	4.41E+00	4.41E+00	**0.0%**
Pb-212	1.13E+00	1.07E+00	**5.8%**
Pb-214	9.12E+01	8.51E+01	**6.9%**
Po-218	1.81E+13	1.81E+13	**-0.2%**
Pu-238	6.14E-02	6.12E-02	**0.2%**
Rn-220	6.71E+00	6.71E+00	**0.1%**
Rn-222	3.39E+00	3.39E+00	**-0.1%**

Table 5. For direct consumption back calculated to water calculations, the values for goat and sheep milk ranged from 60 to 200% different than PRG for all applicable radionuclides.

		Calculated	PRG	% Differ.
Am-241	Goat Milk	4.03E+04	4.06E+01	**200%**
	Sheep Milk	N/A	N/A	N/A
Bi-212	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A
Bi-214	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A
Co-60	Goat Milk	3.34E+02	7.68E+02	**-79%**
	Sheep Milk	8.78E+01	3.90E+02	**-126%**
H-3	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A
Pb-212	Goat Milk	1.74E+02	4.00E+02	**-79%**
	Sheep Milk	9.27E+01	1.88E+01	**133%**
Pb-214	Goat Milk	1.28E+04	2.94E+04	**-79%**
	Sheep Milk	6.83E+03	1.39E+03	**132%**
Po-218	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A
Pu-238	Goat Milk	N/A	N/A	N/A
	Sheep Milk	2.62E+03	1.39E+03	**61%**
Rn-220	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A
Rn-222	Goat Milk	N/A	N/A	N/A
	Sheep Milk	N/A	N/A	N/A

Figure 2. In the PRG output spreadsheet, the Sheep Milk slope column is replaced with a duplicate of the Sheep slope column and the Sheep Milk intercepts are switched.



at pe	Goat Soil Intercept PRG (pCi/g)	Goat Water Intercept PRG (pCi/L)	Goat Milk Slope	Goat Milk Soil Intercept PRG (pCi/g)	Goat Milk Water Intercept PRG (pCi/L)	Sheep Slope	Sheep Soil Intercept PRG (pCi/g)	Sheep Water Intercept PRG (pCi/L)	Sheep Slope	Sheep Milk Water Intercept PRG (pCi/L)	Sheep Milk Soil Intercept PRG (pCi/g)
+00	-	-	-1.27E+01	5.16E+02	9.02E+04	-6.86E+00	3.50E+02	4.93E+04	-6.86E+00	-	-
+00	-	-	-5.90E+00	-	-	-3.19E+00	-		-3.19E+00	-	-
+00	-	-	-5.90E+00	-	-	-3.19E+00	-		-3.19E+00	-	-
+00	-	-	-1.24E+01	2.14E+01	7.45E+02	-6.71E+00	9.61E+01	2.71E+03	-6.71E+00	1.50E+01	3.79E+02
-01	-	-	-2.25E-01	-	-	-1.22E-01	-		-1.22E-01	-	-
+00	-	-	-1.24E+01	4.77E+04	3.88E+02	-6.67E+00	4.36E+05	2.86E+03	-6.67E+00	3.10E+03	1.83E+01
+00	-	-	-1.24E+01	8.37E+07	2.86E+04	-6.67E+00	7.64E+08	2.11E+05	-6.67E+00	5.44E+06	1.35E+03
+00	-	-	-1.27E+01	-	-	-6.86E+00	-		-6.86E+00	-	-
+00	-	-	-1.27E+01	-	-	-6.86E+00	6.46E+02	8.07E+04	-6.86E+00	1.20E+01	1.35E+03
+00	-	-	-1.27E+01	-	-	-6.86E+00	-		-6.86E+00	-	-
+00	-	-	-1.27E+01	-	-	-6.86E+00	-		-6.86E+00	-	-