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Site-Representative Biota Concentration Guides at Los Alamos

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Introduction

Biota dose assessment at Los Alamos National Laboratory, LANL, follows the guidance of the DOE Standard, DOE-STD-1153-2002. As described in Section 2, general screening is performed using Biota Concentration Guides, BCGs, which are defined as "the limiting concentration of a radionuclide in soil, water, or sediment that would not lead to exceeding dose limits for the protection of biota in the environment." For the general screening, the maximum concentrations in water, sediment, and soil are compared with each radionuclide-specific BCG (DOE-STD-1153-2002 Table 2.1) and the sum of the fractions is calculated (DOE-STD-1153-2002 page M1-25.)

The DOE Standard encourages each site to establish site-specific or site-representative BCGs (DOE-STD-1153-2002 Module 1 pages 10, 24-26, 43, 45-47, 50, 59, 61-64, 79, 81-86; Module 2 pages 31, 41, 49, 50, 53; and Module 3 page 29). The purpose of this paper is to establish site-representative BCGs for cesium-137 and strontium-90 in water, sediment, and soil.

Sections 4.1 and 7.1.3.2 of DOE-STD-1153-2002 recommend the use of site-specific "lumped parameter values." The important lumped parameter is the bioaccumulation factor referred to in the DOE Standard as B_{iv}. It is also commonly called the wet-weight concentration ratio C_r; see Module 3 Section 3.1 (page M3-19) of DOE-STD-1153-2002.

Cesium-137, terrestrial

Cesium-137 in the environment is the subject of NCRP Report No. 154 (NCRP 2008). At the Savannah River Site (SRS) cesium bioaccumulates ($C_r > 1$) because the soil is deficient in potassium (NCRP Report No. 76, NCRP 2008 Section 4.1, and Eisenbud and Gesell 1997.) At Los Alamos, however, the cesium concentration ratio is less than one (Salazar 2006), because of the relative abundance of potassium. For a comparison of potassium concentrations within the US, see http://energy.cr.usgs.gov/radon/usak.gif and http://tin.er.usgs.gov/geochem/doc/lower48maps/k_icp40.jpg .

At Los Alamos, cesium-137 concentrations have been measured in soil, vegetation, and animals in and near LANL (Bennett 1996, Fresquez 1996, 1997, 1998a, 1998b, and 2004, Hakonson 1973 and 1975, Miera 1978, White 1981, and the annual site environmental reports. The ratios are variously reported on the basis of wet-weight, dry weight, or ash weight. For the present paper, they are converted to wet-weight ratios using the conversion factors in Fresquez 2007.

The results consistently show that the wet-weight concentrations of cesium-137 in plants and animals are all much less than the concentrations in soil. In other words, the bioaccumulation factors are much less than 1.

Salazar 2006 examined the LANL plant data and concluded that the concentration ratio of wet-weight vegetation to soil is in the range: C_r = 0.01 to 0.06. Comparable numbers have been reported at other locations that are not deficient in potassium, for example refer to NUREG/CR-5512 (1992) and Baes 1984 (ORNL-5786, available at http://homer.ornl.gov/baes/documents/ornl5786.html .)

Appendix A summarizes the deer and elk data (Fresquez 1998b) and also concludes that $C_r < 0.06$ for cesium-137. If $C_r << 1$, the internal dose is much less than the external dose, in which case the total dose is approximately equal to the external dose and the value of C_r does not significantly affect the total dose. For terrestrial biota dose assessment of cesium-137 at LANL, it is assumed that $C_r = B_{iv} = 0.06$.

For a given concentration, the cesium dose may be calculated using the coefficients in Tables 2.3 and 2.4 (page M3-15 to M3-18) of DOE-STD-1153-2002, or using RESRAD-BIOTA with the following changes to the defaults.

- B_{iv} for soil to both terrestrial animal and plant = 0.06.

- Based on these values, the limiting LANL site-representative BCG for cesium-137 soil is 2,000 pCi/g because this concentration would result in less than the DOE limit of 0.1 rad/day to terrestrial animals.

Strontium-90, terrestrial

Whereas uptake of cesium-137 depends on the concentration of potassium, similarly the uptake of strontium-90 depends on the concentration of calcium (Eisenbud and Gesell 1997, NCRP Report No. 76, 1984, NCRP Report No. 110.) For nationwide calcium concentrations, see http://tin.er.usgs.gov/geochem/doc/averages/ca/usa.html and http://tin.er.usgs.gov/geochem/doc/lower48maps/ca_icp40.jpg . Calcium is relatively abundant in New Mexico soil and water so bioaccumulation is not expected.

The concentration ratio for strontium-90 has been measured at and near Los Alamos (Fresquez 1997, Salazar 2006.) For edible crop tissues, the ratios of wet-weight vegetation to soil are consistently less than 1 (Salazar 2006.) However, Fresquez 1997 reported a ratio of 4 for the non-edible tissues of pinto beans. It is possible that this measurement may have been influenced by rain splash (White 1981, Hackonson 1993) or by the low calcium content of the soil used in this study. In contrast, recent measurements of common lambsquarters and pigweed amaranth in low-calcium soil (LANL 2007) indicated a dry-weight ratio of 2, which corresponds to a wet-weight ratio less than 1.

Furthermore, a comparison of the strontium-90 wet-weight concentrations in deer and elk (Fresquez 1998) with the concentrations in soil (Fresquez 1996) (Appendix A) shows the concentration ratio is 3.3 for bone and 0.01 for muscle. To be conservative, the worstcase bioaccumulation factor for strontium-90 is assumed to be 4 for both plants and animals.

Therefore, the following changes were made to the RESRAD-BIOTA defaults.

- B_{iv} for soil to terrestrial animals and plants = 4.

- Based on these values, the limiting site-representative BCG for strontium-90 in soil is 300 pCi/g because this concentration would result in less than the DOE limit of 0.1 rad/day to terrestrial animals.

Cesium-137, aquatic

There are no measurements of the concentration ratio in aquatic animals at LANL because there are no suitable aquatic animals to measure. Although there are a few locations that support limited aquatic life such as insect larvae, most of the water is ephemeral or intermittent, and the few locations with perennial water are not contaminated with radionuclides, so there is no suitable aquatic location to study.

The Rio Grande is an important aquatic habitat but the levels of contamination are too small to support meaningful measurements of the concentration ratio. Effluent Canyon, had significant contamination in the past, but it has received no contaminated water from TA-50 recently and is not expected receive any in the future.

Therefore we rely on calculations. The following examples refer to Effluent Canyon because in the past it received radioactive effluent and it is the only location that can serve as an example. Although there are no fish in Effluent Canyon or anywhere else at LANL, we discuss fish as an example that may be relevant to other locations such as the Rio Grande.

The concentration ratio, C_r, for fish could be estimated from the potassium concentration, K, (micro-mol/L) and the sediment load, SL, (mg/L) using the following equation for non-piscivore fish from NCRP Report No. 154, p 244.

$$\log C_r = 4.332 - 0.718 \log(K) - 0.233 \log(SL).$$

According to Table S6-4 of the 2006 Environmental Surveillance Report, for Effluent Canyon, $K = 200 \pm 40$ micro-mol/L and $SL = 3 \pm 1$ mg/L, so $C_r = 400 \pm 200$. See also Fig. 3.9 of NCRP Report No. 76, which indicates an upper bound of $C_r = 600$ for a potassium concentration of 8 mg/kg.

However, there are no fish at LANL, so consider the equation for invertebrates (NCRP Report No. 154, p 243.)

$$\log C_r = 3.628 - 0.583 \log(K)$$

So for invertebrates, $C_r = 190 \pm 30$.

For simplicity, assume $C_r = 200$. If the ^{137}Cs concentration in the water is 20,000 pCi/L, the concentration in aquatic biota is 200*20,000 = 4,000,000 pCi/L = 4,000 pCi/g, which results in a dose of 0.17 rad/day. This is 17% of the limit of 1 rad/day for aquatic biota.

Using the default parameters in RESRAD-BIOTA, there would be an additional dose of 0.2 rad/day from cesium-137 in sediment. In this case, the total dose would be 0.17+0.2 = 0.37 rad/day, which is well below the limit of 1 rad/day for aquatic biota.

The following examples use these parameters with riparian and terrestrial habitats.

There are few riparian locations at LANL and none that contain significant concentrations of cesium-137 in the water. Nevertheless, as an example, we consider the dose to a hypothetical riparian animal. The contaminated section of Effluent Canyon is small and has almost no food. There is more food available in the uncontaminated wetlands, 10 m upstream of the radioactive-liquid-waste outfall, and in the nearby human areas replete with irrigated picnic areas. Therefore, an area factor is appropriate.

The site-representative riparian animal is the southwestern willow flycatcher, which has a minimum individual home range of 0.4 ha and a minimum population area of 40*0.4 = 16 ha (Ryti 2004, Gonzales 2006.) The area of the highly contaminated riparian habitat of Effluent Canyon is 0.05 ha (LANL 2006) so the population area factor is 0.05/16 = 0.003. If this area factor is entered into RESRAD-BIOTA it is apparent that the dose to a riparian animal is less than 2% of the DOE limit.

With C_r = 200, RESRAD-BIOTA is used to calculate the dose to terrestrial animals. The dose to terrestrial animals from water containing 20,000 pCi/L is 3% of the DOE limit.

In summary, the following changes were made to the RESRAD-BIOTA default values.

- B_{iv} for water to aquatic and riparian animals = 200;
- calculate the sediment concentration from the default K_{d};

- Based on these values, the limiting site-representative BCG for cesium-137 in water is 20,000 pCi/L.

Strontium-90, aquatic

Fig. 3.10 of NCRP Report No. 76, 1984, shows the bioaccumulation factor for fish as a function of calcium concentration (based on Vanderploeg 1975, ORNL-5002). According to the annual site environmental report for 2006 (LA-14341-ENV) the calcium concentration in filtered water at Effluent Canyon is 21 mg/L, and for this concentration, the bioaccumulation factor is 450 for bone and 4 for flesh. For reference man (ICRP 23) the mass of bone is less than 20% of the total body mass, and the proportion in fish is less than in humans; for example, Toppe et al.(2007) indicate that 10 to 15% of total fish biomass are bones from the head and vertebrae. To be conservative, assume 20% bone for fish; then the average bioaccumulation factor is 100, with an uncertainty of a factor of 2.

According to RESRAD-BIOTA, if the concentration of ^{90}Sr in water is 30,000 pCi/L and the bioaccumulation factor is 100, the total dose to aquatic biota would be 0.2 rad/day, which is 20% of the DOE limit.

Using the area factor discussed previously, the dose to the representative riparian animal is 3 mrad/day, which is 3% of the limit.

The limiting dose from strontium-90 in water is to terrestrial animals that drink the water. Using the RESRAD-BIOTA defaults parameters, the dose to terrestrial animals from a ^{90}Sr concentration of 30,000 pCi/L would be 55% of the DOE limit.

In summary, the following changes were made to the RESRAD-BIOTA defaults for strontium-90.

- B_{iv} for water to aquatic animals = 100;
- B_{iv} for water to riparian animals = 400;
- calculate the sediment concentration from the default K_d;
- riparian animal area factor = 0.003

- Based on these values, the limiting site-representative BCG for strontium-90 in water is 30,000 pCi/L.

Sediment

RESRAD-BIOTA includes default distribution coefficients, K_d, which are "for use in calculating BCGs for sediment or water for an aquatic system evaluation in the absence of co-located water and sediment," (DOE-STD-1153-2002 Module 3, page M3-52, Table 4.3.) In the absence of LANL site-specific data, these should be used for aquatic evaluations. For terrestrial evaluations of dry sediment in arroyos or stream banks, the soil BCGs should be used.

Conclusion

The LANL limiting site-representative biota concentration guides, BCGs, are summarized in the following table.

Radionuclide	soil (pCi/g wet)	water (pCi/L)
Cesium-137	2,000	20,000
Strontium-90	300	30,000

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Appendix A: Wet Weight Concentration Ratios for Elk and Deer based on Fresquez 1996 and Fresquez 1998b.

Notes

1. Deer and elk have relatively large home ranges: about 100 ha for deer and 1,000 ha for elk. Therefore, it is assumed that the average LANL soil concentrations reported in Fresquez 1996 are representative for the deer and elk of Fresquez 1998b. There are some obvious exceptions. For example, two deer were road-kill near DP Canyon and had probably been foraging on contaminated land that is not represented by the soil data of Fresquez 1996. However, to be conservative, all data have been included in the averages.

2. The soil data extend from 1974 to 1994, whereas the deer and elk data extend from 1991 to 1998. Therefore, in the tables, the "corrected average" includes a correction factor of 1.26 for ten years of radioactive decay.

Strontium-90	pCi/g dry	dry/wet	pCi/g wet	pCi/g soil	ratio
Deer muscle LANL	0.049	0.25	0.0123	0.6	0.02
Deer muscle regional	0.014	0.25	0.0035	0.32	0.01
elk muscle LANL	0.025	0.26	0.0065	0.6	0.01
elk muscle regional	0.001	0.26	0.0003	0.32	0.00
average	0.022	0.26	0.0056	0.46	0.01
SR90 corrected average					**0.01**

Strontium-90	pCi/g dry	dry/wet	pCi/g wet	pCi/g soil	ratio
deer bone LANL	2.6	0.7	1.82	0.6	3.0
deer bone regional	0.9	0.7	0.64	0.32	2.0
elk bone LANL	1.6	0.79	1.26	0.6	2.1
elk bone regional	1.3	0.79	1.03	0.32	3.2
average	1.6	0.75	1.19	0.46	2.6
SR90 corrected average					**3.3**

Cesium-137	pCi/g dry	dry/wet	pCi/g wet	pCi/g soil	ratio
Deer muscle LANL	0.068	0.25	0.0170	0.6	0.03
Deer muscle regional	0.015	0.25	0.00375	0.43	0.01
elk muscle LANL	0.035	0.26	0.0091	0.6	0.02
elk muscle regional	0.095	0.26	0.0247	0.43	0.06
average	0.053	0.26	0.0136	0.515	0.03
Cs137 corrected average					**0.04**

Cesium-137	pCi/g dry	dry/wet	pCi/g wet	pCi/g soil	ratio
deer bone LANL	0.024	0.7	0.017	0.6	0.03
deer bone regional	0.010	0.7	0.007	0.43	0.02
elk bone LANL	0.032	0.79	0.025	0.6	0.04
elk bone regional	0.043	0.79	0.034	0.43	0.08
average	0.027	0.75	0.021	0.515	0.04
Cs137 corrected average					**0.05**