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Estimating Radiological Doses to Predators Foraging in a Low-Level Radioactive Waste Management Area

Los Alamos
NATIONAL LABORATORY

Edited by Hector Hinojosa, Group IM-1

Front Cover: Coyotes (*Canis latrans*) are one of the most common predators found on the Pajarito Plateau.

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by

Lars Soholt, Gil Gonzales, Philip Fresquez, Kathryn Bennett, and Edward Lopez

ABSTRACT

Since 1957, Los Alamos National Laboratory has operated Area G as its low-level, solid radioactive waste management and disposal area. Although the waste management area is developed, plants, small mammals, and avian and mammalian predators still occupy the less disturbed and revegetated portions of the land. For almost a decade, we have monitored the concentrations of selected radionuclides in soils, plants, and small mammals at Area G. The radionuclides tritium, plutonium-238, and plutonium-239 are regularly found at levels above regional background in all three media. Based on radionuclide concentrations in mice collected from 1994 to 1999, we calculated doses to higher trophic levels (owl, hawk, kestrel, and coyote) that forage on the waste management area. These predators play important functions in the regional ecosystems and are an important part of local Native American traditional tales that identify the uniqueness of their culture. The estimated doses are compared to Department of Energy's interim limit of 0.1 rad/day for the protection of terrestrial wildlife. We used exposure parameters that were derived from the literature for each receptor, including Environmental Protection Agency's exposure factors handbook. Estimated doses to predators ranged from 9E-06 to 2E-04 rad/day, assuming that they forage entirely on the waste management area. These doses are greater than those calculated for predators foraging exclusively in reference areas, but are still well below the interim dose limit. We believe that these calculated doses represent upper-bound estimates of exposure for local predators because the larger predators forage over areas that are much greater than the 63-acre waste management area. Based on these results, we concluded that predators foraging on this area do not face a hazard from radiological exposure under current site conditions.

INTRODUCTION

Beginning in 1994, small mammals occupying a low-level, radioactive waste management area have been trapped and analyzed for radionuclides (Biggs et al. 1995, 1997, Bennett et al. 1996, 1998, 2002). This program has been carried out to meet the requirements of Department of Energy (DOE) Order 5400.1 that specifies that environmental media within operating radioactive waste disposal areas must be monitored. The goal of this monitoring has been to determine if small mammals serve as a significant pathway for release of radioactive materials from the waste management area.

Low-level, solid radioactive waste has been disposed below ground at Los Alamos National Laboratory (LANL) since operations began in the 1940s. The 63-acre site (Area G), which began operation in 1957, is located in Technical Area 54 at the east end of the Laboratory, adjacent to San Ildefonso Pueblo lands and near the village of White Rock. Over the last decade, environmental surveillance activities at Area G have focused on evaluating the presence and mobilization of radionuclides in surface soils, vegetation, and small rodents. The principle radionuclides associated with releases to the environment at LANL are cesium-137, strontium-90, tritium, and the actinides uranium, plutonium, and americium. All these radionuclides are known to be transported through the food chain and could lead to elevated doses to non-human biota foraging in areas where these radionuclides have been released to the environment.

In recent years, there has been an increased interest in estimating doses to non-human biota that arise from radiological releases into the environment to evaluate the impacts to environmental resources (Gonzales et al. 2000, Ferenbaugh et al. 2002). The Laboratory, in 1998, developed an ecological risk assessment model for application to evaluating radiological doses in LANL's corrective action program (Environmental Restoration Project 1999). The DOE recently released a dose assessment model for non-human biota to support the DOE's environmental radiation protection requirements for ecological systems (Department of Energy 1993, 2000). At the same time, the Department established an interim dose limit of 0.1 rad/day for protection of terrestrial animal resources.

This report focuses on the evaluation of doses to predators that forage on Area G to establish whether operations are in compliance with the DOE interim standard. The receptors assessed here were the American kestrel (*Falco sparverius*), the great horned owl (*Bubo virginianus*), the red-tailed hawk (*Buteo jamaicensis*), and the coyote (*Canis latrans*).

BACKGROUND

Surveillance activities at Area G. Waste management Area G is a 63-acre, low-level, solid radioactive waste management area located on the east end of Mesita del Buey at Technical Area 54 (Figure 1). This area was established as a waste management area in 1957 and is currently the Laboratory's operating radioactive waste burial and storage site (Soholt 1990). Wastes managed here include contaminated equipment, clothing, paper, plastic, building material, soils, and process wastes. These wastes have been deposited in pits, trenches, and shafts and covered with fill material (Hansen et al. 1980). In addition, transuranic wastes have been stored on pads in the northeast portion of the site. As part of the Laboratory's Environmental Surveillance Program, the Ecology Group has sampled media at Area G, including soils/sediments (Fresquez et al. 1996, 1997, 1998, 1999; Nyhan et al. 2000, 2001), vegetation (Fresquez et al. 1995, 1996, 1997, 1998, 1999; Nyhan et al. 2000, 2001), and small mammals (Biggs et al. 1995, 1997; Bennett et al.

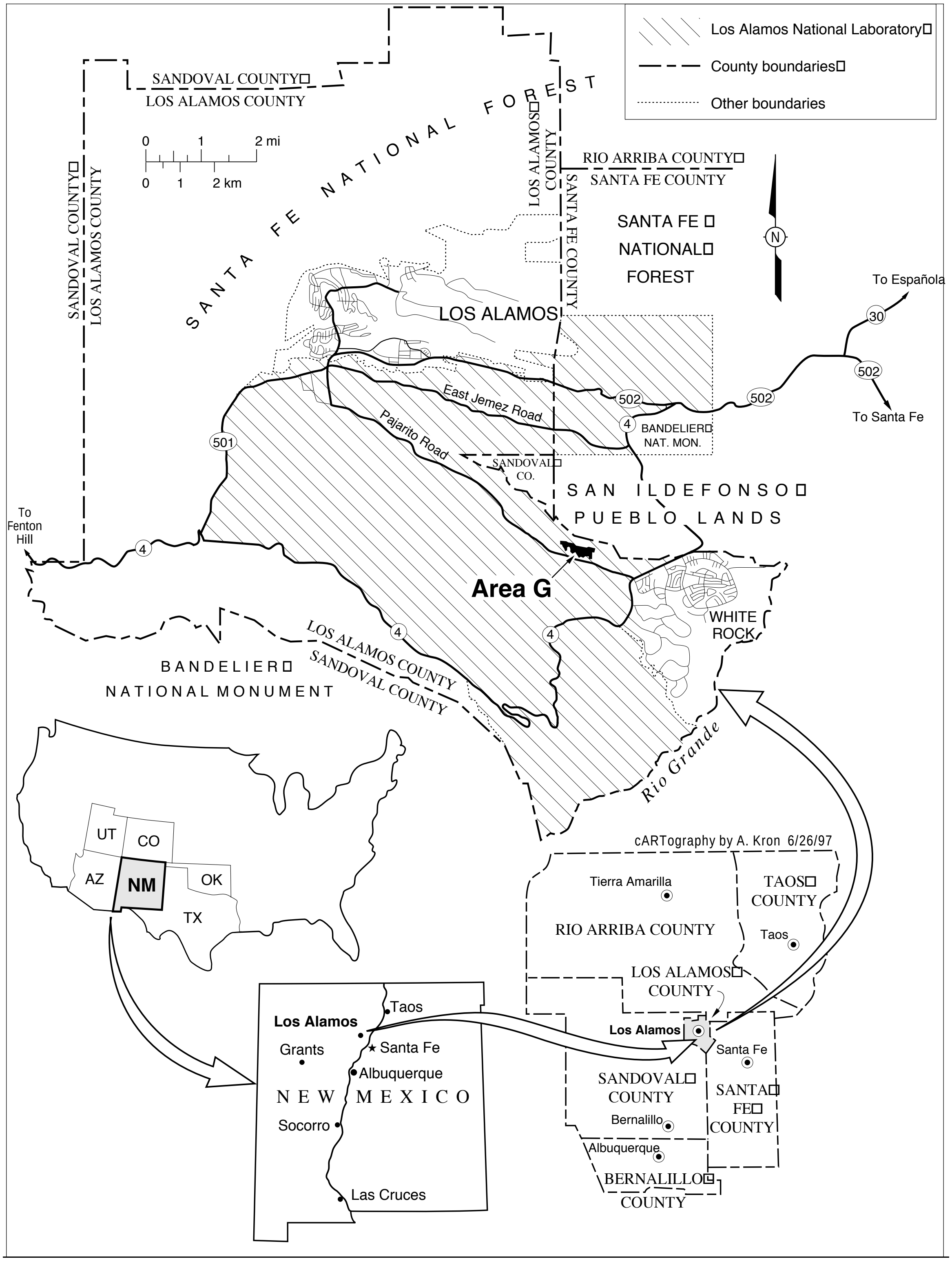

Figure 1. The location of Area G at Los Alamos National Laboratory.

1996, 1998, 2002; Gonzales et al. 2000). These sampling and analytical activities have revealed elevated levels of several radionuclides in these media. The radionuclides of interest include tritium, cesium-137, strontium-90, and the actinides uranium, plutonium, and americium. These elevated levels may be available for transfer to higher trophic levels such as predators that forage in the area.

Dose limits for non-human biota. In June 2000, the DOE Air, Water, and Radiation Division (EH-412) issued interim DOE Technical Standard ENR-0011, entitled "A Graded Approach for Evaluating Radiation Dose to Aquatic and Terrestrial Biota" (Department of Energy 2000 [available at http://homer.ornl.gov/oepa/public/bdac/]). The interim standard provides guidance for the evaluation of ionizing-radiation doses to aquatic animals and terrestrial animals and plants. DOE sites can use this guidance to establish if site conditions are in compliance with established radiation dose limits for protection of non-human biota. DOE Order 5400.5 establishes a dose limit of 1 rad/day for protection of aquatic organisms. Based on this limit and a review of the radiation protection literature, the DOE technical standard adopts biota dose limits as follows:

- Aquatic animals: absorbed dose that does not exceed 1 rad/day
- Terrestrial plants: absorbed dose that does not exceed 1 rad/day
- Terrestrial animals: absorbed dose that does not exceed 0.1 rad/day

These limits are based on concerns for limiting reproductive impairment in free-living populations of organisms. Although the goal of the standard is to provide protection for population viability, population dose limits are inferred from observations of individual impairment among the most radiosensitive organisms. These dose limits for protection of populations ensure that there would be no observable adverse effects to members of populations for which protection of individual viability and productivity is of concern. Such considerations are of interest when evaluating impacts to threatened, endangered, or otherwise protected species of biota.

The assessment framework in DOE's technical standard proceeds from the screening phase through more detailed, site-specific dose assessment if the available data warrant such detail. The screening assessment uses parameters for radionuclide uptake that are deemed to ensure protection of the most sensitive and most exposed biota. For example, transfer factors for radionuclides from environmental media to organic tissue are selected from the high end of the range of the empirical data; higher rates of contaminated food uptake are included in the screening assessment; organisms are assumed to spend 100% of their life in contaminated areas; and decay of radionuclides taken up by an organism is assumed to deposit all its energy within the organism's body.

Receptors. The predator receptors assessed here include the great horned owl, red-tailed hawk, American kestrel, and coyote. These represent common predators in the region that forage on small mammals among other prey. These were selected because they represent a variety of foraging habits and ranges and body sizes and are known to breed in the area around Area G.

The great horned owl is mainly a nocturnal hunter, but also forages during early-morning and late-evening hours (crepuscular). Its diet consists primarily of small mammals and birds, with some other vertebrates and invertebrates (Elphick et al. 2001, Ehrlich et al. 1988). They are relatively common in the eastern part of Los Alamos County and have breeding territories of about 2 to 4 mi^2 (Travis 1992). These owls are resident all year. The western subspecies ranges in body mass from 900 to 2000 g (Dunning 1984). Assuming the mid-point of this range (1450 g), the daily food intake for the great horned owl can be calculated from equation 3-3 in Environmental Protection Agency (1993) as 246 g fresh weight or approximately 0.170 g/g-day.

The red-tailed hawk is very common and a yearlong resident (Travis 1992). Its diet consists primarily of rodents (85%) and it forages primarily during the day (diurnal) (Ehrlich et al. 1988, Elphick et al. 2001, Environmental Protection Agency 1993, sec. 2.1.6). The home ranges of red-tailed hawks are from 3.5 to 9.5 mi^2 (Environmental Protection Agency 1993, sec. 2.1.6). Environmental Protection Agency (1993, sec. 2.1.6) reports that the daily food intake for the red-tailed hawk is about 0.1 g dry food/g body weight-day, which converts to 0.344 g fresh food/g-day.

The American kestrel is the smallest of the receptors addressed here, weighing in at 100 to 140 g (Environmental Protection Agency 1993, sec 2.1.8). The kestrel is quite common in Los Alamos County and is known to breed near Area G (Travis 1992). This species is more of a generalist, foraging on small mammals and birds, as well as invertebrates (Ehrlich et al. 1988, Elphick et al. 2001, Environmental Protection Agency 1993, sec. 2.1.8). Environmental Protection Agency (1993, sec. 2.1.8) reports that the foraging range of the kestrel is about 0.04 to 0.16 mi^2 at the lower end of the distribution for this species. Environmental Restoration Project (1999) uses a body weight of 103 g and a daily food intake rate of 0.31 to calculate doses to the kestrel, as have we here.

The coyote is the only mammalian predator considered here and is the largest receptor at 11,000 g (Bekoff 1977). Coyotes are commonly seen throughout Los Alamos County. Although coyotes are opportunistic and feed on a wide variety of animal and plant material, 90% of their intake is mammalian, including small to medium sized species (Bekoff 1977, Findley 1987). The foraging range of coyotes can be quite large; Harestad and Bunnell (1979) report a range averaging about 29 mi^2. Using equation 3-7 in Environmental Protection Agency (1993), we calculate that an 11,000-g coyote would consume about 0.141 g/g-day.

METHODOLOGY

Since 1994, small mammals have been captured, processed, and submitted for radiochemical analysis from six areas within and outside of Area G: in the active waste disposal zone, near the historical tritium disposal pits, near historical disposal trenches, near the transuranic waste storage areas, and in areas undisturbed by past or present waste disposal activities (Figure 2). The small mammal fauna is dominated by members of the deer mouse genus, *Peromyscus* spp. (Bennett et al. 2002). Individuals were pooled into

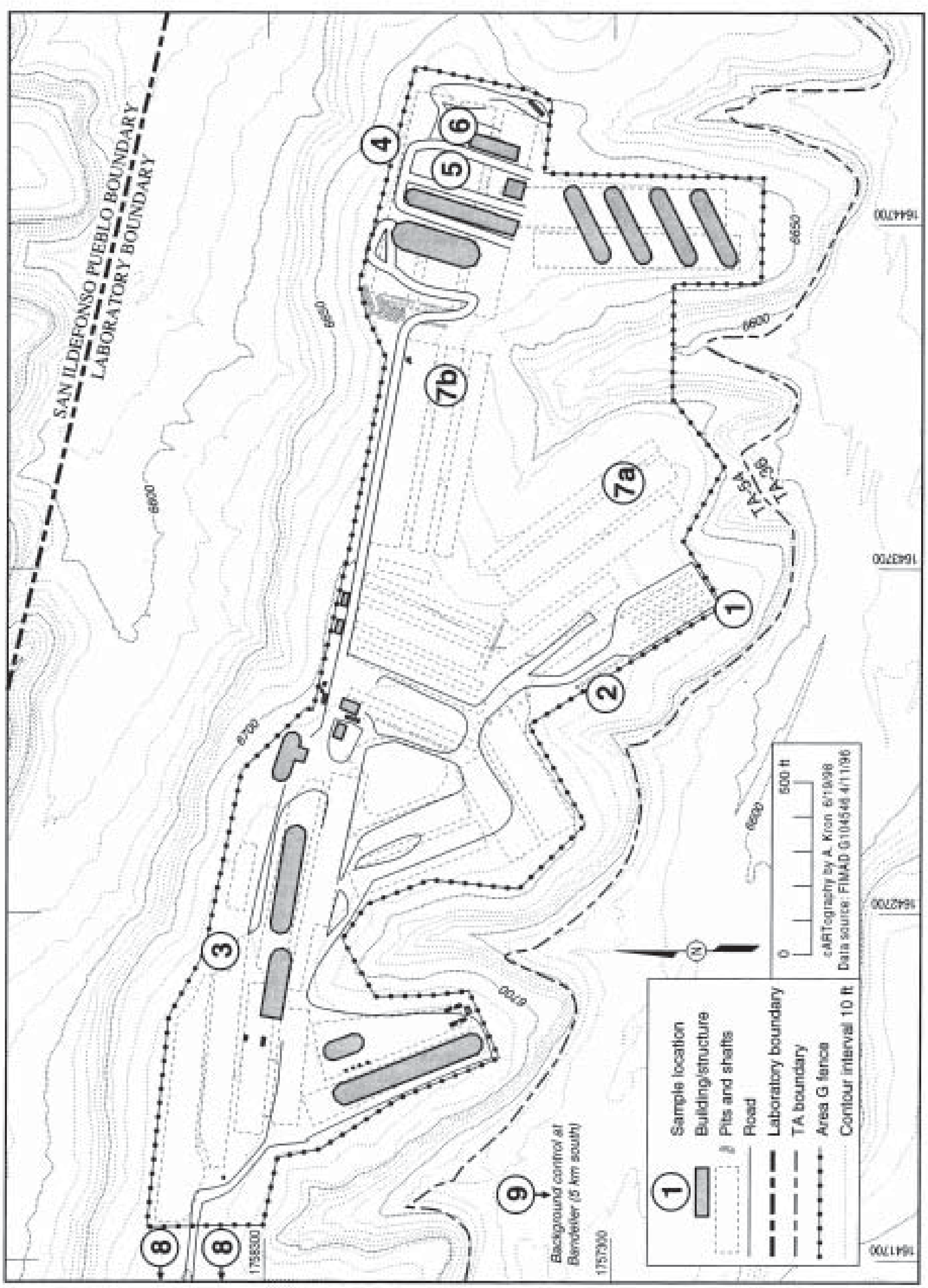

Figure 2. Site/sample locations for soils and vegetation at Area G. (Site #8 is located farther west and Site #9 is located farther south than what is shown here.)

samples to achieve the desired post-processing weight of material for radiochemical analysis. This sometimes necessitated pooling members of different species.

For tritium analyses, moisture was distilled from carcasses and collected for submittal as water samples and analyzed using liquid scintillation counting (Salazar 1984). For analyses of cesium-137, strontium-90, plutonium-238, plutonium-239, and americium-241, the animal samples were ashed before shipment to the analytical laboratory. Cesium-137 was analyzed using gamma spectroscopy. Strontium-90 was analyzed using a gas proportional counter for beta activity. Aliquots of the ash were also submitted for analysis of total uranium by kinetic phosphorescence analysis; isotopic activities were calculated from total uranium results assuming natural distribution of isotopes. This results in a higher dose conversion factor for uranium than if we used the isotopic distribution for depleted uranium, the most common form of uranium wastes at Area G. The remaining radionuclides were determined through alpha spectroscopy. Live weight activity concentrations for whole body were calculated using a measured 68% average water content (for tritium) and a 4% average ash content (for the other isotopes).

Calculations of doses to predators were made using the following equations (Environmental Restoration Project 1999):

Dose = Body burden in predator × Dose conversion factor

Body burden = Concentration in food × Ingestion rate of food
× Food to predator transfer factor × Retention time,

where

Dose = rad/day;
Body burden = pCi/(g BW),
BW = fresh tissue mass of the predator;

Dose conversion factor = (rad/day) per (pCi/(g BW));

Concentration in food = pCi/(g FF),
FF = fresh tissue mass of the food;

Ingestion rate = (g FF)/g BW/day;

Transfer factor = unitless; and

Retention time = days.

The values for the input parameters in the equations were derived from

- literature values for predator body weights and prey ingestion rates,
- average measured concentrations in the whole body of the prey (Table 1),
- fractional food to tissue transfer factors from the Laboratory’s dose assessment methodology (Los Alamos National Laboratory 2002),
- dose conversion factors assuming 100% deposition of decay product energy in the predator’s body (Department of Energy 2000), and

- radionuclide retention time based on radiological and biological half-lifes and estimated life spans (Environmental Restoration Project 1999, Los Alamos National Laboratory 2002).

Table 1. Concentrations of radionuclides in small mammals (pCi/g fresh weight) at Area G (on site) and at reference (off site) areas.

	On Site		**Off Site**	
	Mean	*Std Dev*	*Mean*	*Std Dev*
Americium-241	0.41	1.6	0.0063	0.023
Cesium-137	0.030	0.028	0.027	0.050
Plutonium-238	0.0060	0.017	0.0001	0.0004
Plutonium-239	0.11	0.41	0.0005	0.0007
Strontium-90	0.052	0.045	0.067	0.052
Tritium	1159	2639	7.1	29
Uranium-234	0.0054	0.0035	0.0037	0.0035
Uranium-235	0.0003	0.0002	0.0002	0.0002
Uranium-238	0.0056	0.0037	0.0039	0.0036

RESULTS

Average activity concentrations on a live weight basis are higher for small mammals captured on the Area G site than in the off site areas (see Table 1), with the exception of strontium-90.

However, on site and off site data sets for cesium-137, strontium-90, and americium-241 are statistically indistinguishable from each other ($\alpha = 0.05$; Student's t-test for unequal variances [Kvanli 1988]); the others exhibited a statistical difference between on site and off site data sets. There is considerable variability within each analyte's data set. This is illustrated in Figures 3 through 9.

Although, tritium values range widely, on site measurements are consistently higher than off site measurements. In contrast, strontium has a narrower range of values with considerable overlap in the on site and off site measurements. This reflects the degree of heterogeneity found in the environmental distribution of these radionuclides at Area G and its surroundings. For example, the highest tritium values are associated with the areas around the tritium disposal shafts and are localized. Similarities in strontium-90 concentrations in small mammals parallel the similarities in environmental concentrations in Area G and regional background soils. The largest differences in activity concentrations (Table 1) are seen in tritium, plutonium-238, plutonium-239, and americium-241, which are routinely found in soils at Area G above background levels.

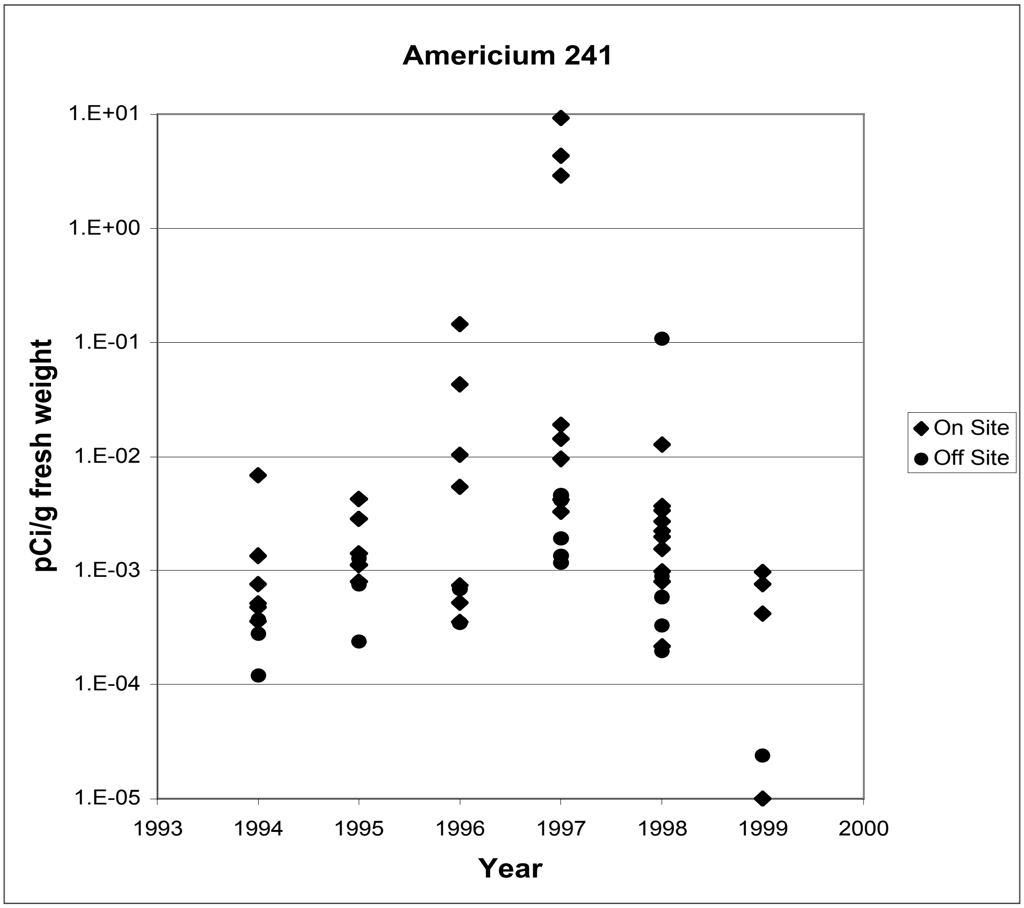

Figure 3. Concentrations of americium-241 in small mammals at Area G (on site) and the reference areas (off site).

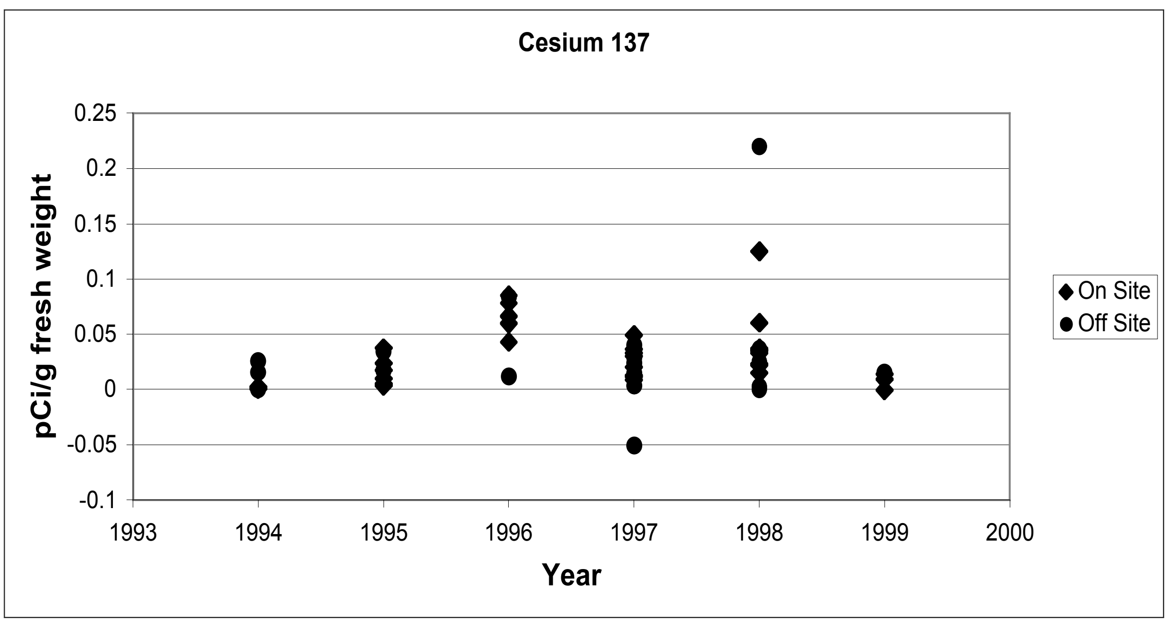

Figure 4. Concentrations of cesium-137 in small mammals at Area G (on site) and the reference areas (off site).

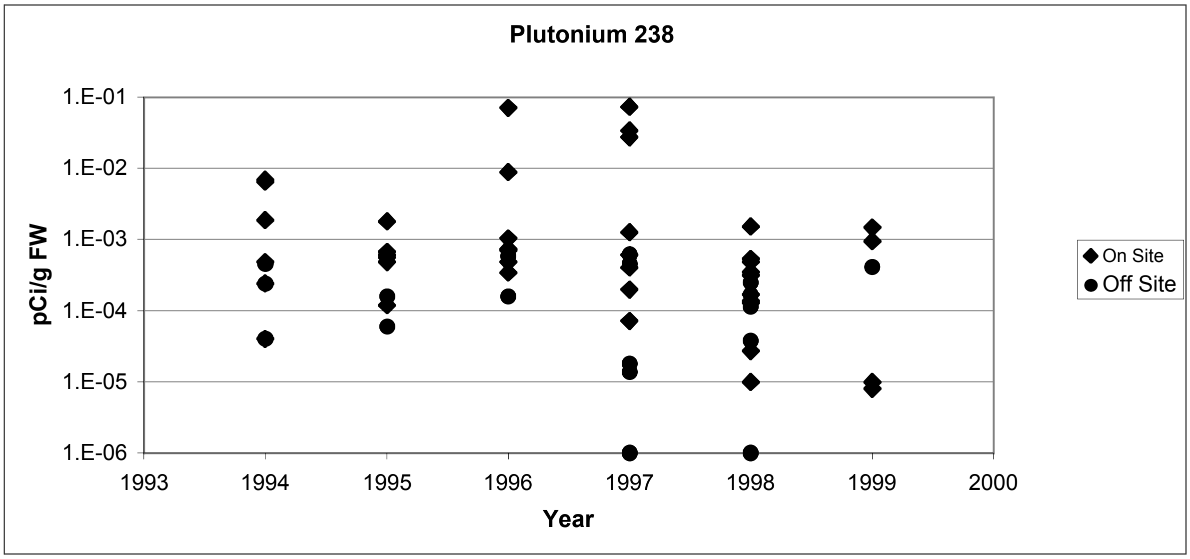

Figure 5. Concentrations of plutonium-238 in small mammals at Area G (on site) and the reference areas (off site).

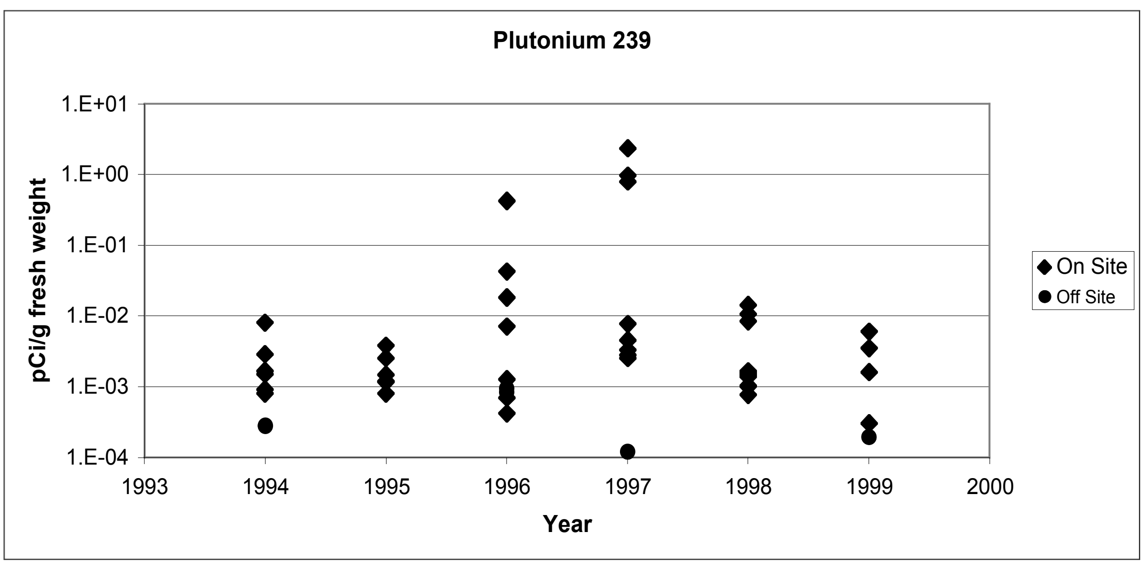

Figure 6. Concentrations of plutonium-239 in small mammals at Area G (on site) and the reference areas (off site).

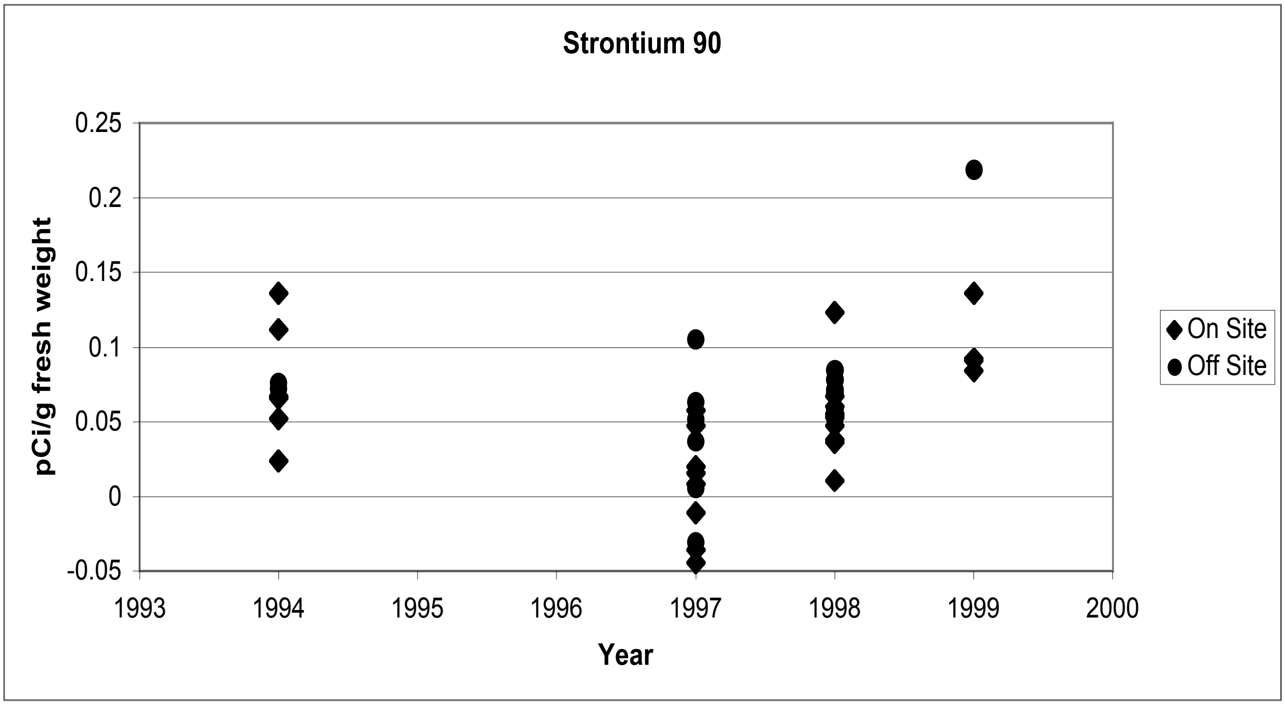

Figure 7. Concentrations of strontium-90 in small mammals at Area G (on site) and the reference areas (off site).

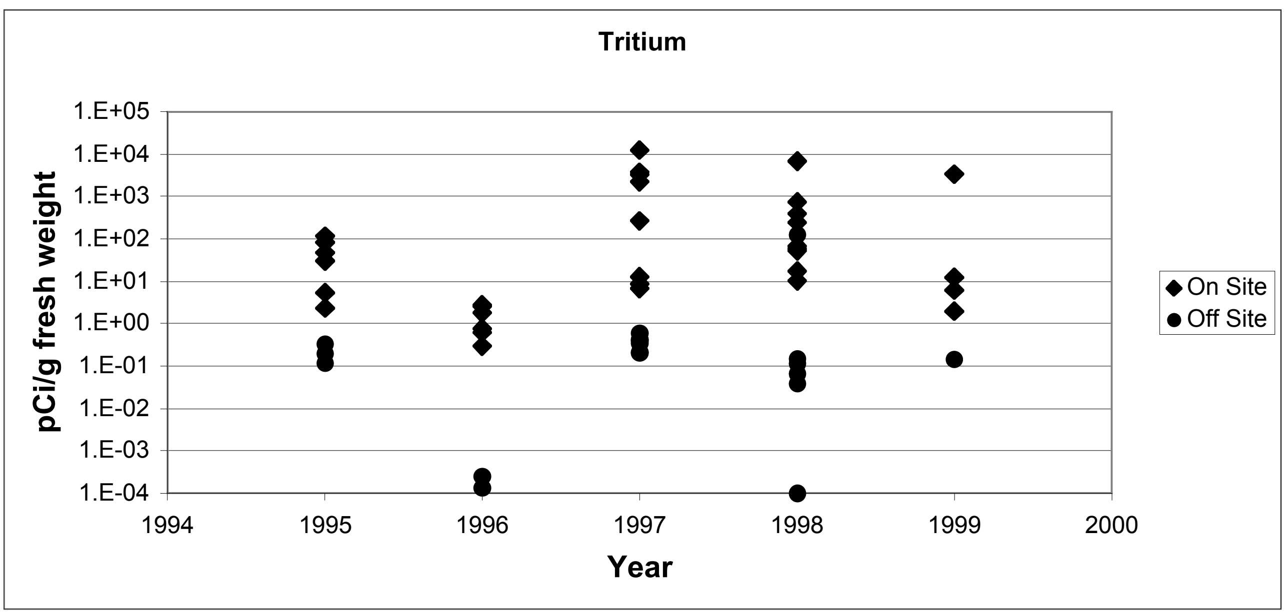

Figure 8. Concentrations of tritium in small mammals at Area G (on site) and the reference areas (off site).

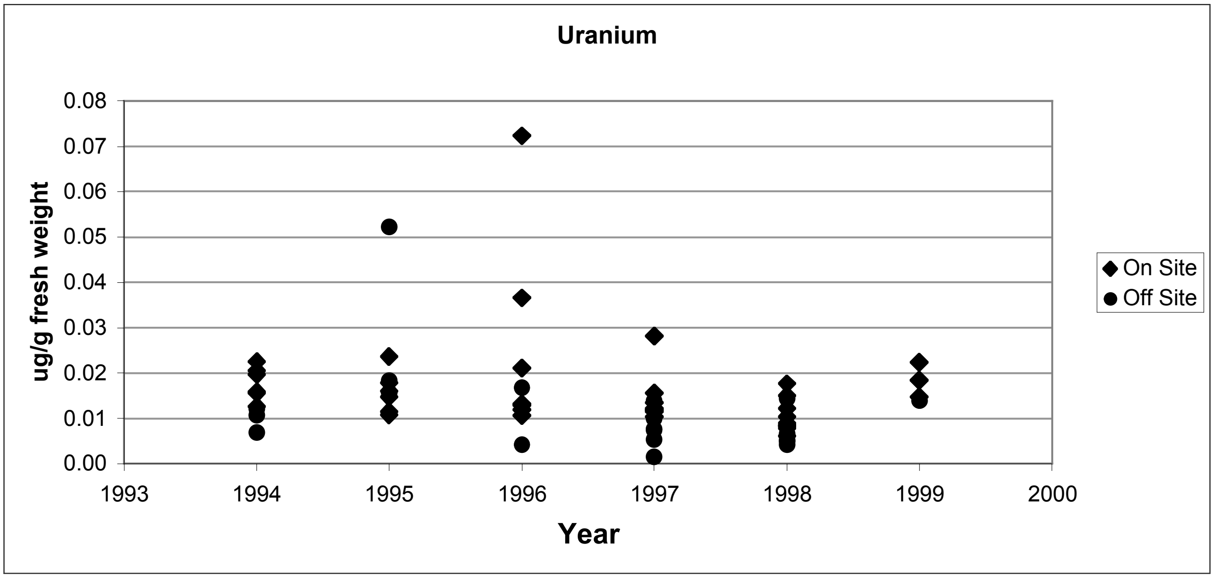

Figure 9. Concentrations of uranium in small mammals at Area G (on site) and the reference areas (off site).

Tables 2 through 5 present the dose calculations for the selected receptors.

Table 2. Dose calculations for the great horned owl.

Radionuclide	**Owl Ingestion Rate (g fresh flesh/g BW per day)**	**Body Weight (g)**	**Transfer Factor, food to tissue**	**Dose Conversion Factor (rad/day per pCi/g BW)**	**Retention Time (day)**	**On Site Dose (rad/day)**	**Off Site Dose (rad/day)**
Americium-241	0.170	1450	7.88E-06	5.69E-03	3083	1.12E-05	1.24E-06
Cesium-137 + Barium-137	0.170	1450	4.73E-03	9.39E-05	164	4.26E-07	2.49E-08
Plutonium-238	0.170	1450	1.58E-05	5.71E-03	3117	3.34E-07	7.49E-08
Plutonium-239	0.170	1450	1.58E-05	5.37E-03	3228	6.16E-06	1.35E-06
Strontium-90 + Yttrium-90	0.170	1450	1.26E-03	1.44E-04	2746	5.12E-06	2.04E-06
Tritium	0.170	1450	1.89E-03	9.51E-07	14	5.91E-06	1.22E-10
Uranium-234	0.170	1450	5.36E-05	4.94E-03	133	3.75E-08	1.05E-09
Uranium-235	0.170	1450	5.36E-05	4.95E-03	144	2.47E-09	7.57E-11
Uranium-238	0.170	1450	5.36E-05	4.57E-03	144	3.88E-08	1.10E-09
				Total Dose to Owl =		2.94E-05	4.73E-06

Table 3. Dose calculations for the red-tailed hawk.

Radionuclide	Hawk Ingestion Rate (g fresh flesh/g BW per day)	Body Weight (g)	Transfer Factor, food to tissue	Dose Conversion Factor (rad/day per pCi/g BW)	Retention Time (day)	On Site Dose (rad/day)	Off Site Dose (rad/day)
Americium-241	0.344	1000	1.72E-05	5.69E-03	3083	4.28E-05	1.29E-05
Cesium-137 + Barium-137	0.344	1000	1.03E-02	9.39E-05	164	1.62E-06	2.58E-07
Plutonium-238	0.344	1000	3.44E-05	5.71E-03	3117	1.27E-06	7.78E-07
Plutonium-239	0.344	1000	3.44E-05	5.37E-03	3228	2.35E-05	1.40E-05
Strontium-90 + Yttrium-90	0.344	1000	2.75E-03	1.44E-04	2746	1.95E-05	2.12E-05
Tritium	0.344	1000	4.13E-03	9.51E-07	14	2.25E-05	1.27E-09
Uranium-234	0.344	1000	1.17E-04	4.95E-03	144	1.56E-07	1.30E-08
Uranium-235	0.344	1000	1.17E-04	4.57E-03	144	8.70E-09	6.70E-10
Uranium-238	0.344	1000	1.17E-04	4.35E-03	144	1.41E-07	1.03E-08
				Total Dose to Hawk =		**1.12E-04**	**4.92E-05**

Table 4. Dose calculations for the American kestrel.

Radionuclide	Kestrel Ingestion Rate (g dry flesh/g BW per day)	Body Weight (g)	Transfer Factor, food to tissue	Dose Conversion Factor (rad/day per pCi/g BW)	Retention Time (day)	On Site Dose (rad/day)	Off Site Dose (rad/day)
Americium-241	0.309	103	1.59E-06	5.69E-03	3083	3.56E-06	1.02E-08
Cesium-137 + Barium-137	0.309	103	9.55E-04	9.39E-05	164	1.35E-07	2.05E-10
Plutonium-238	0.309	103	3.18E-06	5.71E-03	3117	1.06E-07	6.17E-10
Plutonium-239	0.309	103	3.18E-06	5.37E-03	3228	1.95E-06	1.11E-08
Strontium-90 + Yttrium-90	0.309	103	2.55E-04	1.44E-04	2746	1.62E-06	1.68E-08
Tritium	0.309	103	3.82E-04	9.51E-07	14	1.87E-06	1.01E-12
Uranium-234	0.309	103	1.08E-05	4.95E-03	144	1.29E-08	1.03E-11
Uranium-235	0.309	103	1.08E-05	4.57E-03	144	7.23E-10	5.31E-13
Uranium-238	0.309	103	1.08E-05	4.35E-03	144	1.17E-08	8.19E-12
				Total Dose to Kestrel =		**9.30E-06**	**3.90E-08**

Table 5. Dose calculations for the coyote.

Radionuclide	Coyote Ingestion Rate (g fresh flesh/g BW per day)	Body Weight (g)	Transfer Factor, food to tissue	Dose Conversion Factor (rad/day per pCi/g BW)	Retention Time (day)	On Site Dose (rad/day)	Off Site Dose (rad/day)
Americium-241	0.141	11,000	7.8E-05	5.69E-03	3083	7.9E-05	1.2E-03
Cesium-137 + Barium-137	0.141	11,000	4.7E-02	9.39E-05	164	3.0E-06	2.4E-05
Plutonium-238	0.141	11,000	1.6E-04	5.71E-03	3117	2.4E-06	7.1E-05
Plutonium-239	0.141	11,000	1.6E-04	5.37E-03	3228	4.3E-05	1.3E-03
Strontium-90 + Yttrium-90	0.141	11,000	1.2E-02	1.44E-04	2746	3.6E-05	1.9E-03
Tritium	0.141	11,000	1.9E-02	9.51E-07	14	4.2E-05	1.2E-07
Uranium-234	0.141	11,000	5.3E-04	4.94E-03	133	2.6E-07	1.0E-06
Uranium-235	0.141	11,000	5.3E-04	4.95E-03	144	1.7E-08	7.2E-08
Uranium-238	0.141	11,000	5.3E-04	4.57E-03	144	2.7E-07	1.0E-06
				Total Dose to Coyote =		**2.1E-04**	**4.5E-03**

The doses calculated for predators foraging in Area G ranged from 0.009E-04 rad/day for the American kestrel to 2E-04 rad/day for the coyote; generally, these doses were about four times those found for predators that would forage off site, but are still several orders of magnitude below the interim dose limit. The differences in the doses were dominated by tritium, plutonium, and americium.

UNCERTAINTY ANALYSIS

The dose calculations herein are deemed to be representative of upper bounding limits for predators foraging in the area, because

1) The dose conversion factors were developed assuming that 100% of the energy released in a decay is deposited in the body. This may not be true for the gamma emitters dependent upon the track and energy of a given photon emission. However, because of the lack of dosimetric models specific to non-human biota, all models that we know of for ecological dose assessment make this simplifying assumption.

2) The dose conversion factors are based on the assumption that alpha emissions carry a factor of 20 to account for their higher biological effectiveness over beta and gamma emissions. There is some information in the literature that indicates this factor is high. Because development of this factor for radiation protection of humans is based upon evaluating stochastic endpoints (cancer) and non-human endpoints of interest are deterministic (systemic), the factor of 20 may be too high. Limited studies suggest that a factor of 5 to 10 is more appropriate (Kocher and Trabalka 2000).

3) The dose estimates carry an implied area use factor of 1; i.e., the predators spend 100% of their foraging effort either on Area G or off site. The area occupied by Area G is about 63 acres, which translates to 0.1 mi^2. The medium-sized predators have foraging ranges that extend from 0.5 to 30 mi^2, dependent upon season and habitat. Thus, average medium-sized predator use of Area G would approach <1% to 20% of the foraging period. The smaller American kestrel could forage 100% of its time on Area G on occasion, but their foraging range can reach 1 mi^2; they are also migratory and can spend much of the year off the Pajarito Plateau.

CONCLUSIONS

Based on these bounding assumptions, we can conclude that under current conditions at Area G, the calculated doses to predators foraging here are well within the protective dose limit of 0.1 rad/day and the facility is operating in compliance with DOE Order 5400.1 requirements for protection of the environment.

ACKNOWLEDGMENTS

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