Radionuclide Transport by Cottontail Rabbits at a Radioactive Waste Disposal Area

Abstract
A study extending over 21 months was conducted to determine the importance of cottontail rabbits as a radionuclide vector at a solid radioactive waste disposal site in southeastern Idaho. A greater diversity of activation-fission products and significantly (P < 0.05) greater concentrations of $^{137}$Cs were detected in carcass tissues of cottontails inhabiting the waste disposal area; however, no significant (P > 0.05) difference was found for total radionuclide inventories between the waste disposal site (11.2 nCi) and control (13.2 nCi) rabbit populations. Ninety-six and 99 percent of the respective inventories were attributed to $^{241}$Am and $^{137}$Cs activity. Because of the low quantities of radionuclides in rabbit tissues and feces and limited use of the area, cottontail rabbits likely do not transport appreciable quantities of radionuclides to the surrounding environment.

Introduction
The Idaho National Engineering Laboratory (INEL) of the U.S. Department of Energy is located in southeastern Idaho and used for nuclear research and engineering development. Facilities at the INEL generate low-level radioactive wastes which are disposed at the Radioactive Waste Management Complex (RWMC). The RWMC, established in 1952, is used for disposal of solid activation and fission wastes, and for storage of transuranic wastes mainly from the U.S. Department of Energy Rocky Flats facility in Colorado.

Approximately $8.8 \times 10^6$ Curies ($\text{Ci} = 3.7 \times 10^{10}$ disintegrations/second) of activation and fission wastes and transuranics have been disposed or stored at the RWMC. Since 1970, transuranic wastes have been stored on an above-ground asphalt pad. Past disposal methods, deterioration of the waste packages, flooding from snowmelt, and soil resuspension have resulted in radioactive contamination of surface and subsurface soils (Harness and Passmore 1976, Card 1977, Markham 1978, Markham et al. 1978). Concentrations of radionuclides exceeding background levels have been detected in vegetation samples collected from some areas of the RWMC (Arthur 1982). Above background exposures occur in the RWMC partially as a result of open pits and trenches currently used for disposal of radioactive wastes (Wickham and Janke 1980).


Northwest Science, Vol. 59, No. 3, 1985 221
The mountain cottontail rabbit (*Sylvilagus nuttallii*) is an important prey species on the INEL (Hansen and MacCracken 1978). Since cottontails are mobile, the possibility exists that these animals could transport radioactivity from the RWMC. Therefore, the objectives of this study were to determine the relative abundance and local movements of cottontail rabbits at the RWMC; determine the concentrations of activation, fission, and transuranic radionuclides in cottontail rabbit tissues; and estimate the quantity of radionuclides that could be transported from the RWMC by cottontail rabbits.

**Study Area**

The RWMC occupies 62 ha of the 230,000 ha INEL in southeastern Idaho. The RWMC occurs in a small valley (elevation 1524 m) surrounded by basaltic ridges rising to 18 m above the landscape. Soils vary in thickness from 0 to 7 m and consist of unconsolidated clay, silt, and gravel. Surrounding the RWMC are large tracts of undisturbed areas dominated by big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass (*Agropyron spicatum*), and green rabbitbrush (*Chrysothamnus viscidiflorus*) (McBride et al. 1978). Annual precipitation averages 22 cm, with maximum moisture occurring in late spring. Mean temperature is 5.6°C, with recorded extremes of −42°C to 39°C. Mountain ranges to the west and north of the INEL influence local wind patterns causing diurnal southwestern and nocturnal northeasterly winds.

Rodent species occurring in or inhabiting the RWMC include 11 small mammal species (Groves 1981) of which the deer mouse (*Peromyscus maniculatus*), Ord's kangaroo rat (*Dipodomys ordii*), and montane vole (*Microtus montanus*) are the most common. Pygmy rabbit (*Sylvilagus idahoensis*), mountain cottontail rabbit, and the black-tailed jackrabbit (*Lepus californicus*) also occur at the RWMC. Commonly occurring game species include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), sage grouse (*Centrocercus urophasianus*) and mourning doves (*Zenaida macroura*). The most common predator species in the area include the long-tailed weasel (*Mustela frenata*), coyote (*Canis latrans*), rough-legged hawk (*Buteo lagopus*), golden eagle (*Aquila chrysaetos*), and the great horned owl (*Bubo virginianus*).

The RWMC consists of a 36 ha Subsurface Disposal Area (SDA), 22 ha Transuranic Storage Area (TSA), and a 4 ha administrative and operational facility area. Radioactive wastes are segregated according to radiation levels and container type and size, then disposed in pits or trenches. Each filled pit or trench is covered with a minimum 0.6 m of soil and seeded with crested wheatgrass (*Agropyron cristatum*). Invader species, Russian thistle (*Salsola kali*) and summer cypress (*Kochia scoparia*), predominate in areas not seeded with wheatgrass.

The SDA was of most importance to this study because of disposed radioactive waste and radionuclide contamination in surface and subsurface soils. Examination of buried waste indicated some waste containers had deteriorated and were rusted severely or breached (Card 1977). Low-level transuranic contamination of SDA surface soils occurred during flooding in 1962 and 1969. The greatest concentrations of plutonium were found in soil samples collected in the northeast section of the SDA and in areas northeast (downwind) of the SDA facility (Markham et al. 1978).
Methods and Materials

Sixty-one trapping areas (12 within SDA and 49 within 500 m of its boundary) were located by direct observation of rabbits, tracks, and fecal deposits. We assumed that cottontail rabbits inhabiting areas greater than 500 m from the SDA boundary were not likely to encounter the waste disposal area (R. Gates, personal communication). The total trapping area included 275 ha of which 36 ha were comprised of the SDA.

Five control rabbits were collected 40 km east of the RWMC on the INEL boundary, an area away from prevailing wind patterns of INEL facilities. An air sampler, operated in the area since 1982, indicates no difference in radioactivity levels between the boundary station and distant (off-INEL) sampler stations (U.S. DOE 1983).

Rabbits were captured by positioning a 23 x 23 x 81 cm steel-wire live trap near burrow entrances, culverts, or areas exhibiting rabbit activity. Trapping was conducted during January-February, May-June, and September-October with approximately 4 days trapping effort conducted at each location per seasonal period. All captured rabbits were ear-marked with either a metal fingerling tag or two 1.3 cm diameter green plastic discs. The location of each captured rabbit was plotted on a 2075:1 scale color aerial photograph of the SDA and surrounding area. Habitat type at each capture location was categorized as native sagebrush, disturbed areas (culverts, buildings, storage containers), or reseeded grasslands.

Notes were taken 3 days each week on the number of cottontail rabbits residing in or near the SDA. Rabbits observed by culverts immediately adjacent to the SDA fenceline were counted as an SDA inhabitant. The occurrence of cottontail rabbit feces on pellet plots was recorded within the SDA (87 plots) and surrounding area (203 plots). Each pellet plot (2 m in diameter) was initially examined in June 1978, cleared, then reexamined in May of the following year. Small feces were discounted from the pellet plots to discriminate from any contribution of pygmy rabbits. Also, jackrabbit populations were low during the study period (Stoddart 1983), and it was assumed that their feces contribution was minimal.

Fifteen cottontail rabbits were sacrificed for radionuclide analysis, 10 from the SDA and five from the control area. The hide and remaining carcass were sampled, weighed, dried at 80°C for 5 days, then reweighed. Instruments were cleaned between each sample dissection to assure no cross-contamination. Tissues were analyzed for gamma-emitting radionuclides on a lithium-drifted germanium crystal detector coupled to a computerized multichannel analyzer. Counting time for each sample analysis was 60 minutes. Minimum detectable concentrations (pCi/g dry weight) for gamma-emitting radionuclides in rabbit tissues were 0.2 (60Co), 0.1 (90Sr), 1.0 (106Ru), 0.02 (137Cs), and 1.1 (144Ce).

Transuranic radionuclide analyses were limited to those nuclides prevalent in waste disposed at the SDA prior to 1970, specifically 239Pu, 240Pu, and 241Am (U.S. DOE 1979). Carcass and hide samples were sent to a commercial laboratory for 86Sr and transuranic analysis (Wessman et al. 1971). Tissues were oven-dried prior to analysis; therefore, data were adjusted to wet tissue radionuclide concentrations using correction factors of 72 percent for lung, GI tract, and carcass, and 54 percent for hide. Minimum detectable concentrations (pCi/g dry weight) for those radionuclides in rabbit tissues were 0.009 (85Sr) and 0.0004 (239Pu, 240Pu, and 241Am). A student t-test was used to determine whether radionuclide concentrations in SDA cottontail rabbit were significantly different from control samples.
Total radionuclide concentrations in SDA and control area rabbits were estimated using a mean weight of 616 g obtained from 128 live-trapped rabbits. Data were obtained on the mean percentage wet weight of hide (13 percent) and remaining carcass (87 percent) from dissection of the 10 SDA and 5 control rabbits. Mean radionuclide concentrations (pCi/g) in each tissue group were multiplied by the tissue weight, then summed to give the whole body concentration of each radionuclide. Those summations were multiplied by the estimated number of rabbits occurring at the SDA and control area to obtain an overall inventory of radionuclides in rabbits.

**Results**

Between January 1978 and September 1979, 3,725 trap nights were conducted to live-trap 128 cottontail rabbits in and adjacent to the SDA, a capture ratio of 1/14.9 trap nights. Thirty-eight cottontail rabbits were trapped within the SDA, usually in culverts or beneath buildings and storage containers. Ninety cottontail rabbits were trapped outside the SDA: 58 in undisturbed sagebrush; 26 in disturbed areas of the TSA, the service facility area, and a monitoring well building; and 6 within crested wheatgrass stands. Cottontail rabbit fecal occurrence on pellet plots indicated that only 22 percent of the SDA plots contained rabbit feces compared with 65 percent in the sagebrush areas.

Approximately 42 percent of the cottontail rabbits (56 animals) were recaptured, of which one-half were recaptured at their initial capture station. Based on linear movements between successive captures, the mean movement distance for cottontail rabbits was 90 m. Maximum distance of linear movement for an individual rabbit was 839 m. The rabbits exhibited a large variability in movement pattern and did not appear restricted by habitat type.

Radionuclides detected in SDA rabbits included $^{51}$Cr, $^{54}$Mn, $^{60}$Co, $^{60}$Co, $^{90}$Sr, $^{134}$Cs, $^{137}$Cs, and $^{140}$Ba. Cobalt-60, $^{85}$Sr, and $^{137}$Cs were detected in control rabbits. With the exception of $^{90}$Sr and $^{137}$Cs, most of the above radionuclides were detected in only one sample. Strontium-90 and $^{137}$Cs were frequently detected in rabbits from both the SDA and control area (Table 1); concentrations of the radionuclides in carcass and hide samples indicated no significant ($P > 0.05$) differences between the rabbit groups. Other gamma-emitting radionuclides detected in rabbit tissues occur naturally ($^{7}$Be, $^{40}$K, $^{204}$Tl, $^{212}$Po, $^{214}$Po, and $^{214}$Bi) in the environment; therefore, no statistical analyses were conducted for those radionuclides.

Transuranic radionuclides were detected in rabbits from both the SDA and control area (Table 1). No significant ($P > 0.05$) differences were observed between SDA and control area concentrations of $^{238}$Pu or $^{239,240}$Pu in carcass or hide samples. Americium-241 concentrations in SDA rabbit carcass samples (0.01 pCi/g) were significantly ($P < 0.05$) greater than in the control area rabbit carcasses (0.001 pCi/g). No significant difference was observed between the SDA and control area concentrations of $^{241}$Am in hide samples.

The total inventory of $^{89}$Sr, $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am in hide and carcass were not significantly different between animals inhabiting the SDA and control areas, even though $^{241}$Am concentrations in rabbits inhabiting the SDA were 10 times greater than that in control area rabbits (Table 2). No significant differences were observed for whole body inventories of $^{89}$Sr, $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am.
<table>
<thead>
<tr>
<th>Tissue</th>
<th>Radionuclide</th>
<th>SDA</th>
<th>CONTROL</th>
<th>SDA</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X ± SD</td>
<td>Range</td>
<td>X ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Hide</td>
<td>^113 Sr</td>
<td>0.43 ± 0.18</td>
<td>0.23 - 0.75</td>
<td>0.44 ± 0.15</td>
<td>0.32 - 0.66</td>
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<tr>
<td></td>
<td>^137 Cs</td>
<td>0.18 ± 0.15</td>
<td>0.31 - 0.44</td>
<td>0.31 ± 0.07</td>
<td>0.22 - 0.38</td>
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<td></td>
<td>^239 Pu</td>
<td>0.002 ± 0.001</td>
<td>MDC</td>
<td>0.003 ± 0.003</td>
<td>0.006 - 0.008</td>
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<tr>
<td></td>
<td>^239,240 Pu</td>
<td>0.009 ± 0.010</td>
<td>0.0005 - 0.007</td>
<td>0.002 ± 0.001</td>
<td>0.002 - 0.003</td>
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<tr>
<td></td>
<td>^241 Am</td>
<td>0.029 ± 0.046</td>
<td>0.0007 - 0.157</td>
<td>0.002 ± 0.001</td>
<td>0.0007 - 0.003</td>
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<td>Carcass</td>
<td>^113 Sr</td>
<td>0.30 ± 0.24</td>
<td>0.30 ± 0.73</td>
<td>0.30 ± 0.24</td>
<td>0.30 ± 0.73</td>
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<td></td>
<td>^137 Cs</td>
<td>0.14 ± 0.33</td>
<td>MDC</td>
<td>0.16 ± 0.12</td>
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<tr>
<td></td>
<td>^239 Pu</td>
<td>0.001 ± 0.003</td>
<td>MDC</td>
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<tr>
<td></td>
<td>^239,240 Pu</td>
<td>0.004 ± 0.003</td>
<td>MDC</td>
<td>0.002 ± 0.001</td>
<td>MDC</td>
</tr>
<tr>
<td></td>
<td>^241 Am</td>
<td>0.010 ± 0.006</td>
<td>MDC</td>
<td>0.001 ± 0.001</td>
<td>MDC</td>
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</tbody>
</table>

^a Less than the minimum detectable concentration.

^b Significant (P ≤ 0.05) difference between SDA and control area radionuclide concentrations in tissues.
TABLE 2. Total radionuclide inventory (pCi) in selected tissues and whole body of an average cottontail rabbit (616 g) inhabiting the SDA and control area in southeastern Idaho.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tissue</th>
<th>$^{85}$Sr</th>
<th>$^{137}$Cs</th>
<th>$^{239,240}$Pu</th>
<th>$^{241}$Am</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$^{85}$Sr</td>
<td>$^{137}$Cs</td>
<td>$^{239,240}$Pu</td>
<td>$^{241}$Am</td>
<td></td>
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<tr>
<td>SDA</td>
<td>Carcass</td>
<td>160.6</td>
<td>75.0</td>
<td>0.54</td>
<td>2.14</td>
<td>5.35</td>
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<td>34.4</td>
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<td>0.16</td>
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<tr>
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<td>Whole Body</td>
<td>195.0</td>
<td>89.4</td>
<td>0.7</td>
<td>2.9</td>
<td>7.7</td>
</tr>
<tr>
<td>Control</td>
<td>Carcass</td>
<td>198.2</td>
<td>85.6</td>
<td>0.54</td>
<td>1.07</td>
<td>0.54</td>
</tr>
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<td></td>
<td>Hide</td>
<td>35.2</td>
<td>24.8</td>
<td>0.24</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Whole Body</td>
<td>233.4</td>
<td>110.4</td>
<td>0.8</td>
<td>1.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
between SDA (296 pCi) and control area (347 pCi) rabbits. Ninety-six percent of
the SDA rabbit radionuclide body burden and 99 percent of the control rabbit
radionuclide body burden were comprised of $^{90}$Sr and $^{137}$Cs. By multiplying the
total radionuclide body burden presented in Table 2 by the 38 rabbits trapped
in the SDA between January 1978 and September 1979, a total inventory of 11.2
nCi radioactivity ($^{90}$Sr, $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am) occurred in those rabbits.
In order to make a uniform comparison between SDA and control rabbits, it was
assumed the control area had an equal number of rabbits. Therefore, a total of
13.2 nCi activity would have occurred in control rabbits.

Discussion

Cottontail rabbits were trapped in both the disturbed areas of the SDA and
sagebrush habitat adjacent to the facility. All rabbits captured in the SDA were
trapped in culverts or beneath storage and waste containers. Since no rabbit bur-
rows were located in the SDA, it is doubtful that cottontail rabbits directly con-
tacted disposed waste; however, on a few occasions rabbits were observed in open
pits and trenches used for waste disposal. Previous research in Wisconsin con-
cluded that cottontail rabbits used woodpiles and junkpiles as daytime resting loca-
tions (Trent and Rongstad 1974).

Eighty-four percent of the rabbits trapped at the SDA (N = 38) were trapped
in culverts at the boundary; therefore, it is probable that some of those rabbits
were not permanent residents of the SDA. The implications are that cottontail rab-
bits use the culverts for shelter and, based on the lower occurrence of feces in
the SDA, more readily utilize sagebrush areas elsewhere. Notwithstanding, the ra-
donuclide inventories projected in the paper were based on the 38 rabbits trapped
at the SDA.

No significant difference was determined for $^{90}$Sr and $^{137}$Cs concentrations in
SDA versus control area cottontail rabbits; however, transuranic radionuclide
analyses indicated that SDA rabbit carcass tissues contained a statistically greater
concentration of $^{241}$Am than control rabbits. The total average body burden of
$^{241}$Am was less than 2 percent of the total average radionuclide burden occurring
in SDA cottontail rabbits (Table 2). The source of $^{241}$Am in SDA rabbit tissues was
likely due to ingestion of soil and vegetation since above background concentra-
tions of $^{241}$Am have been detected in SDA soil and vegetation (Markham et al. 1978,
Arthur 1982).

One radionuclide transport mechanism not examined in this study was cot-
tontail rabbit defecations in the SDA and surrounding sagebrush. Rabbits ingesting
vegetation and soil in the SDA could transport radioactivity outside of the facility.
This type of transport mechanism has been documented for jackrabbits at the Han-
ford Reservation in Washington (O'Farrell and Gilbert 1975). The jackrabbits fed
in radioactive contaminated areas and transported and eliminated contamination
to areas surrounding the radioactive waste disposal trenches. Fecal elimination may
be an important transport vector for transuranic radionuclides since minimal quan-
tities of these radionuclides would be expected to be assimilated by body tissues.

The overall quantity of radionuclides transported by rabbits inhabiting the Sub-
surface Disposal Area in southeastern Idaho (11.2 nCi) is smaller than estimated
inventory quantities of 66 μCi/yr for small mammal burrowing (Arthur and
Markham 1983), 77 μCi/yr for vegetation (Arthur 1982), and 7.2 μCi/yr for coyotes (Arthur and Markham 1982). Due to these low inventories of radioactivity and the low use of the SDA by cottontails, the role of this species as a mode of radionuclide transport will not likely result in the addition of appreciable quantities of radionuclides in the environment surrounding the SDA.

Acknowledgments

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Literature Cited


