

Radiation Dosimetry on Revegetated Uranium Mill Tailings in Western South Dakota

Abstract

Measurement of gamma radiation using thermoluminescent dosimeters on three uranium mill tailings areas and a control area showed exposure rates below ground depended on the amount and type of soil covering. Covering tailings with 30 cm of shale and 60 cm of topsoil reduced gamma radiation exposure belowground to rates similar to the control area. Soil covering of 30 cm was adequate to reduce gamma radiation exposure rates aboveground to background levels. Gamma exposure rates to small mammals were correlated to measurements belowground near the surface. Gamma radiation exposure to small mammals inhabiting uranium mill tailings exceeded standards recommended for the general public.

The waste materials from uranium milling processes (tailings) contain low amounts of radioactive materials in the U-238 decay series. To assess the health risks from these radioactive materials, it is necessary to determine the amounts of nuclear waste materials in soils and vegetation on these sites, and the radiation exposure to fauna, including humans.

Studies have been conducted to evaluate the levels of radiation exposure to small mammals (Halford and Markham 1978, Gano 1979) and waterfowl (Halford *et al.* 1982) inhabiting spent nuclear fuel waste disposal sites. However, these sites contain nuclear reactor by-products, higher in radioactivity than uranium mill sites. Information pertaining to the radiation received by small mammals inhabiting uranium mill tailings sites is lacking. This study compares the levels of gamma radiation exposure to small mammals and their environment on uranium mill tailings to background levels on a control site.

Study Area and Methods

The uranium mill tailings immediately west of Edgemont, South Dakota were selected for this study. The mill has been inactive since 1972 and is scheduled for decommissioning. Four sites were selected for study. Sites 1 and 2 were uranium mill tailings covered with 30 cm of topsoil, with established vegetation dominated by crested wheatgrass (*Agropyron cristatum*) and yellow sweetclover (*Melilotus officinalis*) seeded in the fall of 1973 and spring of 1974, respectively.

Site 2 differed from site 1 in that background gamma scan counts measured 1 m aboveground indicated a higher level of gamma radiation on the site. Site 3, also uranium mill tailings, was covered with 30 cm of shale and 60 cm of topsoil with the dominant species of vegetation being crested wheatgrass, western wheatgrass (*Agropyron smithii*), and yellow sweetclover all seeded in 1978. The control site was a pasture located west of the mill, dominated by crested wheatgrass, red threeawn (*Aristada longiseta*), and sand dropseed (*Sporobolus cryptandrus*).

On each site, a grid of 77 (7 x 11) Sherman collapsible small mammal live-traps (23 x 9 x 8 cm) spaced at 7 m intervals, was established. Trapping was conducted monthly from June through September of 1981 and April through September of 1982. The goal was to catch as many small mammals as possible, attach dosimeters and recapture these animals at a later date. Because trapping success was poor on the control site during the first trapping period, an additional 30 traps were set adjacent to the control site. All traps were baited with rolled oats mixed with peanut butter and were opened five consecutive nights at monthly intervals. Animals captured on all sites were toe-clipped for identification and age, sex, weight, and species were recorded.

During 1981 all animals captured were anesthetized and surgically implanted (subcutaneously) with a waterproof packet containing two, 0.32 x 0.32 cm thermoluminescent dosimeters (TLD's) (Halford and Markham 1978, Gano 1979). A different technique was used during

¹Silver King Mines, Inc., manages the site for the Tennessee Valley Authority.

1982; TLD's were attached to both ears of the animals with two Monel metal tags. Each TLD chip was affixed to the ear tag by a piece of 0.3%cm heat-shrink tubing. The animals were then released at the capture location. Animals with TLD's recaptured after 30 or more days had the old TLD's replaced with new ones and the animal was released again. No new TLD's were put on small mammals in September of 1981.

Gamma radiation on the sites was measured by sets of TLD's attached to wooden rods at 80, 60,40, and 20 cm belowground and at 0, 10,20, 40,60, and 80 cm aboveground. One set of TLD's was placed at the center of each small mammal trap grid and one set of TLD's was placed at the center of each quarter of the small mammal grid. These TLD's were in the field 30 days. Exposed TLD's were placed in lead containers while in the field and during storage.

The TLD's, which had been calibrated with a Ra-226 source were initially selected to be within ± 10 percent error due to chip variability and error associated with the reading. All TLD's exposed in the field and some TLD's stored in a lead container in the laboratory were sent for analysis. Analyses were conducted by Eberline Laboratories.' Exposure levels of TLD's kept in the laboratory were subtracted from those exposed in the field to account for irradiation during shipping and handling. TLD exposure data are given in milliRoentgens per day (mR/day). Radiation exposure data from these TLD's are only representative of gamma and some high-energy beta forms of radiation. Differential shielding by the techniques used for attaching TLD's was not of consequence since most gamma radiation easily passes through up to 1.0 inches of iron (U.S. Department of Health, Education and Welfare 1970).

Radiation exposure data on all treatments were analyzed separately for aboveground and belowground in a split-plot design (Steel and Torrie 1960). Sites were considered whole plot effects and depths were treated as subplot effects. Since the interaction of site by depth for the belowground analysis was significant ($P < 0.01$),

separate one-way analyses of variance were performed at each depth. Differences among exposure rates belowground for sites at each depth were evaluated using Dunnett's T3 method for non-homogeneous variances (Dunnett 1980). Significant differences from the aboveground procedure were evaluated using Tukey's multiple comparisons method for homogeneous variances (Steel and Torrie 1960). Radiation exposures to the small mammals were analyzed by two-way analysis of variance for species and sites. Tukey's method was used to determine where differences occurred. Probability level for all tests was $\alpha = 0.05$.

Results

The relationships of gamma radiation estimates from TLD's placed in the field are displayed in Figure 1. Belowground exposure rates suggest a decrease in radiation exposure as the distance between tailings materials and the TLD's increased. Estimates of gamma radiation at the various heights aboveground were variable. Exposure rates aboveground and belowground on site 2 remained relatively constant. Radiation estimates from site 3 and the control site increased aboveground versus belowground.

Belowground radiation rates differed significantly among sites, depths, and site by depth (Table 1). Analyses of radiation exposure estimates 80 cm belowground indicated that higher levels occurred on site 1 compared to the other sites. Gamma exposure estimates from site 2 were higher than those from the control site, but not different from estimates from site 3. Site 3 and the control site were not significantly different. At 60 cm belowground, gamma radiation estimates from site 1 were not different from site 2 estimates; but were greater than those from site 3 and the control site. Gamma radiation estimates from site 2 were higher than those from the control site, but not different from those from site 3. Site 3 and the control site were not different. Estimates of radiation exposure 40 cm belowground indicated no differences between site 1 and site 2, but site 1 had higher estimates than did site 3 and the control site. At 20 cm belowground, no statistical differences were found among the sites.

Aboveground radiation exposure estimates were significantly higher on site 2 versus sites

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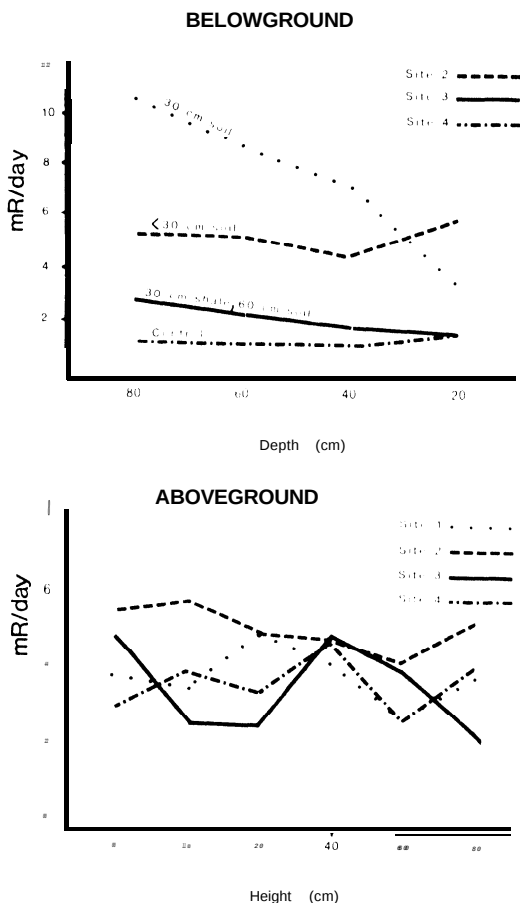


Figure 1. Belowground and aboveground estimates of gamma radiation from three uranium mill tailing sites with topsoil and/or shale covering and a control site. Plotted values are means, $n = 5$.

1, 3, and the control site (Table 1). Estimates of radiation exposure among the heights aboveground were not statistically different.

Small mammals inhabiting the four sites were exposed to variable levels of radiation (Table 2). Differences in estimated radiation exposure were found among sites, but not among species. Averaged across species, small mammals on site 2 were exposed to higher levels of radiation than on the other three sites ($P < 0.001$). Radiation received by the individual species averaged across sites were not different ($P = 0.06$) which may have been related to the limited sample size. Estimates of radiation received by the small mammals inhabiting all sites was positively cor-

related with averaged gamma radiation estimates measured at ground level. For all species together $r = 0.68$, for western harvest mice (*Reithrodontomys megalotis*) $r = 0.50$, and for prairie voles (*Microtus ochrogaster*) $r = 0.86$. There were not enough deer mice (*Peromyscus maniculatus*) captured to get meaningful correlations of exposure rates across sites. Higher correlations of 0.97, 0.78 and 0.86 were found for exposure rates 20 cm below ground for all species, western harvest mice and prairie voles, respectively. Mean gamma exposure to the small mammals on each site was less than the exposure rates measured either aboveground or belowground.

Discussion

Measurements of belowground radiation exposures suggested some differences between sites with supposedly similar soil covering and vegetation (site by depth interaction belowground). These differences were attributed to the uneven spreading of topsoil over mill tailings on site 2 versus site 1. Near the center of the grid area on site 2, the top soil depth was as shallow as 10 cm. Thus, at least some TLD's at all depths belowground were in the raw tailings materials. Covering the mill tailings materials with 30 cm of shale and 60 cm of topsoil reduced belowground estimates of radiation exposure in this study to rates not different from those at the control site (background rates) down to 80 cm.

An evenly spread soil covering of 30 cm over uranium mill tailing materials reduced aboveground radiation exposure to levels not different from background. Schaiger (1974) indicated 61 cm of soil was needed to reduce gamma exposure to natural background levels. However, the fact that these data were highly variable may have obscured some differences. On other uranium mill tailing sites, gamma counts at 1 m aboveground varied between 2.2 mR/day at Gunnison, Colorado, to 7.5 mR/day near Rifle, Colorado, when covered with 15 to 30 cm of soil. In this study, gamma radiation measurements for sites 1 and 2 averaged 4.3 mR/day aboveground. Gamma radiation counts on uranium mill tailing sites with no soil covering varied from 17.1 mR/day at Tuba City, Arizona, to 31.7 mR/day at Mexican Hat, Utah (unpublished data, U.S. Dept. Energy Uranium Mill Tailings Project Office, Albuquerque, New Mexico).

TABLE 1. Mean $\pm$ SE radiation estimates (mR/day) from three uranium mill tailings sites covered with topsoil and/or shale and a control site.¹

	Site 1 30 cm topsoil	Site 2 30 cm topsoil	Site 3 30 cm shale & 60 cm topsoil	Control
Belowground				
80 cm	10.6 $\pm$ 0.2 ^a	5.3 $\pm$ 0.6 ^b	2.8 $\pm$ 0.3 ^{b,c}	1.2 $\pm$ 0.5 ^c
60 cm	8.6 $\pm$ 0.9 ^a	5.2 $\pm$ 0.7 ^{a,b}	2.2 $\pm$ 0.2 ^{b,c}	1.0 $\pm$ 0.2 ^c
40 cm	7.1 $\pm$ 0.8 ^a	4.4 $\pm$ 0.7 ^{a,b}	1.6 $\pm$ 0.2 ^b	1.0 $\pm$ 0.1 ^b
20 cm	3.3 $\pm$ 0.5	5.8 $\pm$ 1.4	1.5 $\pm$ 0.2	1.4 $\pm$ 0.2
Aboveground²				
$\bar{x}$	3.5 $\pm$ 0.3 ^b	5.5 $\pm$ 0.5 ^a	3.4 $\pm$ 0.4 ^b	3.7 $\pm$ 0.5 ^b

¹Means followed by superscripts with different letters across rows are different ($P \leq 0.05$) based on Dunnett's T3 method for nonhomogeneous variances belowground and Tukey's w-procedure aboveground.

²No differences were found among heights aboveground so only site means are presented.

TABLE 2. Gamma radiation (mean $\pm$ SE)¹ in mR/day to small mammals inhabiting three uranium mill tailings sites and a control site in South Dakota.²

Species	Site 1	Uranium Mill Tailings Site 2	Site 3	Control	All treatments averaged
Western harvest mice					
	1.49 $\pm$ 0.49 (8) ²	3.12 $\pm$ 0.36 (6)	1.69 $\pm$ 0.48 (3)	0.63 (1)	2.02 $\pm$ 0.31 (18)
Deer mice					
	1.26 $\pm$ 0.40 (8)	0.51 (1)	—	0.53 $\pm$ 0.39 (2)	1.06 $\pm$ 0.31 (11)
Prairie voles					
	0.45 (1)	4.19 $\pm$ 1.64 (4)	0.32 $\pm$ 0.34 (8)	0.19 $\pm$ 0.04 (12)	0.87 $\pm$ 0.38 (25)
All species averaged					
	1.32 $\pm$ 0.29 (17) ^a	3.27 $\pm$ 0.66 (11) ^b	0.69 $\pm$ 0.22 (11) ^a	0.26 $\pm$ 0.06 (15) ^a	1.30 $\pm$ 0.22 (54)

¹Means with different letters as superscripts are significantly different at $P \leq 0.05$.

²Number in parenthesis is the sample size.

Small mammals in the field received lower rates of radiation exposure than were observed aboveground on the study sites. This indicates that the animals spent at least part of the time in situations where radiation rates were less than measured on the four sites. Undoubtedly TLD's placed at ground level in the field received some gamma radiation from both below- and aboveground. The relationships of 20 cm belowground and ground level exposure rates to small mammals exposure rates would indicate the primary source of radiation exposure to small mammals inhabiting mill tailing sites was the uranium mill tailings. All three mammal species in this study

are active at night and nest on or near the surface (Burt and Grossenheider 1964) and, with the exception of prairie voles, are active at night (Leichleitner 1969). Thus, the small mammals were not exposed to some of the external sources of radiation (*i.e.* solar) that were measured with the stationary TLD's at or aboveground. Higher gamma exposure rates belowground compared to small mammals exposure rates indicates some degree of attenuation of gamma radiation from the mill tailing by the soil covering.

Information to compare gamma exposure rates to small mammals on other uranium mill tailing sites is lacking. However, if one assumes

that humans would receive doses similar to the small mammals, some comparisons can be made. The U.S. Department of Health, Education and Welfare (1970) published a standard that exposure to the general public in uncontrolled areas not be more than 1.4 mR/day (assuming 1.0 mR results in 1.0 millirems of absorbed gamma radiation). However, the Department of Energy (1977) recommended that 170 millirems per year should be the limit for individuals and population groups in uncontrolled areas. This would be equivalent to 0.5 mR/day if an exposure of 0.5 mR/day results in an absorbed dose of 0.5 millirem. The average exposure to small mammals on tailings covered with 30 cm of soil exceeded this limit,

even after exposures from the control were subtracted as background. The uranium tailings with 30 cm of shale and 60 cm of topsoil also had exposure rates that slightly exceeded this recommendation. If exposure to animals on the control were subtracted as background, then exposure to small mammals on the site with 30 cm of shale and 60 cm of soil was below the U.S. Department of Energy (1977) recommendation. If the U.S. Department of Health, Education and Welfare published standard were accepted, the soil covering of at least 30 cm of soil adequately reduced gamma exposure rates to below 1.4 mR/day.

Literature Cited

- Burt, W. H., and R. P. Grossenheider. 1964. A Field Guide to the Small Mammals. Houghton Mifflin Co., Boston.
- Dunnett, C. W. 1980. Pairwise multiple comparisons in the unequal variance case. J. Amer. Stat. Assoc., 75:796-800.
- Gano, K. A. 1979. Analysis of small mammal populations inhabiting the environs of a low-level radioactive waste pond. PNL-2479/UC-11, Battelle Pac. Northw. Lab., Richland, Washington.
- Halford, D. K., and O. D. Markham. 1978. Radiation dosimetry of small mammals inhabiting a liquid radioactive waste disposal area. Ecology 59: 1047- 1054.
- Halford, D. K., O. D. Markham, and R. L. Dickson. 1982. Radiation doses to waterfowl using a liquid radioactive waste disposal area. J. Wildl. Manage., 46:905-914.
- Leitchner, R. R. 1969. Mammals of Colorado. Pruett Publishing Co., Boulder, Colorado.
- Schaiger, K. J. 1974. Analysis of radiation exposure on or near uranium mill tailings piles. Radiation Data and Reports 15(7):375-476. Off. of Rad. Prog., U.S. Env. Prot. Agency.
- Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc. New York.
- U.S. Department of Energy. 1977. Standards for radiation protection. DOE Manual, Chapter 0524, Appendix, Part 3. Washington, D.C.
- U.S. Department of Health, Education and Welfare. 1970. Radiological Health Handbook. Superintendent of Public Documents, Stock No. 017-011-000430. U.S. Government Printing Office, Washington, D.C.

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