

was investigated further by exposing a second series of discs at various heights above the ground, with these discs being shielded either by about 4 mm plastic or 2.4 mm copper and 2 mm plastic. Once again, the exposure rate was observed to decrease with height even though in this case there were no significant differences at a given height between the exposure rates as recorded by the two shielding configurations. It may be concluded that there is a component of the radiation unable to penetrate 0.1 mm of plastic at a height of 82 cm, and 4 mm of plastic or 0.8 mm of copper at ground level. This strongly suggests that the less penetrating component consists of one or more of soft X-rays or γ -rays, secondary electrons arising from photon interactions or β -particles from the decay of uranium daughters.

The variation with height of the exposure rate due to the penetrating component of the radiation means that the exposure measured by the disc is not a whole body exposure, but a measure of the exposure at the position of the TLD dosimeter on the body.

Conclusions

The results show that provided the appropriate precautions are taken, $\text{CaSO}_4:\text{Dy}$ in teflon discs shielded by approx. 2 mm of copper gives a reliable and accurate estimate of the exposure of workers to external γ -radiation in a uranium mine. Close to ore surfaces there is a less penetrating component of the radiation, due to one or more of soft X- or γ -rays, secondary electrons or β -particles. However these are regarded as being of relatively minor importance as an external radiation hazard to the whole body, because of their short range in tissue.

Acknowledgement—V. Leach and the other members of the Laboratory who worked at Nabarlek are thanked for their cooperation during the field testing of the dosimeters.

J. F. BOAS
A. MURRAY
J. G. YOUNG

Australian Radiation Laboratory,
Lower Plenty Road,
Yallambie, Victoria,
Australia, 3058

References

Be72 Beck H. L., 1972, "The Physics of Environmental Gamma Radiation Fields" in The

Natural Radiation Environment II (Edited by J. A. S. Adams, W. M. Louder and T. F. Gessell). U.S. E.R.D.A. report CONF-72 0805, 2.

Fr81 Frank A. L. and Benton E. V., 1981, "Measurements of γ -Ray Exposures in Uranium Mines". *Health Phys.* **40**, 240.

Ho69 Holaday D. A., 1969, "History of the Exposure of Miners to Radon". *Health Phys.* **16**, 547-552.

Le80 Leach V. A., Lokan K. H. and Martin L. J., 1980, "A Study of Radiation Parameters at Nabarlek Uranium Mine, N. T." *A.R.L. Techn. Rep.* TR028, 1980.

Mc69 McCurdy D. E., Schiager K. J. and Flack E. D., 1969, "Thermoluminescent Dosimetry for Personal Monitoring of Uranium Miners". *Health Phys.* **17**, 415.

Mi77 Miller H. T., 1977, "Radiation Exposures Associated with Surface Mining for Uranium". *Health Phys.* **32**, 523.

Th80 Thomson J. E. and Wilson O. J., 1980, "Calculation of Gamma Ray Exposure Rates from Uranium Ore Bodies." *A.R.L. Techn. Report* TR014, 1980.

So81 Sonne T., 1981, Ranger Uranium Mine, Private communication.

Ya71 Yamishita T., Nada N., Onishi H. and Kitamura S., 1971, "Calcium Sulphate Activated by Tm and Dy for TL Dosimetry". *Health Phys.* **21**, 295.

0017-9078/82/060868-04\$03.00/0
Pergamon Press Ltd.

Health Physics Vol. 42, No. 6 (June), pp. 868-871, 1982
Printed in the U.S.A.

Hakinson, TE 1982

Disturbance of a Low-level Waste Burial Site Cover by Pocket Gophers

(Received 29 June 1981; accepted 21 August 1981)

BIOLOGICAL intrusion of low-level waste sites has been identified as a potential problem in isolating waste radionuclides for extended periods of time (An79). Studies on current and decommissioned low-level waste burial sites in the western U.S. have shown that radionuclides present in the waste can be mobilized by plant roots and burrowing

animals that penetrate through the waste cover (Kl79; Hak77; O'F75; Da73). Biological activity also can modify chemical and physical processes within the soil profile. For example, burrowing animals can change the rates of water infiltration and surface soil erosion (Gr74; Han68; E152).

This paper presents the results of a study to characterize the amount of disturbance of a low-level waste cover resulting from the burrowing activities of pocket gophers (*Thomomys bottae*) at Los Alamos. Data are presented on the amount of soil excavated from the cover profile, the amount of tunnel system created by these soil mining activities, and the particle size distribution and radionuclide content of the cast soil.

Methods and Materials

A 0.95 ha study area was established on a low-level waste burial site that was decommissioned in 1977. The plot was positioned over trenches that were covered with 1 m of crushed tuff (the material excavated from the trenches) and about 0.25 m of topsoil (Fig. 1). A mixture of native grasses and forbs (sweet clover and alfalfa) was seeded into the topsoil in 1977. Species composition and density of the vegetation that was present on the plot in October 1980 was determined using standard survey methods (Ku67; Ph59).

A 0.95 ha sampling grid with 7.5 × 7.5 m cells was established over the covered trenches in August 1979. All of the soil excavated by pocket gophers within each grid cell was collected at 2–11 week intervals over a 1 yr period and was weighted on a spring balance scale accurate to ±1 kg. Sub-samples of the soil were screened to determine the amount of soil in the less than 2 mm diameter size class versus

gravel and rock (>2 mm diameter). The soil fraction was also analyzed for gamma emitting radionuclides on a Packard automated gamma counting system using a 7.6 cm diameter well-type Nai(Tl) detector.

Results and Discussion

Total vegetation cover on the plot was estimated as about 23% with sand dropseed (*Sporobolus cryptandrus*), sweet clover (*Melilotus officinalis*), alfalfa (*Medicago sativa*) and fescue (*Festuca* spp.) contributing the most to the cover estimate. Of the 25 species recorded on the plot, most were not present in the original seed mixture applied to the cover in 1977 but rather were due to natural invasion of the plot with forb species. Grasses, forbs and shrubs comprised 24, 72 and 4% of the species present. About 40% of the forb species were from the sunflower family (Compositae).

In a 401-day period 1998 separate mounds were created by pocket gophers on the 0.95 ha study area for an average of about 5 mounds day⁻¹ ha⁻¹. The total mass of the soil in these mounds was 11,255 kg oven dry weight, for an average excavation rate of about 30 kg day⁻¹ ha⁻¹. Mound building activity was greatest in late summer and fall (Fig. 2) when a total of about 60 kg ha⁻¹ of soil was brought to the surface of the waste burial pit each day.

The composition of the mound soils was almost exclusively the crushed tuff directly overlying the waste (Fig. 1). An average of about 33% of the mound soil was tuff particles in the gravel and rock size range (>2 mm diameter) while the remaining 67% was soil particles less than two millimeters in diameter. Rock sized particles were often up to 6 cm in diameter indicating the ability of the gophers to move relatively large chunks of backfill material. The ratio of gravel and rock to soil in the mound samples was significantly different ($p < 0.05$) from the corresponding ratio in the tuff backfill material. The percentage of particles greater than 2 mm in the mound soil was 33% whereas the corresponding percentage in the tuff backfill was 48%.

The digging activity of pocket gophers on the study plot turned over less than 1/10% of the waste cover during the one year observation period. However, the 11,255 kg of material brought to the soil surface represents a volume of about 8.3 m³; presumably about 8.3 m³ of void space was created within the cover profile. Based on an average tunnel cross sectional area of 30 cm², as measured in the field, 8.3 m³ of void space within the cover profile represents about 2800 m of pocket gopher tunnel system.

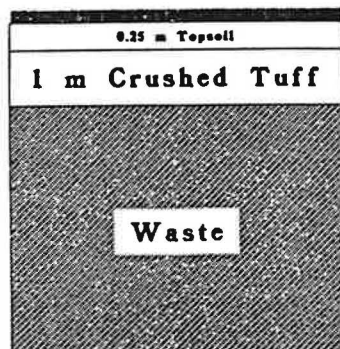


FIG. 1. Cover profile, including vegetation, applied to low-level waste site used to study soil excavation rates by Pocket Gophers (*Thomomys bottae*).

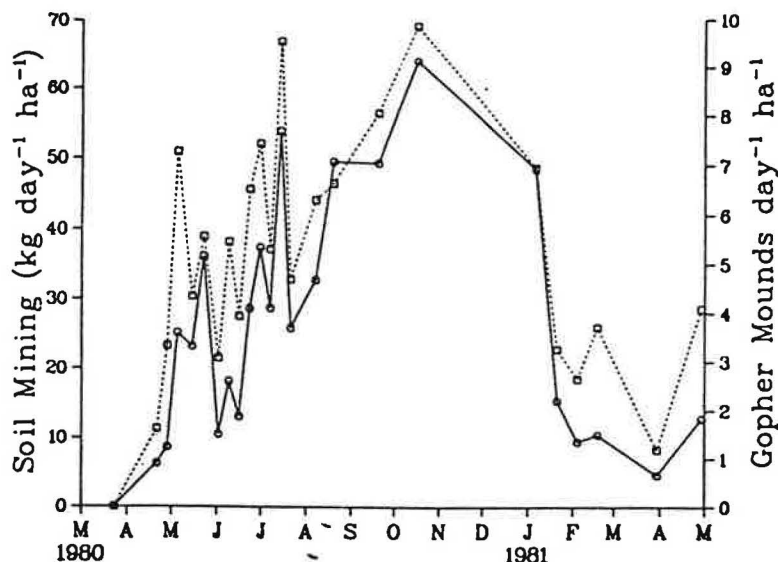


FIG. 2. Rates of pocket gopher mound formation (dashed line) and soil deposited on the surface (solid line) of a low level radioactive waste burial site.

Based on the total number and dimension of individual mounds, the soil in the mounds covered about 1% of the ground surface to a depth of 12.5 cm on the study plot. Soil mounding by the gophers was observed in 76% of the grid cells in the plot although mounds on the soil surface greatly underestimate the extent of tunneling underground (Wi80).

Gamma emitting radionuclides, at levels exceeding worldwide fallout, were not detected in any of the mound soil samples. The lack of waste radionuclides in the mound samples would suggest that the gophers have not penetrated into the waste trench in the four years subsequent to closure of the site.

Pocket gophers modify the soil matrix in many ways. Perturbations to the soil profile that may be detrimental to low-level waste containment systems include excavation of soil from within the cover profile to the ground surface (Ri66; El46), increasing water infiltration rates into the soil profile (Han68; Ab68; Gr80), displacing chemicals vertically within the profile (Ab72), altering rates of soil erosion (El46), and penetrating into waste burial trenches and mobilizing radionuclides (O'F75). The results of this study indicate that the amount of soil brought to the surface of low-level waste site is small relative to the volume of cover material. However, the void space created by their burrowing activity represents a substantial net-

work of tunnel system within the waste cover profile.

The effects that plants and animals have in altering the soil profile must be considered in developing reclamation procedures that have long term effectiveness. Burrowing animals not only directly alter the soil profile through digging activities but also change the physical and chemical processes within the profile that can mobilize buried contaminants.

Acknowledgements—This work was supported by the U.S. Department of Energy under contract No. W-7405-ENG-36 with Los Alamos National Laboratory. We thank T. Foxx, G. Tierny, E. Montoya and B. Drennon for assistance with this work.

T. E. HAKONSON
J. L. MARTINEZ
G. C. WHITE

Los Alamos National Laboratory
Los Alamos,
NM 87545

References

- Ab68 Abaturon B. D., 1968, "Importance of the Digging Activity of the Mole (*Talpa europaea*) on Soil Cover and Vegetation in Broadleaf-Fir Forest", *Pedobiologia* 8, 239-264 (in Russian).

0017-9078/82/060871-03\$03.00/0
© 1982 Health Physics Society
Pergamon Press Ltd.

Health Physics Vol. 42, No. 6 (June), pp. 871-873, 1982
Printed in the U.S.A.

- An79 Anonymous, 1979, Unresolved Technical Issues in Land Burial of Low-Level Radioactive Waste, Oak Ridge National Laboratory Rep. ORNL/NFW-79/62.
- Da73 Dabrowski T. E., 1973, Radioactive Tumblers in the 100 Areas, UNI-65 (Richland, WA: United Nuclear Industries).
- El46 Ellison L., 1946, "The Pocket Gopher in Relation to Soil Erosion in Mountain Ranges", *Ecology* 27, 101-114.
- Gr74 Grant W. E., 1974, "The Functional Role of Small Mammals in Grassland Ecosystems", Ph.D. thesis, Colorado State University, Fort Collins, Colorado.
- Gr80 Grant W. E., French N. R. and Folse, Jr. L. J., 1980, "Effects of Pocket Gopher Mounds on Plant Production in Shortgrass Prairie Ecosystems", *The Southwestern Naturalist* (25)2, 215-224.
- Hak76 Hakonson T. E. and Bostick K. V., 1976, "The Availability of Environmental Radioactivity to Honey Bee Colonies at Los Alamos", *J. Environ. Qual.* 5, 307-310.
- Han68 Hansen R. M. and Morris M. J., 1978, "Movements of Rocks by Northern Pocket Gophers", *J. Mammal.* 49, 391-399.
- ICRP77 International Commission on Radiological Protection, 1977, "Recommendations of the ICRP", *ICRP Publication 26* (Oxford: Pergamon Press).
- Kl79 Klepper E. L., Rogers L. E., Hedlund J. D. and Schreckhise R. G., 1979, Radioactivity Associated with Biota and Soils of the 216-A-24 Crib. Pacific Northwest Laboratory Rep. PNL-1948-UC-70, 54 PP.
- Ku67 Kuchler A. W., 1967, *Vegetation Mapping* (New York: Ronald Press).
- O'F75 O'Farrell T. P. and Gilbert R. O., 1975, "Transport of Radioactive Materials by Jackrabbits on the Hanford Reservation", *Health Phys.* 29, 9-15.
- Ph59 Phillips E. A., 1959, *Methods of Vegetation Study* (New York: Holt, Rinehart and Winston).
- Ri66 Richens V. B., 1966, "Notes on the Digging Activity of a Northern Pocket Gopher", *J. Mammal.* 47, 531-533.
- Wi80 Winsor T. F. and Whicker F. W., 1980, "Pocket Gophers and Redistribution of Plutonium in Soil", *Health Phys.* 39, 257-262.

Radionuclide Emissions From Incineration of Institutional Low-level Radioactive Wastes

(Received 30 June 1981; accepted 2 September 1981)

Introduction

INCINERATION IS an attractive alternative for disposal of institutional low-level radioactive waste. A properly operated incinerator is capable of a volume reduction of 80:1 and organic compounds are decomposed to CO₂ and H₂O. Since the radionuclides are unaffected, they are either deposited in the ash or on the walls of the incinerator or they are emitted in the effluent gases. This study was conducted to investigate the radionuclide emissions if institutional low-level radioactive wastes generated in North Carolina were incinerated.

A survey of state licensees was conducted in 1979 to determine the amount and characteristics of institutional radioactive waste generated in North Carolina (NC79). The results of the survey indicated that 90% of the waste was generated in the Research Triangle Area, with the remaining 10% generated throughout the state. The waste consisted of dry solids, liquids, scintillation vials and fluids, and animal carcasses. Approximately 85% of the waste was combustible and 15% was non-combustible which would require means of disposal other than incineration. The activities of the nuclides in combustible waste are shown in Table 1, with their half-lives.

Method of Analysis

Incinerators have been licensed with the requirement that the annual average radionuclide concentrations in the effluent be less than 10% of the maximum permissible concentrations (MPC) (NRC79). This study evaluated annual average stack top concentrations and ground level concentrations versus maximum permissible concentrations.

It was assumed that the short half-life nuclides, half-life ≤ 60 d, were held for decay before incineration and that the wastes were incinerated at one facility. The operating characteristics for a