Report No. EPA 600/R-94/117
Date: July 1994

RESIDUAL SOIL RADIOACTIVITY AT THE GNOME TEST SITE IN EDDY COUNTY, NEW MEXICO

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1034NRD93

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ABSTRACT

A surface soil characterization was conducted at the Gnome Test Site surrounding areas near Carlsbad, New Mexico to determine the abundances of gamma-emitting radionuclides and total exposure rates. ^{137}Cs was the only man-made nuclide detected in measurements taken at 22 on-site and off-site locations, with a maximum concentration of 11.49 ± 0.13 kBq m^{-2} (31.02 ± 0.35 pCi cm^{-2}). Extended ^{137}Cs verticle distributions and lower than expected inventories at undisturbed sites can be attributed to the unconsolidated sandy surface of the area. Results of the in-situ spectrometry indicate that at all locations the dose rate due to ^{137}Cs is small compared to that of the naturally occurring background.

ACKNOWLEDGEMENTS

The author would like to thank Brian Moore for the strontium analyses and Don James and Max Davis for assistance in collecting field data.

INTRODUCTION

The Gnome Test Site is located in Eddy County, southeastern New Mexico, approximately 35 km southeast of the city of Carlsbad and 12 km southwest of the Department of Energy (DOE) Waste Isolation Pilot Project (WIPP) facility (Fig. 1). Project Gnome was a 3.1 kiloton yield nuclear detonation conducted on 10 December, 1961, as part of the Plowshare Program of the Atomic Energy Commission. The program was initiated in 1957 to investigate the feasibility of the use of nuclear explosives for nonmilitary applications such as large-scale civil engineering projects and scientific studies. The Gnome experiment was specifically designed to explore the possibility of converting the energy of a nuclear explosion to electric power, investigate the production and recovery of radioactive isotopes, collect data on the characteristics of nuclear detonations within a salt medium, and to obtain neutron cross-section measurements over a wide energy range. It was the first of the Plowshare experiments and the first underground nuclear test conducted outside of the Nevada Test Site in the United States (U.S. AEC 1961; Nathans 1965; U.S. DOE 1982).

The nuclear device was detonated 370 m below the surface of the Gnome site in the Salado geological formation, which is composed primarily of halite (NaCl) (Gardner and Sigalove 1970). Access to the shotpoint was provided by a horizontal drift tunnel that led to a vertical shaft 340 m southwest of ground zero. The explosion created a cavity about 21 m in height and 46 m in diameter (Gard 1968). By June of 1962, mine-back activities had connected the shaft to the cavity, allowing it to be entered. A blanket of collapsed material from the upper hemisphere of the chamber provided shielding from the highly radioactive melt produced in the explosion.

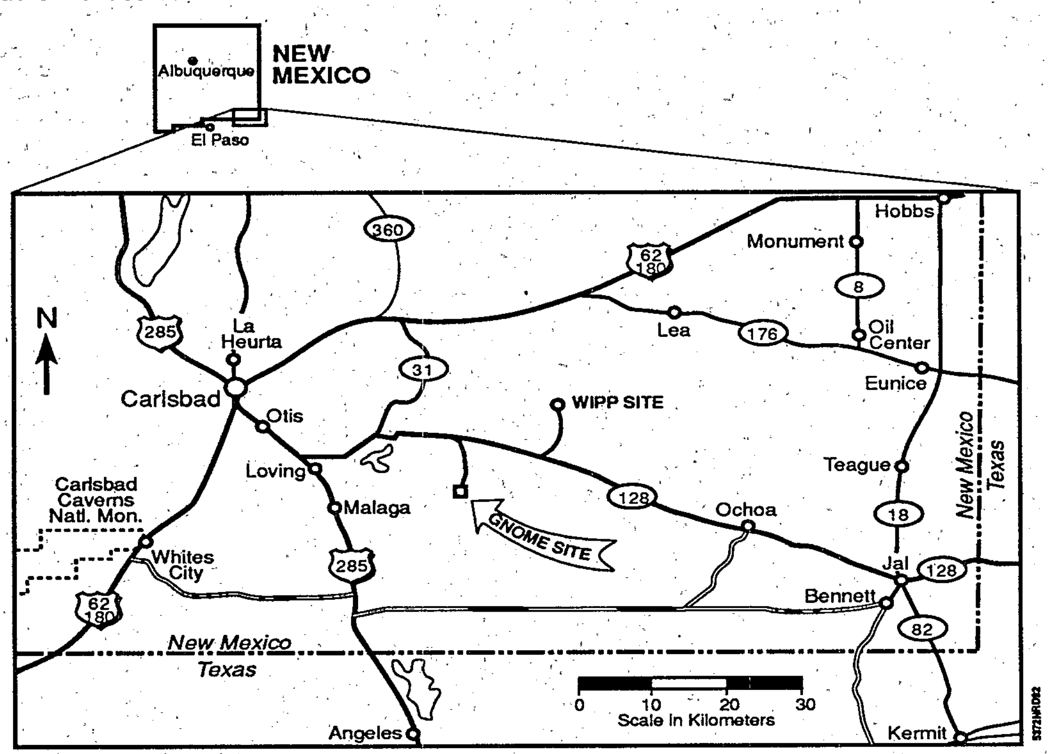

Figure 1. Location of the Gnome Test Site in Eddy County, New Mexico.

SURFACE CONTAMINATION AND REMEDIATION

Immediately following the firing of the device, a low pressure vent from the Gnome shaft occurred owing to the failure of a rupture disk in a blast door in the access tunnel. For more than a day, steam and short-lived radioactive gases vented from the shaft and were carried in a northwest direction from the site (Fig. 2). After the event, a considerable amount of contamination was present on the surface of the site (Gardner and Sigalove 1970). Later reentry mining and core sampling operations also brought contaminated material to the surface, mostly in the form of salt muck.

From 1968 to 1969, a cleanup program was conducted at the site, with guidelines specifying the removal of all radioactive material with a reading of 2.6×10^{-8} C kg^{-1} h^{-1} (0.1 mR h^{-1}, beta plus gamma) as measured with a 30 mg cm^{-2} window Geiger Muller survey probe. Contaminated soil and debris were disposed into the Gnome shaft and drift tunnels or were interred beneath uncontaminated soil. In addition, all surface facilities were removed and all bore holes were plugged except for those retained for hydrological monitoring (U.S. AEC 1973). In 1977, a second more extensive cleanup program was initiated with guidelines for removal of soil with beta-gamma activity above 0.74 Bq g^{-1} (20 pCi g^{-1}) or a moisture ^3H activity above 1.1 kBq ml^{-1} (30 nCi ml^{-1}). This operation included the removal of debris from the contaminated waste dump and salvage yard (Fig. 2) that had been exposed by weathering, and the disposal of contaminated soils and approximately $3 \times 10^{+7}$ kg of salt muck into the Gnome cavity. The Coach shaft denoted on the figure was constructed for a second Plowshare detonation that was later abandoned. It was also used for disposal of contaminated materials, and because the Gnome and Coach shafts were connected by a horizontal drift tunnel, the associated well LRL-7 was used for water monitoring and recovery during the operation. Once the cavity had been filled to near capacity, remaining radioactive materials were removed to the Nevada Test Site for burial in a low-level waste site. The operation concluded in 1979, and the site has since been decommissioned (U.S. DOE 1981, 1982).

In 1991, a study was undertaken to determine in-situ gamma-ray exposure rates and radionuclide concentrations in surface soils at nuclear test locations outside of the Nevada Test Site (Faller 1992). In June of 1992, the Gnome site was selected for a surface characterization that would coincide with the annual hydrological testing of the area (U.S. EPA 1992). This study was conducted to assess the extent of remaining activity at the site and provide data on the distribution of the contamination in the desert environment.

Survey sites were selected from locations of previous operational facilities such as waste disposal sites, building foundations, and shaft sites. In addition, radiological survey maps from previous surveillance reports were used to determine contaminated locations and areas with background levels of radiation (U.S. DOE 1981).

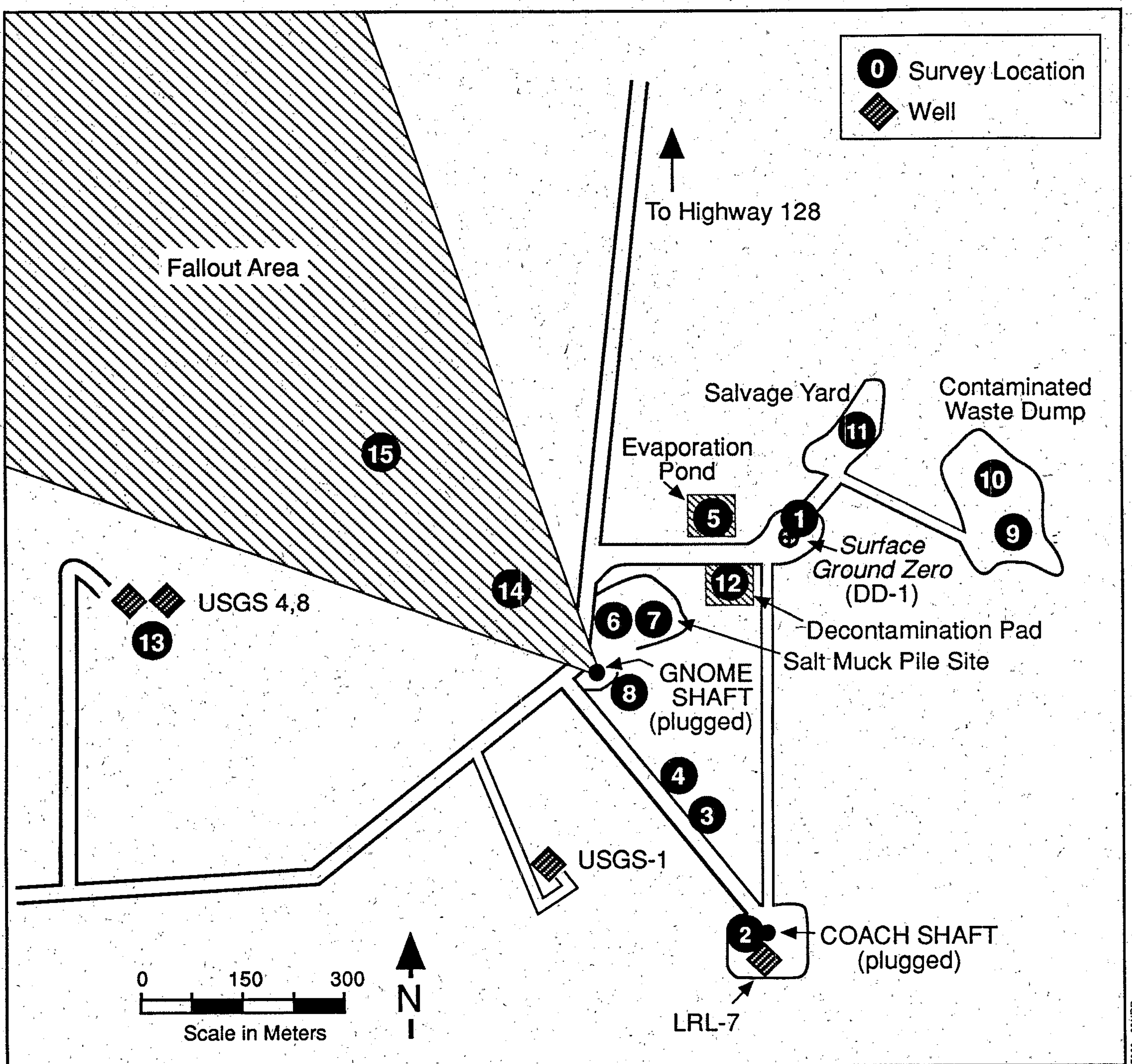

Figure 2. Gnome Site survey locations, shaft sites, and operating wells. Locations 16 through 22 are not shown.

EXPERIMENTAL PROCEDURE

Field gamma-ray spectra were collected with a high-purity germanium detector (HpGe) with a relative efficiency of 30%. The spectra were collected for periods of 45 min with a portable battery-powered multichannel analyzer and recorded on diskettes for later retrieval and analysis with a laboratory mini-computer. Soil core samples were collected as described in Beck (1979) and Miller et al. (1980). Conversion factors to determine dose rates in air and soil activities were obtained from Beck (1980), Murith et al. (1986), and Helfer and Miller (1988). Total gamma-ray flux was measured at each survey site with a pressurized ion chamber (PIC) for periods of 15 min. All measurements were taken at a height of 1 m above ground level. Calibrations of radiation detection equipment were performed with radioactive sources traceable to the National Institute of Standards and Technology (NIST). In a period of 6 d, a total of 22 on-site and off-site locations were surveyed, with core samples taken at 11 locations. Soil samples were packaged and returned to the laboratory for gamma-ray analysis as in Faller (1992). Two soil samples were analyzed for radiostrontium content by total dissolution, ion-exchange separation, and beta-ray analysis.

EXPERIMENTAL RESULTS

Fig. 2 depicts the Gnome Test Site and the approximate path of the plume from the shaft vent. On-site and near-site in-situ survey locations and the positions of facilities that were removed during clean up operations are also shown. On-site wells are sampled and analyzed yearly.

Table 1 lists the gamma-ray dose rates in air measured at each of the survey locations. The combined total rates are the summed contributions from the cosmic-ray component, deduced from the barometric pressure, and the natural and man-made components, derived from analysis of the HpGe spectra. Gross dose rates from PIC measurements, taken at the same survey locations as the gamma-ray spectra, are given as a check of the summed rates.

Table 2 lists the ^{137}Cs inventories for each surveyed site. The depth distribution parameter is expressed as α/ρ, where α is the reciprocal of the relaxation length of the assumed exponential profile in the soil, and ρ is the soil density (Miller and Helfer 1985). At locations where soil cores were not taken, parameters of ∞ (planar distribution) and 0.05 are given to represent a large range in distribution profiles. Corresponding radiocesium abundances per unit area deduced from the depth parameters and the spectral results are listed for each survey site. The minimum detectable concentrations per unit area are also given. ^{137}Cs was the only man-made gamma-emitting nuclide detected in this study.

The one-sigma statistical uncertainties of the nuclide inventories in Table 2 are generally less than 20% of the calculated values, and in some cases, as little as 1%. Uncertainties are as high as 50% for ^{7}Be values, owing to the small concentrations. Uncertainties introduced by literature conversion factors used to determine individual nuclide concentrations are generally less than 15% (Helfer and Miller 1988). In addition, uncertainties of less than 6% exist in the PIC dose rate in air values, and some relatively small errors exist in estimations of vertical distributions where they were determined (Faller 1992).

Table 1. Dose rate inventories at Gnome survey locations (1.0 nGy h^{-1} = 0.11 μRh^{-1}).

	Dose rate in air (nGy h^{-1})							
	Cosmic	^{40}K	^{232}Th[a]	^{238}U[a]	^{7}Be	^{137}Cs	Total	PIC
ON SITE								
1. Surface ground zero (5 m northeast of monument)	45	7.8	8.4	11.1	0.6	4.3[b]	77	75
2. Coach shaft site (well LRL-7)	45	6.7	6.7	15.8	0.4	2.4[b]	77	70
3. 70 m northeast of Coach shaft site	45	5.6	5.3	10.9	0.3	0.3[b]	67	68
4. 130 m northeast of Coach shaft site	45	7.7	6.8	6.3	0.4	0.3[b]	67	67
5. Waste tank/evaporation pond site	45	7.2	7.7	6.5	0.3	0.4[b]	67	69
6. West side of salt muck pile site	45	10.7	10.5	9.7	0.1	0.1[b]	76	73
7. East side of salt muck pile site	45	10.6	8.5	10.4	0.2	1.0[b]	76	72
8. Gnome shaft (8 m northeast of plug)	45	8.4	6.6	9.4	0.4	4.4[b]	74	73
9. Southeast side of contaminated waste dump	45	4.3	4.8	7.0	0.4	0.8[b]	62	63
10. Central area of contaminated waste dump	45	8.0	5.9	7.7	0.3	5.8	73	75
11. Salvage yard	45	9.8	10.6	8.9	0.3	0.1[b]	75	70
12. Decontamination pad	45	9.0	7.3	7.5	0.3	4.1	73	73
OFF SITE								
13. Wells USGS 4 and 8	45	11.5	8.8	9.0	0.5	3.3[b]	78	79
14. 150 m northwest of Gnome shaft	44	11.4	10.2	9.1	0.3	9.8	85	83
15. 400 m northwest of Gnome shaft	44	11.4	10.4	9.7	0.3	4.1	80	76
16. 2.5 km northwest of Gnome shaft	45	13.0	13.4	10.6	0.3	0.4	83	76
17. 10 km northwest of Gnome shaft	45	9.2	11.2	10.8	0.4	1.4	78	67
18. 16 km northwest of Gnome shaft	45	13.8	12.9	8.9	0.5	0.8	82	77
19. 2.5 km west of surface ground zero	45	10.3	7.0	9.0	0.4	0.4	72	70
20. 3 km east of surface ground zero	44	8.4	6.8	7.5	0.3	0.5	68	68
21. 4 km northeast of surface ground zero	44	10.1	9.0	7.6	0.3	0.5	72	80
22. 3 km south of surface ground zero	44	8.4	6.5	6.3	0.3	0.3	59	65

[a] *Contribution from series.*
[b] *Assuming α/ρ = 0.05 (no core taken).*

Table 2. Spectrometry results at Gnome on-site and off-site locations; calculated distribution parameter, ^{137}Cs content, and minimum detectable activity (1.0 kBq m^{-2} = 2.7 pCi cm^{-2}).

		^{137}Cs Distribution		
		α/ρ	Activity abundance (kBq m^{-2})	MDA
	ON SITE			
1.	Surface ground zero (5 m northeast at monument)	∞	1.42 ± 0.03	0.05
		0.05	9.51 ± 0.17	0.34
2.	Coach shaft site (well LRL-7)	∞	0.80 ± 0.02	0.04
		0.05	5.38 ± 0.14	0.25
3.	70 m northeast of Coach shaft site	∞	0.096 ± 0.009	0.03
		0.05	0.63 ± 0.06	0.16
4.	130 m northeast of Coach shaft site	∞	0.10 ± 0.01	0.02
		0.05	0.66 ± 0.06	0.15
5.	Waste tank/evaporation pond site	∞	0.14 ± 0.01	0.02
		0.05	0.91 ± 0.07	0.16
6.	West side of salt muck pile site	∞	0.033 ± 0.008	0.01
		0.05	0.22 ± 0.06	0.16
7.	East side of salt muck pile site	∞	0.32 ± 0.02	0.03
		0.05	3.26 ± 0.15	0.26
8.	Gnome shaft (8 m northeast of plug)	∞	1.45 ± 0.03	0.03
		0.05	9.78 ± 0.17	0.19
9.	Southeast side of contaminated waste dump	∞	0.28 ± 0.01	0.02
		0.05	1.85 ± 0.08	0.16
10.	Central area of contaminated waste dump	0.14	6.77 ± 0.10	0.10
11.	Salvage yard	∞	0.044 ± 0.008	0.03
		0.05	0.30 ± 0.05	0.17
12.	Decontamination pad	0.04	9.96 ± 0.18	0.22
	OFF SITE			
13.	Wells USGS 4 and 8	∞	1.07 ± 0.03	0.03
		0.05	7.16 ± 0.18	0.19
14.	150 m northeast of Gnome shaft	0.14	11.49 ± 0.13	0.12
15.	400 m northwest of Gnome shaft	0.25	3.71 ± 0.08	0.07
16.	2.5 km northwest of Gnome shaft	0.11	0.50 ± 0.05	0.11
17.	10 km northwest of Gnome shaft	0.54	1.00 ± 0.03	0.04
18.	16 km northwest of Gnome shaft	0.26	0.69 ± 0.04	0.07
19.	2.5 km west of surface ground zero	0.09	0.65 ± 0.05	0.10
20.	3 km east of surface ground zero	0.17	0.53 ± 0.04	0.07
21.	4 km northeast of surface ground zero	0.13	0.56 ± 0.04	0.09
22.	3 km south of surface ground zero	0.10	0.42 ± 0.04	0.08

DISCUSSION

The summed totals of the dose rates from cosmic radiation and radionuclides at all surveyed locations are in close agreement with the measured PIC rates at the same sites. The average PIC value in this study is 2.0% lower than the average summed value, and differences in the two values at each location are within the estimated uncertainties.

A large variability in ^{137}Cs activity is evident across the Gnome site (locations 1 through 12). However, at all of the on-site locations and other survey sites close to the Gnome shaft, the range of ^{137}Cs values should be considered only an estimate because the ground has been disturbed several times since the original contamination, and it is unlikely that the radiocesium has an exponentially decreasing vertical distribution, as assumed in the calculation of the inventories and dose rates. Also, at locations 9 and 10, it is quite possible that the observed ^{137}Cs activity is due to contaminated materials buried within the waste dump.

It was suspected that the relatively high cesium activity at the surface ground zero, survey location 1, may have been caused by overflow or spillage from well DD-1 which is used to monitor the water within the Gnome cavity. A surface soil sample was taken next to the wellhead and returned to the laboratory for radiochemical analysis. The ratio of ^{90}Sr to ^{137}Cs in soil was found to be 0.029 ± 0.010, while the ratio in water obtained from well DD-1 was 0.24 ± 0.05 (U.S. EPA 1979). The large difference implies that the source of the soil contamination was not the well water, and was probably the post detonation venting and drilling operations. Ratios of ^{90}Sr to ^{137}Cs determined for many soil samples at the site prior to the cleanup program of 1977 were also generally very small (U.S DOE 1978).

Survey location 13 is located between two U.S. Geological Survey wells used for a tracer experiment in 1963 (Beetem 1964). The experiment was designed to determine physical characteristics of dispersion and chemical absorption reactions of radionuclides in the Culebra Dolomite Aquifer, which is considered to be the only significant aquifer at the Gnome site (Gardner and Sigalove 1970). The nuclides were injected into well USGS 8 and recovered from USGS 4 for analysis and reinjection. Nuclides ^{131}I, ^{3}H, ^{90}Sr, and ^{137}Cs in a range of 0.4 to 1.8 TBq (10-50 Ci) were introduced during the course of the experiment (U.S. DOE 1982), and the latter three nuclides are presently detected in the waters of both wells. A laboratory analysis of a surface soil sample taken near USGS 8 showed a ^{90}Sr to ^{137}Cs activity ratio of 0.11 ± 0.03 while the water of USGS 8 had a ratio of 0.74 ± 0.11, again indicating that the activity is probably not due to well water spillage.

Survey sites 14 through 18 were selected for a cursory investigation of remaining fallout from the Gnome vent. The sites lie within the general path of the fallout plume (Fig. 2) at varying distances from the Gnome shaft. Of all locations surveyed in this study, site 14 which lies 150 m from the shaft, showed the highest ^{137}Cs inventory. This is not unexpected because in aerial surveys flown before and after the 1977 to 1979 decontamination operation, the region immediately northwest of the

Gnome shaft was found to have the most extensive ^{137}Cs contamination (U.S. DOE 1981). The final survey showed a small area at the same location as survey site 14 that had a ^{137}Cs count rate equivalent to an exposure rate of 25 to 28 nGy h^{-1} (2.8 to 3.3 μR h^{-1}) at a height of 1 m. In Table 1, it is evident that the dose rate from ^{137}Cs measured in this study is about one third of that value, or approximately equal to the contribution from the ^{232}Th series.

Survey sites 14, 15, and 17 all show elevated ^{137}Cs abundances. Site 16 is an area that appeared to be frequently drained, and is not likely to have the same retention characteristics as the other locations. In all, it would be difficult to draw conclusions about the extent of remaining fallout activity without a thorough investigation. Decay and weathering in the elapsed 31 y would have altered the original distribution, and the plume itself which was released for several hours would certainly not have left a simple contoured pattern of fission products.

Sites 19 through 22 were selected for off-site control measurements because of their distance from the Gnome site and because they do not lie in the recorded path of the plume. The sites have similar abundances and extended vertical distributions of ^{137}Cs. The activities are somewhat low considering the average 30 cm of rainfall the area receives (Gardner and Sigalove 1970; Miller et al. 1980; Arnalds et al. 1989). The surface of the region around the Gnome site consists primarily of alluvial material and quartz sand (Mackallor 1965), and in the immediate vicinity consists of caliche outcroppings, sand, and sand dunes sparsely covered with desert vegetation. Poor water retention characteristics likely account for the low ^{137}Cs fallout activity and the deep dispersion relative to other arid regions in North America.

SUMMARY

The dose rates deduced from in-situ spectrometry and soil core analysis are in close agreement with the measured PIC rates at all surveyed locations. As in previous surveys, ^{137}Cs abundances were found to be highly variable in the Gnome area, with the highest concentration lying 150 m northwest of the Gnome shaft site. Presumably this activity was deposited from the low-pressure venting that occurred immediately after the detonation, and it currently accounts for a dose rate about equal to the contribution from the naturally occurring ^{232}Th series, or about one-eighth of the total dose rate measured at that location.

Considering the time elapsed since the earlier surveys, radiocesium concentrations at contaminated locations detected in this study were lower than expected. Also, surveys conducted at surrounding control areas away from the path of the vent plume show low ^{137}Cs abundances relative to other regions that receive less or equal rainfall. Both discrepancies are probably due to the predominance of an unconsolidated sandy surface with poor water retention characteristics.

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