MONITORING OF HEAT AND MOISTURE MIGRATION FROM RADIOACTIVE WASTE DISPOSED IN AN AUGERED SHAFT

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ABSTRACT

Soil temperature and moisture data have been collected for the past 4 years at the Greater Confinement Disposal Test (GCDT) being conducted at the Nevada Test Site. High-specific-activity radioactive waste with a thermal output of 3.4 kW was buried at a depth of 30 m in tuffaceous alluvium. Prior to waste emplacement the ambient subsurface temperature was about 17°C and the volumetric soil moisture content was 10-12%. Two years after waste emplacement the soil temperature exceeded 100°C and the soil moisture content dropped below 4% at a radius of approximately 3 m from the thermal waste. Drying of the soil has occurred as the high temperature radiating from the thermal sources propels water vapor from the waste zone to a zone where dew-point temperatures are reached. The temperature and moisture data will be used in combination with data from gaseous tracer release tests in predicting and appraising the long-term performance of the GCDT.

INTRODUCTION

In 1981 the U.S. Department of Energy's (DOE) National Low-Level Waste Management Program and the DOE Nevada Operations Office initiated a greater confinement disposal demonstration project at the Nevada Test Site Area 5 Radioactive Waste Management Site. The GCDT consists of an augered shaft containing environmentally mobile and high-specific-activity radioactive waste. Heat and moisture have been monitored since January 1983 using an array of thermocouples and thermocouple psychrometers and a neutron moisture probe. The monitoring system has been used to gather data that will assist in long-term projection and appraisal of the performance of this greater confinement disposal concept (1).

FACILITY DESIGN

The GCDT facility consists of a central waste emplacement shaft and nine monitoring shafts (Fig. 1) located in the vadose zone in soil developed in tuffaceous alluvium (2). The emplacement shaft is 36 m deep and 3 m in diameter. The monitoring shafts are 36 m deep and 0.6 m in diameter and are orbitally staggered at radii of 3, 4.9 and 6.7 m. The GCDT has nine instrument lines with a total of 144 monitoring stations, each containing a soil-atmosphere sampler, thermocouple psychrometer and an independent thermocouple (Fig. 2). Three instrument lines are positioned around the perimeter of the emplacement shaft, the other six are in monitoring shafts. Four aluminum tubes provide access for a neutron moisture probe.

In 1984 several high-specific-activity encapsulated sources of Sr-90, Cs-137 and Co-60 were placed in a thermal dissipation source drum at a depth of 30.5 m in the emplacement shaft. The

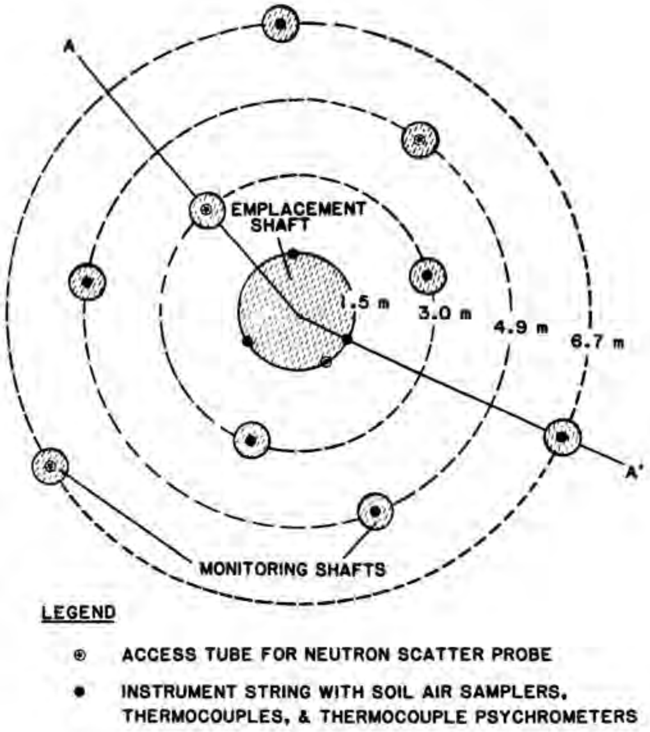

Fig. 1. Facility plan view showing positioning of waste emplacement and monitoring shafts.

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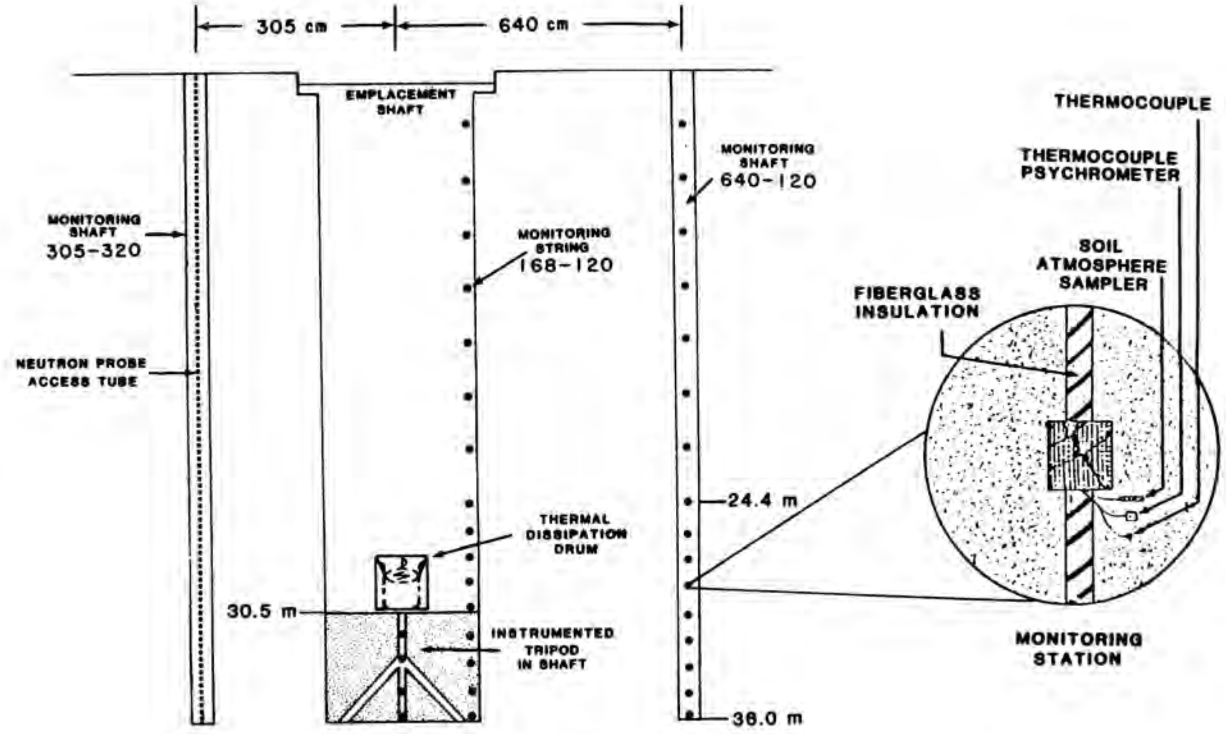

Fig. 2. Cross-sectional view through transect A-A' in Fig. 1 showing monitoring station distribution.

total activity of these sources was approximately 517 kCi, 96% of which was Sr-90. Approximately 593.5 kCi of tritium contained in 210-L drums were placed between 18 and 27 m. The total thermal output is 3.46 kW with 92% radiating from the encapsulated sources.

After the instrumentation and waste were emplaced, the shafts were backfilled with sifted alluvium.

MONITORING OF HEAT

Temperature was measured with the thermocouple portions of the psychrometers as well as with the individual thermocouples. Omega Engineering Type J thermocouples and Wescor PC-55 psychrometer probes were used. The thermocouple psychrometers had greater sensitivity but a maximum temperature limit of about 50°C. The independent thermocouples, though less sensitive to minor temperature changes, were rated to have a maximum temperature limit of about 450°C. Due to the wider operating range, the independent thermocouples provided a more complete data set and this data is reported here.

Baseline measurements were made in the latter part of 1982 and beginning of 1983. The ambient subsurface temperature was approximately 17°C. Waste was emplaced in the central shaft from December 1983 through March 1984. Temperature changes were observed at a radius of 1.6 m and a depth of 30.5 m immediately after the central shaft was backfilled on March 12, 1984. Changes in temperature were first observed at a radius of 2.8 m after 30 days, 4.5 m after 90 days, and 6.3 m after 120 days. At a radius of 1.6 m, temperatures exceeded 100°C within 30 days of waste emplacement and 300°C within 100 days. Temperatures exceeded 100°C at a radius of 2.8 m approximately 2 years after waste emplacement.

Isotherm maps were generated using kriging, a geostatistical method which creates regularly spaced data grids from irregularly spaced data. Each temperature profile map represents a 40-m-deep, 14-m-wide cross section of the GCDT site and allows visual interpretation of the temperature data.

Figure 3 represents the ambient subsurface temperature profile before waste emplacement. With the exception of a hole cover, the central emplacement shaft was open and temperature data is exclusively from the monitoring shafts. The slightly elevated central temperatures could be an artifact of the kriging routine or the result of warmer air trapped in the emplacement shaft. Figure 4 shows conditions on March 20, 1984, less than 30 days after emplacement of the encapulated sources and 8 days after backfilling the emplacement shaft. Vertical heating in the emplacement shaft clearly exceeds that in the horizontal direction. The anisotropic heating is due to the inherent stratification of the alluvium versus the homogeneous backfill. By March 20, 1986, anisotropic heating is pronounced and skewed vertically upward (Fig. 5). This thermal distribution results from the nonhomogeneous system structure, a tendency for upward convection, and an 8% thermal contribution from waste placed above the 30-m level.

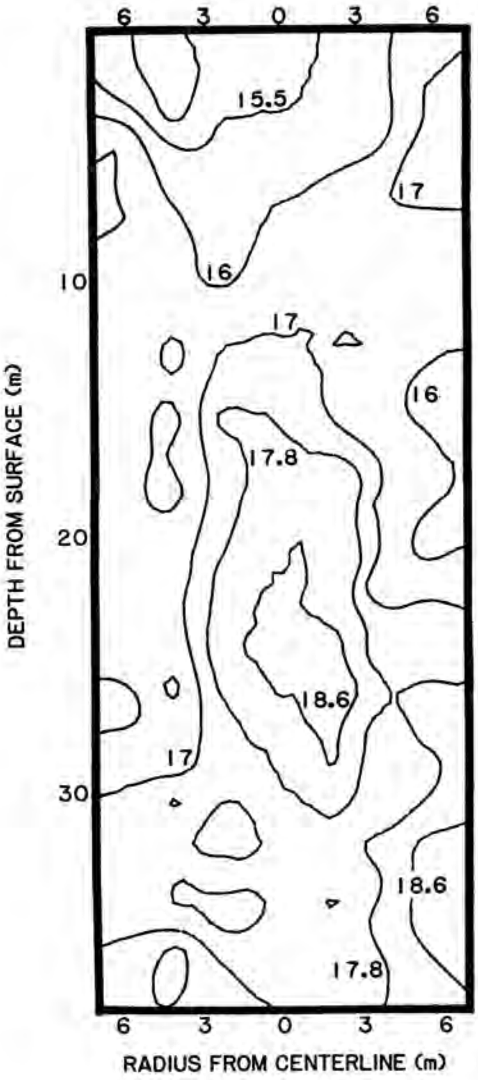

Fig. 3. Soil temperature (°C) profile for February 13, 1983, 1 year before waste emplacement.

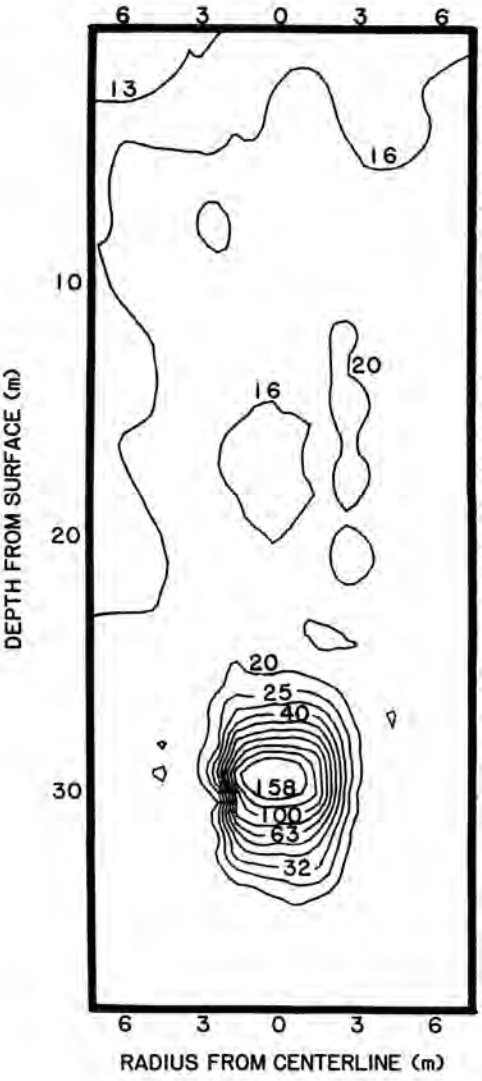

Fig. 4. Soil temperature (°C) profile for March 20, 1984, 1 month after waste emplacement.

To conclude, the temperature data gathered by the thermocouples is very interpretable and of high quality. Data will be collected on a quarterly basis for as long as the thermocouples are measurable or until the soil reaches equilibrium.

MONITORING OF MOISTURE

Soil moisture measurements were taken with the thermocouple psychrometers and a neutron scatter probe. The psychrometers performed poorly because of their limited range and susceptibility to failure at elevated temperatures. The neutron probe provided the most reliable data and is used in this report.

Measurements taken in February 1984 showed the initial soil moisture content to be approximately 10 to 12% volumetrically. During July and August of 1984 localized thunderstorms caused infiltration to occur in the emplacement and monitoring shafts. Volumetric soil moisture content increased to approximately 26% near-surface after each precipitation event. A wetting front, clearly visible at the 4-m level, gradually declined to background moisture content at a 5.5-m depth. Downward distribution of the wetting zone moisture, due to hydraulic head, is partially impeded by soil hysterisis but is also a function of the initial soil wetness, texture, structure, and layering. The concrete pad on top of the GCDT facility prevents moisture utilization by the desert flora. After a 2-year residency, the near-surface volumetric moisture content remains between 20 and 25% and decreases to 10% at the 6-m depth.

From 6 to 27 m below the surface, the volumetric soil moisture content has remained relatively constant at approximately 10%. The initial drying of the high-temperature zone in the emplacement shaft was unseen. For a radius of 3 m, the moisture content at 30.5-m level had decreased to 6% by July 1985 and 3.5% by July 1986.

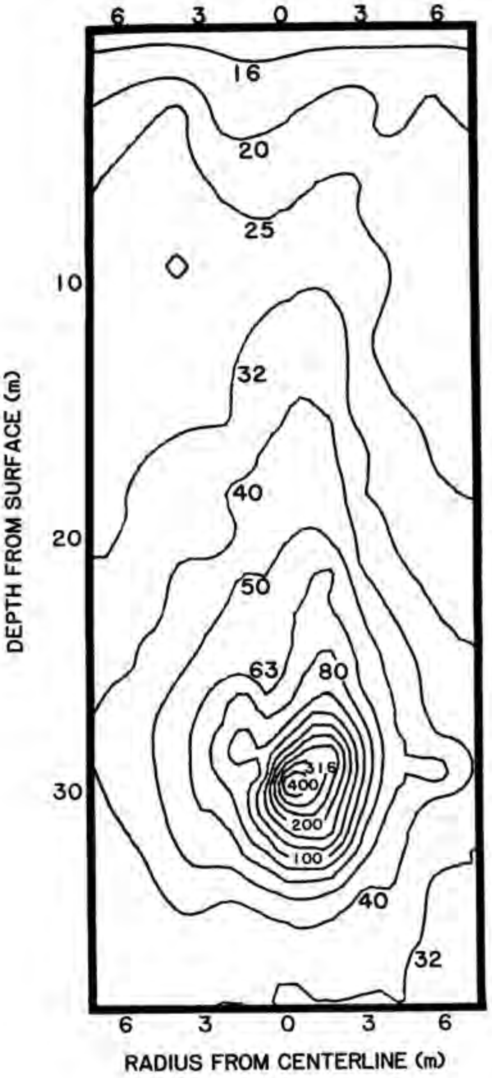

Fig. 5. Soil temperature (°C) profile for March 20, 1986, 2 years after waste emplacement.

Figure 6 depicts the soil moisture distribution in July 1986. To develop this moisture profile map, data points were added to represent the dry heat source. The effects of the 1984 summer infiltration events are visible as well as the drying out at the heat source. The drying appears greater in areas lateral to the heat source. Also, moisture has increased below the heat source. This is believed to be due to the redistribution of water from the hottest zone.

The exact mechanism of moisture movement from the thermal zone is not known. It is believed that initially the thermal energy increased the rate of natural water movement processes until soil temperatures neared 100°C. The natural processes of redistribution are matric potential and vapor transport and possibly gravity drainage. As temperatures exceeded 100°C, it is believed the high temperatures in the waste zone propelled water vapor to a zone where dew-point temperatures were reached. The vapor migrated laterally through the bedded alluvium as evidenced by the documented anisotropy of the GCDT system with respect to heat flux and water movement.

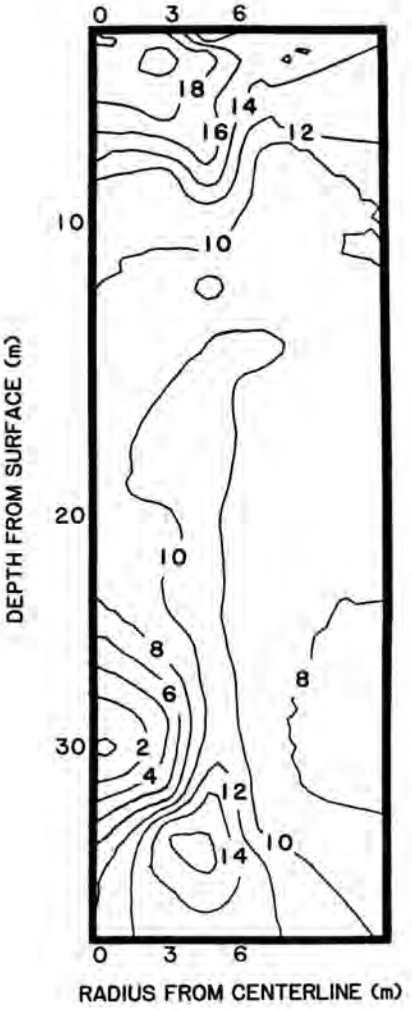

Fig. 6. Volumetric soil moisture content (%) profile for July 1986, 2 1/4 years after waste emplacement.

To conclude, the moisture data collected by the neutron probe is very interpretable and of high quality. The moisture data collected by the psychrometers showed a high degree of variability and inconsistency and contained little useful information. Data will continue to be collected by the neutron probe on a quarterly basis.

CONCLUSION

This environmental monitoring data will be used with data from subsurface gaseous diffusion studies to validate predictive performance models (2).

REFERENCES

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