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TRITIUM MIGRATION STUDIES AT THE NEVADA TEST SITE

Topical Report

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ABSTRACT

Emanation of tritium from waste containers is a commonly known phenomenon. Release of tritium from buried waste packages was anticipated; therefore, a research program was developed to study both the rate of tritium release from buried containers and subsequent migration of tritium through soil. Migration of tritium away from low-level radioactive wastes buried in Area 5 of the Nevada Test Site was studied. Four distinct disposal events were investigated. The oldest burial event studied was a 1976 emplacement of 3.5 million curies of tritium in a shallow land burial trench. A plot area 7 m x 14 m centered over the buried containers was established as a vegetative sampling area. Tritium transport to the atmosphere by plant transpiration was determined to have risen sharply with the passage of time to about 6 curies per year in 1990 and decreased to about 1 curie per year by 1992. In another event, 248 thousand curies of tritium was disposed of in an overpack emplaced 6 m below the floor of a low-level waste disposal pit. Measurement of the emanation rate of tritium out of 55 gallon drums to the overpack was studied, and an annual doubling of the emanation rate over a seven year period, ending in 1990, was found. During the past two years the rate of increase has slowed appreciably. No evidence of significant migration of tritium away from the overpack was found. In a third study, upward tritium migration in the soil, resulting in releases in the atmosphere were observed in a greater confinement disposal test. Here, the movement was suspected largely to be the result of experimental anomalies and heat generated by other radionuclides present in the waste. Releases of tritium to the atmosphere were found to be insignificant. The fourth event consisted of burial of 2.2 million curies of tritium in a greater confinement disposal operation. Emanation of tritium from the buried containers has been increasing since disposal, but no significant migration was found four years following backfilling of the disposal hole.

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INTRODUCTION

In the ideal case, when radionuclides are disposed of by land burial, they are to stay put, *i.e.* not migrate. Most radionuclides are cations and as such they are strongly adsorbed on soil colloids and will not readily migrate, even under the influence of flowing water. Other radionuclides, such as iodine-129 or technetium-99, may be present in waste as anions and will not be strongly adsorbed on soils by cation exchange processes. These anionic radionuclides will move freely under the influence of flowing water.

Tritium (hydrogen-3), when present in wastes in the oxidized state, will isotopically dilute with ordinary water (hydrogen-1 oxide). This reaction gives rise to tritiated water, *i.e.* ordinary water "tagged" with hydrogen-3. This will include water present in both liquid and gaseous phases. Any movement of soil water, then, either as liquid or vapor, will result in tritium migration away from the buried waste. In addition to transport by net water movement, either liquid or vaporous, tritium movement can take place by diffusion and isotopic dilution of tritiated water in both the liquid and vapor phases. In this case, no net movement of water is required. The inherent ability of tritium oxide to be transported readily in both the liquid phase and the gaseous phase accounts for its high mobility. It is no surprise, then, that tritium migration has been found at all commercial Low Level Radioactive Waste (LLRW) disposal sites studied (1).

The Nevada Field Office of the U.S. Department of Energy (DOE/NV) has been quite aware of this mobility of tritium, including the propensity of small percentages of tritium to be released routinely from waste packages. For this reason, DOE/NV invited the University of California at Berkeley to carry out tritium migration studies in conjunction with waste burials at the Area 5 Radioactive Waste Management Site (RWMS). These waste-related tritium migration studies have been under way during the past ten years. The study has confirmed the emanation of tritium from the waste containers and subsequent migration of an extremely small percentage of buried tritium to the atmosphere.

The purpose of this manuscript is to report findings on tritium movement at the defense low-level radioactive waste disposal site in Area 5 of the Nevada Test Site (NTS) and update the last report on that work (2).

METHODS AND MATERIALS

The tritium migration studies at the Area 5 RWMS at NTS have been undertaken as four distinct efforts. The first effort was a study of transport of tritium from buried waste to the atmosphere by plant transpiration. This work has been carried out on Trench T-4 where burial activities were completed in 1976. The second effort is related to tritium emanation from waste containers and migration into surrounding soil. That waste disposal operation took place in 1983 under Pit 1. The third study effort is concerned with tritium migration and atmospheric release from the Greater Confinement Disposal Test (GCDT). The fourth study, and the one most recently undertaken, was soil migration of tritium from Greater Confinement Disposal (GCD) in Area 5.

In 1976, solid form radioactive waste containing 3.5 million curies of tritium was buried at one location in Trench T-4. The waste was delivered to the test site in 55 gallon drums, and the drums were placed in overpacks of surplus aircraft jet engine containers prior to burial. The tops of the overpacks are covered with approximately 2.5 m (8 ft) of local soil, which serves as the trench cap. Tritium migration studies were initiated on this area in 1983. A plot area 7 m x 14 m centered over the buried containers was established as a vegetative sampling area. This plot area was centered 150 m north of the south concrete trench T-4 marker. Initially, the plot area had an Alta Fescue grass cover. The grass cover was followed in succession by a native plant cover of various Atriplex and creosote bushes. Plant transpiration of tritium was estimated by foliage sampling, followed by room temperature vacuum distillation of the foliage. The tritium concentration in the distillate was determined by liquid scintillation directly based on standards supplied by the National Institute of Standards and Technology (formerly the U.S. Bureau of Standards).

The second effort is related to a tritium waste disposal in 1983. That burial took place under the floor of Pit 1. That effort is pictorially shown and described in Fig. 1. Sixteen 55 gallon barrels containing a total of 248,000 curies of tritium wastes were placed in an overpack consisting of a used engine container. The two halves of the overpack were bolted together so as to leave a 0.6 cm longitudinal gap entirely around the overpack. Soil atmosphere samplers were spatially distributed and the waste emplaced as shown in Fig. 1. The tritium emanation rate from the barrels to the void space in the overpack was determined periodically by pumping air into the bottom of the overpack at 2 liters per minute and pumping air out the top of the overpack at 2 liters per minute. The tritium concentration of the airflow was then measured until the concentration was reasonably constant. At that time pumping was discontinued for several months to a year, when another emanation rate determination was made. The concentration of tritium in the atmosphere of the soil in the near vicinity of waste was determined time to time using the soil atmosphere samplers. An extremely low pumping rate ($1 \text{ m}^3/\text{year}$) was used to obtain each air sample consisting of approximately 30 liters. Tritiated water was recovered with a freeze trap and the air volume measured with a piston.

Fig. 1 - Emplacement of 248,000 curies of tritium waste under pit floor, March 22, 1983. Sixteen 55 gallon barrels containing tritium wastes were placed in a surplus aircraft engine container depicted as a shaded cylinder. The black dots represent the spatial arrangement of the soil atmosphere samplers which are connected to the surface with 3/16" dia. copper tubing. Periodically, the soil atmosphere samplers were used to obtain ^3H concentration in the soil air. Soil air sampling was at the extremely low flow rate of $1 \text{ m}^3\text{-air/year}$. Tritium emanation from the barrels (source term) is determined by flowing air into the bottom of the aircraft container and out the top of the container with the ^3H concentration in the airstream being measured. Locations of the in-and-out ports in the aircraft container are shown as white circles in the drawing.

As noted earlier, tritium analyses were by liquid scintillation directly based on tritium standards supplied by the National Institute of Standards and Technology. No vegetation was present at this location.

The third study on tritium migration was carried out at the Greater Confinement Disposal Test (GCDT) facility. A total of 594,000 curies of tritium were disposed of in this facility in 1984. Here, tritium was disposed of at a depth ranging from 20 m to 27 m below grade. Other radionuclides emitting heat were disposed of at lower depths. Complete details of the GCDT facility are given in earlier publications (3, 4, 5). From 1984 to 1987 the GCDT facility was used for *in-situ* gas tracer experiments. Tritium migration studies were begun in 1987. Soil atmosphere tritium sampling was generally similar to that used in Pit 1, except that higher flow rates were necessitated due to water vapor diffusion through the teflon sampling lines. Experimental measurements showed that flow rates of 200 ml/min were necessary to ensure that vapor diffusion would have negligible effects on the measured results. An approximation of the tritium being released from the facility to the atmosphere was made in a fashion generally similar to the emanation rate determination from the barrels to the overpack void described above. In this case, the void was enclosed space at the surface of GCDT, with air being pumped into the void at 5 liters per minute and pumped out at 5 liters per minute. The tritium concentration of the outflow air was periodically measured. No vegetation was present at this site, so no plant transpiration data was obtained.

The fourth study of tritium migration at the Area 5 waste management site was in connection with a greater confinement disposal (GCD) of 2.2 million curies of tritium in a 3 m diameter by 36 m deep borehole. The waste was emplaced over a three year period, in 1985 through 1987. The top layer of waste was placed 20 m below grade and the hole was backfilled with soil. Soil atmosphere samples were located in the borehole at various intervals beginning at the bottom of the hole, (the 36 m depth), while the uppermost samplers were placed 3 m below the surface. Soil atmosphere sampling and tritium determinations were identical to those described for Pit 1. This borehole has recently been backfilled; no vegetation is present and no transpiration data were obtained.

RESULTS AND DISCUSSION

Trench T-4 Studies

The first tritium migration studies of this effort were begun on trench T-4 in 1983. Investigation of tritium transport to the atmosphere by plant transpiration was carried out from 1983 through 1993. Data obtained is given in Table 1 and presented graphically in Fig. 2. The important finding is that the release of tritium to the atmosphere is not in a steady-state condition, but that the emanation went through a maximum and is now decreasing. The rapid rise of tritium release during the first 8 years occurred in spite of the 1.3 year half-life of tritium. Some of the increase can possibly be attributed to growth of the vegetation and deeper penetration of roots with the passage of time. However, as we will see in the second effort of this work described below, a large part of this increase can probably be attributed to increased emanation of tritium from the waste containers. The subsequent rapid decrease of tritium release to the atmosphere during the past two years can also not be attributed to the tritium half-life. The decrease of tritium transport in the atmosphere during the past two years is probably due, in large part, to the current drought. It is thought likely that there is less plant root activity at the deeper depths, due to lack of moisture. The tritium emanating from the waste containers is probably simply building up nearby the containers and migrating slowly. In any event, the current release to the atmosphere is only about 1 curie per year. After taking decay into account, there is still about 1.4 million curies of buried tritium at that location, thus giving a current annual release of somewhat less than 1 part per million of that buried. This is an extremely low rate of release and certainly no cause for alarm. However, it should be noted that even this very low release rate could be reduced or perhaps eliminated entirely by burial deeper than the maximum rooting depth.

Table 1 - Annual transport of tritium from buried waste to atmosphere, trench T-4

Year	Grass*	Shrub*
	mCi/year	
1983	24	--
1984	97	--
1985	230	250
1986	--	992
1987	--	1290
1988	--	3370
1989	--	4038
1990	--	5619
1991	--	2550
1992	--	1153

* Tritium transport by plant transpiration. Grass cover was followed in succession by native shrubs.

Fig. 2 - Transport of tritium to atmosphere by plant transpiration. Initially, a grass cover was utilized on the trench cap plot area. The grass cover was followed in succession by native shrubs. The tritium transpiration in 1985 was the sum of grass plus shrub transpiration. After 1985 no grass was present.

Pit 1 Studies

The next study carried out was designed to answer two questions: What is the release rate of tritium, with the passage of time, from the original 55 gallon drums as delivered to the site by the waste generators? and What is the migration rate of the tritium through soil? In this study a 1983 disposal of 0.25 million curies of tritium was carried out by placing 16 drums of tritium waste in an overpack and burying the overpack 6 m (20 ft) below the floor of Pit 1, which was being utilized for low-level waste disposal. As described in the methods and materials section, the overpack was deliberately designed to release tritium to the surrounding soil. That is, a longitudinal gap was created in the overpack so that tritium emanating from the drums would be released to the soil. The emanation rate at various measurement times during 1983 through 1992 is given in Table 2 and presented in a graphical form in Fig. 3. Here again the movement of tritium from the point of disposal rises rapidly with passage of time. Up to two years ago, the emanation rate was approximately doubling annually, but during the past two years the rate of increase has slowed appreciably. It also should be noted that this burial is 7 years "younger" than the previous burial, *i.e.* the Pit 1 burial is now a 9-year-old burial, whereas the T-4 burial is now a 16-year-old burial. At this time about 49 mCi of tritium is being released from the 16 barrels over a one year period. If the trend continues, approximately one-half curie amounts can be expected to be released annually five years hence. This release rate is probable, based on the performance of the past seven years and taking into account the data obtained in the T-4 study. The second question addressed in this Pit 1 study has not been answered.

**Table 2 - Emanation of tritium from 55 gallon drums to void space in overpack.
Entire package was emplaced under Pit 1 floor on March 22, 1983.
See Fig. 1.**

Measurement period	Tritium emanation*
	$\mu\text{Ci/day}$
Oct - Dec 1983	0.6
Jan - Jun 1984	0.7
Nov - Dec 1985	2.2
Jan - Mar 1986	1.4
Apr - Jul 1987	4.7
Jul - Oct 1987	4.4
Oct - Nov 1988	13.3
Dec - Feb 1989	36.4
Jan - Feb 1990	85.5
Nov - Feb 1991	98.1
Oct - Dec 1992	134.6

* Total amount of tritium emanating from sixteen 55 gallon drums.

Fig. 3 - Emanation of tritium from sixteen 55 gallon drums placed in overpack and buried below floor of Pit 1. See Fig. 1.

The voluminous data obtained from the Pit 1 study are presented in Table 3. A summary of that data is presented graphically in Fig. 4. Inspection of Fig. 4 shows a relatively high concentration of tritium near the level of the floor of Pit 1. This would tend to indicate that the main source of tritium at that location was from the waste disposed of in Pit 1, not from that disposed of in the overpack buried 6 m below the floor of Pit 1. Since the source term is indeterminate, tritium migration rates cannot be calculated with confidence.

GCDT Studies

The third study effort regarding tritium migration at the Area 5 disposal site was at the GCDT facility. Migration of tritium with the passage of time was given in the 1991 report on that study (2). That data showed very little lateral migration of tritium, but showed very substantial upward migration. It was pointed out that findings from that test should be applied with extreme caution to a routine GCD application since two conditions were present here that will not be present in a routine GCD. One, large amounts of heat are being generated by other radioisotopes present in this test that will (or at least should) be absent from further GCD tritium disposals. The heat drives soil water and tritium oxide in isotopic equilibrium with the water away from the site of disposal. Heat in this test destroyed teflon sampling lines, causing possible channels in the soil. Fiberglass insulation surrounding sampling lines may have become damaged, especially the plastic coverings, thus causing a channel for tritium movement. In addition to concentration of tritium in the soil atmosphere, measurements of tritium releases to the atmosphere have been made. This was done by supporting a cover and walls above the soil surface forming an enclosure. Tritium-free air was pumped continuously through the void, and the tritium concentration of the exhaust air was measured. The data obtained are given in Table 4. The results show a variable but continuous very small release of tritium to the atmosphere. This release is not significant and, unless it were to increase dramatically, is of no practical importance. This release does not, however, necessarily meet the criterion of "as low as reasonably achievable," which probably would have been more nearly met had the experimental anomalies not been present.

GCD Studies

The fourth study, and the one most recently undertaken, was in connection with an operational GCD tritium disposal. Lessons learned in the earlier three types of disposals were taken into account. Improvements in waste packaging have been made since the 1976 burial, and shipments employing the old type of packaging previously used by Mound Laboratories have not been received for a number of years. Even with the improved packaging, some tritium emanation from waste packages was expected, so it was decided to further reduce tritium transport to the atmosphere by providing the longer soil pathway offered by deeper burial using the GCD procedure. Here 2.2 million curies were disposed of in one borehole during the period May 1985 to May 1987. In the last report, Tritium Migration at the Nevada Test Site, August 1991, (2), it was stated, "Data obtained one and one-half years after the hole was backfilled show extremely low concentrations of tritium in the soil atmosphere and little migration has occurred. However, based on past experience in cases one and two cited in this report, the

Table 3 - Spatial distribution of tritium in soil atmosphere in the region of the emplaced tritium waste, Plt 1. See Fig. 1.

Tritium DPM/L In Soil Atmosphere

Depth (m)	Lateral (m)	8/14/84	8/28/84	9/11/84	9/20/84	10/22/84	10/31/84	11/15/84	12/05/84	12/20/84
0.3 N	1.5	-	-	0.6	0.9	NS	0.5	0.5	0.4	0.1
1.5 N	•	-	-	-	-	-	-	-	-	-
3.0 N	•	-	-	-	-	-	-	-	NS	-
4.5 N	•	-	-	-	-	-	-	-	-	-
6.0 N	•	-	-	-	-	-	-	-	-	-
•	3.0	-	-	-	-	-	-	-	-	-
•	4.0	-	-	-	-	-	-	-	-	-
7.5 N	1.5	NS	-	-	-	-	-	-	-	-
9.0 N	•	-	-	-	-	-	-	-	-	-
0.3 S	•	-	0.8	0.5	0.1	0.3	0.2	0.2	0.1	0.1
1.5 S	•	-	-	-	-	-	-	-	-	0.2
3.0 S	•	-	-	-	-	-	-	-	-	-
4.5 S	•	-	-	-	-	-	-	-	-	-
6.0 S	•	NS	-	-	-	-	-	-	-	-
•	3.0	-	-	-	-	-	NS	-	-	-
•	4.0	-	-	-	-	-	-	-	-	-
7.5 S	1.5	-	-	-	-	-	-	-	-	-
9.0 S	•	-	-	-	-	-	-	-	-	-
0.3 C	center	-	-	0.1	-	-	-	-	-	-
1.5 C	•	0.2	-	-	1.0	-	-	-	0.1	0.1
3.0 C	•	-	0.4	0.5	0.4	0.3	0.5	0.3	0.2	0.3
9.0 C	•	-	0.2	0.4	-	-	-	-	-	-
10.5 C	•	-	-	-	-	-	-	-	-	-
11.5 C	•	-	-	-	-	-	-	-	-	-
0.3 E	1.5	-	0.5	0.2	1.0	0.1	0.1	0.1	0.1	0.1
1.5 E	•	-	-	-	-	-	-	-	-	-
3.0 E	•	-	-	-	-	-	-	-	-	-
4.5 E	•	-	-	-	-	-	-	-	-	-
6.0 E	•	-	-	-	-	-	-	-	-	-
•	3.0	-	-	-	-	-	-	-	-	-
7.5 E	1.5	-	-	-	-	-	-	-	-	-
9.0 E	•	-	-	-	-	-	-	-	-	-
0.3 W	•	-	17.1	0.4	-	-	-	-	-	1.5
1.5 W	•	-	-	-	-	-	-	-	0.4	-
3.0 W	•	-	-	-	-	-	-	-	-	-
4.5 W	•	-	-	-	-	-	-	-	-	-
6.0 W	•	-	-	-	-	-	-	-	-	-
•	3.0	-	-	-	-	-	-	-	-	-
•	4.0	-	-	-	-	-	-	-	-	-
7.5 W	1.5	-	-	-	-	-	-	-	-	-
9.0 W	•	-	-	-	-	-	-	-	-	-
Overpack Top		NS	411.0	64.2	13.9	79.9	NS	14.8	29.5	NS
Overpack bottom		NS	NS	NS	NS	NS	18.4	NS	NS	9.1

NS = no sample

- = below detection limit

• = ditto

Table 3 continued. Spatial distribution of tritium in soil atmosphere.

Tritium DPM/L In Soil Atmosphere

Depth (m)	Lateral (m)	1/24/85	2/8/85	2/22/85	3/21/85	4/15/85	5/31/85	6/21/85	7/15/85	8/30/85
0.3 N	1.5	0.3	1.1	3.0	5.7	5.1	7.4	7.1	9.3	35.2
1.5 N	•	-	-	0.6	NS	4.5	10.2	11.3	8.0	65.1
3.0 N	•	-	-	0.4	1.1	1.8	6.9	4.5	6.2	NS
4.5 N	•	-	-	0.3	3.2	2.1	5.8	0.5	8.0	16.0
6.0 N	•	-	-	-	0.3	0.4	1.4	-	1.9	6.0
•	3.0	-	-	-	0.1	0.9	2.0	1.1	1.1	3.2
•	4.0	-	-	-	-	-	0.6	0.3	1.0	NS
7.5 N	1.5	-	-	-	-	-	0.3	0.4	1.2	1.7
9.0 N	•	-	-	-	-	0.1	0.4	0.2	0.9	3.2
0.3 S	•	0.6	0.3	2.2	12.2	7.1	11.7	22.8	26.3	64.3
1.5 S	•	-	-	-	1.6	6.8	23.1	27.2	NS	126.0
3.0 S	•	-	-	-	0.1	1.0	3.3	1.3	35.2	36.1
4.5 S	•	-	-	-	0.5	1.1	2.8	4.6	9.0	6.7
6.0 S	•	-	-	-	0.2	0.5	1.4	2.7	10.2	10.9
•	3.0	-	-	-	NS	1.2	4.2	NS	17.4	14.3
•	4.0	-	-	-	-	0.4	1.4	0.9	1.9	6.4
7.5 S	1.5	NS	-	-	0.3	-	0.3	NS	3.3	13.2
9.0 S	•	-	-	-	0.4	0.5	1.0	0.8	1.3	3.4
0.3 C	center	-	0.2	2.2	6.5	6.6	7.2	11.8	8.5	68.2
1.5 C	•	-	-	0.8	3.7	3.2	13.7	10.7	8.3	31.8
3.0 C	•	0.1	0.4	NS	4.4	4.1	10.5	19.0	18.8	44.9
9.0 C	•	0.1	0.6	0.1	0.6	0.8	1.2	1.4	2.2	5.2
10.5 C	•	-	-	-	0.2	0.4	1.0	0.8	1.1	2.8
11.5 C	•	-	-	-	0.2	0.5	1.0	0.8	1.2	2.5
0.3 E	1.5	-	0.3	1.6	2.4	3.7	2.5	6.6	7.0	49.7
1.5 E	•	-	-	-	0.5	0.6	8.5	7.3	8.6	19.2
3.0 E	•	-	-	-	0.2	3.0	5.4	7.8	19.6	38.4
4.5 E	•	-	-	-	0.2	0.5	NS	1.9	2.9	5.7
6.0 E	•	-	-	-	0.1	0.1	0.7	0.3	0.9	2.6
•	3.0	-	-	-	NS	-	0.2	0.1	1.9	3.5
7.5 E	1.5	-	-	-	-	0.1	0.7	0.6	1.9	4.6
9.0 E	•	-	-	0.2	-	0.1	0.8	0.3	0.8	1.4
0.3 W	•	0.2	0.3	3.5	4.9	3.7	-	8.0	12.8	34.4
1.5 W	•	-	-	0.4	2.6	2.2	10.8	4.6	6.3	22.6
3.0 W	•	-	-	-	1.3	4.8	6.0	5.3	4.6	9.5
4.5 W	•	-	-	-	1.5	2.2	2.4	NS	4.2	6.8
6.0 W	•	-	-	-	0.7	0.3	0.8	0.6	2.0	3.3
•	3.0	-	-	-	0.4	0.5	0.7	0.5	1.0	3.1
•	4.0	-	-	-	0.2	0.3	0.8	0.4	0.8	1.3
7.5 W	1.5	-	-	-	0.2	0.5	1.1	0.8	0.9	1.9
9.0 W	•	-	-	-	-	-	-	-	0.7	1.1
Overpack Top		113.0	NS	126.0	NS	103.0	68.3	25.1	112.0	212.0
Overpack bottom		NS	21.8	NS	42.0	21.8	27.9	20.7	29.2	91.3

NS = no sample
 - = below detection limit
 • = ditto

Table 3 continued. Spatial distribution of tritium in soil atmosphere.

Tritium DPM/L In Soil Atmosphere

Depth (m)	Lateral (m)	10/2/85	12/4/85	1/31/86	3/03/86	4/24/86	5/27/86	6/23/86	7/25/86	8/20/86
0.3 N	1.5	44.8	39.8	140.0	124.0	121.0	89.2	86.7	38.4	47.6
1.5 N	•	98.2	166.0	95.3	151.0	135.0	97.9	51.8	59.8	58.2
3.0 N	•	22.4	28.1	23.4	17.5	30.8	24.7	18.9	19.2	18.5
4.5 N	•	25.2	17.6	42.7	31.5	28.3	22.5	19.4	19.2	18.2
6.0 N	•	5.2	12.0	8.7	9.3	7.5	7.3	7.2	6.8	6.6
•	3.0	3.2	6.4	6.6	5.9	5.6	5.3	5.4	5.6	NS
•	4.0	1.3	2.4	4.0	4.2	5.3	6.3	7.7	5.6	5.6
7.5 N	1.5	1.8	4.9	5.7	4.8	5.5	5.4	6.8	5.5	5.2
9.0 N	•	3.6	6.5	24.8	7.8	7.5	7.7	8.8	7.5	6.9
0.3 S	•	74.5	188.0	279.0	236.0	233.0	326.0	248.0	237.0	NS
1.5 S	•	134.0	154.0	273.0	160.0	101.0	74.5	162.0	51.0	43.4
3.0 S	•	37.4	41.4	71.0	39.3	43.6	30.1	39.1	19.1	19.2
4.5 S	•	8.1	9.8	14.1	9.7	10.1	11.8	11.1	9.6	9.2
6.0 S	•	11.6	12.0	27.4	16.5	22.3	16.2	13.7	11.4	12.0
•	3.0	18.0	42.4	109.0	46.4	35.6	33.9	28.3	24.2	25.7
•	4.0	7.9	20.3	40.0	24.1	25.9	25.8	23.6	20.5	19.4
7.5 S	1.5	38.2	26.7	43.3	36.5	36.4	39.9	33.4	31.1	27.2
9.0 S	•	4.7	8.9	31.2	NS	20.6	20.4	16.5	14.4	13.4
0.3 C	center	56.8	279.0	126.0	116.0	124.0	115.0	98.9	48.7	51.9
1.5 C	•	28.6	35.2	55.6	33.6	100.0	86.4	30.6	16.7	17.8
3.0 C	•	67.2	19.7	140.0	5436.0	66.3	62.4	39.6	41.4	36.3
9.0 C	•	8.6	15.0	12.4	10.0	13.1	15.6	13.8	14.4	14.2
10.5 C	•	2.8	7.7	3.5	3.3	3.9	3.9	3.7	3.8	3.6
11.5 C	•	2.6	5.2	NS	3.3	2.9	2.9	2.8	3.0	2.8
0.3 E	1.5	99.9	309.0	170.0	263.0	281.0	385.0	373.0	434.0	503.0
1.5 E	•	30.2	44.7	142.0	84.8	71.9	39.9	36.2	26.7	NS
3.0 E	•	31.6	68.6	299.0	99.3	80.4	65.4	57.4	50.4	49.0
4.5 E	•	8.7	16.3	50.0	17.5	15.3	14.7	13.7	12.3	13.7
6.0 E	•	1.9	8.0	6.7	6.6	7.2	7.9	6.9	6.2	NS
•	3.0	7.2	61.7	37.8	8.7	7.0	11.8	10.9	11.7	NS
7.5 E	1.5	9.7	16.9	28.2	29.9	26.9	23.0	17.2	15.7	13.4
9.0 E	•	2.0	3.0	4.4	2.6	3.9	4.2	4.3	4.1	3.7
0.3 W	•	59.4	103.0	81.1	246.0	153.0	167.0	97.4	64.2	87.0
1.5 W	•	23.2	74.5	63.7	76.0	73.6	187.0	71.2	41.1	NS
3.0 W	•	13.1	10.7	17.3	12.0	26.5	11.3	10.5	7.7	7.3
4.5 W	•	10.1	12.0	13.1	9.5	8.0	6.5	8.7	8.1	8.5
6.0 W	•	4.4	8.4	5.4	5.0	4.8	4.3	4.2	4.2	4.3
•	3.0	3.7	6.2	10.5	5.9	5.7	4.8	4.6	4.1	4.4
•	4.0	2.2	4.0	4.4	4.6	3.2	2.8	3.3	2.7	2.9
7.5 W	1.5	2.5	7.2	5.2	3.9	4.0	5.0	4.9	5.0	5.4
9.0 W	•	1.1	1.7	4.8	2.4	2.6	2.5	1.2	2.2	NS
Overpack Top		308.0	513.0	400.0	397.0	526.0	561.0	516.0	520.0	451.0
Overpack bottom		93.4	152.0	NS	141.0	141.0	151.0	167.0	163.0	151.0

NS = no sample
 - = below detection limit
 • = ditto

Table 3 continued. Spatial distribution of tritium in soil atmosphere.

Tritium DPM/L In Soil Atmosphere

Depth (m)	Lateral (m)	9/22/86	11/3/86	12/1/86	1/27/87	3/18/87	5/28/87	7/17/87	9/29/87	12/03/87
0.3 N	1.5	38.3	86.7	71.5	129.0	219.0	136.0	276.0	226.0	405.0
1.5 N	•	72.9	141.0	148.0	246.0	42.8	8.7	92.2	48.8	37.5
3.0 N	•	20.2	27.4	39.8	96.0	28.6	38.3	27.5	26.5	27.3
4.5 N	•	29.5	30.0	31.7	47.8	30.2	48.1	44.8	44.9	35.6
6.0 N	•	7.4	9.0	7.4	21.6	9.6	12.0	71.4	11.3	13.9
•	3.0	5.3	6.5	6.8	18.1	9.4	18.1	13.8	12.8	8.9
•	4.0	4.9	6.8	5.9	35.8	6.8	13.4	115.0	12.1	8.0
7.5 N	1.5	6.0	3.9	6.4	11.8	6.8	9.2	1191.0	12.0	76.9
9.0 N	•	6.6	8.4	6.9	31.0	10.3	17.6	16.9	12.7	19.6
0.3 S	•	224.0	294.0	258.0	390.0	416.0	493.0	590.0	514.0	353.0
1.5 S	•	32.2	30.6	38.4	68.5	49.5	1086.0	87.8	57.6	242.0
3.0 S	•	15.5	49.2	32.2	69.5	16.6	106.0	104.0	32.5	31.5
4.5 S	•	8.3	11.8	36.2	74.8	4.6	17.4	63.2	14.8	40.0
6.0 S	•	11.8	17.8	29.1	79.6	13.2	1630.0	21.8	17.2	41.0
•	3.0	20.3	27.1	19.2	81.1	24.1	53.5	42.8	31.5	31.8
•	4.0	16.8	31.1	19.7	44.7	13.2	31.6	35.0	24.2	62.8
7.5 S	1.5	26.1	30.8	32.3	118.0	17.9	56.4	30.0	27.8	28.6
9.0 S	•	12.8	15.6	35.0	70.4	14.2	44.0	124.0	21.9	22.1
0.3 C	center	51.0	84.3	84.1	109.0	231.0	359.0	461.0	373.0	362.0
1.5 C	•	20.0	29.4	19.0	47.6	99.8	392.0	48.3	42.4	36.2
3.0 C	•	36.1	56.6	55.3	79.9	69.5	65.0	75.0	76.7	82.5
9.0 C	•	14.6	19.1	21.9	26.1	23.0	37.6	33.8	31.4	30.1
10.5 C	•	3.4	5.0	5.8	20.4	5.8	11.9	18.4	7.5	85.2
11.5 C	•	3.0	4.3	3.6	12.5	4.0	25.2	22.0	5.7	6.6
0.3 E	1.5	563.0	928.0	700.0	864.0	1717.0	2078.0	3405.0	3392.0	3354.0
1.5 E	•	17.8	21.9	28.4	110.0	100.0	120.0	148.0	34.1	40.2
3.0 E	•	41.7	52.3	48.7	119.0	46.0	80.9	323.0	52.6	89.6
4.5 E	•	11.2	12.8	112.0	32.6	36.0	36.0	19.9	15.5	17.4
6.0 E	•	1.8	0.6	NS	18.0	13.7	10.0	10.3	11.1	64.6
•	3.0	11.4	10.1	13.0	22.2	6.8	28.2	12.9	15.4	19.6
7.5 E	1.5	13.3	14.5	14.1	13.5	10.8	1514.0	16.7	15.0	18.2
9.0 E	•	4.0	7.9	4.6	7.5	8.4	6.9	7.8	5.4	7.2
0.3 W	•	78.2	106.0	115.0	233.0	210.0	270.0	449.0	280.0	303.0
1.5 W	•	23.3	31.8	31.0	89.7	62.9	139.0	68.6	31.0	51.6
3.0 W	•	7.1	6.2	19.9	51.1	37.0	116.0	28.9	21.0	11.8
4.5 W	•	8.0	9.5	18.8	56.8	11.7	18.9	16.9	16.3	18.6
6.0 W	•	4.1	4.6	7.7	26.0	5.3	7.5	6.7	11.1	11.0
•	3.0	4.6	5.6	15.1	31.2	8.0	26.6	23.0	8.5	16.8
•	4.0	3.6	5.0	NS	11.8	4.7	195.0	7.5	16.4	6.7
7.5 W	1.5	3.8	7.5	6.6	8.9	7.1	12.1	17.0	92.7	76.6
9.0 W	•	1.9	3.1	3.4	5.2	3.3	8.4	14.9	4.1	335.0
Overpack Top		671.0	515.0	923.0	1942.0	1522.0	1366.0	1161.0	1087.0	2072.0
Overpack bottom		143.0	208.0	129.0	287.0	251.0	361.0	321.0	386.0	NS

NS = no sample
 - = below detection limit
 • = ditto

Table 3 continued. Spatial distribution of tritium in soil atmosphere.

Tritium DPM/L In Soil Atmosphere

Depth (m)	Lateral (m)	3/7/88	5/16/88	7/20/88	9/15/88	3/08/89	11/08/89	11/01/90	6/19/91	9/23/92
0.3 N	1.5	197.0	374.0	1337.0	579.0	0.8	NS	943.0	3799.0	2859.0
1.5 N	•	49.0	111.0	42.6	37.4	NS	26.2	156.0	234.0	407.0
3.0 N	•	49.7	80.7	44.2	23.1	20.9	NS	58.0	76.0	128.0
4.5 N	•	50.4	45.3	38.6	39.6	NS	26.9	58.0	190.0	329.0
6.0 N	•	15.7	19.2	12.4	11.7	9.0	13.4	32.0	75.0	80.0
•	3.0	19.2	28.2	14.1	10.4	11.2	7.4	26.0	57.0	35.0
•	4.0	9.9	18.9	6.5	10.4	1.5	3.4	8.0	36.0	38.0
7.5 N	1.5	12.1	10.2	7.7	7.1	12.2	14.7	32.0	112.0	243.0
9.0 N	•	10.3	10.1	10.6	9.5	7.3	7.2	15.0	37.0	43.0
0.3 S	•	3.0	743.0	1036.0	651.0	445.0	NS	3221.0	7522.0	16432.0
1.5 S	•	44.4	77.7	75.5	45.6	41.0	NS	152.0	468.0	555.0
3.0 S	•	28.4	32.6	44.1	26.7	32.7	17.7	103.0	81.0	92.0
4.5 S	•	46.9	59.9	27.4	10.6	11.4	9.4	44.0	91.0	146.0
6.0 S	•	54.0	22.4	16.8	14.7	17.0	16.8	32.0	95.0	132.0
•	3.0	29.5	30.2	31.2	23.9	20.6	13.2	38.0	92.0	95.0
•	4.0	18.9	18.4	20.4	15.4	16.2	8.8	65.0	79.0	98.0
7.5 S	1.5	35.2	20.6	22.5	20.4	30.2	13.9	30.0	81.0	108.0
9.0 S	•	16.9	19.7	19.3	17.1	20.9	16.3	37.0	80.0	76.0
0.3 C	center	308.0	1196.0	1179.0	737.0	394.0	1145.0	2787.0	5744.0	6043.0
1.5 C	•	63.5	86.2	80.3	34.4	28.0	40.2	75.0	195.0	298.0
3.0 C	•	121.0	210.0	149.0	102.0	77.8	230.0	848.0	2024.0	3378.0
9.0 C	•	NS	55.2	54.6	46.2	50.8	140.0	658.0	1753.0	2093.0
10.5 C	•	5.4	7.3	7.8	40.4	105.0	6.5	11.0	20.0	18.0
11.5 C	•	8.7	7.0	13.7	7.8	6.3	NS	11.0	16.0	14.0
0.3 E	1.5	7394.0	11640.0	15390.0	9713.0	5083.0	11900.0	20511.0	45069.0	35760.0
1.5 E	•	59.3	63.8	70.5	26.6	26.5	53.5	162.0	972.0	1386.0
3.0 E	•	104.0	106.0	37.0	34.4	36.8	21.0	88.0	126.0	211.0
4.5 E	•	25.2	62.8	20.7	19.5	8.1	12.5	49.0	82.0	153.0
6.0 E	•	12.5	16.1	34.2	NS	15.9	9.5	37.0	98.0	88.0
•	3.0	13.0	22.2	12.0	NS	12.3	7.2	23.0	113.0	64.0
7.5 E	1.5	16.1	NS	13.9	12.2	13.2	13.8	29.0	64.0	118.0
9.0 E	•	7.0	6.3	5.8	3.7	7.1	7.4	20.0	272.0	442.0
0.3 W	•	321.0	236.0	418.0	NS	110.0	174.0	323.0	928.0	1152.0
1.5 W	•	39.3	58.8	46.4	127.0	34.5	18.7	58.0	116.0	185.0
3.0 W	•	25.5	33.3	31.6	16.9	9.7	7.0	26.0	26.0	152.0
4.5 W	•	26.8	66.9	19.3	14.9	32.5	23.1	39.0	77.0	215.0
6.0 W	•	13.5	15.2	11.3	6.5	9.7	8.0	19.0	71.0	100.0
•	3.0	20.2	12.0	7.1	6.4	8.9	6.0	23.0	37.0	32.0
•	4.0	7.5	8.9	6.9	3.9	4.8	5.1	9.0	26.0	25.0
7.5 W	1.5	641.0	13.3	13.7	10.1	14.2	52.6	56.0	1260.0	350.0
9.0 W	•	3.6	6.9	7.6	10.8	227.0	7.7	10.0	52.0	23.0
Overpack Top		4806.0	3152.0	2188.0	1919.0	3115.0	10890.0	20704.0	53556.0	50577.0
Overpack bottom		586.0	604.0	NS	514.0	2535.0	NS	NS	19396.0	16272.0

NS = no sample
 • = below detection limit
 • = ditto

Fig. 4 - Spatial distribution of tritium in the soil atmosphere under the floor of Pit 1.

waste containers can be expected to degrade thus releasing increaisng amounts of tritium to the soil with the passge of time and the migration rate will probably then be important." This has indeed occurred. See Table 5, and Fig. 5.

As previously stated in the Methods and Materials section, the tritium waste was placed in the hole from the bottom at the 36 m level up to the 20 m level. From the 20 m level up, the hole was backfilled with clean fill. Inspection of Fig. 5 shows no evidence of any significant migration of tritium upward in the hole. However, it must be noted that the soil atmosphere samplers were placed at 3 m vertical intervals. A very recent tritium migration model (6) predicts that significant tritium migration would be less than 3 m, given the conditions of this particular disposal.

Table 4 - Tritium transport to the atmosphere from GCDT central borehole.

Date	$\mu\text{Ci/day}$	Date	$\mu\text{Ci/day}$	Date	$\mu\text{Ci/day}$
1/29/88	2.3	8/11/88	41.1	3/07/91	14.0
2/02/88	2.7	8/18/88	29.1	3/15/91	19.1
2/03/88	1.7	8/24/88	28.4	3/22/91	12.1
2/10/88	3.2	8/25/88	28.7	3/29/91	31.6
2/11/88	3.1	9/01/88	28.8	4/05/91	19.7
2/12/88	3.3	9/19/88	18.7	4/12/91	16.1
2/23/88	5.4	9/27/88	22.4	4/25/91	29.5
2/24/88	5.2	10/05/88	49.3	5/02/91	11.9
2/25/88	4.2	10/17/88	18.5	5/09/91	40.1
3/03/88	6.1	10/26/88	36.8	5/16/91	25.4
3/09/88	3.9	11/16/88	15.3	5/23/91	25.6
3/15/88	7.2	11/21/88	11.3	5/30/91	42.2
3/16/88	4.9	12/01/88	10.2	6/05/91	31.0
3/17/88	4.7	12/07/88	11.8	6/11/91	40.0
3/18/88	4.6	12/14/88	22.5	6/21/91	35.2
3/23/88	9.4	1/10/89	4.9	6/27/91	35.2
3/24/88	9.3	1/20/89	8.0	7/03/91	37.0
3/31/88	11.4	1/26/89	8.1	7/12/91	34.7
4/01/88	9.2	2/01/89	9.1	7/26/91	46.5
4/05/88	4.7	2/16/89	10.1	7/30/91	32.1
4/13/88	16.7	2/24/89	14.2	8/09/91	32.1
4/14/88	13.8	10/19/89	21.9	8/14/91	33.1
4/20/88	16.3	10/24/89	3.7	9/04/92	77.9
5/05/88	23.8	10/27/89	13.9	9/10/92	64.7
5/13/88	22.5	11/02/89	11.1	9/16/92	58.0
5/16/88	37.4	11/09/89	12.4	9/25/92	51.2
5/23/88	25.0	11/30/89	8.7	10/01/92	77.9
6/08/88	21.1	12/07/89	8.4	10/09/92	49.6
6/13/88	28.4	1/04/90	6.3	10/19/92	49.9
6/15/88	27.9	1/17/90	11.4	10/26/92	40.0
6/20/88	27.2	1/23/90	6.8	11/03/92	36.6
7/07/88	32.3	2/14/90	25.6	11/13/92	43.4
7/14/88	26.0	2/22/90	9.6	11/19/92	28.2
7/19/88	24.6	1/15/91	8.7	11/25/92	14.5
7/21/88	20.3	2/05/91	32.2	12/04/92	25.3
7/26/88	22.2	2/21/91	12.8	12/10/92	18.1
8/02/88	52.0	2/28/91	27.2	12/21/92	17.9

Table 5 - Tritium concentration in soil atmosphere in GCD. Borehole backfill completed on June 19, 1987, and tritium sampling carried out on various dates listed.

Sampler Depth		Tritium Concentration in Soil Atmosphere ($\mu\text{Ci}/\text{m}^3$)			
m	ft	12/13/89	10/3/90	4/3/91	9/9/92
3	10	0.001	0.002	0.001	0.004
6	20	0.004	0.022	0.021	0.020
9	30	0.001	0.011	0.009	0.010
12	40	0.004	0.011	0.010	0.011
15	50	0.001	0.006	0.006	0.007
20	65	0.010	0.062	0.062	0.083
26	85	0.220	1.125	1.473	10.059
36	119	0.070	0.342	0.268	0.399

Fig. 5 - Tritium concentration in GCD soil atmosphere as a function of depth in the soil profile and at various times. The waste was emplaced 36 to 20 meters below the soil surface, then clean backfill to surface. Note, no observed tritium migration away from locality of burial.

CONCLUSIONS AND RECOMMENDATIONS

Data obtained in the Pit 1 study show that tritium emanation from those buried waste containers has been increasing rather rapidly with the passage of time. It appears that the rate of increase of release may double annually for a significant period of time. The initial emanation rate is extremely low, so that even with large annual percentage increases, the total releases so far have been small. The increasing release rates from the containers do point out the necessity of having accurate site-specific soil tritium migration rate data available. Clearly the soil must ultimately be charged as the primary containment media. Accurate site-specific migration rate data would enable prediction of tritium release rates to the atmosphere or migration downwards toward the water table. It should be noted that all tritium studies to date at Area 5 have been in conjunction with actual radionuclide disposal operations and, therefore, the source term of the tritium available for migration is always unknown. A specific experiment, with a completely soluble tritium oxide source should be conducted to obtain accurate site-specific tritium migration rates for the Area 5 disposal site. The recently published, January 1993, tritium migration model (6) predicts a very slow migration of tritium, either upward, resulting in atmospheric release, or downward toward the water table. Specifically, the model predicts that given the conditions present at the Area 5, NTS, GCD disposal, no tritium will ever reach the water table or escape to the atmosphere. This is a three-dimensional deterministic model based on soil physics. However, it is urged that this model be validated by means of the experiment mentioned above.

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