Simulated Impacts of Water Introduced into Pits 37 and 38 at Technical Area 54, Area G, Los Alamos National Laboratory – 17386

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ABSTRACT

Water is used in the disposal of bulk waste generated by cleanup activities at LANL, including large quantities of waste retrieved from Material Disposal Area (MDA) B. This water is used to wash material from the metal bins in which the material is transported to Area G, to decontaminate the containers so they can be returned to service, to decontaminate the trucks used to transport the bins, and for general dust suppression during waste placement. The introduction of this water into pits 37 and 38 at Area G during disposal of MDA B waste in those pits may affect the rates at which water percolates through, and leaches contaminants from, the waste in the disposal pits, and thus may hasten the transport of contamination to the regional aquifer below the disposal facility. A special analysis was conducted to evaluate the potential impacts of the water used during bulk waste disposal on the long-term performance of the disposal facility.

INTRODUCTION

Los Alamos National Laboratory (LANL) generates radioactive waste as a result of various activities. Operational waste is generated from a wide variety of research and development activities including nuclear weapons development, energy production, and medical research; environmental restoration, and decontamination and decommissioning waste is generated as contaminated sites and facilities at LANL undergo cleanup or remediation. The majority of this waste is low-level radioactive waste (LLW) and is disposed of at the Technical Area 54 (TA-54), Area G disposal facility.

U.S. Department of Energy (DOE) Order 435.1 [1] requires that radioactive waste be managed in a manner that protects public health and safety, and the environment. To comply with this order, DOE field sites must prepare site-specific radiological performance assessments for LLW disposal facilities that accept waste after September 26, 1988. Furthermore, sites are required to conduct composite analyses that account for the cumulative impacts of all waste that has been (or will be) disposed of at the facilities and other sources of radioactive material that may interact with the facilities.

Revision 4 of the Area G performance assessment and composite analysis was issued in 2008 [2]. These analyses estimate rates of radionuclide release from the waste disposed of at the facility, simulate the movement of radionuclides through the environment, and project potential radiation doses to humans for several on-and off-site exposure scenarios. The assessments are based on existing site and disposal facility data, and on assumptions about future rates and methods of waste disposal.

The performance assessment and composite analysis include an assessment of the potential impacts of waste disposal at Area G on water drawn from the regional aquifer. Those analyses used steady-state estimates of infiltration through the final cover placed over Area G to estimate rates of water movement through the waste and the unsaturated zone beneath the disposal units. No impacts were projected to the regional aquifer during the 1,000-year compliance period or for tens of thousands of years following closure of the disposal facility.

The impacts of water introduced into disposal pits during disposal operations were not taken into account in the Revision 4 modeling, but an assessment of the potential impacts of this transient moisture was conducted in 2011 [3]. The results of that analysis indicated that water may penetrate below the disposal units more quickly and to greater depths than previously estimated, especially below pits that were open for long periods of time. Preliminary modeling conducted using the Finite Element Heat and Mass (FEHM) computer code indicated that radionuclides released from these units may discharge to the regional aquifer within 1000 years of disposal facility closure.

The Area G disposal facility consists of Material Disposal Area (MDA) G and the Zone 4 expansion area; disposal operations will be confined to MDA G until that portion of the facility is closed in 2017. Recently, MDA G has received large quantities of bulk LLW that were generated by cleanup efforts at LANL, including a large amount of material generated by the retrieval of waste at MDA B. Approximately 1,450 containers of this waste were disposed of in pits 37 and 38 in 2011 and 2012. Containers of waste retrieved from MDA B make up about 90 percent of the total.

Water was used in the 2011 and 2012 disposal of most of the bulk waste to wash material from the metal bins used to transport the material to Area G, to decontaminate the containers so they can be returned to service, to decontaminate the trucks used to transport the bins, and for general dust suppression during waste placement. To minimize the spread of contamination to other portions of the disposal facility, the used water was discharged into the pit along with the waste. The introduction of this water into the disposal units may affect the rates at which water percolates through the disposal pits and leaches contaminants from the waste therein, and thus hasten the transport of contamination to the regional aquifer below the disposal facility.

The transient flow analysis [3] estimated past and future quantities of water introduced into active disposal pits. The amounts of water added to the disposal pits in conjunction with the disposal of the cleanup waste and the timing of those additions differ from the assumptions made by Levitt. The special analysis presented here is being conducted to evaluate the potential impacts of these differences on the long-term performance of the disposal facility and to ensure protection of the regional groundwater.

METHODS

Water Utilization Rates

Water was used in the disposal of approximately 60 percent of the containers of bulk waste; the remaining waste was either packaged in bags that were disposed of with the waste or did not require the use of water for rinsing and decontamination. Water application rates for the containers of waste for which water was used were estimated for three phases of waste disposal. The first phase addresses the disposal of approximately 600 containers of waste in pits 37 and 38 from January 2011 through February 2012. Phase 2 corresponds to the disposal of 150 containers of waste in pit 38 from July 2 through August 1, 2012; the final phase is the period required to dispose of the remaining waste in pit 38 during 2013. The water utilization rates for these phases are shown in Table 1.

Table 1
Water Utilization Rates for the Disposal of Bulk Waste

Disposal Phase	Total Water Usage (m^3)
Phase 1 (January – February 2012)	
Pit 37	1.3E+03
Pit 38	1.3E+03
Phase 2 (July 2 – August 1, 2012)	3.4E+02
Phase 3 (2013)	1.5E+02

Performance Modeling

The introduction of large quantities of water in conjunction with the disposal of the bulk waste will impact temporal and spatial patterns of water percolation through pits 37 and 38. These changes will influence the rates at which radionuclides are leached from the waste, the amount of time required for those releases to discharge from the bottoms of the pits, and the time required for those releases to discharge to the regional aquifer and arrive at the downgradient well where the water may be consumed by a member of the public. Model simulations were conducted using HYDRUS 2D modeling software to estimate water fluxes exiting the bottoms of pits 37 and 38; these fluxes served as input to the 3-D FEHM model (fehm.lanl.gov) that was used to estimate the times at which contaminants in the waste reach the top of the Cerros del Rio basalt, a surrogate time horizon for the hypothetical compliance well. Breakthrough at the hypothetical compliance well is approximately equal to this time, as no credit is taken for travel time in either the

Cerros del Rio basalt or the regional aquifer. The output from the FEHM modeling was used in the Area G performance assessment and composite analysis GoldSim™ model to estimate the exposures received by the groundwater user.

For the analysis presented in this paper, we focus on the behavior of pit 37 and the eastern half of pit 38 (pit 38E). This is because the primary contaminant of concern, C14, is located within pit 38E.

The HYDRUS 2D modeling builds upon the transient flow analysis conducted by Levitt [3]; details about the general approach adopted for that modeling may be found in the referenced report. The modeling conducted in support of the special analysis improves on the earlier analysis by more accurately representing the configuration of pits 37 and 38; the initial moisture conditions in the units; and the addition of water to the pits as a result of precipitation, general dust suppression, and the disposal of the bulk waste.

Table 2
FEHM and Hydrus simulations

Summary of FEHM Scenarios Simulated

FEHM Simulations		Hydrus Simulations	
FEHM 1	Wettest	37	Scenario 2
FEHM 1	Wettest	38E	Scenario 3
FEHM 2	Intermediate	37	Scenario 2
FEHM 2	Intermediate	38E	Scenario 1
FEHM 3	Intermediate	37	Scenario 1
FEHM 3	Intermediate	38E	Scenario 2
FEHM 4	Driest	37	Scenario 1
FEHM 4	Driest	38E	Scenario 1

Summary of Hydrus Pit 37 and 38E Scenarios

Pit 37	Scenario 1	Assumed 20% initial saturation of waste and pit fill
Pit 37	Scenario 2	Assumed 33% initial saturation of waste and pit fill
Pit 38E	Scenario 1	Assumed 20% initial saturation of waste and pit fill.
Pit 38E	Scenario 2	Assumed 33% initial saturation of waste and pit fill.
Pit 38E	Scenario 3	Assumed 33% initial saturation of waste and pit fill. 2 x observed precip rate 2014 through 2016 due to uneven fill.

The water fluxes projected by HYDRUS 2D depend, in part, upon the initial moisture contents of the materials in the pit, where the moisture content is given by the product of the initial saturation and the porosity of the material. Bulk or uncontainerized waste was modeled using a porosity of 0.3 and an initial saturation of 33 or 20 percent; the largely impermeable containers used to dispose of a portion of the waste were assigned a porosity of 0.001 and the same initial saturation. The crushed tuff placed between layers of waste packages and between packages within layers was modeled using a porosity of 0.3 and an initial saturation of 33 or 20 percent. The initial saturation of the crushed tuff is generally consistent with the moisture contents measured in pit 37 using neutron probes. The four FEHM simulations test wettest to driest scenarios from Hydrus simulations based on initial saturation conditions of waste and pit fill in pit 37 and 38, as well as conceptual pit fill elevations of pit 38 east (Table 2). While the study only considers transport from pit 38E, transient moisture conditions from nearby pit 37 may also contribute to local vadose zone conditions and can therefore influence transport of waste stored in pit 38.

Precipitation data collected at TA-54 from 1993 through 2015 were used to conduct the HYDRUS modeling, with the meteorological record repeated as necessary to carry out simulations beyond the initial 20-year period. The rate of potential evaporation from the waste surface was assumed to be 25 percent of the potential evapotranspiration used to conduct the earlier evaluation of transient flow impacts [3]. The water loss rate is expected to be relatively small because of the lack of vegetation on the waste surface and because the surface lies below natural grade.

The HYDRUS 2D modeling projected water fluxes (m^3/ (m-day)) exiting pit 37, the eastern and western ends of pit 38 proper, and the pit 38 extension as functions of time following the initial placement of waste (Fig. 1). These fluxes were used as input to the FEHM modeling that was used to estimate radionuclide breakthrough curves for the compliance well located 100 m (330 ft) downgradient of Area G. The FEHM modeling accounts for the downward movement of transient moisture to the regional aquifer during the time pits 37 and 38 receive waste and after the disposal units are closed. In contrast, the Revision 4 performance assessment and composite analysis modeled steady-state flow conditions that were projected to exist after the disposal units at Area G underwent final closure and included simulations for all waste disposal units.

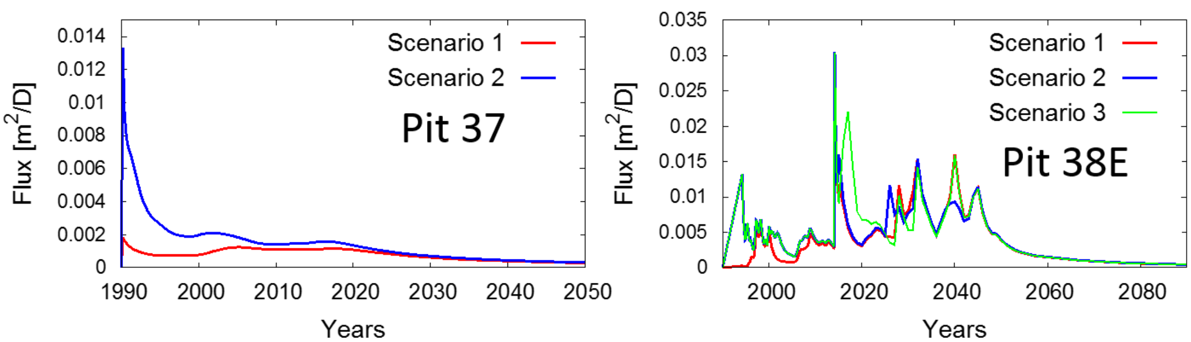

Fig. 1 The infiltration flux through pits 37 and 38E for each scenario simulated using Hydrus (see Table 2). Fluxes are then used as boundary conditions for FEHM simulations.

In the current R&D analysis, a set of four simulations are used to simulate uncertainty in initial conditions and explore the impact of this uncertainty on predicted travel times (Table 2). Two initial saturation conditions are used for pit 37, while pit 38E is assigned five uncertain initial conditions. From the combination of 12 HYDRUS 2D simulations, we selected four that span a range of water infiltration from the wettest to the driest.

The FEHM simulations conducted for this special analysis use a three-dimensional (3-D) numerical mesh with variable spacing in all dimensions. The lateral extent of the model domain is 480 m × 352 m (1,575 × 1,155 ft). The mesh spacing in the horizontal direction is 1 m (3.3 ft) in the region of interest (pits 37 and 38); the locations of pit 37, the eastern and western portions of pit 38 proper, and the pit 38 extension were established using GIS and mapped into the numerical mesh. The nodes included in the mesh for each pit, or portion thereof, represent the entire volume and floor of each unit. Pits 37 and 38 are placed near the center of the mesh, surrounded by buffer zones that are approximately 100 m (328 ft) on each side. The bottom of the mesh extends below the interface between the Otowi Member and Cerros del Rio basalts to a depth of 1,929 m (6,329 ft), where saturation is fixed at 0.99 to allow unimpeded drainage from the mesh. Mesh spacing in the vertical direction is 1 m (3.3 ft) from the land surface to the top contact with the basalts in the high-resolution area around the pits. Away from the pits, mesh spacing increases to the far-field boundaries, and the lateral boundaries allow no lateral flow. As particles cross the boundary between the Bandelier Tuff and the top of the basalts, they are counted toward breakthrough for dose calculations. Placing the breakthrough plane at this interface assumes all contaminant mass leaving the Otowi Member of the Bandelier Tuff enters the regional aquifer immediately; no credit is taken for storage or retardation within the fractured basalts. Plume spreading is accounted for during transport in the regional aquifer and only a fraction of the plume that reaches the regional aquifer is captured in the hypothetical compliance well. The same assumption was adopted for the Area G performance assessment and composite analysis.

The hydraulic properties of the geologic units are generally the same as those used in the performance assessment and composite analysis. Updates made by Levitt [3] were incorporated into the FEHM modeling conducted for this special analysis, including revised properties for the 1-m (3.3-ft) thick vapor phase notch found between units 1v and 1g of the Tshirege Member of the Bandelier Tuff. Additionally, the Guaje Pumice is included in the present work as a thin layer lying on top of the basalt. Layers in this version of the numerical mesh are informed by the most recent geologic model for Area G and include dipping surfaces and thin units that are discontinuous. The basalt dips significantly across the model domain from an elevation of 1,975 m (6,480 ft) in the northeast to less than 1,965 m (6,450 ft) in the southwest. Because of the transient nature of the flow, longitudinal dispersivity was set to 6 m (19.7 ft) or approximately 10 percent of the flow-path length. The value used in these simulations is a typical value for a saturated system; it is unclear what values are appropriate for use in modeling unsaturated flow.

The FEHM model was run initially at a background infiltration rate of 1 mm/yr (0.039 in./yr) to achieve a steady-state flow field. This background infiltration rate is consistent with moisture data collected from boreholes at Area G, although a range of infiltration from 0.1-1 mm/yr span the range of measured data (this remains a major uncertainty in the model, but 1 mm/yr background leads to faster BTC). The transient fluxes at the bottoms of pits 37 and 38 projected forward from the year 1990 by HYDRUS 2D were used as input to FEHM simulations to drive nonsteady-state particle migration toward the regional aquifer. FEHM calculates the movement of the wetting front caused by increased moisture in the waste pits and tracks the movement of particles released in the year 2053 to yield breakthrough curves for the disposal scenarios listed in Table 2. The HYDRUS 2D simulations projected water fluxes from the pits over 1,088 years. The FEHM modeling assigned an infiltration rate of 1 mm/yr (0.039 in./yr) to the buffer zone surrounding the pits until the final cover was placed over Area G in 2046. An infiltration rate of 0.1 mm/yr (0.0039 in./yr) was applied after this time, consistent with assumed postclosure conditions.

Breakthrough curves generated by the FEHM modeling are used in the Area G performance assessment and composite analysis models to simulate the movement of radionuclides released from the pits to a well located 100 m (330 ft) downgradient of the disposal facility (Fig. 2). Breakthrough curves were generated for post-2053 performance; the curves represent the transport behavior of from the eastern portions of pit 38 and were used to model the transport of the radionuclide inventories disposed of throughout pits 37 and 38. Using a single breakthrough curve, rather than separate breakthrough curves for pit 37 and the different regions of pit 38, simplifies the modeling and assumes all radionuclides disposed of in the two pits are subject to transient moisture levels that are as great as, or greater than, those observed in pit 37, the eastern portion of pit 38 proper, and the pit 38 extension. The Area G performance assessment and composite analysis models developed using GoldSim employ one-dimensional (1-D) abstractions of the FEHM modeling to estimate radionuclide concentrations in groundwater at the compliance well. These concentrations are used to estimate potential exposures to members of the public who consume contaminated water. Exposures are projected for two groundwater pathway exposure scenarios. The All Pathways–Groundwater Scenario considers exposures received from a range of domestic water uses including crop irrigation, animal watering, and direct consumption. The Groundwater Resource Protection Scenario estimates doses for a person who uses water drawn from the aquifer for drinking water only.

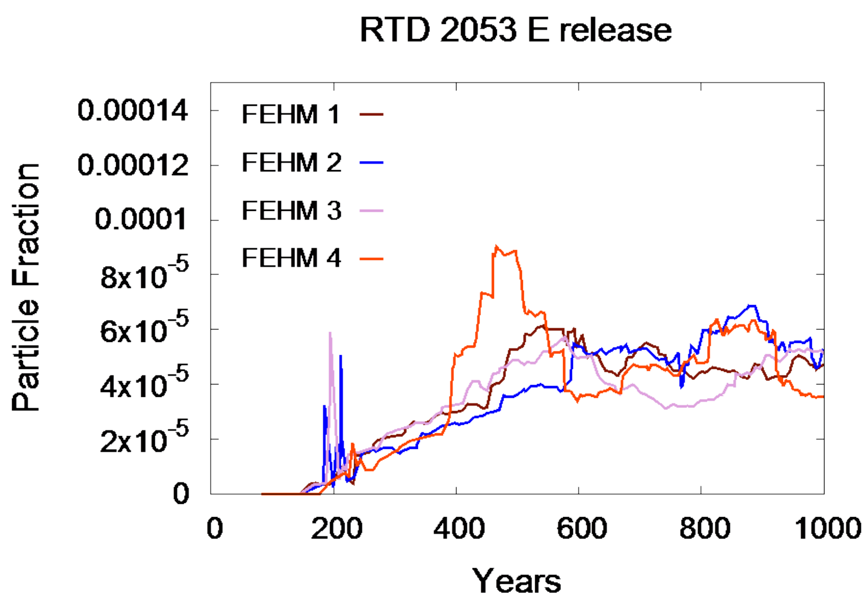

Fig. 2
Particle Breakthrough RTD curves produced by FEHM

The radionuclide inventories used in the special analysis rely on information from LANL's disposal database and assumptions about the nature of the waste that will be used to fill the remainder of pit 38. The institutional and headspace layers of pit 37 and the institutional waste layer of pit 38 proper have been filled; disposal capacity remains for waste in the headspace of pit 38 proper and the institutional and headspace layers of the pit 38 extension. The remaining headspace within pit 38 proper was assumed to be filled with waste having radionuclide concentrations equal to the average concentrations observed in all non-MDA B waste that was disposed of in this layer through September 30, 2012.

The results of previous simulations revealed that C-14 was the dominant contributor to the groundwater pathway doses. The primary source of C-14 is the graphite thermal column that was removed from the Omega West Reactor, packaged in metal containers, and disposed of in 2003. The graphite is in the form of 10.8 × 10.8 cm (4.25 × 4.25 in.) bars that are up to 122 cm (4 ft) in length. Depending upon the disposal scenario under consideration, 82 to 86 percent of the C-14 inventory is represented by the graphite waste. Given the importance of the C-14 to the projected impacts, the rates at which this radionuclide may be released from the graphite were researched.

The rate at which C-14 is released from graphite depends upon many factors, among them the source of the graphite (i.e., reactor core or thermal column), the conditions under which the leaching tests were conducted, and the exposure conditions of the material. Graphite within a reactor core is exposed to fast neutrons whereas the thermal column from the Omega West Reactor was exposed to less energetic thermal neutrons. The exposure to fast neutrons causes more damage to graphite and is expected to result in higher leachability. Many of the leachability tests were conducted using reactor core graphite. Important test conditions include the temperature at which experiments were conducted, the time over which leachability was measured, and the saturation conditions. The leachability of the C-14 tends to be greater at high temperatures, over short periods of time, and under saturated conditions. Finally, the conditions to which the graphite is exposed may play an important role in the rate at which C-14 is leached from the waste form. For example, relatively high leach rates have been observed for graphite that has undergone oxidation by CO_2 coolant during irradiation; very little oxidation occurs during irradiation in other core designs and lower leach rates are observed.

Fractional release rates that have been estimated by a number of investigators for temperatures ranging from 20°C to 25°C, a thermal range that is consistent with the conditions found in the disposal pits at Area G. The estimated fractional release rates range from 2.2×10^{-5} to 0.03 per year. The highest rates found in the literature pertain to highly oxidized graphite taken from French reactors, conditions different from those that apply to the graphite disposed of at Area G (Gray and

Morgan, 1989). The fractional release rates for graphite similar to the material disposed of in pit 38 range from 2.2 × 10^{-5} to 5.5 × 10^{-4} per year.

The GoldSim modeling conducted for the special analysis considered the potential impact of the graphite-modified C-14 release rates on the projected performance of Area G. The 1000-realization simulations initially considered the effects of slowed releases from the graphite waste form. The C-14 in the graphite was assumed to leach from the waste over a period of 1,818 years following placement of the waste in pit 38; the C-14 inventory disposed of in pits 37 and 38 that was not in graphite was available for immediate release. The period over which the C-14 leaches from the graphite is consistent with a fractional release rate of 5.5 × 10^{-4} per year.

RESULTS AND DISCUSSION

Dose results from the Composite Analysis model are shown in Fig. X. The flat red line at zero dose represents results obtained using the previous groundwater pathway analysis that does not include the effects of increased water within the pits. Clearly, the inclusion of additional water in the pits leads to a significant change in the predicted dose for both the All Pathways and Groundwater Protection scenarios. Although the predicted relative dose increase is infinite, the absolute dose from C14 remains well below regulatory limits (4 mrem/yr). After a sharp increase in the years following breakthrough (150-400 yrs), the rate of change of the dose predictions drops and begins to level out by 1000 yrs. The Groundwater Protection scenario shows higher doses at a given time because this scenario assumes that the receptor obtains all their water from the compliance well, while the All Pathways scenario includes only a fraction of water usage from the compliance well.

Further analysis will be done as part of the continuing work on the MDA G PA/CA and will include prediction to longer times. We note that the estimated water pulse based on particles released in 2053 will over predicted dose because the rate at which water (and C14) move through the system are fixed at the 2053 rate for all time. A more realistic approach will be to include particle releases in the FEHM simulations that are tied to the release rate of the graphite rods.

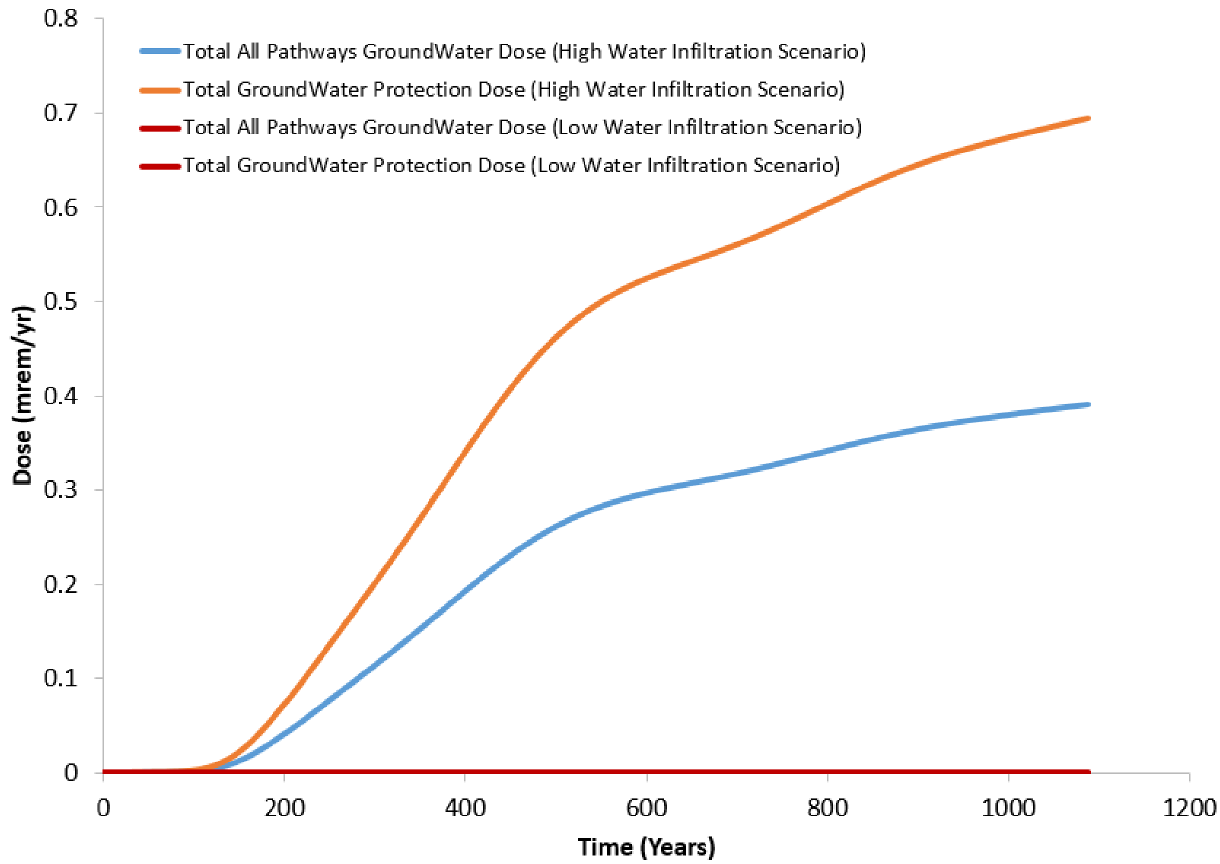

Fig. 3
Dose Projections Over 1,000 Years

CONCLUSION

The inclusion of transient moisture in nuclear waste pits at MDA G, Los Alamos, has a measurable impact on predicted doses associated with a Performance/Composite analysis. The breakthrough of the most conservative species, C14, appears during the 1000 yr. compliance period. However, doses from this species remain well below regulatory limits. The predicted travel times and doses employ assumptions that would tend to over predict dose and the speed of migration, and these R&D calculations should be considered preliminary. The work presented herein suggests that other nuclear waste sites should include transient moisture processes that are often ignored in long-term dose calculations.

REFERENCES

1. Department of Energy (DOE), 2001, *Radioactive Waste Management*, U.S. Department of Energy Order DOE O 435.1 (change 1 to document issued July 9, 1999), August 28.

2. Los Alamos National Laboratory (LANL), 2008, *Performance Assessment and Composite Analysis for Los Alamos National Laboratory Technical Area 54, Material*

Disposal Area G – Revision 4, Los Alamos National Laboratory Report LA-UR-08-06764, October.

3 Levitt, 2011, *Modeling the Movement of Transient Moisture through Disposal Units at Technical Area 54, Area G*, Los Alamos National Laboratory Report LA-UR-11-05424, September.

4. Gray, W.J. and W.C. Morgan, 1989, *Leaching of C-14 and Cl-36 from Irradiated French Graphite*, PNL-6989, Battelle Pacific Northwest Laboratories, Richland, WA, December.

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