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JUN 2002
NMED Hazardous Waste Bureau

Mr. James Sales, 6PD-O
Environmental Protection Agency, Region 6
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

Dear Mr. Sales:

The Los Alamos National Laboratory (LANL) would like to thank you for the opportunity to comment on the draft approval letter and draft fact sheet for the reauthorization of the Technical Area (TA) 54, Area G polychlorinated biphenyl (PCB) disposal site. The draft letter and fact sheet were provided to LANL via a March 19, 2002 email. LANL also welcomes the opportunity to respond to the comments incorporated into the fact sheet from a March 11, 2002 letter from James Bearzi of the New Mexico Environment Department (NMED), which you also provided to LANL via an email dated March 18, 2002.

First, we would like to address issues raised in the discussion section of the fact sheet. We agree that the primary consideration of the proposed reauthorization is for PCB waste and understand that conditions of approval, in accordance with 40 CFR 761.75 (c)(3)(ii) may be made to ensure that operation of the PCB waste landfill does not present an unreasonable risk of injury to health or the environment from PCBs. The fact sheet states that NMED has concerns on the role of fracture flow and the transport of some contaminants via colloids because the geology and hydrology at TA-54 are poorly understood. However, TA-54 is one of the most intensely studied areas at Los Alamos National Laboratory. Colloid and fracture-facilitated contaminant transport of PCBs would require 1) open, continuous, coated fractures, 2) colloidal material, and 3) saturated flow conditions. None of these occurs at this site.

Further, in a recent paper, researchers reported on modeling of well injection experiments previously conducted at LANL that evaluated matrix versus fracture flow and referred to in the fact sheet. The paper entitled "Hydrologic Behavior of Unsaturated, Fracture Tuff: Interpretation and Modeling of a Wellbore Injection Test and Implications for Contaminant Transport" reported agreement between the numerical model and previous well injection data referred to in the fact sheet. The migration of moisture injected in the open interval of the wellbore exhibited flow that was controlled by both gravity and capillary forces. In addition to qualitative agreement with moisture cross sections constructed from neutron log data, the model provided an adequate match to data on rates of migration of the water plume in the vertical and lateral directions. The modeling study concluded that since matrix-dominated flow was observed at the high effective

infiltration rates in the wellbore injection test, then it is even more likely to be the case under natural conditions on the Pararito Plateau, which includes Area G. This supports the conceptual model that matrix flow rather than fracture flow is the dominant flow mechanism in the Bandelier Tuff. A copy of the paper is enclosed.

Previous studies at Area G found that: 1) The Bandelier Tuff is characterized by very low moisture content, typically in the range of two to five percent. This value coupled with high capillary tension results in moisture movement via unsaturated flow processes predominate over saturated flow. 2) The tuff is very porous, averaging 50 percent porosity and has high moisture retention properties. 3) Soil water tension as measured by thermocouple psychrometers range from one to fifteen bars. Monthly averages typically range from two to seven bars. 4) Neutron measurements of vadose zone moisture show that seasonal variation of moisture occurs in the upper 10 to 15 feet of the vadose zone. Moisture content below 15 feet does not appear to change with time. 5) Neutron measurements of moisture after precipitation events indicate the maximum depth of wetting to be approximately 10 feet. The consensus of every investigation conducted at the site is that the tuff beneath the disposal areas is dry and conditions that would lead to saturated flow have not been discovered.

The fact sheet discusses tritium in well R-22. The completion report for well R-22 is enclosed. The first sample collected from the well, which was at the time of drilling on 9/30/00, had a tritium concentration of 109 pCi/L. Several rounds of subsequent sampling of the well show tritium concentrations at lower levels. The sample collected in January 2002 had 14 pCi/L, which is similar in magnitude to levels found at other LANL wells drilled at locations away from the disposal areas at TA-54. LANL will continue to evaluate geochemistry at all wells, but at such low concentrations, it is difficult to distinguish what might be tritium resulting from worldwide fallout versus past disposal activities. It should be noted that tritium migration from solid waste disposal areas has been limited in extent. Tritium has a much greater mobility in the subsurface than do PCB compounds. The mechanism of transport for tritium at Area G is typically as vapor diffusion. In contrast, the mechanism necessary to transport PCB as liquid is not readily available. It would therefore be inappropriate to apply significance between the low levels of tritium detected in well R-22 and the potential for liquid migration of PCBs through the subsurface at Area G.

Section 5 of the fact sheet includes a discussion on past references submitted in support of previous PCB disposal reauthorizations for Area G. The discussion should include a reference to the "Hydrogeologic Assessment of Technical Area 54, Areas G and L, Los Alamos National Laboratory, Docket Number NMHWA 0010007". The report was prepared in response to a compliance order issued by the then New Mexico Environmental Improvement Division. The order mandated that certain tests and investigations be performed at Areas G and L to obtain information on the hydrogeologic characteristics of the waste disposal areas relevant to the potential for migration of waste constituents to ground water. The report was later submitted to EPA Region 6 in 1991 in support of the review of the Area G PCB disposal reauthorization. Beginning in 1985, eighteen boreholes 100 to 135 feet deep, were drilled into the mesa top where

TA-54 is located, five of which were drilled next to disposal pits at Area G. Hydrologic testing and geophysical logging were performed in the boreholes. Selected boreholes were also completed for pore gas sampling, neutron moisture monitoring and psychrometer installation. One of the conclusions of this study was "The combination of very low moisture content in the tuff, empirical determination that moisture from precipitation does not infiltrate below a depth of ten to 22 feet, and very low calculated flux rates all suggest that aqueous transport of contaminants through Bandelier tuff is not a viable mechanism for contaminant migration at Area G and L".

The fact sheet states that NMED has required additional vadose zone characterization. Indeed, LANL's Solid Waste Regulatory Compliance Group installed 2 additional pore gas monitoring systems located at the east and west boundaries of Area G. Also, LANL, as part of the Environmental Restoration Project, drilled twenty additional boreholes adjacent to disposal pits at Area G; two in 1994 and 18 in 1995. Some of the boreholes were inclined towards pits and depths ranged from 17.5 to 153 feet. Core samples were analyzed for PCBs as well as VOCs, SVOCs, metals, pesticides, cyanide and radionuclides. Of the 124 samples submitted, one was found to have a PCB compound: Aroclor 1251 at 0.31mg/kg. These results are discussed in the "RFI Report for Material Disposal Areas (MDAs) G, H, L at Technical Area (TA) 54", LA-UR-00-1140. A copy of the chapter that applies to Area G is enclosed with this letter. As part of the decision process described in the report, PCBs were not retained as a contaminant of potential concern. None of these additional boreholes were adjacent to the PCB disposal shaft field. However it is worth re-iterating that, as stated in the fact sheet, PCBs were not detected in samples collected from an 80 foot deep borehole drilled in 1994 within 10 feet of the oldest Area G PCB shaft and within 15 feet of two adjacently located PCB disposal shafts.

Again, it is LANL's understanding that a conditional approval may be made to ensure that operation of the PCB disposal landfill does not present an unreasonable risk of injury to health or the environment from PCBs. From the previous studies referenced above, it is unclear as to where additional subsurface monitoring for PCBs is needed. It has been LANL's practice to dispose of the higher concentration PCB waste (>500 ppm) in shafts and lower concentration PCB waste in pits. As previously mentioned, the borehole drilled next to one of the oldest shafts did not detect the presence of any PCBs nor did any of the RFI boreholes drilled at several locations at Area G. After you have reviewed the reports referenced above on the previous subsurface investigations, we would like to discuss with you the areas at Area G that you believe are in need of further investigation.

In addition, LANL has comments on the conditional approval letter:

II.D. <u>New PCB Storage Areas:</u>

"PCBs shall not be stored in a new storage area, other than those authorized in condition II. B. above, without first notifying the EPA Region 6, OK/TX RCRA Permits Section, before PCBs may be stored in the new storage facility. LANL shall submit to the EPA Region 6, OK/TX RCRA Permits Section, a Notification of PCB Activity (EPA form 7710-53) 30 days before beginning to use the new PCB storage area."

LANL requests section II.D be modified as follows: *"PCBs shall not be stored in a new storage area, other than those authorized in condition III.E below..."*and section III.E.1 be modified as follows:. *"The PCB storage facilities, located in Areas G and L, shall comply with PCB storage requirements in 40 CFR 761.65"*. LANL currently stores most of its PCB waste at Area L for disposal off-site at an approved facility. A lesser amount of PCB waste with a higher amount of radioactivity is stored at Area G. LANL also temporarily stores PCB waste, as allowed by 40 CFR 761(c)(1). at locations throughout the 43 square mile complex. However, since LANL does not meet the definition of a commercial storer of PCBs, there seems to be no requirement for approval of storage. While LANL agrees to the conditions of this approval for storage at TA-54 facilities, we also understand the condition of this approval does not prohibit the temporary storage of PCBs throughout other facilities at LANL.

III. C. <u>PCB Pit Operating Requirements:</u>

"4. The ponding of snowmelt or stormwater is not permissible over a PCB pit."

LANL requests this condition (III.C.4) be required for completed pits only. LANL has graded the areas around operational pits to prevent run on of stormwater or snowmelt into the pits. However, since these operational pits are open to the weather, direct precipitation into the pits will result in temporary accumulations of water or snow that could be interpreted as a possible violation of the condition, as written.

III.F. <u>Surface and Ground Water Monitoring Requirements:</u>

"5. Any instance of detection of PCBs in any samples collected and analyzed under conditions III. F. 1- 4 above shall be reported in writing within five (5) working days of its discovery. The report shall be submitted to the OK/TX RCRA Permits Section at EPA Region 6."

As a point of clarification, LANL understands that this requirement for 5 day reporting will apply only to Aroclor PCB detection. LANL, in cooperation with NMED, will be analyzing selected water samples from various locations at LANL for individual PCB congeners. The method to be used has a detection limit in the parts per trillion range. At such a low detection limit, LANL anticipates the possibility of frequent detection of trace PCB congeners, as well as the possibility of false positive detections. These congener data will be available to EPA upon request, but in order to avoid potentially frequent 5 day notifications to EPA Region 6, LANL proposes to report only Aroclor detections following the methods required under 40 CFR 761.75(b)(6)(iii).

IV.B Closure and Post Closure

"LANL shall submit a closure plan to EPA Region 6, OK/TX RCRA Permits Section, at least 60-days prior to the planned beginning of closure of an authorized pit or shaft under this approval. The closure plan shall include a proposal and design for a cap over the PCB pits or shafts to be closed. The closure plan must be approved by EPA in writing before beginning closure."

The projected use of Area G as a disposal site extends to the year 2044. At that time, LANL will use the best management practices available at that time to close Area G. Until that time, LANL proposes to place operational covers over the pits and shafts. The procedure to be followed is discussed in the document, "Area G Preliminary Closure Plan", Report 54G-027-R0. A final revision of the closure plan for Area G is now being drafted and will be forwarded to your office when it has been completed.

V. M. Spills:

"PCB spills occurring at the disposal site or from any LANL owned PCB transport vehicle, shall be cleaned up according to the PCB Spill Cleanup Policy, 40 CFR Part 761, Subpart G. PCB spills occurring outside PCB storage areas shall be reported within twenty-four (24) hours of the event to the EPA Region 6, PCB Spill Coordinator, Toxics Enforcement Section. The EPA may order cessation of PCB disposal at LANL if spills are not cleaned up to acceptable levels defined by EPA."

As a point of clarification, it is requested that the phrase "in accordance with the requirements 40 CFR 761.125(a)(1)" be inserted in the second sentence after the word "reported".

Finally, LANL has the following comments on the fact sheet.

Under the Background section, paragraph 3 for information submitted, a reference to the document "Hydrogeologic Assessment of Technical Area 54, Areas G and L, Los Alamos National Laboratory, Docket Number NMHWA 0010007" should be added.

Under the Background section, paragraph 5, LANL requests the second sentence be deleted.

Under Discussion item number 2 it should be clarified that LANL complied with NMED request for vadose zone characterization with the submittal of the above referenced Hydrogeologic Assessment of Technical Area 54, Areas G and L and subsequent monitoring of pore gas continues.

Under Discussion item number 3, LANL does not agree with inclusion of the statement that the source of tritium at R-22 is most likely from the older pits at Area G. LANL requests that you delete from the end of the third sentence the phrase "...but the source is most likely from the older pits that were in use before

the RCRA or TSCA regulations were put into effect which limit the type of wastes disposed" and insert the sentence "Based on the extremely low tritium concentrations detected, it is difficult to determine if the tritium is a result of fallout seen at similar levels or from past disposal activities." LANL also requests, in the fourth sentence, the word "would" be replaced with "could".

Under Discussion Item number 4, first sentence, LANL requests the phrase "...LANL's Environmental Surveillance sampling, analysis and reporting program ..." replace the words "...the groundwater monitoring requirements,". This will help clarify that monitoring of well R-22 will be included as part of LANL's overall Environmental Surveillance Program and not as a separate and additional monitoring requirement.

Under Discussion Item number 5, Issue #3 discusses a study in which water was injected into Bandelier tuff and references modeling data in the report "Los Alamos County Landfill Groundwater Monitoring Program Request for Suspension" and states "...LANL concluded that lateral movement of PCBs was unlikely in Area G." LANL conclusion of no lateral movement of PCBs was based on the results of the borehole drilled next to a PCB shaft that is addressed in Issue #2.

Under the State Review of the Proposal section, LANL requests that the seventh sentence in the first paragraph be revised as follows: "Finally, the LANL RCRA permit is currently up for renewal, and it is important to the NMED that closure issues related to Area G in the RCRA permit be considered in approving the PCB disposal reauthorization."

Under the 6E Compliance Review section, it is stated that there may have been some PCB storage violations for PCB storage over the one-year limit. Waste that has been stored for more than year is mixed radioactive PCB waste only and is exempt from the one-year storage limit.

Again thank you for the opportunity to comment on the fact sheet and approval letter. If you need any additional information please contact me at 667-4715. If needed, LANL representatives are available to meet with you to discuss any of the points addressed above.

Sincerely,

Albert Dye

Albert Dye
SWRC

Enc. a/s

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Title: Hydrologic Behavior of Unsaturated, Fractured Tuff: Interpretation and Modeling of a Wellbore Injection Test and Implications for Contaminant Transport

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Hydrologic Behavior of Unsaturated, Fractured Tuff: Interpretation and Modeling of a Wellbore Injection Test and Implications for Contaminant Transport

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May 16, 2001

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Abstract

An injection zone test in the Tshirege Member of the Bandelier tuff reported by Purtymun et al. (1989) has been interpreted and modeled using a continuum model that considers only matrix flow. The agreement of the numerical model and the data was quite acceptable, both qualitatively and quantitatively. The migration of moisture injected in an open interval of the wellbore exhibited flow that was controlled by both gravity and capillary forces. In addition to qualitative agreement with moisture cross sections constructed from neutron log data, the model provided an adequate match to data on the rates of migration of the water plume in the vertical (upward and downward) and lateral directions. Although more complex model formulations are possible, the continuum model is demonstrated to reproduce the injection data, and therefore is to be favored due to its simpler formulation and ease with which it is implemented in large-scale flow and transport simulations. Since matrix-dominated flow is observed at the high effective infiltration rates of this injection test, then it is even more likely to be the case under natural conditions on the Pajarito Plateau, the location of Los Alamos National Laboratory (LANL). Additional field scale monitoring and site characterization efforts are required to extend the results to solute transport, so that calibrated models can be used reliably to predict the transport of contaminants introduced to the groundwater from past LANL operations.

Keywords: unsaturated flow; fractured tuff; fluid injection test; groundwater modeling

Various techniques have been employed to confirm this element of the conceptual model and to estimate infiltration rates. Rogers et al. (1996) combined moisture content measurements from cores with measurements of the unsaturated characteristic curves to estimate infiltration rate at various locations around the Laboratory. This method assumes steady state, vertical flow under unit-gradient conditions, for which the unsaturated conductivity estimated at the measured water content equals the local infiltration rate. Infiltration rates on mesas were estimated to be as low as 0.06 mm/y, with much higher values only found where surface disturbances such as ponds altered the natural surface conditions. Newman (1996) and Birdsell et al. (2000) report similar results from estimates using the chloride mass balance method (e.g. Allison et al., 1985), choosing a conservative upper bound of 10 mm/y for performance assessment calculations. By contrast, Robinson et al. (1999), using a water budget study of Gray (1997), estimated infiltration rates on the order of 200-1000 mm/y in Los Alamos canyon in the vicinity of Laboratory technical areas. Numerical simulations presented by Robinson et al. (1999) showed that these high infiltration rates provided a good match to water content profiles measured in Los Alamos canyon in well LADP-3, whereas rates on the order of 1 mm/y were needed on the mesa tops to match the results from LADP-4, a well located on a mesa adjacent to Los Alamos canyon.

In all mesas and at many locations within canyons, the Bandelier tuff is the first rock type encountered beneath surface soils or alluvium. Therefore, contaminants released at the surface must migrate through the Bandelier Tuff. The Bandelier tuff is comprised of the Tshirege Member and the Otowi Member. These rocks are multiple-flow ash-flow sheets that typically represent the first unit exposed on the mesas of the Plateau. Beneath the Bandelier tuff is typically a horizon of fanglomerate deposits called the Puye Formation, which may or may not be intercalated with Basalts such as the Cerros del Rio Basalt. The Puye formation consists of a wide range of rock fragments, from sandy or clayey materials to bolder-sized. The Basalts are likely to exhibit fracture flow under unsaturated or saturated conditions due to their low matrix permeability and columnar jointing pattern. Contaminants reaching the water table of the regional aquifer do so within the Puye formation, where they are presumed to travel laterally subject to the prevailing direction and velocity of groundwater flow. The main potential receptors of contaminated groundwater under this scenario are the users of the domestic water supply, which is derived from a network of water supply wells in the area.

Given the characteristics of the Puye Formation and the Basalts, there may be rapid transport of water and contaminants once they reach these units. The Bandelier Tuff, on the other hand, may provide a significant barrier to contaminant migration due to its relatively porous and permeable character. However, there are various degrees of welding within the Bandelier Tuff, and many of the sub-units contain fractures that must be considered as possibly fast pathways. Therefore, for this rock to attenuate the infiltration of contaminated groundwater, it must be demonstrated that water percolates through the porous rock matrix, rather than channeling through fractures. The purpose of the water injection test analysis presented in this

paper is to make interpretations from experimental observations and modeling that are relevant to the critical issue of fracture versus matrix flow in the Bandelier Tuff.

Conceptual and Numerical Models for Flow in Unsaturated Fractured Tuffs

There are several different approaches for simulating unsaturated flow and transport in fractured tuff systems. Viswanathan et al. (2000) summarize the available models that have been used to examine the role of fractures in unsaturated tuffs, with emphasis on understanding the hydrologic behavior of tuffs. The work performed to date has focussed at present on Yucca Mountain, Nevada, the potential site of the Nation's high-level radioactive waste repository. With varying degrees of assumption, each modeling approach seeks to capture the role of fractures on hydrology and transport. Three common modeling approaches are:

- Discrete Fracture Model: The discrete fracture representation embeds fractures with distinct hydrologic properties within a model domain that includes the rock matrix. Water can either channel through the fracture or imbibe into the matrix, depending on the hydrologic properties of each medium. Nitao and Buscheck (1991), Soll and Birdsell (1998), and Viswanathan et al. (2000) used this approach to study fracture-matrix interactions under unsaturated conditions.

- Dual Permeability Model: In the dual permeability method, both the fracture and matrix domains are discretized using the same numerical grid, giving rise to two individual continua with a one-to-one mapping of grid points between each domain. At each grid point, the matrix is also coupled to the fractures through a first-order interaction term. Depending on the nature of this interaction term, either a fracture-dominated, matrix-dominated, or a combined fracture-matrix flow regime results. Details of the model formulation can be found in Bodvarsson et al. (1997) or Tseng and Zyvoloski (2000).

- Equivalent Continuum Model: The equivalent continuum model simply attempts to capture characteristics of both the fractures and matrix with a single set of properties. The primary assumption in the model is that the capillary pressure in the fractured medium equals that in the matrix (Peters and Klavetter, 1988). This approach is simpler computationally, but it cannot easily reproduce fracture-dominated flow and transport. Limits of the applicability of the ECM for fluid flow were explored by Pruess et al. (1990), and Viswanathan et al. (1998) extended the analysis to include solute transport.

Each method has its trade-offs between the realism with which the actual physical system is represented, the available data characterizing the system and processes, and the efficiency and applicability of the numerical method. Fundamentally, the issue of greatest importance is the degree to which fractures channel flow through the rocks under unsaturated conditions. This issue has been explored both theoretically and experimentally. Nitao and Buscheck (1991) examined an idealized system of parallel, equally spaced

fractures with water entering at the top, and migrating downward under gravity. They showed that rocks with large porosities and permeabilities have a strong driving force for water to quickly imbibe into the rock matrix. Under these conditions, the water front is quickly attenuated, and in the limit, the downward-migrating wetting front essentially behaves as though the fractures are not present. Experimentally, Bussod et al. (2000) are studying the transport of water and tracers under unsaturated conditions in an experimental facility at Busted Butte, Nevada, located near the potential repository at Yucca Mountain. Robinson and Bussod (2000) showed the results of an injection test in which the presence of a fracture in the nonwelded, permeable Calico Hills tuff appeared to have no effect on the migration of water and tracer away from the injection point.

Because of these results, we chose, in an initial attempt to simulate the results of the water injection test described in the present study, to model the flow behavior using a continuum approach that considers fluid percolation through the matrix, with no fracture contribution. Therefore, we have simplified the equivalent continuum model by ignoring fractures altogether, assigning matrix flow properties to the rocks in accordance with the hydrologic parameters measured on laboratory samples. In so doing, we are testing the hypothesis that for the Bandelier Tuff, the matrix dominates the flow behavior under unsaturated conditions. An adequate match to the data will validate the flow mechanism, whereas a poor fit, especially one that underpredicts downward travel velocities, will be cause to consider more complex models.

Water Injection Tests in the Unsaturated Bandelier Tuff

In the 1960's, Los Alamos National Laboratory and the U.S. Geological Survey conducted a series of tests to explore the possible use of injection wells for water disposal. The original intent of these studies was to determine if shallow injection wells drilled into the unsaturated zone on the Pajarito Plateau could be used to safely dispose of liquid effluent from Laboratory operations. The method was never used at Los Alamos, and current regulations, along with the Laboratory's desire to be responsible stewards of the environment, preclude this concept from ever being implemented. Nevertheless, data collected from injection tests carried out in 1965, which used uncontaminated water, can be used to understand the hydrologic processes controlling the movement of moisture in the unsaturated Bandelier tuff.

Information collected from two test areas is available for interpretation. A report by Purtymun et al. (1989) summarizes the goals of these tests to be:

- To investigate the rates of injection and the operating conditions under which the tuffs would accept water; and
- To monitor the movement of moisture from the injection well to the surrounding tuff.

Detailed descriptions of the testing methodology, layout, and measurement techniques are presented in Purtymun et al. (1989), so only a brief summary is given here. The complex of injection and observation wells are located on a narrow mesa adjacent to Technical Area 50 (TA-50), the site of the Laboratory's

radioactive waste treatment facility. These wells, shown in map view in Figure 2, are all completed in the upper Tshirege Member, a series of nonwelded to welded ash flow tuffs. The injection tests were conducted in a phased approach, with four preliminary gravity-flow tests of 50-140 hour duration used mainly to design subsequent injection and monitoring experiments. Then, three longer duration tests were performed in which moisture monitoring was carried out to track the movement of fluids through the unsaturated tuffs.

The test for which numerical modeling is performed in the present study (called "Test 1 at Site 2" in Purtymun et al., 1989), consists of an injection period of 89 days. Figure 3 shows the injection system used for the test. Water from municipal water sources was pumped into a 500 gallon storage tank, which discharged into a smaller drum controlled with a float valve to maintain a constant pressure at the ground surface. The 5-inch diameter injection well was completed to a depth of 65 feet, with gravel located in the injection zone from 55 to 65 feet, and cement above and below. The 1.25-inch injection pipe was fitted with a perforated endpiece to distribute the flow. A second pipe was also installed to monitor the downhole pressure.

Figure 4 shows the measured flow conditions during the test. Despite the constant pressure controlled at the surface, the injection-zone pressure (Figure 4a) exhibited variations within the first 20 days before stabilizing for the remainder of the injection period. In general, the injection rate (Figure 4b) was inversely proportional to the pressure. Purtymun et al. (1989) cite possible causes to be variations in atmospheric temperature and pressure, and dissolved gas in the injected fluid. Any of these effects could cause the local conditions in the rock immediately adjacent to the injection region to be affected. We view these effects to be of relatively minor consequence for the purpose of the study, which is to monitor and model the migration of fluid through the unsaturated zone. For simulating the processes controlling this migration, the time-varying rate of water injection is required. Therefore, the time dependent injection rate of Figure 4b is used as direct input to the model. The cumulative mass of water injected versus time is shown Figure 4c. A total of 1.27×10^6 kg of water was injected during the 89-day injection phase of the experiment.

Moisture monitoring was carried out using neutron logs of the surrounding wells (see Figure 2). These data were used by Purtymun et al. (1989) in two ways. First, data from wells N-1 and SE-3, located close to the injection well, were used directly to determine the rates of movement vertically upward and downward from the injection region. These data are presented with the model comparison in the next section. Also, data from all wells were used to measure the extent of lateral migration and to construct representative cross sections of moisture content at various times. These cross sections were constructed by projecting the results from all boreholes onto a single cross section. Figure 5, reproduced from Purtymun et al. (1989), shows these cross sections. The first four, constructed from data at 7, 29, 55, and 89 days after the start of injection, are during the pumping phase, while the last one is from data collected at day 327, some eight months after injection was stopped. As a check of the validity of these two-dimensional representations of the data, Purtymun et al. (1989) also confirmed that the integrated amount of injected

water implied by the constructed cross section agreed closely with the known amount of water injected. Therefore, all injected water is approximately accounted for in the cross sections shown.

Interpretations of measured shape and velocity of movement of the water plume will be presented in the next section.

Numerical Model

We use the Finite Element Heat and Mass (FEHM) code to perform the numerical simulations presented in this paper. This code has been used extensively to model unsaturated and saturated flow and contaminant transport in porous and fractured media (see for example Viswanathan et al., 1998, Robinson and Bussod, 2000, Viswanathan et al., 2000). Detailed derivations of the governing equations of two-phase flow as implemented in FEHM have been described previously (Zyvoloski, 1983, Tseng and Zyvoloski, 2000). The code uses a control volume finite volume approach to discretize the finite element domain. This technique provides the flexibility needed to capture the complex geometries often encountered when modeling subsurface flow and transport. In the present study, the model uses a simplified subset of the balance equations by assuming isothermal, two-phase flow of air and water. This simplification reduces the computational burden without sacrificing needed physics. Several solute transport options are also available but are not used in the present study. For details, see Zyvoloski et al. (1997), Viswanathan et al. (1998), and Robinson et al. (2000).

For unsaturated media, the relationship between permeability and fluid saturation is required. For this model, we use the moisture characteristic curve model of van Genuchten (1980) because the available site data measured on core samples have been reduced using this model. Table 1 gives the characteristic curve parameters, the saturated permeability, and porosity for each hydrogeologic unit in the model. The data are obtained from Rogers and Gallaher (1995), who compiled the data collected for the Bandelier Tuff from samples collected from numerous boreholes on the Pajarito Plateau. The values cited in Table 1 are mean values of the parameters published in that study.

A three-dimensional numerical grid was constructed to perform the numerical modeling. Figure 6 shows a top, side, and perspective view of this grid. Increased horizontal resolution is used to capture the flow system near the injection region in detail. The vertical resolution is variable for the same reason, and to allow the interfaces between the various hydrogeologic layers (shown in the side view) to be captured. Vertical locations of the layers are based on the geologic model of the LANL site constructed by Carey et al. (1999). At this location on the Plateau, the interfaces are close to horizontal, so they are represented this way for simplicity. The numerical grid contains 53,391 nodes.

The boundary conditions are no-flow on the four vertical faces of the model, and constant fluid saturation on the top and bottom. All boundaries are far enough removed from the injection interval that they have no effect on the simulated moisture patterns of the injected fluid. To establish a background flow field suitable for starting the injection simulation, a fluid volumetric water content of 0.05 was set at the

top, and the system was run to a steady-state condition. Fluid injection is simulated with a source flow rate versus time shown in Figure 4b. The wellbore and injection zone is not captured in detail in the model. Instead, injected water is input at a single node at the appropriate location in the model. The z-dimension of the control volume associated with this node is similar to the size of the injection interval, so the input of water into the rock mass is captured in the model, even if the detailed patterns near the wellbore are not. Interpretations will focus on the movement of the moisture plume at significant distances from the injection point, and no attempt will be made to match data controlled by processes occurring near the injection point, such as the injection-zone pressure.

Figure 7 shows two-dimensional cross sections of volumetric water content through the three-dimensional model at times corresponding to the moisture plumes constructed from the data (Figure 5). Many elements of the measured moisture migration are captured well by the model. The general movement of moisture is in all directions, but predominantly downward. Zones of high water content build near the injection point, gravitational forces pull the plume downward, and capillary forces transmit fluid laterally and upward, as the plume grows during the injection (Figures 7a-c). There is a noticeable effect, both in the data and the model, of the transition in hydrologic properties at the location of the Qbt3/Qbt2 interface. Moisture migration is controlled by somewhat different hydrologic properties in the two units, causing the formation of two overlapping zones of higher water content, one near the injection point and one within the Qbt2 Formation (Figures 7c and d). After injection ends, redistribution of moisture in the rock mass continues during the post-injection monitoring period. The plume continues to migrate downward as well as laterally, resulting in lower water contents spread out over a larger volume (Figure 7e).

Quantitative comparisons of model and data are also possible by examining the data on the extent of injection water migration, as measured by the location of the 5% water content front. Table 2 presents the model and data comparison in the form of average rates of movement during different intervals of the test. The upper portion of the table represents downward migration rates. Both model and data show an initial high rate of movement, followed by a tapering off of the rate as the moisture plume spreads. The center portion of Table 2 records lateral movement of the moisture front from the injection point, which exhibits a similar trend, but starting at slower rates. Since lateral migration is driven only by capillary forces, the rates are lower than for downward migration, for which gravity also contributes. Finally, the bottom section of Table 2 shows the upward distance that the plume migrated at two measurement times, the second being after the eight-month post-injection period. These distances are also controlled by capillary forces, in this case working against gravity. The agreement of model and data illustrate that the conceptual model is capable of describing capturing the key hydrologic processes in effect in the injection test, and that no further calibration is needed to provide a quantitative agreement.

Discussion and Conclusions

An injection zone test in the Tshirege Member of the Bandelier tuff reported by Purtymun et al. (1989) has been interpreted and modeled using a continuum model that considers only matrix flow. The agreement of the numerical model and the data was quite acceptable, both qualitatively and quantitatively. The migration of moisture injected in an open interval of the wellbore exhibited flow that was controlled by both gravity and capillary forces. Flow was preferentially downward, as would be expected under conditions of relatively high flow rate. Lateral and upward migration also occurred due to the capillary driving forces in this unsaturated rock. The effects of an abrupt transition in hydrologic properties at the interface between two sub-units were also observed in both the data and the numerical model. In addition to this qualitative agreement, the model provided an adequate match to data on the rates of migration of the water plume in the vertical (upward and downward) and lateral directions. This agreement was achieved using hydrologic properties derived from laboratory measurements performed on samples collected from boreholes on the Pajarito Plateau, though not from the site of the injection test itself. This result may imply that if the conceptual model is correct, then the exact values of the hydrologic properties are not critical, as long as the parameters are derived from the same hydrologic unit.

Confirmation that a conceptual and numerical model agrees with field scale data, though encouraging, does not guarantee that other conceptualizations are not also valid. For example, a dual permeability model of fractures and matrix reduces to matrix-dominated flow behavior under certain limiting conditions. It can also be argued that a discrete fracture formulation, such as that of Nitao and Buscheck (1991), is consistent with the results in the sense that it predicts rapid imbibition of water into the matrix for these types of rocks. However, the critical issue is whether the relevant processes are captured, not which mathematical formulation is chosen. The continuum model is demonstrated to reproduce the injection data, and therefore would be favored due to its simpler formulation and ease with which it is implemented in large-scale flow and transport simulations.

The representativeness of the experimental results also requires discussion, given that the data are for a point-source injection from a wellbore, rather than natural infiltration. In determining whether preferential flow through fractures is occurring, the downward flux of water is a key factor, along with the hydrologic properties of the rock. To estimate the equivalent infiltration rate during the test, we divide the fluid injection rate by the cross sectional area of the water plume at a particular time. Applying this method at day 55 of injection, we obtain an estimated flux of about 2.7×10^4 mm/y. This rate is much higher than the average infiltration rates estimated for the Pajarito Plateau, even in canyons. Values this large probably occur only locally in areas of ponding or underneath locations with streamflow. The implication of this calculation is that if matrix-dominated flow is observed at the high effective infiltration rates of this injection test, then it is even more likely to be the case under natural conditions on the Plateau.

With respect to the hydrologic conditions encountered in locations where dissolved contaminants are an issue, the consequence of matrix-dominated flow is to decrease travel velocities beyond what would

be the case if preferential channeling through fractures were to occur. For example, for an infiltration rate of 1 mm/y, typical of a mesa location, and a water content of 0.1, downward velocities will be on the order of 0.01 m/y. Under these conditions, a non-sorbing contaminant front would take 10,000 years to percolate through 100 m of unsaturated Bandelier Tuff. A similar calculation for a wet-canyon scenario (500 mm/y, water content of 0.25) yields a transport velocity of 2 m/yr, or a travel time of 50 yr to traverse 100 meters of Bandelier Tuff. Corresponding estimates if the hydrology were controlled by fractures would be to reduce the water contents to 10^{-3} or lower to account for the small fraction of the total rock volume that is taken up by the fracture void space. Travel times to traverse the same 100 meters of Bandelier Tuff would be 100 years for the mesas and 0.2 yr for the wet canyons. In addition, if water containing contaminants percolates through the rock matrix, it is likely to be in intimate contact with the rock surfaces. Therefore, for contaminants that sorb to the rock, matrix-dominated flow increases the likelihood of retardation. This process can also occur during fracture flow, but sorption is not as effective because the contaminant must first diffuse to the fracture surface and into the rock matrix in order to sorb. As a result, even sorbing contaminants are probably relatively mobile under fracture flow conditions.

Qualitatively, the existing information on groundwater contaminant migration from Laboratory facilities agrees with this assessment of the role of the Bandelier Tuff in the unsaturated zone. There is evidence that some nonsorbing contaminants such as tritium have traveled significant depths through the unsaturated zone, even to the regional aquifer (Rogers, 1998) during the 50+ years of Laboratory operation. This is probably a consequence of releases into canyons, and transport at high percolation rates through regions where the Bandelier Tuff is thin or not present. However, most known contaminant releases have not traveled that far, and thus still reside in the unsaturated zone. Releases on mesas, with low infiltration rates, or sorption of contaminants such as Strontium and Uranium onto the Bandelier Tuff, are probably the explanation.

In addition to providing a context for assessing the risk of Laboratory-derived groundwater contamination, the results also provide direction for future unsaturated zone characterization activities. At present, there appears to be no need to embark on a costly and time-consuming effort to characterize the fracture systems in the Bandelier Tuff for the purpose of predicting water percolation and contaminant transport. Note that this conclusion refers only to liquid movement through the Bandelier Tuff, and does not apply to other rock types of interest such as the Basalt units, and is not meant to imply that other types of fracture studies are not important and useful site characterization activities. Another implication of the results is that contaminants released on mesas or in canyons with significant thicknesses of Bandelier tuff should be able to be approximately mapped using a series of relatively shallow, vertical boreholes to determine the vertical extent of transport. Contaminant fronts that are mapped in this way would provide information on field scale infiltration rates and sorption characteristics that could be applied to calibrate models of flow and transport. They would also provide confirmation of the results presented in this study, especially with respect to contaminant transport. Finally, although flow was demonstrated to occur in the matrix, this does not mean that flow is necessarily uniform within the matrix. An instrumented monitoring

system constructed and operated in the Bandelier Tuff would provide additional confirmation of flow processes and important insights into the transport system, including the role of heterogeneities on the detailed flow and transport system. Such a field invetigation would likely improve transport predictions and provide additional confidence in the conceptual model.

Thus, although the conclusions of the present study do not apply to all contaminants at all Laboratory sites, the observations and accompanying modeling provide an important perspective on flow and transport through the tuffs in the unsaturated zone under the Pajarito Plateau. If followed up with appropriate additional characterization and monitoring efforts, the results should contribute to a strategy for cost-effectively dealing with many of the groundwater contamination issues facing the Laboratory.

Acknowledgements

This work was conducted under the auspices of the U.S. Department of Energy, Los Alamos Environmental Restoration Project. The authors also wish to thank the many staff of the Laboratory's Environmental Restoration Project for many useful discussions during the course of this work. Special thanks go to Diana Hollis for supporting the modeling effort and suggesting that this test be used to test the conceptual model presented in this study, and to Kay Birdsell for her thorough review of this manuscript.

References

Allison, G.B., W.J. Stone, and M.W. Hughes, 1985. Recharge in karst and dune sediments of a semi-arid landscape as indicated by natural isotopes and chloride, J. Hydrol., 76, 1-26.

Birdsell, K.H., A.V. Wolfsberg, D. Hollis, T.A. Cherry, K.M. Bower, 2000. Groundwater flow and radionuclide transport calculations for a performance assessment of a low-level waste site, *J. Contam. Hydrol.*, in press.

Bodvarsson G.S., T.M. Bandurraga, and Y.S. Wu, 1997. The site-scale unsaturated zone model of Yucca Mountain, Nevada, for the Viability Assessment. Technical Report LBNL-40378, Lawrence Berkeley National Laboratory, Berkeley, California.

Bussod, G.Y., B.A. Robinson, H.S. Viswanathan, C.W. Gable, H.J. Turin, W.E. Lowry, 2000. Unsaturated zone transport test, Busted Butte, Nevada. 1. Experimental design and field observations, *Water Resour. Res.*, submitted.

Carey, B., G. Cole, C. Lewis, F. Tsai, R. Warren, And G. WoldeGabriel, 1999. Revised Site-Wide Geologic Model for Los Alamos National Laboratory (FY99), Report LA-UR-00-2056, Los Alamos National Laboratory, Los Alamos, New Mexico.

Gray, R.N., 1997. Hydrologic budget analysis and numerical simulations of groundwater flow in Los Alamos canyon near Los Alamos, New Mexico. Master's Thesis, University of New Mexico, Albuquerque, New Mexico.

LANL (Los Alamos National Laboratory), 1998. May 22, 1998. Hydrogeologic Workplan. Los Alamos, New Mexico.

Newman, B.D., 1996. Vadose zone water movement at Area G, Los Alamos National Laboratory, TA-54: Interpretations based on chloride and stable isotope profiles. Los Alamos National Laboratory document LA-UR-96-4682, Los Alamos, New Mexico.

Nitao, J.J. and T.A. Buscheck, 1991. Infiltration of a liquid front in an unsaturated, fractured porous medium, *Water Resour. Res.*, 27, 8, 2099-2112.

Peters, R.R. and E.A. Klavetter, 1988. A continuum model for water movement in an unsaturated fractured rock mass, *Water Resour. Res.*, 24, 3, 416-430.

Pruess, K., J.S. Wang, and Y.W. Tsang, 1990. On thermohydrologic conditions near high-level waste emplaced in partially saturated fractured tuff. 1. Simulation studies with explicit consideration of fracture effects, *Water Resour. Res.*, 26, 6, 1235-1248.

Purtymun, W.D., E.A. Enyart, and S.G. McLin, 1989. Hydrologic characteristics of the Bandelier tuff as determined through an injection well system. Report LA-11511-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

Robinson, B.A., and G.Y. Bussod, 2000. Radionuclide transport in the unsaturated zone at Yucca Mountain: numerical model and field validation studies, Geophysical Monograph 122, Witherspoon Volume, AGU, Washington, D.C., 323-336.

Robinson, B.A., M. Witkowski, C.J. Elliott, L. Dale, and R. Koch, 1999. Numerical model of flow and transport for Los Alamos canyon, Environmental Restoration Project technical report, Los Alamos National Laboratory, Los Alamos, New Mexico.

Robinson, B.A., H.S. Viswanathan, and A.J. Valocchi, 2000. Efficient numerical techniques for modeling multicomponent ground-water transport based upon simultaneous solution of strongly coupled subsets of chemical components, *Adv. in Water Resour.*, 23, 307-324.

Rogers, D.B., and B.M. Gallaher, 1995. The unsaturated hydraulic characteristics of Bandelier tuff, Report LA-12968, Los Alamos National Laboratory, Los Alamos, New Mexico.

Rogers, D.B., B.M. Gallaher, and E.L. Vold, 1996. Vadose zone infiltration beneath the Pajarito plateau at Los Alamos National Laboratory. New Mexico Geological Society Guidebook, 47th Annual Field Conference, Jemez Mountains Region, 413-420.

Rogers, D.B., 1998. Impact of tritium disposal on surface water and groundwater at Los Alamos National Laboratory through 1997. Report LA-13465-SR, Los Alamos National Laboratory, Los Alamos, New Mexico.

Soll, W.E. and K.H. Birdsell, 1998. The influence of coatings and fills on flow in fractured, unsaturated porous media systems, *Water Resour. Res.*, 34, 2, 193-202.

Tseng, P.H. and G.A. Zyvoloski, 2000. A reduced degree of freedom method for simulating non-isothermal multi-phase flow in a porous medium, *Advan. in Water Resour.*, 23, 731-745.

van Genuchten, M.T., 1980. A closed-form solution for predicting the hydraulic conductivity of unsaturated soils, *Soil Science Soc. of Amer. J.*, 44, 892-898.

Viswanathan, H.S., B.A. Robinson, A.J. Valocchi, and I. Triay, Nov. 1998, A reactive transport model of neptunium migration from the potential repository at Yucca Mountain, *J. Hydrol.*, 209, 251-280.

Viswanathan, H.S., G.Y. Bussod, B.A. Robinson and H.J. Turin, 2000. Unsaturated zone transport test, Busted Butte, Nevada: 2. Model development and comparison to field data. *Water Resour. Res.*, submitted.

Zyvoloski, G., 1983. Finite-element methods for geothermal reservoir simulation, *Int. J. Numer. and Analyt. Meth. in Geomech.*, 7, 75-86.

Zyvoloski, G.A., B.A. Robinson, Z.V. Dash, and L.L. Trease, 1997. Summary of the models and methods for the FEHM application - A finite-element heat- and mass-transfer code. Report LA-13307-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

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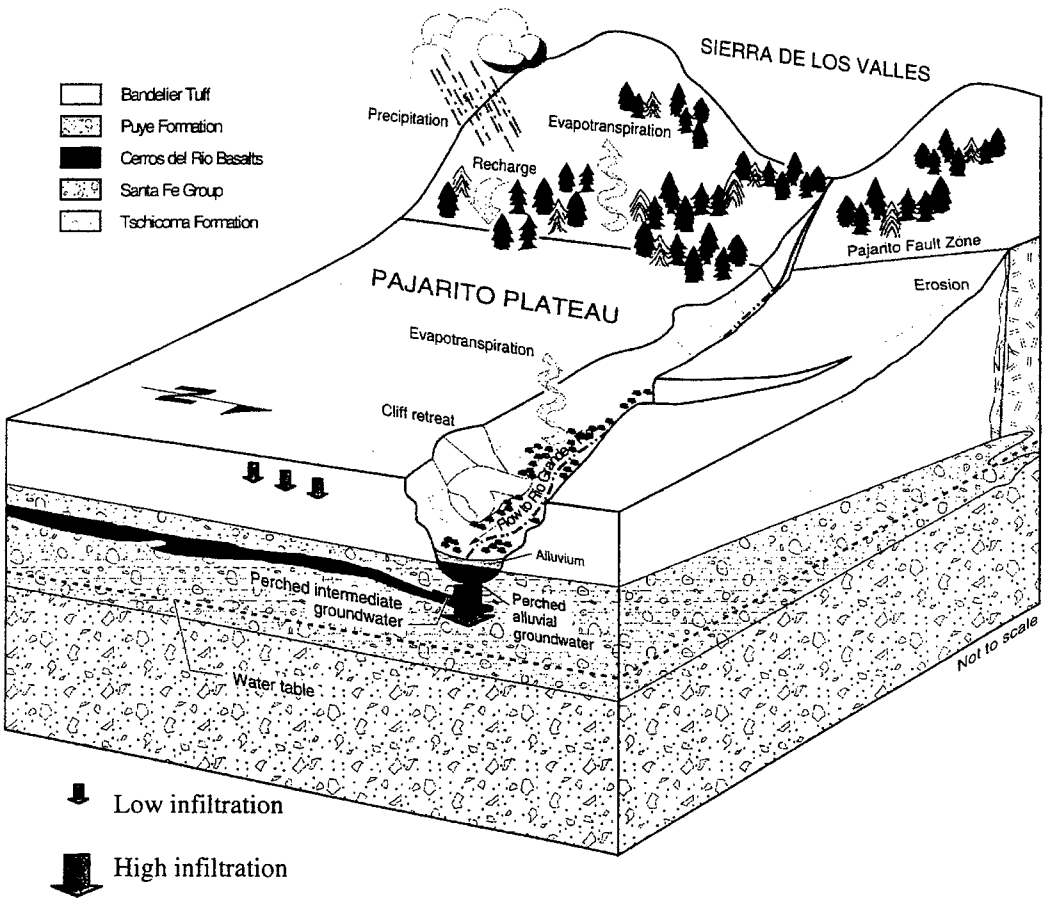

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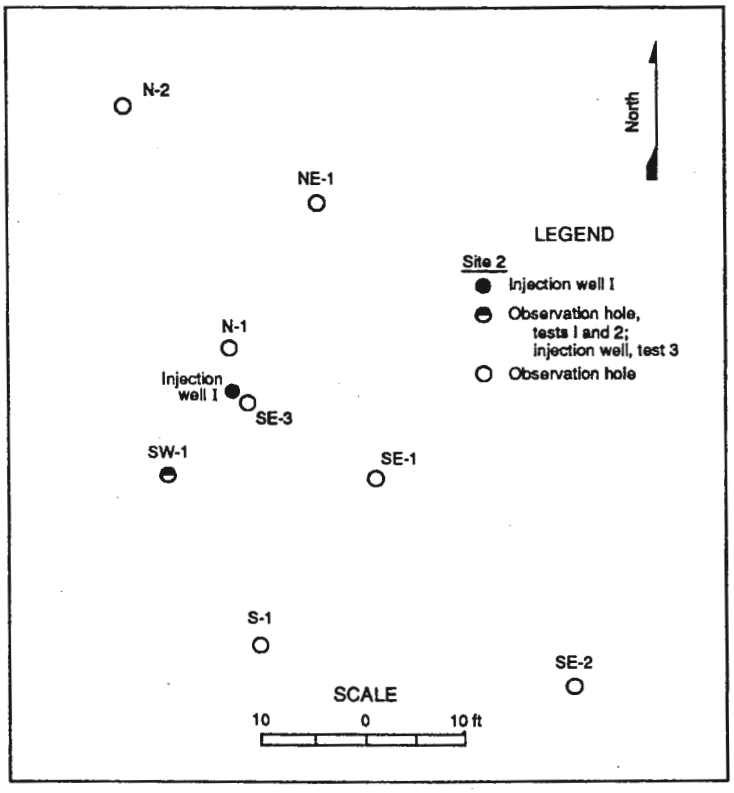

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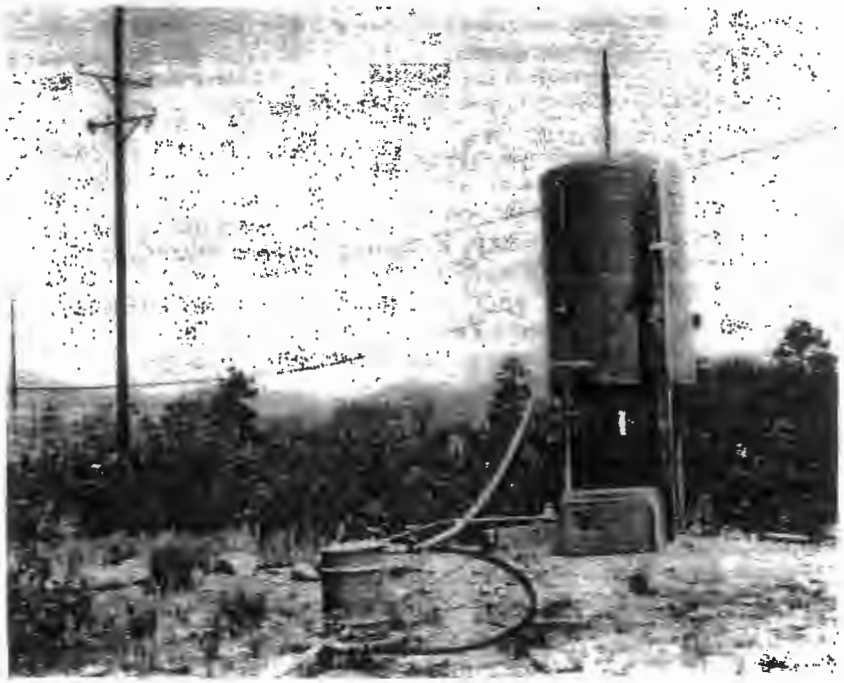

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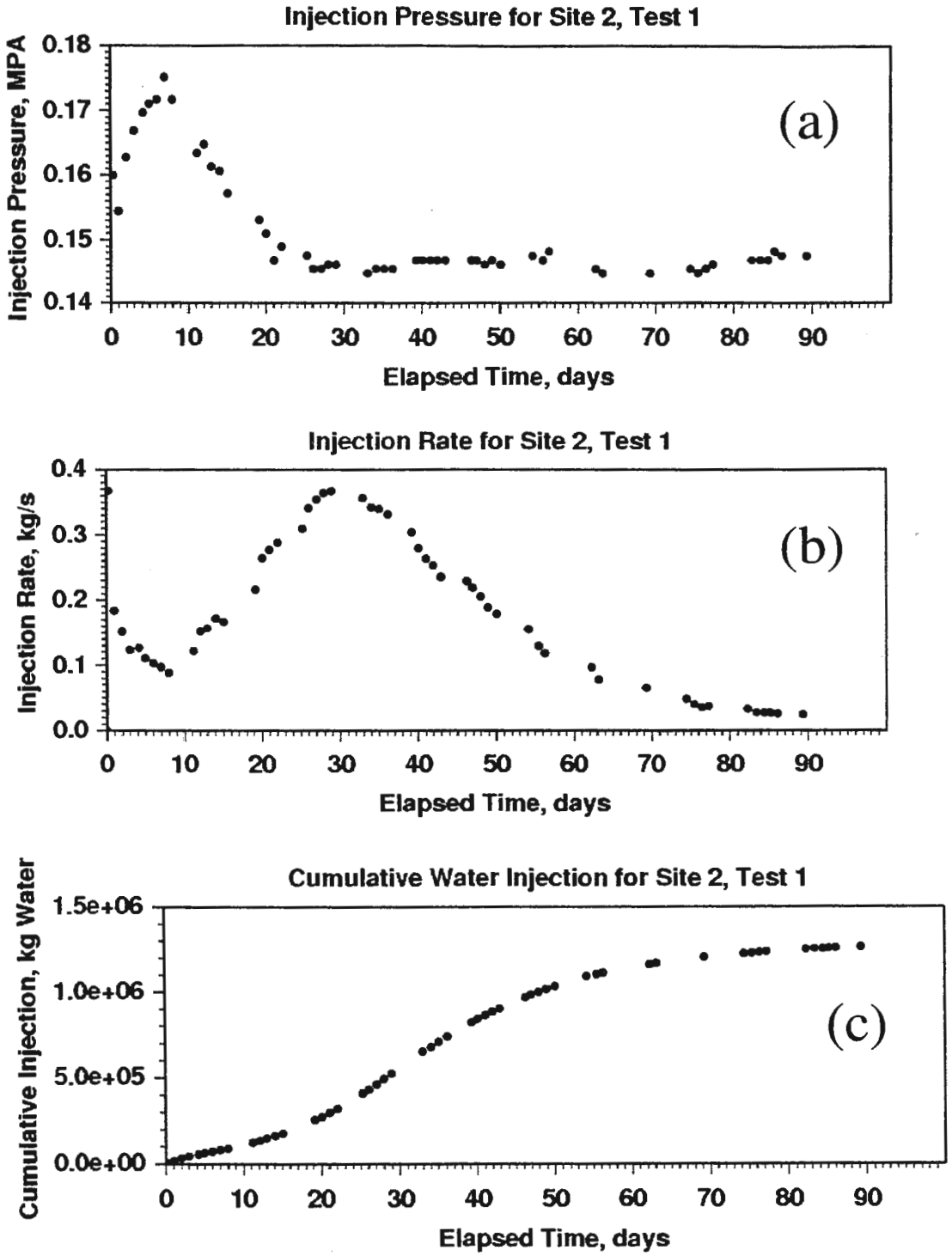

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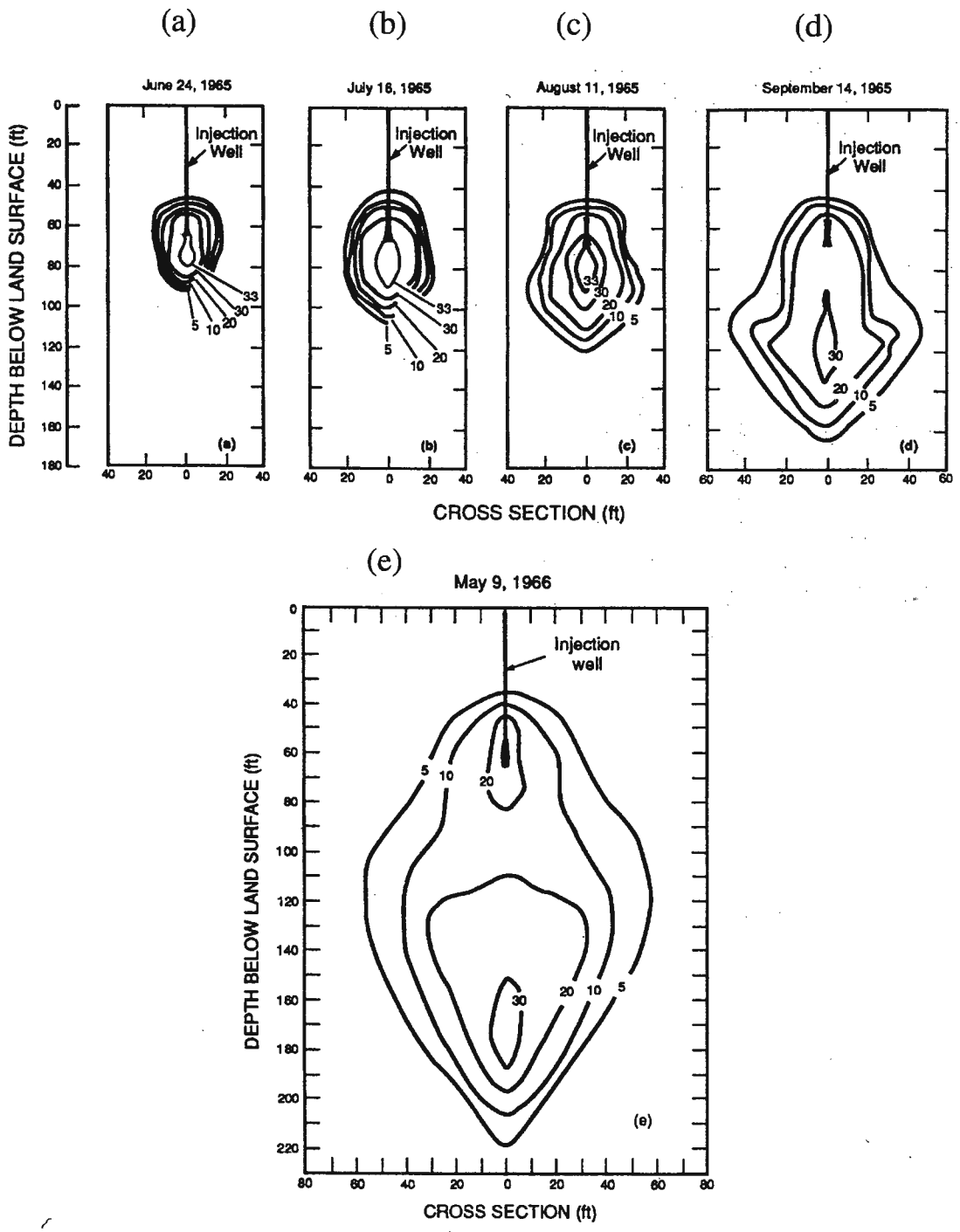

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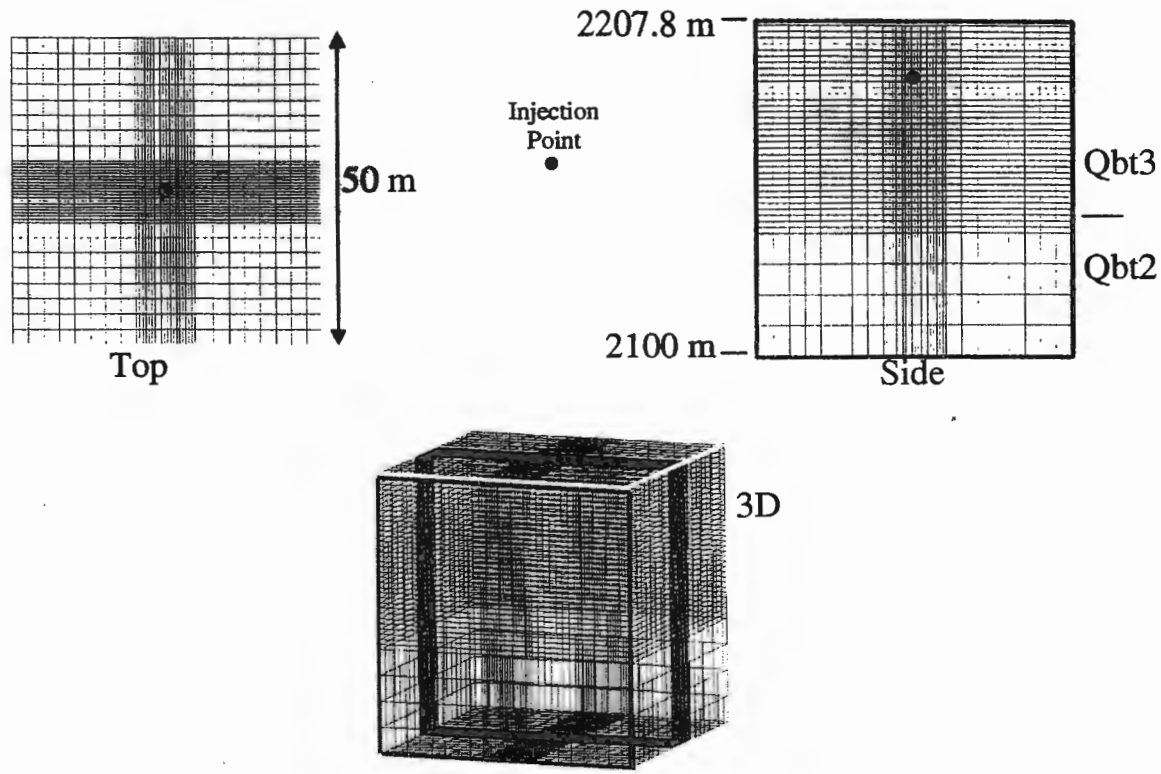

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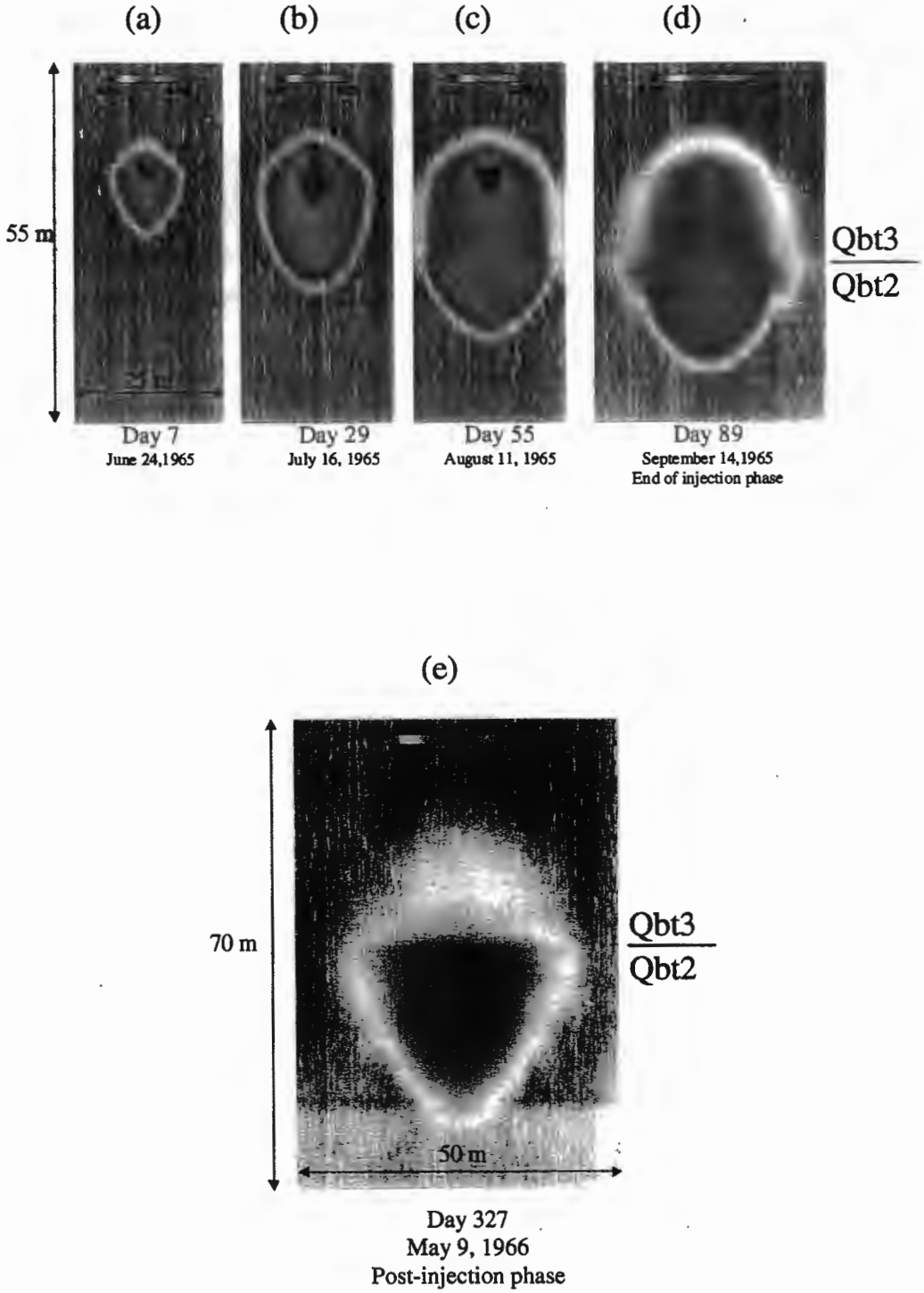

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Hydrogeologic unit	Geologic designation	Permeability, m^2	Porosity	van Genuchten α parameter, m^{-1}	Residual moisture content	van Genuchten n parameter, unitless
Unit 3	Qbt3	1.01e-13	0.469	0.29	0.045	1.884
Unit 2	Qbt2	7.48e-13	0.479	0.66	0.032	2.09
Vitric unit	Qbt1v	1.96e-13	0.528	0.44	0.009	1.66
Glassy unit	Qbt1g	3.68e-13	0.509	2.22	0.018	1.592

Data Source: Rogers and Gallaher (1995)

Table 2. Comparison of model and data for the migration rates of the water plume

Date		Vertical Movement of 5% Contour (m/day)	
From	**To**	**Data**	**Model**
06-17-65	06-24-65	1.2	1.4
06-24-65	10-25-65	0.24	0.19
10-25-65	11-19-65	0.12	0.080
11-19-65	12-22-65	0.061	0.061
12-22-65	05-09-66	0.006	0.029
Date		**Horizontal Movement (m/day)**	
From	**To**	**Data**	**Model**
06-17-65	07-16-65	0.24	0.28
07-16-65	08-11-65	0.15	0.04
08-11-65	09-14-65	0.061	0.03
09-14-65	11-19-65	0.030	0.08
11-19-65	05-09-66	0.061	0
Date		**Upward Movement (m above injection point)**	
		Data	**Model**
09-14-65		4.3	8
05-09-66		7	10

FACT SHEET
PCB LANDFILL RE-AUTHORIZATION
FOR
LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM

(TSCA PCB Permit Reauthorization)

BACKGROUND

1. In January 2001, LANL requested re-authorization of its PCB landfill approval at Area G (LANL uses the terminology of "pits" for land disposal cells, and "shafts" for land disposal isolation units- the general terms for these disposal areas is "landfill"). The approval was issued on June 25, 1996, with an expiration date of June 25, 2001. LANL was notified by e-mail and in the cover letter of the proposed approval that the PCB approval conditions would remain in effect until EPA makes its final determination on its request for re-authorization.

2. Staff visited the facility in February 2001 to gather information. No 6E compliance inspection had been conducted by EPA for the five year approval period, so LANL was asked to send all of its information in regard to PCB storage reports, annual document logs, and spill reports for the previous 5 years. This information was sent to 6E in a series of submittals in the April-May 2001 time frame for its review.

3. The new approval is being issued following a re-evaluation of the hydro-geology of the Area G disposal area where PCBs and other low-level radioactive wastes are disposed. Information submitted included, "Performance Assessment and Composite Analysis for LANL Material Disposal Area G, January 1997", "Hydrologic Workplan, May 1998", and Annual Document logs for PCB storage from 1991-1999 as well as PCB storage and spill-cleanup information was submitted for our review (LANL also noted that no PCB spills had occurred in the 5-year approval period).

4. The NMED reviewed this proposal and provided written comments requesting that EPA's clarification and consideration of certain issues. These are discussed in more detail in the "State Review of the Proposal" section below.

5. The PCB pits and shafts that are being approved are not RCRA permitted, and are not being used for disposal of RCRA hazardous wastes. It should be noted that the NMED has been working with LANL to resolve what areas at Area G should come under RCRA permitting authority.

DISCUSSION

1. It should be pointed out clearly here that the primary consideration of this proposal is for non-liquid PCB wastes, and not RCRA wastes that could include solvents, or tritium wastes that have been shown to be migrating through the tuff at Area G. PCBs are large molecules that are slightly positively charged which gives PCBs the proclivity to adhere to generally negatively charged soil particles. This accounts for the common visible "oil spot" on soils where PCBs

have been spilled. The rationale for approving the disposal of non-liquid PCBs at Area G, and the specific conditions listed in the PCB Conditions of Approval have taken into account that the interpretation and application of the available data are for the implementation of the regulations for PCBs under the Toxic Substances Control Act (TSCA). The conclusions drawn from hydrogeology reports and models on this site took into account the nature of non-liquid PCBs as they are known to behave in soils, and may not be applicable for other types of wastes at this facility.

2. The most recent work on the examination of the hydrogeology of Area G, as reported in the two documents sited above in #2 of the Background section, did not uncover any new information that would show a direct connection between fractures in the volcanic tuff and groundwater bearing zones in the mesa in terms of PCB migration potential. However, it is the opinion of the NMED (see attached letter dated March 11, 2002) that, "... LANL's transport modeling of hazardous constituents likely underestimates the role of fracture flow and, for some contaminants, transport via colloids, primarily because the geology and hyrdogeology at TA-54 are poorly understood." The NMED has required additional regional ground water wells and vadose zone characterization in hopes that these additional contaminant release investigations will provide more information.

3. These new wells have found levels of tritium. The primary well, R-22, has a total depth of 1489 feet, and has five sampling ports at 906, 962, 1273, 1379, and 1449 feet. The source and causes of the tritium are being investigated by the NMED and LANL, but the source is most likely from the older pits that were in use before the RCRA or TSCA regulations were put into effect which limit the type of wastes disposed. The consensus is that tritium would move much faster than PCB molecules through the tuff since PCBs molecules are not only comparatively large, but slightly positively charged which results in them binding to negatively charged soil particles near the point of initial contact with the soil. Also, only non-liquid PCBs are allowed for disposal.

4. In order to ensure that PCBs are not a contaminant in Area G, the proposed approval adds the new R-22 monitoring well into the groundwater monitoring requirements, and eliminates the requirement to sample the springs at the bottom of the mesa which is at a remote distance from Area G. The proposed approval requires that LANL sample for PCBs at all five ports once per year, and report any positive results. If PCBs were to be detected in the ground water samples, LANL would be required to report this to EPA. Under TSCA, this is would be defined as illegal disposal, and would be referred to Enforcement for action under TSCA. Depending on the situation, an NOV would be issued with 6PD technical input to resolve the problem which would include whatever remediation requirements are necessary to halt further contamination as well as cleaning up the contaminated area as appropriate.

5. To add a historical reference in this Fact Sheet, in 1994 when EPA visited the issue of potential PCB contamination at Area G, LANL's conclusions were as follows as they were evaluated against PCB non-liquid waste disposal (not RCRA wastes):

Issue #1: Has there been any evidence of PCB contamination of surface soils or sediments?

LANL made the assumption that any significant discharge of PCB-contaminated liquids from transformers or capacitors would eventually exit the mesa walls and be deposited in soils and sediments at or below the discharge points. LANL collected 69 sediment samples along drainage channels off the mesa and in areas where there was evidence of sediment accumulation. No PCBs were detected in the 69 samples.

Issue #2: Is there any evidence of PCB migration in the subsurface?

A core hole was drilled in the summer of 1994 within 10 feet of the oldest PCB disposal shaft. The oldest shafts contained small and large capacitors with liquid PCBs inside. Eight core samples were taken at 10 foot intervals down to a depth of 80 feet. No PCBs were detected in the core samples.

Issue #3: Is there any evidence that fractures in the Bandelier Tuff has or would become a conduit for lateral migration of PCBs?

LANL conducted an experiment whereby 335,000 gallons of water was injected into the Bandelier Tuff. The tuff is unsaturated, and the large volume of water was shown to be redistributed by capillary forces. Saturation of the tuff resulted in a radial redistribution from the injection point into adjacent unsaturated rock. Based upon this experiment, and the modeling data provided in Enclosure 4 ("Los Alamos County Landfill Groundwater Monitoring Program..."), LANL concluded that the lateral movement of PCBs was unlikely in Area G.

STATE REVIEW OF THE PROPOSAL

The NMED provided comments after the close of the 45-day comment period in a letter dated March 11, 2002. The NMED concurred with this proposed re-authorization provided that the Fact Sheet, approval letter and conditions are clear on certain points. These points are specifically addressed as follows:

Comment #1. 3rd paragraph, second sentence: In the Fact Sheet, EPA should clarify that the non-migration discussion and conclusion apply only to PCBs.

EPA Response: From the start in 1980, the review of the LANL request for approval to dispose of PCBs was focused on PCBs and how PCBs behave in soils. The pits and shafts LANL proposed for disposal approval were for PCB and low-level radioactive waste sites only, and it was this consideration that led to EPAs' conclusions. The Fact Sheet has been modified to make this point clear. It was not EPA's intention to imply that no chemical compounds could migrate through the mesa tuff. It has been sown that tritium can migrate through the tuff, but it remains EPA's conclusion that non-liquid PCBs have a much lower probability of migration. Every effort has been made to make

this clear in the approval letter as well.

Comment #2: 3rd paragraph, 5th sentence: The Fact Sheet should reflect that the NMED's endorsement of the PCB re-authorization is not without some conditions. These

EPA Response: The Fact Sheet has been modified to enumerate NMED's concerns and how each has been addressed.

Comment #3: 4th paragraph, 4th sentence: NMED was concerned that the rationale for granting some of the technical requirements for PCB landfills appeared to broad in scope.

EPA Response: The rationale for granting the waivers to some of the technical requirements for PCB landfills has been modified in the approval letter to make clear that the review was focused on the known behavior and characteristics of the PCB molecule in soils.

Comment #4: 4th paragraph, 5th sentence: The NMED wanted a statement in section III. A.1. of the Conditions of Approval that waives the provision for a synthetic liner (see 761.75(b)(2)).

EPA Response: The requirement for a synthetic liner in the PCB regulations is left to the EPA Regional Administrator's judgement if the soils criteria under 761.75(b)(1) were not met at a particular facility. Since the soils requirement was waived, there was no need to waive the synthetic liner provision. However, a sentence has been added in the Conditions of Approval in section III.A.1. that makes the reason clear why no synthetic liner would be required in this approval action.

Comment #5: 4th paragraph, second to last sentence: The NMED wanted the conditions to make clear that no liquid PCBs or items containing liquid PCBs coudl be placed in the pits or shaft disposal areas (see section III.D.2 and III.D.3.)

EPA Response: There are conditions in each section for pits and shafts that prohibit liquid PCbs or items containing liquid PCBs from disposal in a pit or shaft.

Comment #6: 4th paragraph, last sentence: The NMED wanted a condition that made the ponding of snowmelt or stormwater on a pit or shaft not permissible.

EPA Response: Condition has been added that prohibits the ponding of snowmelt or stormwater over a PCB disposal pit or shaft.

Comment #7: 5th paragraph, 1st sentence:

Comment #8: 5th paragraph, last sentence:
First, that the rationale for the waivers granted to some of the PCB landfill requirements were based upon the known behavior of PCBs in soils, not RCRA hazardous constituents. Second,

that no liquid PCBs be allowed in the landfill. Third, that additional investigations be pursued. These additional investigations included adding additional boreholes in the vicinity of each PCB shaft field and pit. Finally, the LANL Area G landfill RCRA permit is currently up for renewal, and it is important to the NMED that closure issues for the PCB approval and the RCRA permit be coordinated. These issues are discussed in the section on closure below.

The comments and suggestions provided by the NMED for this Fact Sheet and the PCB approval letter and conditions were welcomed and valuable for the re-issuance of this approval.

CLOSURE ISSUES

6E COMPLIANCE REVIEW

The Enforcement Division reviewed the PCB storage reports, Annual Document Logs, and spill reports submitted by LANL at 6PD-O request. The 6E review noted that there may be some PCB storage violations for PCB storage over the one year limit, bu that these violations were not related to environmental harm and therefore did not warrant a non-concurrence on the re-authorization request. 6E has concurred on this re-authorization.

PUBLIC NOTICE

A Public Notice was issued in the Sante Fe New Mexican on October 22, 2001 which opened a 45-day comment period. The comment period expired on December 6, 2001. No comments were received.

CONCLUSION

Based upon review of LANL's submittals, a review by NMED, review of the compliance history, and the conditions of this approval, it is EPA's conclusion that the re-authorization of this approval for non-liquid PCBs will not result in endangerment of public health or the environment.

RECOMMENDATION

I recommend that this request for re-authorization of the Area G PCB landfill be granted.

James Sales, PCB Disposal Facility Coordinator

Date