TA 49

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NMED Hazardous Waste Bureau

Dr. John R. Wiley, Study Director
Nuclear and Radiation Studies Board
National Academy of Sciences
500 Fifth Street, NW
Washington, DC 20001

Re: Hydronuclear Experiments at LANL's TA-49
LANL Groundwater Assessments

Dear Dr. Wiley:

On December 19, 2006, you asked Joni Arends, Executive Director of Concerned Citizens for Nuclear Safety (CCNS), for information on the hydronuclear experiments performed at TA-49 at the Los Alamos National Laboratory (LANL) and the danger of the contamination produced by the experiments to contaminate the groundwater. The nature and extent of groundwater contamination beneath TA-49 is not known because LANL has not installed the required monitoring wells.

Robert H. Gilkeson, Registered Geologist and RCRA Qualified Groundwater Scientist, took the lead in putting these materials together for the National Academy of Sciences. Please forward these materials to all of the member of the Committee for the Technical Assessment of Environmental Program at LANL.

The enclosed LANL report, *Hydronuclear Experiments* (LA-10902-MS, February, 1987), describes the purpose for the experiments and that some of the experiments involved a fission energy release.

The experiments were performed in Areas 1, 2, 3 and 4 within Material Disposal Area (MDA) AB at TA-49. Maps that show the location of TA-49 at LANL and the location of MDA AB within TA-49 are in the enclosed report by Levitt, et al., that was published in *Vadose Zone Journal* 4: 789-797 (2005).

Figure 2 in Levitt, et al., shows the locations of the four Test Areas within MDA AB. The experiments were conducted in a total of 37 test shafts that were 1 to 2 meters in diameter with depths ranging between 9 and 33 meters. In 1961, an asphalt pad was placed over Area 2 to

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control the spread of contamination in surface soils. The activities that brought the contamination to the land surface are described below in an excerpt from page 789 in Levitt, et al.,

> "During the drilling of a new test shaft in 1960, transuranic materials were encountered from an adjacent shaft, resulting in contamination of surface soils. The area of contamination, within Area 2, was covered by a cap of clay and gravel in the spring of 1961. Then to prevent erosion, the cap was covered with a 2.5- to 20-cm-thick asphalt cover in the fall of 1961. Years later it was discovered that the asphalt cap had adversely affected the water balance of the site by allowing infiltration through cracks and a collapsed area of the cap, and by greatly reducing [evapotranspiration] ET. In addition, some ponding probably occurred on the asphalt cap because natural drainage was reduced by the elevated edge of the cap."
>
> "In 1975, many cracks and a large collapsed area (1.8 by 0.9 m wide and 0.9 to 1.2 m deep) of the asphalt cover were discovered. It was also discovered that Core Hole 2 (CH-2), a 5-cm-diameter, 155-m-deep cased borehole (originally drilled for hydrogeologic characterization) located in the center of Area 2, contained about 15 m of standing water. It was suspected that the cracks and the collapsed area in the asphalt cover allowed focused infiltration of water into CH-2. In 1976, the asphalt cap was repaired, but more cracks and standing water were again found in CH-2 in 1979, 1980, and 1991."
>
> "An aerial photograph of the asphalt cover, taken in 1998, is shown in Fig. 3. The circular collapsed area can be seen close to the center of the asphalt cover."

A report by the Institute for Energy and Environmental Research (IEER) estimates the amount of plutonium-239 and -240 buried in the hydronuclear test shafts at MDA AB to be 39.19 kilograms. *Dangerous Discrepancies: Missing Weapons Plutonium in LANL Waste Accounts,* reissued with corrections April 21, 2006, p. 14.

The travel of contamination from MDA AB to the regional aquifer is not known because LANL relies on water samples collected from three old LANL test wells that do not produce reliable and representative water samples. Information on the locations and construction of the three wells, known as DT-5A, DT-9 and DT-10, are in the enclosed pages from the LANL Report, *Geologic and Hydrologic Records of Observation Wells, Test Holes, Test Wells, Supply Wells, Springs, and Surface Water Stations in the Los Alamos Area,* by W.D. Purtyman (LA-12883-MS, January 1995).

To put the location of the DT wells in perspective, please also see Figure 1-1, Map showing the location of the characterization wells from LANL's Well Screen Analysis Report, ER2005-0841, November 2005.

"TA-49 is located on a mesa in the upper part of the Ancho Canyon drainage and part of the area drains into Water Canyon. TA-49 was used for underground hydronuclear testing in the early 1960s. The testing consisted of criticality, equation-of-state, and calibration experiments involving special nuclear materials."

"The testing produced large inventories of radioactive and hazardous materials, such as isotopes of uranium and plutonium, lead, and beryllium; explosives such as 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (research department explosive, or RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (high-melting explosive, or HMX); and barium nitrate. Much of this material remains in shafts on the mesa top."

From page 7-2 of the *Interim Plan.*

7.4 Scope of Activities
Ancho Canyon
Monitoring locations in Ancho Canyon are situated near or downstream from areas of past Laboratory weapons-testing activities. Most monitoring locations in Ancho Canyon access the regional aquifer. Three decades of water quality records from regional wells in this area (DT-5A, DT-9, and DT-10), and recent data from R-31, show no substantial changes in water chemistry or the presence of Laboratory contaminants in the regional aquifer.

The LANL *Interim Facility-Wide Groundwater Monitoring Plan* continues the long-standing LANL record of using the spurious water quality data from the three old test wells as reliable and representative of formation water beneath MDA AB at TA-49.

In addition, LANL characterization well R-31 does not produce usable water quality data to assess groundwater contamination from the hydronuclear experiments at MDA AB because of the following factors:

1). Well R-31 is located at a distance of approximately 3 miles from MDA AB.

2). The screened intervals in well R-32 are contaminated with a new mineralogy of iron precipitates that were formed by the organic drilling additives. The iron precipitates have strong sorption properties to remove many contaminants of concern from the hydronuclear experiments from the water samples produced by well R-31.

3). Water samples are collected from well R-31 with the Westbay^{R} no-purge water sampling equipment that collects water samples that was in contact with the new mineralogy for a long period of time.

The factors that prevent the wells from producing reliable and representative water samples for the detection of contamination from the four test areas at MDA AB include the following:

1). The wells are not at appropriate locations as shown by intercomparison of Figures IX-C and IX-V in the Purtyman report. Well DT-5A is located within Area 5 and at a distance of approximately 1000 feet from Areas 1 and 3, and approximately 900 feet from Areas 2 and 4. In addition, well DT-5A is located upgradient of the direction of groundwater travel beneath Areas 2 and 4. Well DT-9 is located approximately 3500 feet to the east of Area 2 and well DT-10 is located approximately 4500 feet to the southeast of Area 4. The regional direction of groundwater flow is shown on an enclosed map.

2). The three test wells were drilled with the mud-rotary drilling method that allowed a very large quantity of bentonite clay drilling mud to invade the screened intervals.

3). The three test wells have very long screened intervals –

DT-5A, torch-cut slots over a total interval of 649 feet.
DT-9, torch-cut slots over a total interval of 461 feet.
DT-10, torch-cut slots over a total interval of 329 feet.

4). Corrosion products of the common steel casing and galvanized steel well fittings have strong properties to mask detection of contaminants in the water samples produced from the three wells.

It is common knowledge in the monitoring well industry that the above factors prevent the old test wells from detecting groundwater contamination from MDA AB. Nevertheless, the LANL reports over the past 40 years up to the present time, present the water quality data from the old test wells as proof that MDA AB has not contaminated the groundwater. This letter includes excerpts from four recent LANL *Environmental Surveillance Reports* (2002 through 2005) that present water quality data from the three old test wells as valid for the detection of groundwater contamination from the four Test Areas at MDA AB.

The LANL *Interim Facility-Wide Groundwater Monitoring Plan, Rev. 1 (Interim Plan)* has the following discussion of groundwater monitoring at TA-49.

From page 7-1 of the *Interim Plan.*

7.0 ANCHO/CHAQUEHUI/FRIJOLES CANYONS WATERSHEDS
7.1 Introduction
Ancho Canyon

The NMED LANL Consent Order has the following discussion of TA-49 MDA AB:

From page 124 of the Consent Order:

> "Activities conducted at MDA AB included nuclear device safety tests and HE detonations conducted in 37 shafts at depths ranging from 30 to 78 ft. Materials released at MDA AB include HE, lead, beryllium, and radionuclides, which are not addressed under this Consent Order."

From pages 131 and 132 of the Consent Order:

> "IV.C.4.c.vii Technical Area 49 Regional Groundwater Well Installation"
>
> "Install one monitoring well that intersects the regional aquifer downgradient of TA-49. Respondents may address this requirement through the installation of Regional well R-30." [R-30 is at an important location that meets the requirements for monitoring releases from MDA AB. See Figure 4.3.1, PRSs and proposed wells in Aggregate 3, *Groundwater Annual Status Report-FY98,* p. 59.]
>
> "IV.C.4.c.viii Technical Area 49 Groundwater Monitoring"
>
> "Groundwater samples shall be collected from each saturated zone intersecting the regional aquifer wells CdV-37-2, DT-5A, DT-9, DT-10, and all regional wells installed in the future."

The Consent Order allows LANL to continue to collect the spurious water samples produced from the old test wells and to present the water quality data as reliable and representative of the formation water beneath MDA AB at TA-49.

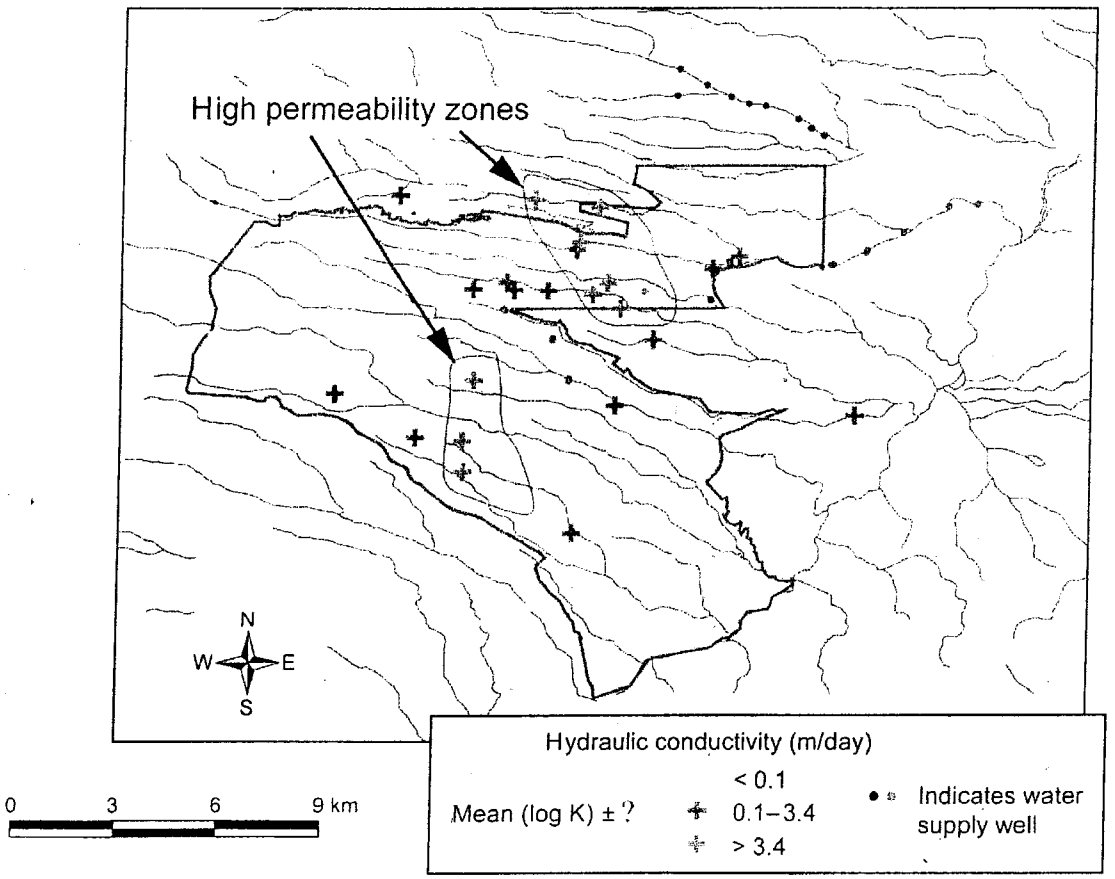
<u>The valuable groundwater resource beneath TA-49</u>. The data gathered from drilling the boreholes for the old test wells and for the recent characterization wells have established the presence of a very large groundwater resource in the southern region of the Laboratory property including beneath TA-49. Please see Figure 4-1, Water table elevation and location of Hydrogeologic Workplan wells, *Workplan for R-Well Rehabilitation and Replacement,* ER2006-0465, June 2006, p. 16.

The map below shows that LANL recognizes two "high permeability zones" in the regional aquifer beneath the Laboratory. The most productive water supply wells for Los Alamos County are located in the northern zone. There are no supply wells located in the southern zone.

The southern "high permeability zone" is much larger than shown on the map. The "red well" located southeast of the zone is characterization well R-31 and the borehole log and drilling record show the regional aquifer to have thick sections of aquifer strata

that warrant an estimated hydraulic conductivity of greater than 15 m/day. The presence of a very productive aquifer at the location of well R-31 is also shown by the fact that the air rotary drilling method produced a vary large amount of groundwater, and drilling was often interrupted waiting on availability of storage tanks to contain the water.

From north to south, the three "green wells" displayed in the southern "high permeability zone" are characterization well R-19 and the old test wells DT-10 and DT-9. The "red well" located immediately west of the southern zone is old test well DT-5A.



The above figure is figure 2-26 from the LANL *Synthesis Report*
LANL Report LA-14263-MS, December 2005

[This report is not publicly available on the web, except to select government agencies.]

Stewardship of the large groundwater resource located in the southern region of the Laboratory requires installation of a network of monitoring wells to investigate groundwater contamination with radionuclides and chemicals beneath and

downgradient of MDA AB that were caused from the hydronuclear experiments. The first monitoring well should be located immediately east of Area 2 at MDA AB.

The location of supply wells in the southern zone may become necessary because of the chromium plume that is present in the northern zone. The chromium plume is located in strata with very high hydraulic conductivity and there is a high probability that the plume will eventually contaminate the drinking water wells of Los Alamos County.

The enclosed map from LANL Report LA-UR-04-6777 shows the much greater annual decline in water levels for the region of the chromium plume beneath Mortandad Canyon because of the large production of groundwater from the northern region of the Laboratory. The best knowledge of the chromium plume at this time shows the highest contamination to be beneath Mortandad Canyon between wells R-13 and R-15. High levels of chromium contamination may be present below Sandia Canyon to the south of Los Alamos County drinking water well Otowi-4 (O-4). LANL has not installed the important sentry wells that are necessary for knowledge of the dimensions of the chromium plume and the travel of the plume to the nearby drinking water wells.

Based on the limited available data, wells O-4 and Pajarito Mesa-3 (PM-3)are the two Los Alamos County supply wells that are most threatened by the chromium plume. The two wells are also the most productive wells in the network of Los Alamos County wells. It would be prudent for the Department of Energy to now install a minimum of two new supply wells for Los Alamos County at locations in the southern part of the Laboratory. The new wells would allow Los Alamos County to reduce the pumpage of the supply wells that are threatened by the chromium plume and possibly prevent the plume from contaminating the water produced from the wells.

Thank you for the opportunity to provide the National Academy of Sciences with information about TA-49. Please contact us should you have any questions or comments.

Sincerely

Robert H. Gilkeson
ja

Joni Arends

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Enclosures.

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New Mexico Attorney General Gary King
NM Environment Department Secretary Ron Curry and
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Hydronuclear Experiments

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HYDRONUCLEAR EXPERIMENTS

Robert N. Thorn and Donald R. Westervelt

Abstract

Hydronuclear experiments, a method for assessing some aspects of nuclear weapon safety, were conducted at Los Alamos during the 1958 - 61 moratorium on nuclear testing. The experiments resulted in subcritical multiplying assemblies or a very slight degree of supercriticality and, in some cases, involved a slight, but insignificant, fission energy release. These experiments helped to identify so-called one-point safety problems associated with some of the nuclear weapons systems of that time. The need for remedial action was demonstrated, although some of the necessary design changes could not be made until after the resumption of weapons testing at the end of 1961.

Introduction

In his 1976 memoir "A Scientist at the White House," Presidential Science Advisor George Kistiakowsky refers to "single-point safety experiments" performed at Los Alamos in the early 1960s. These safety experiments were laboratory-type high explosive driven criticality experiments carried out to assure the safety of U.S. nuclear weapons in the event of accidental detonation of their high explosive components. They are most accurately described as "hydronuclear experiments," and our purpose here is to describe them and the surrounding circumstances in order to make this experience available for future reference.

Background

U.S. weapon design and testing by 1958 had established two significant new concepts and incorporated them into the weapons stockpile. The first of these was the thermonuclear (TN) weapon (or H-bomb), whose development President Truman had ordered in 1950. Thermonuclear principles were demonstrated in 1951 U.S. tests, and the first large TN explosion occurred in 1952. A very high yield fission weapon was tested at that time as a backup, but it had been supplanted by the first deliverable TN weapons by 1954 (the same year in which Soviet Deputy Premier Mikoyan had announced that the Soviet Union had "put the hydrogen bomb in the hands of its troops").

The "fission triggers," or primaries, of the early TN weapons did not differ significantly from the pure fission weapons already deployed, and they suffered in this new role from safety and reliability problems. They also were relatively inefficient in their use of fissile material, and the early TN weapons were very large and heavy, severely taxing the bomber aircraft of that time and scarcely suitable for delivery by guided or ballistic missiles.

Many of these problems soon were addressed by the second new concept: the boosted fission primary, which was first tested in 1955. In this design, the

efficiency of a fission weapon was increased markedly by the incorporation of small amounts of the hydrogen isotopes deuterium and tritium. Under certain conditions, a thermonuclear reaction between these isotopes produced energetic neutrons in large quantities. These neutrons greatly enhanced the fission yield even though the thermonuclear component of the total device yield was very small. This concept contributed to reliability, efficiency, and significant reduction in size and weight as well. The 1955 tests proved the feasibility of this approach to primary design. Developmental weaponization followed quickly in a 1956 test series directed toward the B47 and B52 bombers that were to replace the ponderous, propellor-driven B36, and toward future missile systems.

The United States began a voluntary suspension of nuclear weapons tests on October 31, 1958. The Soviets joined after two further weapons tests in November. On December 29, 1959 the President, in announcing his decision to continue the test suspension, made it clear that "during the period of voluntary suspension of nuclear weapons tests the United States will continue its active program of weapon research, development and laboratory-type experiments."

By this time, a trend toward smaller, lower yield, more reliable and safer TN weapons with boosted primaries was well established. The United States also had adopted payload criteria for the relatively small ballistic missiles it would deploy in the 1960s. These criteria were based largely on projections of TN design technology using the new boosted primary concept. In addition, the key nuclear tests that later would be the basis of modern multiple independently targetable reentry vehicle (MIRV) and cruise missile technology had been done. Thus, in several ways, U.S. TN weapon design was well developed when President Eisenhower decided to suspend further testing.

However, unforeseen problems were soon to arise. The first was a safety problem that will be the focus of the remainder of this report.

One-Point Safety

Nuclear safety at all times has been a basic military requirement and a fundamental goal of U.S. weapons designers. The goal always has been to assure that no accident involving a nuclear weapon has a significant chance of resulting in an appreciable nuclear yield. In the case of the early unboosted fission weapons, nuclear safety was achieved by mechanical means. In most cases, fissile components were separated in part or completely from high explosive components so that an accidental detonation of the latter would not result in assembly of a critical mass of fissile material (that is, a mass whose size and geometry makes it capable of sustaining a nuclear chain reaction). In a few cases, other mechanical means had to be employed. As a result of these measures, none of the few accidents that actually occurred up to that time (nor any since) resulted in any release of nuclear energy.

The advent of boosted primaries in 1955-56 greatly complicated the safety problem, because mechanical solutions were now much more difficult and in some cases impossible. They also were somewhat incompatible with the requirement for reduced size and weight. It thus became a major design objective to assure that even when the fissile and high explosive components were fully assembled, there

would be no nuclear yield if an accident resulted in detonation of the high explosive. Since such a detonation might start at any single point on or in the explosive components, this design objective came to be known as "one-point safety."

At that time, one-point safety behavior of fission weapons could not reliably be calculated, nor could it be inferred from laboratory experiments that did not involve high explosive compression of fissile material (hydronuclear experiments). Both the available computers and the physical models of that time were inadequate, and the safety of a particular design could only be established by a nuclear test. If the design in question was safe, the nuclear yield of such a test would be essentially zero; but if it was not, the nuclear yield might be measured in tons of high explosive equivalent. It soon was recognized that the latter result might be avoided in an experiment by a sufficient reduction in the amount of fissile material. In this case, the one-point safety experiment might be conducted in a reusable containment vessel, and by early 1958 a design for such a laboratory-type facility was under study.

By the time of the moratorium, one-point safety tests had come to be a significant fraction of all of the nuclear tests involved in development of new boosted designs. For example, of 29 Los Alamos tests of such designs during the 1955, '56, and '57 series, more than one-third were safety tests. In addition, many additional development tests sometimes became necessary because of the results of safety tests. The last nuclear series before the moratorium was conducted at the Nevada Test Site (NTS) in September and October 1958, following announcement by the President of the October 31 date for the suspension of testing. It was almost entirely directed toward the one-point safety objective, and it was only partially successful. Certain designs whose full-yield performance already had been validated appeared to meet requirements for safety, while others did not. The reasons were discovered only later, well after the suspension of weapons tests had begun and production and deployment of certain designs believed to be safe had proceeded.

Analysis of Past Data

After U.S. nuclear weapons tests were suspended on October 31, 1958, the designers of boosted fission primaries took advantage of the resulting opportunity to study in more detail the somewhat puzzling results of recent one-point safety tests. For this purpose, they used older, relatively crude methods of calculation as well as more realistic methods and physical models that had only recently begun to be developed. The startling result of this effort first was reported in a June 1959 memorandum by Robert K. Osborne and Arthur R. Sayer, who represented the design group responsible for implosion (fission) weapon design. In this memo, they reported that " . . . the empirical one-dimensional method . . . has yielded one result which appears to be of such a grave nature that a report on it seems in order." The problem brought to light by analysis of the recent data, supplemented by local, nonnuclear experiments, was that the safety behavior of a given design seemed to depend critically on the particular point at which detonation of the high explosive was initiated. This explained some of the unsatisfactory results obtained in the last series of safety tests, and it also cast a serious shadow upon the validity of those that appeared to be satisfactory. The authors conclude: "If it is true that the mode of detonation is very crucial, then several of the . . . systems now in stockpile or about to go into stockpile may not be one-point safe."

Calculations and local hydrodynamic experiments, however, were insufficient to resolve the problem. The safety of four weapon systems that had become operational in 1958 suddenly was in question. The response of the military was immediate. Production was halted in some cases. Weapon handling procedures were severely constrained.

With this new information, only two responsible courses of action were available to the Laboratory: (a) redesign the weapons, and (b) resort to mechanical safing. The latter was very undesirable, and in some important cases was not feasible. The first appeared to be impossible without further nuclear testing, now ruled out by the moratorium. It was in response to this dilemma that the hydronuclear safety program was devised and carried out at Los Alamos.

The Hydronuclear Safety Program

As noted above, it had been recognized well before the suspension of nuclear testing that significant experiments with explosive systems and fissile material could be performed in which the fission energy released was small enough so that containment in fabricated vessels was at least theoretically possible. Such experiments are described by the term "hydronuclear." They involve a combination of high explosive, usually in a nuclear weapon configuration, and fissile material (enriched uranium and/or plutonium) whose quantity is reduced far below the amount required for a nuclear explosion as the term usually is understood. Such experiments are sometimes referred to as "zero-yield tests," although the energy released by fissions, while small, is not necessarily zero. (A nuclear explosion has never been defined officially, but we consider a reasonable definition to be a specific fission energy release that is comparable to or greater than that of high explosive itself, about one kilocalorie per gram.)

When the moratorium began, there was no discussion of the issue of small, unobservable hydronuclear experiments, and no policy was established in regard to them, but the events described above forced development of such a policy. The gravity of the situation was explained to government officials in Washington, and on August 26, 1959 Los Alamos proposed a series of experiments on one of the fission primaries whose safety was now in question. The proposal described a series of experiments that began with a mass of fissile material so small that no nuclear reaction could occur. Successive firings would use increased amounts of active material in small increments until a subcritical, but multiplying nuclear reaction was detected. The series would conclude below an agreed maximum allowable energy release, and from this it should be possible to assess the specific one-point safety behavior of the stockpiled weapon.

For the other weapons in question, and for other methods of detonation, additional creep-up series of this kind would be required, although it was felt that the number of experiments in later series would be smaller as experience was gained.

Along with this proposal, Los Alamos Director Norris E. Bradbury made the observation that " . . . (our) people must be confident that what they are being asked to do is honest and consistent with established national policy and that the President knows and understands the full implications of the experiments whether

announced or not announced." (TWX-DIR-1479) In September 1959 a letter from Atomic Energy Commission (AEC) Chairman John McCone stated that Eisenhower had decided to go ahead with the safety experiments. No immediate announcement was to be made of plans or preparations, but the Kistiakowsky memoir makes it clear that such an announcement was to be in readiness should it become necessary. It was directed that the experiments be done underground at Los Alamos, and preparations to do so began immediately at a remote unused site.

On December 18, McCone wrote to Eisenhower stating that Los Alamos would be ready for the first experiment early in January 1960, and he advised Presidential approval of the series. The letter stated that any nuclear yield would not exceed one pound of high explosive equivalent. Bradbury received a message dated December 31, 1959 stating that the approval of the President had been received and that this type of experiment was "not a nuclear weapon test" under the terms of the moratorium.

The first laboratory hydronuclear experiment was conducted on January 12, 1960. Eight more were to follow in rapid succession, each based on the results of the one before, this first series concluding on February 11. A second series, involving fewer experiments than the first but with a different point of detonation, ended on March 15. The safety experiments then shifted to another stockpile weapon and the process was repeated. By April 1 the most urgent safety questions had been answered. The largest fission energy release in any experiment thus far, all of which were conducted at burial depths of 50 to 100 feet, was on the order of one-thousandth of a pound of high explosive equivalent.

Further direct safety experiments would resume some months later, but first an effort was made to use the hydronuclear technique to obtain improved equation of state data for the fissile materials involved. Inadequate data of this kind was one of the reasons for the difficulty in predicting one-point safety behavior. Again, the highest fission energy release was about one-thousandth pound. These experiments were followed by further safety tests on a system soon to enter production, with notably discouraging results. The largest fission yield in this series was about one-hundredth of a pound. It was possible from the results obtained to specify a design that would be one-point safe, but the nuclear yield for that design was unknown, in contrast to that of the safer version of the weapon studied in the first hydronuclear series. By good fortune, the safer design for that first system already had been subjected to a full nuclear test well before the moratorium began, and the stockpile weapons could confidently be retrofitted with this version and further production could be altered to the new specifications. No such tested option existed for the weapon not yet in production, and its availability therefore was delayed until well after the resumption of nuclear weapons tests late in 1961.

The value of the retrofit in the first case was demonstrated later at Palomares, Spain, when a B-52 crash resulted in weapons dropped from such height that the high explosive in one of them detonated. Plutonium was scattered (a problem that since has been dealt with by the introduction of insensitive high explosives in many newer weapons), but there was no nuclear yield. If the weapon had not been modified as a result of the hydronuclear program, the chance of a significant nuclear explosion would have been more than a thousand times greater.

Hydronuclear safety experiments were done for several other weapon systems, and the most critical safety issues were identified and in a few cases resolved, although in a other cases it was clear that further nuclear weapons tests would be necessary when the suspension ended. There were 35 hydronuclear experiments in all at Los Alamos, and a smaller number were conducted at the Nevada Test Site by the Livermore Laboratory. In June 1961, near the end of the program, a criticality experiment was performed at Los Alamos on a modified unboosted weapon design. This experiment produced four-tenths of a pound of fission energy, the highest by an order of magnitude of the entire Los Alamos series. The experiments were terminated when the Soviets abruptly resumed full-scale nuclear weapons tests on September 1 and President Kennedy directed the AEC and the Laboratories to prepare to do the same.

Lessons Learned

When the one-point safety problem suddenly arose, the initial response was faltering. Even though the moratorium was less than a year old, much of the Los Alamos testing expertise had dispersed to other activities. A new team was assembled rapidly, however, and the program was supported across the Laboratory much as some of the earlier nuclear test operations had been. One result of this effort was restoration of some of the capability that would be needed for the prompt resumption of underground nuclear testing at the NTS following the surprise abrogation of the moratorium by the Soviets.

As already noted, the hydronuclear program was virtually unnoticed outside of Los Alamos until it was discussed more than a decade later by Kistiakowsky. As in all weapons programs, the details were and remain classified and limited to those with a need to know. The experiments were publicly endorsed, however, by such knowledgeable nuclear testing opponents as Herbert Scoville in a review of the Kistiakowsky memoirs as "not bomb tests because there was no nuclear yield." We have seen that the yields, while negligibly small, were not zero in all cases, but certainly the experiments could in no way be characterized as nuclear explosions.

This point illustrates an issue that became central during the Carter Administration. A major unresolved question during the trilateral (United States, United Kingdom and Soviet Union) negotiations on a Comprehensive Test Ban (CTB) was that of the scope of the prohibition. Specifically, what kinds of experiments would <u>not</u> be prohibited, and thus would be permitted, under a CTB? The interagency system labored interminably over this question, and a decision finally was reached that small-yield experiments like those in the Los Alamos hydronuclear program would be allowed, that their fission energy release would be limited to 100 pounds (two orders of magnitude larger than any in the hydronuclear program), and that the permitted experiments would be done underground at the NTS. The last point was arrived at only after extensive consideration of a variety of above-ground containment facilities like the one referred to earlier in this discussion. The fact is that simple physics mitigated against such containment approaches for hydronuclear experiments, and earlier attempts to use this scheme had resulted in failure. Much of the internal debate during the Carter CTB negotiations was informed and driven by the experience of the Laboratories during the moratorium, although this experience was unknown to most of the participants in the debate.

It is clear that high explosive driven criticality experiments (hydronuclear experiments) can address only a limited range of questions. They can contribute essentially nothing to the design of new boosted weapons, nor can they give an adequate assessment of the performance of stockpile primaries when serious questions arise. This is because the conditions for the thermonuclear boosting reaction are established only after considerable fission yield already has been generated. Their useful role therefore is sharply limited, but it is far from zero under circumstances like those of the moratorium. Even though only a few of the hydronuclear experiments described here even reached criticality, they made it possible to identify, and in some cases to resolve, otherwise crippling safety issues. The hydronuclear experiments served also to maintain some small design and diagnostic capability that was to prove essential when nuclear weapons testing resumed. The ability to conduct such experiments can delay, but not prevent, the eventual disappearance of the nation's nuclear weapon design expertise under a CTB; and in some few cases, it may allow critical stockpile questions to be addressed experimentally.

The most important lesson learned from this experience was that a nation that depends on nuclear weapons for its security can get into serious trouble during a testing moratorium or prohibition. Even with the results that have been described here, it was only by chance that one of the important weapons studied could be retrofitted with a safer design, because the nuclear performance of that design already had been confirmed. The same was not true in another important system because a safe version of that design, even though its specifications now could be defined, had not been, and could not then be, proof tested. When testing resumed, in fact, a long series of nuclear tests was required to arrive at a final design that was both safe and adequate. In addition, the test resumption led to discovery of a number of unforeseen stockpile reliability problems and allowed them to be resolved by further tests. These problems could not have been identified or solved by hydronuclear experiments alone; thus the experiments described in this report could reduce the risk of a test suspension, but they could not eliminate it.

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Comparison of the Water Balance of an Asphalt Cover and an Evapotranspiration Cover at Technical Area 49 at the Los Alamos National Laboratory

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ABSTRACT

Two different types of waste covers, an asphalt cap and an evapotranspiration (ET) cover, have been used to contain a contaminated site at Technical Area (TA) 49 at the Los Alamos National Laboratory (LANL). In 1961, a 2.5- to 20-cm-thick asphalt cap and gravel and clay cover was constructed to isolate contamination of surface soils associated with subcritical hydronuclear safety experiments conducted at TA-49 between 1959 and 1961. The asphalt cap remained in place for 37 yr until 1998 when it was replaced with an ET cover. Cracks and subsidence features in the asphalt cap were periodically filled during that time. The thickness of the ET cover is 2.1 m at its center, tapering to zero thickness at its edges. The ET cover is instrumented with three neutron logging access tubes, and four time domain reflectometry (TDR) probes, and covered by a galvanized steel mesh biointrusion layer. Soil moisture monitoring was conducted immediately after the removal of the asphalt cap in 1998, and continuously since 1999 within the ET cover, providing a unique comparison of the performance of these cap and cover types at a semiarid site. Soil moisture monitoring results indicate that the soils within and beneath the ET cover have been drying since its installation, and infiltration of precipitation and snowmelt has been minimized. The replacement of the asphalt cap with the ET cover has significantly decreased shallow subsurface moisture contents. With continued growth of vegetation and increased transpiration, the site should continue its return to native conditions where net infiltration and associated groundwater recharge rates are <7 mm yr^{-1}.

In 1959 through 1961, subcritical hydronuclear safety experiments were conducted at TA-49 at LANL. Hydronuclear experiments were conducted in 1- or 2-m-diameter shafts at depths ranging between 9 and 33 m, with the majority of the tests conducted at a depth of 17 m. Test shafts were drilled, test materials were placed at the bottom of the shafts, shafts were backfilled with sand or local crushed tuff, tests were detonated, subsidence in shafts was backfilled, and cement caps were poured over the test shafts. The diameter of the affected detonation zones is believed to be <6 m. Most test shafts were drilled on 8-m grid spacing in four main areas within TA-49. The area within TA-49 where the test experiments were conducted is now referred to as Material Disposal Area (MDA) AB. The areas within MDA AB where the underground experiments were conducted are referred to as Areas 1, 2, 2A, 2B, 3, and 4. These Areas are also referred to as Potential Release Sites (PRSs) (LANL, 1992; Levitt et al., 2003). Refer to Fig. 1 for the location of TA-49 and LANL within New Mexico, and refer to Fig. 2 for the locations of the Areas and PRSs within TA-49.

During the drilling of a new test shaft in 1960, transuranic materials were encountered from an adjacent shaft, resulting in contamination of surface soils. The area of contamination, within Area 2, was covered by a cap of clay and gravel in the spring of 1961. Then to prevent erosion, the cap was covered with a 2.5- to 20-cm-thick asphalt cover in the fall of 1961. Years later it was discovered that the asphalt cap had adversely affected the water balance of the site by allowing infiltration through cracks and a collapsed area of the cap, and by greatly reducing ET. In addition, some ponding probably occurred on the asphalt cap because natural drainage was reduced by the elevated edge of the cap. In 1975, many cracks and a large collapsed area (1.8 by 0.9 m wide and 0.9 to 1.2 m deep) of the asphalt cover were discovered. It was also discovered that Core Hole 2 (CH-2), a 5-cm-diameter, 155-m-deep cased borehole (originally drilled for hydrogeologic characterization) located in the center of Area 2, contained about 15 m of standing water. It was suspected that the cracks and the collapsed area in the asphalt cover allowed focused infiltration of water into CH-2. In 1976, the asphalt cap was repaired, but more cracks and standing water were again found in CH-2 in 1979, 1980, and 1991 (LANL, 1992; Rofer et al., 1999). In 1994, two 46-m-deep boreholes (49-2906 and 49-2907) were drilled through the asphalt cover to evaluate the subsurface conditions below the depths of the shafts and to augment the existing moisture monitoring holes at MDA AB (LANL, 1992). An aerial photograph of the asphalt cover, taken in 1998, is shown in Fig. 3. The circular collapsed area can be seen close to the center of the asphalt cover. The collapsed area encompassed the location of CH-2.

In 1998, the asphalt cap was removed. Boreholes CH-2, 49-2906, and 49-2907 were removed and grouted, and an ET monolayer cover was constructed with three neutron logging access tubes for manual moisture monitoring and an automated soil moisture monitoring system using four TDR probes. During removal of the asphalt cover, a large zone of soil with elevated moisture contents was

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Abbreviations: CH, Core Hole; ET, evapotranspiration; LANL, Los Alamos National Laboratory; MDA, Material Disposal Area; PRSs, Potential Release Sites; TA, Technical Area; TDR, time domain reflectometry.

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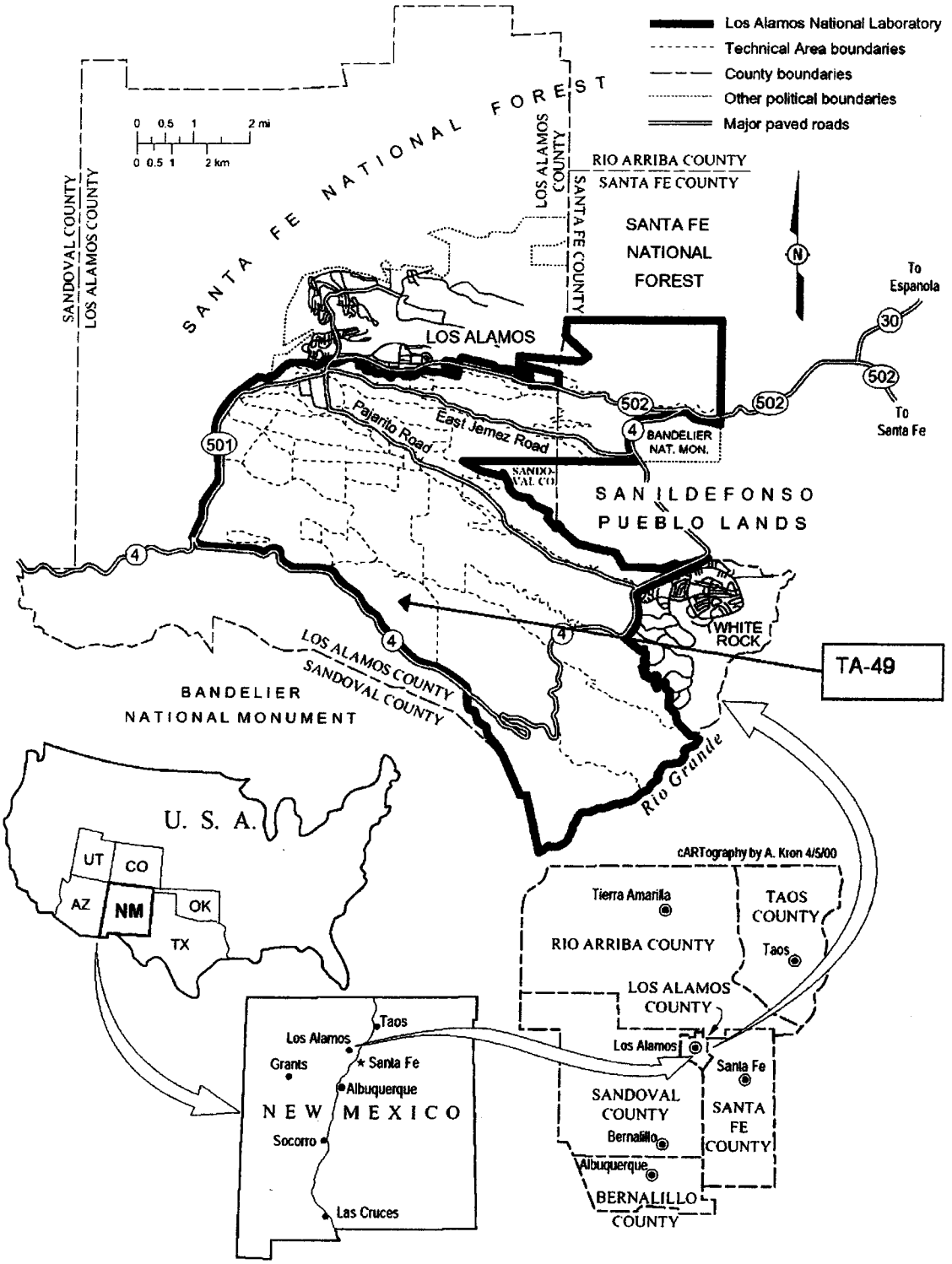

Fig. 1. Location of Technical Area 49 and the Los Alamos National Laboratory.

encountered on the northeast corner of the site. The elevated moisture contents were suspected to have resulted from lateral movement of moisture that had accumulated beneath the asphalt cap, probably within the old gravel and clay fill materials (LANL, 1999). Soil moisture measurements were taken immediately after the removal of the asphalt cover in 1998, and continuously since 1999 within the ET cover, providing a unique comparison of the performance of these cap and cover types at a semiarid site (LANL, 1999; Levitt et al., 2003).

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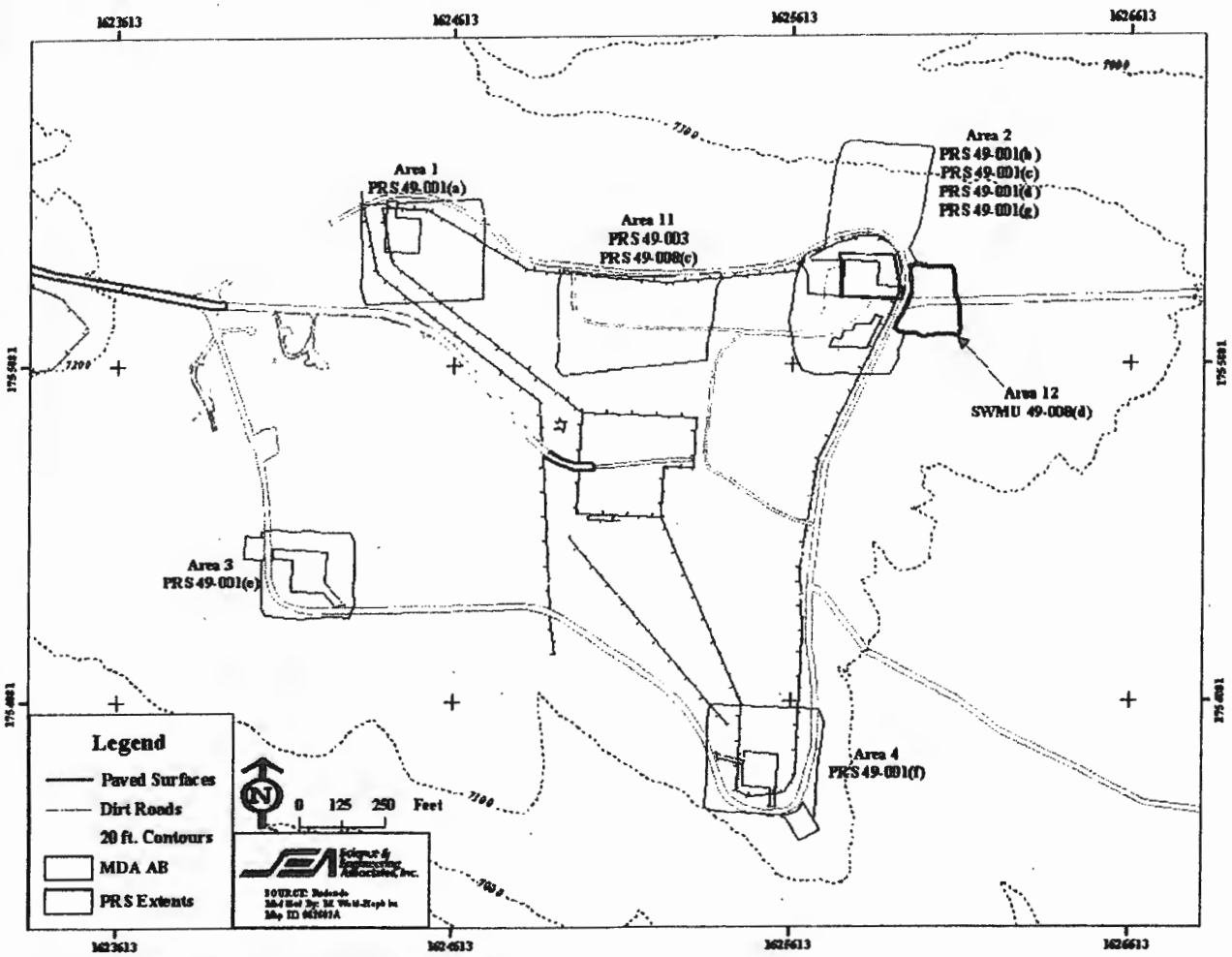

Fig. 2. Location of areas and potential release sites at Technical Area 49.

SITE DESCRIPTION

Los Alamos National Laboratory is located in north-central New Mexico, and TA-49 is located on Frijoles mesa on the southwestern boundary of LANL (Fig. 1). The mesa is relatively flat and has a vadose zone comprised of 285 m of volcanic tuff (Bandelier tuff) over 74 m of alluvial fan sediments (Stimac et al., 2002). The soil thickness on the mesa is generally 1 m or less and can be classified as a sandy loam. In general, the thickness of the soil cover is closely related to topographic slope; the soil thins out rapidly from the crown of the mesa to the edge of the mesa (Weir and Purtymun, 1962). Intermittent occurrences of the El Cajete Pumice layer can be found beneath the surface soils and within the Bandelier tuff. Storm water runoff and erosion are minimal at TA-49. There are no perennial sources of water at or near the site, with no established runoff channels. Any surface water movement occurs as sheet flow during strong rainfall events or rapid snowmelt (LANL, 1992).

TA-49 is located at an elevation of approximately 2130 m above sea level in a semiarid, temperate mountain climate. The average annual precipitation at TA-49 is 45 cm. This includes both rainfall and snowfall liquid equivalents (Bowen, 1990).

The regional aquifer is located approximately 360 m below the surface of Frijoles Mesa. Volumetric water

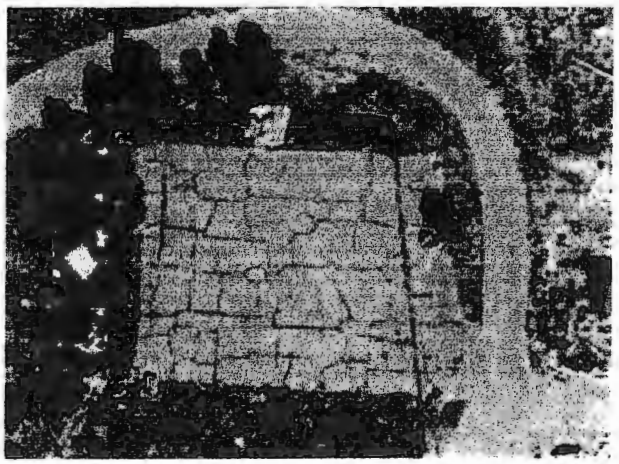

Fig. 3. Aerial photograph of the asphalt cover at Area 2, TA-49 (photographed in 1998).

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contents within the volcanic tuff are usually quite dry and range between 5 and 10% (Weir and Purtymun, 1962; Abeele et al., 1981). Gravimetric moisture analysis was performed on core samples from a 213-m-deep borehole within TA-49 in 1993 and 1994. Results indicated moisture contents of approximately 11% in near-surface soil and fill material, with a rapid decrease to 1 to 4% within the upper tuff unit (Stimac et al., 2002). Hydraulic properties for crushed tuff are reported for TA-54, located approximately 5 km from TA-49. The saturated volumetric water content for crushed tuff is reported to be approximately 38.3% (Hollis et al., 1997). The saturated water content for El Cajete Pumice is not reported, but is believed to be quite high (≈70%) because of its low bulk density. Hydraulic properties for alluvium are not reported, but a large range in hydraulic properties is expected based on the degree of disturbance by human activities (Hollis et al., 1997).

MATERIALS AND METHODS

After the asphalt cap was removed, the underlying fill (clay and gravel) was regraded to promote storm water runoff and eliminate ponding. Above the clay and gravel fill (old cover materials), a layer of crushed tuff was placed and compacted (new cover material). The final surface consisted of approximately 15 cm of topsoil, seeded with native shallow rooting grasses, overlain with a thin layer of gravel and a galvanized steel mesh bio-intrusion barrier. The final cover thickness of the new cover of topsoil and crushed tuff (from cover surface to original ground surface level) ranges from 2.1 to 0 m. The topsoil was hand-seeded with a mixture of native grasses, including 40% blue grama [*Bouteloua gracilis* (Kunth) Lag. ex Griffiths], 40% western wheatgrass [*Agropyron smithii* Rydb. (*basionym*)], and 20% annual ryegrass (*Lolium multiflorum* Lam.). After seeding, the site was covered with a thin layer of gravel to increase erosion protection and protect the seed from animals and act as a mulch to enhance germination. The steel bio-intrusion layer is made of 11-gauge steel with 1.25-cm openings and was installed primarily to prevent gophers (*Thomomys talpoides*) from digging through the cover (LANL, 1999).

After installation of the ET cover, three neutron access holes (designated 49-10046, 49-10047, and 49-10048) were drilled and cored through the cover so soil water contents could be monitored. These boreholes range in depth from 3.4 to 4.3 m, and total depth is located just below the contact of soil or fill with weathered volcanic tuff (LANL, 1999). The geologic stratigraphy encountered during drilling and coring of these three boreholes immediately after construction of the ET cover is shown in Fig. 4. Water contents were found to be lowest in the new ET cover material (crushed tuff) and the clay rich soils of the old cover (10–25%), and higher within crushed tuff and the El Cajete Pumice layers of the old cover (25–60%). The El Cajete Pumice was encountered at two of the three boreholes. Photographs of the ET cover are shown in Fig. 5 and 6. These photographs were taken 2 Sept. 2004, approximately 6 yr after construction and seeding of the cover.

During the construction of the ET cover, TDR probes were installed within the cover material at two depths at two locations (Table 1, Fig. 7). The TDR probes (model CS615, Campbell Scientific Inc., Logan, UT) were wired into a Campbell Scientific data logger (model 23X) for automated measurements. The TDR probe wires were placed in PVC casing between the monitoring location and the data logger to prevent rodent damage to the wires. The calibration equation used to convert raw voltage measurements into volumetric water contents was taken from the CS615 users' manual. Volumetric water contents are measured with the four TDR probes twice per day. At the western location, TDR probes were buried at depths of 15 and 183 cm. At the eastern location, TDR probes were buried at depths of 15 and 305 cm. At both locations, the shallow probe was buried in a horizontal position at the base of the topsoil layer while the deep probe was buried in a vertical position. At both locations the deep probe was buried in a vertical position because this only required excavation of a borehole using a hand auger rather than requiring a larger excavation for installation of the 30-cm-long probes. At the western location the deep probe was buried in soil, while at the eastern location the deep probe was buried in the El Cajete Pumice layer. The shallow probes were installed in ET cover materials, so initial data do not represent natural conditions. Deeper probes were installed in preexisting geologic media, so they better represent the results of site improvements compared with the shallow probes. The TDR probes and an onsite precipitation gauge allow for characterization of the ET cover's performance in response to precipitation events.

To supplement the TDR data, eight neutron access holes surrounding Area 2 (2A-O, 2A-Y, 2B-Y, TH-1, TH-2, TH-3, TH-4, and TH-5) and the three boreholes through the Area 2 ET cover were neutron logged on a monthly basis from September 1999 until September 2002, after which they were monitored every 2 mo. The 2A/2B boreholes, TH boreholes, the 46-m-deep boreholes (49-2906 and 49-2907), and the CH-2 borehole were periodically neutron logged before 1998 using the same logging techniques as were used after 1998. Water content profiles were measured at 49-2906, 49-2907 in 1994, and at CH-2 in 1998, and represent moisture conditions beneath the asphalt cover. Water content profiles from the five TH boreholes represent undisturbed soil moisture conditions in the Frijoles Mesa. Water content profiles from the three 2A/2B boreholes represent disturbed soil moisture conditions because these boreholes were installed into unused test shafts that were backfilled with crushed tuff. The 2A/2B boreholes represent moisture conditions of disturbed soils after four decades of redistribution. Therefore, moisture conditions in the ET cover should eventually be equivalent to or drier than those in the 2A/2B boreholes. The locations of the four TDR probes and the 11 neutron logging access tubes described above are shown in Fig. 7. A summary of the boreholes used for water content measurements (by core sampling and neutron logging) is shown in Table 2.

Volumetric water contents were calculated using calibration equations from the neutron probe users' manual. Different calibration equations were used for the different casing types for the 2A/2B, TH, and ET cover casings. However, the same calibration equation was used for topsoil, clay layers, crushed tuff, and intact tuff for a given borehole. The 2A/2B boreholes were drilled through backfilled crushed tuff materials, the TH boreholes were drilled through thin soil and intact tuff, and the ET cover boreholes (49-10046, 49-10047, and 49-10048) were drilled through a thin topsoil layer, crushed tuff, thin clay layers, and in some cases, the El Cajete Pumice layer. Water contents provided by neutron logging in the El Cajete Pumice may be higher than actual water contents, but these measurements are adequate for comparing relative changes in water content with time.

RESULTS AND DISCUSSION

During the past 4 yr, volumetric soil water contents measured with the shallow (0.15 m deep) TDR probes

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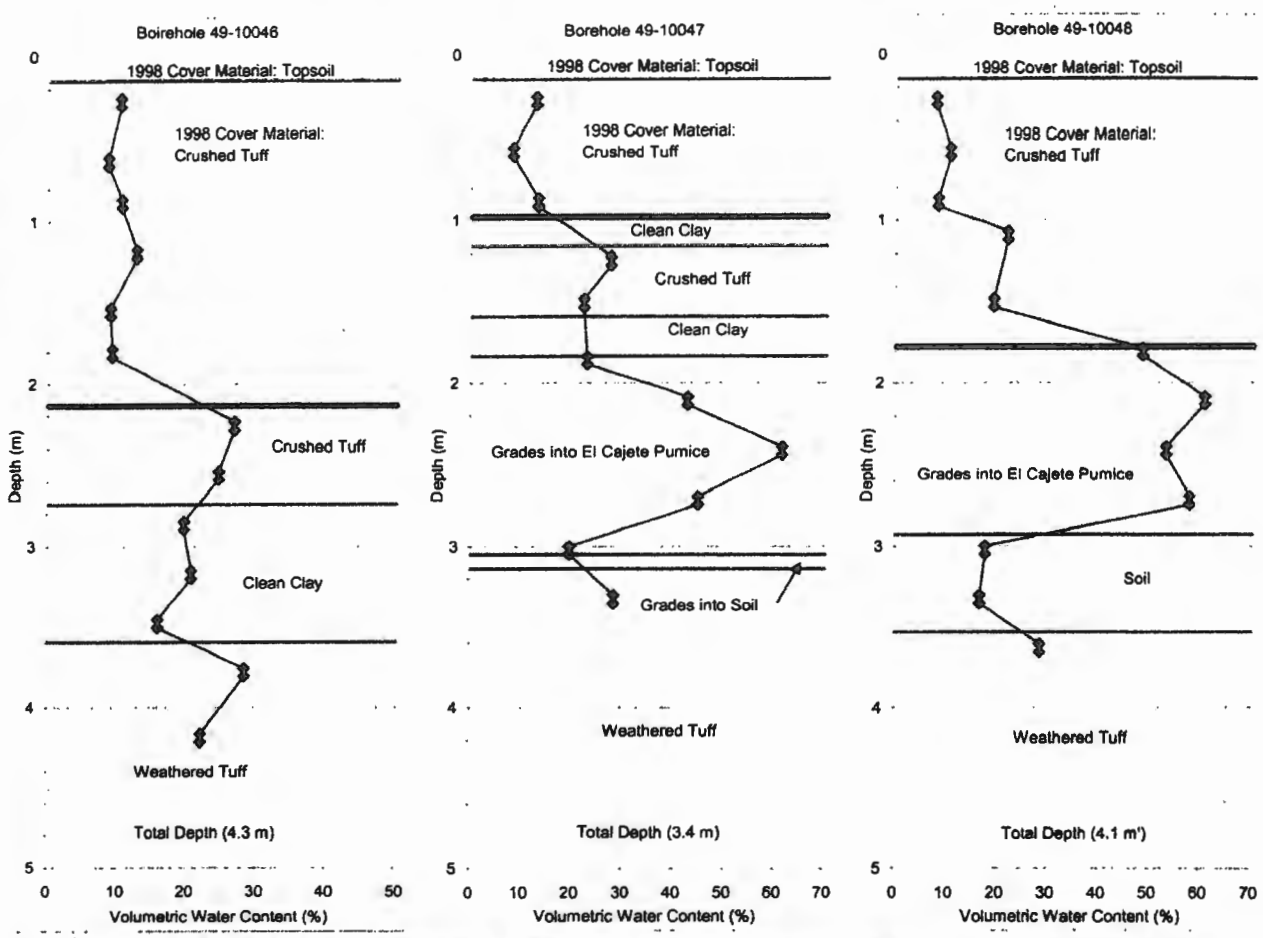

Fig. 4. Stratigraphy and soil water contents encountered during coring of the three boreholes through the evapotranspiration (ET) cover in 1998. The green lines indicate original ground surface and "1998 Cover Material" refers to the ET cover installed in 1998. Layers between the 1998 cover material and original ground surface are the remnant layers from the pre-1998 cover.

in the ET cover have ranged from approximately 8 to 44%. The shallow TDR probe at the west site, which is upslope from the east site, measured maximum water contents of about 31% in the winter of 2000–2001, and lower maximums in subsequent winters and springs. The shallow TDR probe at the east site measured maximum

Fig. 5. Photograph of ET cover (facing west) taken 2 Sept. 2004.

Fig. 6. Photograph of ET cover taken 2 Sept. 2004. Neutron logging Borehole 49-10048, PVC protection for wires from TDR West station, and the galvanized steel bio-intrusion mesh can be seen in the photograph.

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Table 1. TDR array descriptions.

TDR number	Array type	Depth
		m
TDR1	vertical, within soil overlaying Bandelier Tuff	1.83
TDR2	horizontal, at bottom of topsoil	0.15
TDR3	vertical, within El Cajete pumice formation	3.05
TDR4	horizontal, at bottom of topsoil	0.15

water contents >40% during three of the past four winters and springs. These measurements indicate near-saturated to saturated soil conditions. The deep TDR probes measured water contents that remained fairly steady, with water contents at approximately 10% at the east site (in the pumice layer), and 16 to 17% at the west site (in soil). The exception to this was an increase in water content from 10 to 17% at a depth of 3 m at the east site in April 2004. This increase was in response to a period of sustained rainfall (8.3 cm in a 10-d period). However, water contents at this depth quickly returned to a residual water content of 10% within 2 mo. These data indicate that occasional pulses of infiltration can penetrate the entire depth of the ET cover following periods of high rainfall. These pulses may be mitigated or eliminated once vegetation on the ET cover has reached maturity. Although the vegetation appear to be quite mature in the photographs in Fig. 5 and 6, large bare areas are currently present and vegetative cover and rooting depth are expected to increase in the future. A time series plot of the water content measurements from the TDR probes, with cumulative precipitation, is shown in Fig. 8.

Moisture content data collected from the neutron logging boreholes in the ET cover during the past 4 yr indicate a significant decrease in subsurface moisture due to the removal of the asphalt cover. The current moisture contents observed in these boreholes range from 12 to 22%, a decrease of as much as 48% volumetric water content (61% to 13%) from values measured just after removal of the asphalt cap. Figure 9 illustrates soil water contents from neutron logging measurements from CH-2, just before it was abandoned in 1998, soil water contents from core taken from the three boreholes in the ET cover as they were drilled in 1998, and the average 2004 (January–September) soil water contents from neutron logging measurements. These data indicate that the removal of the asphalt cap and installation of an ET cover

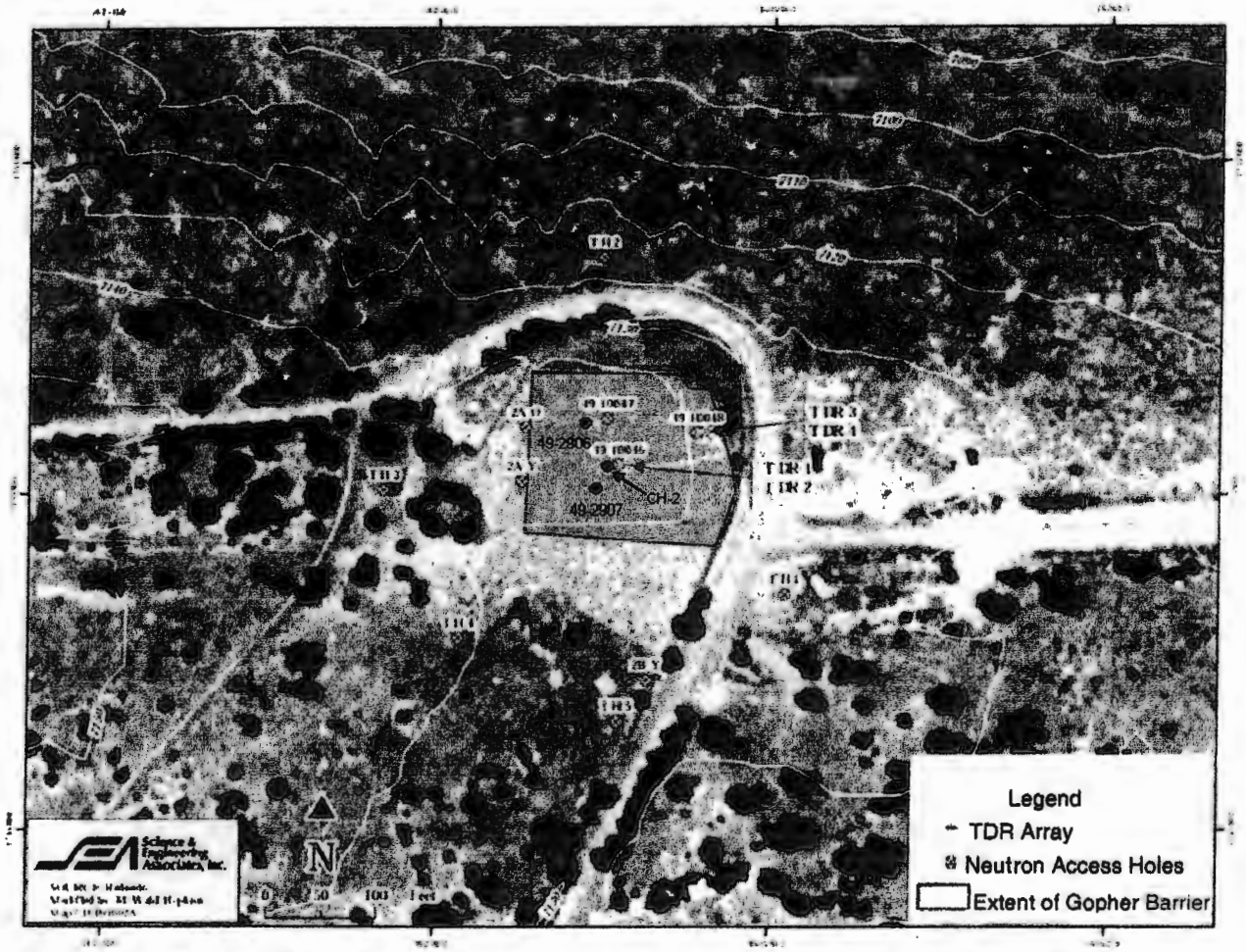

Fig. 7. Aerial photograph of Area 2 showing locations of the neutron logging boreholes, the two boreholes sampled in 1994 (49-2906 and 49-2907), CH-2, the four TDR probes, and the extent of the bio-intrusion barrier.

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Table 2. Details of boreholes used for water content measurements.

Borehole	Type of data	Location	Conditions	Media	Depth	Dates of data collection
					m	
TH-1	neutron logging	surrounding cover	undisturbed	surface soils and intact tuff	37	1980–current
TH-2	neutron logging	surrounding cover	undisturbed	surface soils and intact tuff	37	1980–current
TH-3	neutron logging	surrounding cover	undisturbed	surface soils and intact tuff	37	1980–current
TH-4	neutron logging	surrounding cover	undisturbed	surface soils and intact tuff	37	1980–current
TH-5	neutron logging	surrounding cover	undisturbed	surface soils and intact tuff	37	1980–current
2A-O	neutron logging	surrounding cover	disturbed	shaft backfilled with crushed tuff	23	1980–current
2A-Y	neutron logging	surrounding cover	disturbed	shaft backfilled with crushed tuff	24	1980–current
2B-Y	neutron logging	surrounding cover	disturbed	shaft backfilled with crushed tuff	24	1980–current
CH-2	neutron logging	through asphalt cover	disturbed/undisturbed	asphalt cover, old cover material, and intact tuff	155	1959–1998
49-2906	core sample	through asphalt cover	disturbed/undisturbed	asphalt cover, old cover material, and intact tuff	46	1994
49-2907	core sample	through asphalt cover	disturbed/undisturbed	asphalt cover, old cover material, and intact tuff	46	1994
49-1006	neutron logging	through ET cover	disturbed	ET cover material	4.3	1999–current
49-1007	neutron logging	through ET cover	disturbed	ET cover material	3.4	1999–current
49-1008	neutron logging	through ET cover	disturbed	ET cover material	3.6	1999–current

has resulted in significant drying of the soil profile, particularly at depths of 1.5 to 3.0 m. The very large decreases in water content at depths of 1.5 to 3.0 m for Boreholes 49-1007 and 49-1008 indicate that the El Cajete Pumice layer has dried out significantly in the past 6 yr. It should be noted that the elevation of the CH-2 borehole was approximately 1.5 m below that of the ET cover surface, so the top of the water content profile from CH-2 begins 1.5 m below the ET cover water content profiles. It should also be noted that the calibration used for conversion of neutron counts to water content for CH-2 is not documented, and it is suspected that the water content measurements for CH-2 should be higher to be consistent with the water content measurements from the core samples in Boreholes 49-1006, 49-1007, and 49-1008. Therefore, the water contents measured at CH-2 in 1998 were multiplied by 2 and plotted in Fig. 9 (dashed line) because this profile is a close match to the core sample data.

Neutron logging data indicate that the five undisturbed boreholes surrounding Area 2 (TH-1, TH-2, TH-3, TH-4, TH-5) have peak moisture contents between 10 and 20% at depths of 0.3 to 2 m (Fig. 10). This depth range corresponds to the thickness of soil covering the weathered tuff of the Tshirege Member of the Bandelier tuff. Moisture contents then drop rapidly, and stay relatively

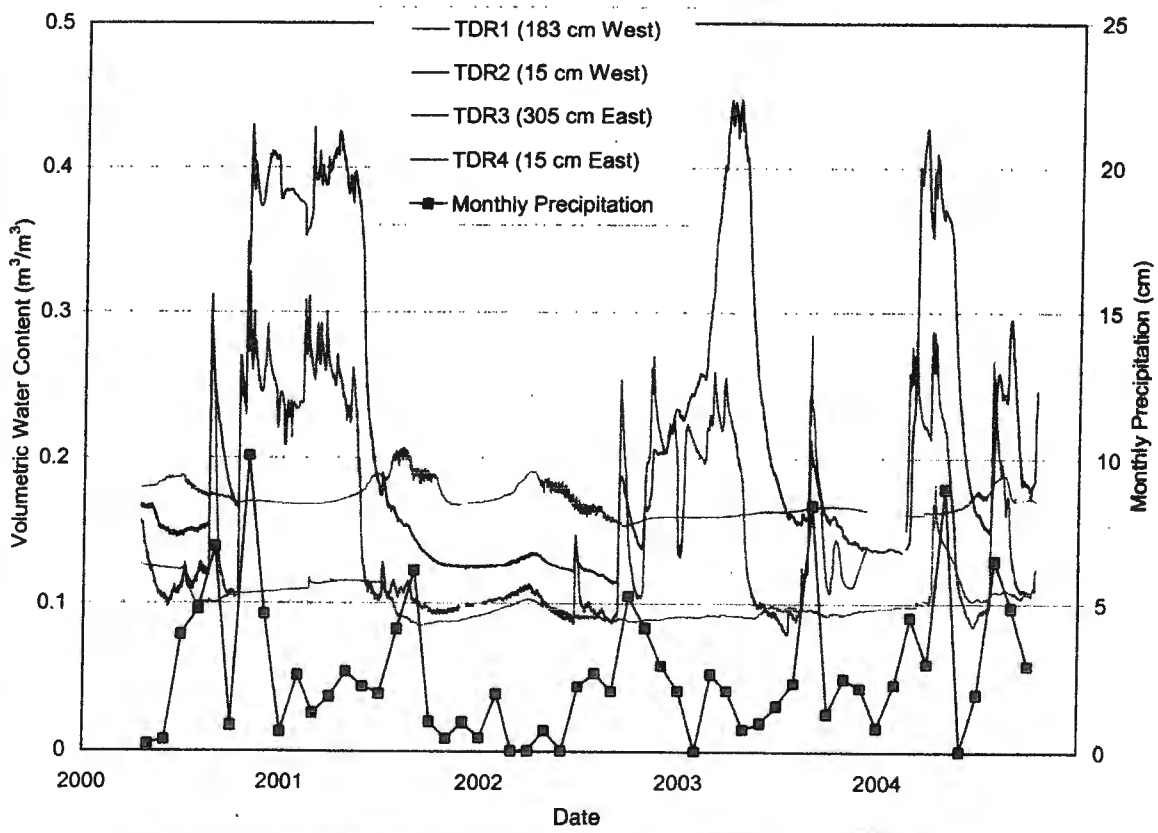

Fig. 8. Soil water contents from TDR measurements within the ET cover from April 2000 to October 2004 with monthly precipitation totals.

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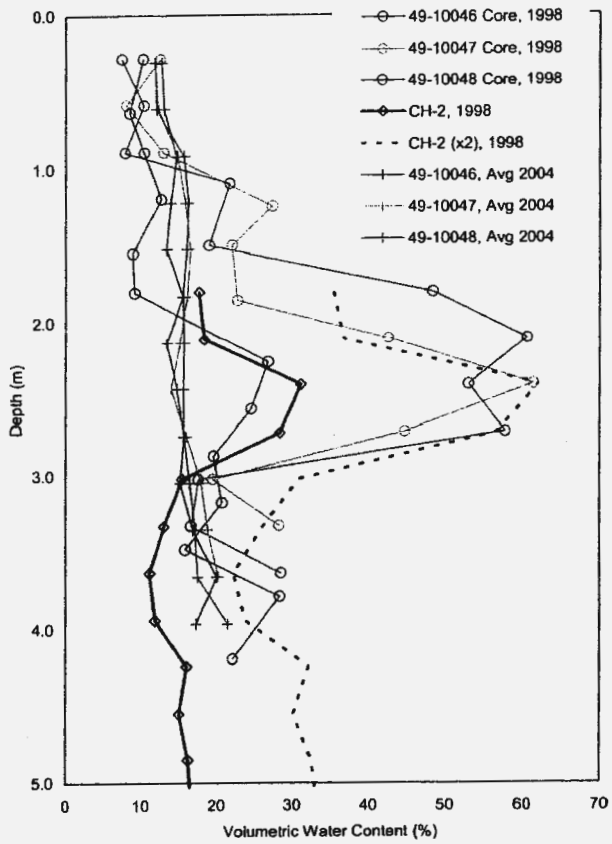

Fig. 9. Soil water contents measured from ET cover core samples and neutron logging CH-2 (1998) and from neutron logging three boreholes in the ET cover (average of 2004 measurements).

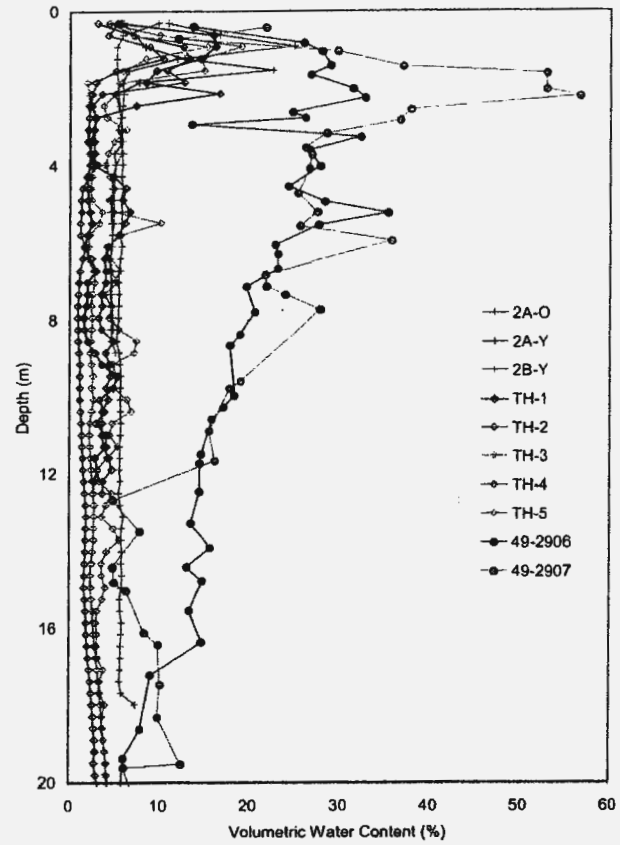

Fig. 10. Water content measurements (average of 1999–2004) from neutron logging the TH (undisturbed conditions) and 2A/2B (disturbed conditions) boreholes, and water content measurements from core samples collected in 1994 from Boreholes 49-2906 and 49-2907.

constant between 0 and 5% to total depth of the borehole (27–35 m) (Birdsell et al., 2005). Neutron logging data from the three boreholes representing disturbed but stable conditions (2A-O, 2A-Y, and 2B-Y) are also shown in Fig. 10 and indicate a similar trend to that measured in the undisturbed TH boreholes, except that water contents in the three 2A/2B boreholes are generally slightly wetter than in the TH boreholes. This is because the three 2A/2B boreholes were filled with crushed tuff (or sand) while the TH boreholes were drilled through native tuff, and because the 2A boreholes may have experienced ponding conditions while the asphalt cover was in place. Gravimetric sampling data from the two 46-m boreholes (49-2906 and 49-2907) are also shown in Fig. 10. These water content profiles were developed from samples collected during drilling of the boreholes in 1994, and the water contents are much higher than the 2A/2B and TH boreholes. Water content profiles from these two boreholes clearly indicate highly elevated water contents from just beneath the asphalt cover, then a steady decrease to water contents <10% at a depth of 20 m. The highest water content measurement of 57% at a depth of 2.2 m corresponds to a clay layer in the old (pre-1999) cover material.

Vertical fluxes were determined for Boreholes 49-10046, 49-10047, and 49-10048 in 1998 on the basis of chloride concentrations from core samples collected immediately after the removal of the Area 2 asphalt cover (Newman and Ludwig, 2000). Flux estimates determined from this study indicated a range of 0.6 to 1.3 cm yr^{-1}. These values are similar to fluxes estimated beneath disturbed areas within TA 54, where fluxes ranged form 0.02 to 0.9 cm yr^{-1} (Newman et al., 1999). Fluxes determined for undisturbed mesa top localities within LANL range from −9.5 to 0.69 cm yr^{-1} (Rogers et al., 1996). The neutron logging data generally support the fluxes determined from chloride data for disturbed and undisturbed sites. The water contents measured during drilling of the two 46-m (49-2906 and 49-2907) boreholes in 1994 were the highest. Birdsell et al. (2005) matched a simulated flux of 60 mm yr^{-1} to the data from these boreholes. The original water contents from the ET cover boreholes were wetter than recent measurements, indicating relatively higher fluxes, while the recent water content data from ET cover boreholes is drier, corresponding to lower fluxes. The water contents from the 2A/2B boreholes (disturbed conditions) are generally drier than the ET cover water contents, but slightly wetter than the water contents from the TH (undisturbed conditions) boreholes. Infiltration rates were modeled for the TH boreholes and an infiltration

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rate of 0.1 mm yr^{-1} fit the water content data well for these boreholes (Birdsell et al., 2005).

The data clearly indicate that the ET cover design is performing better than the asphalt cover design, especially if recent profiles for 2004 in the three ET cover boreholes are compared with 1994 sampling data. However, more moisture monitoring data from the ET cover should be collected for this conclusion to be definitive. This is because the winter of 1997–1998 was an "El Nino" winter, with an average of approximately 54 cm precipitation for the 2-yr period of 1997 and 1998, while the 4-yr period of 2000 to 2003 was quite dry with an average precipitation of approximately 32 cm yr^{-1} (www.weather.lanl.gov). The average annual precipitation for the area is approximately 45 cm yr^{-1} (Bowen, 1990).

CONCLUSIONS

Soil moisture monitoring data provided by TDR and neutron logging measurements indicate that the ET cover is performing well at returning infiltrating precipitation and snowmelt to the atmosphere by ET, isolating soil contamination at a depth of approximately 2 m below the cover surface and the radiological inventory located approximately 19 m below the cover surface, and thereby mitigating deep percolation and possible mobilization of contaminants to the regional groundwater aquifer located at a depth of about 360 m below ground surface. If percolation from precipitation and focused infiltration reached the radiological inventory at a depth of 17 m while the asphalt cover was in place, that pathway has been mitigated with the installation of the ET cover, and any areas of elevated moisture content at depth should redistribute to drier areas in the subsurface. Although moisture conditions have not returned to those observed in stable disturbed or undisturbed areas, the neutron logging data indicate that the soils beneath the ET cover continue to dry. With continued growth of vegetation and increased transpiration, the site should continue its return to natural vadose zone conditions. Moisture monitoring activities should continue to ensure that the drying trend observed in the ET cover is due to the improved cover design rather than due to climatic conditions.

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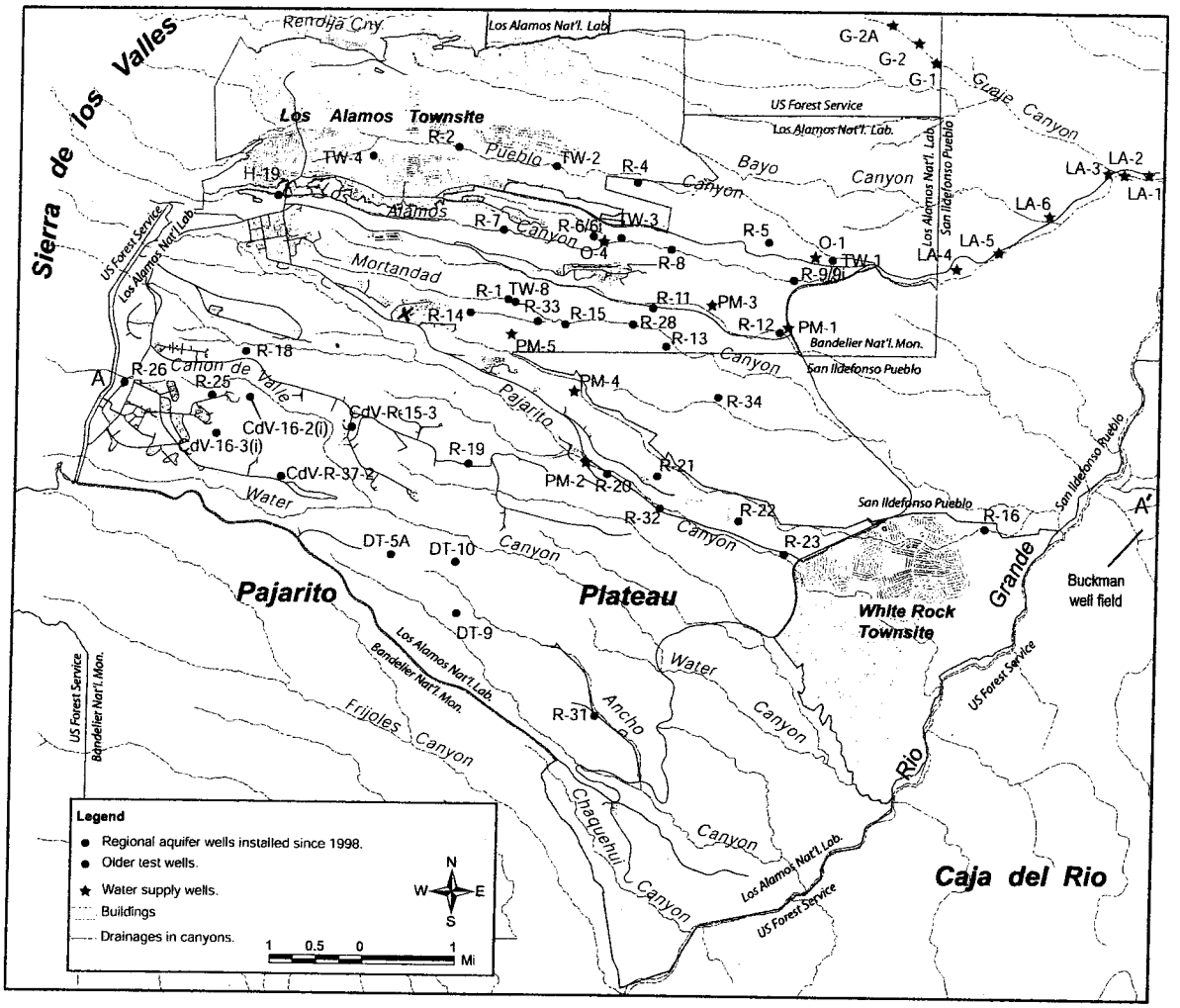

Figure 1-1. Map showing the location of characterization wells

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Dangerous Discrepancies: Missing Weapons Plutonium in Los Alamos National Laboratory Waste Accounts

Arjun Makhijani, Ph.D.
Brice Smith, Ph.D.

November 29, 2005
Reissued with Corrections April 21, 2006

Takoma Park, Maryland

We can get a rough high estimate of the amount of weapons plutonium in Los Alamos buried waste by assuming it had the same isotopic composition as the WIPP waste, the values of which are decay-corrected to 2001. This procedure yields an estimate of about 87 kilograms of plutonium in Los Alamos buried waste.

There are a variety of other sources of plutonium in the underground environment at Los Alamos. The main one other than buried waste is the plutonium dispersed underground during hydronuclear testing in the 1958 to 1961 test moratorium period. We have not found any data for the use of weapons plutonium in subsequent sub-critical or hydronuclear tests at Los Alamos. The tests conducted at the Nevada Test Site would, of course, not contribute to sub-surface plutonium at Los Alamos.

Table 6 shows the various sources and estimates of subsurface waste at Los Alamos.

Table 6: Plutonium in the subsurface environment in Los Alamos – High estimate

	Pu-239/240 (kilograms)	Comments
TA-21 Material Disposal Area A	0.24	
TA-21 Material Disposal Area B	0.10	Uses WIPP Isotopic Ratios
TA-50 Material Disposal Area C – Pits	0.39	
TA-54 Material Disposal Area G – Pits	86.99	Uses WIPP Isotopic Ratios
TA-50 Material Disposal Area C - Shafts	0.24	Uses WIPP Isotopic Ratios
TA-54 Material Disposal Area G - Shafts	15.15	Uses WIPP Isotopic Ratios
TA-21 Material Disposal Area T - Shafts	1.27	
TA-49 Material Disposal Area AB - Hydronuclear Test Shafts	39.19	
TA-21 Material Disposal Area T - Adsorption Beds	0.04	Uses WIPP Isotopic Ratios
TA-21 Material Disposal Area V - Laundry Adsorption Beds	0.0004	Uses WIPP Isotopic Ratios
Total (high estimate)	**143.60**	

Except for hydronuclear tests, Table 6 gives a high estimate of plutonium in waste, since the WIPP isotopic ratios are assumed for most components. A better estimate of the total plutonium in the Los Alamos subsurface environment, taking into consideration the available information about the time of emplacement of the various components of waste, is about 100 kilograms (of which 50 kilograms is buried waste, 39 is subsurface plutonium dispersed due to hydronuclear tests, and the rest consists of the relatively small categories in the Los Alamos subsurface environment). We will use this value in our analysis unless otherwise specified.

Liana Matthews
ESH-18

LA-12883-MS

UC-903 and UC-940
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Geologic and Hydrologic Records of Observation Wells, Test Holes, Test Wells, Supply Wells, Springs, and Surface Water Stations in the Los Alamos Area

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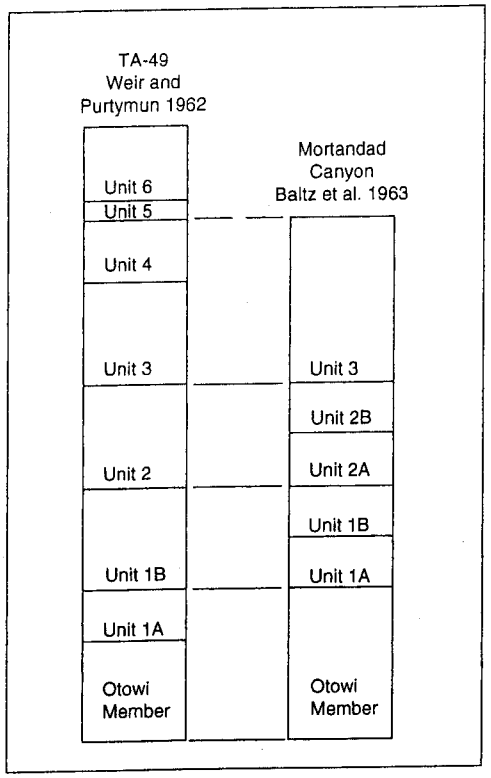

Fig. IX-B. Correlation of the units of the Tshirege Member of the Bandelier Tuff at TA-49 with the type section in Mortandad Canyon.

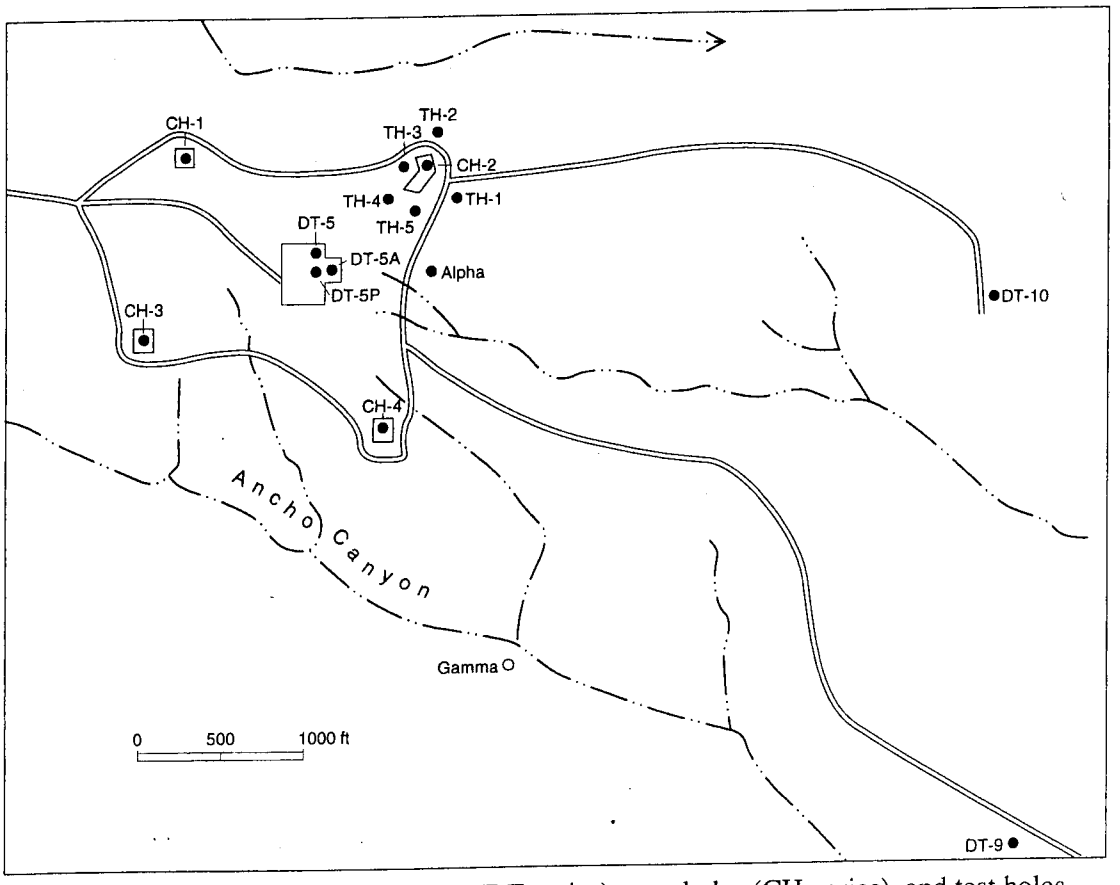

Fig. IX-C. Location of deep test wells (DT-series), core holes (CH-series), and test holes (TH-series) (Purtymun 1994).

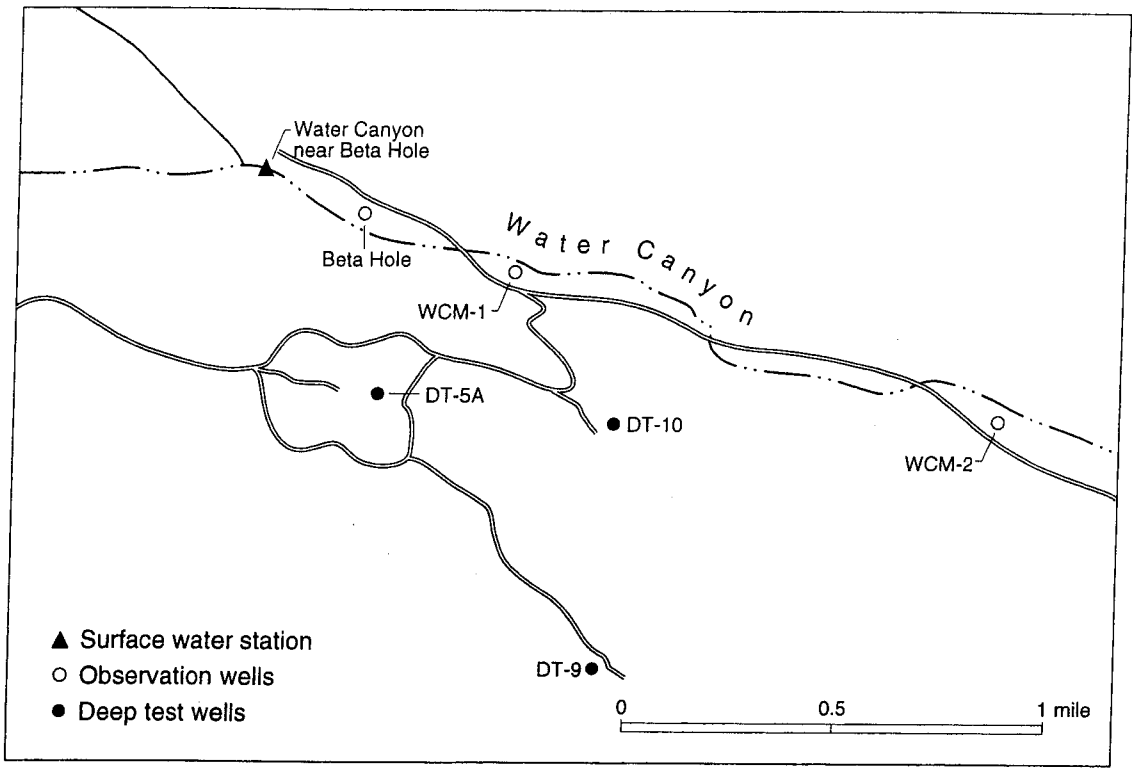

Fig. IX-U. Locations of wells, holes, and a surface water sampling station in Water Canyon north of TA-49.

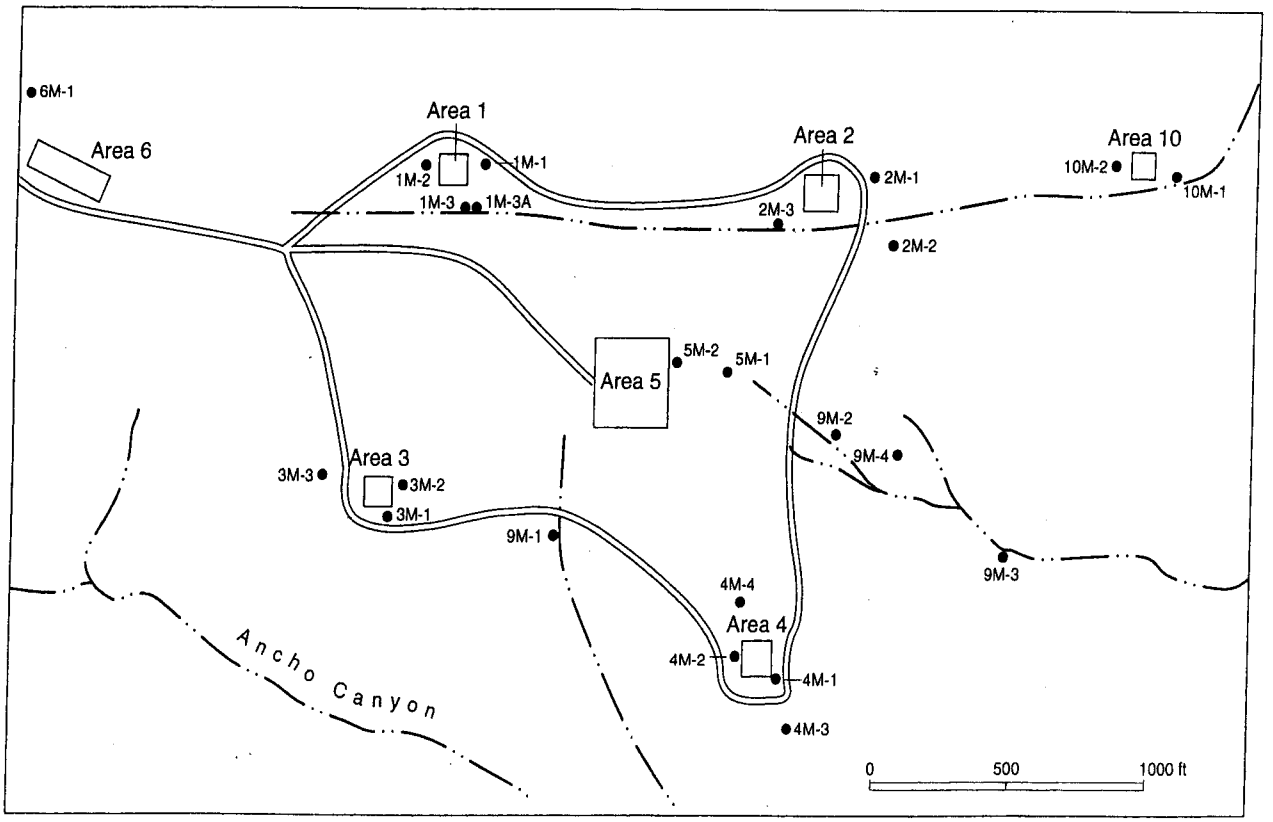

Fig. IX-V. Locations of moisture-access holes at TA-49.

TABLE IX-B. Geologic Logs and Construction Data for Test Holes and Test Wells (5 Test Holes and Wells) (Continued)

2. Test Hole DT-5

Elevation (LSD) 7143 ft — Water Level: Dry

Geologic Log	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tshirege Member	641	641
Otowi Member	198	839
Guaje Member	101	940
Puye Conglomerate		
Fanglomerate member	22	962

Casing Schedule
180 ft of 8-in.-diam steel casing set 0–180 ft; open hole 180–962 ft.

Geophysical Logs
Gamma-ray/neutron, induction-electrical, and temperature logs.

3. Test Well DT-5A

Elevation (LSD) 7144 ft — Water Level: 1173 ft, April 1960

Geologic Log	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tshirege Member	641	641
Otowi Member	198	839
Guaje Member	91	930
Puye Conglomerate		
Fanglomerate member	237	1167
Basaltic Rocks of Chino Mesa		
Unit 2[a]	126	1293
Puye Conglomerate		
Fanglomerate member	138	1431
Basaltic Rocks of Chino Mesa		
Mesa Unit 2[a]	26	1457
Puye Conglomerate		
Fanglomerate member	18	1475
Totavi Lentil	52	1527
Santa Fe Group		
Chaquehui Formation	294	1821

Casing Schedule
525 ft of 12-in.-diam steel casing cemented in 0–525 ft; 1821 ft of 8-in.-diam steel casing hung 0 to 1821 ft with a total of 220 ft of torch-cut slots throughout the area below 1172 ft.

Geophysical Log
Gamma-ray/neutron, induction-electrical, temperature, microlog-caliper, laterlog, and sonic logs.

[a]Logged by Weir and Purtymun (1962) as Tschicoma Formation (see text).

TABLE IX-B. Geologic Logs and Construction Data for Test Holes and Test Wells (5 Test Holes and Wells) (Continued)

4. Test Well DT-9

Elevation (LSD) 6935 ft

Water Level: 1003 ft, February 1960

Geologic Log	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tshirege Member	676	676
Otowi Member	126	802
Guaje Member	48	850
Puye Conglomerate		
Fanglomerate member	74	924
Basaltic Rocks of Chino Mesa		
Unit 2[a]	238	1162
Puye Conglomerate		
Fanglomerate member	157	1319
Totavi Lentil	38	1357
Santa Fe Group		
Chaquehui Formation	144	1501

Casing Schedule

1335 ft of 12-in.-diam steel casing set 0–1335 ft, lower 295 ft torch slotted; 186 ft of 8-in.-diam steel casing swaged into the 12-in. casing at 1315 ft, set on bottom with 183 ft of torch-cut slots.

Geophysical Log

Gamma-ray/neutron, induction-electrical, temperature, laterlog, and sonic logs.

5. Test Well DT-10

Elevation (LSD) 7020 ft

Water Level: 1085 ft, April 1960

Geologic Log	Thickness (ft)	Depth (ft)
Bandelier Tuff		
Tshirege Member	672	672
Otowi Member	157	829
Guaje Member	35	864
Puye Conglomerate		
Fanglomerate member	108	972
Basaltic Rocks of Chino Mesa		
Unit 2[a]	319	1291
Puye Conglomerate		
Fanglomerate member	65	1356
Totavi Lentil	46	1402
Santa Fe Group		
Chaquehui Formation	7	1409

Casing Schedule

1130 ft of 12-in.-diam steel casing set 0–1130 ft, lower 50 ft torch slotted; 310 ft of 8-in.-diam casing set swaged into the 12-in.-diam casing at 1098 ft, set on bottom with a total of 141 ft of torch-cut slots throughout the section.

Geophysical Log

Gamma-ray/neutron, induction-electrical, temperature, and sonic logs.

[a]Logged by Weir and Purtymun (1962) as Tschicoma Formation (see text).
Source: Weir and Purtymun 1962, modified by Purtymun for this report.

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Environmental Surveillance at Los Alamos during 2002

Environmental Surveillance Program:

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Water Quality and Hydrology (Group RRES-WQH)
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Solid Waste Regulatory Compliance (Group RRES-SWRC)
505-665-9527

Ecology (Group RRES-ECO)
505-665-8961

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Two chlorinated solvents, PERC and TCE, were found in samples from several ports at R-25 throughout their sampling history. Both solvents have EPA MCLs of 5 µg/L. PERC was detected in three of five samples in the upper port at an average concentration of 1.2 µg/L (EPA tap water screening level of 1.08 µg/L). This compound was detected in two of five sampling events at two other intermediate perched ports, including the most recent two samples at the 1,197-ft port 4 at the base of the perched zone. The average of these results was 0.8 µg/L. TCE was found in all five samples from the upper port at an average concentration of 1.5 µg/L (EPA tap water screening level of 1.63 µg/L). The two most recent analytical results were 1.7 µg/L. TCE was detected in the two most recent (2002) samples at port 4 (as was PERC) and also one time in each of three other ports (Figure 5-22). The analytical results for PERC and TCE indicate that the chlorinated solvents are present at screening levels and at 30% to 40% of the MCL.

Several R-25 ports showed levels of iron and manganese (EPA MCLs), a temporary effect of well construction found in other recently drilled wells (Longmire 2002d). Nickel and chromium occurred at levels above EPA MCLs, possibly another temporary effect of well construction. Boron in port 2 was 77% of the New Mexico groundwater standard and was above background in port 1. Boron may be the result of infiltration of Laboratory effluents. In addition to analyzing samples for HE compounds, RRES-WQH personnel analyzed samples for SVOC and VOC compounds. Other than the compounds previously discussed, no compounds were detected that were not also found in field, trip, or equipment blanks.

Samples from the Water Canyon gallery, which came from intermediate perched groundwater flowing from volcanics in the Sierra de los Valles west of the Laboratory boundary, contained no detected radionuclides or constituents above drinking water standards.

8. Ancho Canyon

Area AB at TA-49 was the site of underground nuclear weapons component testing from 1959 to 1961 (Purtymun and Stoker 1987; ESP 1988). The tests involved HEs and fissionable material insufficient to produce a nuclear reaction. In 1960, the US Geological Survey drilled three deep wells to monitor regional aquifer water quality. No radionuclides were detected in these wells in 2002 and no other inorganic constituents except aluminum (related to turbidity) exceeded regulatory standards. All three wells were sampled for HE compounds, with no HE compounds detected. Monitoring well DT-9 was sampled for other organic compounds. Only methylene chloride was detected: this is a common analytical laboratory contaminant and was detected in a trip blank at a similar level.

9. White Rock Canyon Springs

The springs that issue along the Rio Grande in White Rock Canyon represent the principal discharge of regional aquifer groundwater that flows underneath the Laboratory (Purtymun et al. 1980). The springs serve as boundary monitoring points for evaluating the Laboratory's impact on the regional aquifer. Other than very low levels of tritium, the only radionuclide detections in White Rock Canyon springs were uranium in La Mesita Spring and plutonium-238 in Spring 2. Naturally occurring uranium is commonly detected in La Mesita Spring. The plutonium-238 value was just above the detection limit and is likely a false positive.

The RRES-WQH Group analyzed several springs using the low-detection-limit tritium method. Except where impacted by effluent discharge, activities of tritium in the regional aquifer in other parts of the Laboratory range between 1 and 3 pCi/L. Tritium concentrations in northern New Mexico surface water and rainwater range from 30 to 40 pCi/L. Rainfall around the Laboratory may have higher tritium activity (Adams et al. 1995). Most of the springs had tritium values ranging between nondetection (less than about 1 pCi/L) and 3 pCi/L. Three springs (4, 4B, and 4C) issue within a few hundred feet of each other near the Rio Grande. Spring 4B had tritium values near 45 pCi/L, while the other two springs had tritium values near 10 pCi/L. Spring 4B has a low flow rate and all the spring samples may be affected to some degree by rainfall. The largest spring in the area, Spring 4A, had a nondetect for tritium.

Perchlorate was not detected in 2002 in any springs at the 4 µg/L detection limit of the IC method. Two analyses of a sample from Spring 4 had results of 12 µg/L. However, the analyst apparently spiked the original sample (as a matrix spike); multiple reanalyses of the sample resulted in nondetects.

Tetryl, an HE compound, was found at Spring 6. Several semivolatile compounds were found in the Spring 4 sample. Bis (2-ethylhexyl) phthalate is a plastics component; it and di-n-butylphthalate are

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505-665-0453

Solid Waste Regulatory Compliance (Group RRES-SWRC)
505-665-9527

Ecology (Group RRES-ECO)
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zone. The average of these results was 0.8 µg/L. TCE was found in all six samples from the upper port at an average concentration of 1.5 µg/L (EPA tap water screening level of 0.3 µg/L). TCE was detected in the three most recent samples at port 4 (as was PERC) and also twice at the intermediate port at 891 ft.

Several R-25 ports showed levels of iron and manganese (EPA MCLs), a temporary effect of well construction found in other recently drilled wells (Longmire 2002d). Nickel and chromium occurred at levels above EPA MCLs, possibly another temporary effect of well construction. Boron in port 2 was 57% of the New Mexico groundwater standard. Boron may be the result of infiltration of Laboratory effluents. In addition to analyzing samples for HE compounds, samples were analyzed for SVOC and VOC compounds. Other than the compounds previously discussed, no compounds were detected that were not generally also found in field, trip, or equipment blanks.

Samples from the Water Canyon Gallery, which comes from intermediate perched groundwater flowing from volcanics in the Sierra de los Valles west of the Laboratory boundary, contained no detected radionuclides or constituents above drinking water standards. Strontium-90 was detected in a field blank for the Water Canyon Gallery.

9. Ancho Canyon

Area AB at TA-49 was the site of underground nuclear weapons component testing from 1959 to 1961 (Purtymun and Stoker 1987; ESP 1988). The tests involved HEs and fissionable material insufficient to produce a nuclear reaction. In 1960, the US Geological Survey drilled three deep wells to monitor regional aquifer water quality. During 2003, americium-241 was found in a sample from DT-9 but not confirmed by reanalysis, suggesting it was a false positive. Tritium was detected in this well using a MDA of 200 pCi/L; however, this value is likely a false positive as prior values using the low-detection limit method have been mainly nondetects below 1 pCi/L. Otherwise, no radionuclides were detected in these wells in 2003, and no other inorganic constituents except aluminum, iron, and manganese (related to aging well casings or to turbidity) exceeded regulatory standards. All three wells were sampled for HE compounds, with no HE compounds detected. Monitoring wells DT-5A and DT-10 were sampled for other organic compounds. Only acetone was detected: this is a common analytical laboratory contaminant.

10. White Rock Canyon Springs

The springs that issue along the Rio Grande in White Rock Canyon represent the principal discharge of regional aquifer groundwater that flows underneath the Laboratory (Purtymun et al. 1980). New evidence indicates that springs such as Spring 2B represent discharge of perched groundwater, in the case of Spring 2B fed by sources near the river such as sanitary effluent discharge. The springs serve as boundary monitoring points for evaluating the Laboratory's impact on the regional aquifer and the Rio Grande. Other than tritium near background levels, the only radionuclide detections in White Rock Canyon springs were uranium in La Mesita Spring and plutonium-238 in Spring 2. Naturally occurring uranium is commonly detected in La Mesita Spring. The plutonium-238 value was just above the detection limit and is likely a false positive.

Samples from several springs were analyzed using the low-detection-limit tritium method. Except where impacted by effluent discharge, activities of tritium in the regional aquifer in other parts of the Laboratory range from nondetection to between 1 and 3 pCi/L. Tritium concentrations in northern New Mexico surface water and rainwater range from 30 to 50 pCi/L. Rainfall around the Laboratory may have higher tritium activity because of atmospheric tritium releases (Adams et al. 1995). Most of the springs had tritium values ranging between nondetection (less than about 1 pCi/L) and 2 pCi/L. Three springs (4, 4B, and 4C) issue within a few hundred feet of each other near the Rio Grande. In 2002, Spring 4B had tritium values near 45 pCi/L, whereas the other two springs had tritium values near 10 pCi/L. Spring 4B has a low flow rate, and all the spring samples may be affected to some degree by rainfall. The largest spring in the area, Spring 4A, had a nondetect for tritium during 2002. The 2003 low-detection-limit tritium results for the springs were similar to earlier data. The newly identified Spring 2B had 12 pCi/L of tritium, also in the range of rainfall values.

Liquid scintillation tritium results ranged from 200 pCi/L to 600 pCi/L with an MDA of 160 pCi/L and, in addition to being contradicted by the low-detection-limit results, were found by the analytical laboratory to result from analytical error. Sample reanalysis resulted in nondetections for these locations.

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Environmental Surveillance Program:

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Water Quality and Hydrology (Group ENV-WQH)
505-665-0453

Solid Waste Regulatory Compliance (Group ENV-SWRC)
505-665-9527

Ecology (Group ENV-ECO)
505-665-8961

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7. Ancho Canyon

Area AB at TA-49 was the site of underground nuclear weapons component testing from 1959 to 1961 (Purtymun and Stoker 1987; ESP 1988). The tests involved HEs and fissionable material insufficient to produce a nuclear reaction. In 1960, the US Geological Survey drilled three deep wells to monitor regional aquifer water quality. Perchlorate levels in the three wells ranged from 0.17 ppb to 0.25 ppb. Aluminum, iron, and manganese (related to aging well casings or to turbidity) often exceed regulatory standards in these wells. In 2004, only iron in DT-5A and manganese in DT-10 were at such levels. One PCB detection and several phthalate detections occurred in these wells in 2004 and are likely sampling or analytical artifacts.

8. White Rock Canyon Springs

The springs that issue along the Rio Grande in White Rock Canyon represent the principal discharge of regional aquifer groundwater that flows underneath the Laboratory (Purtymun et al., 1980). A few springs such as Spring 2B appear to represent discharge of perched groundwater; in the case of Spring 2B, it is supplied by municipal sanitary effluent discharge near White Rock. The springs serve as boundary monitoring points for evaluating the Laboratory's impact on the regional aquifer and the Rio Grande. Other than tritium near background or precipitation levels, the only radionuclide detection in White Rock Canyon springs was uranium in La Mesita Spring. Naturally occurring uranium is commonly detected in La Mesita Spring.

We were unable to sample a number of springs in 2004 because they lacked sufficient flow. Samples from several springs were analyzed using the low-detection-limit tritium method. Except where impacted by effluent discharge, activities of tritium in the regional aquifer in other parts of the Laboratory range from nondetection to between 1 and 3 pCi/L. Tritium concentrations in northern New Mexico surface water and rainwater range from 30 to 50 pCi/L. Rainfall around the Laboratory may have higher tritium activity because of atmospheric tritium releases (Adams et al., 1995). Most of the springs had tritium values ranging between nondetection (less than about 1 pCi/L) and 2 pCi/L. Three springs (Springs 2, 5A, and 6) had detections in some analyses or samples but not in duplicate samples or reanalyses: these values are near the detection limit. Three springs (4, 4B, and 4C) issue within a few hundred feet of each other near the Rio Grande. In 2002, Spring 4B had tritium values near 45 pCi/L, whereas the other two springs had tritium values near 10 pCi/L. Spring 4B has a low flow rate, and all the spring samples may be affected to some degree by rainfall. The largest spring in the area, Spring 4A, had a nondetect for tritium during 2002. The 2003 low-detection-limit tritium results for the springs were similar to earlier data; only Spring 4 was analyzed in 2004, and the result of near 10 pCi/L was similar to prior data.

Many of the springs were sampled for perchlorate in 2004. The results ranged from nondetection (<0.05 ppb) to 0.85 ppb. Of 41 analyses for 23 sampled springs, the average and standard deviation of the results (including detection limit for nondetections) were 0.39 ppb and 0.19 ppb. The perchlorate values found in the springs appear to relate to the geologic setting where they discharge. Most of the springs discharge from one of two geologic units: the Tesuque Formation and the Totavi Lentil (the lower part of the Puye Formation) (Purtymun et al., 1980). The Tesuque Formation consists of sandstones, siltstones, and interbedded basalts. The Totavi Lentil is a channel fill deposit made up of grain sizes ranging from gravel to boulders.

Purtymun (1980) divided the springs into four groups based on geologic unit and chemistry. Most of the sampled springs are in groups I and II. Group I springs discharge from the Totavi Lentil on the west side of the river. These springs follow the outcrop of the Totavi Lentil, increasing their elevation above the river in a downstream direction. In 2004, perchlorate concentrations for the group I springs (Sandia Spring, Spring 3 series, 4 series, Spring 5) averaged 0.47 ppb. Group II springs discharge from coarse-grained Tesuque Formation sediments on both sides of the river. For the group II springs (Springs 5A, 6, 6A, 8A, 9, 9A, Doe Spring), perchlorate concentrations averaged 0.27 ppb. Group III Springs 1 and 2 had 0.29 ppb and a nondetect, respectively. Other springs were quite variable, with group IV springs east of the river having a nondetect (Ancha Spring) and the highest value of 0.85 ppb (La Mesita Spring). Sacred Spring, north of Los Alamos Canyon, had 0.15 ppb.

Spring 2 contained fluoride at 74% of the New Mexico groundwater standard and arsenic at 50% of the EPA MCL of 50 ppb. The fluoride and arsenic occur naturally in springs and wells in the area. Spring 4A

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Environmental Surveillance at Los Alamos during 2005

Environment & Remediation Support Services Division
505-667-0808

Water Stewardship Program
505-667-0132

Corrective Actions Program
505-667-2623

Environmental Protection Division
505-667-2211

Ecology and Air Quality Group
505-665-8855

Water Quality and RCRA Group
505-665-0453

Office of Risk Reduction
505-667-4348

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standard. That well also showed the highest perchlorate value for this area, just above background at 0.9 µg/L. A large number of other perchlorate results for alluvial wells were nondetections.

In addition to aluminum, iron, and manganese related to sample turbidity, many other metals were above standards in alluvial groundwater samples in Cañon de Valle. Among these metals were arsenic, barium, beryllium, cadmium, nickel, lead, and vanadium. High values for these metals frequently correlate with high sample turbidity as well. Selenium also was above the NMWQCC Wildlife Habitat Standard in CDV-16-02655 and CDV-16-02657 (values were by SW-846:6010B but not estimated). (The surface water standard would apply if the ground water flowed to the surface.) Most of the high metal values occurred in two wells: CDV-16-02655, located in a swampy area on the mesa top west of building 260; and CDV-16-02657, located just below the 260 outfall. Barium, present due to past high explosives wastewater discharges, was above the NM groundwater standard in numerous wells, often by a factor of 10 or more (Figure 5-28).

Alluvial well samples contained several HE compounds. As with intermediate perched groundwater, RDX (Figure 5-28) was present at concentrations comparable to risk levels: up to two to six (and in one case, 43) times the 6.1 µg/L EPA 10^{-5} excess cancer risk level. Numerous PAH compounds, including benzo(a)pyrene were found in one well sample and one field blank from a different well. PAH compounds are subject to carryover between analytical laboratory samples and are readily transferred as field contamination from sources such as used motor oil, diesel fuel, and combustion products. In the first example, benzo(a)pyrene was found in Canon de Valle alluvial well CDV-2655 above the EPA MCL in January 2005 but not in five other sample rounds since 1997. The results for every detected semivolatile compound from that sample (including the PAH compounds) were rejected in secondary validation, as the validator identified quality deficiencies in the reported data. Tetrachloroethene was found in CDV-2655 at 10 percent of the EPA MCL; the compound is commonly found in groundwater in Cañon de Valle.

7. Ancho Canyon

Area AB at TA-49 was the site of underground nuclear weapons component testing from 1959 to 1961 (Purtymun and Stoker 1987; ESP 1988). The tests involved HEs and fissionable material insufficient to produce a nuclear reaction. In 1960, the US Geological Survey drilled three deep wells (named DT-5A, DT-9, and DT-10) to monitor regional aquifer water quality. Another well, R-31, lies downstream from firing sites at TA-39. In 2005, strontium-90 was detected slightly above the detection limit in one field blank and one sample from 670 ft in regional well R-31. The detection was in an unfiltered sample and the filtered sample was nondetect for strontium-90. Perchlorate values were either in the range for background or nondetections. Aluminum, iron, and manganese (related to aging well casings or to turbidity) were above or standards in the three DT wells. Iron and manganese are high in R-31 due to persistent effects of drilling fluids.

8. White Rock Canyon Springs

The springs that issue along the Rio Grande in White Rock Canyon represent the principal discharge of regional aquifer groundwater that flows underneath the Laboratory (Purtymun et al., 1980). A few springs such as Spring 2B appear to represent discharge of perched groundwater; that spring is supplied by municipal sanitary effluent discharge near White Rock. The springs serve as boundary monitoring points for evaluating the Laboratory's impact on the regional aquifer and the Rio Grande.

Other than tritium, the only radionuclide detection in White Rock Canyon springs was uranium in La Mesita Spring. Naturally occurring uranium is commonly detected in this and a few other springs. Few low-detection-limit tritium samples were collected from springs in 2005; results for the remaining springs are summarized in prior reports in this series. For the majority of White Rock Springs, tritium activities lie within a range for regional aquifer background; for a few springs, the tritium activity might reflect recent infiltration of precipitation or possibly LANL influence. Except where impacted by effluent discharge, activities of tritium in the regional aquifer in other parts of the Laboratory range from nondetection to between 1 and 3 pCi/L. Tritium concentrations in northern New Mexico surface water and precipitation range from 30 to 50 pCi/L; tritium activity in precipitation is higher near LANL (Adams et al. 1995). Most of the springs had tritium values ranging between nondetection (less than about 1 pCi/L) and 2 pCi/L, in the background range.

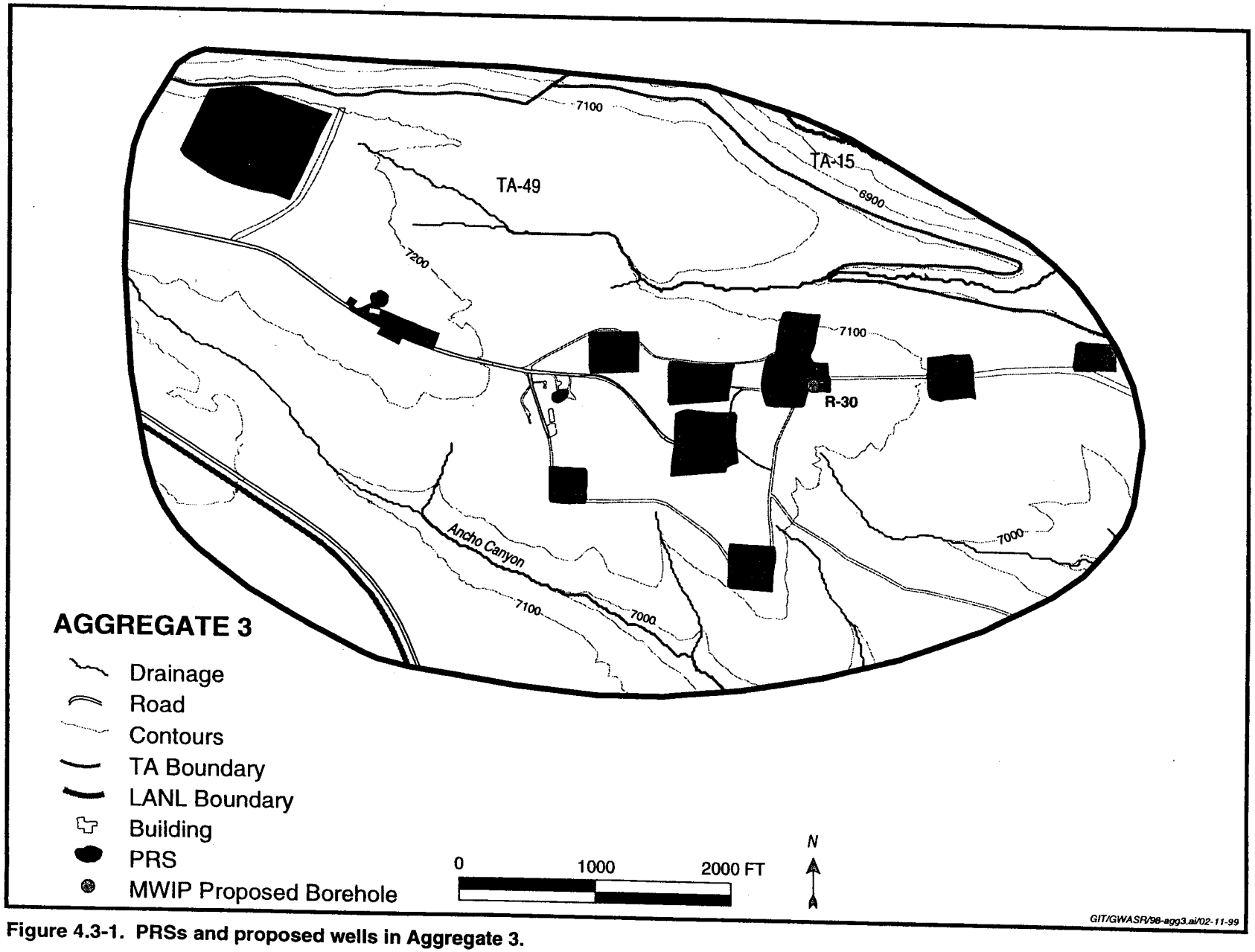

Figure 4.3-1. PRSs and proposed wells in Aggregate 3.

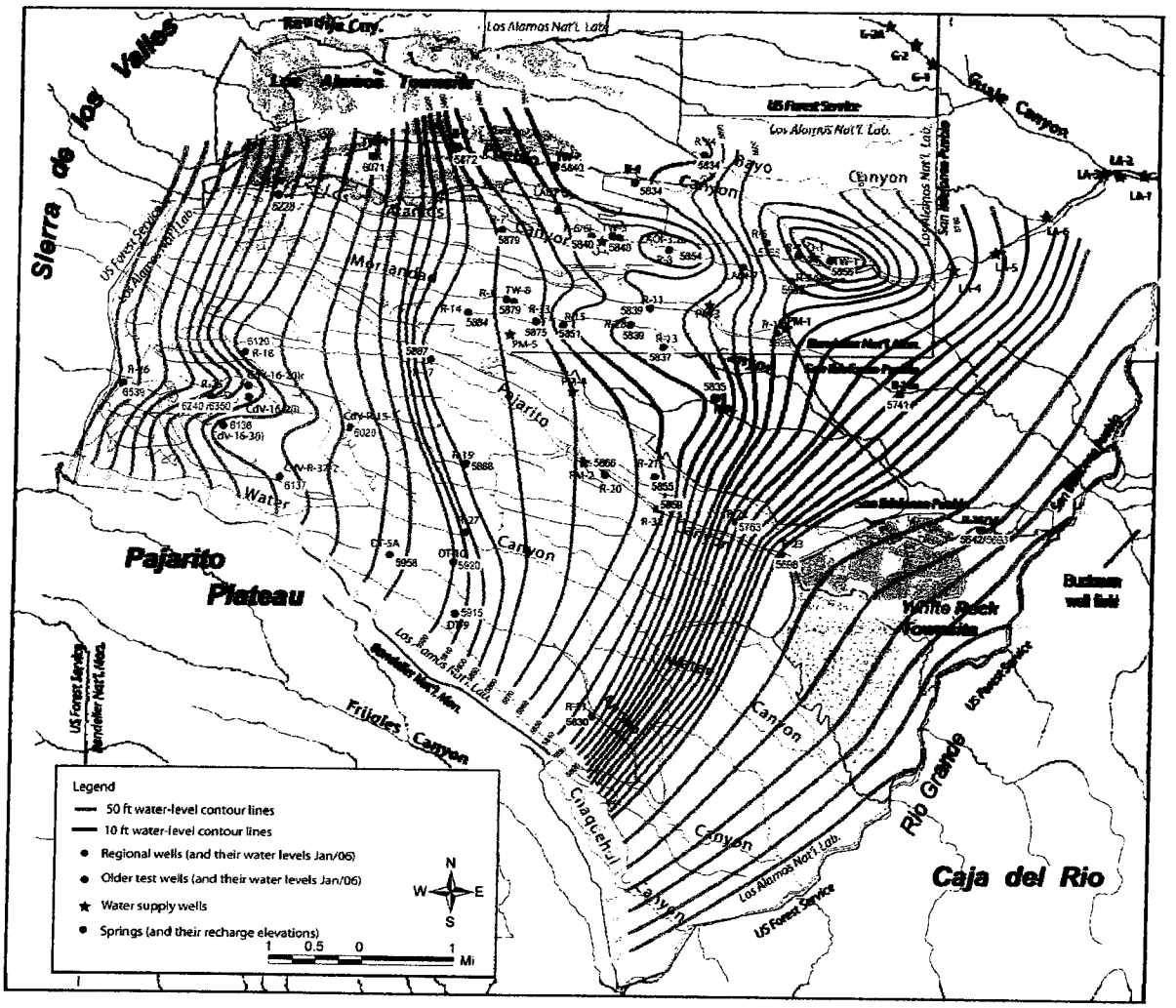

Figure 4-1. Water table elevation and location of Hydrogeologic Workplan wells

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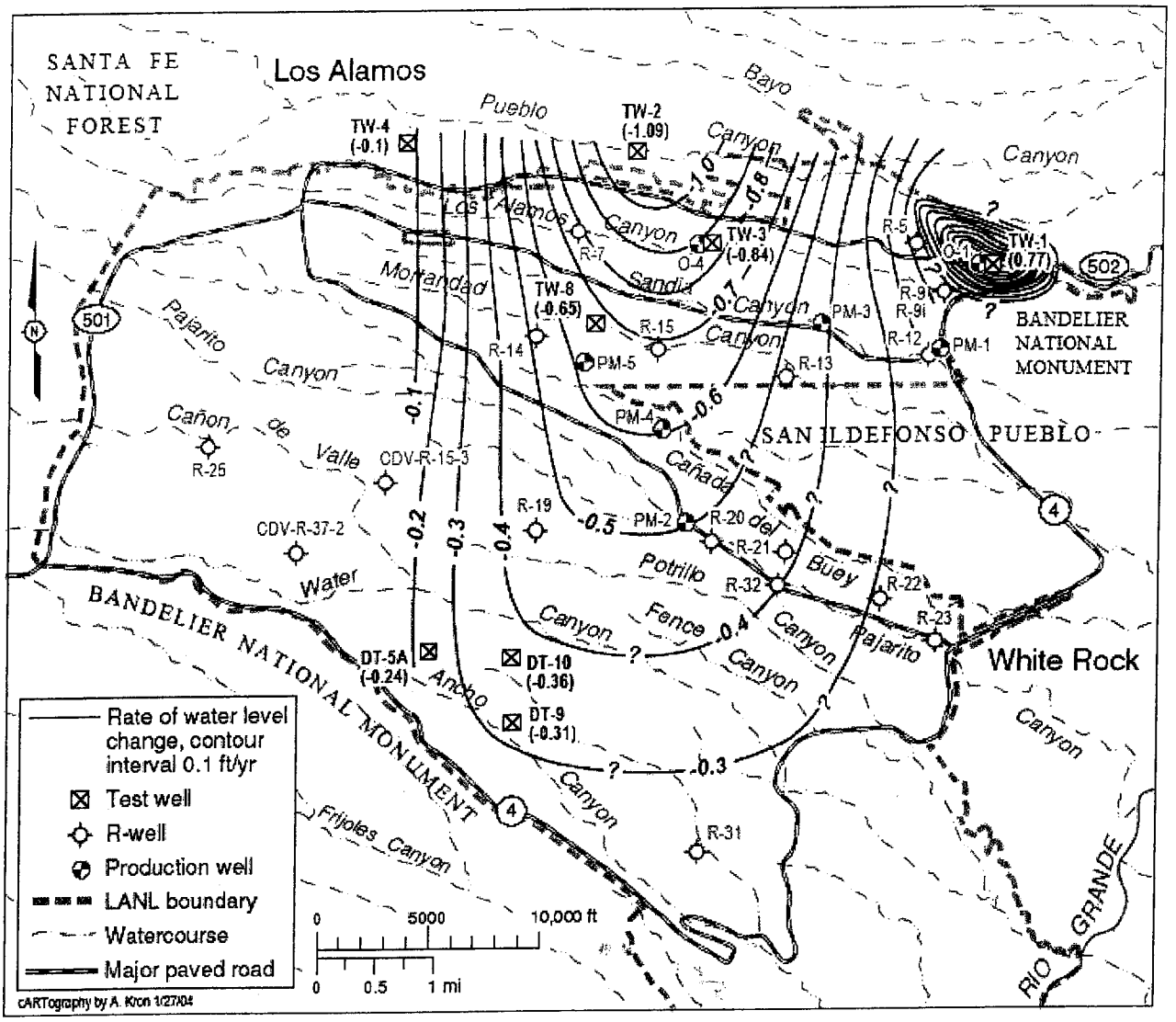

Figure 2. Annual rate of change of water level in test wells, 1992-2003 (ft/yr) from Koch et al. (2004)

Well Design at Specific Wells

The specifics of well drilling, hydrogeologic conditions, and well design for the wells cited by Gilkeson (2004) are provided in Table 3. Each of these wells achieved the primary objective of providing access to the regional aquifer either near the water table or within representative hydrostratigraphic units.