Nevada Offsites Long-Term Hydrologic Monitoring Program – 9424

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ABSTRACT

The U.S. Department of Energy (DOE) Office of Legacy Management has long-term stewardship responsibility for DOE's Nevada Offsites Project. The Nevada Offsites consist of eight sites, outside the boundaries of the Nevada Test Site, where underground nuclear tests were conducted between 1961 and 1973. The eight Nevada Offsites are Amchitka (Alaska), Shoal and Central Nevada Test Area (Nevada), Rio Blanco and Rulison (Colorado), Gasbuggy and Gnome-Coach (New Mexico), and Salmon (Mississippi). The underground tests resulted in the release of multiple radionuclides to the detonation zone (cavity, chimney, and nuclear-fractured region); however, tritium is the most likely contaminant to migrate significant distances from the detonation zone because of its occurrence both as tritiated liquid water, which moves with ground water, and as tritiated water vapor.

The U.S. Environmental Protection Agency has conducted environmental sampling and long-term monitoring for tritium and other radionuclides since 1972 at the Nevada Offsites under the Long-Term Hydrologic Monitoring Program (LTHMP). The objectives of the monitoring were to detect denotation-related radionuclides, track the fate and transport of other constituents, ensure public safety, inform the public and the news media, and document compliance with state and federal regulations. By and large, the LTHMP has achieved its objectives, because monitoring results have shown that areas outside the withdrawn lands are unaffected by the underground nuclear detonations.

The past two decades have witnessed a gradual change in land use near some of the Nevada Offsites locations. In Colorado and New Mexico, these changes have included increasing population and increased extraction of natural gas near the detonation sites. In Nevada, there is a growing interest in tapping the vast ground water reserves that are contained in the rural intermountain valleys and piping the water to areas where it can be put to beneficial use. Because of these changes, the LTHMP is being modified to provide more focused monitoring near the underground test locations. Distant monitoring locations are being phased out and are being replaced with monitoring networks closer to the detonation sites. The revised monitoring approach will emphasize early detection of radionuclide movement through a network that monitors potential transport pathways near the detonation zone, before potential users of ground water, surface water, or natural gas near the monitored sites could be exposed to radiological contaminants. This approach will provide DOE with sufficient warning to implement protective measures, if necessary.

INTRODUCTION

The Nevada Offsites consist of eight sites, outside the boundaries of the Nevada Test Site, where the U.S. Atomic Energy Commission (AEC) conducted underground nuclear tests between 1961 and 1973 (Figure 1). Seven of these

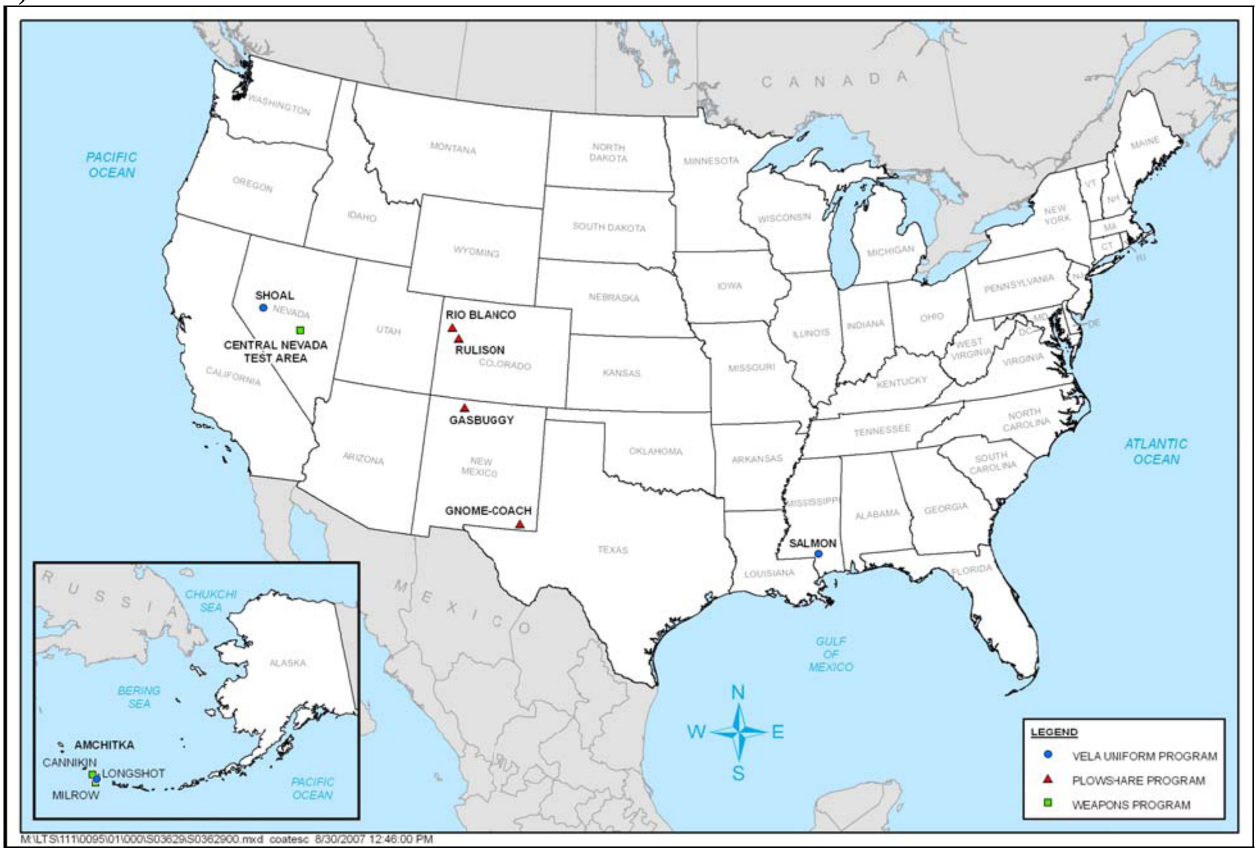

Figure 1. Nevada Offsites Locations

sites are: (1) the Shoal site in Nevada, (2) the Central Nevada Test Area (CTNA) in Nevada, (3) the Rio Blanco site in Colorado, (4) the Rulison site in Colorado, (5) the Gas Buggy site in New Mexico, (6) the Gnome-Coach site in New Mexico, and (7) the Salmon site in Mississippi. The eighth site is on the island of Amchitka, Alaska where three underground tests were conducted. Primarily because the Amchitka test sites are so remote, they were never included as part of the Long-Term Hydrologic Monitoring Program (LTHMP); consequently, they are not discussed in this paper.

The AEC conducted nuclear tests for various non-military purposes under the Plowshare and Vela Uniform Programs. These nuclear-test programs had three main objectives: (1) to improve the recovery of natural gas from low-permeability host rock, (2) to develop instrumentation that can distinguish seismic waves caused by earthquakes from those caused by nuclear tests, and (3) to evaluate the performance of new remote sites for underground nuclear tests. The tests occurred in various geologic settings and at depths ranging from 1,200 to 8,400 feet below the surface.

The AEC began the LTHMP to monitor radionuclides in ground water and surface water potentially impacted by the Nevada Offsites testing program. Prior to 1972, the Public Health Service, the U.S. Geological Survey (USGS), or the AEC Technical Assistance Contractor (TAC) did the monitoring for the Nevada Offsites Program. Beginning in 1972 and continuing through 2007, the Environmental

Protection Agency (EPA) directed the LTHMP hydrologic monitoring of the Nevada Offsites locations. The original goals of the LTHMP were to (1) ensure public safety around the test sites, (2) inform the public and media about the test sites and the monitoring that was taking place, and (3) document compliance with state and federal regulations.

Thirty years of monitoring ground water near the Nevada Offsite locations demonstrates that the LTHMP accomplished its primary objective of ensuring public safety. The monitoring mainly focused on tritium, because it is relatively mobile both in ground water and in the vapor phase, and because nuclear detonations typically release large quantities of tritium. Tritium has a relatively short half-life of 12.32 years. When combined with the limited distance to which tritium would spread in a ground water flow system over the course of 50 years, there is little technical justification for monitoring beyond a short radial distance from a detonation. Numerical transport modeling of the region surrounding the blast sites has also shown that advective transport over a 1000-year period is limited to a distance of approximately five cavity radii from surface ground zero. The main problem facing DOE is how to constrict the detection-monitoring network at the Nevada Offsites, and thereby improving the sensitivity of the detection-monitoring program.

In addition to the technical rationale for a narrowed focus to the detection-monitoring program, the land use patterns are changing near some of the Nevada Offsites. For example, residential use and gas development are spreading to within one mile of the detonation near the Rulison site. In another instance, the potential for development of nearby ground water resources near the Central Nevada Test Area increases the importance of implementing a more sensitive detection-monitoring network. These political considerations and heightened public awareness are increasing the imperative for a refined scope to future monitoring near the Nevada Offsites.

Project Shoal Area – Nevada

The Shoal site is on approximately 4 square miles (2,560 acres) of withdrawn federal lands about 30 miles southeast of the city of Fallon in Churchill County, Nevada. The underground nuclear test at the Shoal site was conducted on October 26, 1963, in granitic bedrock that forms the mountains of the Sand Springs Range. Code-named Project Shoal, the test was part of the Vela Uniform program and was jointly sponsored by the Department of Defense and AEC. This research program was directed toward locating, detecting, and identifying underground nuclear detonations, particularly for the purpose of differentiating nuclear tests from other seismic events such as earthquakes. Project Shoal was a 12–kiloton nuclear detonation at a depth of 1,211 ft bgs.

The monitoring network in the early years of the LTHMP consisted of springs, wells, and windmills outside the withdrawn area because there were no open wells on the withdrawn land for the Shoal site in 1972. The program was improved after the on-site HC wells became available for monitoring in the late 1990s. Data collected from 1972 through 2006 at all monitoring locations were evaluated to assess the effectiveness of the LTHMP. The LTHMP included the collection of samples from wells H-3, HS-1, Frenchman Station, Flowing Well, and Hunts Station; however the LTHMP evolved through the years to include on-site monitor wells HC-1 through HC-8 and MV-1 through MV-3, off-site well H-2, Spring Windmill, Flowing Springs, and Smith/James spring locations. Samples collected from these locations have been analyzed for tritium and gamma emitters using high-resolution gamma spectrometry. The analysis for tritium was performed using conventional and electrolytic enrichment methods. The electrolytic enrichment method offers greater sensitivity than the conventional tritium analysis method and is used when the conventional method yields a nondetect for an analysis result.

Since the beginning of long-term monitoring at Shoal, samples collected from three locations have contained dissolved radionuclides at concentrations above laboratory detection limits. Tritium was detected at the Smith/James Spring in Fairview Valley, approximately 8.1 miles from the detonation, from 1989 through 1995. All measured tritium concentrations at this location were below 100 pCi/L and were consistent with recorded tritium concentrations in atmospheric precipitation and natural ground water recharge at the time.

Water samples recently collected from well HC-3, located 3,100 ft southeast of SGZ, have exhibited cesium-137 concentrations below 8 pCi/L. Though no drinking water limit exists for cesium-137, it is subject to an EPA guideline that limits exposures to beta- and photon-emitting radionuclides to 4 millirems per year (mrem/yr) (EPA 2002). Given that the guidance states that daily ingestion of two liters of water containing 200 pCi/L of cesium-137 results in a dose of 4 mrem/yr, it can be deduced that the cesium-137 levels measured at well HC-3 are below the maximum contaminant level for beta and photon emitters. Analysis by the electrolytic enrichment method has also detected tritium in samples from well HC-3; however, all of the tritium activities in this case have been less than 50 pCi/L.

Since 1997, tritium has been regularly detected at well HC-4, which is located about 500 ft south of the detonation. Tritium activities at the well were initially as high as 863 pCi/L but have since steadily decreased to below the detection limit in 2007. The presence of small amounts of tritium at well HC-4 can be attributed to its proximity to the detonation (approximately 600 ft to the south) and the process of prompt injection, rather than advective transport.

Subsurface contaminant transport beyond one mile from the Shoal site is considered unlikely. For this reason, DOE will probably discontinue ground water sampling beyond the immediate site area. However, it may be beneficial to measure water levels in wells beyond the immediate site vicinity, given that exact ground water flow directions are somewhat uncertain beneath the withdrawn-land area. Seven locations currently in the long-term sampling program will likely be dropped from the monitoring network and fifteen wells and piezometers will continue to be monitored, resulting in a more discrete monitoring network.

Monitoring will occur annually during the remaining 3 years of the 5-year *proof-of-concept* period defined by Nevada Department of Environmental Protection. Samples collected from wells MV-1, MV-2, MV-3, HC-1, and HC-4 will be analyzed for tritium, isotopic uranium, gross alpha, elemental uranium, carbon-14, and iodine-129. Samples collected from the remaining onsite wells (HC-2, HC-3, HC-5, HC-6, HC-7, and HC-8) will be analyzed for tritium and gamma emitters. The locations of wells and additional details regarding the monitoring results at the Shoal site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Central Nevada Test Area - Nevada

The nuclear test at the Central Nevada Test Area (CNTA) was designed to gauge the seismic effects of a relatively large, high-yield detonation completed in Hot Creek Valley and to determine the suitability of the site for future large detonations. The yield of the CNTA underground nuclear test was between 200–kilotons and 1–megaton. The site is located in Nye County, Nevada, about 60 miles northeast of Tonopah and about 100 miles southwest of Ely, Nevada. The underground detonation at the CNTA occurred on January 19, 1968 in borehole UC-1 at a depth of 3,199 feet below ground surface, and was code-named Project Faultless.

The LTHMP included sampling of ground water from locations up to several miles from the nuclear detonation zone. The initial planning document for the program at CNTA, directed EPA to collect samples from wells UC-1-P-2SR, HTH-1, HTH-2, Hot Creek Ranch Domestic Water supply, Six Mile Well, Blue Jay Spring, and Blue Jay Maintenance Station Well. Since 1972, the program evolved into monitoring an array of off-site wells, including: Base Camp Site C, Jim Bias Well, Twin Springs Ranch, and Tybo Well, and recently to include on-site wells MV–1 through MV–3, drilled in 2006. Samples collected from these locations were analyzed for tritium and gamma radiation.

Review of LTHMP data collected at CNTA sampling locations from 1972 through 2006 indicates no tritium above the laboratory method detection limit when conventional analytical methods were used. Similarly, no other radionuclides were detected using gamma spectroscopy. Tritium was occasionally detected using the electrolytic enrichment method in water samples collected at Blue Jay Maintenance Station, Tybo well, and well HTH–2. However, all concentrations in these cases have been less than 50 picocuries per liter (pCi/L), much below the Nevada drinking water standard for tritium of 20,000 pCi/L.

According to an evaluation of historical monitoring results at numerous sampling locations and the results of the modeling by Desert Research Institute, it is improbable that wells installed beyond one mile from well UC-1 will ever be affected by contaminant transport from the detonation zone. The permeability of the volcanic sediments, through which radionuclide contaminant transport is most likely to occur, is very low, thereby limiting ground water velocities to very low values. For this reason, the sample locations outside a one mile radius from the UC–1 withdrawal area will be removed from the long-term monitoring network. The locations of these wells and additional details regarding the monitoring results at the CNTA site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Rio Blanco Test Site – Colorado

The nuclear test at the Rio Blanco site was designed to evaluate the use of a nuclear detonation to fracture the tight sandstone formation and enhance natural gas production. Three 33–kiloton nuclear devices were detonated simultaneously, one just above the other, at depths of 5,838 feet, 6,230 feet, and 6,689 feet below surface ground zero. The goal of this test was to form an elongated cavity to interconnect overlying gas reservoirs and to improve gas production. The detonations took place in the Fort Union Formation and in the upper part of the Williams Fork Formation. LTHMP monitoring of the wells near the Rio Blanco site began in 1976 after the initial cleanup of the test site. In 1976 there were three wells, five springs and three creek locations that were being monitored. The surface water and shallow alluvial wells in the Rio Blanco area are fed primarily by snowmelt. None of the wells are sufficiently deep to penetrate the area affected by the nuclear test. There is currently no feasible pathway from the detonation zone to the surface or to any of the Rio Blanco LTHMP monitoring locations. In 1990, tritium was detected at over 300–pCi/L in the water from CER–1 Black Sulfur Spring. However, in the 17 years since this result, there have been no detections of tritium at either the CER–1 Black Sulfur Spring or the other sampled locations.

On October 1, 2006 the DOE Office of Legacy Management (LM) assumed management of the monitoring at the Rio Blanco test site. Current sampling near the Rio Blanco test site includes surface water and ground water from shallow monitoring wells. There is currently no monitoring of the deep subsurface environment.

The most likely way for radioactive constituents to migrate through the subsurface is for them to be drawn into a gas-producing well that was drilled in the reservoir near the detonation site. New gas wells drilled close to the site of detonation could be used to monitor the potential migration of radionuclides in the gas phase. Tritiated water vapor and krypton–85 are two mobile contaminant species that might be included in a revised monitoring plan. Initially, any new gas wells could be sampled quarterly or semiannually to establish a statistical baseline. Sampling might be less frequent during the early stages of gas recovery but more frequent during later stages because the probability of detecting radionuclides would presumably increase as the volume of gas production increases. The current array of monitoring wells and additional details regarding the monitoring results at the Rio Blanco site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Rulison Test Site – Colorado

The nuclear test at the Rulison site was designed to evaluate the use of a nuclear detonation to fracture a tight sandstone formation and enhance natural gas production. The 43–kiloton nuclear device was detonated on September 10, 1969, at a depth of 8,426 ft in the Williams Fork Formation of the Mesa Verde Group. The detonation resulted in a cavity and a rubble chimney surrounded by a fracture zone. Four production tests conducted on the reentry well between October 1970 and August 1971 produced a total of 455 million standard cubic feet of natural gas, or approximately 10 times the recovery of a conventionally stimulated well in the same production zone. The test was successful in enhancing gas production, but the presence of radionuclides in the gas rendered it unmarketable at that time.

Sampling under the LTHMP began in 1976 and included three wells, five springs, and three creek locations. Samples from those locations were tested annually for tritium, gross alpha, gross beta, and gamma spectral analysis. There have been single sampling events from 12 gas-producing wells in the Williams Fork Formation at distances ranging from 2.6 to 7.5 miles away from the test.

There is currently no feasible pathway from the detonation zone to the surface or to any of the Rulison LTHMP monitoring locations. LTHMP monitoring of the shallow wells in the alluvial aquifer and the surface water locations has not detected any site-derived contamination. The tritium levels seen at the historic monitoring locations are indistinguishable from the worldwide tritium distribution in precipitation during the 1950s and early 1960s (Brown 1995). However, because tritiated water vapor is a mobile species, the monitoring of water wells near the test should continue until more data on the gas reservoirs near the site are available.

A monitoring plan is being developed to sample drilling fluids from nearby gas wells as they are drilled and fluids from nearby gas wells. The location of gas wells and their sampling frequency will be evaluated continually as additional wells are drilled around the detonation site. The locations of these wells and additional details regarding the monitoring results at the Rulison test site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Gas Buggy – New Mexico

The Gas Buggy test was conducted as the first natural gas reservoir stimulation experiment under the Plowshare program. Its purpose was to enhance gas production from the Pictured Cliffs Formation in the San Juan Basin, Rio Arriba County, New Mexico. The nuclear detonation at Gasbuggy was conducted at 4,240 feet below ground surface and had an estimated yield of 29–kilotons. The device was detonated on December 10, 1967. It created a rubble chimney 333 ft high and 160 ft in diameter.

From 1968 to 1973 gas-flaring tests were conducted at the site. That activity, along with historically measured tritium concentrations related to nuclear testing fallout, provide opportunities to monitor for radionuclides in surface water and ground water sampled during the LTHMP.

The current LTHMP sampling regime has been in effect for 35 years. Sampling results indicate that a few radionuclides have been detected at some LTHMP-monitored locations; however, all the LTHMP sampling locations have either been surface waters or ground water in the shallow alluvium or in the Nacimiento Formation (no deeper than 400 ft bgs).

With the exception of well EPNG 10–36, which is a former gas well near the detonation, tritium concentrations detected during the LTHMP ground water sampling have been very low. Well EPNG 10–36 was a producing gas well but was later modified to be a monitoring well. Initial monitoring at EPNG 10–36 indicated both strontium–89 and strontium–90 concentrations in ground water and tritium activities approximately one order of magnitude lower than the EPA drinking water standard when the well was abandoned in 2003. Based on the fact that recent tritium detections in all ground water and surface water locations have been consistent with background concentrations, DOE recommends 2009 will be the last year for tritium sampling of wells and surface locations previously sampled under the LTHMP.

The locations of the wells and additional details regarding the monitoring results at the Gas Buggy site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Gnome – Coach Site

The Gnome test was the first U.S. Atomic Energy Commission nuclear test conducted under the Plowshare program. It was designed to study the possibility of converting the energy from nuclear detonations into electricity, investigate the production and retrieval of radioactive isotopes, measure neutron activation cross sections of specific isotopes, collect data on the characteristics of nuclear explosions in salt formations, and collect data for use in future Plowshare programs. The underground nuclear test at the Gnome-Coach site was conducted on December 10, 1961 in the thick, bedded-salt deposit of the Salado Formation. The Gnome-Coach test had a yield of 3.1–kilotons and was detonated at a depth of 1,184 ft bgs.

In 1963 the U.S. Geological Survey conducted a radiological tracer test at the site using wells USGS 4 and 8. The tracer test was conducted by injecting tritiated water, iodine-131, strontium-90 and cesium-137 into injection well USGS 8 and recovering the injected water from pumping well USGS 4. Beetem (1971) estimated a total tritium injection of approximately 18.5 curies (Ci). No attempt was ever made to recover the injected radioactive tracers.

In addition to the two tracer-test wells, monitoring at the Gnome-Coach site comprises two wells (DD–1 and LRL–7), which are completed in the blast cavity and in the emplacement adit, respectively. Initial environmental restoration at the site included the pumping of contaminated materials down well DD–1 and the filling of the Coach adit; therefore, samples from these wells contain elevated concentrations of radionuclides.

Offsite monitoring wells PHS–6 and PHS–8 both contain detectable levels of tritium, but the levels are below 100 pCi/L and are consistent with tritium levels in modern precipitation. Both wells are over 4 miles away from SGZ and would not be exposed to detonation-derived contaminants.

In summary, there have been no radioactive contaminants detected in the Gnome-Coach sampling locations, other than in the four wells where radioactive materials were injected. The contaminated wells are DD–1, LRL–7, USGS–4, and USGS–8.

DOE will propose to discontinue sampling wells PHS–6, PHS–8, PHS–9, and PHS–10 for which no well-completion data are available. The rationale is that the integrity of the samples collected from these wells cannot be verified. These wells are 3 to 5 miles away from the detonation site. Additionally DOE will recommend no further sampling for on-site wells DD–1 and LRL–7, which were contaminated from either scientific use or waste-disposal activities. The fact that these wells are in zones of known contamination makes them unsuitable for monitoring the long-term effects of the Gnome test with respect to ground water quality.

DOE will continue annual monitoring at the two USGS wells that were used as part of the tracer test and USGS–1, a well that is completed in the Culebra Dolomite. Depending on future sampling results, additional monitoring of the down gradient movement of the tracer-test plume may be warranted. DOE plans to install additional monitor wells at the Gnome-Coach site to improve the coverage and efficiency of the monitoring network.

The locations of the wells and additional details regarding the monitoring results at the Gnome-Coach site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

Salmon Site – Mississippi

Two nuclear tests (Project Dribble) and two nonnuclear tests (Project Miracle Play) were conducted in the Tatum Salt Dome geologic structure between 1964 and 1970. The four tests were conducted by the U.S. Atomic Energy Commission (AEC) for the U.S. Department of Defense under the Vela Uniform Program. The two nuclear tests, codenamed Salmon and Sterling, were designed to study seismic waves from the decoupling of a nuclear detonation and to test detection instrumentation (AEC 1966).

The Salmon nuclear test was conducted on October 10, 1964, at a depth of 2,710 feet (ft) below ground surface. The detonation occurred about 1,200 ft below the top of the salt dome and had a yield of 5.3–kilotons, creating a nearly spherical cavity (DOE 2000). The Sterling test was conducted December 3, 1966, and had a 0.38–kiloton yield and was suspended in the cavity created by the Salmon test. The two nonnuclear tests, codenamed Diode Tube and Humid Water, were conducted within the Salmon/Sterling cavity on February 2, 1969, and April 19, 1970, respectively.

After the detonation, a reentry hole was advanced into the resulting test cavity. The cavity contained nuclear-fission products due to the nuclear detonation, and the salt formation surrounding the cavity was highly fractured. Approximately 10,800 cubic yards of contaminated soil and 1,300,000 gallons of contaminated liquid and fresh water were disposed of in the test cavity before the reentry well was plugged (AEC 1972). Approximately 338,000 gallons of radioactive liquid waste were injected into Aquifer 5 through well HT–2 into the Cook Mountain Limestone Formation, accompanied by 90,000 gallons of water to drive the liquid waste away from the injection point (Binkley 1972).

The purpose of the LTHMP was to collect samples for analysis to determine if contaminants had migrated from the test cavity or the Aquifer–5 source areas. Sampling confirmed that the alluvial aquifer contained volatile organic compounds and tritium, which were deemed to be the consequence of drilling mud from the underground nuclear detonation. Arsenic and chromium were also detected in the local aquifer and Aquifer–3, respectively. Two of the wells that monitor the cavity, alluvial well HM–S, and local aquifer well HM–L, have shown elevated tritium because of proximity to the drilling mud left within 100 meters of SGZ. Of the offsite private and municipal wells that were sampled, only the Baxterville municipal city well contained tritium concentrations above the laboratory detection limit by the enriched tritium analysis method. The six on-site wells contain elevated tritium concentrations in ground water from the flushing of the residual contaminated drilling mud.

Future monitoring at the Salmon site will consist of the continued use of the current on-site ground water monitoring network and evaluation of each on-site network intended for the source pathways. A new monitoring strategy to monitor ground water flow in the area around the Salmon test site will allow early detection of potential radionuclide migration. Monitoring of the six on-site surface water locations will continue, as well as additional sampling from Half Moon Creek. Offsite ground water monitoring and surface water monitoring may be terminated under the new monitoring program because of undetected radionuclides at all of the sampling points in the 35 years since the detonation.

The locations of the wells and additional details regarding the monitoring results at the Salmon site may be obtained at the following web address: http://gems.lm.doe.gov/imf/ext/gems/jsp/launch.jsp.

CONCLUSION

The EPA successfully conducted the LTHMP since its inception in 1972. Environmental monitoring at the Nevada Offsites included the collection and analysis of water samples from wells and springs in the vicinity of the underground nuclear test sites. The transport of dissolved radionuclides in ground water has been very slow; consequently, no contamination has been detected at locations beyond each site boundary. The slow rate of subsurface transport indicates that the detection of contamination at off-site locations will be unlikely for several hundreds of years to come. Because test-related contamination has not been detected in the distal wells which comprise the LTHMP monitoring network, DOE's future environmental monitoring will focus more on wells that are closer to the detonation. Additional monitoring wells might be proposed at some of the Nevada Offsite locations to improve individual detection-monitoring networks.

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