LMS/MON/S06584

Radiological Assessment of Stained Soils at the Monument Valley Processing Site

June 2010

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Abbreviations

ANL	Argonne National Laboratory
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	foot
LM	(DOE) Office of Legacy Management
m	meter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mrem	millirem
pCi/g	picocuries per gram
NRC	U.S. Nuclear Regulatory Commission
pCi/L	picocuries per liter
RAP	Remedial Action Plan
^{226}Ra	Radium-226
^{228}Ra	Radium-228
RDC	radon daughter concentration
SOWP	Site Observational Work Plan
^{234}U	Uranium-234
^{238}U	Uranium-238
UA	University of Arizona
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act
WL	working level

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1.0 Introduction

This report summarizes the data and information that the U.S. Department of Energy (DOE) Office of Legacy Management (LM) has obtained in the evaluation of the recently discovered colored soil precipitate and elevated uranium in soils at the Monument Valley, Arizona, Processing Site. The site, a former uranium mill, is located on the Navajo Nation in northeastern Arizona (Figure 1–1) in an area that is characteristically rich in uranium ore; this ore body crops out near the surface (on Yazzie Mesa) just west of the site (Figure 1–2). Groundwater beneath the site was contaminated by milling operations that were ongoing from 1955 through 1968. Contaminated surface materials from tailing piles, leach areas, and an evaporation pond were completely removed from the site by January 1994 in accordance with Title 40 Code of Federal Regulations Part 192 (40 CFR 192) Subpart A, as part of the DOE Uranium Mill Tailings Remedial Action (UMTRA) Project. The former evaporation pond, shown in Figure 1–3, is the primary area of focus herein, as this is where recent field measurements and soil sampling indicated areas of elevated radioactivity.

The primary purpose of this report is to present all the available analytical data and information regarding the nature and extent of reported soil contamination (and all related media). This evaluation begins by revisiting historical characterization data to assess the potential source of the elevated levels. Site remediation activities (1992–1994) and post-cleanup verification data are then summarized to verify that previous DOE commitments (in the context of U.S. Nuclear Regulatory Commission [NRC] cleanup requirements) were fulfilled. Because the core of DOE's mission is the protection of human health and the environment, this evaluation culminates in a conservative evaluation of potential doses to workers resulting from exposure to radiological constituents in soils of the former evaporation pond.

1.1 Overview and Rationale for this Evaluation

In 1994, DOE removed mill tailings and other contaminated surface materials from the Monument Valley site. Nitrate and ammonium used during the milling process remain in a shallow groundwater plume spreading from the former mill site area. These two constituents, along with sulfate, are the primary groundwater contaminants of concern at the site. Uranium is also a contaminant of concern, but elevated levels in groundwater appear to be localized and are not as widespread as the primary contaminants. In 1999, in collaboration with the University of Arizona (UA), LM initiated pilot studies of remediation alternatives for contaminated groundwater at the site, focusing on nitrate. These pilot studies investigate remedies that rely on natural and enhanced attenuation processes. Plots were planted in the area of the former new tailings pile and later, in 2006, expanded to include some surrounding areas, including the former evaporation pond.

In August 2009, colored deposits were noticed on the surface of the soil in the phytoremediation plots. Samples were collected and analyzed, and the yellow- and green-colored samples from the former evaporation pond area were high in vanadium and uranium. In March 2010, additional samples were taken of the yellow- and green-colored soils for further evaluation. Radiological scanning was also conducted to evaluate if the colored soils posed any risk to site workers. Analytical results of the soil samples confirmed the elevated levels of vanadium and uranium, and the scanning indicated elevated gamma and beta activity in the former evaporation pond area. DOE documented these initial findings in a letter to NRC on April 1, 2010 (Appendix A). Table 1–1 summarizes the chronology pertinent to this evaluation. Since then, DOE has obtained

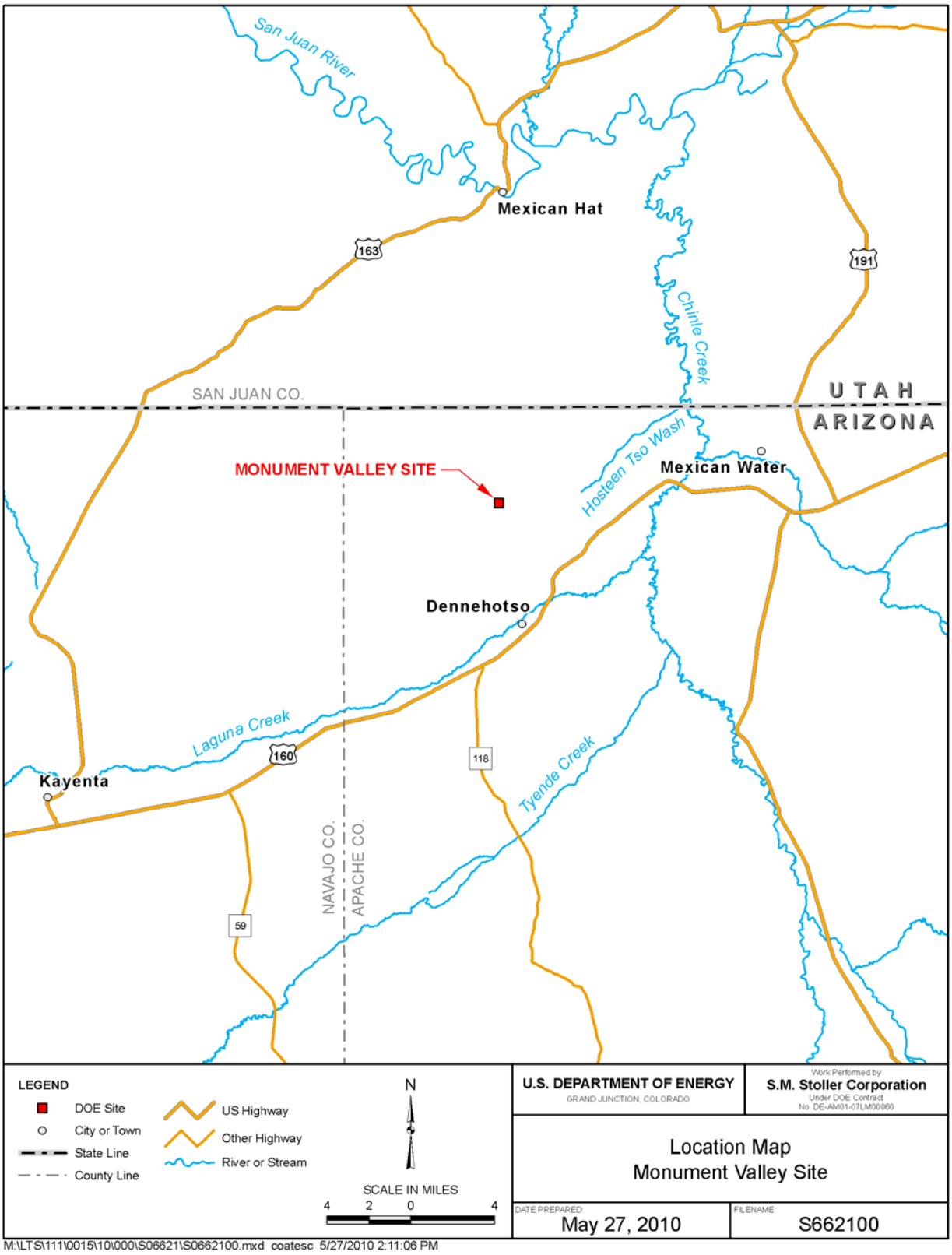

Figure 1–1. Monument Valley, Arizona, Processing Site Location Map

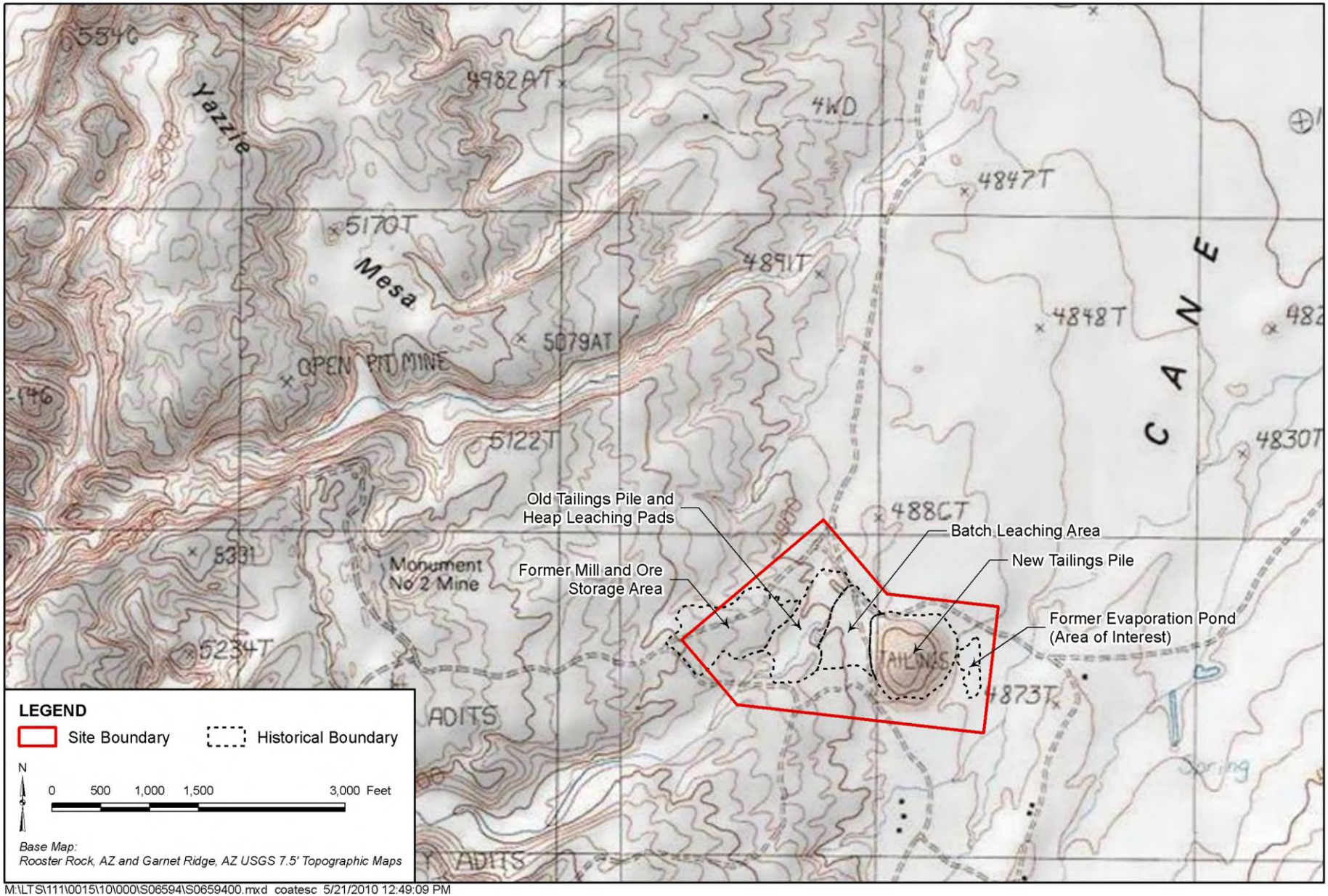

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Figure 1–2. Monument Valley Site Regional Setting and Topography

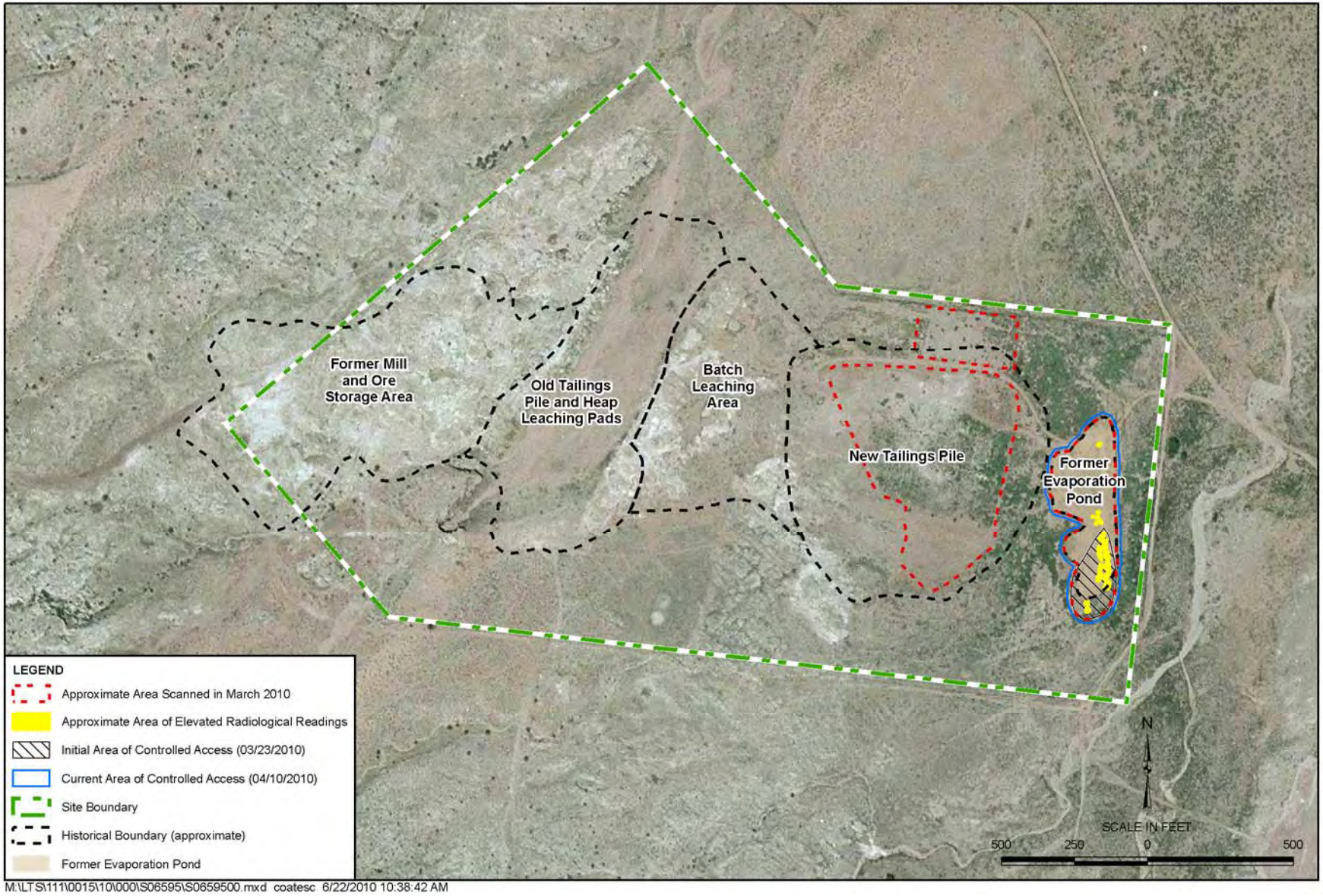

Figure 1–3. Site Layout Showing Areas of Recent Radiological Scans and Investigations

Table 1–1. Site Chronology Relevant to this Evaluation

Date/Period	Monument Valley Site Observations and Activities
1955–1968	The mechanical milling operations at the Monument Valley site continued from 1955 to 1964. A batch-leach process was used from 1964 until 1968, when the mill closed and the lease expired.
1992–1994	Surface remediation began in 1992 and was completed in January 1994. During this period, the tailings piles, windblown tailings, contaminated radioactive materials, concrete foundations, and debris were removed and placed in the Mexican Hat UMTRA Project disposal cell, approximately 10 miles north of the former mill site.
1995–1997	Verification and approval—Final Completion Report issued. NRC Concurrence on September 16, 1997 (Appendix A).
1999–present	Groundwater monitoring (nitrate, ammonium, and sulfate are primary contaminants) and phytoremediation pilot studies. Phytoremediation pilot studies conducted in collaboration with the University of Arizona (UA) and Diné College.
2007–2008	UA personnel had earlier identified areas with poor plant growth in locations with red- and blue-hued surface soils. The soils were analyzed, and they contained elevated levels of manganese; however, the manganese was within background levels found in other soils, and the soils did not present a risk.
August–December 2009	UA personnel noticed surface soils in the former evaporation pond with yellow and green stains. These stains were dispersed mostly in the southern area of the former evaporation pond and did not appear to correlate to the irrigation water emitters. Samples of the stained surface soils were sent to a laboratory for analysis. The purpose of this investigation was to determine why poor plant growth occurred in this area. UA issued a memorandum documenting the results of the analyses and demonstrating that stained soil areas contain elevated levels of uranium and vanadium (this memorandum was issued on December 17, 2009, and is provided in Appendix C).
March 22–23, 2010	To further evaluate UA's findings, DOE collected additional samples from the same area where UA had collected the yellow- and green-stained soils.
March 23, 2010	Stoller conducted a radiological screening survey as a best management practice. The focus of this initial survey was the yellow- and green-stained soils in the former evaporation pond.
April 1, 2010	DOE issued a letter notifying NRC of the elevated radiological measurements in surface soils.
April 7, 2010	Fences in the area were upgraded to prevent livestock access to the area.
April 13, 2010	Because of concerns that elevated radiological levels may exist in other areas of the site, a second radiological screening survey was conducted using a crutch scintillometer. No elevated gamma activity outside of the former evaporation pond was detected. A more spatially comprehensive scan of the former evaporation pond was also performed at this time, and the survey area was expanded to include outlying areas (Figure 1–3).
April 14, 2010	Soil samples collected on March 22 were sent to an analytical laboratory for isotopic analysis; analytical results were obtained on this date. They indicated the highest activity for total uranium (^{238}U plus ^{234}U) was 985 picocuries per gram (pCi/g). These results also indicated that the highest Ra-226 activity was 1.67 pCi/g, which is below the 40 CFR 192 surface soil cleanup standard of 5 pCi/g above background averaged over 100 square meters.
April 20, 2010	Radiological technicians revisited the site to rope off and post the entire area of the former evaporation pond and to collect a surface soil sample (this sample was intended to be a worst-case sample based on field readings) for gamma spectroscopy analysis. The results of this analysis showed a total uranium concentration from all isotopes of 790 pCi/g.

additional data to determine the nature and extent of this material. Although the area is currently controlled (access restricted), the evaluation presented in this document will demonstrate that there is no imminent or potential health risk.

1.2 Regulatory Framework

The Monument Valley Processing Site is regulated under Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) (Public Law 95-605). Under this law, DOE remediated Monument Valley and 21 other inactive uranium-ore processing sites in accordance with standards promulgated by the U. S. Environmental Protection Agency (EPA) in 40 CFR 192. According to cleanup criteria in Subpart B of 40 CFR 192, the concentration of radium-226 (Ra-226) in land averaged over any area of 100 square meters shall not exceed the background level by more than

- 5 picocuries per gram (pCi/g) averaged over the first 15 centimeters (cm) of soil below the surface, and
- 15 pCi/g averaged over 15-cm-thick layers of soil more than 15 cm below the surface.

These single-contaminant cleanup criteria were mostly risk-based, although the ability to use field instrumentation rather than laboratory analysis to determine the location of buried tailings at depth was also a consideration in the development of the cleanup standards.

EPA evaluated the risk associated with the dispersal of tailings off the former processing sites and concluded that the principal risk was exposure to radon daughter products (primarily from inside buildings that might be constructed on contaminated land).

In addition to the Ra-226 cleanup criteria, many UMTRCA Title I remediations also used thorium-230 as a cleanup standard to ensure that after 1,000 years of decay and radium ingrowth, site materials will not exceed the Ra-226 standards.

1.3 Scope, Content, and Organization

Section 2 presents pertinent background information, including a site description and an overview of pre-remediation and post-remediation radiological conditions. NRC approved the cleanup, but given the presence of elevated levels of uranium, DOE revisited historical information to verify that cleanup was performed in accordance with guidelines and that the radium-based cleanup standards were met.

Many investigations associated with phytoremediation and the active remediation of groundwater at the Monument Valley site have taken place since the Site Observational Work Plan (SOWP) was prepared in 1999 (DOE 1999). This evaluation focuses on only those data that are germane to the recent identification of elevated radioactivity. Therefore, Section 3 presents all available historical data since the remediation that are potentially related to this evaluation. For soils, these findings are presented in chronological order; Section 3 concludes with an evaluation of relevant groundwater and phytoremediation test plot data, as these studies are ongoing.

Section 4 documents results of analyses and investigations directly related to the stained soils. Although NRC approved the remediation of the Monument Valley site, the recently discovered elevated concentrations of uranium have raised concerns about the protection of site workers. To address this issue, Section 5 documents the results of a recent risk evaluation conducted to ensure that—in accordance with LM's primary mission—elevated levels of residual radioactive material do not pose a risk to human health and the environment. Section 6 summarizes the findings of this report. References are provided in Section 7, and detailed supporting information is provided in the Appendix A through Appendix C.

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2.0 Background

This section documents relevant aspects of site history, site conditions prior to remediation, information on the site cleanup and verification, and details on the NRC concurrence that the Monument Valley site was remediated to applicable standards.

2.1 Site History

A uranium-ore processing mill operated at the site from 1955 to 1968 on property leased from the Navajo Nation. During operation, approximately 2.2 million tons of ore were processed to produce 5700 tons of uranium oxide (U_30_8) concentrate (DOE 1993). The mill closed in 1968, and control of the site reverted to the Navajo Nation. Most of the mill buildings were removed shortly thereafter. The milling process produced radioactive mill tailings, a predominantly sandy material. From 1955 until 1964, ore at the site was processed by mechanical milling using an upgrader, which crushed the ore and separated it by grain size. The finer-grained material, which was higher in uranium content, was shipped to other mills for chemical processing; coarser-grained material was stored on site. These source materials and other site-related contamination were removed during surface remediation at the site from 1992 through 1994.

The total volume of contaminated material at the site was 1,083,000 cubic yards (yd^3) on 83 acres. All the contaminated material was moved to the Mexican Hat, Utah, disposal cell 17 road miles to the north, and surface remedial action was completed in May 1994.

The site areas on which previous investigations have largely focused are the old tailings pile and heap-leach area, the new tailings pile, and the evaporation pond (the focus of this report). The old tailings pile was composed of the sandy tailings that were a product of the mechanical upgrading of ore. The upgrading process used water containing minor amounts of flocculent but no other processing chemicals. Thus, tailings solutions in the old pile were water-equilibrated to minerals in the ore. Heap-leaching of these old tailings occurred in the area where they were stored. Old tailings were placed on the heap-leach pad, and sulfuric acid was added to the tailings. Heap-leach pads were lined to collect the acidic leachate. By contrast, the new tailings pile contained sandy tailings and processing solutions, which contained sulfate, nitrate, and ammonium from the processing chemicals. According to both the SOWP and the Environmental Assessment (DOE 1999, DOE 2005), the evaporation pond was probably used to retain seepage from the new tailings pile. Whether or not the pond was lined is not clear in the site documentation.

2.2 Site Conditions Prior to Remediation and Initial Characterization

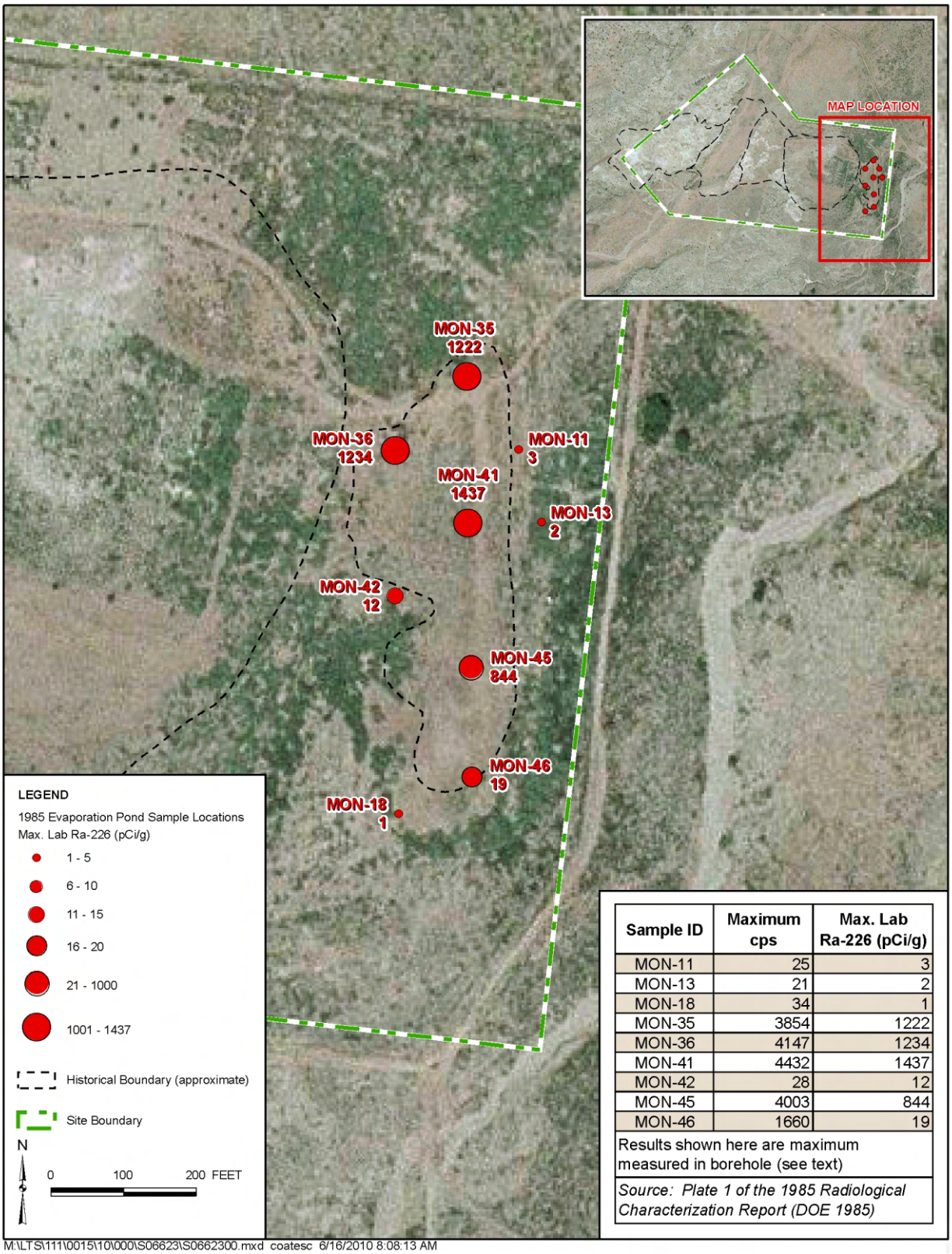
Although radiological data from the Monument Valley processing site have been collected in numerous investigations dating back to 1961 (Ford, Bacon, and Davis 1981; DOE 1993), the 1985 Radiologic Characterization report (DOE 1985) served as the primary source for initial (pre-remediation) characterization data summarized in this section. The field investigation preceding the report's development yielded an extensive and detailed evaluation of radiological conditions at the site—sample collection was comprehensive both laterally and with depth (sample depths ranged from the surface to 58 feet [ft]). That report demonstrated that the evaporation pond contained some of the highest concentrations of radium at the site. This was also shown in an earlier engineering assessment conducted by Ford, Bacon and Davis (1981).

Figure 2–1 plots the maximum soil Ra-226 concentrations measured at nine locations in the evaporation pond area during the 1985 characterization effort. This figure was adapted from the sitewide sample location map provided in the corresponding report (DOE 1985, Plate 1). For reference, maximum field gamma measurements taken during the initial radiological scans are also provided (expressed in counts per second [cps]). Five samples were collected within the pond area and four were peripheral.[1] Given the risk and regulatory drivers described in Section 1, Ra-226 was the primary analytical endpoint. Figure 2–1 shows that highly elevated concentrations of Ra-226, ranging up to 1437 pCi/g (also the sitewide maximum), were previously measured within the central portion of the evaporation pond. Comparison of this figure with Figure 1–2 and soil analytical data discussed later in this report indicates that evaporation pond areas with the highest soil Ra-226 concentrations prior to remediation correspond closely to those areas where elevated radioactivity was recently identified. (Note, however, that only uranium has been detected in elevated concentrations; the following sections will document that remediation efforts were effective in satisfying both the surface [5 pCi/g] and subsurface [15 pCi/g] radium-226 based regulatory standards.)

In light of the recently discovered areas of elevated radioactivity, an obvious question might be: how deep was the contamination in this area relative to the depth of the excavation? To address this question, Figure 2–2 provides a three-variable "bubble plot" perspective of the data shown in Figure 2–1. In this figure, the vertical (*y*) axis corresponds to the sample depth, and the point size reflects the relative magnitude of Ra-226 measured in the soil (*x* axis sample locations do not correspond to any spatial scale). Because of the wide range in the data set (1–1437 pCi/g) and the relative size of the "bubble" or point corresponds to the magnitude of these data, some points are barely discernible. Therefore, all points are labeled with the corresponding Ra-226 concentration to facilitate review. This figure demonstrates that, at the time of the initial characterization, Ra-226 concentrations exceeding 5−15 pCi/g were largely limited to the uppermost 3 ft soil depth. Based on information provided in the Remedial Action Plan (RAP) (DOE 1993), the average excavation depth during remediation was approximately 2.5 ft.

Given the risk and regulatory drivers described in Section 1, Ra-226 was the primary analytical endpoint; Th-230 and uranium were analyzed for only a subset of site samples, and for only one sample (MON-41) in the evaporation pond. Figure 2–3 plots Ra-226 in this sample versus the corresponding uranium and Th-230 concentrations. To provide a more comprehensive (sitewide) data set, Figure 2–4 plots data for the same variables (Ra-226, uranium, Th-230), but for all 1985 characterization data (DOE 1985). Because the majority of the data points are difficult to discern in the upper portion of this figure, the bottom plot excludes the outlier (high Ra-226) data points. These figures demonstrate that uranium concentrations were quite low relative to Ra-226 concentrations—the maximum was 268 pCi/g (2 ft depth)—and there is no apparent relationship (i.e., no equilibrium). This finding is not unexpected, given that milling processes should (in theory) have removed most of the uranium. However, these results are interesting in light of more recent findings, which revealed uranium levels as high as 1000 pCi/g.

[1] As noted in all figures, the historical boundaries shown in the figures are approximate. These boundaries were established over two decades ago, before the now-universal and well-established Global Positioning System surveying techniques were developed. Although the boundaries are approximately correct, the aerial photographs in the figures provided herein suggest that they may be offset somewhat in some areas.



Sample ID	Maximum cps	Max. Lab Ra-226 (pCi/g)
MON-11	25	3
MON-13	21	2
MON-18	34	1
MON-35	3854	1222
MON-36	4147	1234
MON-41	4432	1437
MON-42	28	12
MON-45	4003	844
MON-46	1660	19

Results shown here are maximum measured in borehole (see text)

Source: Plate 1 of the 1985 Radiological Characterization Report (DOE 1985)

Figure 2–1. 1985 Field Gamma Measurements and Soil Ra-226 Concentrations in Evaporation Pond Area

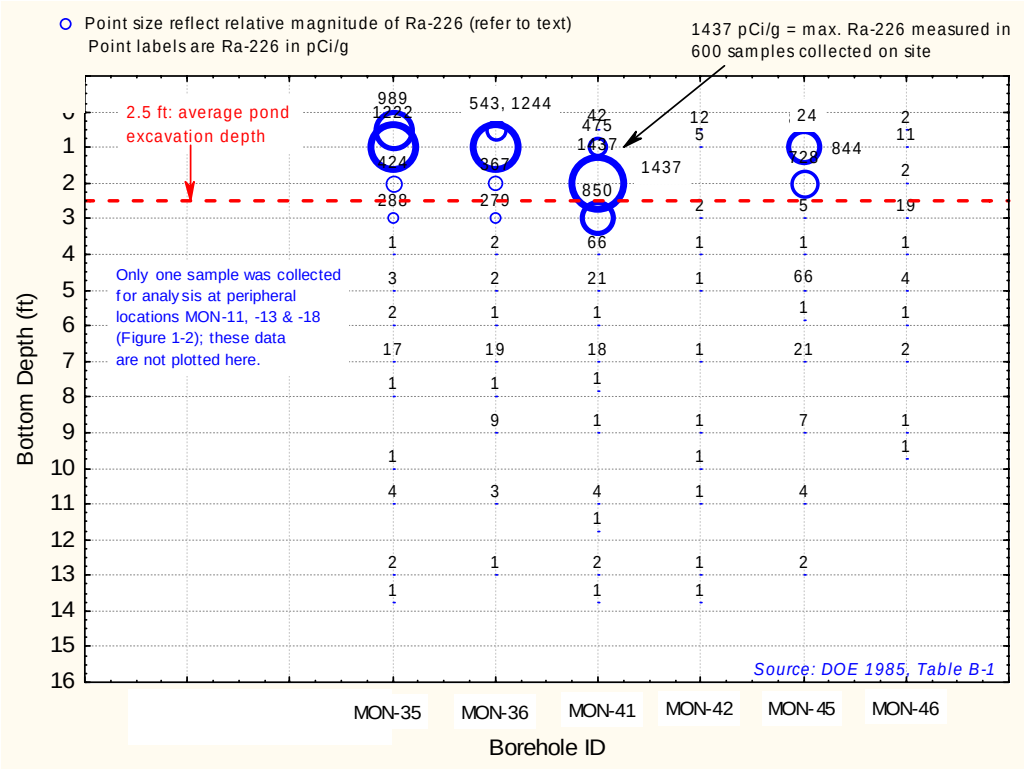


Figure 2–2. Bubble Plot of Ra-226 Concentrations in Evaporation Pond Area Borings (DOE 1985)

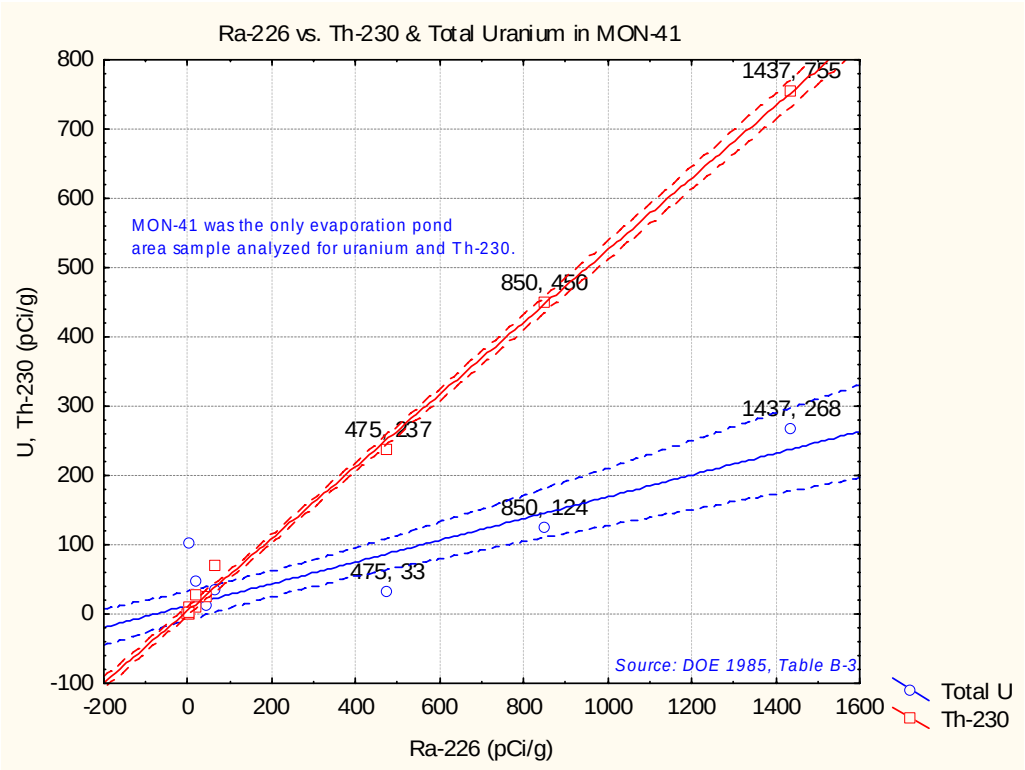


Figure 2–3. Corresponding Th-230 and Uranium Concentrations in One Sample

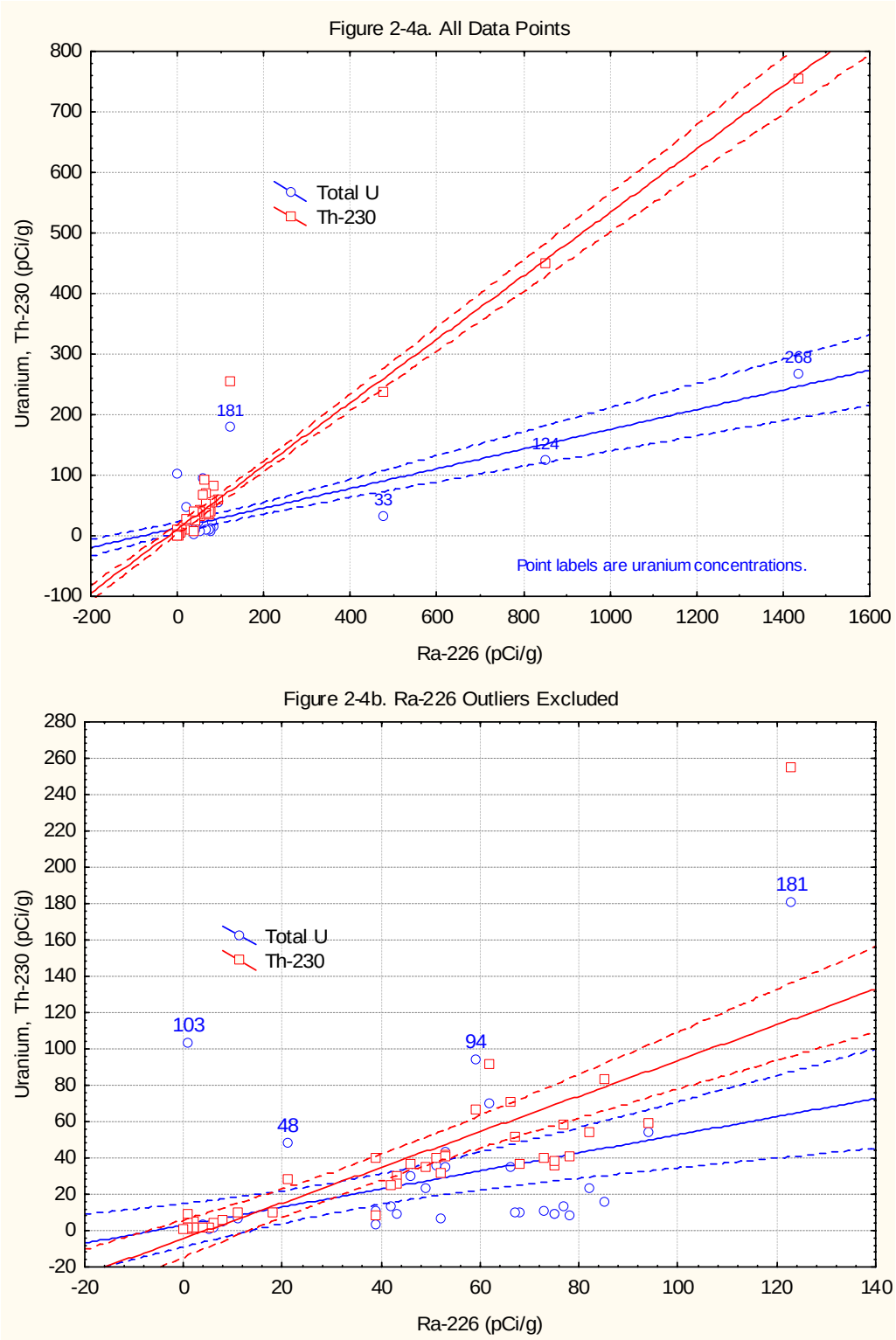


Figure 2–4. Plot of Ra-226 vs. Uranium and Th-230: All 1985 Characterization Data

2.3 Summary of Cleanup Efforts, Verification, and NRC Concurrence

The findings discussed in this section are based largely upon information in the following documents:

- *Remedial Action Plan for the Codisposal and Stabilization of the Monument Valley and Mexican Hat Uranium Mill Tailings at Mexican Hat, Utah* (DOE 1993)
- *Mexican Hat, UT, Monument Valley, AZ Final Completion Report* (DOE 1997)

2.3.1 Remedial Action Plan

The remedial action consisted of two phases: Phase I remedial action consisted primarily of demolishing the remaining mill buildings (except the sheet metal shop), constructing a vehicle decontamination pad and retention basins, and fencing the site. Phase II included the placement of demolition debris in the Mexican Hat disposal cell (the lower tailings pile), removal and disposal of upper tailings and windblown and waterborne materials in the disposal cell, and incorporation of permanent drainage features (DOE 1993).

Table 2–1 summarizes the volumes of contaminated material and Ra-226 concentrations of all major areas on the site. The total volume of contaminated material is about 1,083,000 yd^3.

Table 2–1. Excavation Volumes and Volume-Weighted Ra-226 Concentrations of Contaminated Material at the Monument Valley Site

Area Description	Contaminated Volume (yd^3)	Average Ra-226 (pCi/g)
Lower pile	759,964	46.7
Evaporation pond	9,000	219.6
Heap leach pads (upper pile)	258,936	51.2
Ore storage (RAP Area "E", miscellaneous area	32,922	66.0
Batch leach yard (RAP "Area C")	14,036	38.3
Old pile remnant (RAP "Area D"	1,406	40.0
Rubble piles	4,129	67.8
Roads	3,000	37.3
Total	**1,083,393**	**49.7**

Adapted from Table 3.1 of the RAP (DOE 1993); average Ra-226 concentrations are volume-weighted averages.

The RAP does not explicitly document the depths of the excavation; this information would be particularly useful for the former evaporation pond. However, the average depth of the excavation for this area can be estimated by dividing the contaminated volume by the area of the evaporation pond (9,000 yd^3 divided by 10,648 square yards (2.2 acres), yielding an estimated 0.85 yard, or an approximately 30-inch (2.5-ft) excavation depth.

2.3.2 Final Completion Report

The Final Completion Report documents the site conditions after cleanup and the verification procedures used to ensure that the site was remediated according to 40 CFR 192. Information from the Final Completion Report (mostly extracted from Appendix J, “Verification Measurements”) that is applicable to this evaluation is summarized below:

- Approved procedures for soil verification measurements on the UMTRA Project were used at the Monument Valley site; verification measurements using both sampling and in situ techniques were employed during the site cleanup. Two types of in situ measurements were performed, RTRAK gamma survey measurements using a gamma scanning tractor and Hand-held Gamma Verification System (HGVS) measurements.
- Since Th-230 is the radioactive parent of Ra-226, elevated levels of Ra-226 can develop over long periods of time when Th-230 is present in elevated concentrations. Excavation control was conducted at the Monument Valley site such that the EPA limits would not be exceeded due the ingrowth of Ra-226 from levels of Th-230 in 1,000 years. Verification measurements for Th-230 were conducted on nearly 5 percent of the grids at the Monument Valley site. Additional measurements were conducted for areas suspected of having elevated concentrations of Th-230 in underlying soil such as heap-leach areas, raffinate ponds, and the upper tailings pile. If sampling indicated Th-230 in excess of the guideline, the surrounding grids were also sampled and analyzed for Th-230.
- Due to the natural error associated with radiological measurements, occasionally an independent laboratory result exceeded the limits while the site verification measurement met the limits. Review of Appendix J data indicates that "false negatives" (i.e., field measurements below criteria when laboratory results indicated otherwise) were infrequent. Also, these anomalous measurements are to be expected and are typical for a cleanup effort of this magnitude.
- The average Ra-226 concentration, including background, for 4,502 site verification samples was 1.4 pCi/g, and the maximum concentration was 6.3 pCi/g. Of the 221 verification samples analyzed by an independent laboratory for Th-230, the average concentration was 1.9 pCi/g, and the maximum was 29 pCi/g.
- Samples of backfill material were collected and analyzed to determine the levels of Ra-226. The average Ra-226 concentration for 236 backfill samples taken at the Mexican Hat and Monument Valley site was 0.6 pCi/g, and the maximum concentration was 4.6 pCi/g.

2.3.3 NRC Concurrence

On February 27, 1996, NRC notified the DOE UMTRA Project Office that NRC staff had completed its review of the final RAP and all associated documents pertinent to the proposed remedial action for the co-disposal and stabilization of the Monument Valley (and Mexican Hat) site. The staff's review was documented in the Final Technical Evaluation Report for the Monument Valley/Mexican Hat sites and transmitted with the February 1996 letter.

NRC's concurrence letter (September 18, 1996) stated that DOE's proposed remedial action complies with the EPA standards in 40 CFR 192, Subparts A–C, with the exception of the groundwater cleanup program at the Monument Valley site. As indicated in the Technical Evaluation Report, DOE must demonstrate compliance with EPA's final groundwater standards,

Subparts B and C, at the Monument Valley site. As with most Title I UMTRCA sites, DOE proposed deferral of the Monument Valley groundwater cleanup aspect of the remedial action and planned to handle this action in the separate groundwater program.

2.4 Discussion

Early (pre-remediation) characterization studies provide some insight as to the potential source of the elevated levels in the evaporation pond.

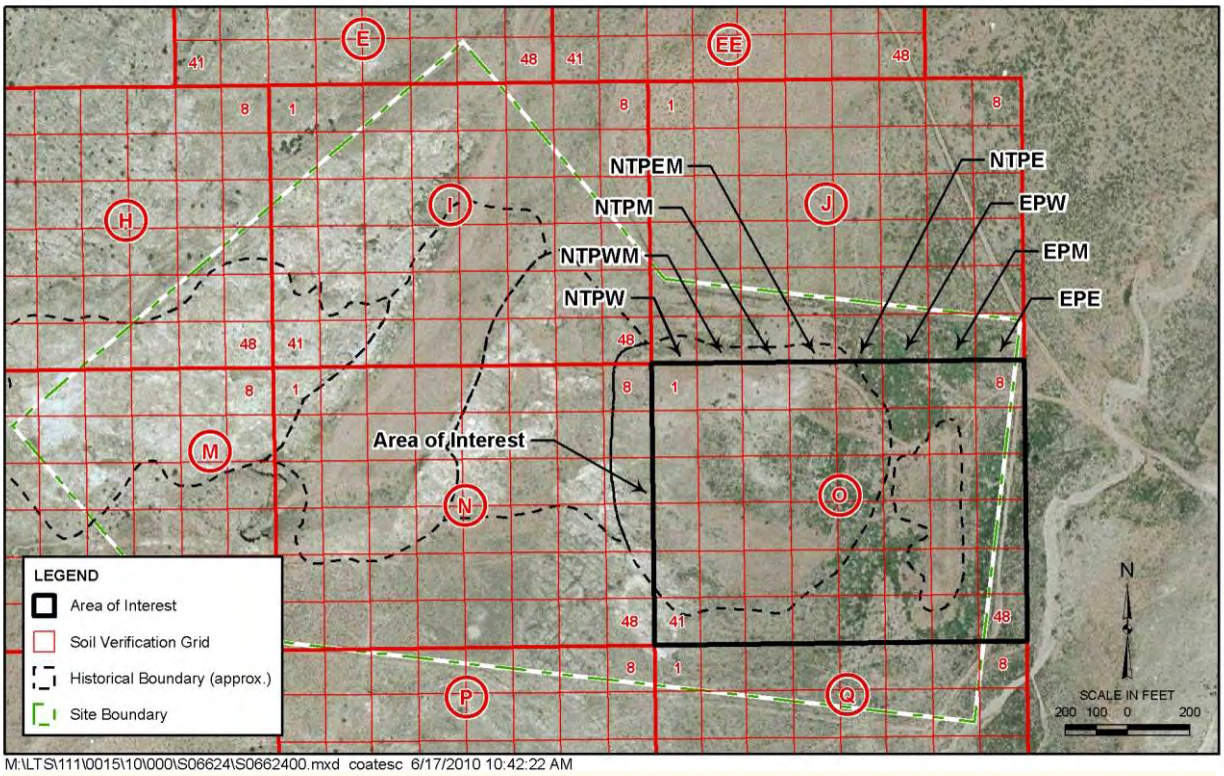
The information presented in the RAP and Final Completion Report indicates that the Monument Valley site was remediated in accordance with 40 CFR 192, and appropriate verification procedures were followed that included a quality control program and independent laboratory confirmation of field instrumentation. Moreover, NRC concurred that the remediation complies with requirements of 40 CFR 192. Figure 2–5 shows the site prior to remediation, and Figure 2–6 shows the Monument Valley site after cleanup was complete.

Because the recent elevated uranium in soils has been limited to the area of the former evaporation pond, a more robust evaluation of the data in the Final Completion report was performed for the evaporation pond and the surrounding areas; the results are shown in Figure 2–7. This figure shows that radium levels left after cleanup in the evaporation pond generally have a more widespread distribution and are more elevated than levels in surrounding areas; however, the surface standard for radium (5 pCi/g above background averaged over 100 square meters) was met. Although the cleanup standard was met, no indication was provided (or required) on the uranium that was left on site.

Figure 2–5. Contaminated Excavation and Haul from the Heap-Leach Area Prior to New Tailings Pile and Evaporation Pond Excavation (March 1993)

Figure 2–6. Monument Valley Site Post-Remediation and Cleanup Verification (February 1994)

† Source: Figure 4 and Figure 9 from the April 1997 Final Completion Report (DOE 1997).



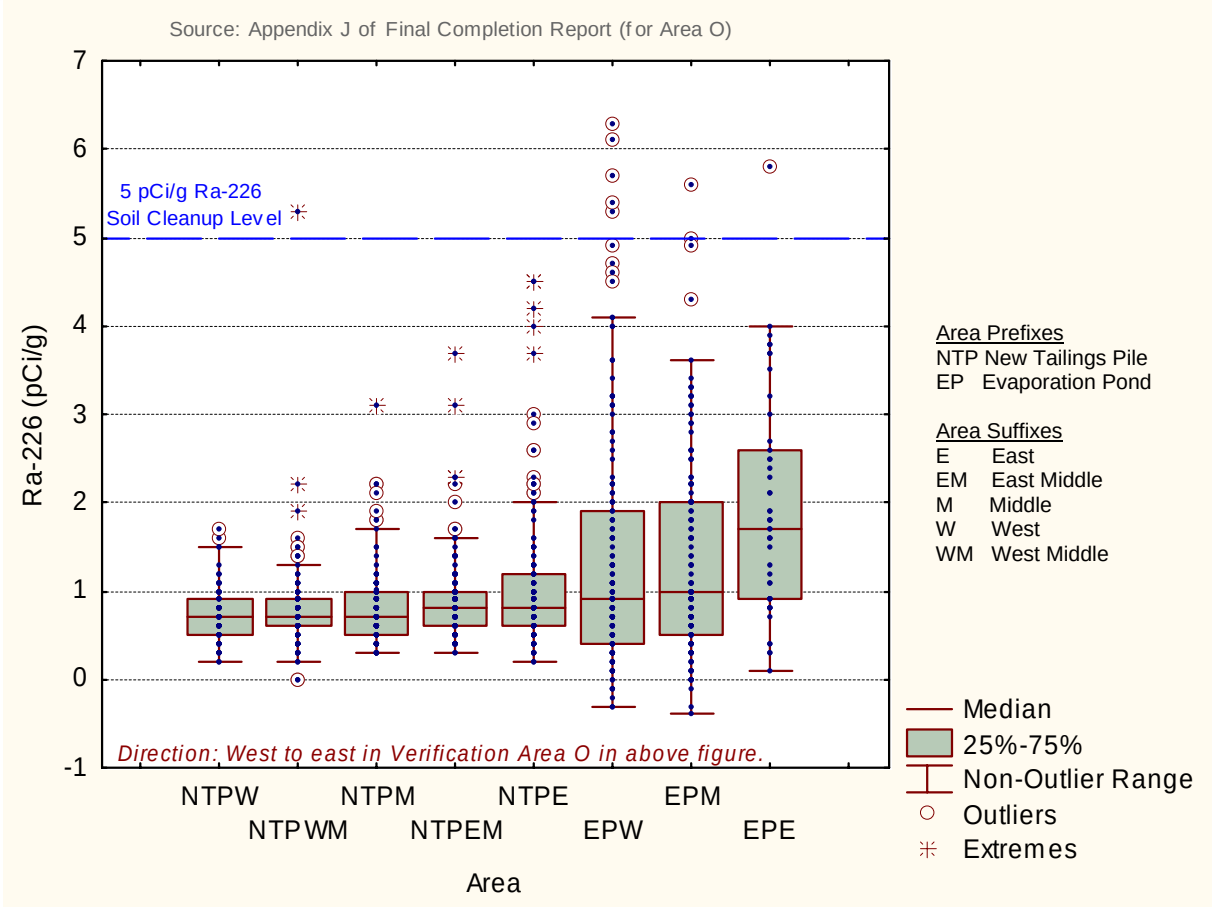


Figure 2–7. Final Completion Report Verification Results for Evaporation Pond and Surrounding Areas

3.0 Summary of Historical Data and Investigations

As with other UMTRCA Title I processing sites, the Monument Valley site was transferred to DOE for long-term care after remediation of the surface materials was complete. The post-remediation focus has been on contamination in groundwater, and additional characterization of on-site soils was therefore limited. However, some additional data have been gathered to support other purposes, such as ongoing phytoremediation pilot studies and the development of required regulatory documents. This section summarizes all data collected since the surface remediation was complete that is potentially relevant to this evaluation (the focus is on uranium results). Figure 3–1 plots all uranium soil data for the Monument Valley site, including results of recent investigations documented in Section 4 of this report. The results plotted in Figure 3–1 are the maximum uranium concentrations over all depths sampled.

Section 3.1 summarizes data from subpile soil samples collected in 1998 and 2004, Section 3.2 summarizes a salt crust evaluation, Section 3.3 summarizes pertinent information from phytoremediation pilot studies, and Section 3.4 summarizes information that can be gleaned from groundwater data that are relevant to this evaluation.

3.1 Subpile Soil Sampling (1998 and 2004)

To better understand site conditions and to thoroughly investigate the most appropriate way to address residual groundwater contamination at UMTRCA Title I processing sites, DOE generates a Site Observational Work Plan (SOWP). The SOWP documents the site-specific strategy that DOE will use to comply with EPA groundwater standards and provides a mechanism for stakeholder participation, review, and acceptance of the recommended remedial alternative. In 1999, DOE completed the *Final Site Observational Work Plan for the UMTRA Project Site at Monument Valley, Arizona* (DOE 1999),

During early characterization efforts conducted for the SOWP, DOE determined that soils beneath the surface of the historical tailings pile locations (subpile soils) likely represented a continuing source of ammonium and nitrate contamination to the alluvial aquifer. On the basis of pilot studies conducted before 2002, DOE concluded that phytoremediation would be a viable option for remediating nitrate and sulfate in the shallow areas of the alluvial aquifer and the subpile soils area. This option is also consistent with revegetation and land management goals at the site. However, DOE also determined that additional pilot studies should be conducted prior to final selection of the compliance strategy for nitrate and sulfate in the alluvial aquifer.

Data collected as part of initial groundwater characterization efforts (conducted while developing the SOWP) indicated that trace elements including manganese, uranium, and vanadium were present above background concentrations. Therefore, DOE conducted investigations to better assess areas of the site that could be a continuing source of groundwater contamination. Efforts were focused on the former tailings area: subpile soil samples were collected beneath the "footprint" of the former tailings piles. Two investigations were undertaken, one as part of the SOWP (in 1998), and a second in late 2004. Relevant findings are discussed below.

3.1.1 1998 Subpile Soil Sampling

Although soils at the site were remediated according to the radium standards in 40 CFR 192, the potential exists for nonradionuclide contaminants to have seeped into the soils. Contaminated soils could contaminate infiltrating water as it passes through them and prolong the groundwater cleanup effort. Soil samples were collected and analyzed to evaluate the distribution of selected site-related constituents in the soils underlying the former tailings piles, heap-leach pads, and evaporation ponds. Background soil samples were also collected and analyzed.

Subpile Soil Sampling Procedures

Twenty-six samples from nine soil borings were analyzed. Three soil borings were located in the former new tailings pile, two in the former heap-leach pads, two in the former evaporation pond, and two upgradient of the site (background soil borings). Figure 3–1 shows the location of the samples (see triangular symbols in this figure). Each soil boring was hand augered to a depth of 3.5 to 8.5 ft. The upper 1–2 ft was loose fill material that had been placed on the surface and graded after removal of the tailings and was not representative of the subpile soils. Samples were collected at approximately 1-ft intervals below the fill. Chemical extractions were used to determine the potential mobility of contaminants. Each sample was extracted by using three separate lixiviants, and the residue was completely digested and analyzed. The lixiviants were deionized water, alluvial groundwater, and 5 percent hydrochloric acid.

Table 3–1 summarizes the results, and Figure 3–2 shows the distribution of uranium concentrations from the 1998 subpile samples. The highest and most widely distributed concentrations of uranium were found in the subpile soils beneath the former evaporation pond.

3.1.2 December 2004 Subpile Soil Sampling

From 1998 to 2004, uranium concentrations in the groundwater at well 662 at the Monument Valley site rose approximately seven-fold. The purpose of the 2004 subpile sampling was to assess whether the former Old Tailings Pile and Heap Leach area is a potential source of leachable uranium.

Sampling was performed on a radial sampling grid; 25 samples were collected at the locations shown in Figure 3–1 (see circular symbols in this figure). Samples were collected at 1-meter intervals to a depth of 4 meters below the surface (i.e., at 3.3 ft, 6.3 ft, 6.6 ft, 10 ft, 13 ft). Figure 3–1 presents the sampling results, which are shown as the maximum uranium concentration measured in the depth profile.

This sampling was a limited, reconnaissance-level sampling event designed to answer the question of whether the former Old Tailings Pile and Heap Leach Pad area is a potential continuing source of leachable uranium. Most of the samples had uranium levels under 1 milligram per kilogram (mg/kg), three locations had uranium results greater than 3 mg/kg, and the highest was approximately 4.5 mg/kg. Uranium concentrations in several samples from this study were greater than those found in the 1998 soil sampling, including samples collected from the former evaporation pond.

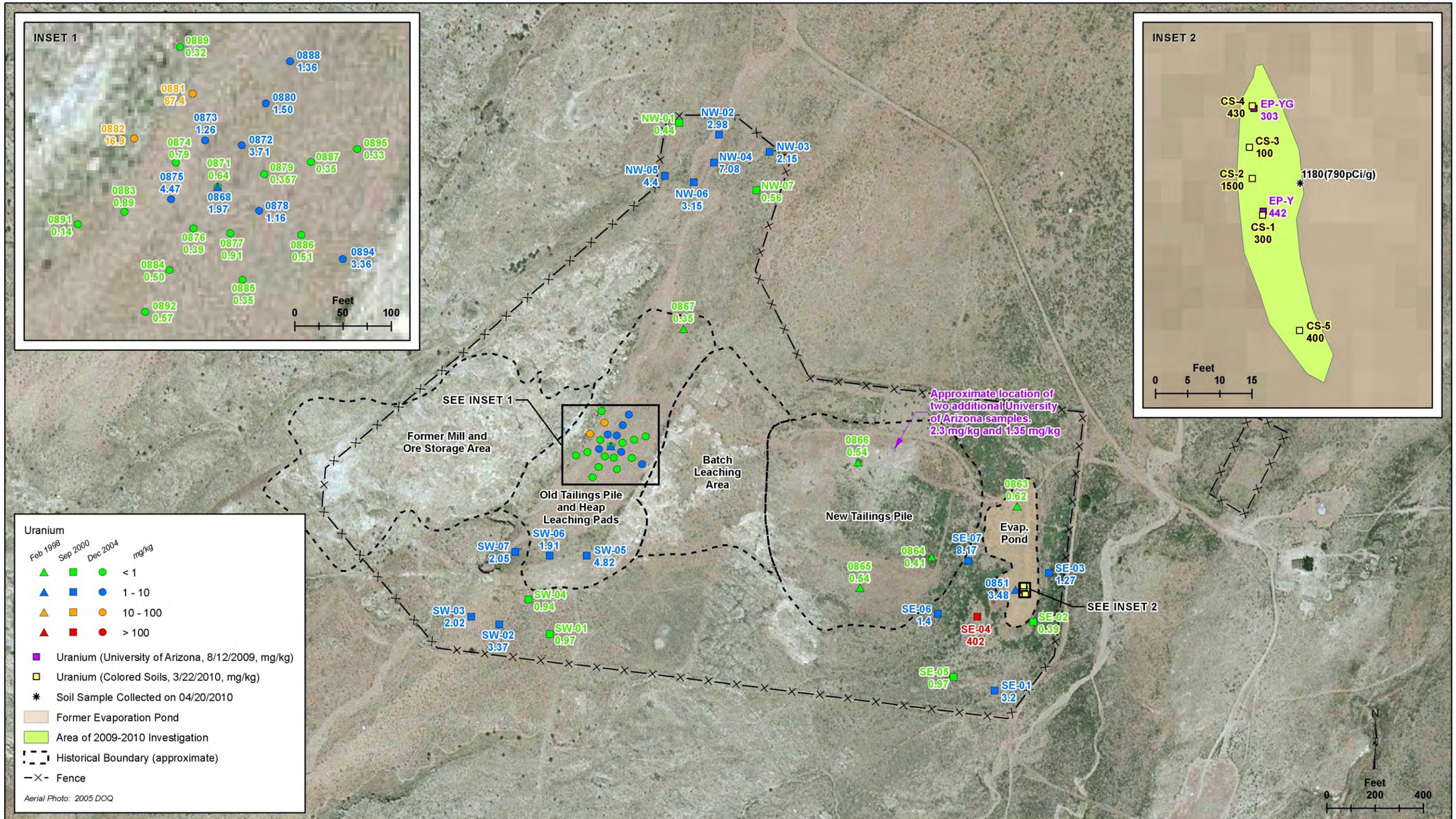


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Figure 3–1. Uranium Soil Sample Analytical Results

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Table 3–1. Summary of 1998 Subpile Soil Sampling Results

Sample ID	Depth (ft)[a]	Area	Manganese mg/kg	Uranium mg/kg	Vanadium mg/kg	Ammonium mg/kg	Nitrate mg/kg	Sulfate mg/kg
851–2	2.5–3.5	EP	134.93	3.48	202.4	27.24	1775.8	7270
851–3	4.5–5.5	EP	122.89	1.11	142.1	10.81	942.7	2866
851–4	7–8	EP	188.28	1.57	89.11	30.6	252.9	375
863–2	3.5–4.5	EP	96.19	0.55	20.09	9.58	637.2	1690.3
863–3	6–7	EP	70	0.55	14.93	8.86	456.5	1389.9
863–4	8–8.5	EP	151.4	0.62	21.29	13.74	632.9	1768.1
864–2	2.5–3.5	NT	103.69	0.41	23.09	13.73	273.7	9337
864–3	4.5–5.5	NT	110	0.39	22.01	10.21	1407.4	1571
864–4	6.5–7.5	NT	125.87	0.38	22.58	9.71	351	431.5
865–2	2.5–3.5	NT	85.5	0.54	47.82	9.93	881.9	3307.4
866–2	2.5–3.5	NT	134.53	0.54	56.21	137.17	1157.1	2028
866–3	4–5	NT	48.46	0.33	21.44	154.17	1095.5	1913.4
866–4	5–6	NT	40.36	0.42	33.57	214.37	882.6	471
866–5	6 -7	NT	34.85	0.32	11.29	270.31	914.2	396.9
866–6	7–8	NT	32.69	0.36	6.85	310.47	956	308.8
867–2	2.5–3.5	HL	75.2	0.35	5.3	7.91	275.1	168.5
867–3	5–6	HL	66.68	0.32	5.4	8.15	207.4	165.7
868–2	4–5	HL	102	0.7	11.13	10.95	1612	243.1
868–3	5.5–6.5	HL	189.8	0.92	18.22	6.09	153.7	267.2
868–4	7–8	HL	328.1	1.97	34.47	7.77	161.2	530
869–2	2–3	BG	224.6	0.78	16.51	7.33	231.2	562
869–3	3–4	BG	139.8	0.58	9	7.79	114.2	611
869–4	4–5	BG	98.2	0.44	7.7	8.15	941.3	499
870–2	1–2	BG	108.38	0.33	5.7	9.38	90	311
870–3	2–3	BG	86.61	0.36	5.7	9.2	362.9	295
870–4	3–4	BG	84.84	0.56	6.2	6.99	372.2	291.9

Table adapted from Table 4-8 of the SOWP (DOE 1999).

[a] Sample depths are not clearly documented in the SOWP; those listed above are inferred based on lithologic logs provided in Figure 4-10 of the SOWP.

mg/kg = milligrams per kilogram
EP = Evaporation Pond
NT = New Tailings Pile
HL = Heap Leach
BG = Background

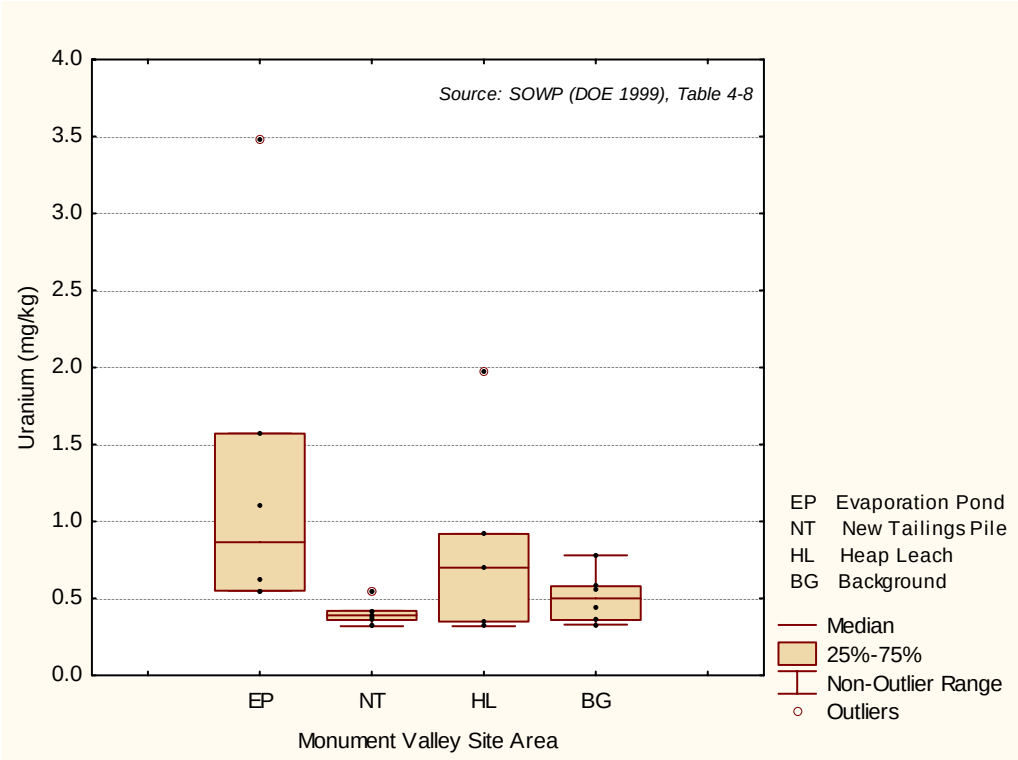


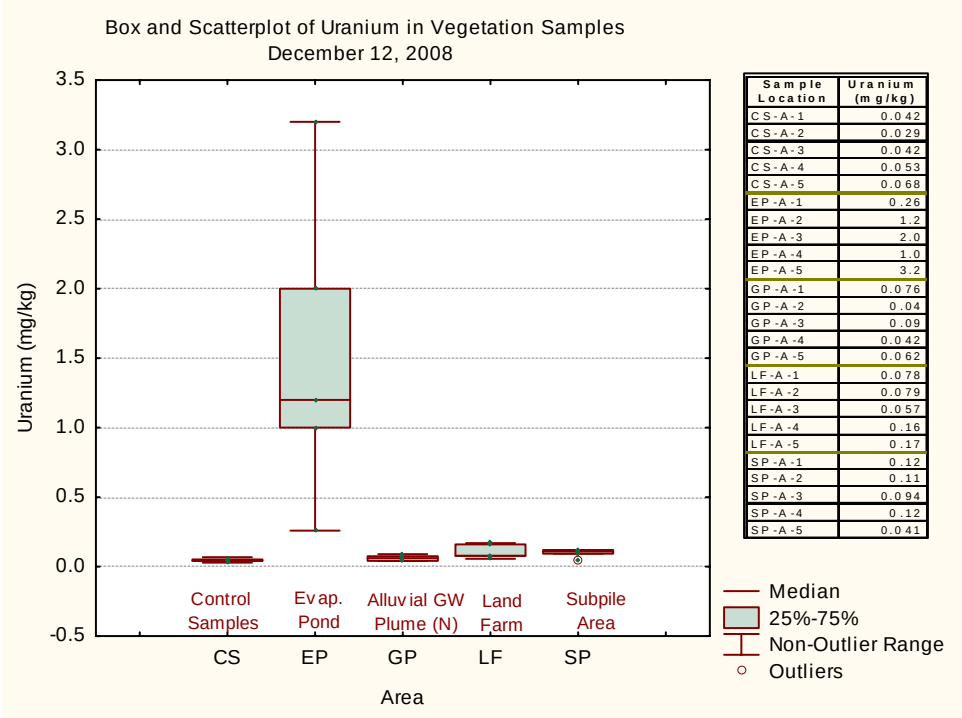
Figure 3–2. Distribution of Uranium in 1998 Subpile Soil Samples by Site Area

3.2 Salt Crust Evaluation

In September 2000, DOE undertook a more spatially comprehensive evaluation than the preceding subpile soil investigation, in that all site areas were addressed (DOE 2001b). These results are plotted in Figure 3–1 (see square symbols in this figure), which indicates that most uranium concentrations were less than 10 mg/kg, but above background (average crustal composition is 1.80 mg/kg). An exception to this was the result for SE-04, just east of the evaporation pond (Figure 3–1), where concentration is 402 mg/kg. Given that samples were not surveyed, the mapped sample location is approximate, so it is possible that this sample was actually located closer to or even within the former evaporation pond, coinciding more closely with areas exhibiting elevated radioactivity identified within the last year.

3.3 Pertinent Information from Phytoremediation Pilot Studies

To support a groundwater compliance strategy for the Monument Valley site, DOE initiated a native plant phytoremediation pilot study to remove ammonia and nitrite from subpile soils and groundwater in the summer and fall of 1999. Although most of these efforts were focused on the primary contaminant of concern, nitrate, some limited data were collected for uranium in vegetation samples. Figure 3–3 presents the results of this effort. This figure shows that the highest concentrations of uranium were found in the former evaporation pond. The concentrations in vegetation samples from the former evaporation pond were similar to, and in some cases higher than, those found in soils. Concentrations of uranium in vegetation from all other areas were significantly lower and similar to the control samples.



Sample Location	Uranium (mg/kg)
CS-A-1	0.042
CS-A-2	0.029
CS-A-3	0.042
CS-A-4	0.053
CS-A-5	0.068
EP-A-1	0.26
EP-A-2	1.2
EP-A-3	2.0
EP-A-4	1.0
EP-A-5	3.2
GP-A-1	0.076
GP-A-2	0.04
GP-A-3	0.09
GP-A-4	0.042
GP-A-5	0.062
LF-A-1	0.078
LF-A-2	0.079
LF-A-3	0.057
LF-A-4	0.16
LF-A-5	0.17
SP-A-1	0.12
SP-A-2	0.11
SP-A-3	0.094
SP-A-4	0.12
SP-A-5	0.041

Figure 3–3. Box and Scatter Plot of Uranium in December 2008 Vegetation Samples

3.4 Groundwater

It is not the objective of this evaluation to address groundwater – see instead the most recent (December 2009) Data Validation Package (DOE 2010a). However, to provide a more comprehensive presentation of all available data potentially relevant to this issue, and because groundwater is the primary medium being monitored at this and other LM sites—this discussion will examine uranium trends in all wells, and then focus on those in the evaporation pond area.

Three aquifers exist in the Monument Valley area: the alluvial (uppermost) aquifer, the Shinarump (directly underlying the alluvial aquifer), and the De Chelly (the deepest of the three aquifers). Of these, only the alluvial and De Chelly aquifers have shown evidence of site-related contamination.

3.4.1 Extent of Uranium Contamination in Groundwater

As stated previously, monitoring has focused on the nitrate plume; uranium has not been considered a primary contaminant of concern, in that its presence above the groundwater standard is not widespread. Figure 3–4 shows the locations of the groundwater monitoring locations at the Monument Valley site. As shown in Figure 3–5 through Figure 3–8, only a small subset of wells have had historical uranium concentrations exceeding the 0.044 milligram per liter (mg/L) standard in 40 CFR 192. These wells form a cluster in the northern section of the former tailings pile and batch-leaching area (see Figure 3–4).

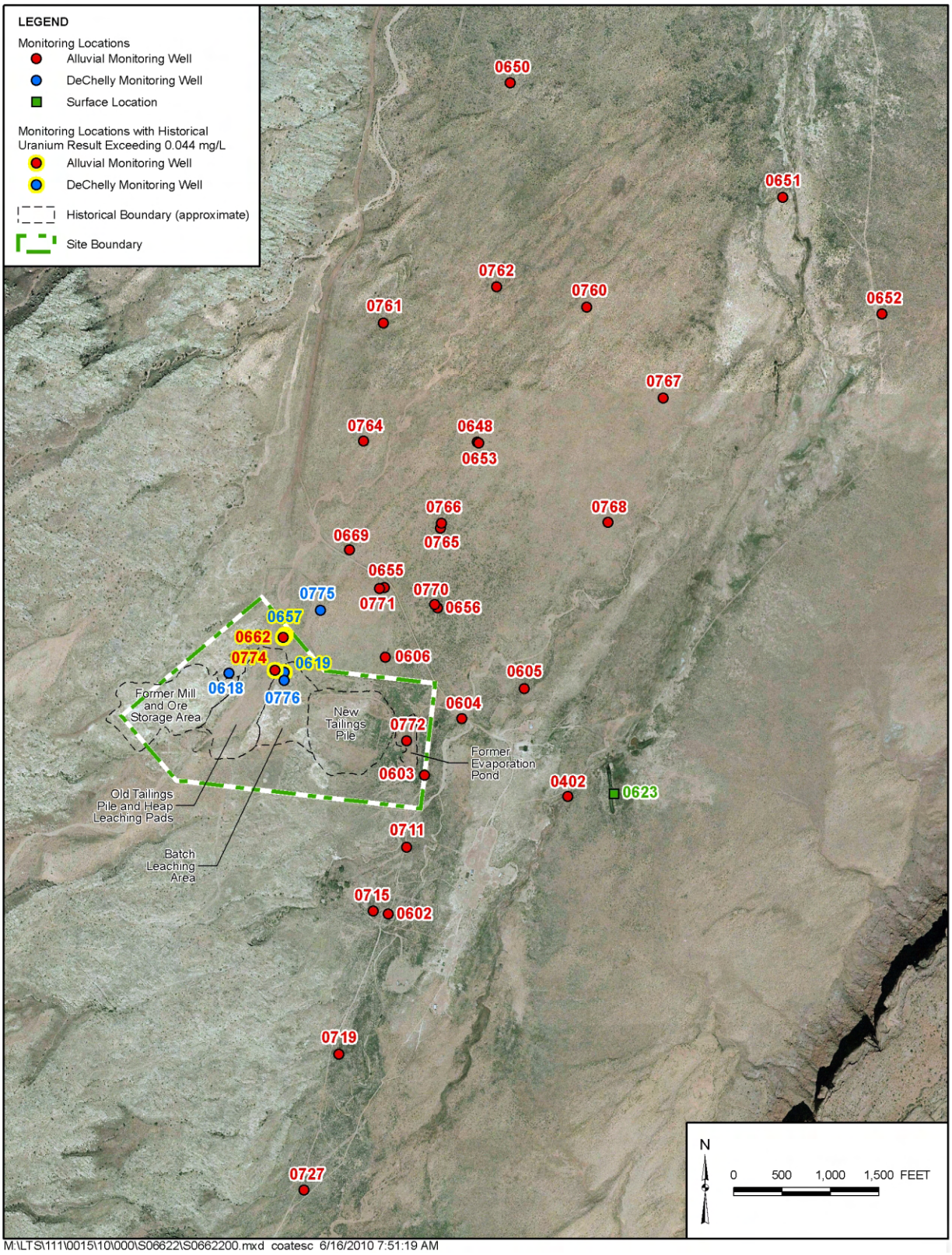
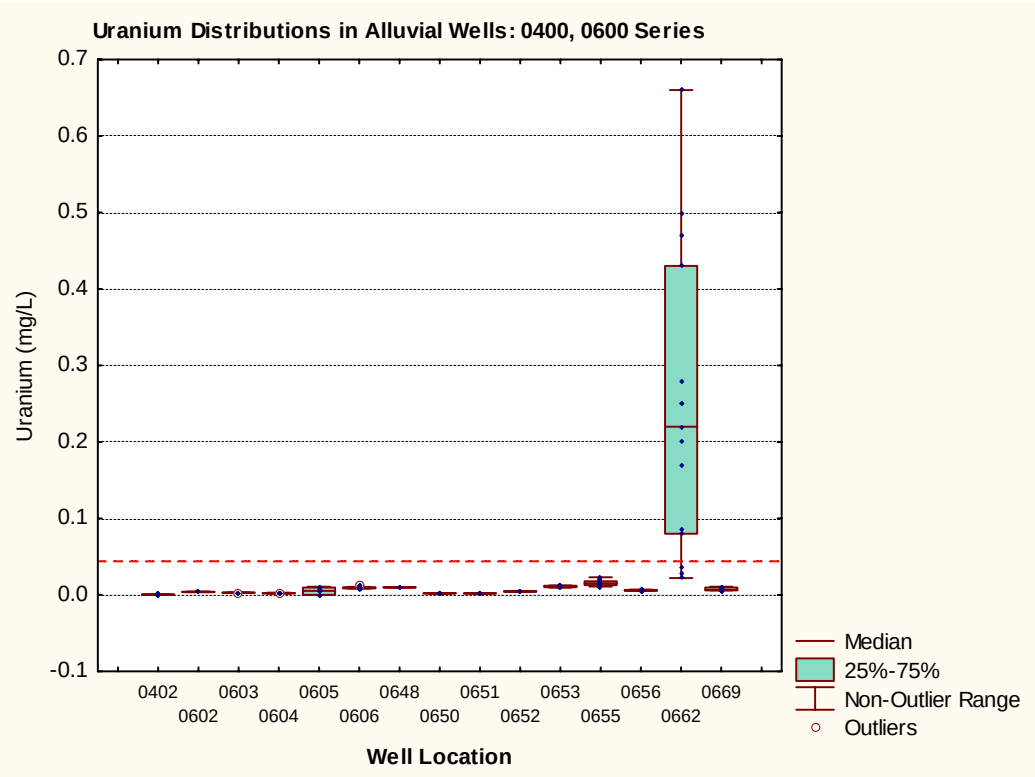


Figure 3–4. Monument Valley Processing Site Groundwater Monitoring Locations



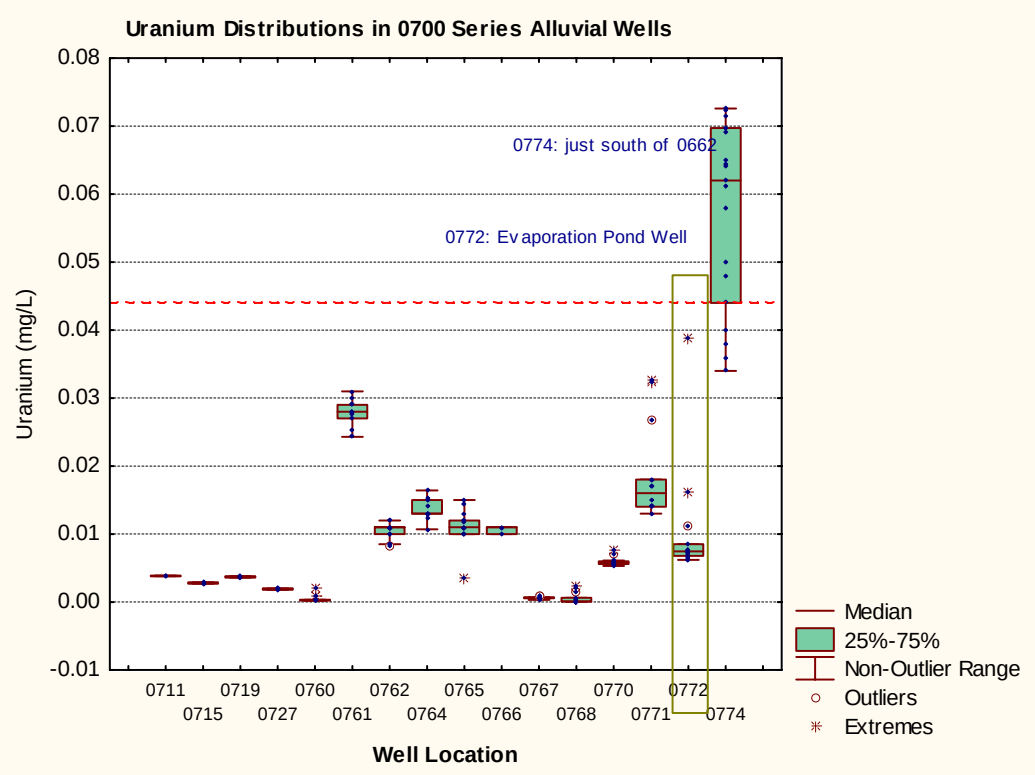


Figure 3–5. Uranium Distributions in Monument Valley Alluvial Wells

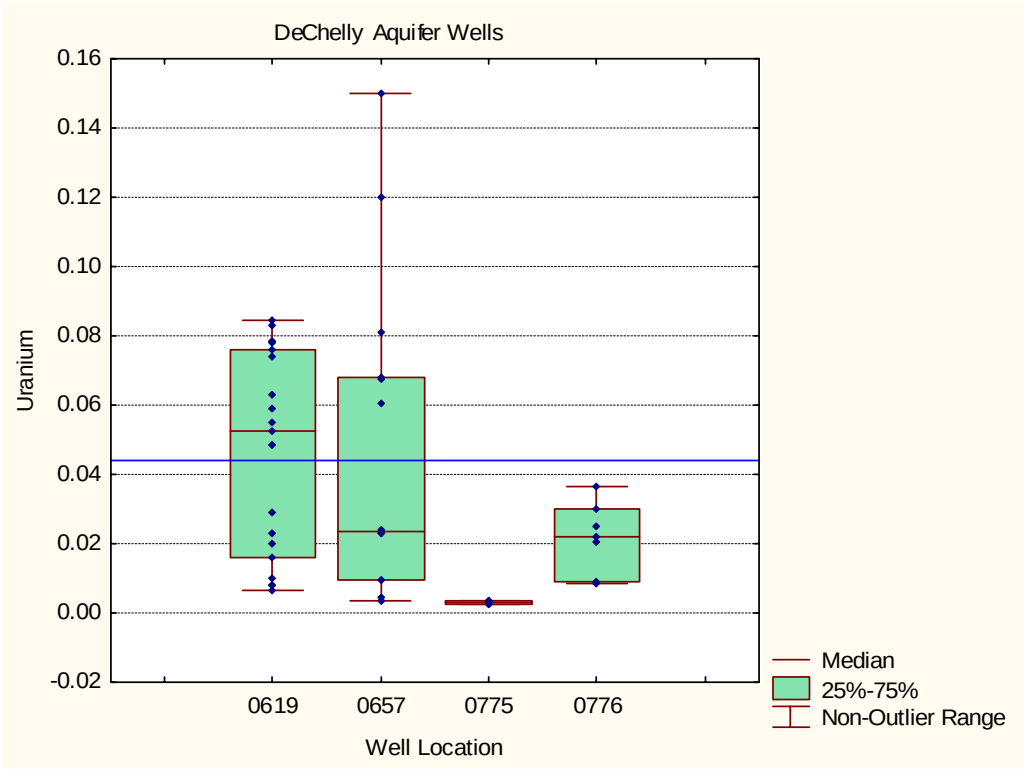


Figure 3–6. Uranium Distribution in De Chelly Aquifer Wells

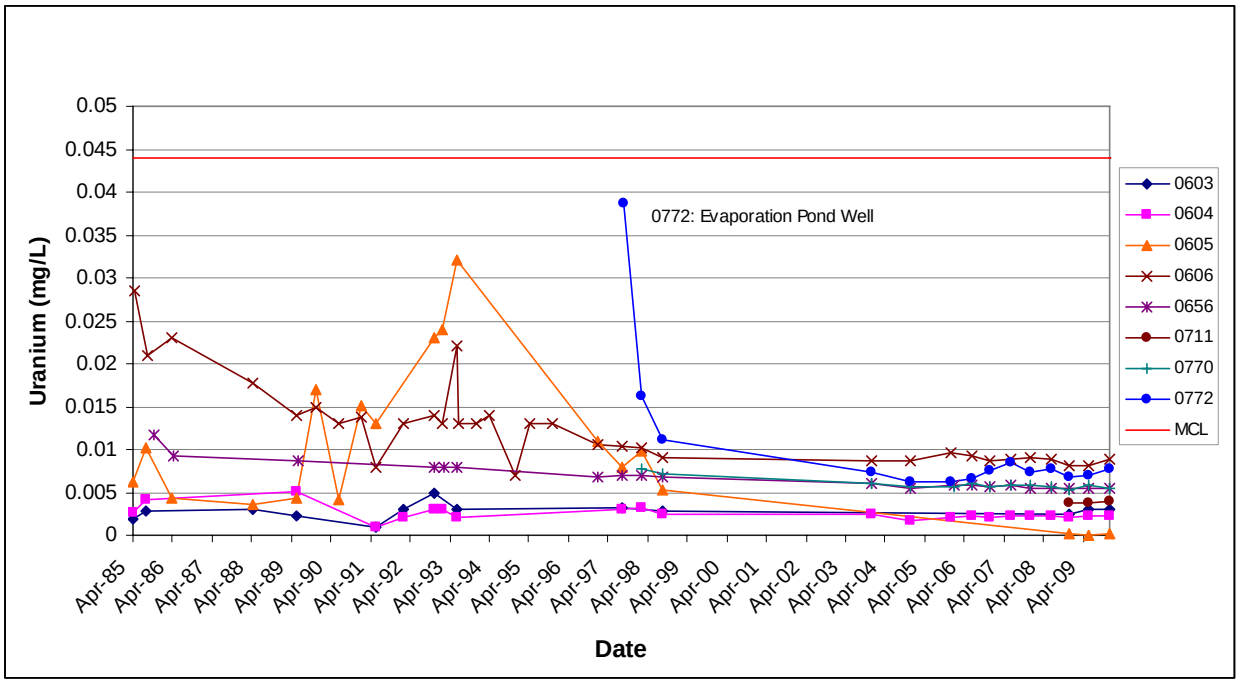


Figure 3–7. Time-Concentration Plots of Uranium in Evaporation Pond Area Wells

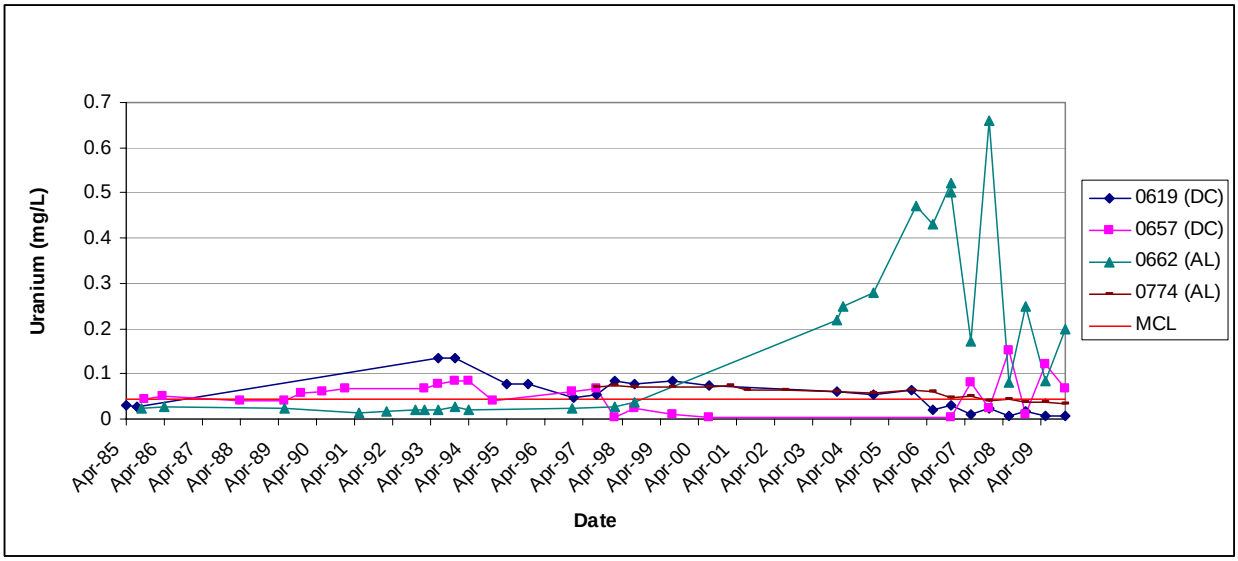


Figure 3–8. Time-Concentration Plots of Uranium in 0619 Area Wells

Elevated uranium concentrations in the groundwater do not appear to be widespread, although some elevated concentrations have been detected. Previous documents have focused on uranium in the De Chelly aquifer (wells 0619 and 0657), but it is present at elevated levels in two alluvial wells as well (0662 and 0774). Uranium concentrations at all other monitoring locations are below the standard and within the range of background concentrations established in the SOWP for the site region (<0.001−0.021 mg/L) (DOE 1999).

Given elevated levels in the evaporation pond soils discussed in this and subsequent sections, the fact that uranium is not elevated in evaporation pond alluvial well 0772 is surprising. This condition may change as water infiltrates through soil in this area.

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4.0 Summary of Recent Investigations in the Evaporation Pond and Surrounding Areas

Starting in 2007, personnel working on the phytoremediation pilot studies noticed poor plant growth in areas with discolored surface soils in the former evaporation pond. To investigate this phenomenon, soils samples were collected and analyzed for numerous elements that could be contributing to the negative impacts on plant growth. The results showed elevated soil concentrations of uranium in several samples. Subsequent investigations began in March 2010 (after snow melt) to better delineate the extent and nature of the uranium in the surface soils (Table 1–1 presented the chronology of these events). This section presents the results of these more recent investigations. **Note:** Data and findings presented in this section likely represent worst-case conditions, because soil-sampling results documented herein were biased samples collected from discolored soil areas.

4.1 University of Arizona Analyses, Samples Collected August 12, 2009

The University of Arizona collected and analyzed samples of the discolored soils in the former evaporation pond area on August 12, 2009. These results were documented in a letter dated December 17, 2009 (memo to: Jody Waugh, re: "Uranium in Former Evaporation Pond Area at Monument Valley," provided in Appendix C). Samples were collected from stained surface soils in the former evaporation pond area and an extended field west in the subpile soil area for a suite of heavy metals to determine if potential toxic substances were associated with the chemical stains observed in some areas of the site. Two samples—EP Y and EP YG—were collected in stained areas in the former evaporation ponds (EP prefix), and an additional two samples were collected in the extended field west (EFW prefix), by scraping samples from soils with yellow (Y), green (G) or red (R) staining. Samples were analyzed by the Water Quality Center Laboratory of the University of Arizona's Environmental Research Laboratory. Samples were analyzed for calcium, vanadium, manganese, iron, strontium, and uranium; analytical results are summarized in Table 4–1. These analyses showed elevated concentrations of uranium in stained soil samples collected from the former evaporation pond.

Table 4–1. Results of Heavy Metal Analyses of Surface Soils at Monument Valley Site: August 12, 2009

Sample Number	Location/ Description	Calcium (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Strontium (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)
EP Y	Evaporation pond, yellow-stained soils	27,949	4301	134	107	442	2672
EP YG	Evaporation pond, yellow-green stained soils	21,067	4242	96	71	303	1352
EFW R	Extended field west, red-stained soils	31,117	54,741	148	134	2.31	895
EFW G	Extended field west, green-stained soils	31,585	2395	174	130	1.35	884

Calcium reported as calcium-40 (^{40}Ca); iron as Fe-56 (^{56}Fe); manganese as Mn-55 (^{55}Mn), strontium as Sr-88 (^{88}Sr); uranium as U-238 (^{238}U); vanadium as V-51 (^{51}V).

4.2 Scan Results, March–April 2010

Because of the elevated uranium levels in the surface soils, DOE conducted a radiological screening survey as a best management practice. The focus of this initial survey was the yellow- and green-stained soils in the former evaporation pond. The survey was performed using two types of instrumentation: (1) a crutch scintillometer capable reading gamma radiation and (2) a hand-held frisking instrument capable of reading gamma and beta radiation. The survey was performed by walking the area with the crutch scintillometer to identify areas of elevated gamma activity and placing the hand-held instrument directly above the soil to obtain a rough estimate of gamma and beta radiation in disintegrations per minute. The equipment used to conduct this screening-level survey was not appropriate to determine quantitative estimates of radiation. The main purpose was to determine the general level of radioactivity being emitted from the surface soils and to quickly screen the site for elevated radioactivity being emitted from surface soils outside the former evaporation pond. Besides the former evaporation pond, no other areas of the site exhibited elevated radioactivity levels. Table 4–2 provides a summary of the radiological scanning performed in March and April 2010 and the associated findings.

Table 4–2. Summary of March–April 2010 Screening Level Radiological Scanning Efforts and Findings

Scan Date	Instrument/ Specificity	Area(s) Scanned[a]	Findings	Comments
3/23/2010	Initial (screening) scan: Mt. Sopris Model SC132 ("crutch") scintillometer (gamma only)	Lower (southern) portion of former evaporation pond coinciding with phytoremediation test area and stained-soil areas (as shown in Figure 1–3)	Several areas with elevated (i.e., above background) gamma activity were identified in the southern portion of the former evaporation pond	The focus of this initial survey was the yellow- and green-stained soils in the former evaporation pond. In areas measurements exceeded background, some soils were stained (yellow or yellow-green, and in some cases gray), but some were not.
	Eberline Frisker[b] Model FH40G-L, FHZ732 Probe alpha/beta/gamma (α, β, γ)	Elevated areas confined to the teardrop-shaped area (as shown in Figure 1–3).	This was used to confirm the gamma scans. Although this instrument shows values in disintegrations per minute, it does not accurately depict radiation levels from a soil matrix.	

Scan Date	Instrument/ Specificity	Area(s) Scanned[a]	Findings	Comments
4/13/2010	Scintillometers (see above)	To address all areas potentially accessed by site personnel, the survey covered the entire former evaporation pond and all irrigated phytoremediation study areas (as shown in Figure 1–3).	A few more areas of elevated gamma activity (although of less magnitude than initial) were identified north of the initially identified teardrop-shaped area.	The focus of this survey was to better delimit the other areas of the site with elevated gamma activity and to more extensively evaluate the former evaporation pond.
	Eberline Frisker Model FH40G-L with FHZ732 Probe	Elevated areas in the northern portion of the evaporation pond (as shown in Figure 1–3)	Although this was used to confirm the gamma scans, it was not the appropriate instrument to yield quantitative radiation levels from soil.	

[a] The initial scan covered a broad area with the crutch scintillometers—these instruments are typically used to perform quick, large-area surveys. Once elevated levels were identified, the Ludlum Frisker (FH40G-L) was used. For all areas, the scan was performed on approximately 6–10-ft transects at normal walking pace.

4.3 Analytical Results of Soil Samples Collected March 22, 2010

As a follow-up to the results from the University of Arizona soil sampling, DOE collected additional soil samples from the former evaporation pond. Samples were collected from the same area where the University of Arizona collected the yellow- and green-stained soils. Discolored surface samples were collected, and soils up to a depth of 6 feet were also obtained. The analytical results were obtained on April 14, 2010. Table 4–3 summarizes the results, conversions of chemical to radiometric uranium (pCi/g), and some calculated values.

Table 4–3. Uranium and Vanadium Concentrations Measured in April 14, 2010, Soil Samples

Sample Number	Uranium (mg/kg)	Uranium (pCi/g)[a]	Uranium (pCi/g)[b]	Vanadium (mg/kg)
CS-1	300	204	275	1,200
CS-2	1,500	1,020	985	1,000
CS-3	100	68	72	1,700
CS-4	430	292	388	680
CS-4-3	84	57	57	1,300
CS-5	400	272	264	930
CS-5-3	70	48	31	1,000

Note: Sample numbers are denoted as CS-X, with X being the number 1 to 5. In cases where the sample number is denoted as CS-X-3, the samples were taken 3 inches below the surface. All other samples were taken at the surface. At each location, soil samples were taken on the surface and at 3 inches, 6 inches, 1 ft, 3 ft, and 6 ft below the surface. The samples were placed in bags, and all bags were scanned for gamma radiation; only bags with elevated radiological readings were sent for laboratory analysis. This approach resulted in the highest likely values for each sample location.
[a] Calculated from chemical uranium values.
[b] Measured ^{234}U plus ^{238}U.

The samples were also sent for isotopic analysis, as summarized in Table 4–4.

Table 4–4. Radiometric Results

Sample Number	Uranium (pCi/g)[a]	^{234}U (pCi/g)	^{238}U (pCi/g)	Ratio of ^{234}U to ^{238}U (pCi/g)	^{230}Th (pCi/g)	^{226}Ra (pCi/g)
CS-1	275	133	142	0.94	10.8	1.67
CS-2	985	488	497	0.98	26.4	1.59
CS-3	72	36.4	35.6	1.02	3.32	1.62
CS-4	388	194	194	1.00	16.9	0.883
CS-4-3	57	29.3	27.7	1.06	0.347	1.15
CS-5	264	129	135	0.96	5.87	1.50
CS-5-3	31	15	15.7	0.96	1.02	1.12

[a]Measured ^{234}U + ^{238}U

Data Interpretation

- Chemical uranium concentrations are reasonably close to concentrations from radiometric analyses (Table 4–3, columns 3 and 4). The differences are likely due to the relatively high reported uncertainties in the radiometric data (values not shown here but provided in the analytical report). This observation provides an element of confidence in using the radiometric results for the following interpretations.

- $^{234}U/^{238}U$ ratios (Table 4–4, column 5) are very nearly 1.0. Ratios near unity are characteristic of uranium ores. These ratios are also consistent with tailings. Ratios of unity are also possible in natural settings and in a situation where uranium is dissolved from rock and redeposited. Thus, at first glance, it doesn't seem as if the U isotopic ratios can be used to distinguish possible sources of the uranium in these soils.

- Activities of ^{230}Th and ^{226}Ra (Table 4–4, columns 6 and 7), both of which are in the ^{238}U-^{234}U decay scheme, are far less than the activities of ^{238}U and ^{234}U (Table 4–4, columns 3 and 4) indicating a non-equilibrium condition. The uranium ores milled at Monument Valley are old in geologic time and would have near equilibrium isotopic ratios due to radiometric ingrowth, provided no additions or depletions occurred from chemical transfer. Thus, it is expected that ^{230}Th and ^{226}Ra should be nearly in equilibrium with U isotopes if the uranium in the soils is due to solid ore particles. Tailings should have radiometric values of ^{230}Th and ^{226}Ra that are higher than ores, because the milling process selectively removes uranium. Thus, the thorium and radium data indicate that it is unlikely that the soils contain ore or tailings. In other words, the uranium and vanadium in the soils were deposited from solution and are not particulate remnants of ore or tailings.

- The molar concentrations of vanadium in the soils (Table 4–3, column 5) far exceed the molar concentrations of uranium (Table 4–3, column 2). The solutions that deposited the uranium and vanadium likely had higher concentrations of vanadium than uranium or the uptake by the sediments favored vanadium.

- The concentrations of uranium (up to 1500 mg/kg) and vanadium (up to 1700 mg/kg) in the soils are relatively high. Average crustal abundance of uranium is 1.8 mg/kg and vanadium is 135 mg/kg. The highest concentration of uranium (0.15 %) approximates that of low grade uranium ores.

4.4 Gamma Spectroscopy Semiquantitative Soil Sample Collected April 20, 2010

Radiological technicians visited the site and collected a surface soil sample for gamma spectroscopy analysis on April 20, 2010. This sample was selected from an area exhibiting high gamma readings using a scintillometer, and it was intended to show worst-case results. The analysis was done at the DOE, Environmental Management Office in Moab, Utah.

Review of the spectrum indicates that the gamma activity in the sample is due to uranium-238, uranium-235, and progeny nuclides[1]. Background concentrations of potassium-40 and radium 226 were found to be present, but no other gamma-emitting nuclides are evident based on this spectra analysis. The uranium concentration was estimated to be 790 pCi/g. The concentration is estimated by comparison to a uranium reference material. In addition to uranium, the gamma spectroscopy analysis showed a radium concentration of 0.1 pCi/g. The results reported should be considered semiquantitative, since certified, traceable standards were not used for calibration. Although these results are semiquantitative, they are similar and offer some confirmation of the analytical results from the soil samples collected on March 22.

[1] Progeny nuclides from U-238 are thorium-234, protactinium-234, and protactinium-234m; those from Ra-226 are bismuth-214 and lead-214.

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5.0 Risk Evaluation

Preliminary calculations were performed to evaluate the potential dose to workers from the uranium isotopes identified in the area of the former evaporation pond at the Monument Valley site. Two types of calculations were developed: (1) a deterministic calculation that results in one dose estimate and (2) a probabilistic calculation that provides bounding estimates using a distribution of potential input parameters for the most sensitive (important) calculation inputs. In both cases, the dose calculations were developed using numerous default parameters and conservative exposure assumptions. Dose calculations were performed using computer software that is widely accepted for this purpose (See Section 5.1). In addition to the technical approach in Section 5.1, Section 5 also includes a discussion of the assumptions (Section 5.2) and the results (Section 5.3).

5.1 Technical Approach or Methodology

The basic premise of risk assessment is that a receptor (person, animal) comes in contact with, or is exposed to, a contaminated medium (water, soil, air). Effects of this exposure will be dependent on the length, frequency, and amount of exposure (one time, every day, large or small volume); the manner in which the contact occurs (e.g., ingested, inhaled, or absorbed through the skin); and the toxicity of the contaminant. The exposure scenario, exposure pathways, and exposure assumptions are tailored to the site-specific conditions and activities being evaluated. The outcome of this evaluation is the estimated dose to the radiological constituents at a site, which can then be compared to established dose levels that are considered to acceptable to workers or members of the general public.

All dose calculations for this evaluation were performed using RESRAD (Version 6.5)[1], a code developed by Argonne National Laboratory (ANL 2001) used to estimate potential risks from radiological contaminants. This code has undergone extensive verification and validation and has been used by DOE, EPA, other federal agencies, and by academia to estimate potential risks from radiological contaminants.

As mentioned, both deterministic and probabilistic risk assessments were used to estimate potential doses to workers at the site. Deterministic risk assessments provide a single point estimate of risk using a single value for each of the input parameters. Probabilistic risk assessments generate a range of values from probability distribution functions. The primary advantage of a probabilistic evaluation is that it quantifies the degree of variability or uncertainty in the dose estimates. In RESRAD, this type of analysis uses a range of assumptions (focused on exposure) as input to thousands of individual dose estimations to come up with possible distributions or ranges of dose.

[1] RESidual RADioactivity (RESRAD) model and computer code, Argonne National Laboratory, October 30, 2005 (http://web.ead.anl.gov/resrad/home2/).

5.2 Assumptions

5.2.1 Exposure Pathways Evaluated

The Monument Valley site is in a sparsely populated area. Access to the site is limited to workers who maintain the irrigation system and care for the plants in the phytoremediation plots. The climate is arid; average annual precipitation is 6.4 inches. There are no known threatened or endangered species at or near the site, so this evaluation focuses on risks to human health.

After human exposure scenarios are conceived, the second key element to be considered in constructing representative exposure models is determining which pathways are potentially complete from source to receptor. The conceptual pathway model in RESRAD includes all conceivable pathways for human exposure to residual radioactivity associated with a site; a specific dose calculation is done by matching the applicable pathways to the scenario being evaluated (site workers).

Table 5–1 identifies the pathways that have been retained for the analysis and provides an explanation for those pathways that were not retained.

Table 5–1. Exposure Pathways Evaluated in this Risk Evaluation

Pathway	Retained	Comments
Direct Exposure	Yes	The source term found in the surface soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall potential dose of workers at the site.
Particulate Inhalation	Yes	A potential pathway is for surface soils containing uranium isotopes to be liberated (via wind) and suspended in the breathing air of site workers.
Radon	No	The uranium in the surface soils is not a significant producer of radon. Moreover, the work at the site would not involve confined spaces or building structures where radon gas and associated daughter radionuclides would be expected to reach equilibrium concentrations.
Plant Ingestion	No	This site does not contain edible plants.
Drinking Water	No	This exposure scenario addresses surface soils only.
Meat Ingestion	No	This exposure scenario addresses surface soils only.
Milk Ingestion	No	This exposure scenario addresses surface soils only.
Aquatic Foods Ingestion	No	This exposure scenario addresses surface soils only.
Direct Ingestion	Yes	Site workers may ingest relatively small amounts of sediment through incidental contact with their hands.

5.2.2 Exposure Assumptions

A combination of default values from RESRAD and conservative exposure parameters were used to estimate dose. Table 5–2 presents the key parameters for the deterministic estimate, and Table 5–3 presents the key inputs for the probabilistic estimate.

Table 5–2. Most Sensitive Parameters Used to Model Dose Using the Deterministic Approach

Parameter	Units	Default Value	Modeled Value	Remark
Area of Contaminated Zone	m^2	10,000	325	Assumed a circular area of exposure. This was the approximate area found to have elevated gamma readings in the former evaporation pond.
Isotope Concentration in Soil	pCi/g	NA	500	Based on the recent isotopic data for uranium, 500 pCi/g (rounded value) was used for uranium-234 and uranium-238. This was consistent with the highest value found on site. As a worst-case assumption, all exposure is assumed to occur over an area having the highest on-site value.
Mass Loading Available for Inhalation	g/m^3	0.0001	0.0001	RESRAD default.
Depth of Contamination	m	2	2	RESRAD default. This default parameter was retained, although the highest levels of contamination appear to be in the surface soils.
Indoor Time Fraction	unitless	0.5	0.0	The exposure scenario is for a site worker; no exposures will occur indoors.
Outdoor Time Fraction	unitless	0.25	0.001	This parameter is the fraction of a total year spent outdoors exposed to elevated levels of uranium at the site. Exposure occurs only when the worker is on the area that has elevated levels of gamma radiation. Based on the time a site worker may spend in these areas in the former evaporation pond, it was assumed they would be there one day a month for one hour during the day. This corresponds to an annuitized exposure of 12 hours/year out of 8760 hours per year, or a yearly fraction of 0.001 (rounded). This value is conservative, since the areas with elevated gamma radiation (high isotopic uranium values) occur in a very small area compared to the total site area. A worker will spend nearly their entire day on site in areas that do not have elevated levels of uranium-234 and uranium-238.

m^2 = square meters
g/m^3 = grams per cubic meter

Table 5–3. Most Sensitive Exposure Parameters Used to Model Dose Using the Probabilistic Approach

Parameter	Units	Default Value	Range Modeled	Remark
Area of Contaminated Zone	m^2	10,000	100–40,000	Assumed a log uniform distribution of values. The estimated value from the gamma scans was 325 m^2. A log uniform distribution emphasizes higher-end values (more worst-case); the high range of this distribution is more than two orders of magnitude greater than estimated value.
Isotope Concentration in Soil	pCi/g	NA	566–605	Specific values from recent isotopic data for uranium-234 (605 pCi/g) and uranium-238 (566 pCi/g). These were the highest values found on site. As a worst-case assumption, all exposure is assumed to occur over an area having the highest on-site values for these isotopes.
Mass Loading Available for Inhalation	g/m^3	0.0001	0- 0.0001	RESRAD default value of 0.0001 g/m^3 is considered to be a worst-case value. A continuous linear distribution of values was assumed, with 0 g/m^3 being the low end of the distribution (no or very low wind).
Depth of Contamination	m	2	0.01–2	Assumed a lognormal distribution. In this case to better approximate field conditions (contamination in the surface soils), the RESRAD default was used as the upper part of the range.
Indoor Time Fraction	unitless	0.5	0.0	The exposure scenario is for a site worker; no exposures will occur indoors. A distribution was not used since it is known to be 0.
Outdoor Time Fraction	unitless	0.25	0.0014–0.047	This parameter is the fraction of a total year spent outdoors exposed to elevated levels of uranium at the site. Exposure occurs only when the worker is on the area that has elevated levels of gamma radiation. Based on the time a site worker may spend in these areas in the former evaporation pond, it was assumed they would be there one day a month for one hour during the day. This results in an annualized exposure of 12 hours/year out of 8760 hours per year, or a yearly fraction of 0.0014. To provide a worst-case analysis, the estimated annualized exposure was assumed to be the low end of the range for this parameter. A triangular distribution was used for this parameter. The high end of this distribution range equates to 412 hours of exposure per year (over an hour per day).

m^2 = square meters
g/m^3 = grams per cubic meter

5.3 Results

Dose estimates are compared to established benchmarks to evaluate if the contaminants at a site pose an unacceptable dose to the exposed population. Both public and occupational dose limits are set by federal agencies (i.e., EPA, NRC, and DOE). A widely accepted dose to members of the general public is 100 millirem per year (mrem/yr), as established by NRC. NRC has also established a more conservative criterion for site decommissioning of 25 mrem/yr. For the purposes of this assessment, calculated risks will be compared to the more conservative (protective) value of 25 mrem/yr.

The deterministic risk evaluation yielded a maximum dose of 0.0811 mrem/yr, which is well below the 25 mrem/yr benchmark. The results for the probabilistic evaluation are presented in Table 5–4.

Table 5–4. Dose Estimates Using the Probabilistic Approach in RESRAD

Result Type	Dose (mrem/yr)	Benchmark (mrem/yr)	Comments
Minimum	0.14	25	Result is similar to the deterministic approach, demonstrating the conservative input parameter distributions used in the probabilistic risk evaluation.
Mean	1.7	25	Most likely result; dose is approximately 15 times lower than the benchmark.
Maximum	3.7	25	Worst-case result; dose is still approximately 7 times lower than the benchmark.

This risk assessment demonstrates that the elevated levels of uranium-234 and uranium-238 found in the former evaporation pond at the Monument Valley site are well below established benchmarks and do not pose an unacceptable dose to site workers.

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6.0 Summary

- The site was remediated from 1992 to 1994. All areas of the site, including the former evaporation pond, were verified clean under the UMTRCA surface soil cleanup standard of 5 pCi/g Ra-226 and the subsurface standard of 15 pCi/g. NRC approved the Monument Valley cleanup on April 5, 2001.
- Initial radiological characterization studies (e.g., DOE 1985) indicated that the evaporation pond had the highest concentrations of radium at the site. Locations with highest concentrations coincide closely with the areas where elevated levels of radioactivity were observed based on both recent sampling and radiological scans. Therefore, the evaporation pond probably represents worst-case conditions in terms of contamination. Post-cleanup verification studies, as corroborated by NRC (2001) indicate that cleanup commitments were fulfilled.
- The plants in the area of the former evaporation pond had a poor growth rate compared to those in other areas of the site. In the summer of 2009, DOE contractor personnel noticed surface soils in the former evaporation pond with yellow and green stains. Samples of the stained surface soils were collected and sent to a laboratory for an analysis, the results indicated that the soils have elevated levels of uranium and vanadium. As a best management practice, DOE conducted a radiological screening because of the higher-than-expected uranium results. The survey was performed by walking the area with the crutch scintillometer to identify elevated gamma activity, and then rechecking with a radiological frisker. The results indicated higher-than-anticipated gamma levels in the former evaporation pond; other areas of the site did not have elevated gamma activity.
- As a follow-up to the radiological screening, soil samples from the former evaporation pond were sent to a contract laboratory for isotopic analysis. The results indicated measured values for uranium-234 plus uranium-238 from 31 to 985 pCi/g. The ratio between uranium-234 and uranium-238 was consistently close to 1. The concentrations of thorium and radium were much lower than those of uranium. The highest measured value for radium was less than 2 pCi/g.
- To ensure that workers have not been exposed to excessive dose levels from isotopic uranium in surface soils, risk calculations were performed using RESRAD. RESRAD is a widely accepted tool used to estimate risks from radiological constituents. Risks were estimated using an allowable exposure rate of 25 mrem per year, the highest measured results for the isotopes of uranium, and very conservative exposure assumptions. The results indicate that risks are well below the allowable exposure rate of 25 mrem per year.
- Residual uranium exists, but this does not this imply a deviation from DOE's commitments under UMTRCA.

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