EVALUATION OF THE FINAL RADIOLOGICAL STATUS OF THE WATERTOWN GSA SITE

WATERTOWN GSA SITE
670 ARSENAL STREET
WATERTOWN, MASSACHUSETTS 06095

Prepared for:

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers, New England District (CENAE) has contracted Harding ESE to evaluate the existing radiological data from the Watertown GSA Site located at 670 Arsenal St., Watertown, Massachusetts (GSA Site or Site). The evaluation was performed to identify data gaps in the existing radiological data relative to the recently developed soil DCGL for the Site (Harding ESE, 2001a). This report documents the data gap analysis performed and presents the final radiological status of the Site prior to release from radiological controls under the U.S. Nuclear Regulatory Commission's (NRC) Site Decommissioning Management Plan (SDMP) program.

The GSA Site was used by the U.S. Army in support of operations at the nearby Watertown Arsenal facility. At the Arsenal, the Army conducted munitions research and development using depleted uranium (DU) starting approximately in the mid 1950's. Scrap DU from the Arsenal was collected and transported to the GSA Site where it was placed in large bins and ignited in order to chemically stabilize and reduce the volume of the depleted uranium waste. The burning operations were conducted on a concrete pad (since removed) in what is now termed survey unit GSA-03 near the north end of the Site. Based upon extensive research as well as solid analytical evidence, it is believed that no other uses of or operations at the Site involving radioactive material were undertaken. The buildings located at the southern, paved end of the Site predate the use of depleted uranium at the Arsenal, indicating that the land beneath the buildings is unimpacted.

A Historical Site Assessment (HSA) was performed by Harding ESE in 2000 (Harding ESE, 2000). Final Status radiological surveys of the buildings on the Site were performed by Morrison Knudson (MK) in 1994, demonstrating that the buildings on site met the unrestricted release criteria for residual surface radioactivity (NRC, 1974).

Four sampling and measurement events have been completed at the Site since 1981. The first, performed by Argonne National Laboratory (ANL), was performed to identify the highest concentrations of residual uranium activity in soil at the Site and was completed prior to any extensive remediation. The second was performed by Chem-Nuclear Systems, Inc. (CNSI) as a comprehensive site characterization in support of their remedial efforts. These surveys and samples were also biased to the identification and demarcation of the highest uranium activity in soil. CNSI performed extensive remediation in the burn area, removing the most highly contaminated soils and debris. The third, and most robust, data set is derived from the sampling and surveys performed by MK. MK performed further remediation of the Site including those areas identified by ANL and CNSI as having activity in excess of the then approved soil limit (35 pCi/g) but particularly in and around the burn area. MK survey and sampling data is a mixture of judgment sampling (biased to locations with highest activity), systematic grid sampling, and random sampling.

The forth sampling and measurement event was completed by Harding ESE in 2002 (Harding ESE, 2002). This sampling event was a focused uranium tailings investigation that included biased sampling in four areas where it had been theorized by ANL and/or MK that the presence of uranium tailings in soils at these locations might be responsible for isotopic anomalies and

slightly elevated gamma exposure rates encountered in these areas. Harding ESE's sampling confirmed the presence of slightly elevated gamma exposure rates near the north property line but showed that these were attributable to naturally occurring radioactivity (Harding ESE, 2002).

For the purpose of data evaluation and to ensure that data sets were appropriately treated, the Site was subdivided into 6 onsite survey units, plus one unit for offsite data collected from unimpacted areas around the site perimeter.

Table E-1. Summary of Survey Units

Survey Unit	Location / Description
GSA-01	Paved area at the south end of the Site
GSA-02	Central portion of the Site, known as the "clinker area"
GSA-03	The burn area
GSA-04	The fill area immediately north of the burn area
GSA-05	Western boundary area (Area between the property line and the fence)
GSA-06	Property 20 / North boundary area
Offsite	Areas around the perimeter of the Site

The design and interpretation of the final radiological status survey of the GSA Site is based on a weight-of-evidence approach in which individual data subsets from a given survey unit are compiled and compared with one another and the residual soil radioactivity release criterion (DCGL) derived for the Site (Harding ESE, 2001a). The DCGL established for the site is as follows:

- The average (median) total uranium residual radioactivity concentration in soil in each survey unit is below 340 pCi/g

The weight of evidence created by the wealth of radiological survey and sampling data in each of the 6 survey units demonstrates that the Site meets the DCGL established for the Watertown GSA Site. The data gap analysis concludes that, when considered on the whole, there are no significant data gaps in the existing data sets that warrant the collection of additional radiological data. The evaluation concludes that the final radiological status of the Watertown GSA Site meets the conditions and requirements for unrestricted radiological release and that it is acceptable to recommend that this Site be released from radiological controls without restriction and removed from the NRC's SDMP list.

1.0 INTRODUCTION

1.1 BACKGROUND

The General Services Administration (GSA) of the federal government currently owns the 11.9-acre parcel of land located in Watertown, Massachusetts and known as the "Watertown GSA Site". The Site was once owned by the Commonwealth of Massachusetts and was withdrawn by the federal government in 1920 for use by the U.S. Army, when the nearby Watertown Arsenal was in need of additional space. The Watertown GSA Site is located at 670 Arsenal Street in Watertown, and is bounded by Arsenal Street to the south, Greenough Boulevard to the east, Grove Street to the north, and properties abutting Coolidge Avenue to the west. The property was used for the support of various Arsenal operations. In 1967, the Army, having discontinued operations at the Arsenal and having no further need for the property, transferred the 11.9-acre parcel to the GSA (hence, the name Watertown GSA Site). The GSA has made several uses of the property since taking title but has also now determined that the property is excess to the needs of the federal government.

As a condition of the federal land withdrawal, a "reverter clause" was established. The reverter clause specifies that in the event that the land is no longer required for use by the federal government, that title rights to the property would be reverted to the original owner, the Commonwealth of Massachusetts. The reverter clause specifically designates the Commonwealth's Metropolitan District Commission (MAMDC) as the title recipient.

Past use of the Watertown GSA property by the U.S. Army involved the use of hazardous and potentially hazardous materials, most notably the oxidation, stabilization, and off-site disposal of depleted uranium scrap. Previous Site characterization activities have indicated the presence of detectable quantities of radioactivity in surface soils resulting from the deposition of depleted uranium (Harding ESE, 2000). The Site was listed under the Massachusetts Contingency Plan (MCP) as a Tier 1A Site and is subject to the MCP criteria for de-listing and release. In addition, the U.S. Nuclear Regulatory Commission (NRC) identified the Watertown GSA Site as a Site Decommissioning Management Plan (SDMP) Site, thus invoking their authority to regulate the residual radioactivity at the Site. The Massachusetts Department of Public Health (MADPH) also regulates residual radioactivity on the Site resulting from former operations involving depleted uranium.

To dispose of this property, the potential human health impacts associated with exposure to hazardous materials originating at the Site must be evaluated and demonstrated to be within acceptable limits. To comply with the MCP, the response actions conducted at this Site shall ensure a level of control of each identified substance such that no substance of concern shall present a substantial hazard or significant risk of harm to health, safety, public welfare, or the environment during any foreseeable period of time.

The evaluation of potential risks posed by substances present at the Site is being carried out on two parallel tracks. Chemical contamination at the Site has been evaluated by a series of investigations. A Draft Final Supplemental Phase II Comprehensive Site Assessment (Harding ESE, 2001b) has been prepared based on the results of Harding ESE's chemical investigations.

The Phase II also evaluates ecological risks posed by the Site. Residual radioactivity at the Site is being addressed separately through a series of steps including:

1) The preparation and submission of a Historical Site Assessment (Harding ESE, 2000);

2) The derivation and approval of a risk/dose-based cleanup level (known as the derived concentration guideline levels or DCGL) (Harding ESE, 2001a); and

3) An evaluation of the measured residual radioactivity concentrations in soil on the Site in comparison with the approved DCGL (presented in this report).

1.2 DOSE-BASED RELEASE STANDARDS SITE STEERING GROUP

To facilitate the process of deriving the risk/dose-based concentration guideline for depleted uranium in soil at the Watertown GSA Site, CENAE commissioned the formation of a steering group comprised of technically competent individuals representing CENAE, the site regulators, GSA, and the Commonwealth of Massachusetts. The steering group has representatives from:

- CENAE
- Army Research Laboratory (ARL)
- US Army Corps of Engineers, Baltimore District
- Nuclear Regulatory Commission:
  - Region I
  - Headquarters
- GSA
- Commonwealth of Massachusetts:
  - Department of Public Health (MADPH)
  - Department of Environmental Protection (MADEP)
  - Metropolitan District Commission (MAMDC)
- Town of Watertown, Massachusetts

The steering group members include public health professionals and health physicists who are well versed in the details associated with the derivation of site-specific radionuclide concentration guideline values and responsible individuals appointed to represent the interests of their constituency. While the NRC retains the federal regulatory authority and responsibility to approve the criteria for the radiological release of the property, it is clear that CENAE, the U.S. Army, and the NRC desire the cooperative input from the identified parties and state regulators so that the decision is acceptable not only to NRC but also to the Commonwealth of Massachusetts and the impacted community.

1.3 PUBLIC INVOLVEMENT

In addition to the steering group's key role in facilitating the technical development of the site-specific DCGLs, CENAE has also sought to communicate the process and receive input from the affected public. A number of public outreach efforts have been employed to communicate the activities and decisions involving the Watertown GSA Site.

- A local citizen's Restoration Advisory Board (RAB) was already in place in support of the nearby Watertown Arsenal site being remediated as a Formerly Utilized Defense site (FUDS). CENAE chose to include the RAB in its public communication efforts for this site and has provided monthly status reports to the RAB on the activities and decision basis for the development of the site-specific DCGL as well as the ongoing efforts to establish compliance.

- CENAE sponsored two special presentations on the scientific basis, regulatory framework, and decision logic used at the GSA Site to derive the site-specific radionuclide DCGL. These presentations were held in conjunction with the monthly RAB meetings and were followed by an opportunity for the public to ask questions or comment on the process being used. Special effort was made to publicize these presentations to the local citizenry and particularly to those residing on abutting properties.

- The RAB has been notified of steering group meetings and invited to attend as observers.

- CENAE sponsored a GSA Site tour that was open to the public and specifically advertised to residents of the abutting condominium properties. The tour was followed by a monthly meeting of the RAB held at the Charles River Condominium complex to encourage and facilitate attendance by the local residents.

- Copies of documents submitted to regulators for review have been placed in the public reading section of the Watertown Public Library for members of the public interested in their content. Documents are routinely distributed to RAB members and discussed at subsequent RAB meetings.

1.4 REGULATORY FRAMEWORK FOR RELEASE OF THE SITE REGULATORY CONTROL

1.4.1 Nuclear Regulatory Commission Regulations

The regulatory criteria for license termination and release of real property with residual radioactive material under NRC jurisdiction are contained in the U.S. Code of Federal Regulations, Title 10, "Energy," Parts 20, 30, 40, 50, 51, 70, and 72, *Radiological Criteria for License Termination* (NRC, 1997).

The applicable NRC regulation is a performance-based standard that requires the responsible party (licensee) to demonstrate to a satisfactory degree that a member of the public potentially exposed to residual radioactivity at the Site will not receive an annual dose in excess of 25 mrem in any one year, having considered all credible sources and pathways for exposure.

Although the Watertown GSA Site is currently unlicensed, the license termination regulations will be applied.

1.4.2 State of Massachusetts Regulations

As an NRC agreement state, the Commonwealth of Massachusetts publishes regulations governing the licensure, control, and use of radioactive materials within the State. The MADPH administers the State's regulation, which includes a provision with the criteria for license termination and release of a site. The MADPH administered regulation is parallel to the NRC regulation. MADPH differs from the NRC in the annual dose criterion for unrestricted release: 10 mrem/y instead of 25 mrem/y.

The MADEP administers the MCP regulations. MADEP has determined that response actions for radionuclides are also governed by the MCP[1] (MADEP, 2000). The regulatory framework for releasing a site under the MCP criteria is fundamentally consistent with the NRC and MADPH regulatory framework. The principle conceptual difference is found in the basic measure of potential significant risk to human health. The MCP measures detriment on the basis of excess lifetime cancer risk (ELCR) for mortality. The acceptable ELCR under the MCP is on the order of 1×10^{-5}, or one in 100,000.

1.4.3 Approach to Deriving a Specific Property Guideline

Figure 1–1 below summarizes the overall approach used to establish the site-specific DCGL and determine whether the GSA Site meets the radiological release criteria. For the GSA Site, the first step to obtaining approval of a dose/risk-based limit was to establish the acceptable dose and risk limits.

The NRC post decommissioning dose limit is constrained by the maximum allowable annual dose from all sources (in excess of background radiation contributions) of 100 mrem/y. Since it is possible that public exposure may occur not only at a regulated Site, but also from other contributors, only a fraction of the maximum allowable dose is typically allotted to any single site. A number of federal regulations and agencies as well as nationally and internationally recognized bodies recommending safe levels for public exposure (ICRP 1990, NCRP 1993) specify the total radiation dose contribution of 100 mrem/y. Within the jurisdiction of the NRC, the fraction allotted to a single site is specified in regulation. The MADPH also has specified an allowable fraction to be allotted to the GSA Site. A third limit, human health risk as measured by ELCR resulting from human exposure to radionuclides, is also required for this Site. The GSA Site compliance limits for unrestricted release and reuse are:

- 25 mrem/y—NRC
- 10 mrem/y—MADPH
- ELCR on the order of 1×10^{-5}—MADEP

1 The GSA site was listed as a Tier 1A site under the provisions of the MCP based on constituents other than radionuclides. Nonetheless, MADEP has determined that the human health risk criteria of the MCP apply also to the radionuclides on the site. In a letter iterating the State's position (MADEP, 2000), MADEP determined that excess lifetime cancer risk from radionuclides (excluding background) should be considered but independently from the risk associated with other (non-radioactive) contaminants of concern present on the site.

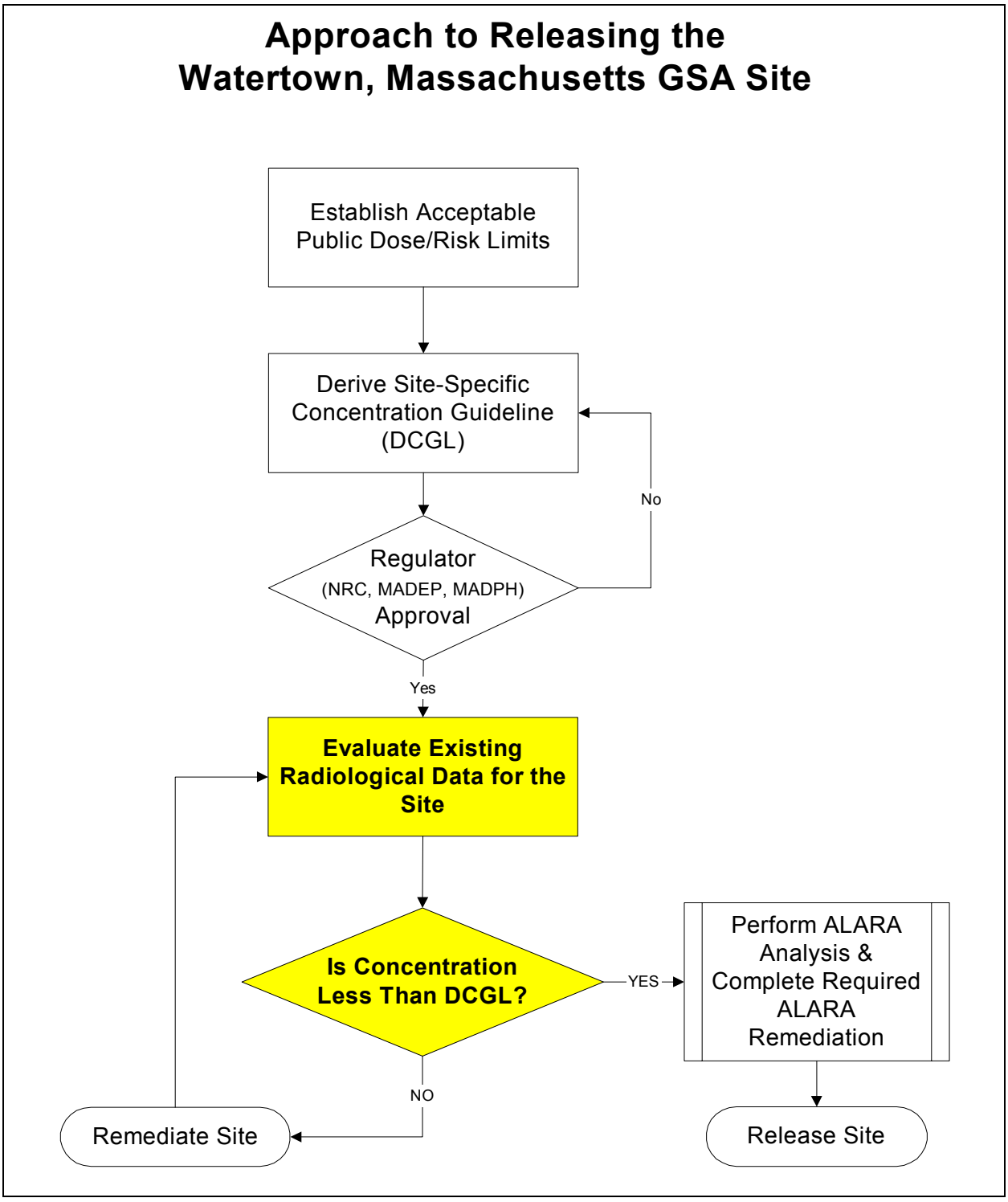


Figure 1-1. Approach to Releasing the Watertown GSA Site

With these dose and risk limits in hand, computer modeling codes were used to ***derive*** a concentration-based ***site-specific guideline*** that is protective of each of the dose/risk limits established. A concentration-based guideline is critical since future potential dose or projected ELCR are measures of predicted future significant risk to human health, which cannot physically be measured. On the other hand, a media specific concentration derived from the expected future human exposure scenarios can physically be measured.

The Watertown GSA Site-specific DCGL for residual depleted uranium activity in soils was approved in September 2001 by each of the regulating agencies. The approved site-specific soil DCGL at the Watertown GSA Site is 340 pCi/g Total Uranium.

The final step is to evaluate the available data collected from the Site to determine whether the residual concentration of depleted uranium radioactivity in soil is, with an acceptable degree of confidence, at or below the permissible concentration.

1.5 EVALUATION OF THE RADIOLOGICAL STATUS OF THE SITE

This report documents the radiological status of the Watertown GSA Site and serves as the basis for the regulatory decision to remove the Site from the SDMP list and to complete a Response Action Outcome (RAO) for the radiological constituents at the Site in accordance with the MCP criteria.

This report evaluates the radiological data collected in four separate sampling events and by four different contractors from August 1981 through September 2002. The data set includes data collected at the Site prior to the Site remediation efforts and data collected across the Site following the last remediation efforts undertaken in 1993 and 1994. The three principle data sets used in this evaluation are:

- Argonne National Laboratory (ANL) Site Characterization (ANL, 1984)
- Chem-Nuclear Systems, Inc. (CNSI) Comprehensive Site Assessment (CNSI, 1990)
- Morrison Knudsen (MK) Radiological Characterization and Final Survey Report (MK, 1996)

The ANL data set was collected prior to remediation activities initiated by the CENAE. Data collected by CNSI and MK is a combination of data collected before and after remedial efforts performed at the site and is thus more indicative of current residual radioactivity concentrations. A small data set collected by Harding ESE in September 2002 is also considered in this evaluation (Harding ESE, 2002).

1.5.1 Data Evaluation Methodology

Because there is a wealth of previously collected data from the Site, CENAE, NRC, MADEP, and MADPH agreed early in the decontamination and decommissioning process to utilize the

existing radiological site data to the maximum extent possible in determining whether the Site met the approved release criterion.

As indicated, the available data have been compiled over several sampling events and include many different types and analytical measures of the uranium activity present in soils on the Site. Statistical limitations on the combining of data prevent the use of a classic statistical evaluation of the data as a single data set. Subsets of the data are, in some cases, insufficient when taken alone to provide risk managers with an adequate assessment of the concentration of residual radioactivity in soil needed to arrive at a confident and defensible decision. Yet, much of the data collected at the Site was biased toward identifying and characterizing the locations on the Site having the highest concentrations of residual radioactivity. When several of these subsets of the data are independently evaluated in the context of the approved soil DCGL, the risk manager is able to consider the totality of the available evidence in a quantitative, if not statistically rigorous, manner. Such an approach is akin to that used in the medical sciences in which a series of studies evaluating a cause and effect are done. Individual studies, taken alone, may not have the statistical power to draw definite conclusions. However, when a series of such studies consistently point to a certain conclusion, the weight of the evidence is used to draw a conclusion. Such an approach has been used in evaluating the radiological data from the Watertown GSA Site.

This data evaluation approach presents a clear and unambiguous picture of the radiological condition of the Site relative to the approved soil DCGL.

1.6 SAMPLING AND SURVEY REPORT ROAD MAP

Following this introductory background, Section 2 presents a brief discussion of the Watertown GSA Site history and a description of the data subsets that have been collected at the Site. Section 3 presents the decision framework including a description of the survey units considered. Section 4 presents summary statistics of the sampling results for each subset of data and evaluates these in the context of compliance with the DCGL. Section 5 provides an analysis of whether uranium concentrations are As Low As Reasonably Achievable (ALARA). Section 6 summarizes the assessment of the concentrations of residual radioactivity found in soils at the Site, and offers conclusions and recommendations for release of the Site from regulatory controls. Appendices are included to provide additional detail where appropriate.

2.0 SITE HISTORY & DESCRIPTION

2.1 LOCATION AND SETTING

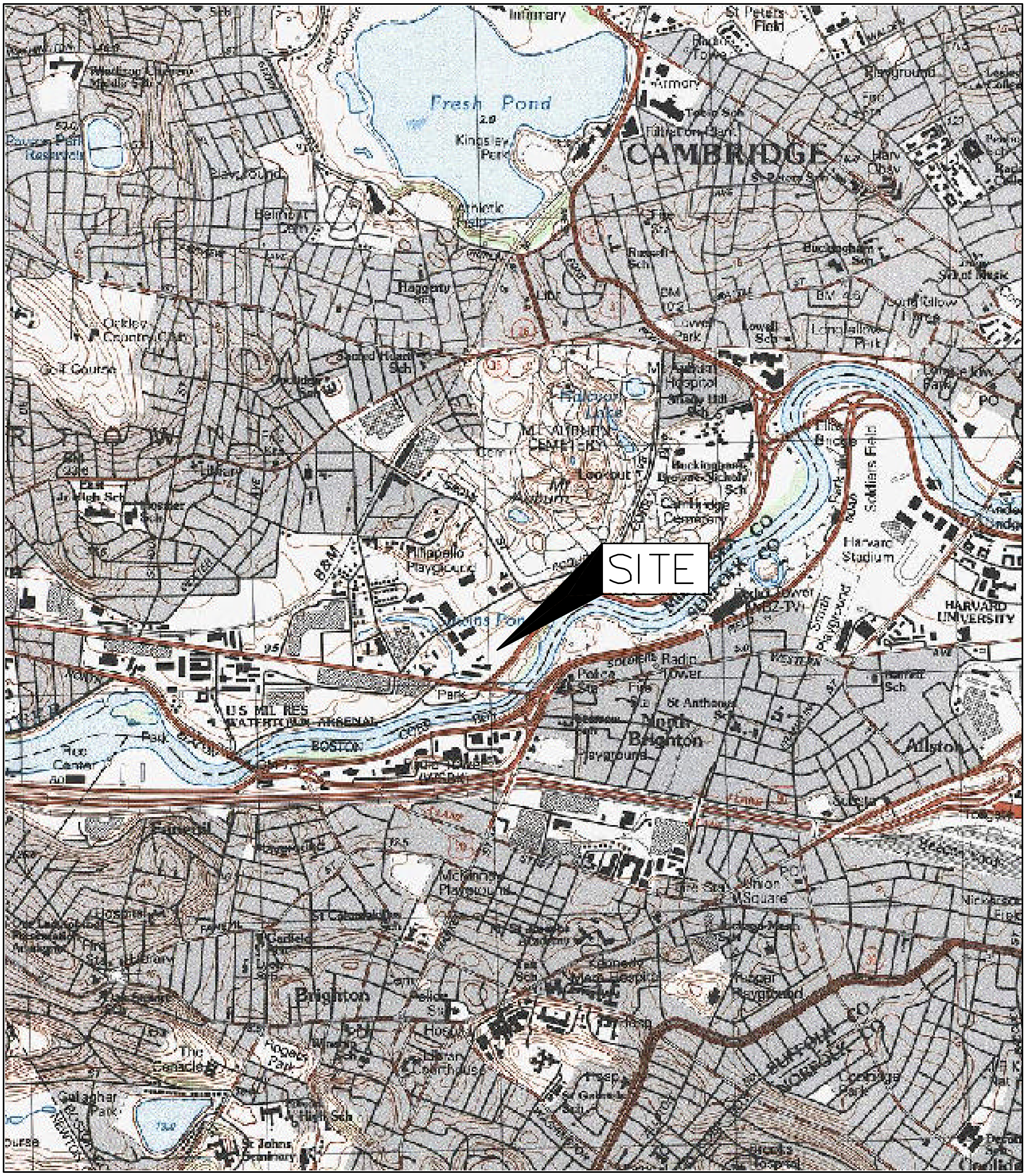
The Watertown GSA Site (hereafter referred to as the Site) is located at 670 Arsenal Street in the eastern portion of the town of Watertown in Middlesex County, Massachusetts (Figure 2–1). The Site is located on an elongated north-south trending tract of approximately 12 acres separated from the Charles River to the east by Greenough Boulevard. The Site is situated among degraded urban wetland areas on three sides. The Site is part of the U.S. Army's former Watertown Arsenal, but located north of the former main Arsenal complex. The Site contains the 11.91 acre GSA property parcel and a small portion (approximately 0.1 acres) of the MAMDC-owned parcel known as Property 20, which adjoins the GSA Property on the north. The Site is bounded on the north by Grove Street, on the south by Arsenal Street, on the east by Greenough Boulevard, and on the west by privately held properties facing Coolidge Avenue (Figure 2-2).

2.2 SITE HISTORY

The pertinent site history begins with the acquisition of the property by the Federal government. In March of 1920, the Commonwealth of Massachusetts transferred the 11.91 acres that comprise the GSA property to the United States for the use of the Department of the Army with a quitclaim deed (ABB-ES, 1993). In the ensuing years, the Army developed the Watertown Arsenal Complex, primarily on the Army Materials Technology Laboratory (AMTL) and FUDS properties, south of the Watertown GSA Site. Historical documents indicate that the Site was filled, primarily during World War II. Filling activities had reached the northern edge of the GSA property by approximately 1948, and the adjoining Property 20 was leased to the Army in June of 1948 (CNSI, 1990) in order to allow filling activities to continue. Historical documents and aerial photographs indicate the buildings at the southern end of the Site were constructed following World War II, prior to 1952. The Site was in use by the Army until June of 1967, when the Army transferred the property to GSA control[2].

Arsenal activities included the processing of depleted uranium for munitions. Most sources describe this use as having begun in the mid-1950s, although there is not complete agreement. The machining operations performed with DU at the Arsenal included grinding, milling, heat treating and melting, cutting, drilling, electrochemical plating, and polishing. The DU scrap was stored in barrels packed with cooling oil to prevent exposure to the air, since small particles of DU are pyrophoric. When filled, the barrels of scrap were transported from the main Arsenal property south of Arsenal Street to the GSA property where they were transferred to large steel bins. The 3½ feet wide by 6 feet long by 3½ feet deep bins were specially constructed of ½ inch steel plate designed to contain, stabilize, and dispose of the DU waste material (ABB-ES, 1993).

2 This Site history section is provided as a brief summary of the history and characterization of the Watertown GSA Site. Only those features directly applicable to the description of the site conceptual model and the derivation of the site-specific DCGL have been included. A detailed site history and compendium of past characterization efforts and results is contained in the report, *Historical Site Assessment, GSA Property, Watertown Massachusetts* (Harding ESE, 2000), prepared in October 2000.



SOURCE: TOPO, WILDFLOWER PRODUCTIONS

SCALE IN MILES 0 .5 1

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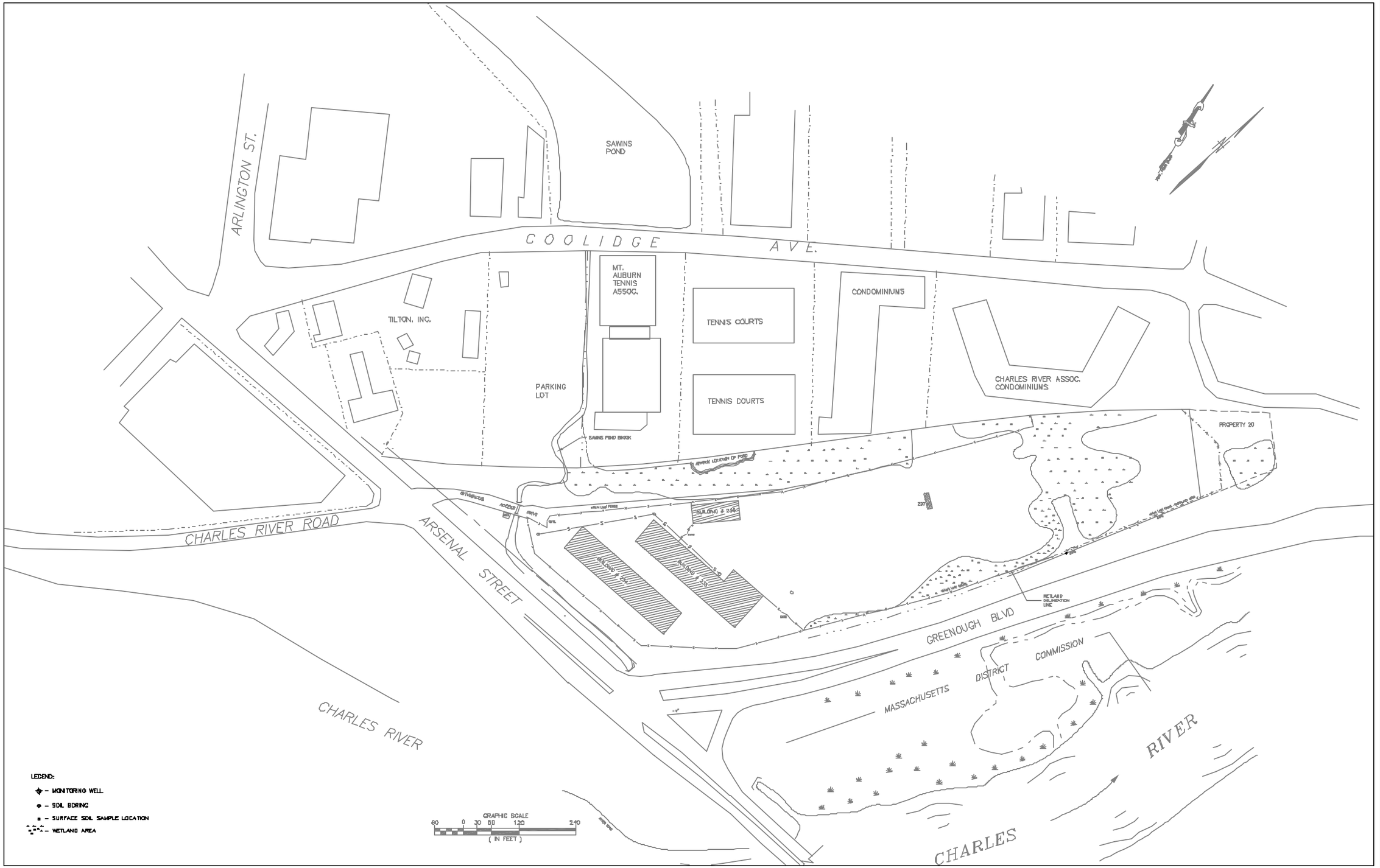
Harding ESE
A MACTEC COMPANY

FIGURE 2-1
SITE LOCATION
GSA PROPERTY
WATERTOWN, MA

GSA_EE.dwg



Harding ESE
A MACTEC COMPANY

FIGURE 2-2
GSA PROPERTY AND VICINITY MAP
GSA PROPERTY
WATERTOWN, MA

DRAWN MCR
FILE

GSA_A

An area in the northern portion of the GSA Property was designated for the stabilization of the DU turnings and waste generated by machining operations at the Arsenal. The "burn area" was provided with a concrete pad and a locked wire fence enclosure. When enough scrap DU had accumulated in the bins, the scrap was ignited and allowed to burn, converting the DU metal to a more chemically stable oxide form and reducing the waste volume. When the burn container was full of depleted uranium oxide, a top was welded on the bin, and the whole container was then shipped offsite for disposal (PAL, 1992).

Offsite disposal shipments of DU originating at the Arsenal are well documented and listed and provide no indication that DU waste materials were systematically disposed of on-site.

In 1968, the Site began to be used by GSA, other agencies, and private organizations following transfer of the Site from the Army. By 1981, the GSA; the U.S. Customs Service; the Bureau of Alcohol, Tobacco, and Firearms (ATF); the Internal Revenue Service (IRS); and the Drug Enforcement Administration (DEA) were all using the Site. Buildings on the Site were being used for storage, equipment maintenance, and a pistol firing range. An outdoor fenced area (the clinker area) was being used for storage of excess federal vehicles pending disposal at auctions, some of which were conducted at the property. In addition, the Federal Bureau of Investigation (FBI) used the Site as a Motor Pool, changing oil, repairing radios, and performing other related work. The DEA stored vehicles in one of the buildings, and the GSA and IRS stored miscellaneous materials such as lights, partitions, and bulk paper supplies. (NRC File Report, 1993, and CNSI, 1990).

The GSA also leased parts of the Site for use by private organizations. The fenced area immediately north of the buildings was leased to Oste Chevrolet and Peter Fuller from 1985 to 1988 for the storage of motor vehicles and mechanical work, and Building 237 was used for tire storage. Building 236 was leased to the television production company Spencer for Hire from 1986 to 1988. A pistol range was housed in Building 234 (CNSI, 1990), and decontaminated (non-radiological) in 1989 by Dennison Oil, under contract to GSA.

2.3 HISTORICAL PROCESS KNOWLEDGE

As already described above in Section 2.0, the historical knowledge of the operations conducted and the materials handled at the Site are well known. The suite of radionuclides found in depleted uranium is fixed by the physical and chemical processes used to produce DU and by the laws of physics describing radioactive decay. The same physical laws govern the relative concentrations of these radionuclides, making their proportions known with a high degree of certainty. Isotopically, depleted uranium does not vary substantially by batch or treatment process.

The deposition mechanisms likely include aerial dispersion of DU particles in relatively close proximity to the burn area and evidence that suggests non-discrete spillage of DU fragments. There is no evidence to support a supposition that discrete on-site disposal of DU waste has ever occurred at the Site.

2.4 CURRENT USE

The Site is protected by a locked chain link security fence and is not currently in use. The Site is heavily overgrown and not easily accessible.

The properties abutting the GSA Site are a mixture of recreational, residential, light industrial, and commercial areas. The area west of the Site is zoned for heavy industry, the area to the north is zoned residential, and to the east and the southeast the classification is open space conservancy. Upgradient properties along Coolidge Avenue contain light industrial and commercial uses, as well as two condominium complexes, a parking lot, and tennis courts. The area to the east of the Site contains recreational pedestrian paths and open and wetland areas (CNSI, 1990).

2.5 PREVIOUS CHARACTERIZATION AND REMEDIATION ACTIVITIES

A number of radiological characterization and remediation activities have been undertaken at the Site over the years. These efforts have yielded a well-defined understanding of residual radioactivity in soils of the Site in comparison to the site-specific DCGL. A brief summary of the characterization activities to date is provided below. Detailed descriptions of the characterization and remedial actions described below are contained in the report entitled Historical Site Assessment, GSA Property, Watertown, Massachusetts (Harding ESE, 2000) and the Focused Uranium Tailings Investigation Report (Harding ESE, 2002).

2.5.1 Army Characterization and remediation (1966-1967)

Arsenal personnel under the direction of the Army performed decontamination activities at the Site in late 1966. These activities included radiological surveys and soil removal. The area surrounding the burn pad was gridded and surveyed for radiological contamination. Contaminated soil (generally from the top 6 to 12 inches of surface soil) identified by the survey was collected using bulldozers and payloaders, placed in waste containers and shipped offsite to the Maxey Flats, Kentucky low-level radioactive waste disposal facility. Radiological survey and sampling data from this effort are determined to be of insufficient quality in their supporting documentation to be considered in this evaluation.

2.5.2 1973 Radiological Survey

Army Materials and Mechanics Research Center (AMMRC) personnel performed a follow-up radiological survey, the results of which are documented in a report from October of 1973. The survey was undertaken only within the burn area, and found measurable residual surface radioactivity levels. Surveys included penetrating radiation measurements, both on-contact and at 3 feet above the ground surface. The concrete pad in the burn area was surveyed for fixed alpha and beta-gamma surface activity levels. The burn area was surveyed for beta-gamma soil radiation levels, and soil samples were collected. An unknown quantity of soils and fill materials identified as contaminated were removed from the burn area and disposed of offsite. Subsequent samples indicated the highest uranium concentration in soil was 9.5 μg/g (approximately 3.8

pCi/g DU). The ground area surveyed measured 70 feet by 100 feet and included the 20 foot by 30 foot concrete pad.

As with the 1966/1967 projects, more specific detail on the surveying process is not available.

2.5.3 DOE-Argonne National Laboratory Radiological Survey of the Watertown GSA Site

Argonne National Laboratory (ANL) undertook a radiological survey of the Site in 1981 at the request of the Department of Energy. The survey consisted of several parts.

Surveys were performed to measure surface radioactivity levels on all accessible building surface areas, interior and exterior, of Buildings 234, 235, 236, and 237. No radiological surface contamination was detected on or in any building on the Site.

Direct reading portable instrument surveys were conducted over the entire Site. Within the burn area, elevated radioactivity was found at 13 locations and it was determined by subsequent mass spectrometric analyses of several samples that the contamination was due to DU.

A few localized spots in the area north of the burn area exhibited somewhat elevated radiation levels. The ANL report suggests that the slightly elevated levels may be the result of natural radioactivity in the fill material.

Soil samples were collected at representative locations, and subsurface soil sampling and borehole logging were performed at select locations. Throughout the Site, 23 soil corings were conducted in areas that had been identified by surface surveying as potentially contaminated. Soil core samples, 4 inches in diameter and 12 inches deep, were taken from selected undisturbed locations throughout the Site (Harding ESE, 2000). Soil core samples were sectioned and analyzed for uranium (uranium fluorometric) as well as radium and thorium decay chains (gamma spectral analysis). The segmented coring technique was used to determine whether any contaminant migration had occurred, to reduce the dilution of lower-level soil with the upper-level segments with respect to the surface deposition of the contaminants (or vice-versa), and to reveal whether any overburden or backfill had been added. In the top 6 inches of soil the cores were segmented into 2 inch lifts representing the 0-2”, 2-4”, and 4-6” depths below ground surface (bgs). The remaining (forth) segment of the core was collected from the section from the 6-12” lift bgs.

Most core samples indicated total uranium concentrations less than the DCGL. None of the samples showed elevated levels of radium or thorium as determined by gamma spectral analysis of the radium and thorium decay chains. Based on the absence of radium and thorium sub-chains, the residual radioactivity in soil was determined to be consistent with depleted uranium.

Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet, down to the groundwater table at the Site. Soil samples collected from several of the more radioactive soil boring samples were subjected to mass spectrometric analyses. These measurements were made to determine whether the radioactivity in the sample resulted from DU, as had been reported. All of the samples except one (a rock sample taken from an outcropping) were depleted in the U-235

isotope relative to U-238, confirming that the radioactivity in soil was due to DU. Elevated radiation levels in the rock outcropping sample were determined to be indigenous to the Site, having secular equilibrium concentrations of thorium, uranium, and radium isotopes expected for natural uranium.

2.5.4 Comprehensive Site Assessment Survey and Remediation, 1990

In 1990, Chem-Nuclear Systems Inc. (CNSI) conducted a study covering both chemical and radiological contamination with sampling focused on the residual radioactivity in the burn area.

The CNSI field investigation was conducted in accordance with the MCP requirements in effect at the time. The investigation consisted of:

- the installation of 31 shallow (10 to 17 foot) and 4 deep (48-51 foot) borings;
- installation of 11 shallow and 4 deep monitoring wells in selected borings to evaluate the aquifer and analyze the ground water quality in the two uppermost hydrologic units;
- groundwater sampling;
- marsh and sediment sampling;
- surface water sampling;
- a topographic elevation survey; and
- aquifer hydraulic conductivity tests.

Shallow soil borings were continued through an upper fill layer into an underlying peat and terminated at depths of 10 to 17 feet. Four deep borings were driven to depths of 48 to 51 feet, into the stratified sand layer beneath the peat, and completed as monitoring wells. Twenty shallow borings, B-1 through B-20, were completed solely to collect samples for radiological and or chemical analysis and geologic characterization of the shallow overburden. Eleven additional shallow borings were to facilitate the installation of shallow monitoring wells.

Samples were collected for total uranium analysis from each sample interval of all borings in which there was sufficient sample recovery. Samples collected by this field investigation in the burn area did not indicate elevated uranium levels at depths below the original undisturbed grade of the Site.

Groundwater sampling in the installed wells was performed to assess the nature and extent of possible groundwater contamination on the Site. Four ground water samples (three from shallow wells and one from a deep well) exhibited detectable total uranium concentrations at or near the expected background concentrations in groundwater. All other groundwater well samples were below detection limits. The groundwater detection of uranium occurred in areas removed from the burn area, while many samples collected in the immediate vicinity of the burn area contained undetectable concentrations of dissolved uranium. Together, these factors suggest that the depleted uranium residue on the Site (and notably the highest concentrations associated with the burn area) is not contributing uranium to the groundwater.

Sediment and surface water samples were collected at 4 marsh locations along Greenough Boulevard and at two locations in Sawins Pond Brook, one set of samples 20 feet down gradient

of the existing bridge and a second at the mouth of the culvert in the southwest portion of the Site, two days after a rainfall event. No detectable concentrations of uranium were found in any samples indicating that surface water runoff is an insignificant mechanism for transport of depleted uranium residue in on-site soils to areas offsite.

2.5.5 Radiological Characterization and Survey, January, 1993-1995

Morrison-Knudsen together with Scientific Ecology Group (MK/SEG) performed additional investigations in October and November of 1993, including characterization and termination surveys. At NRC's request, additional characterization and termination surveys were performed from August through December of 1994. These additional surveys included the riverbank of the Charles River to determine potential windborne DU contamination, Property 20 because of slightly elevated surface radiation levels that were measured on the property, and boundary areas due to residual radioactivity found outside the original burn area fence. In 1995, in-situ gamma spectroscopy surveys were conducted in boundary areas that had not been previously surveyed in 1994 due to inclement weather, and in large portions of the fenced Site interior. The final phase of MK/SEG work consisted of documentation of estimates made for background natural uranium, total uranium contamination at the Site, and potential groundwater contamination at the Site.

The continued excavation of the burn area confirmed that the material in and around the burn area was 6 inches to 2 feet of topsoil over 5 to 8 feet of construction debris. Debris terminated at an organic peat layer. The water table at the Site was determined to lie from 0 to 2 feet beneath the surface, depending on seasonal conditions. MK excavated large volumes of soil and debris from the burn area along with other areas that had been previously identified by ANL, CNSI, and MK/SEG. Excavation in the burn area was halted because of the possibility that the remediation effort might be spreading fine particle size DU.

A Gamma Exposure Rate Survey was performed on the GSA Property and in the building interiors. The gamma radiation was determined to be fairly uniform throughout the Site, with elevated areas near the center of the Survey Unit 2 (the "clinker area") at grid nodes E-16 through E-20 and near the access road on the southwestern edge of the Site at grid node L-3 (the grid for the entire Site is shown on Figure 4-1). Random soil samples showed the source of these elevated readings to be natural radioactivity.

Random soil samples were collected over the entire Site to provide an unbiased estimate of the soil concentration at the Site. Samples were collected at the surface and at 2 feet below the ground surface (bgs) and were analyzed by gamma spectroscopy. Average concentrations of all nuclides on the Site were found to be generally low, although, as expected, several samples contained elevated uranium concentrations but below the DCGL. MK/SEG results indicated that contamination by DU is higher on the surface than below 1-foot bgs.

To obtain information about the depth profile of the DU chip distribution, five areas, each about 60 m², were scraped and repeatedly scanned. The results of the survey indicate that there are DU chips at all levels down to a depth of approximately 1 foot in the burn area. The data subset resulting from this survey are not evaluated in this report because they do not relate specifically to the concentration of radioactivity in soil (i.e., pCi/g) and because they do not provide a

qualitative indication of the general radiological condition of the Site. It is noteworthy, however, to recognize that this survey was performed over a rather large portion of the interior section of the Site using gas-flow beta proportional detectors. This instrument is particularly sensitive to the presence of U-238 (and thus DU). This survey not only confirmed that the DU was nominally confined to the top 12" of soil, but served to bias the selection of locations from which subsequent samples were collected and measurements made using quantitative techniques.

To evaluate the relative contribution to total radioactivity in soil from various soil size fractions, three large volume bulk soil samples were collected from the surface, at 0 to 3.5 inches bgs, and three from 1 to 12 inches bgs. Each sample was separated into coarse (>1 inch), medium (1/16 to 1 inch), and fine (<1/16 inch) size fractions. DU chips were contained in the large and medium size fractions. The medium and large fractions were then ground to less than ¼ inch, and analyzed for Th-234, Ra-226, Ac-228, and U-235 by gamma spectroscopy (Th-234 was used as a surrogate for U-238 in gamma spectroscopy measurements). The sample results showed that the surface soils contained the highest concentrations of DU, and that the fines fraction from each zone had a higher DU concentration than the middle and coarse fractions. Thus, it is evident that in spite of the presence of some visible DU chips in the soil, the radioactivity present tends to be associated with the fine fraction of the upper soil layer. The higher DU concentrations in the fines fraction is attributed to:

- the presence of some fines in the originally generated waste,
- *in-situ* oxidation and particle size breakdown of the larger chips, and
- the oxidation and breakdown of DU scrap in the burning process.

Property 20 was surveyed using in-situ gamma spectroscopy and surface soil sampling. In-Situ Gamma spectroscopy served to identify the nuclide mixture for each sample and provide a large area average measurement directly. There were 19 in-situ survey locations, measuring overlapping areas both near and further away from the known locations of higher exposure rates. Soil samples were collected at each in-situ location, and several samples were collected just beyond the estimated boundary of the contaminated region to verify that the area was correctly delineated.

To determine whether windborne transport and deposition had occurred offsite, soil samples were collected from the 0 to 1 foot interval from 5 locations east of the Site across Greenough Boulevard, and analyzed for several radionuclides, including U-235, K-40, Cs-137, Ac-228, Ra-226, and Th-234. No radionuclides associated with the Site were detected in any of the samples.

Sediment and water samples were collected from the sewer system on Site. Th-234 was not present above the MDA in any sewer system sample and it was concluded that DU was not present.

GTS Duratek (formerly SEG) calculated the total background uranium concentration present at the Site and found the background concentration of natural uranium in the fill soil to be 2.12 ± 0.64 pCi/g.

Surveys have shown the area outside the perimeter fence to be free of radiological contamination.

2.5.6 Harding ESE Focused Uranium Tailings Investigation, September, 2002

This sampling event was a focused uranium tailings investigation that included biased sampling in four areas where it had been theorized by ANL and/or MK that the presence of uranium tailings in soils at these locations might be responsible for isotopic anomalies and slightly elevated gamma exposure rates encountered in these areas. These samples yielded measures of the total uranium activity in soil as well as the activity for isotopes associated with uranium tailings. Harding ESE's sampling confirmed the presence of slightly elevated gamma exposure rates near the north property line but showed that these were attributable to naturally occurring radioactivity and not the presence of uranium tailings (Harding ESE, 2002).

2.6 RADIOLOGICAL CHARACTERISTICS OF DEPLETED URANIUM

The processes used to convert uranium in ore to the zero-valent metallic uranium form handled and processed at the Watertown Arsenal serve to produce a consistent isotopic fingerprint. Added to this, the long radioactive half-life of the uranium isotopes in DU means that there is little difference in the isotopic abundance of radionuclides in freshly produced DU compared with that in aged DU.

The radiological characterization survey performed by ANL in 1981 included soil samples that were collected in areas with locally elevated radioactivity concentrations and analyzed by mass spectrometry. As an isotopic differentiation method, mass spectrometry is expensive, but has a clear detection and resolution advantage when the radioactive signal is difficult to detect or when the radioactive half-life is very long as is the case with uranium species. Table 2-1 presents the uranium isotopic fractions in on-site soil samples as measured by mass spectrometry. Table 2-2 presents the typical uranium isotopic abundance (percent by weight) for both natural and depleted uranium in comparison with the mean GSA Site-specific data.

From the site-specific data, it is clear that the relative contributions from each of the five uranium species analyzed is dramatically consistent from sample to sample. Since these samples were collected from across the Site, albeit biased toward areas having more elevated concentrations, it is credible to conclude that the isotopic profile across the Site is consistent. When the average site-specific concentrations are compared with the isotopic abundances associated with naturally occurring uranium (such as would be present in uranium ore and uranium mill tailings) and depleted uranium, it is clear that the radionuclide profile on the Site is typical of depleted uranium. The exceedingly small uncertainty in the relative isotopic abundance typical of natural uranium virtually eliminates an interpretation owing to other than DU.

Table 2-1. GSA Site Specific Uranium Isotopic Data by Mass Spectrometry

Summary of Watertown GSA Site Soil Samples						
	% of Uranium Atoms Present					Sum
Sample	U-233	U-234	U-235	U-236	U-238	% of U Atoms
1-S47-A	0.000%	0.001%	0.228%	0.005%	99.766%	100.000%
1-S47-D	0.000%	0.001%	0.235%	0.005%	99.759%	100.000%
1-S48-A	0.000%	0.001%	0.237%	0.005%	99.757%	100.000%
1-S48-D	0.000%	0.001%	0.273%	0.005%	99.721%	100.000%
1-S49-A	0.000%	0.001%	0.230%	0.005%	99.764%	100.000%
1-S49-D	0.000%	0.001%	0.236%	0.005%	99.758%	100.000%
1-S50-A	0.000%	0.001%	0.227%	0.005%	99.767%	100.000%
1-S50-D	0.000%	0.001%	0.228%	0.005%	99.766%	100.000%
1-S76	0.000%	0.001%	0.226%	0.005%	99.768%	100.000%
1-S103-A	0.000%	0.001%	0.226%	0.005%	99.768%	100.000%
1-S105-A	0.000%	0.001%	0.225%	0.006%	99.768%	100.000%
Avg.	0.000%	0.001%	0.234%	0.005%	99.760%	100.000%

Table 2-2. Comparison of Natural and DU Isotopic Abundance with GSA Uranium Fractions

Isotope	Natural Abundance (%)	Typical DU Abundance (%)	Average abundance at GSA Site (%)
U-238	99.2739 +/-0.0007	99.75	99.760
U-235	0.7204 +/-0.0007	0.25	0.234
U-234	0.0057 +/-0.0002	0.0005	0.001
Source: Schleien 1992			

While, in the case of the Watertown GSA Site, mass spectrometry is superior as an analytical method for differentiating uranium radionuclides, cost and the lack of a real time field analytical instrument have precluded its use as a field method. Instead, chemical and radiolytic methods have been employed. Radiolytic measurements made on the Site also compare favorably with that expected from depleted uranium (See Table 2-3).

Table 2-3. Comparison of Natural and DU Activity Fraction with GSA Uranium Activity Fractions

%Activity as a Function of Total Mass			
Isotope	% Activity in Natural Abundance	% Activity in Typical DU Abundance	% Activity at GSA Site
U-238	47.29	84.70%	82.55%
U-234	50.51	14.20%	15.39%
U-235	2.21	1.10%	1.24%
Sources: Schleien 1992, WISE 2000			

A sensitivity analysis was performed in the development of the site-specific DCGL to gauge the sensitivity of potential future dose to a receptor due to variability in the isotopic ratios that might be reasonably expected in depleted uranium. The sensitivity analysis indicated that projected

annual dose is insensitive to even relatively large variation in uranium isotopic ratios (Harding ESE, 2001a).

The depleted uranium DCGL for the Site was derived using the "typical" isotopic abundance present in DU (as described in Table 2-3 above). The typical isotopic abundance provides a slightly more conservative measure of the amount of the U-238 isotope, which is the isotope in depleted uranium with the greatest dose producing potential. While it is extremely unlikely that the series of chemical extraction and physical separation processes involved in the production of depleted uranium would leave measurable quantities of uranium progeny such as thorium and radium, the isotopic mixture used to derive the DCGL does allow for 0.1% contributions from both Ra-226 and Th-230. Inclusion of these adds an additional measure of conservatism to the DCGL (Ra-226 is the most potent dose producer among all of the radionuclides in the mixture) and accounts for small amounts of naturally occurring radioactive material that might be present in fill materials imported to the Site. Figure 2-3 presents the isotopic mixture used to derive the DCGL for DU contaminated soil.

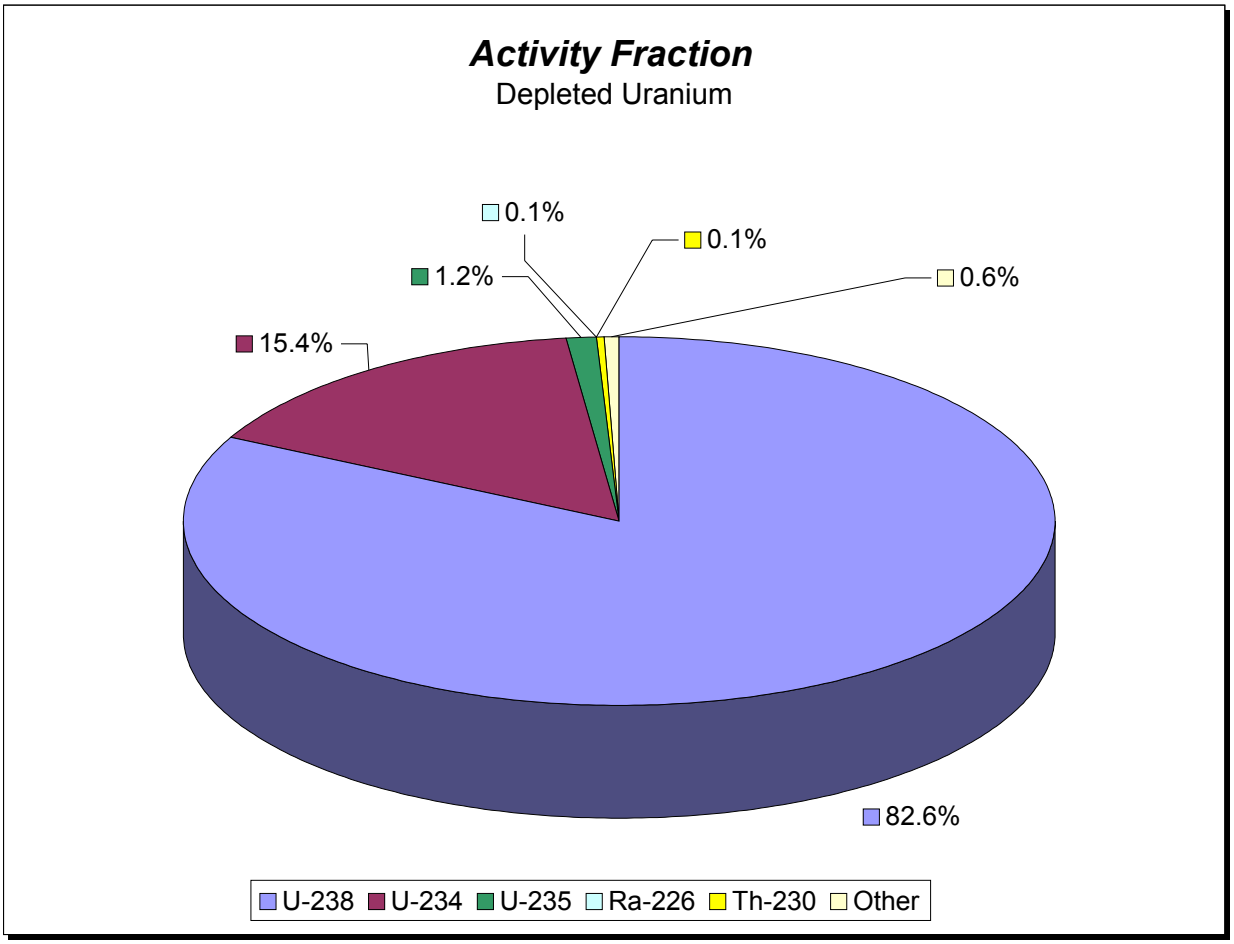


Figure 2-3. Radionuclide Activity Fraction—Depleted Uranium

3.0 DECISION FRAMEWORK

3.1 SITE-SPECIFIC SOIL DCGL

The site-specific soil DCGL for the Site is 340 pCi/g total uranium (Harding ESE, 2001a). The DCGL was derived assuming that the top 1 foot of soil was uniformly impacted with depleted uranium at this concentration. Of course, the reality is that the Site is not uniformly impacted with residual radioactivity; some areas being virtually devoid of the presence of detectable concentrations of residual radioactivity, while other areas were significantly impacted (e.g., the burn area). Like most environmental pollutants, concentrations of radioactivity in soil are typically distributed in skewed (non-normal, non-symmetrical) distributions. As a result, the arithmetic mean is generally a poor indicator of the central tendency value of DU concentration in a given area. Instead, the median or the geometric mean provides a better indication of the concentration of residual radioactivity relative to the DCGL.

3.2 WEIGHT-OF-EVIDENCE EVALUATION

CENAE, NRC, MADEP, and MADPH agreed early in the decontamination and decommissioning process to utilize the existing radiological site data to the maximum extent possible in determining whether the Site met the approved release criterion. As indicated, the available data have been compiled over several sampling events and include many different types and analytical measures of the uranium activity present in soils on the Site. Subsets of the data are, in some cases, insufficient when taken alone to provide risk managers with an adequate assessment of the concentration of residual radioactivity in soil needed to arrive at a confident and defensible decision. But, statistical limitations prevent combining these data for use in a classic statistical evaluation using hypothesis testing.

A reasonable alternative to the classic statistical approach and one which makes the fullest use of the extensive existing radiological data previously collected from the Site is a comprehensive "weight-of-evidence" evaluation. This technique considers each subset of data independently (since it would be inappropriate to combine or pool these data subsets) and focuses on the relevant descriptive statistics from each subset (e.g., median, 95% upper confidence limit [UCL_{95}] for the median, maximum, etc.) in comparison with the approved DCGL. Individual data subsets, when appropriately parsed into survey units, may not contain enough samples or measurements to provide a robust assessment of the residual radioactivity in soil when considered alone. However, when several of these subsets of the data from a given survey unit are independently evaluated in the context of the approved soil DCGL, the risk manager is able to consider the totality of the available evidence in a quantitative, if not statistically rigorous, manner.

Such an approach is akin to that used in the medical sciences in which a series of studies evaluating a cause and effect are done. Individual studies, taken alone, may not have the statistical power to draw definite conclusions. However, when a series of such studies consistently point to a certain conclusion, the weight of the evidence is used to draw a conclusion. Such an approach has been used in evaluating the radiological data from the Watertown GSA Site.

Adding to the conservatism embodied in this evaluation approach are:

1. The fact that much of the data collected at the Site was biased toward identifying and characterizing the locations on the Site having the highest concentrations of residual radioactivity; and

2. The fact that much of the data collected at the Site was obtained prior to extensive remediation efforts undertaken at the Site. Such data will naturally bias the assessment of the radiological conditions at the Site to conditions that once existed at the Site rather than those that are currently present following remediation.

3.3 SURVEY UNIT BREAKDOWN

In consideration of the historical uses of the Site and the wealth of radiological data collected over the years at the Site, the Site was subdivided into survey units to facilitate the data evaluation process. A survey unit is a physical area consisting of structures or land areas for which a separate decision will be made as to whether or not that area exceeds the release criteria (NRC, 2000). As a result, the survey unit is the primary entity for demonstrating compliance with the DCGLs. Individual survey units were created to:

- Ensure that the number of survey data points was relatively uniformly distributed over areas with similar contamination potential, history, and concentration distribution;
- Account for features of the Site having naturally distinguishable sections (e.g., The burn area which has unique deposition mechanisms and the highest expected concentration of residual radioactivity is subdivided from the rest of the Site such that it is a separate survey unit); and
- Group areas of the Site with like histories and contamination potentials into single survey units.

Using these guidelines, the Site was subdivided into six distinct survey units. Each survey unit is itemized in Table 3-1 and portrayed graphically in Figure 3-1. Figure 3-2 is the symbol legend used throughout this report to identify the location of samples and measurements. Each data subset is represented with a unique symbol to allow the reader to discern the location and density of each type of data evaluated.

As a result of the MK/SEG surveys in 1995 and the ANL surveys from 1981, the buildings themselves were previously determined to be unaffected.

Table 3-1. Survey Units Identified for the Watertown GSA Site

Survey Unit Description	Survey Unit
Paved area at the south end of the Site	GSA-01
Central portion of the Site, known as the "clinker area"	GSA-02
The burn area	GSA-03
The fill area immediately north of the burn area	GSA-04
Western boundary area (Area between the property line and the fence)	GSA-05
Property 20 / North boundary area	GSA-06

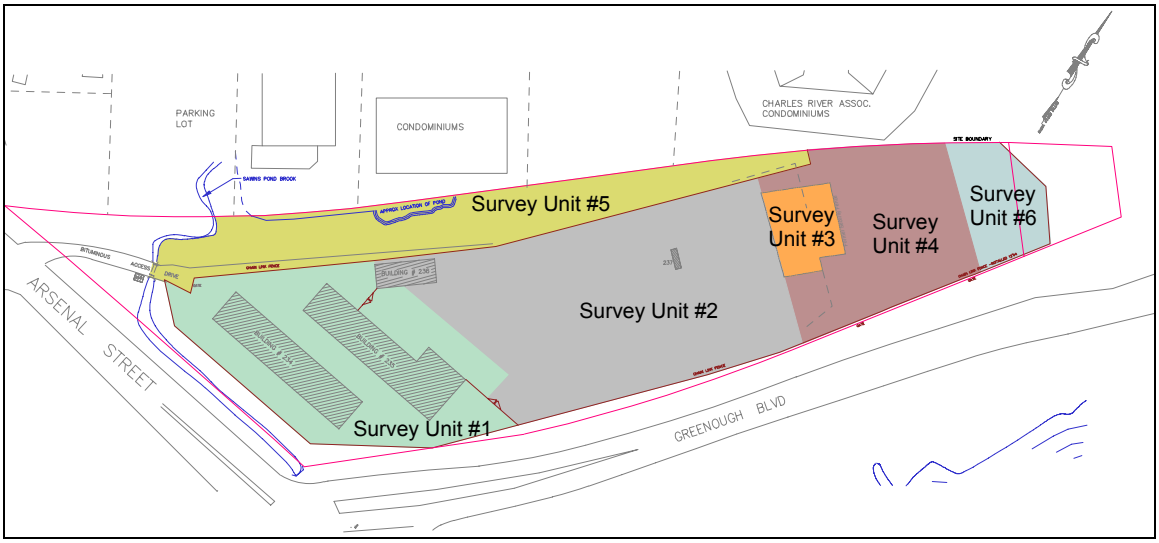


Figure 3-1. Watertown GSA Site—Survey Units

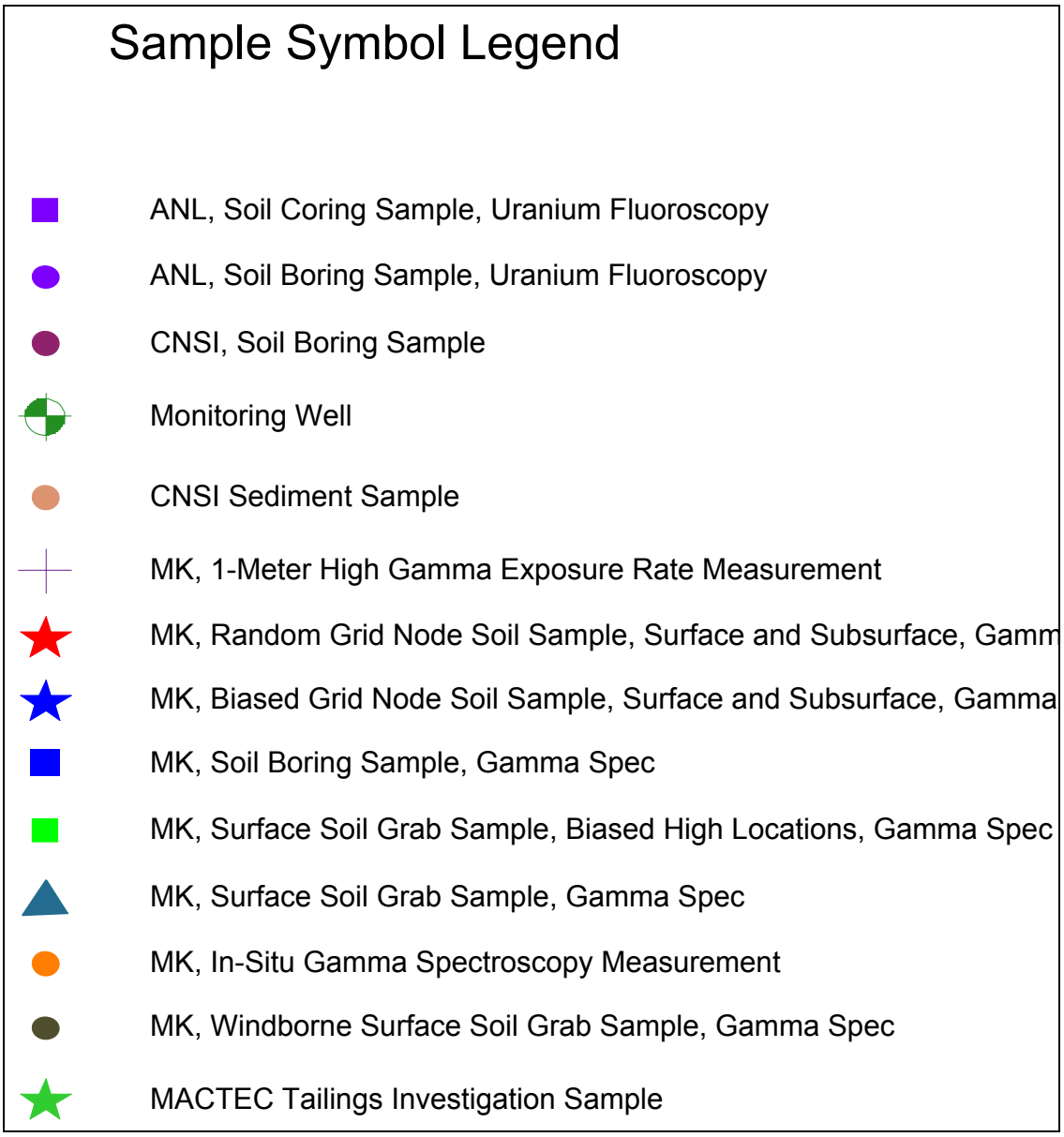


Figure 3-2. Sample and Measurement Symbol Legend

4.0 SAMPLING AND SURVEY RESULTS

Sampling and survey results are presented by survey unit with a discussion of the weight of evidence provided by each data subset. Where anomalies or notable results were identified, additional discussion and data are presented within the section addressing the specific survey unit affected. Data subsets are presented chronologically.

In cases where both surface and subsurface samples have been collected, the data have been evaluated collectively and also as two strata, surface and subsurface. This is done to provide the risk managers and decision makers with a clearer picture of the presence of residual radioactivity in soil with respect surface and subsurface strata. This information is useful in that the conceptual site model used in the derivation of the DCGL conservatively describes the residual radioactivity in surface soils.

Detailed statistical reports for each data subset, together with figures in which the sampling locations are identified are provided in Appendices A through G. Summary statistics were calculated using statistical analysis software (NCSS, 2001). The median, the 95% confidence limit about the median, and the geometric mean are provided as best estimators of the central tendency value of each data subset, along with the maximum value from the data subset. The data subsets are included in Appendix H, along with a compilation of all the radiological data sorted by investigation.

Figure 4-1 well illustrates the abundance and spatial distribution of the available data from across the entire site.

4.1 SURVEY UNIT 1

Survey Unit 1 consists of the paved land area inside of the security fence at the southern most end of the Site. Survey unit 1 is one of the least impacted areas of the Site having been filled, built upon, and paved prior to the use of DU on the Site. Buildings 234 and 235 are located within Survey Unit 1. There are 6 different data subsets associated with Survey Unit 1. Each data subset associated with this survey unit is itemized in Table 4-1 and each sample or measurement location from within Survey Unit 1 is illustrated in Figure 4-2. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-2.

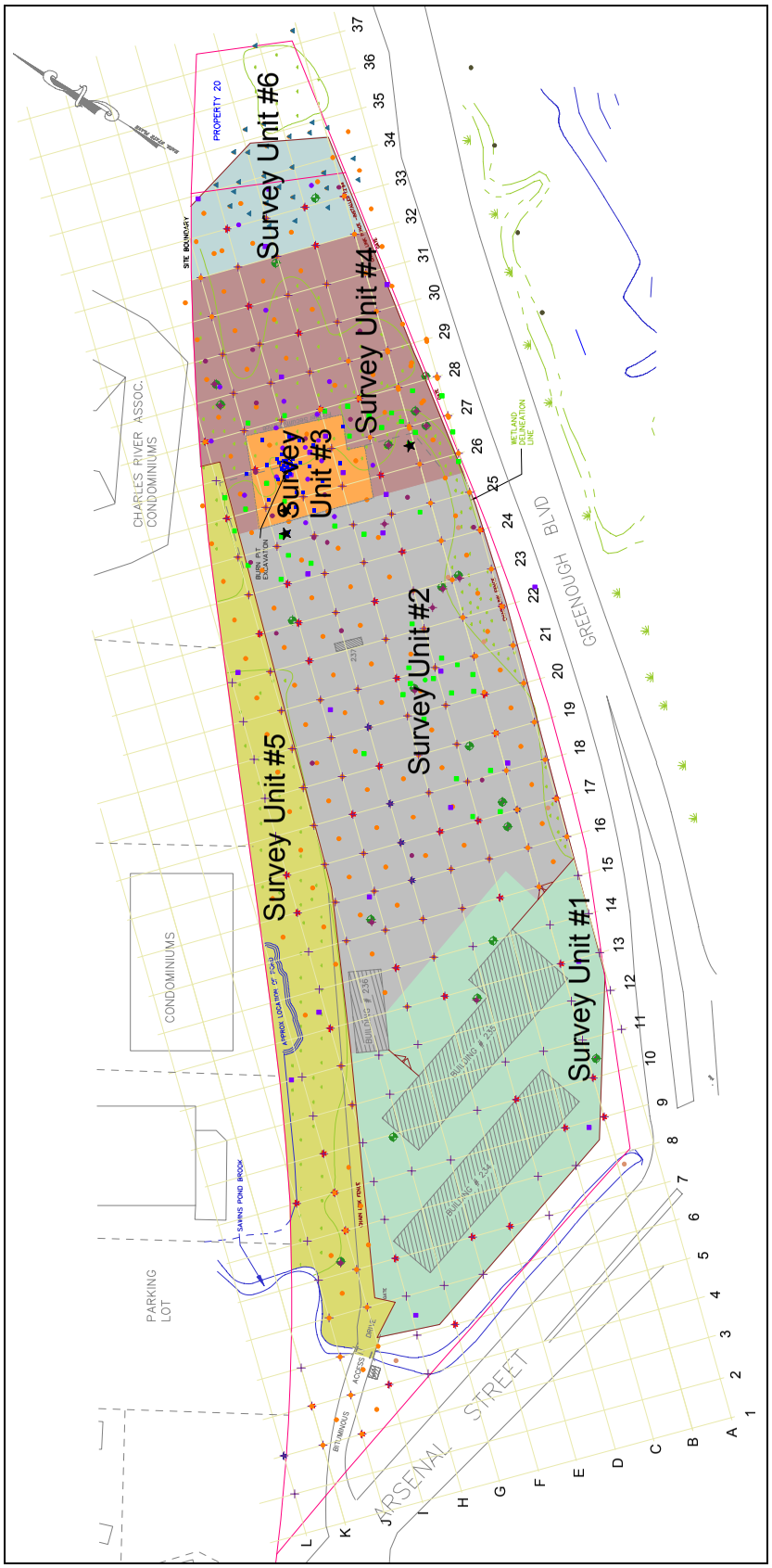


Figure 4-1. Site Map Showing the Location of All Samples Considered in the Evaluation

Table 4-1. Summary of Survey Unit 1 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**12**	**9**	**3**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2 foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**7**	**2**	**5**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**34**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**16**	**8**	**8**
MK Biased Grid Soil Samples	Surface and subsurface soil samples collected from grid nodes where the 1-meter high gamma exposure rate measurements indicated slightly elevated exposure rates.	**2**	**1**	**1**
MK In-Situ Gamma Spec on Grid	High resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**3**	**3**	**0**

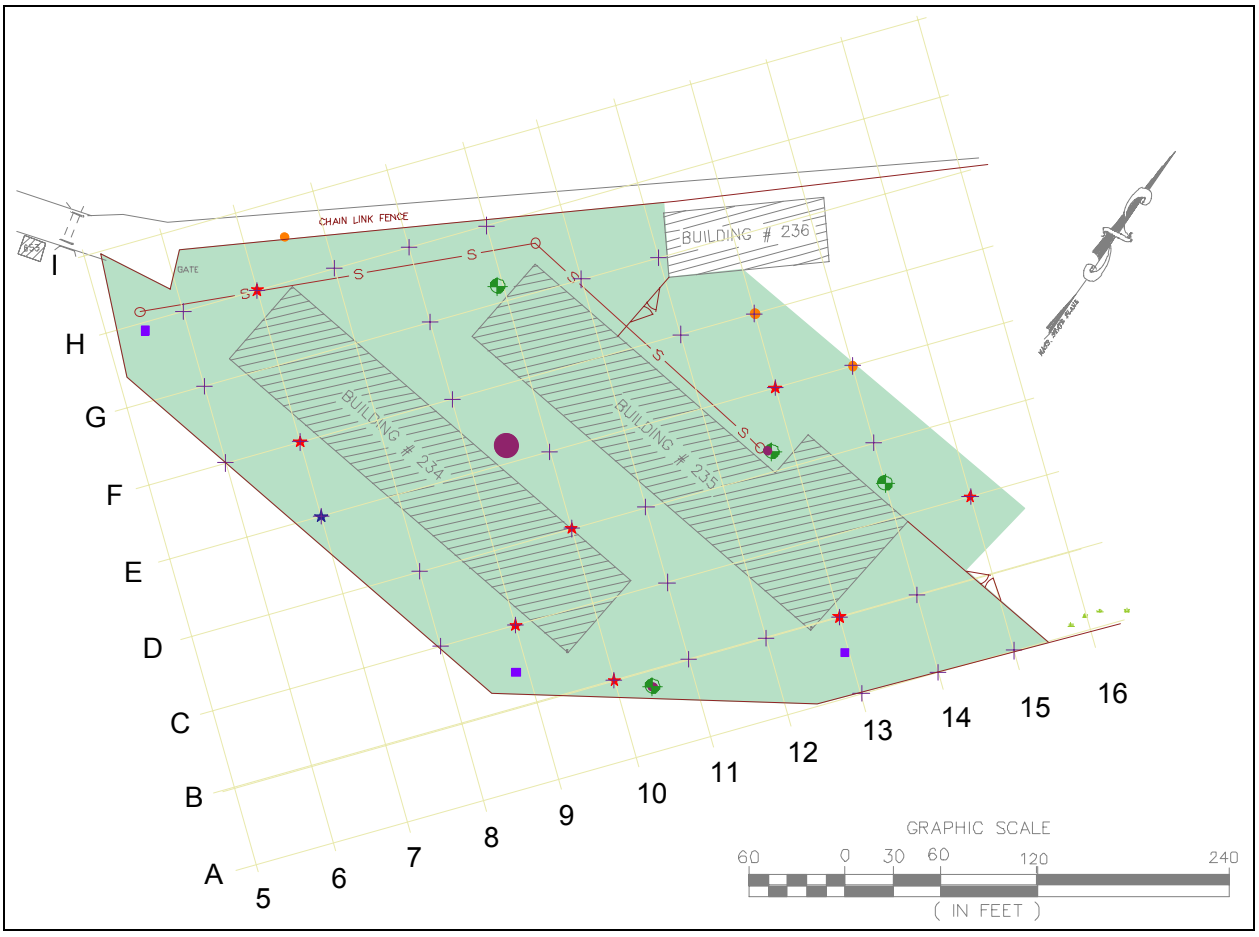


Figure 4-2. Sample and Measurement Locations—Survey Unit 1

Table 4-2. Summary Statistics, Survey Unit GSA-01

Data Subset		Survey Unit GSA-01					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	12	1.2	1.35	3.1	1.7	3.7
	(Surface Soil)	9	1.2	1.3	3.1	1.7	3.5
	(Subsurface Soil)	3	(2)	1.4	(2)	1.8	3.7
CNSI Boring Samples	(All Depths)	7	0.3	0.3	2.7	0.4	2.7
	(Surface Soil)	2	(2)	0.3	(2)	0.3	0.3
	(Subsurface Soil)	5	(2)	0.3	(2)	0.47	2.7
MK Gamma Exposure Rate Measurements		34	13	13.9	14.4	13.8	16
MK Grid Soil Samples	Random+Biased, All Depths	18	2.1	2.1	2.1	2.1	2.1
	Random+Biased, Surface Soil	9	2.1	2.1	2.1	2.1	2.1
	Random+Biased, Subsurface Soil	9	2.1	2.1	2.1	2.1	2.1
	Random, All Depths	16	2.1	2.1	2.1	2.1	2.1
	Random, Surface Soil	8	2.1	2.1	2.1	2.1	2.1
	Random, Subsurface Soil	8	2.1	2.1	2.1	2.1	2.1
	Biased, All Depths	2	(2)	2.1	(2)	2.1	2.1
	Biased, Surface Soil	1	(2)	2.1	(2)	2.1	2.1
	Biased, Subsurface Soil	1	(2)	2.1	(2)	2.1	2.1
MK In-Situ Gamma Spec on Grid		3	(2)	0	(2)	2.0	2.0

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is significantly below the Soil DCGL of 340 pCi/g total uranium. In fact, a strong argument could be made to consider that Survey Unit 1 is in reality an area that is unaffected by activities involving depleted uranium, as would be expected given the site history.

4.2 SURVEY UNIT 2

Survey Unit 2 consists of the unpaved land area inside of the security fence and to the north of Survey Unit 1 and extends to the south boundary of Survey Units 3 & 4 (the south end of the burn area). Survey Unit 2 has been termed the "clinker area" because furnace slag (or clinkers) has been deposited over large portions of the soil surface. Discrete chips of depleted uranium have also been identified I this area. Building 237 is located within Survey Unit 2. There are 11 different data subsets associated with Survey Unit 2. Each data subset associated with this survey unit is itemized in Table 4-3 and each sample or measurement location from within Survey Unit 2 is illustrated in Figure 4-3. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-4.

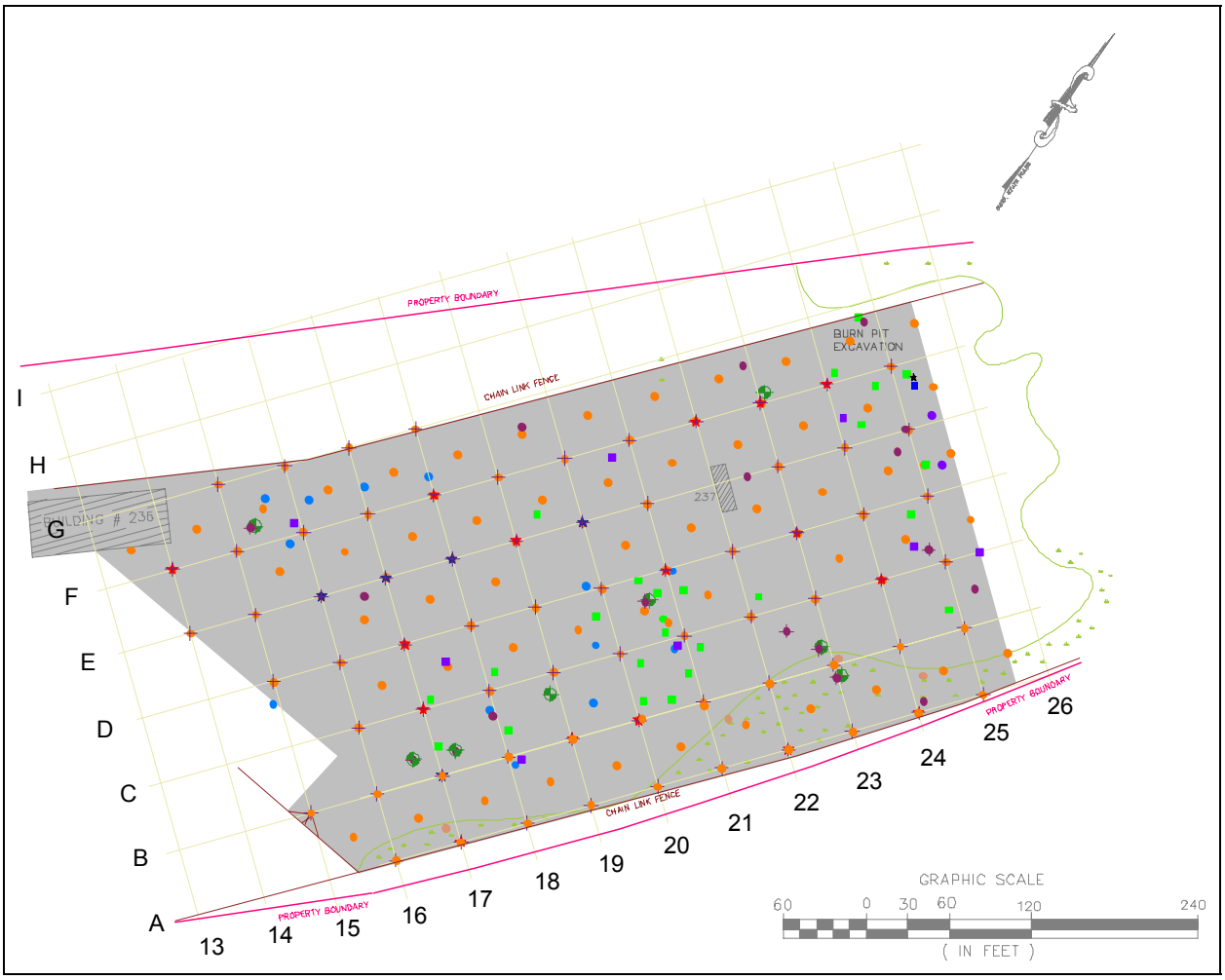


Figure 4-3. Sample and Measurement Locations—Survey Unit 2

Table 4-3. Summary of Survey Unit 2 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**29**	**23**	**6**
ANL Boring Samples	Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet and segmented into 6, 12" samples. The top sample (0-1' bgs) is classified as a surface sample.	**12**	**2**	**10**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2 foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**61**	**15**	**45**
CNSI Sediment Samples	Sediment samples were collected from the surface soils in site surface water drainage areas and wetlands areas on the down-gradient (east) side of the Site.	**4**	**4**	**0**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**68**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**32**	**16**	**16**
MK Biased Grid Soil Samples	Surface and subsurface soil samples collected from grid nodes where the 1-meter high gamma exposure rate measurements indicated slightly elevated exposure rates.	**10**	**5**	**5**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**24**	**24**	**0**
MK Bulk Soil Samples	Large volume samples collected in locations with the highest detected concentrations of depleted uranium radioactivity and fractioned based on particle size.	**6**	**N/A**	**N/A**
MK In-Situ Gamma Spec on Grid	High resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**137**	**137**	**0**
MK In-Situ Gamma Spec at Biased Locations	High resolution in-situ gamma spectroscopy measurements made at locations where the highest radioactivity concentrations were found on the Site.	**3**	**3**	**0**

Table 4-4. Summary Statistics, Survey Unit GSA-02

Data Subset		Survey Unit GSA-02					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	29	1.5	2.5	3.6	6.1	26000
	(Surface Soil)	23	2.0	3.0	4.4	8.8	26000
	(Subsurface Soil)	6	1.3	1.5	1.6	1.4	1.6
ANL Boring Samples	(All Depths)	12	0.9	2.4	5.1	2.4	10.6
	(Surface Soil)	2	(2)	8.6	(2)	8.3	10.6
	(Subsurface Soil)	10	0.6	2.1	4.3	1.9	5.1
CNSI Boring Samples	(All Depths)	61	0.3	0.3	0.4	0.5	330
	(Surface Soil)	15	0.3	0.4	0.9	0.8	330
	(Subsurface Soil)	45	0.3	0.3	0.3	0.4	12
CNSI Sediment Samples		4	(2)	0.3	(2)	0.3	0.3
MK Gamma Exposure Rate Measurements		68	13.3	13.8	14.2	13.9	18.8
MK Grid Soil Samples	Random+Biased, All Depths	42	2.1	2.1	2.1	2.1	3.8
	Random+Biased, Surface Soil	21	2.1	2.1	2.1	2.2	3.8
	Random+Biased, Subsurface Soil	21	2.1	2.1	2.1	2.1	2.1
	Random, All Depths	32	2.1	2.1	2.1	2.1	3.8
	Random, Surface Soil	16	2.1	2.1	2.1	2.2	3.8
	Random, Subsurface Soil	16	2.1	2.1	2.1	2.1	2.1
	Biased, All Depths	10	2.1	2.1	2.1	2.1	2.1
	Biased, Surface Soil	5	(2)	2.1	(2)	2.1	2.1
	Biased, Subsurface Soil	5	(2)	2.1	(2)	2.1	2.1
MK Surface Soil Grab Samples		24	-0.1	0.1	9.8	6.0	54.1
MK In-Situ Gamma Spec on Grid		137	0	2.0	2.0	3.3	49
MK In-Situ Gamma Spec, Biased Locations		3	(2)	13.1	(2)	18.4	78.4
MK Bulk Soil Samples		6	0	4.0	10	2.9	10

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

Considering the summary statistics presented in Table 4-4, it is clear that the central tendency estimates (median and geometric mean) for each data subset is significantly below the applicable soil DCGL. In most cases, the data subset is sufficiently large to provide an estimate of the 95% upper confidence limit (UCL_{95}) about the median estimate as well. The UCL_{95} estimates from each of the data subsets likewise provide solid evidence that the residual uranium radioactivity concentration in soil is well below the DCGL. It is notable that early, biased sampling performed by ANL and CNSI yielded single sample results for uranium in surface soil at or above the DCGL (see the maximum value column). Still, the largest majority of samples collected in these sampling events, even though they were purposely biased toward the assessment of the highest activity to be found on Site, yielded results substantially below the DCGL. In addition, it is reported by MK that locations where ANL or CNSI had previously reported activity >35pCi/g (total uranium) were remediated by MK (MK 1996). This is further supported by the more contemporary data collected by MK showing maximum uranium soil concentrations significantly less than those reported by ANL or CNSI and well below the DCGL.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is below the soil DCGL of 340 pCi/g total uranium.

4.3 SURVEY UNIT 3

Survey Unit 3 consists of the historically fenced, former burn area near the northern end of the Site. Survey Unit 3 is by far the most radiologically impacted area of the Site having been used to handle and stabilize depleted uranium. The burn area has been the focus of extensive sampling and remedial actions in the past, with the bulk of the soils having elevated concentrations of residual radioactivity having been removed. There are 11 different data subsets associated with Survey Unit 3. Each data subset associated with this survey unit is itemized in Table 4-5 and each sample or measurement location from within Survey Unit 3 is illustrated in Figure 4-4. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-6.

Table 4-5. Summary of Survey Unit 3 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**22**	**16**	**6**
ANL Boring Samples	Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet and segmented into 6, 12" samples. The top sample (0-1' bgs) is classified as a surface sample.	**34**	**6**	**28**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2 foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**18**	**4**	**14**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**5**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**2**	**1**	**1**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**2**	**2**	**0**
MK Bulk Soil Samples	Large volume samples collected in locations with the highest detected concentrations of depleted uranium radioactivity and fractioned based on particle size.	**6**	**N/A**	**N/A**
MK In-Situ Gamma Spec on Grid	High resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**13**	**13**	**0**
MK In-Situ Gamma Spec at Biased Locations	High resolution in-situ gamma spectroscopy measurements made at locations where the highest radioactivity concentrations were found on the Site.	**2**	**2**	**0**
MK Soil Boring	High resolution gamma spec measurements of samples collected from borings to depth.	**152**	**24**	**128**
MK Soil Boring	Uranium Fluoroscopy measurement of select soil samples from boring locations.	**18**	**7**	**11**

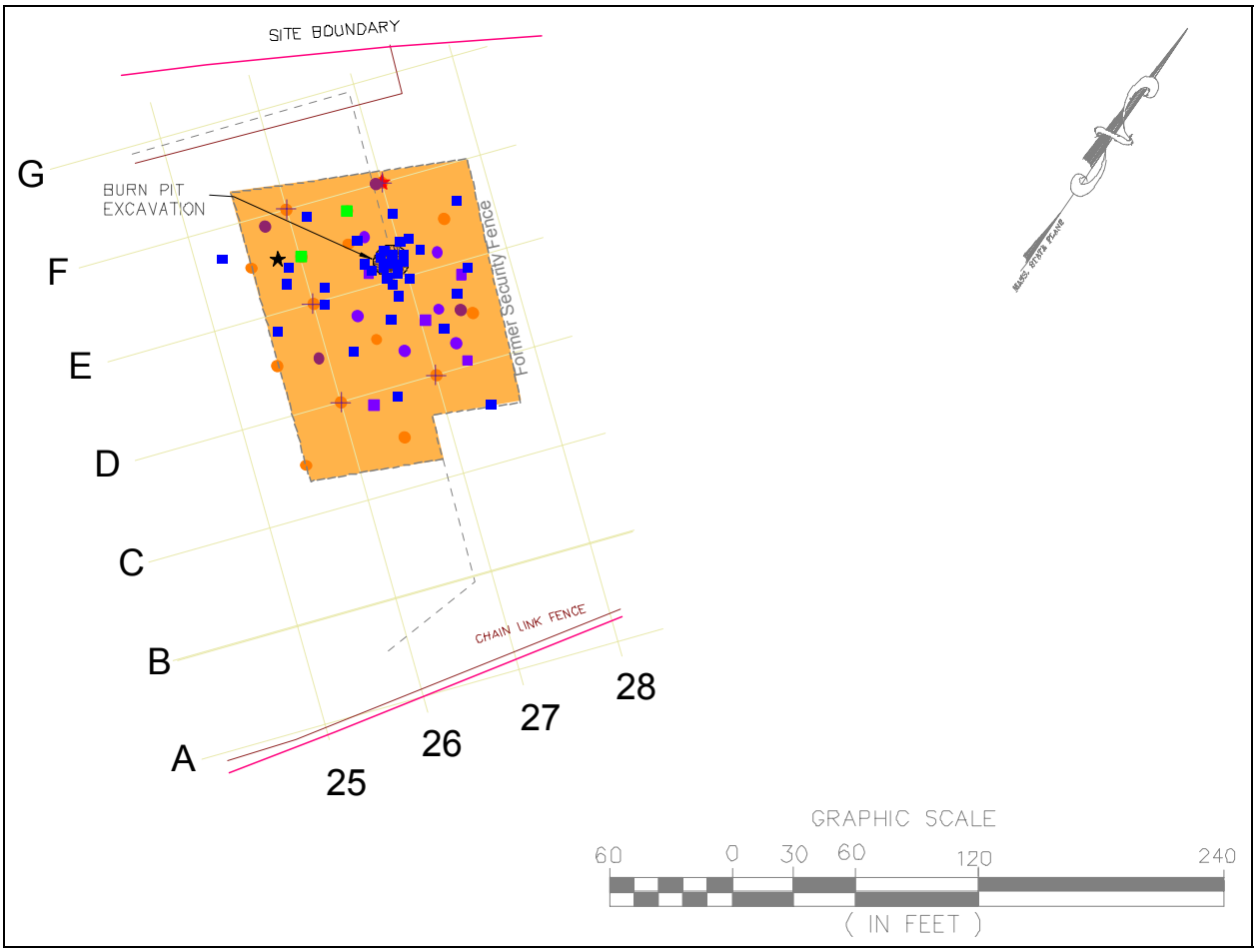


Figure 4-4. Sample and Measurement Locations—Survey Unit 3

Table 4-6. Summary Statistics, Survey Unit GSA-03

Data Subset		Survey Unit GSA-03					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	22	88.3	192	308	213.2	7100
	(Surface Soil)	16	163	269.5	348	356	7100
	(Subsurface Soil)	6	18.7	46.6	258	54.3	258
ANL Boring Samples	(All Depths)	34	6.8	15.2	55.1	22.4	588
	(Surface Soil)	6	48.2	131.5	288	121.3	288
	(Subsurface Soil)	28	4.4	12.3	22	15.6	588
CNSI Boring Samples	(All Depths)	18	0.3	0.5	2.7	0.9	14
	(Surface Soil)	4	(2)	3.3	(2)	1.7	14
	(Subsurface Soil)	14	0.3	0.5	2.7	0.8	4.9
MK Gamma Exposure Rate Measurements		5	(2)	13.8	(2)	13.7	14.7
MK Grid Soil Samples	Random, All Depths	2	(2)	9.6	(2)	6	17
	Random, Surface Soil	1	(2)	17	(2)	17	17
	Random, Subsurface Soil	1	(2)	2.1	(2)	2.1	2.1
MK Surface Soil Grab Samples		2	(2)	17	(2)	17	17.3
MK In-Situ Gamma Spec on Grid		13	7	14	20	11.9	35
MK In-Situ Gamma Spec, Biased Locations		2	(2)	11.4	(2)	11.4	12.3
MK Bulk Soil Samples		6	0	0.1	12	0.3	12
MK Soil Boring Samples	Gamma Spec, All Depths	152	2.1	2.1	3.8	7.6	253.1
	Gamma Spec, Surface Soil	24	3.7	9.3	81.8	18.7	253.1
	Gamma Spec, Subsurface Soil	128	2.1	2.1	2.2	6.3	223.2
	Fluoroscopy, All Depths	18	3	7.6	17.4	7.6	109
	Fluoroscopy, Surface Soil	7	3.9	17.4	109	14.8	109
	Fluoroscopy, Subsurface Soil	11	1.6	5.3	9.8	5	29

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

Considering the summary statistics presented in Table 4-1, it is clear that the residual uranium radioactivity is higher in Survey Unit 3 than in any of the other survey units on the Site. This is of course expected as Survey Unit 3 is where the majority of the handling and stabilization

activities with DU occurred. The earliest sampling done by ANL (prior to any remediation in the burn area) yielded central tendency estimates (median and geometric mean) for uranium activity in surface soil near the 340 pCi/g total uranium soil DCGL with a maximum value of 7,100 pCi/g. As before, the sampling done by ANL was biased toward the assessment of the highest detected activity in the area. Significant soil excavation has occurred in Survey Unit 3 in an effort to remediate the burn area. That these efforts were effective is evidenced by the summary statistics for data subsets collected following remediation. Data collected by both CNSI and MK yield central tendency estimates (median and geometric mean), upper confidence intervals, and maximum values that are significantly below the applicable soil DCGL.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is below the soil DCGL of 340 pCi/g total uranium.

4.4 SURVEY UNIT 4

Survey Unit 4 consists of the unpaved land area inside of the security fence and to the north of the burn area. There are 10 different data subsets associated with Survey Unit 4. Each data subset associated with this survey unit is itemized in Table 4-7 and each sample or measurement location from within Survey Unit 4 is illustrated in Figure 4-5. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-8.

Table 4-7. Summary of Survey Unit 4 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**8**	**6**	**2**
ANL Boring Samples	Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet and segmented into 6, 12" samples. The top sample (0-1' bgs) is classified as a surface sample.	**53**	**9**	**44**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2 foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**44**	**13**	**29**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**31**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**14**	**7**	**7**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**17**	**17**	**0**
MK Bulk Soil Samples	Large volume samples collected in locations with the highest detected concentrations of depleted uranium radioactivity and fractioned based on particle size.	**6**	**N/A**	**N/A**
MK In-Situ Gamma Spec on Grid	High-resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**33**	**33**	**0**
MK In-Situ Gamma Spec at Biased Locations	High-resolution in-situ gamma spectroscopy measurements made at locations where the highest radioactivity concentrations were found on the Site.	**2**	**2**	**0**
Harding ESE Soil Sampling	Soil samples collected at locations previously identified as having residual radioactivity that might have been associated with uranium tailings.	**3**	**3**	**0**

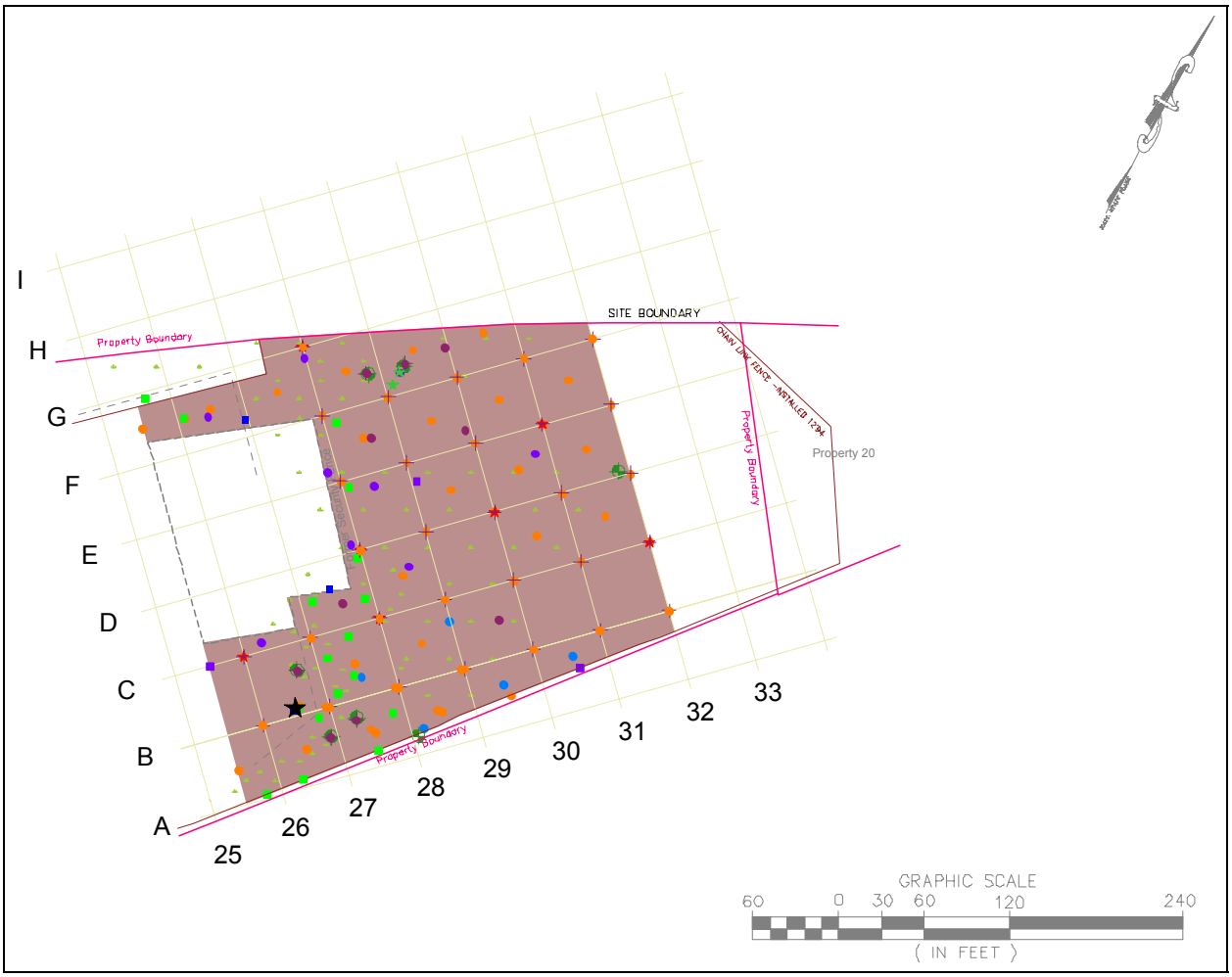


Figure 4-5. Sample and Measurement Locations—Survey Unit 4

Table 4-8. Summary Statistics, Survey Unit GSA-04

Data Subset		Survey Unit GSA-04					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	8	1.7	2.9	7.6	3.4	11.8
	(Surface Soil)	6	2	3.2	11.8	4.1	11.8
	(Subsurface Soil)	2	(2)	2	(2)	2	2.3
ANL Boring Samples	(All Depths)	53	1.7	2	2.5	2.2	17.1
	(Surface Soil)	9	1.8	4.5	10.3	4.6	17.1
	(Subsurface Soil)	44	1.6	1.9	2.2	1.9	4.4
CNSI Boring Samples	(All Depths)	44	0.3	0.3	0.3	0.5	7.5
	(Surface Soil)	13	0.3	0.3	2.7	0.6	7.5
	(Subsurface Soil)	29	0.3	0.3	0.3	0.4	3.5
MK Gamma Exposure Rate Measurements		31	13	13.5	13.8	13.5	15.5
MK Grid Soil Samples	Random, All Depths	14	2.1	2.1	2.1	2.6	21.8
	Random, Surface Soil	7	2.1	2.1	21.8	3.3	21.8
	Random, Subsurface Soil	7	2.1	2.1	2.1	2.1	2.1
MK Surface Soil Grab Samples		17	5.9	11.4	23.6	15.0	123.8
MK In-Situ Gamma Spec on Grid		33	0	2	3	3.2	7
MK In-Situ Gamma Spec, Biased Locations		2	(2)	16.15	(2)	15.9	18.7
MK Bulk Soil Samples		6	-0.7	0.1	177.6	1.9	177.6
Harding ESE Soil Samples		3	(2)	0.9	(2)	1.2	3.2

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

Considering the summary statistics presented in Table 4-8, it is clear that the central tendency estimates (median and geometric mean) for each data subset is significantly below the applicable soil DCGL. In most cases, the data subset is sufficiently large to provide an estimate of the 95% upper confidence limit (UCL_{95}) about the median estimate as well. The UCL_{95} estimates from each of the data subsets likewise provide solid evidence that the residual uranium radioactivity concentration in soil is well below the DCGL. It is notable that even biased sampling performed by ANL, CNSI, and MK did not yield maximum sample results for uranium in surface soil at or above the DCGL. In fact, the largest majority of samples collected in these sampling events,

even though they were purposely biased toward the assessment of the highest activity to be found on site, yielded results substantially below the DCGL.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is below the soil DCGL of 340 pCi/g total uranium.

4.5 SURVEY UNIT 5

Survey Unit 5 consists of the narrow strip of land that is inside of the GSA Site property boundary but outside of the security fence at the western (upgradient) edge of the Site. Survey Unit 5 is one of the least impacted areas of the Site, having large portions of its surface covered with wetlands. A former access road within the survey unit tracks along the existing fence line, and some clinkers are noted to have been placed on the surface in the survey unit. There are 6 different data subsets associated with Survey Unit 5. Each data subset associated with this survey unit is itemized in Table 4-9 and each sample or measurement location from within Survey Unit 5 is illustrated in Figure 4-6. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-10.

Table 4-9. Summary of Survey Unit 5 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**9**	**7**	**2**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2' foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**4**	**1**	**3**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**32**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**18**	**9**	**9**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**3**	**3**	**0**
MK In-Situ Gamma Spec on Grid	High-resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**40**	**40**	**0**

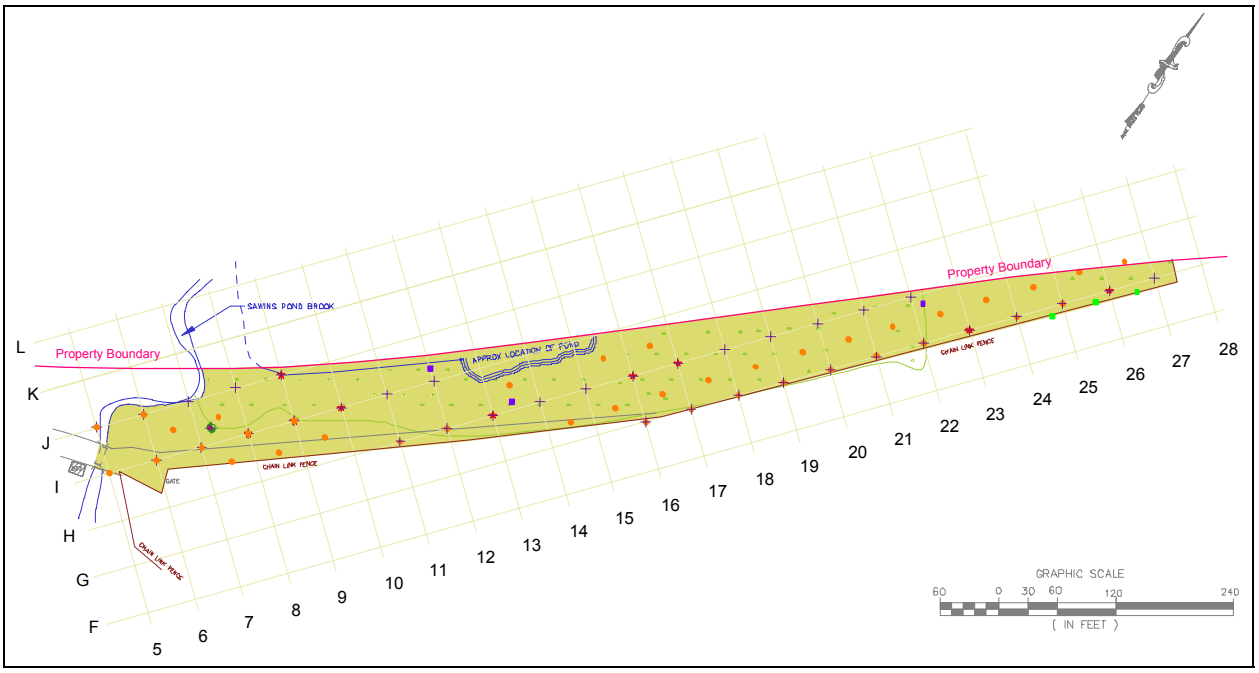


Figure 4-6. Sample and Measurement Locations—Survey Unit 5

Table 4-10. Summary Statistics, Survey Unit GSA-05

Data Subset		Survey Unit GSA-05					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	9	1.7	2.7	4.7	2.8	6.1
	(Surface Soil)	7	1.3	2.9	6.1	3.0	6.1
	(Subsurface Soil)	2	(2)	2.1	(2)	2.1	2.5
CNSI Boring Samples	(All Depths)	4	(2)	0.3	(2)	0.3	0.3
	(Surface Soil)	1	(2)	0.3	(2)	0.3	0.3
	(Subsurface Soil)	3	(2)	0.3	(2)	0.3	0.3
MK Gamma Exposure Rate Measurements		32	12.7	13.6	14.1	13.3	15.2
MK Grid Soil Samples	Random, All Depths	18	2.1	2.1	2.1	2.1	2.1
	Random, Surface Soil	9	2.1	2.1	2.1	2.1	2.1
	Random, Subsurface Soil	9	2.1	2.1	2.1	2.1	2.1
MK Surface Soil Grab Samples		3	(2)	4.7	(2)	8.2	14.2
MK In-Situ Gamma Spec on Grid		40	0	0	0	3.7	38.5

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

Considering the summary statistics presented in Table 4-10, it is clear that the central tendency estimates (median and geometric mean) for each data subset is significantly below the applicable soil DCGL. In cases where the data subset is sufficiently large to provide an estimate of the UCL_{95} about the median, the UCL_{95} estimates also provide solid evidence that the residual uranium radioactivity concentration in soil is well below the DCGL. It is notable that even biased sampling performed by ANL, CNSI, and MK did not yield maximum sample results for uranium in surface soil at or above the DCGL[3]. In fact, the largest majority of samples collected in these sampling events, even though they were purposely biased toward the assessment of the highest activity to be found on site, yielded results substantially below the DCGL, with many results at or below the applicable detection limits.

3 A single sample collected by ANL at a location where slightly elevated gamma radiation levels and surface activity measurements were found did contain elevated concentrations of both uranium and radium. This sample was actually a piece of rock from a surface outcropping (as opposed to soil) and was determined by ANL to be naturally occurring and indigenous to the site. This sample has been omitted from the statistical assessment in this evaluation as it is clearly not associated with former Army activities at the site.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is below the soil DCGL of 340 pCi/g total uranium.

4.6 SURVEY UNIT 6

Survey Unit 6 consists of the unpaved land area inside of the security fence at the northern most end of the Site. The survey unit includes portions of the property owned by the GSA and a portion of the property known as Property 20, which is owned by the MAMDC. Survey Unit 6 is comparable to Survey Unit 4 except that it is the area where it had been theorized that uranium tailings might be present. That has since been disproved by sampling designed specifically to address that potential (Harding ESE, 2002). Still, the survey unit is evaluated discretely because it involves a second property owner. There are 10 different data subsets associated with Survey Unit 6. Each data subset associated with this survey unit is itemized in Table 4-11 and each sample or measurement location from within Survey Unit 6 is illustrated in Figure 4-7. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-12.

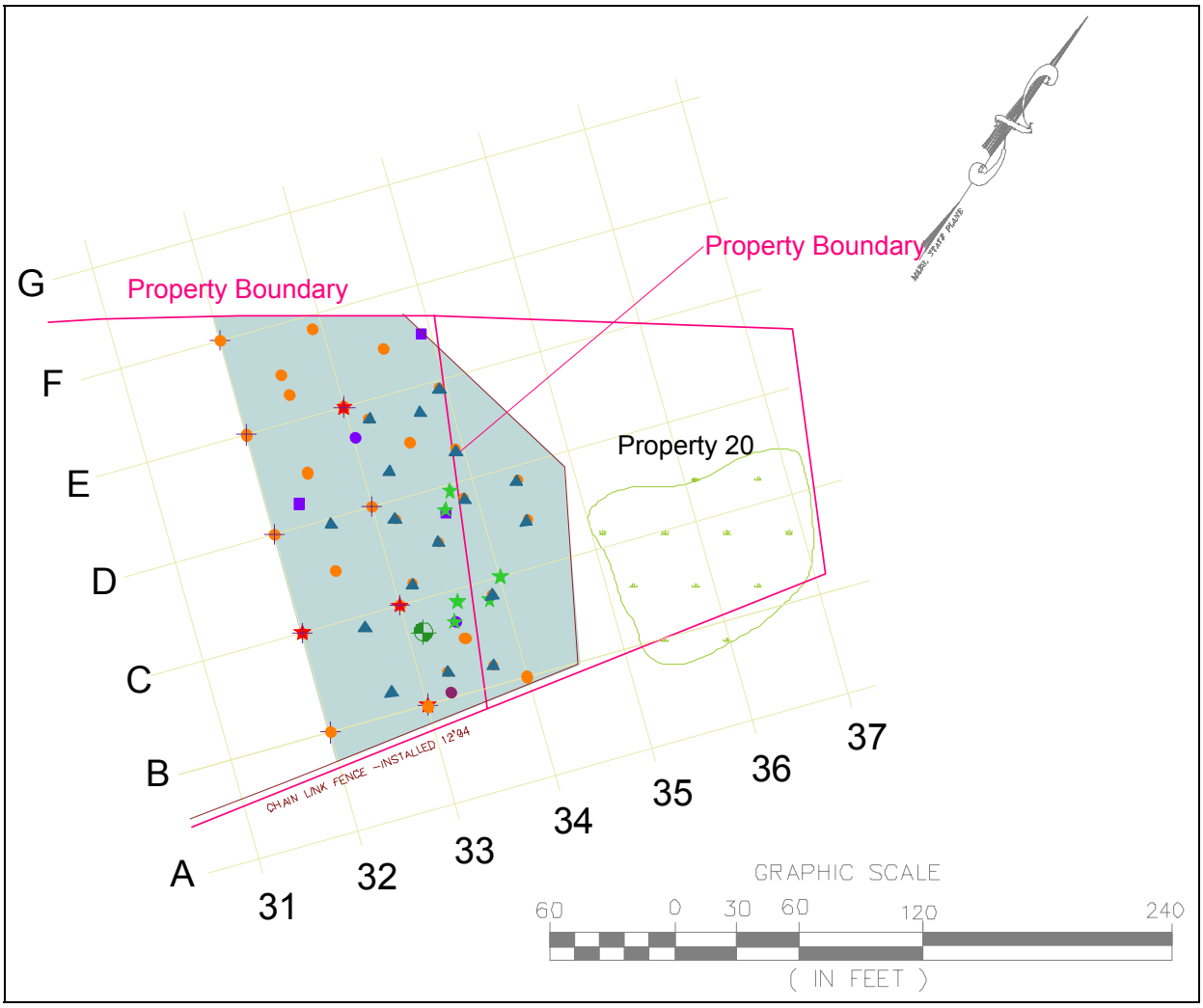


Figure 4-7. Sample and Measurement Locations—Survey Unit 6

Table 4-11. Summary of Survey Unit 6 Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**12**	**9**	**3**
ANL Boring Samples	Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet and segmented into 6, 12" samples. The top sample (0-1' bgs) is classified as a surface sample.	**12**	**2**	**10**
CNSI Boring Samples	CNSI Soil borings were advanced to depths of 10 to 50 feet across the Site. Generally, samples were collected over 2' foot increments down to the completed depth. The top sample (0-2' bgs) is classified as a surface sample.	**4**	**1**	**3**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**9**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**8**	**4**	**4**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**16**	**16**	**0**
MK In-Situ Gamma Spec on Grid	High resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**23**	**23**	**0**
MK In-Situ Gamma Spec at Biased Locations	High resolution in-situ gamma spectroscopy measurements made at locations where the highest radioactivity concentrations were found on the Site.	**11**	**11**	**0**
MK Soil Grab Samples, North Woods	Surface soil samples collected at locations where real time surface measurements identified the possible presence of elevated uranium activity.	**6**	**N/A**	**N/A**
Harding ESE Soil Sampling	Soil samples collected at locations previously identified as having residual radioactivity that might have been associated with uranium tailings.	**14**	**N/A**	**N/A**

Table 4-12. Summary Statistics, Survey Unit GSA-06

Data Subset		Survey Unit GSA-06					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	12	1.8	3.8	130	15.1	390
	(Surface Soil)	9	1.8	4	221	17.8	390
	(Subsurface Soil)	3	(2)	3.4	(2)	9.2	110
ANL Boring Samples	(All Depths)	12	1.6	2.4	9.2	3.2	12.2
	(Surface Soil)	2	(2)	7	(2)	4.7	12.2
	(Subsurface Soil)	10	1.2	2.4	9.2	2.9	9.6
CNSI Boring Samples	(All Depths)	4	(2)	0.6	(2)	0.6	2
	(Surface Soil)	1	(2)	0.8	(2)	0.8	0.8
	(Subsurface Soil)	3	(2)	0.3	(2)	0.6	2
MK Gamma Exposure Rate Measurements		9	13.6	14.4	15.9	14.7	17.9
MK Grid Soil Samples	Random, All Depths	8	2.1	2.1	9.1	3.2	12.8
	Random, Surface Soil	4	(2)	2.1	(2)	3.3	12.8
	Random, Subsurface Soil	4	(2)	2.1	(2)	3.0	9.1
MK Surface Soil Grab Samples		16	-0.3	7.1	14.2	15.2	144.3
MK In-Situ Gamma Spec on Grid		23	0	1.6	3.5	4.4	24
MK In-Situ Gamma Spec, Biased Locations		11	0	4.6	9	6.8	14.4
MK Soil Grab Samples, Biased, North Woods		6	2.1	8.1	10.1	5.5	10.1
Harding ESE Soil Samples		14	3.1	4.5	14	5.6	16.1

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

Considering the summary statistics presented in Table 4-12, it is clear that the central tendency estimates (median and geometric mean) for each data subset is significantly below the applicable soil DCGL. In many cases, the data subset is sufficiently large to provide an estimate of the 95% upper confidence limit (UCL_{95}) about the median estimate as well. The UCL_{95} estimates from each of the data subsets likewise provide solid evidence that the residual uranium radioactivity concentration in soil is well below the DCGL. It is notable that early, biased sampling performed by ANL yielded single sample results for uranium in surface soil above the DCGL (see the maximum value column). Still, the largest majority of samples collected in these sampling events, even though they were purposely biased toward the assessment of the highest

activity to be found on site, yielded results substantially below the DCGL. In addition, it is reported by MK that locations where ANL or CNSI had previously reported activity >35pCi/g (total uranium) were remediated by MK (MK, 1996). This is further supported by the more contemporary data collected by MK showing maximum uranium soil concentrations significantly less than those reported by ANL or CNSI and well below the DCGL.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is below the soil DCGL of 340 pCi/g total uranium.

4.7 OFFSITE SAMPLES

Offsite samples have been collected and measurements have been made to demonstrate that the operations involving depleted uranium at the GSA Site have not impacted the environment outside of the controlled property boundary. There are 9 different data subsets associated with offsite sampling and surveying. Each data subset is itemized in Table 4-13 and each sample or measurement location is illustrated in Figure 4-8. A summary of the relevant descriptive statistics for each data subset is presented in Table 4-14.

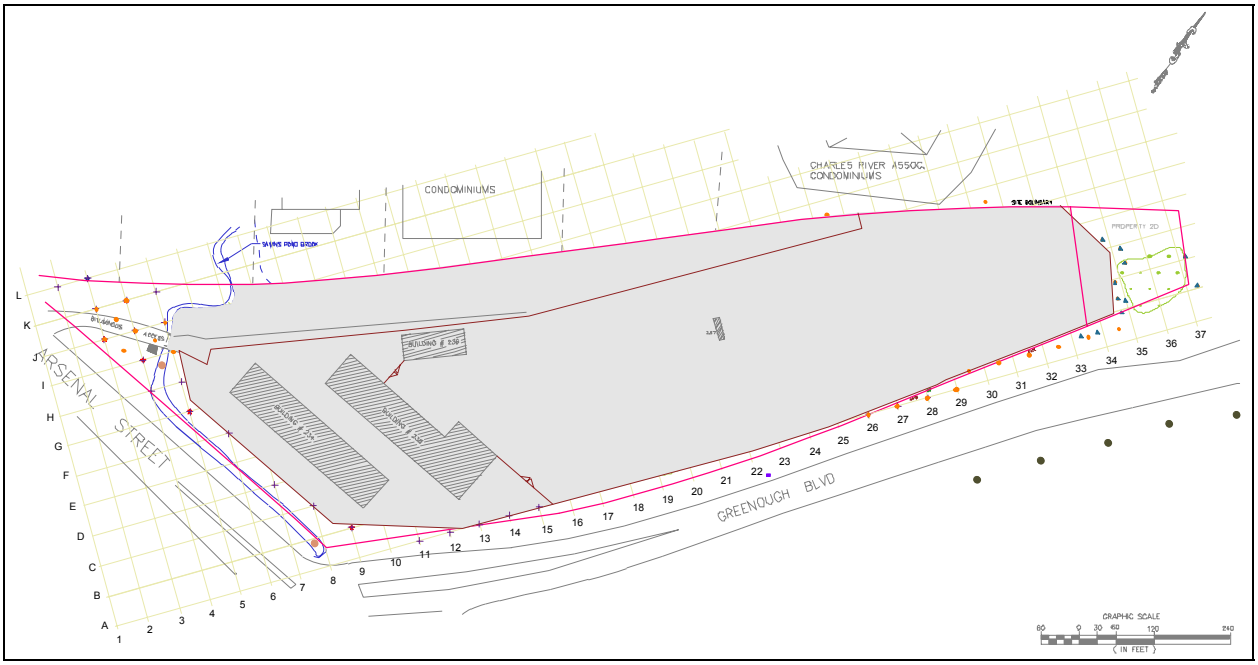


Figure 4-8. Sample and Measurement Locations—Offsite Samples

Table 4-13. Summary of Offsite Data Subsets

Data Subset	Description	Number of Samples / Measurements		
		Total	Surface	Sub-surface
ANL Coring Samples	Coring samples were collected from 0-12" bgs and segmented into 4 depths and designated A, B, C, & D. The "A, B, & C" samples are from the 0-2", 2-4", and 4-6" depths, respectively. The "D" sample is from the 6-12" depth. A, B, & C samples are considered surface samples. The D sample is considered subsurface.	**4**	**3**	**1**
CNSI Sediment Samples	Sediment samples were collected from the surface soils in site surface water drainage areas and wetlands areas on the down-gradient (east) side of the Site.	**2**	**2**	**0**
MK Gamma Exposure Rate Measurements on Grid	Gamma exposure rate measurement at 1-Meter above the ground surface on a 15-m grid system.	**18**	**N/A**	**N/A**
MK Random Grid Soil Samples	Surface and subsurface soil samples collected from a random sampling on the 15-m grid nodes.	**10**	**5**	**5**
MK Biased Grid Soil Samples	Surface and subsurface soil samples collected from grid nodes where the 1-meter high gamma exposure rate measurements indicated slightly elevated exposure rates.	**2**	**1**	**1**
MK Surface Soil Grab Samples	Surface soil samples collected at locations where real time surface measurements and historical information identified the presence of elevated uranium activity.	**11**	**11**	**0**
MK In-Situ Gamma Spec on Grid	High resolution in-situ gamma spectroscopy measurements made on a systematic grid across the Site.	**16**	**16**	**0**
MK In-Situ Gamma Spec at Biased Locations	High resolution in-situ gamma spectroscopy measurements made at locations where the highest radioactivity concentrations were found on the Site.	**7**	**7**	**0**
MK Windborne Soil Samples	Surface soil samples collected in the downwind direction of the prevailing winds at the Site and measured using high-resolution gamma spectroscopy.	**9**	**N/A**	**N/A**

Table 4-14. Summary Statistics, Offsite

Data Subset		Offsite					
		Statistic[1]					
		Number of Measurements	LCL_{95} (median)	Median	UCL_{95} (median)	Geometric Mean	Maximum
ANL Coring Samples	(All Depths)	4	(2)	2.1	(2)	2	2.3
	(Surface Soil)	3	(2)	2.3	(2)	2.0	2.3
	(Subsurface Soil)	1	(2)	1.8	(2)	1.8	1.8
CNSI Sediment Samples		2	(2)	3.9	(2)	1.5	7.5
MK Gamma Exposure Rate Measurements		18	12.5	13.6	15	13.6	19.1
MK Grid Soil Samples	Random+Biased, All Depths	12	2.1	2.1	2.1	2.1	2.1
	Random+Biased, Surface Soil	6	2.1	2.1	2.1	2.1	2.1
	Random+Biased, Subsurface Soil	6	2.1	2.1	2.1	2.1	2.1
	Random, All Depths	10	2.1	2.1	2.1	2.1	2.1
	Random, Surface Soil	5	(2)	2.1	(2)	2.1	2.1
	Random, Subsurface Soil	5	(2)	2.1	(2)	2.1	2.1
	Biased, All Depths	2	(2)	2.1	(2)	2.1	2.1
	Biased, Surface Soil	1	(2)	2.1	(2)	2.1	2.1
	Biased, Subsurface Soil	1	(2)	2.1	(2)	2.1	2.1
MK Surface Soil Grab Samples		11	-0.7	-0.4	-0.1	0.7	5.4
MK In-Situ Gamma Spec on Grid		16	0	0	0	(2)	0
MK In-Situ Gamma Spec, Biased Locations		7	0	0	0	(2)	0
MK Windborne Soil Samples		9	-1.3	-0.9	-0.4	(2)	-0.4

1. All values in units of pCi/g, Total U except for Gamma exposure Rate Measurements which are in units of μR/h.
2. Insufficient number of data points to calculate the statistic.

From the summary descriptive statistics for each of the data subsets it is evident that the weight of the analytical evidence clearly indicates that the residual radioactivity associated with activities involving depleted uranium is significantly below the Soil DCGL of 340 pCi/g total uranium and that offsite areas have not been impacted by past activities involving depleted uranium.

5.0 ALARA ANALYSIS

This ALARA analysis has been conducted to determine whether it is feasible to further reduce the levels of residual depleted uranium radioactivity concentrations in soils at the Watertown GSA Site to levels below those necessary to meet the dose criteria (i.e., to levels that are ALARA).

Since the site ceased to be used for operations involving depleted uranium scrap materials, a number of remedial actions have been affected to address the areas of the site having the highest concentrations of radioactivity in soil. The first such remedial action was performed by the U.S. Army in 1966, followed by a second decontamination program in 1973 (Harding ESE, 2000). Following transfer of the Site to the GSA, CNSI performed additional remediation, particularly in the burn area in an effort to meet new remedial action standards. A significant volume of contaminated soil and debris were removed from the burn area by CNSI between 1988 and 1989. Yet another remedial action was undertaken by MK/SEG in 1993 in which additional soil volume was removed from the burn area and localized areas previously identified by ANL and CNSI were remediated (MK 1996). These latter remedial actions were initiated with the objective of achieving a 35 pCi/g total uranium in soil guideline. As a result of these previously accomplished remedial actions, it is evident that the concentrations of residual radioactivity in soil have been substantially reduced. This is indicated by the fact that the central tendency estimate for total uranium in soils in every survey unit is below 35 pCi/g (an order of magnitude below the approved site-wide average soil DCGL) and that no single current measurement exceeds the site-wide average DCGL. These data support the conclusion that concentrations of residual uranium radioactivity in soils at the site have already been significantly reduced below that required to meet the decommissioning dose standard and to levels that are ALARA.

Based on the decision to achieve compliance with the unrestricted use criteria of 10 CFR 20.1402 (Total effective dose equivalent [TEDE] to an average member of the critical group that does not exceed 25 mrem/y), and using appropriate dose modeling to relate concentrations to dose, one can apply the allowance given in Section 1.5, Appendix D of NUREG-1727 that states:

> *"In certain circumstances, the results of an ALARA analysis are known on a generic basis and an analysis is not necessary. For residual radioactivity in soil at sites that will have unrestricted release, generic analyses show that shipping soil to a low-level waste disposal facility is unlikely to be cost effective for unrestricted release, largely because of the high cost of waste disposal. Therefore shipping soil to a low-level waste disposal facility generally does not have to be evaluated for unrestricted release. In addition, licensees that have remediated surface soil such that it meets the unrestricted use criteria in 10 CFR 20.1402 would not be required to demonstrate that these levels are ALARA."*

5.1 CONCLUSION

Considering that concentrations of depleted uranium in soil have already been substantially reduced below the permissible $DCGL_W$ through remedial actions and NRC guidance acknowledges that it is "known on a generic basis" that compliance with dose-based soil DCGLs achieves concentrations that are already ALARA, it is determined that the residual radioactivity concentrations in soil at the GSA site are ALARA, and no additional remediation is justified.

6.0 SUMMARY AND CONCLUSIONS

The comprehensive in-situ gamma spectroscopy measurements of surface soils on the site grid system (the last set of comprehensive measurements to be made at the Site) provide strong evidence to support the conclusion that the residual radioactivity in surface soils at the Site is well below the DCGL value.

These in-situ gamma measurements also provide the risk managers and decision makers with valuable information concerning the significance of elevated surface soil concentrations. Extreme values are likely due to the presence of discrete chips of depleted uranium in the soil sample matrix and this is to be expected. However, the physics of the measurement technique provide a field of view for the measurement that is larger than the surface that can be physically sampled, yet smaller than that associated with a survey unit or the Site as a whole. This yields a small area average measure of surface soil activity in a localized area where exposure might occur (akin to a hotspot measurement). That no in-situ gamma measurement yielded a total uranium result in excess of the permissible site-wide average DCGL obviates the need for the further assessment of the exposure potential from areas having locally elevated uranium activity in soil samples.

This analysis of the substantial amount of data for depleted uranium activity in soil at the GSA Site provides solid evidence that each of the six survey units meets the quantitative compliance decision rule (the soil DCGL) and qualifies for release from radiological controls, without restriction.

ACRONYMS

ABB-ES .....ABB Environmental Services
ALARA.....As Low As Reasonably Achievable
AMMRC .....Army Materials and Mechanics Research Center
AMTL .....Army Materials Technology Laboratory
ANL .....Argonne National Laboratory
ATF .....Bureau of Alcohol, Tobacco, and Firearms

bgs.....below ground surface

CENAE .....US Army Corps of Engineers, New England District
CFR.....Code of Federal Regulations
CMR.....Code of Massachusetts Regulations
CNSI .....Chem-Nuclear Systems Inc.
CV .....Coefficient of Variation

DCGL.....derived concentration guideline level
$DCGL_W$ .....derived concentration guideline level, survey unit average (median) concentration corresponding to the permissible limit
DEA .....Drug Enforcement Administration
DOE .....Department of Energy
DU.....depleted uranium

ELCR .....Excess Lifetime Cancer Risk
EPA.....(United States) Environmental Protection Agency (See USEPA)

FBI .....Federal Bureau of Investigation
ft .....foot
FUDS .....Formerly Utilized Defense Site

GSA.....General Services Administration

HLA .....Harding Lawson Associates
HSA.....Historical Site Assessment

ISGS.....in-situ gamma spectrometry
IRS .....Internal Revenue Service

K-40 .....potassium 40

LCL_{95} .....95% lower confidence limit

MADEP.....Massachusetts Department of Environmental Protection
MADPH .....Massachusetts Department of Public Health

MARSSIM .....Multi-Agency Radiation Survey and Site Investigation Manual
MAMDC .....Massachusetts Metropolitan District Commission
MCP .....Massachusetts Contingency Plan
MDA .....minimum detectable activity
MK/SEG .....Morrison Knudsen and Scientific Ecology Group, Inc.
μR/h .....micro-Roentgens per hour
mrem .....milli-Roentgen equivalent man
mrem/y .....mrem per year (See mrem)
MSL .....Mean Sea Level
MTL .....(Army) Materials Technology Laboratory (See AMTL)

n.....number of measurements
NCRP .....National Council on Radiation Protection and Measurements
NIST.....National Institute of Standards Technology
NORM.....naturally occurring radioactive materials
NRC .....(United States) Nuclear Regulatory Commission

pCi/g.....pico-Curies per gram
PAL.....Public Archeology Laboratory

Ra-226.....radium 226
RAB .....Restoration Advisory Board

SDMP.....Site Decommissioning Management Plan

TEDE .....total effective dose equivalent
Th-230.....thorium 230
Th-234.....thorium 234

U-233 .....uranium 233
U-234 .....uranium 234
U-235 .....uranium 235
U-236 .....uranium 236
U-238 .....uranium 238
UCL_{95}.....95% upper confidence limit
USEPA.....United States Environmental Protection Agency

WISE.....World Information Service on Energy

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