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Washington Street Quarry Radiological Investigation Report

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TETRA TECH PROJECT NO. 103P4856

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1.0 INTRODUCTION

Tetra Tech Inc. (Tetra Tech) was tasked by Vermilion Development to conduct a radiological characterization study involving a gamma radiation survey of the former Cabot Corporation property as well as evaluating a number of radiological background reference areas for comparative purposes. All of the sites evaluated for this investigation are located in the City of Kokomo, Indiana. The property (referred to herein as the "site"), shown on Figure 1, is presently owned by the City of Kokomo and is being planned for future development. This report provides a historical overview, study objectives, methodology, and presents the results of the radiological investigation performed by Tetra Tech in November 2016. The following section provides a brief summary of pertinent background information which led to the development of this radiological investigation.

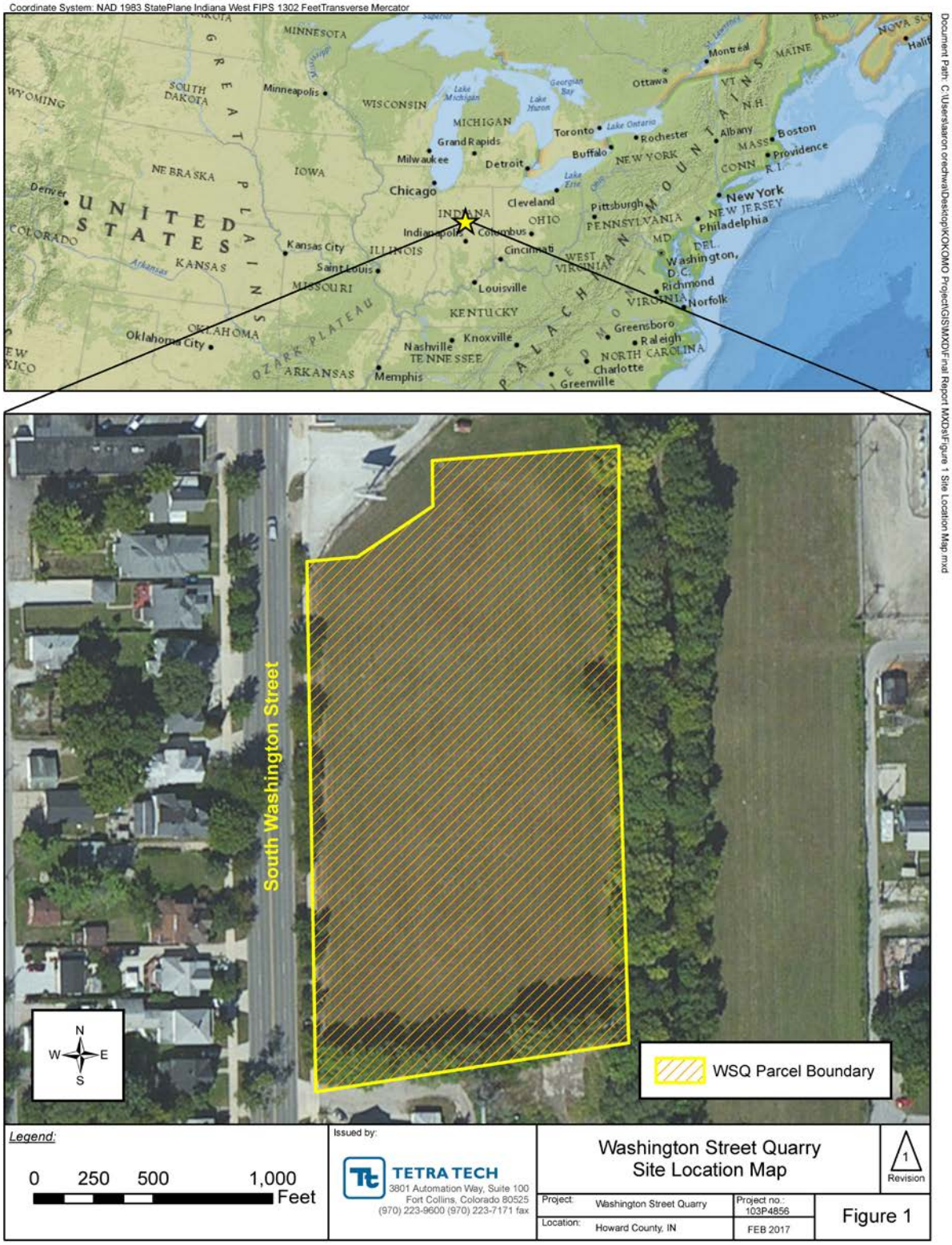

Figure 1 Washington Street Quarry Site Location Map

1.1 Site Description and Background

The 5.53 acre site shown on Figure 1 has previously been referred to as the "*Washington Street Quarry*" or "*WSQ*". This site was formerly owned by the Cabot Corporation, and is located at 410 South Washington Street in Kokomo, Indiana. Originally, limestone was quarried for use as a construction material in and around the City of Kokomo during the late 1800's (Oak Ridge Associated Universities [ORAU] 1990). The site was purchased by Cabot Corporation from the Haynes Department of Union Carbide in 1970. Previously, Haynes had drained the water contained in the 45-foot deep pit that was to be used as landfill. Beginning in the early 1950s and continuing into the 1970s, the site was used as a disposal site for industrial waste. The industrial waste was initially generated by the Stellite Division, owned by the Haynes Department of Union Carbide. In the pre-Cabot era, Stellite was used in aircraft engines and aerospace fields, chemical process industry, and nuclear power equipment. The Cabot Corporation subsequently manufactured high performance nickel and cobalt-base alloys for resisting extreme conditions of wear, heat, and corrosion. The alloys were produced in the forms of mill products, investment castings, conventional castings, fabrications, hard-facing products and powders and powder metallurgy parts as reported in a 1970 Kokomo Tribune news article.

In 1986, Cabot Corporation entered into negotiations to sell this property. However, after conducting due diligence and historical research, they discovered information suggesting that multiple drums of radioactive waste were previously buried in the quarry between the 1960s and early 1970s. According to a letter from Cabot's attorney to the Indiana Department of Environmental Management (IDEM) dated March 18, 1991 (Volz 1991), Cabot Corporation hired a contractor (Bechtel) to remove all hazardous waste drums that had been buried at the quarry. Subsequent removal action began in 1987 and was completed by the mid-1990s. The radioactive waste drums were discovered, removed, and properly disposed of along with over 400 other drums containing mixed-hazardous wastes including polychlorinated biphenyls (PCB), petroleum products, and other hazardous substances. Multiple news articles reported this incident over the course of several years. An article in the Kokomo Tribune stated that as many as 12,000 truckloads or 110,000 cubic yards of backfill were used to fill the 30-foot deep pit after Cabot had removed the potentially hazardous material. It was also documented that abrasive grinding wheels were used to remove small bits of metal from metal alloys during past operational periods at the Site. The grinding wheels that were shown to contain low levels of naturally occurring radioactive materials were segregated and isolated by Bechtel during the cleanup process. The following section describes the pertinent historical investigations that have taken place at the Washington Street Quarry over the past few decades.

1.2 Historical Investigation Summary

Two primary studies and/or investigations have been conducted since the early-1990s regarding the contamination related issues, both radiological and non-radiological, at the Washington Street Quarry. The most comprehensive radiological investigation to date was conducted by ORAU in 1991. The results of this study are presented in *Confirmatory Survey of the Cabot Corporation Washington Street Quarry Kokomo, Indiana* (ORAU 1991). A Phase II Environmental Site Assessment (ESA) was conducted at the property in 2014 by Soils and Materials Engineering Inc. (SME 2014). A summary overview of both of these studies and the key findings are presented in the following subsections.

1.2.1 Oak Ridge Associated University Final Status Survey- Radiological Investigation

During the cleanup operations, radiological and environmental contamination was discovered at the property. Cabot Corporation hired Bechtel Engineering to oversee the cleanup operations at the site for a number of years. During this time period, Cabot Corporation was required to and subsequently obtained a radiological materials license from Region III of the Nuclear Regulatory Commission's (NRC) Material Licensing Division (License number SUC-1538). In May 1990, the entirety of the quarry material had been excavated and surveyed, and the material was placed into its final location. Cabot Corporation requested the NRC perform a verification survey of the WSQ for which ORAU was assigned. The purpose of the verification survey, or Final Status Survey, was to demonstrate removal of radioactive materials from the WSQ project site to an acceptable condition suitable for unrestricted release of the site and termination of the NRC's Materials License.

A letter from Timothy J. Vitkus of ORAU to Bill Adam of NRC Region III, dated August 7, 1990, stated that ORAU verified the acceptable conditions of the site to permit backfilling operations allowed under Amendment No. 1 to Materials License Number SUC-1538. In a letter to the NRC, dated August 6, 1991, Cabot Corporation requested termination of the Materials License SUC-1538. Attached with this letter was a detailed historical account of the environmental and radiological measures conducted at the site, along with a Final Status Survey report which was conducted by ORAU. A copy of ORAU (1991) document can be found in Appendix A. The NRC Region III allowed Cabot Corporation to consolidate the remaining radioactive grinding wheels in steel drums for eventual placement and disposal on-site.

Gamma radiation surveys were performed throughout the cleanup and post-cleanup phases of the project. Exposure rates were measured at 1 meter above the surface. General gamma radiation levels ranged between 5 microroentgen per hour (µR/hr) and 10 µR/hr. There were areas with elevated exposure rates identified during the final status survey. The key findings of this investigation include the following:

- Gamma scans within the quarry identified areas of elevated activity in the southeast portion of the drum storage area. The elevated activity was attributed to the materials contained within the drums.

- A second area of elevated activity east of the drum storage area. The anomaly was identified east of several grinding wheels placed there by Bechtel as equipment supports.

- A third area of elevated activity was identified during the gamma scans, and a buried drum was discovered. The drum and residue were excavated and disposed of offsite. The area was resurveyed. Gamma measurements fell to twice background levels or less.

- A fourth area of elevated activity was due to a buried grinding wheel, which was subsequently removed. The area was resurveyed. Gamma measurements fell to twice background levels or less.

The regional background radiation was established at 8 µR/hr by ORAU. Two locations were observed at the site with potentially excessive activity levels. These were remediated and resurveyed. All final measurements and soil samples, with the exception of the drum storage area and the grinding wheel pile, as noted above, were well below the action criteria and within the range of typical background levels (ORAU 1991). As described above, at the time this study was conducted, there were a drum staging area

and grinding wheel storage piles against the west wall of the quarry. To date, a final status survey has not been conducted to assess the final site conditions once these items were removed from the site or buried for permanent disposal. The next subsection describes the SME Phase II ESA.

1.2.2 Soil and Materials Engineering Inc., Phase II Environmental Assessment

Soils and Materials Engineers, Inc. conducted a Phase II ESA of the former Cabot Corporation property in 2014. The assessment activities were funded by the Kokomo Coalition's United States Environmental Protection Agency Brownfields Assessment Grant for hazardous substances. This ESA focused on non-radiological contaminants of concern. This site assessment included the following elements:

- Soil boring and soil sampling.
- Test pit soil sampling.
- Soil boring and groundwater sampling.
- Chemical analyses of samples.
- Geophysical investigation.

A geophysical investigation was conducted using EM61-MK2 and EM31 data collection techniques. A swath of high readings along the northwestern study area boundary as well as a scattering of smaller metal objects, particularly along the western boundary were discovered (SME 2014). It was noted that the area along the northwestern boundary should be considered as possibly containing buried drums or other features of potential concern. It was documented that the grinding wheels were previously stored in the northeast corner of the site (ORAU 1991), and potentially were buried at another location at the site for permanent disposal and containment.

1.3 Report Organization

This report is organized as follows:

- Section 1.0 provides background, site description, and historical investigation.
- Section 2.0 provides a regulatory and scientific overview.
- Section 3.0 provides the objectives and methods of this radiological investigation.
- Section 4.0 presents the data quality assurance/quality control protocol and results.
- Section 5.0 presents the results of the background investigation.
- Section 6.0 presents the results of the site investigation.
- Section 7.0 presents the conclusions.

2.0 REGULATORY AND SCIENTIFIC OVERVIEW

2.1 BACKGROUND ON NATURALLY OCCURRING RADIOACTIVE MATERIAL

Uranium (U-238, U-235) and thorium (Th-232) are primordial naturally-occurring radionuclides. They have been present in the earth's crust since its formation. They are each the parent nuclide in a decay series that includes other radionuclides. The U-238 decay series include longer lived radionuclides U-234, Th-230, and Ra-226, as well as radon (Rn-222) and its short-lived decay products. U-235 constitutes only 0.72 percent by weight of natural uranium. The Th-232 decay series includes Ra-228 and Th-228 as well as Rn-220 and its short-lived progeny. Decay schemes for primordial radionuclides are shown in Figure 2 and Figure 3.

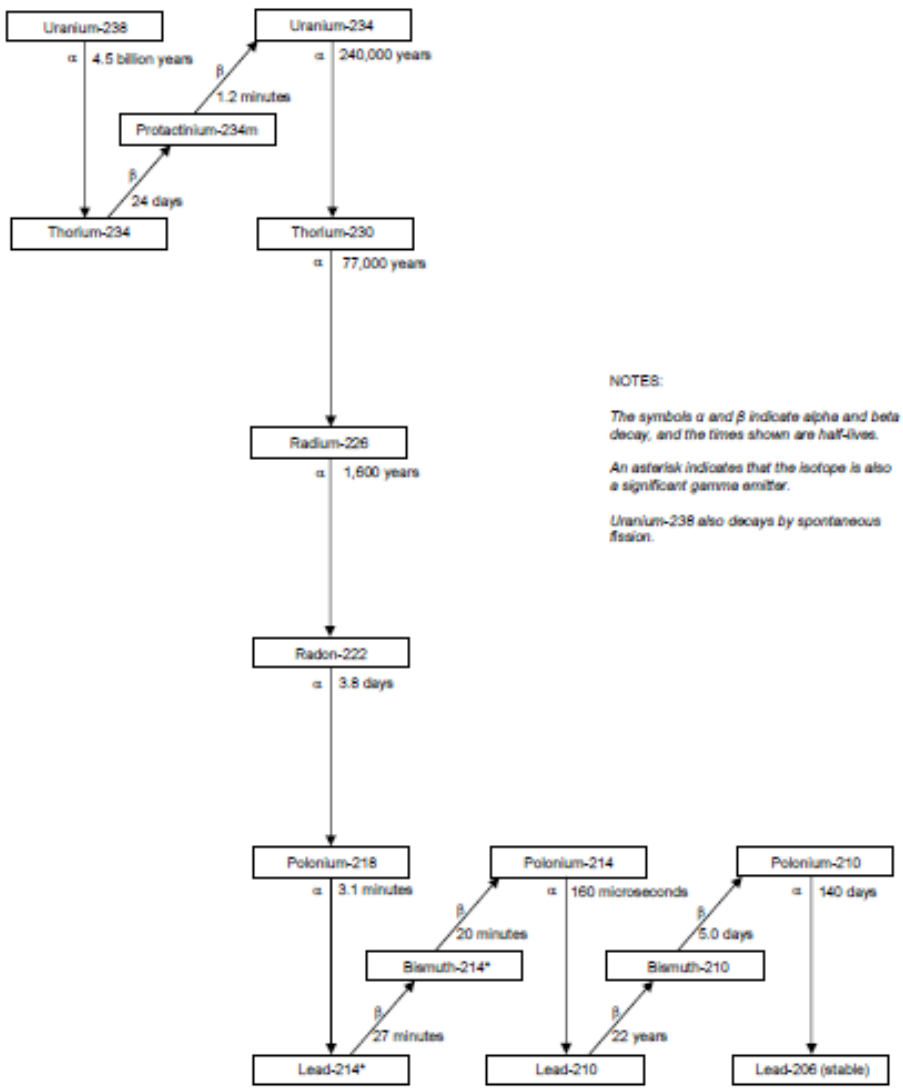

Figure 2 Natural Decay Series of Uranium-238 9 (Taken from Argonne [2014])

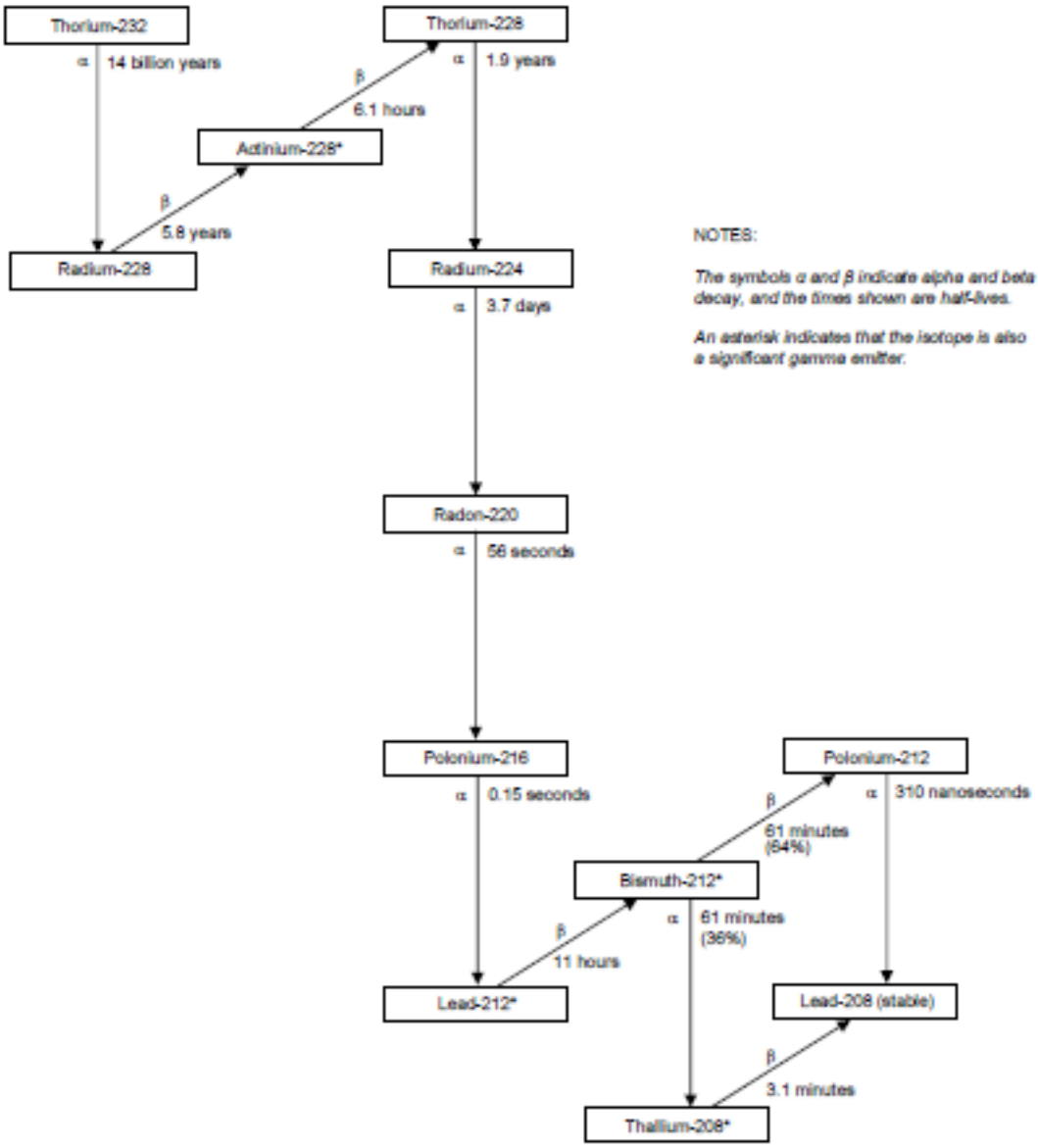

Figure 3 Natural Decay Series of Thorium-232 (Taken from Argonne [2014])

2.2 Terminology and Natural Background Radiation Levels

The amount of radioactivity in a material is expressed in terms of the becquerel (Bq), or more commonly in the United States, the curie (Ci). The Ci is a very large amount of radioactivity, so when natural radioactivity is of concern, the activity is usually expressed in terms of millionths of a Ci (µCi) or trillionths of a Ci (pCi). The activity concentration is expressed as becquerels per kilogram (Bq/kg) or picocuries per gram (pCi/g). The average background activity concentrations in soil are approximately 0.9 pCi/g U-238 and 1.2 pCi/g Th-232 (NCRP 1992).[1]

Radiation doses to humans are generally expressed in terms of millisieverts (mSv), or more commonly in the U.S., in millirem (mrem)[2]. The dose unit represents the amount of energy absorbed in human tissue, the distribution of the energy, and the sensitivity of the whole body or individual organs to radiation. The dose in rem indicates the potential long-term human health risk. Radiation doses to individuals in the U.S. from natural background radiation range from approximately 200 mrem per year (mrem/y) to more than 1,000 mrem/y in high background locations primarily in the Rocky Mountain region. The average background radiation dose in the United States is approximately 310 mrem/y (NCRP 2009). Estimated natural background doses by source are given in Table 1.

Table 1 Annual Average Natural Background Radiation Doses in the U.S. and Indiana

Source	Average U.S. Background (mrem/y) (NCRP, 2009)	Estimated Average Indiana Background (mrem/y)
Cosmic Radiation (radiation from outer space)	33	33[3]
Terrestrial Radiation (radiation from the earth's crust)	21	33[4]
Internal Radiation (from ingestion or inhalation)	29	29
Indoor radon	228	580[5] (Indoor radon dose is highly variable and ranges from 200 to over 1,000 mrem/y, depending on location and specific residence characteristics)
Total	310	675

2.3 National and State Radiation Regulations

Under the Atomic Energy Act and Amendments (AEA) (42 USC 2011 et seq.) the NRC does not have jurisdiction over naturally occurring radioactive material (NORM) or technologically enhanced naturally occurring radioactive material (TENORM) unless it qualifies as source material — natural uranium or

[1] *The internationally accepted units for radioactivity and radiation dose (Bq and Sv) are most often quoted in references; however, this report will use the common units (Ci and rem).*
[2] *One mSv is equal to 100 mrem; one Bq is equal to 27 pCi.*
[3] *Based on the average for the United States (NCRP 2009).*
[4] *Estimated from NCRP (2009) map of annual average terrestrial radiation doses.*
[5] *Calculated based on estimated average screening level radon concentration in Howard County, Indiana homes of < 2 pCi/L to > 4 pCi/L (http://in-radon.info/ accessed 12/13/16) - an average concentration of 3 pCi/L was used for this analysis.*

thorium at concentrations greater than 0.05 percent by weight. For natural uranium at 0.05 percent by weight, the activity concentration of U-238 and each of its decay products is 165 pCi/g; for natural thorium at 0.05 percent by weight, the activity concentration of Th-232 and its decay products is 55 pCi/g. There are several exceptions to this rule, including what the NRC considers "unimportant quantities" (10 Code of Federal Regulations [CFR] 40.13). There is also a special exemption for rare earth products that contain NORM; rare earth materials with NORM concentrations less than 0.250 percent by weight are exempt from regulation under 10 CFR 20 or 10 CFR 40 (10 CFR 40.13(c)(1)). Amendments to the AEA include some forms of NORM such as uranium and thorium processing wastes (11e.[2]) and discrete NORM (11e.[3], 11e.[4]). Transportation of NORM is regulated by the Department of Transportation under 49 CFR 171-173 regardless of the applicability of the AEA. It is up to the states to regulate most NORM that does not qualify as source material or 11e.(2), (3), or (4).

Use and possession of radioactive materials that fall under the purview of the AEA are regulated by the NRC. Certain states have established agreements with the NRC such that they are permitted to regulate all or, in some cases, a portion of, the AEA radioactive materials (these are the Agreement States). Currently, 37 states are Agreement States and have promulgated regulations that are at least as restrictive as the NRC regulations in Chapter 10 of the CFR. Indiana is not an Agreement state, so use and possession of applicable radioactive materials are under the jurisdiction of the NRC. TENORM is not regulated by the NRC; thus, the states have jurisdiction and the responsibility for promulgating regulations that are protective of public health and the environment.

2.4 Grinding Wheels and NORM

In recent years, it has been recognized that materials used or generated in certain industry sectors have higher than average levels of naturally occurring radioactive material [NORM], or may concentrate the NORM into technologically enhanced naturally occurring radioactive material [TENORM] (ASTSWMO 2011). Metal welding and fabrication where metals alloys and products are used may contain thorium series NORM. Furthermore, metal casting, grinding, or sand blasting where foundry sands, grinding wheels from zircon based sands, may contain both uranium and thorium series NORM. Radiation dose to humans from NORM and TENORM is largely driven by radium isotopes from the U-238 and thorium-232 (Th-232) decay chains. Zirconia is used in the manufacturing of abrasives, and these abrasives may be used in grinding wheels. The radioactivity concentration in the raw material in this industry may contain between 4-6 becquerels per gram [Bq/g] or 108-162 picocuries per gram [pCi/g] (Selby 2007). The primary exposure pathways from grinding wheels are external gamma exposure from raw material storage and handling, inhalation from crushing and sizing operations, and further inhalation pathways from the use of grinding wheels (Selby 2007). These raw materials from manufacturing are usually recycled. Other waste from this industry is usually buried in a landfill, as the materials have low external exposure potential and no dust generating properties (Selby 2007).

2.5 State of Indiana Background Radiation Review Summary

An evaluation was performed to determine if any local, regional, or state wide background studies had been done in the State of Indiana or within the vicinity of Kokomo, Indiana. This information is useful for comparative purposes to evaluate the conditions of the site. In the 1970s the Oak Ridge National Laboratory (ORNL) conducted a national study to evaluate the state background radiation levels. The final report was published in 1981 and was titled *State Background Radiation Levels: Results of Measurements*

Taken During 1975-1979 (ORNL 1981). This investigation was performed under Contract No. W-7405-eng-26 under the Health and Safety Research Division of ORNL. The study involved both measurements of external gamma exposure rates as well as collection of soil samples for radionuclide analyses. Two measurements were performed in the State of Indiana as part of this study with reported exposure rates of 6.0 µR/hr and 7.1 µR/hr. Similarly, the ORAU study at the site described in Section 1.2, specified that regional background levels for external gamma exposure rate was 8.0 µR/hr (ORAU 1991), though it is unclear how ORAU established this value.

3.0 OBJECTIVES AND METHODS

This section briefly describes the primary objectives of this investigation and presents the rationale for selection of appropriate radioanalytical methodologies and technologies used to supplement the overall investigation.

3.1 PROJECT OBJECTIVES

As described in ORAU (1991) and presented in Section 1.2, radioactive materials have been discovered at the site in the past. These materials were reported as depleted uranium and thoriated grinding wheels. The Final Status Survey conducted by ORAU in 1991 was reviewed by Tetra Tech. This review found the survey methods used were consistent in data quality, survey design, documentation, and detail that meet current standards. Survey measurements obtained during this phase of the project may be useable in describing the final site conditions, if the location where those measurements were collected has not been subject to subsequent activities that may have altered the radiological status of the site (NRC 1992). However, as noted in ORAU (1991) the survey noted a number of anomalous readings at the site attributed to sources that remained at the site and had yet to be disposed. The SME (2014) Phase II ESA showed potential anomalous readings indicating buried near surface metallic objects. A more advanced gamma radiation survey prior to future development was deemed necessary to assess the existing surficial site conditions. Newer technologies that were not available at the time of the ORAU survey include survey systems using integrated mobile sensors with positioning systems. Tetra Tech was tasked to conduct a gamma radiation survey at the property to evaluate current site conditions and determine whether anomalous radiation levels are present above background levels or of concern to human health and the environment. The primary scope of work is as follows:

- Conduct a gamma radiation survey using mobile GPS-integrated scanning systems across the Washington Street Quarry property. The purpose of this survey was to obtain a comprehensive set of data for comparative purposes to better understand the spatial extent of external gamma exposure rates across the site and to identify potential areas of contamination or to guide future soil sampling.

- Selection of radiological background reference areas within the region to meet specified criterion. Conduct a gamma radiation survey of the selected radiological background reference areas using the same methodology for gamma radiation surveys used at the Washington Street Quarry.

- Conduct a data analysis to statistically evaluate the gamma exposure data collected at the site compared to expected ambient levels from the region and to assess the potential for surface contamination from the historical operations at the site.

- Evaluation of the gamma radiation survey characterization data and identify the estimated limits of soil contamination, if any exist.

- Conduct a dose rate correlation study using a microrem meter (Bicron) in order to provide a correlation between gamma exposure rate and gamma dose rate for the site.

The following subsection presents the gamma radiation survey methods.

3.2 GAMMA RADIATION SURVEY

3.2.1 Overview

The contaminants of concern at the former Cabot Corporation Washington Street Quarry property are radioactive materials [e.g. 11(e)(2) byproduct material and TENORM] associated with the past land use practices at the site. Specific hazardous materials potentially present include depleted uranium and thoriated grinding wheels. The NORM within surface soils potentially consist of uranium decay products and thorium decay products and more specifically from a regulatory standpoint the primary contaminant to measure is Ra-226. Ra-226 is the sixth member of the uranium series which starts with uranium-238 (U-238) and ends with stable lead-206 (Pb-206). Ra-226 is produced by the disintegration of thorium-230 (Th-230). The gamma ray activity of Ra-226 itself can usually be neglected as it is so small; however, Ra-226 decays into radon (Rn), an inert gas, which then decays into polonium-218 (Po-218 or "Ra A"), followed by lead-214 (Pb-214 or "Ra B"), followed by bismuth-214 (Bi-214 or "Ra C"), and finally into polonium-214 (Po-214 or "Ra C") before continuing decay of the series leading to stable Pb-206. Approximately 95 percent of the gamma exposure from the U-238 decay series comes from the Pb-214 and Bi-214 decay products.. On open ground, about two-thirds of the gamma radiation dose comes from radionuclides contained in the top 15 cm of soil (NRC 1994). The prominent gamma ray lines coming from these Ra-226 and Rn decay series can be detected using appropriate instrumentation and tied back to the Ra-226 concentrations present in surface soils. At the time the previous radiological study was conducted, GPS-based gamma survey technologies were not available. In recent years, the advent of such new technologies has introduced mobile sensor systems for acquiring data that include fully integrated global positioning systems (GPS) (NRC 2000). Portable versions of these systems can now record survey data while moving over surfaces to be surveyed, simultaneously recording locations from a GPS receiver (NRC 2000).

The ORAU survey performed in 1991, involved the collection of direct (static) gamma exposure rate measurements across the property. Direct gamma radiation measurements can be accomplished in several ways, including passive methods, direct measurements and scanning methods (NRC 1980). Scanning refers to a portable mobile radiation detection system moved across the surface of the study area at a specified rate, with the intent of identifying elevated radiation levels or radionuclide concentrations (NRC 2000). For this investigation, Tetra Tech designed a survey to achieve a greater coverage area compared to individually-recorded direct gamma radiation measurements as was performed by ORAU in 1991. Another objective of the gamma radiation survey performed by Tetra Tech was to cross-calibrate the energy-dependent detectors used to a less energy-dependent detector, which is described in the following Section 3.3. Additionally, Tetra Tech used geospatial techniques to create continuous radiation maps of the sampling areas as described in Section 3.4.

The objective of the overland continuous gamma radiation survey was to characterize and quantify site-specific levels of radiation at the Washington Street Quarry property. This objective was achieved by scanning the large land area using mobile gamma survey systems with integrated GPS systems, as described in the Multi-Agency Radiation Site Survey Investigation Manual (MARSSIM) (NRC 2000). All measurement data were automatically stored with the measurement locations for later post-processing, data interpretation, and subsequent mapping. The survey methods used for this investigation were intended to meet requirements set forth in MARSSIM (NRC 2000). The gamma survey procedures are described in Section 3.2.2, including scan speed, scan pattern, and spacing of the measurements.

3.2.2 Methods

The objective of the outdoor GPS-based gamma radiation survey was to characterize the site-specific external gamma exposure rate measurements and the background levels of radiation across a number of different radiological background reference areas. There are a variety of principal instrument types for assessing the radiation field from background. *In situ* gamma radiation surveys are preferred to measure the radiation levels over the areas of interest due to cost effectiveness and collection efficiency. Instruments consisting of scintillation detectors with NaI crystals are the most common detector used for gamma detection from gamma-emitting radionuclides (NRC 2002). Outdoor gamma surveys are most commonly conducted with thallium-doped sodium iodide (NaI[Tl]) scintillation instruments (NaI detectors) (Alecksen and Whicker 2016). The NaI(Tl) is the favorite and most widely applied among inorganic alkali halide crystals used for light scintillation of radiation (Knoll 2010). Use of GPS-based gamma radiation survey systems has become a mature methodology for characterizing the spatial distribution of gamma radiation caused by naturally occurring radioactive materials (NORM) in soils (see for example Adsleya and others 2004; Johnson and others 2006; Meyer and others 2005; Vitkus and Bailey 2007; Whicker and others 2008). Selection of radiation instrumentation used for the gamma radiation survey was based on compliance with Section 4.5 of NUREG-1505 (NRC 1998a), NUREG-1507 (NRC 1998b), and MARRSIM (NRC 2000).

The gamma radiation surveys were performed in accordance with SOP-1 provided in Appendix B. Tetra Tech used mobile backpack scanning systems consisting of 2-inch-by-2-inch Ludlum 44-10 NaI detectors and Ludlum 2350-1 data loggers coupled with GPS sensors using the Wide Area Augmentation System (WAAS), providing GPS signal correction to enhance position accuracy to within ±2 meters. NaI detectors are used to scan areas for gamma emitters because they are highly sensitive to gamma radiation and easily portable. A scanning rate of 0.5 meters per second (m/s) (about 1 mph) was used for distributed gamma emitting constituents (NRC 2000). The gamma radiation data were transmitted once per second to a portable computer and logged using proprietary logging and mapping software (Tetra Tech 2013). The GPS-based scanning technologies used for this project were consistent with NRC licensing and decommissioning guidelines (NRC 1982, 2003) and radiological survey guidelines outlined in MARSSIM (NRC 2000). As required by 10 CFR 40.42(j)(2)(i), gamma exposure rate measurements were recorded in microroentgen per hour (µR/hr) at a 1 meter height above the ground surface (NRC 1994, 2003). Scan density of 100 percent was achieved for all of the gamma radiation surveys conducted for this project, with scan transects spaced approximately 2 meters apart in width. As required by 10 CFR 40.42(j)(2)(i), gamma exposure rate measurements were reported in µR/hr, and were taken at a 1 m height above the ground surface (NRC 1994, 2003). An important component of the survey was to achieve the scan height of 1 meter above the ground surface and scan speed of 0.5 m/s consistently across the preoperational area. This detector height is commonly used for baseline radiological studies (OSD 2012; EPA 1999) as seen in other projects (ERG 2009a, 2009b; Tetra Tech 2010; NRC 1992).

MARSSIM (NRC 2000) recommends that instruments be selected that are suited to the physical and environmental conditions at the site. The instruments must be capable of detecting the types of radiation of concern to the appropriate minimum detectable concentration (MDC). The scan MDC for land areas is based on the areal extent of the hot spot, depth of the hot spot, and the radionuclide of interest (NRC 1998b). A scan speed of 0.5 m/s at a detector height of 1 meter was achieved for all of the gamma radiation surveys performed for this investigation. The approximate detection sensitivity for Ra-226 with a 2-inch by 2-inch NaI gamma scintillation detector under the conditions described is 2.8 pCi/g. This MDC

was determined following the guidance in NUREG-1507 (NRC 1998b) using nominal literature values for background, response, and site conditions.

NaI(Tl) detector systems exhibit energy-dependent response characteristics, as shown in Figure 4; the radiation energy spectrum associated with background radiation from soils found at typical NORM and TENORM sites can be adequately characterized using these systems. Tetra Tech's experience at similar sites indicates that NaI(Tl) detector response to significant above-background gamma radiation sources near the ground surface ranges horizontally to about 2 meters, giving the detector an estimated ground surface field of view about 4 meters in diameter.

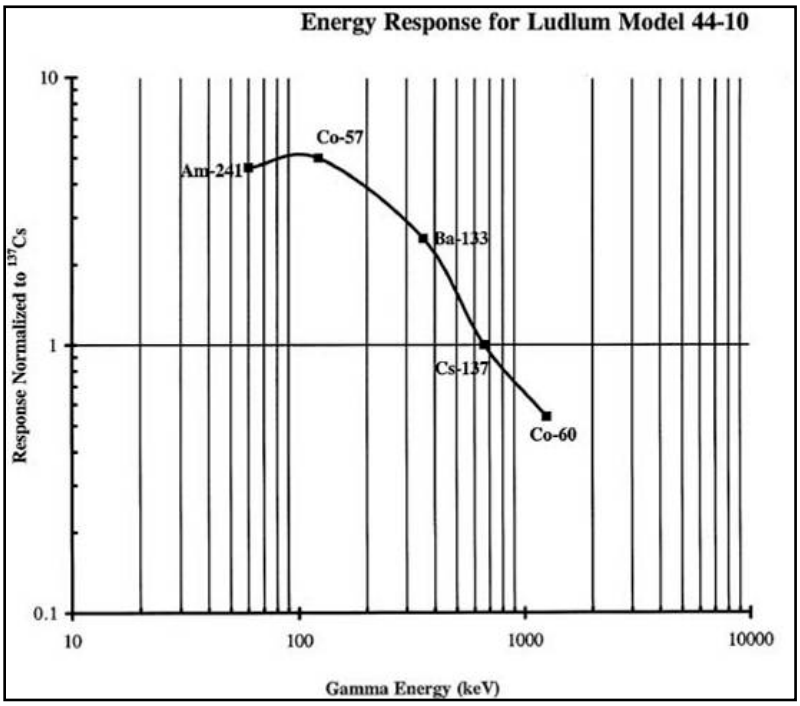

Figure 4 Energy Response for Ludlum Model 44-10 with Cs-137 Source

The radiation detection instruments were factory-calibrated within the preceding 12 months as recommended by the manufacturer (Ludlum Inc.). All members of the gamma survey field crew were trained and experienced in radiation measurement surveys. The gamma radiation survey quality assurance/quality control (QA/QC) methods are described in Section 5.0. The results of the gamma radiation survey are presented in Section 6.0 and Section 7.0. Copies of the Ludlum calibration documents are included in Appendix C.

3.3 Dose Rate Correlation Study Methods

3.3.1 Overview

The GPS-based radiation instruments (thallium doped sodium iodide [NaI(Tl)] detectors) used for this baseline investigation are commonly used for outdoor gamma surveys (Alecksen 2016). These types of instruments represent a widely accepted and applicable technology for characterization of spatial distributions of gamma radiation caused by naturally occurring radioactive material at all types of uranium

facilities. These systems are ideal for their durability, portability, sensitivity, and cost. Some limitations are associated with NaI detectors: their response characteristics vary with photon energy (Whicker and Chambers 2015), which can introduce analytical errors during later comparisons to measurements made with other instrument types. This limitation may be problematic when evaluations of external radiation doses to workers or the public are needed (Whicker and Chambers 2015) or when radiological surveys are conducted at later times. One way to mitigate the drawbacks of the energy dependent system is to conduct site-specific cross-calibration studies, to normalize NaI detector readings to a less energy-dependent instrument. There are a number of different instruments available that are appropriate for such a cross calibration study. Figure 5 provides energy response curves for a variety of different gamma radiation detection instruments, any of which might be used in the field to achieve the objectives of the site-specific cross-calibration.

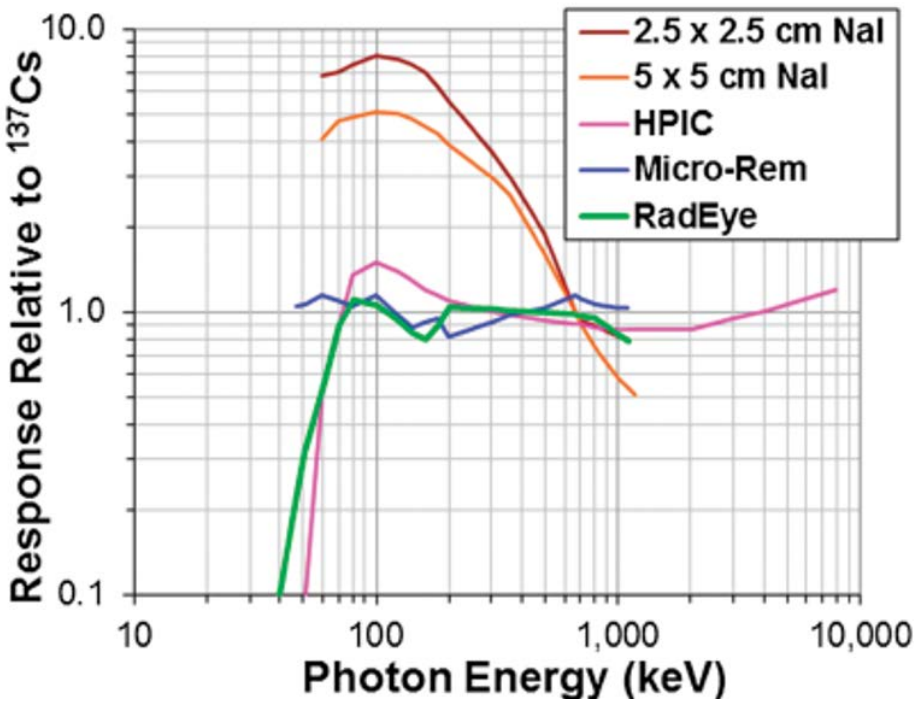

Figure 5 Energy Response Curves for Radiation Instrumentation (from Whicker and Chambers [2015])

The Bicron Micro-Rem meter has similar response characteristics to that of the high pressurized ionization chamber (HPIC) for photon energies 60 keV to 1 MeV and is suited for conducting site-specific cross calibration studies, based on its relatively "flat" energy response across a wide range of photon energies. Section 1.1.5 of Regulatory Guide 4.14, Revision 1 (NRC 1980) specifies gamma exposure rate measurements should be made with passive integrating devices, pressurized ionization chambers, or property calibrated portable survey instruments (NRC 1980). While the HPIC provides the flattest energy response curve compared with other field instruments, it is inconvenient for field use. Therefore, for this project a Bicron Micro-Rem meter was selected to perform the cross calibration analysis. The primary purpose of the cross-calibration study is to calculate the statistical relationship between the more energy dependent NaI(Tl) gamma exposure rate measurements and the HPIC gamma exposure rates. Section 3.3.2 describes the cross calibration methodology followed for the baseline preoperational characterization of gamma radiation across the Washington Street Quarry.

3.3.2 Methods

To perform the Bicron/NaI cross calibration study, continuous gamma measurements were collected across the site, as described in Section 3.2.2 and Appendix B. Data interpretation was used to select a range of plot locations covering the range of gamma exposure rates observed for the site. After the locations were identified using the gamma radiation survey data, locations were selected by the lead radiological field engineer. The center of the sensitive volume of the Bicron was positioned 1 meter above the ground surface at each location, and minimum of 10 readings were measured by the field engineer at each measurement location. The location directly below the Bicron measurement location was marked, and personnel equipped with a backpack-mounted NaI system positioned the detector above the marked location. A 10 second average from the static NaI system using the scanning were logged and averaged. These data pairs were then used to establish the cross-calibration correlation regression model presented in Section 6.3.

3.4 Radiological Background Reference Area

Background ionizing radiation consists of four major sources: terrestrial, cosmic, cosmogenic, and man-made. Terrestrial radiation produces the largest dose to people living in the United States. The remaining three components are relatively minor contributors to the dose from background at sea level compared with terrestrial radiation (NRC 1994). (Indoor radon derived from terrestrial sources of Ra-226 contributes more than two-thirds of the total radiation dose to individuals.) Virtually all materials found in nature have some natural radioactivity. Rocks, soil, water, plants, and animal life all have varying degree of terrestrial radionuclides (NRC 1994). The most significant of these are naturally occurring (such as uranium, thorium, and potassium). Differences in the distribution of both naturally occurring and anthropogenic caused gamma-emitting radionuclides within the terrestrial environment (such as in soil) can be found across sites locally and across the U.S. The concentrations of terrestrial radionuclides vary from place to place in much the same way that mineral deposits can be expected to vary from geologic processes over time; the variation in total gamma radiation levels among sites relates directly to the concentrations of principal gamma-emitting radionuclides in the local soil (NRC 1994).

Background radiation levels should be established from appropriate reference areas and include assessment of exposure rates in various media (Abelquist 2001). The final status survey design review recommended in MARSSIM (NRC 2000) includes the selection of background reference areas and background level determinations. The selection of the reference areas is an important factor that must be considered when comparing on-site Washington Street Quarry radiation exposure rates that could be affected by anthropogenic activities, including the historical activities at the quarry. Tetra Tech conducted a preliminary historical review to evaluate the background radiation for the State of Indiana as presented in Section 2.5. There were two values reported (6.0 µR/hr and 7.1 µR/hr); however, these values were not site-specific or located in the same region and therefore cannot be used for comparative purposes of the data collected at the Washington Street Quarry. Further review, showed available information for regional background radiation level that was presented in ORAU (1991), but not enough information to conduct a comprehensive comparative statistical analysis to determine if the site radiation levels exceed background. The ORAU (1991) study indicated the background radiation for the site is 8.0 µR/hr, but it is unclear how this value was developed.

Tetra Tech conducted a site-specific background investigation. This investigation was designed to provide regional background information for comparative purposes to evaluate the radiation levels collected at the Washington Street Quarry property. The criteria followed in the selection of the radiological background reference areas (RBRA) are as recommended by a number of different sources of information (NRC 1994, 1992, 2000). The use of more than one background reference area are commonly used for the purposes of decommissioning (Albequist 2001). The criteria and considerations followed by Tetra Tech in the selection of appropriate RBRA locations included: (1) the background reference location should be non-impacted by site operations; (2) the background reference location should be representative of the Washington Street Quarry property; (3) the background reference location should have similar radiological, geological, hydrogeological and biological characteristics as the Washington Street Quarry property. Since geologic data for the site was not readily available a database was obtained containing land use and soil properties from the United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS) web soil survey. A data set of a digital soil survey was obtained. It is generally the most detailed level of soil geographic data developed by the NRCS (USDA 2016). The data include a geo-referenced digital map data set and computerized attribute data. This information was reviewed prior to field deployment in order to evaluate potential RBRA locations. Based on the digital maps, the site is primarily classified as *Made land* which is typically associated with a fill material which was brought from an offsite source which is consistent with the information in the historical review conducted by Tetra Tech. A small portion of *Genesee Silt Loam* also occurs within the property boundary. Therefore, the RBRAs selected, were intended to include either or both of these soil types. A total of eight RBRAs within three different park systems were identified for consideration. The three park systems included Foster Park, Kautz Field, and Harrison Park ranging in size between 0.04 acres to 0.71 acres in size. All of the RBRA locations were within 0.5 miles of the main site. Table 2 provides a summary of the different RBRAs selected including size, distance from main site, and primary soil type. Harrison Park was selected due to its proximity of the main site and similar topographic and land use characteristics; however, the indicated soil type was a silt loam, similar to that found at the main site.

Table 2 Summary of Radiological Background Reference Areas

Radiological Background Reference Area ID	Surface Area	Distance from Main Site	Primary Soil Type
	Acres	miles	
Foster Park 1	0.52	0.32	Genesee Silt Loam
Foster Park 2	0.71	0.23	Genesee Silt Loam
Foster Park 3	0.28	0.21	Genesee Silt Loam
Kautz Field 1	0.58	0.40	Made land
Kautz Field 2	0.52	0.45	Made land
Kautz Field 3	0.37	0.49	Made land
Harrison Park 1	0.30	0.42	Crosby silt loam
Harrison Park 2	0.04	0.44	Crosby silt loam

A map showing the RBRA locations with respect to the Washington Street Quarry property is provided on Figure 6. A map showing the regional soil types is provided on Figure 7. The following subsection presents the geostatistical methods used for data visualization. The results of the gamma radiation surveys conducted in the RBRAs is provided in Section 5.0.

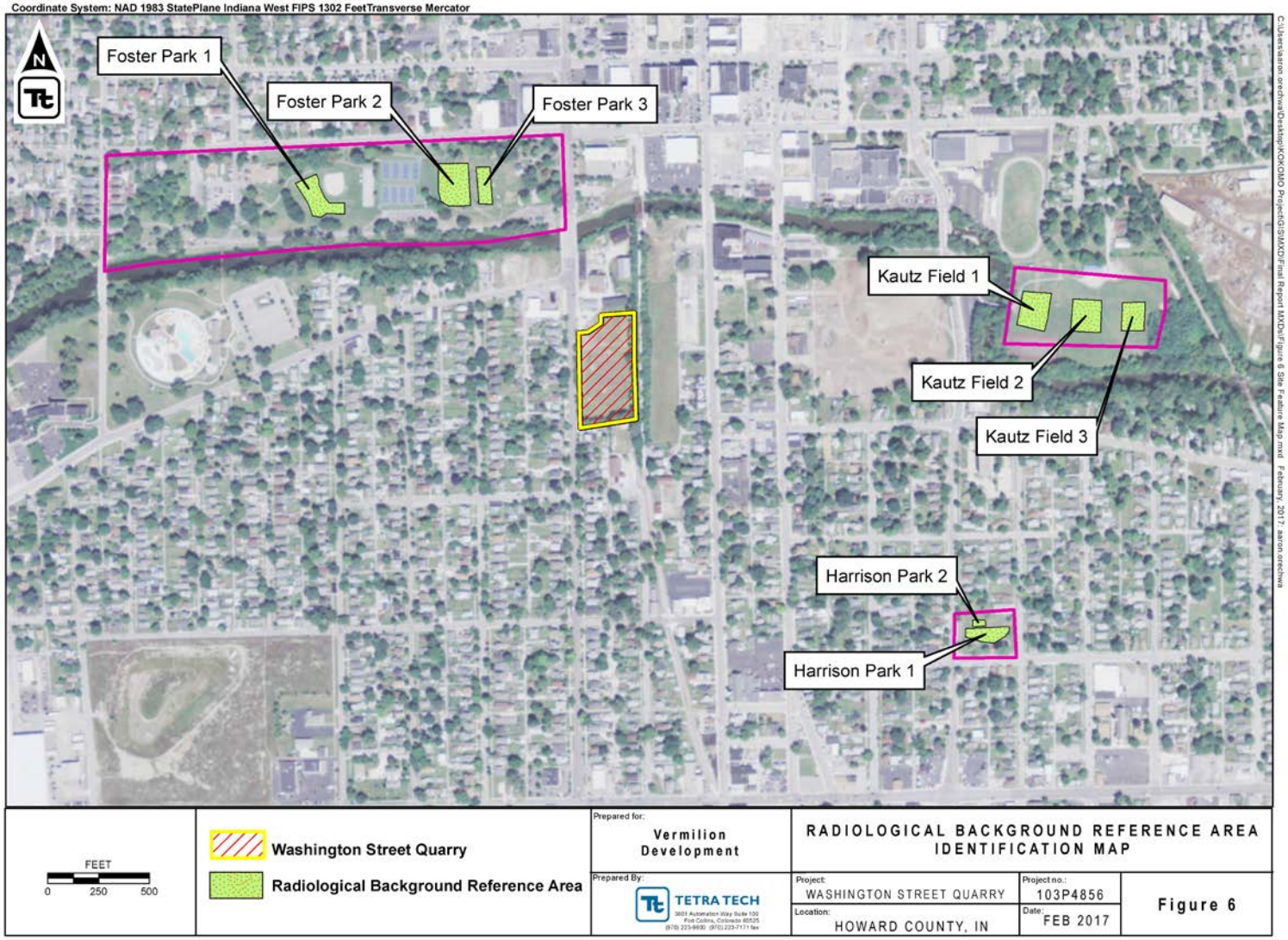

Figure 6 Radiological Background Reference Area Identification Map

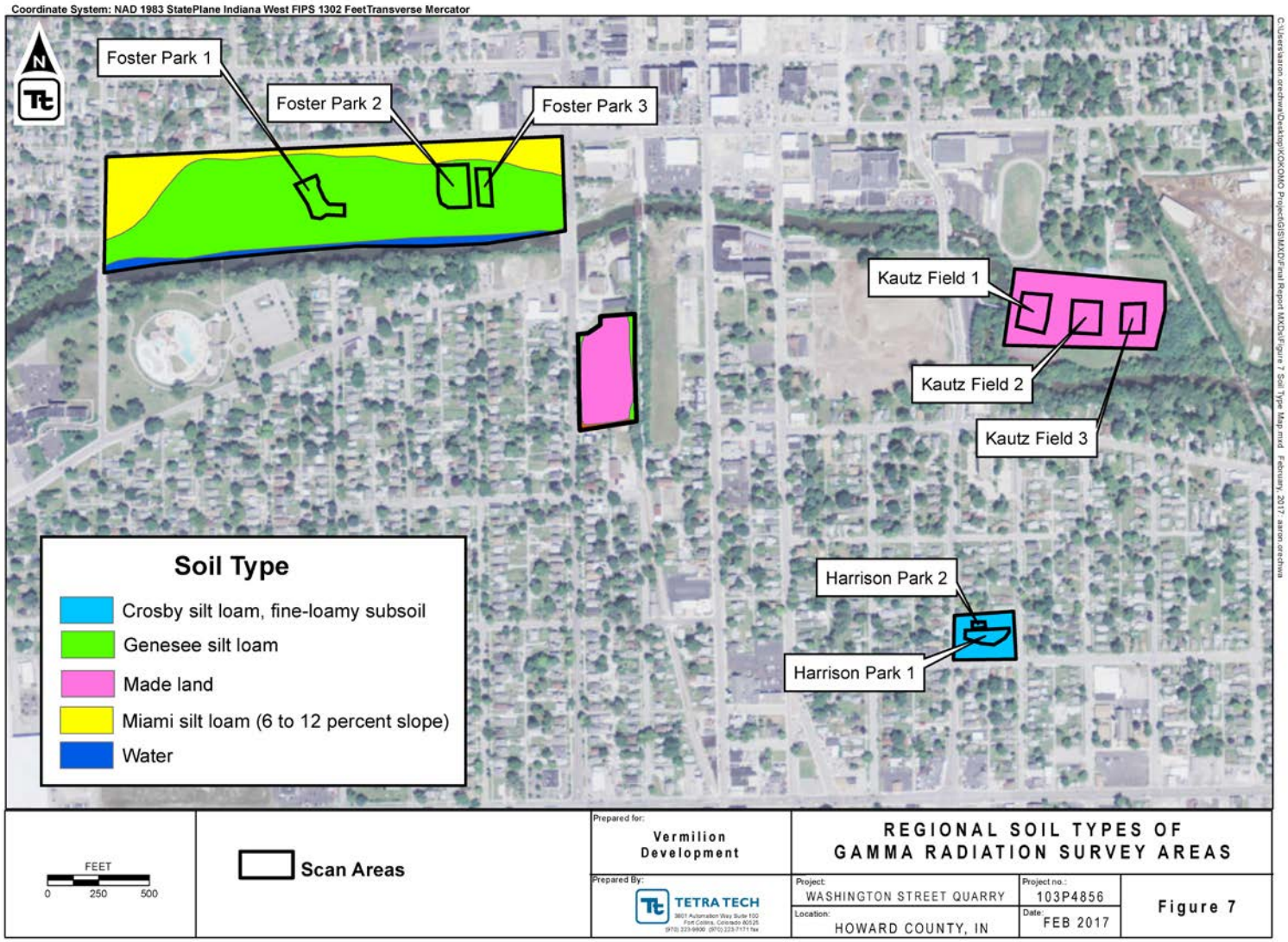

Figure 7 Regional Soil Types of Gamma Radiation Survey Areas

3.5 GEOSTATISTICAL METHODS

Kriging is a method of interpolation that has become an important fundamental tool in the field of geostatistics and earth sciences over the past several decades. The technique of kriging was named after Daniel G. Krige (Krige and Magri 1982), a South African mining engineer who developed the geostatistical tool in an attempt to more accurately predict ore reserves and mineral resources. There are three types of kriging: ordinary, simple, and universal. The kriging results are displayed on a grid or mesh and provide detailed informative characterizations of parameters across an entire site. For this study, the kriging process was applied to gamma radiation survey data, radionuclide soil concentration data and dose rate data collected at the Site.

Tetra Tech used ArcGIS Geostatistical Analyst to perform all kriging analysis on the radiological data sets. The exploratory spatial data analysis tools contained within ArcGIS Geostatistical Analyst allow an engineer specializing in geostatistics to visualize and explore the data sets using various geostatistical methods, to best determine which model and parameters most accurately represent the data. In addition to prediction mapping, ArcGIS Geostatistical Analyst allows for mapping of prediction uncertainties and errors, and provides validation and cross-validation tools that allow the analyst to evaluate the specific model employed and the corresponding predictions. Multiple kriging scenarios were evaluated for the gamma exposure rate maps and soil radionuclide maps presented in Section 6.1. The most appropriate model scenario was selected via the ArcGIS tools, based on a number of criteria prior to final model selection and presentation of the data.

4.0 DATA QUALITY ASSURANCE AND QUALITY CONTROL

This section presents the data collection procedures and the Quality Assurance/Quality Control (QA/QC) protocols applied as part of the radiological investigation study at the Washington Street Quarry.

4.1 GAMMA RADIATION SURVEY QUALITY CONTROL PROTOCOL

All radiological survey projects conducted by Tetra Tech incorporate data QA/QC protocols developed to achieve guidelines established by MARSSIM (NRC 2000). In general, QA includes qualitative factors that provide confidence in the results, while QC involves quantitative field evidence that supports the validity of results. Data quality indicators as recommended in MARRSIM (NRC 2000) and MARLAP (NRC 2004) were used to ensure the data being collected are reliable and of sufficient quality. Tetra Tech utilized GPS-based gamma scanning systems with automated electronic data acquisition software for the gamma radiation surveys described in Section 3.2 and in Appendix B. This type of technology allows for a large amount of radiological data to be collected during the survey. The QA/QC survey procedures used for this investigation are widely used and exceed typically accepted QC techniques for characterization of gamma radiation in the uranium industry. Detailed QA/QC procedures and results of the data validation analysis for the gamma radiation surveys are presented here. Under the QC program, factory-calibrated instruments met on-site field-test criteria (e.g., calibration checks). Tetra Tech field personnel collected quantitative measurements as part of the QC program including:

1. Pre-survey field instrument calibration checks.
2. Daily field instrument calibration checks.
3. Post-survey field instrument calibration checks.

A detailed explanation of the QC methods for the radiation instrumentation, including data validation testing, QC acceptance limits, and results of the calibration checks, is presented in the following subsections. The two primary QC methods for the gamma radiation survey outlined in the report include daily field calibration checks and pre-survey and post-survey calibration checks.

4.1.1 Daily Field Check Instrument Calibration QC Acceptance Limits

For normally distributed data, 99 percent of all measurements are expected to fall within ±3 standard deviations from the mean. Background, field strip, and check source standard deviation values were calculated twice daily throughout the project. Any instrument with a QC measurement result falling outside ±3 standard deviations from the mean of all QC measurements on the field check control chart would require investigation. A detector exceeding control limits on any QC check (background or field strip) is replaced with a different pre-qualified spare detector and sent back to the manufacturer (Ludlum) for evaluation, repair, and recalibration. The data collected from that particular detection system will be flagged for further investigation and removed from the project database as necessary. The results of the daily field checks are provided in Section 4.3.

4.1.2 Pre-survey and Post-Survey Instrument Calibration Check QC Acceptance Limits

The Relative Percent Difference (RPD) is calculated between the mean pre-survey and mean post-survey background and Cs-137 response gamma exposure rate for each instrument used in the survey. The QC acceptance limit is an RPD of less than 10 percent for all radiation survey instruments. Additionally, a parametric analysis is performed on the pre-survey and post-survey data sets for both background and Cs-137 response gamma exposure rates. The Anderson-Darling (AD) statistic is used to assess how well the data follow a particular distribution. For the gamma radiation instrumentation, the data should follow a normal distribution under controlled conditions. The corresponding p-value must be greater than 0.05 in order to accept the null hypothesis that the data follow a specified distribution. For the purposes of the QC data validation testing, the data are plotted on a normal distribution probability plot and the AD statistic and corresponding p-value are calculated using the statistical software Minitab. All of the pre-survey and post-survey data must have a p-value exceeding 0.05 for the instrument data to be considered reliable. The results of the pre-survey and post-survey calibration checks are provided in Section 4.3.

4.2 Gamma Radiation Survey Quality Assurance Protocol

The QA protocol includes instrument calibration. All of the radiation detection instruments employed during the field work were calibrated by an accredited laboratory within the previous 12 months as recommended by the manufacturers. Data developed with the field-qualified instruments are then interchangeable, allowing instrument substitution as needed. Copies of factory calibration documentation for the detectors used during the surveys are provided in Appendix C. Information relating to the field conditions and gamma radiation survey QC calibration checks were recorded in the daily field logbook. All of the radiation instruments used for this project were calibrated according to the QA goals set forth for this project. Appendix C provides the factory calibration documentation for all radiation instrumentation used during the investigation.

4.3 Gamma Radiation Survey QA/QC Results

The QC acceptance criteria for this project are discussed in Section 4.1. Figure 8 through Figure 10 present the QC charts for the background, field strip, and Cs-137 source daily calibration checks conducted during the survey. Table 3 and Table 4 present the pre-survey and post-survey results for the background and Cs-137 source calibration checks, respectively. Figure 11 and Figure 12 present the frequency histogram and probability plots for the background pre-survey calibration checks, respectively. Figure 13 and Figure 14 present the frequency histogram and probability plots for the Cs-137 source pre-survey calibration checks, respectively. The data validation and QC review concluded that the gamma survey portion of the baseline radiological monitoring program meets the project's QC acceptance criteria. All of the pre-survey and post-survey gamma radiation survey calibration checks, and all of the daily field calibration checks, were within the control limits and, therefore, met the QC acceptance criteria. In summary, the gamma radiation survey data collected for this project met all QC acceptance criteria specified for this project; the data should be considered to be reliable and of sufficient quality.

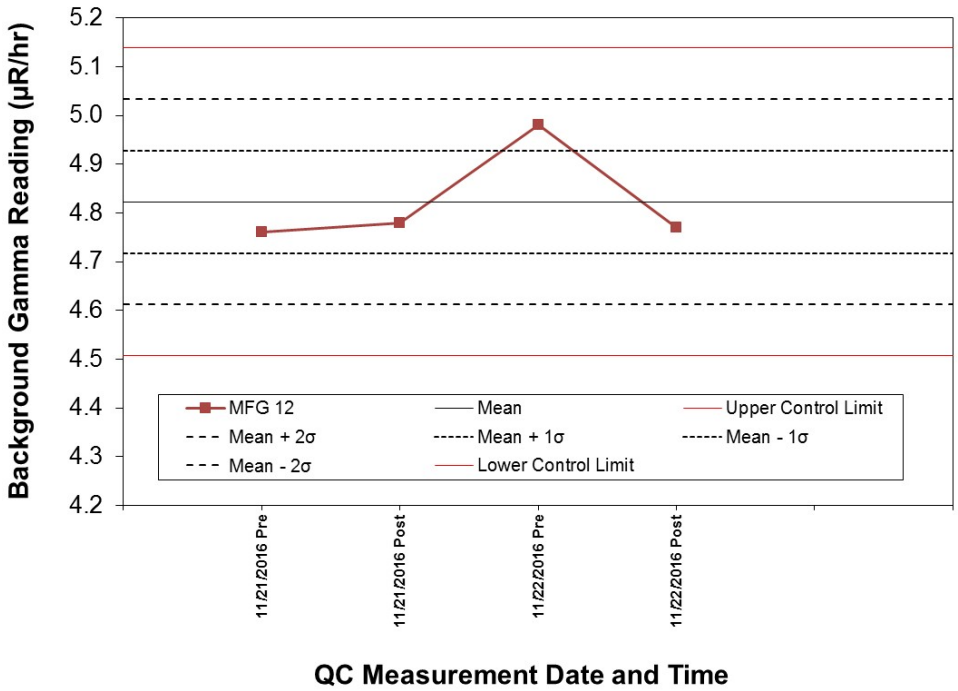

Figure 8 Daily Quality Control Calibration Check (Background)

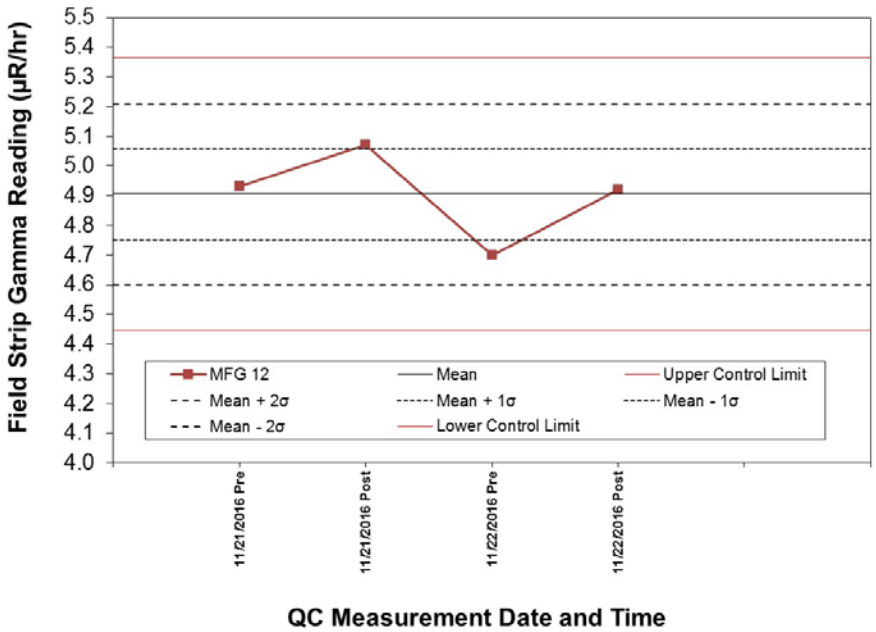

Figure 9 Daily Quality Control Calibration Check (Field Strip)

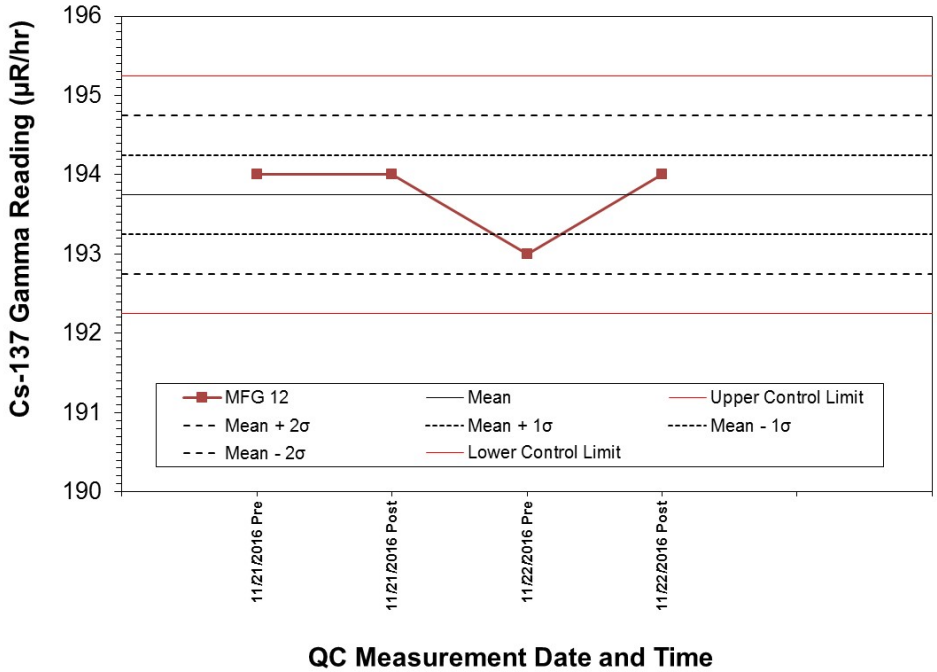

Figure 10 Daily Quality Control Calibration Check (Cesium-137)

Table 3 Summary of Pre-Survey and Post-Survey Background Calibration Checks (Background)

Survey:	**Pre-Survey**	**Post-Survey**	**Relative Percent Difference**
Date:	**May-16**	**December-16**	
Detector ID:	**MFG-12**		
# of Readings	1,000	1,000	-
Average (µR/hr[1])	16.7	16.9	1.37%
Median (µR/hr)	16.7	17.0	1.58%
Standard Deviation (µR/hr)	0.85	0.86	0.95%
95th Percentile (µR/hr)	18.1	18.3	1.25%
99th Percentile (µR/hr)	18.7	18.9	0.88%

Note:
1 µR/hr = microroentgens per hour

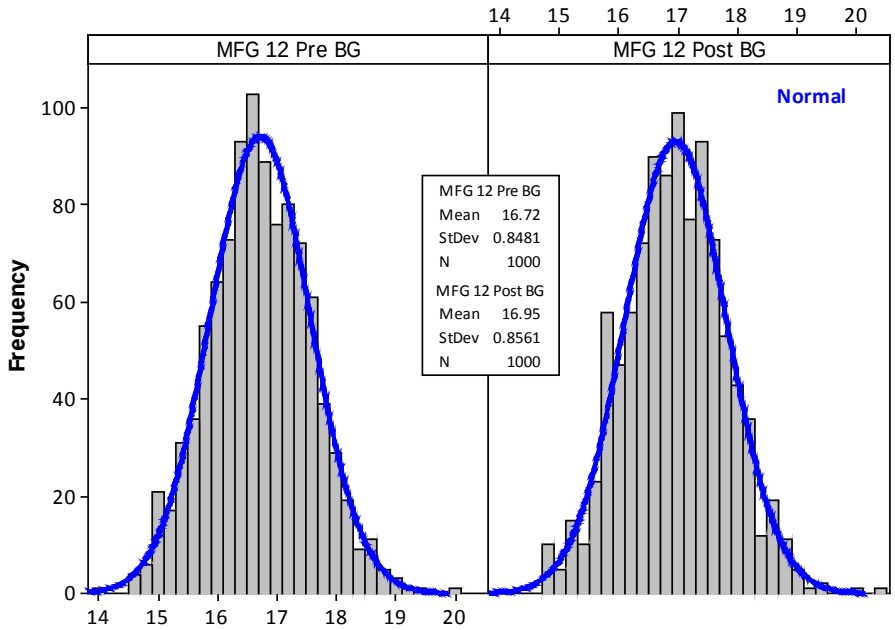

Figure 11 Frequency Histograms of Pre-Survey and Post-Survey Calibration Checks (Background)

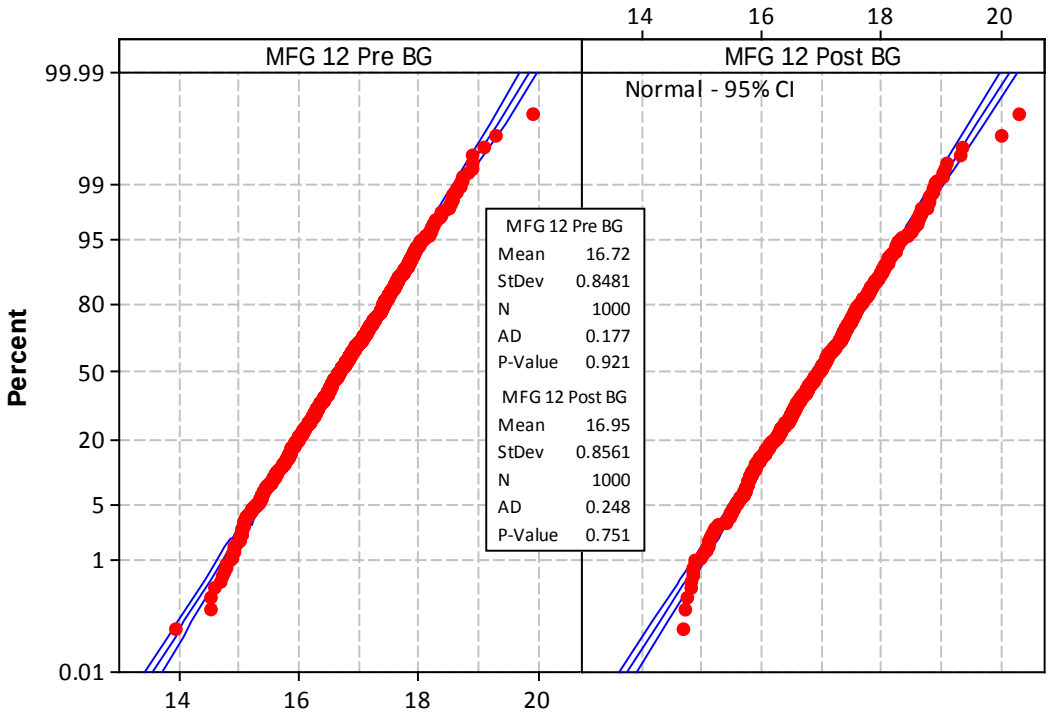

Figure 12 Probability Plot of Pre-Survey and Post-Survey Calibration Checks (Background)

Table 4 Summary of Pre-Survey and Post-Survey Background Calibration Checks (Cs-137 Source)

Survey:	Pre-Survey	Post-Survey	Relative Percent Difference
Date:	May-16	December-16	
Detector ID:	MFG-12		
# of Readings	1,000	1,000	-
Average (µR/hr[1])	214.4	209.6	2.26%
Median (µR/hr)	214.4	209.5	2.27%
Standard Deviation (µR/hr)	3.05	3.04	0.43%
95th Percentile (µR/hr)	219.3	214.7	2.10%
99th Percentile (µR/hr)	221.6	216.7	2.26%

Note:
1 µR/hr = microroentgens per hour

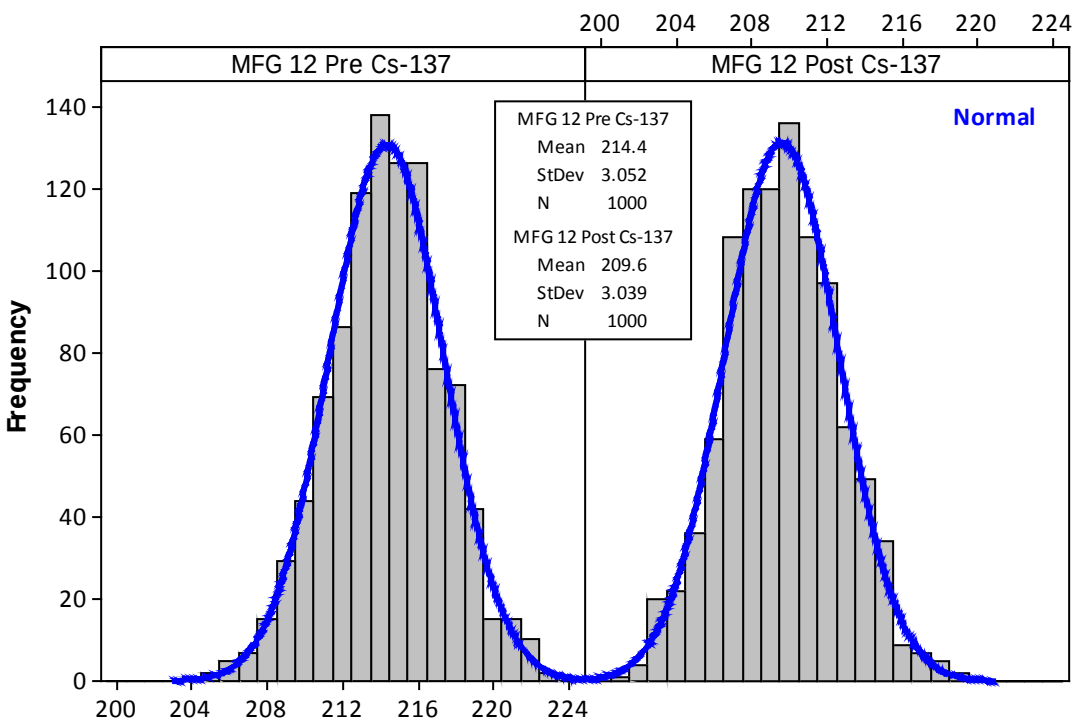

Figure 13 Frequency Histograms of Pre-Survey and Post-Survey Calibration Checks (Cs-137 Source)

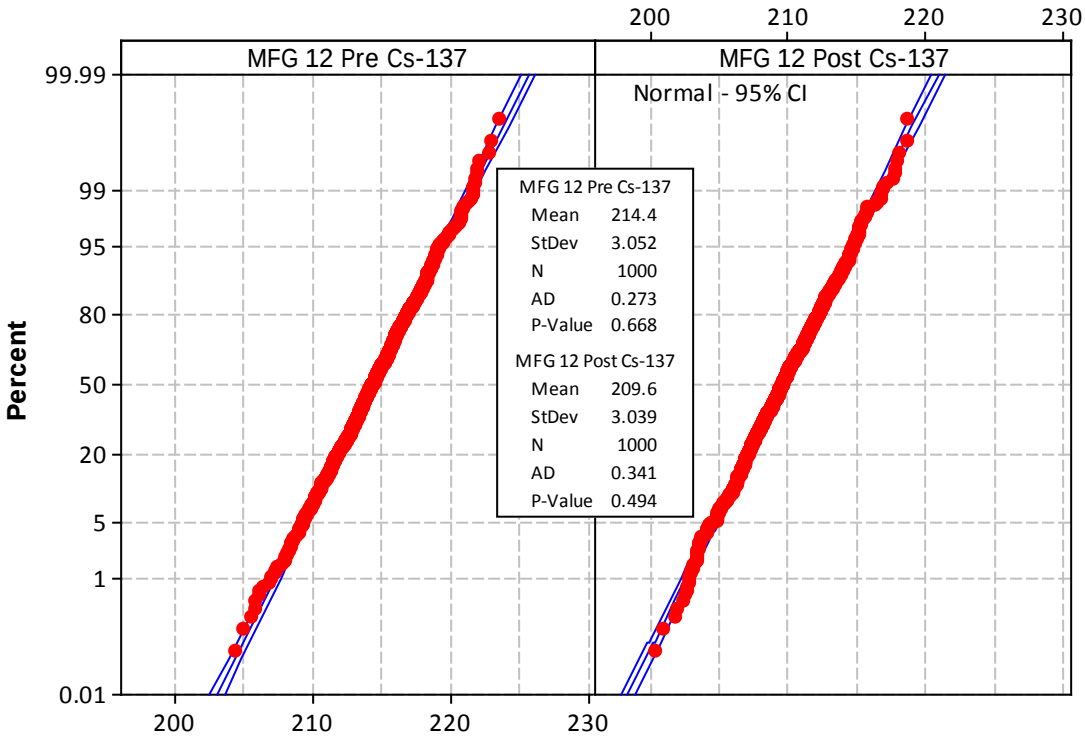

Figure 14 Probability Plot of Pre-Survey and Post-Survey Calibration Checks (Cs-137 Source)

5.0 RADIOLOGICAL BACKGROUND REFERENCE GAMMA RADIATION SURVEY RESULTS

This section presents the results of the gamma radiation survey of the RBRAs selected by Tetra Tech to for comparison with data collected at the Washington Street Quarry property.

5.1 RESULTS

A discussion on the selection process to determine the RBRAs within the region for comparison to the main site is presented in Section 3.4. Tetra Tech selected eight RBRAs (radiological background reference areas) following recommendations and considerations presented in Section 3.4. The RBRAs were selected based on soil type and radiological characteristics similar to those observed at the site. All of the RBRAs selected were unimpacted from the site activities and represent the regional background levels for this area of the country. Based on the historical literature review this is the most comprehensive background study for external gamma exposure rates conducted within the City of Kokomo to date. Maps showing the RBRA locations and the regional soil types are presented in Figure 6 and Figure 7, respectively. Table 2 in Section 3.4 provides summary information regarding surface area, distance to the main site, and primary soil types for the RBRAs.

The gamma radiation surveys performed at the RBRAs were conducted in the same manner as the gamma radiation survey conducted at the site. The gamma radiation surveys were performed on November 21, 2016 and November 22, 2016 by a Tetra Tech radiological engineer qualified and familiar with radiation detection and instrumentation. Table 5 provides the summary statistics of the raw gamma exposure rate measurements collected during the gamma radiation survey at all of the RBRAs.

Table 5 Summary of Gamma Exposure Rate Data Collected at RBRAs

Summary Statistic	Units	Foster Park 1	Foster Park 2	Foster Park 3	Kautz Field 1	Kautz Field 2	Kautz Field 3	Harrison Park 1	Harrison Park 2
Number of Measurements	*# of points*	277	272	139	301	244	210	241	48
Minimum	*µR/hr*[1]	5.83	6.25	7.11	4.64	4.63	6.30	6.13	8.18
Maximum	*µR/hr*	9.72	10.7	10.7	9.13	9.09	9.67	11.2	13.4
Median	*µR/hr*	7.71	8.10	8.74	6.18	6.65	8.00	8.31	10.7
Average	*µR/hr*	7.70	8.10	8.69	6.32	6.78	7.99	8.30	10.5
Standard Deviation	*µR/hr*	0.66	0.67	0.65	0.98	0.71	0.59	0.76	1.58
75th Percentile	*µR/hr*	8.14	8.57	9.10	7.01	7.25	8.44	8.74	11.6
90th Percentile	*µR/hr*	8.52	8.93	9.48	7.74	7.72	8.73	9.26	12.5
95th Percentile	*µR/hr*	8.75	9.17	9.60	7.99	8.04	8.94	9.61	13.2
99th Percentile	*µR/hr*	9.20	9.47	10.1	8.79	8.40	9.28	10.1	13.4

Note:
1 µR/hr = microroentgens per hour

A total of 1,732 gamma exposure rate measurements were collected across the eight RBRAs. The gamma exposure rate measurements ranged between 4.64 µR/hr to 13.4 µR/hr across all of the RBRAs evaluated. The average gamma radiation level was lowest at the Kautz Field 1 (6.32 µR/hr) and highest at the Harrison park 2 location (10.5 µR/hr). An analysis was performed to evaluate the parametric distributions of the raw gamma exposure rate data collected at each individual RBRA. Relative frequency histograms and probability plots were constructed for each data set and presented in Figure 15 through Figure 22. In general, all of the data sets followed a normal or lognormal distribution which is indicative of natural radiation levels expected across a uniform soil type and geology. The levels measured in this investigation are within the range expected based on the historical review (6 µR/hr to 8 µR/hr); with the exception of the Harrison Park 2 location which was above 10 µR/hr. This appeared to be an isolated area within the park that is likely attributed to fill materials containing NORM with levels higher than the other RBRAs. Graphical representation of all of the data sets plotted on a single chart for histograms and normal probability plots are presented in Figure 23. The following section presents the results of the gamma radiation survey for the Washington Street Quarry property. A comparative analysis of the RBRAs with the Washington Street Quarry is presented in Section 6.2.

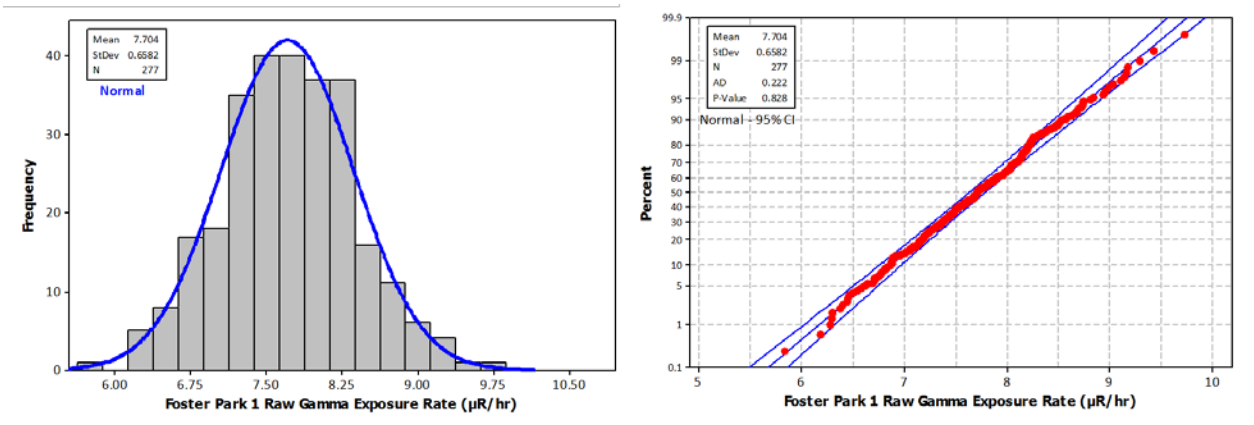

Figure 15 Foster Park 1 RBRA Gamma Exposure Rate –Histogram and Probability Plot

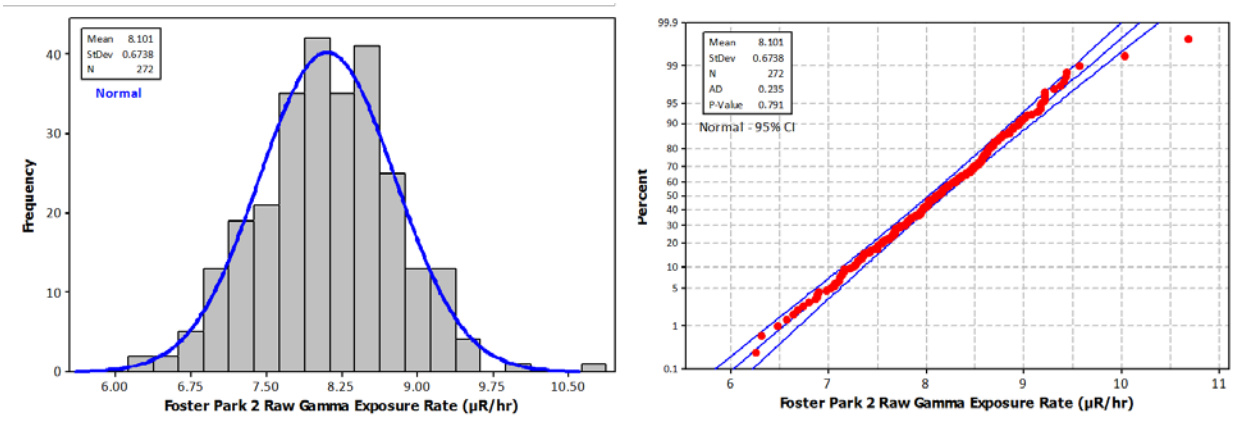

Figure 16 Foster Park 2 RBRA Gamma Exposure Rate –Histogram and Probability Plot

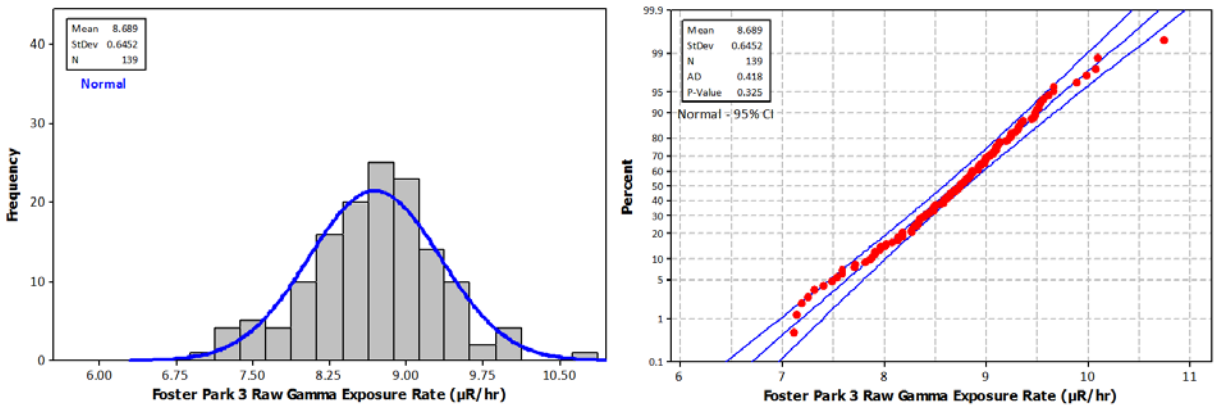

Figure 17 Foster Park 3 RBRA Gamma Exposure Rate –Histogram and Probability Plot

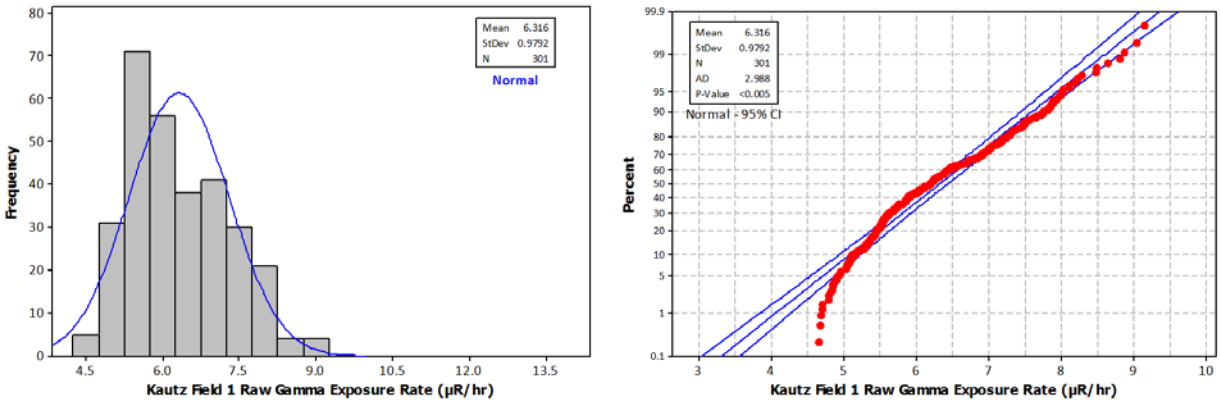

Figure 18 Kautz Field 1 RBRA Gamma Exposure Rate –Histogram and Probability Plot

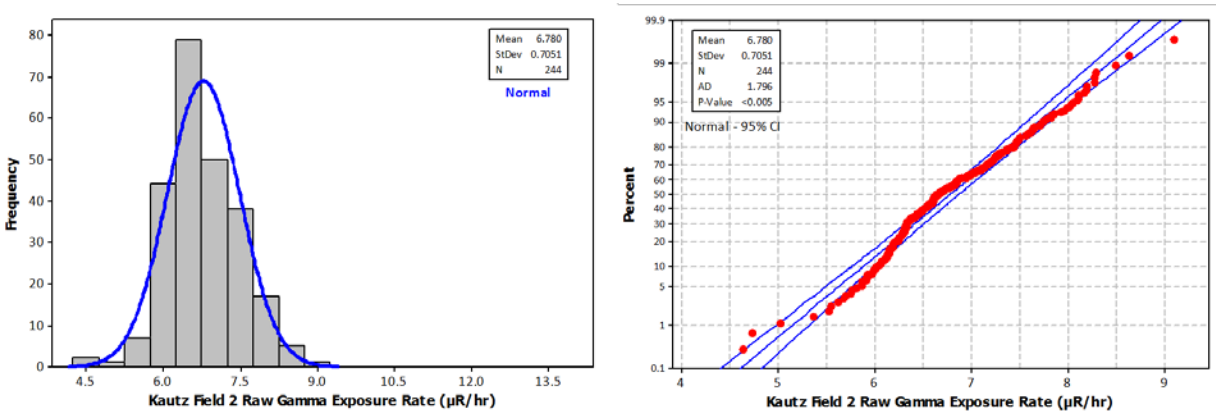

Figure 19 Kautz Field 2 RBRA Gamma Exposure Rate –Histogram and Probability Plot

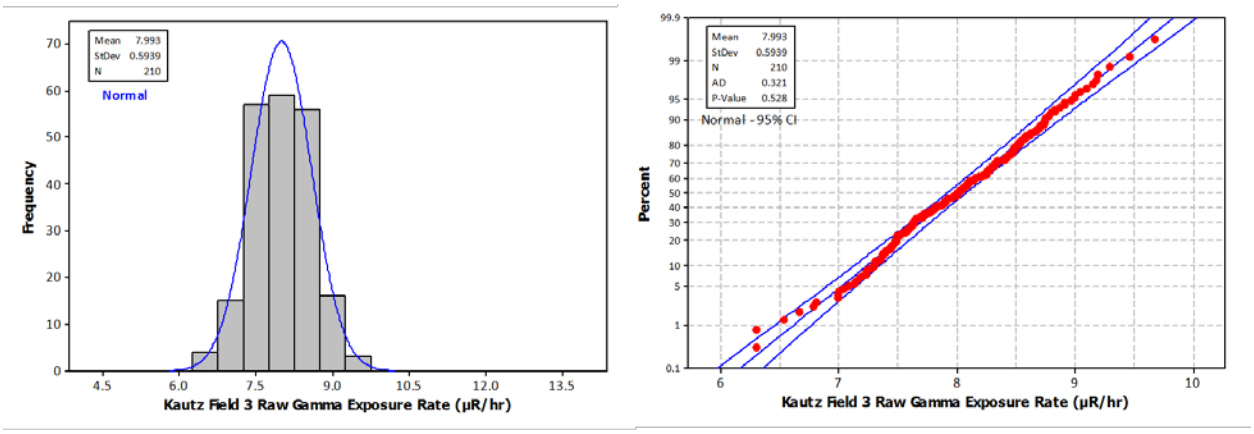

Figure 20 Kautz Field 3 RBRA Gamma Exposure Rate –Histogram and Probability Plot

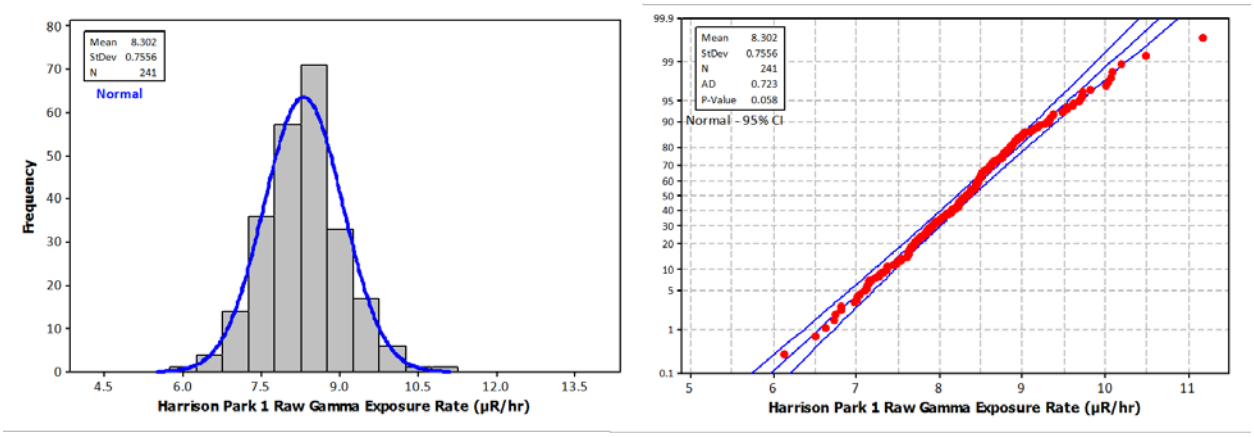

Figure 21 Harrison Park 1 RBRA Gamma Exposure Rate –Histogram and Probability Plot

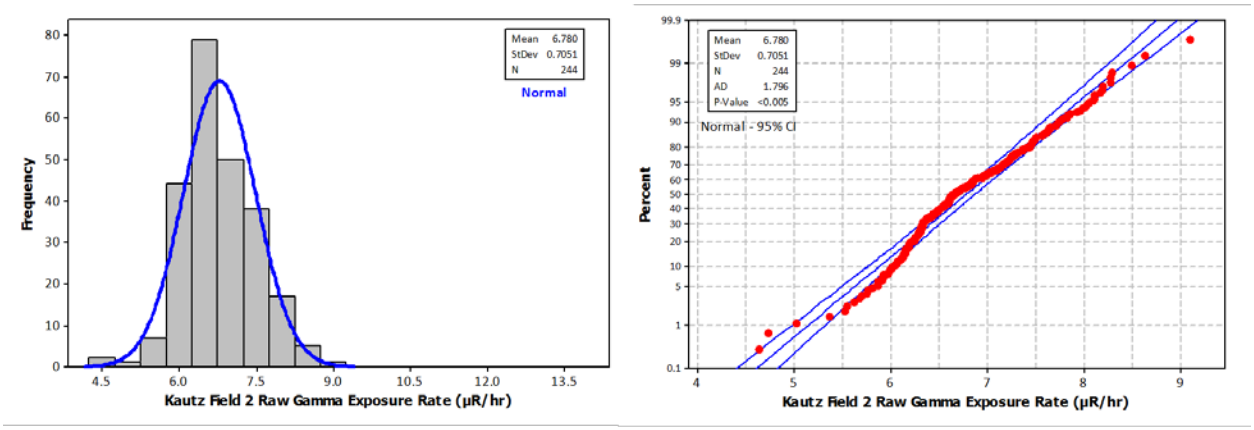

Figure 22 Harrison Park 2 RBRA Gamma Exposure Rate –Histogram and Probability Plot

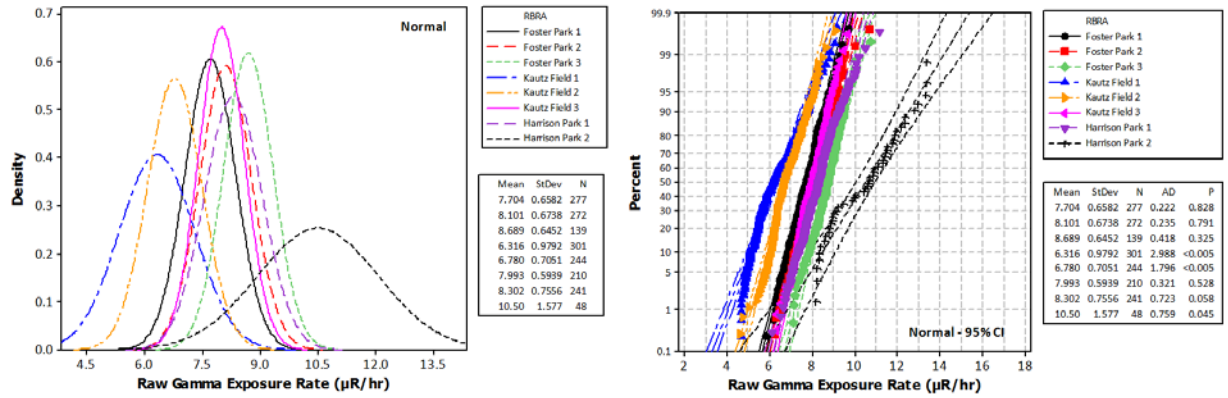

Figure 23 All RBRAs Gamma Exposure Rate –Histogram and Probability Plot

6.0 GAMMA RADIATION SURVEY RESULTS

This section presents the results of the gamma radiation surveys, comparative analysis of gamma radiation survey, and the results of the Bicron/NaI cross calibration study.

6.1 RAW GAMMA RADIATION SURVEY RESULTS

A comprehensive gamma radiation survey was performed at the Washington Street Quarry property on November 21, 2016 by a Tetra Tech radiological engineer who is qualified in the use of radiation detection and instrumentation. Stringent QA/QC protocol was followed for the gamma radiation surveys as described in Section 4.0. All project acceptance criteria were met for the instrumentation and results of the gamma radiation survey. The gamma radiation survey was conducted in accordance with the methodology presented in Section 3.2 and Appendix B. A total of 4,687 gamma exposure rate measurements were collected within the site boundary of the Washington Street Quarry property. Table 6 presents the summary statistics of the raw external gamma exposure rate measurements collected at the site.

Table 6 Summary of Gamma Exposure Rate Data Collected at Washington Street Quarry

Summary Statistic	Units	Washington Street Quarry
Number of Measurements	*# of points*	4,687
Minimum	*µR/hr*[1]	5.32
Maximum	*µR/hr*	9.71
Median	*µR/hr*	7.40
Average	*µR/hr*	7.39
Standard Deviation	*µR/hr*	0.67
75th Percentile	*µR/hr*	7.85
90th Percentile	*µR/hr*	8.24
95th Percentile	*µR/hr*	8.47
99th Percentile	*µR/hr*	8.92

Note:
1 µR/hr = microroentgens per hour

The gamma exposure rates ranged between 5.32 µR/hr and 9.71 µR/hr across the site. The average and median gamma exposure rate measured at the site was 7.40 µR/hr and 7.39 µR/hr, respectively. A map showing the kriged gamma exposure rates across the site is provided in Figure 24**.** There were certain areas which we inaccessible due to dense vegetation as shown on the map.

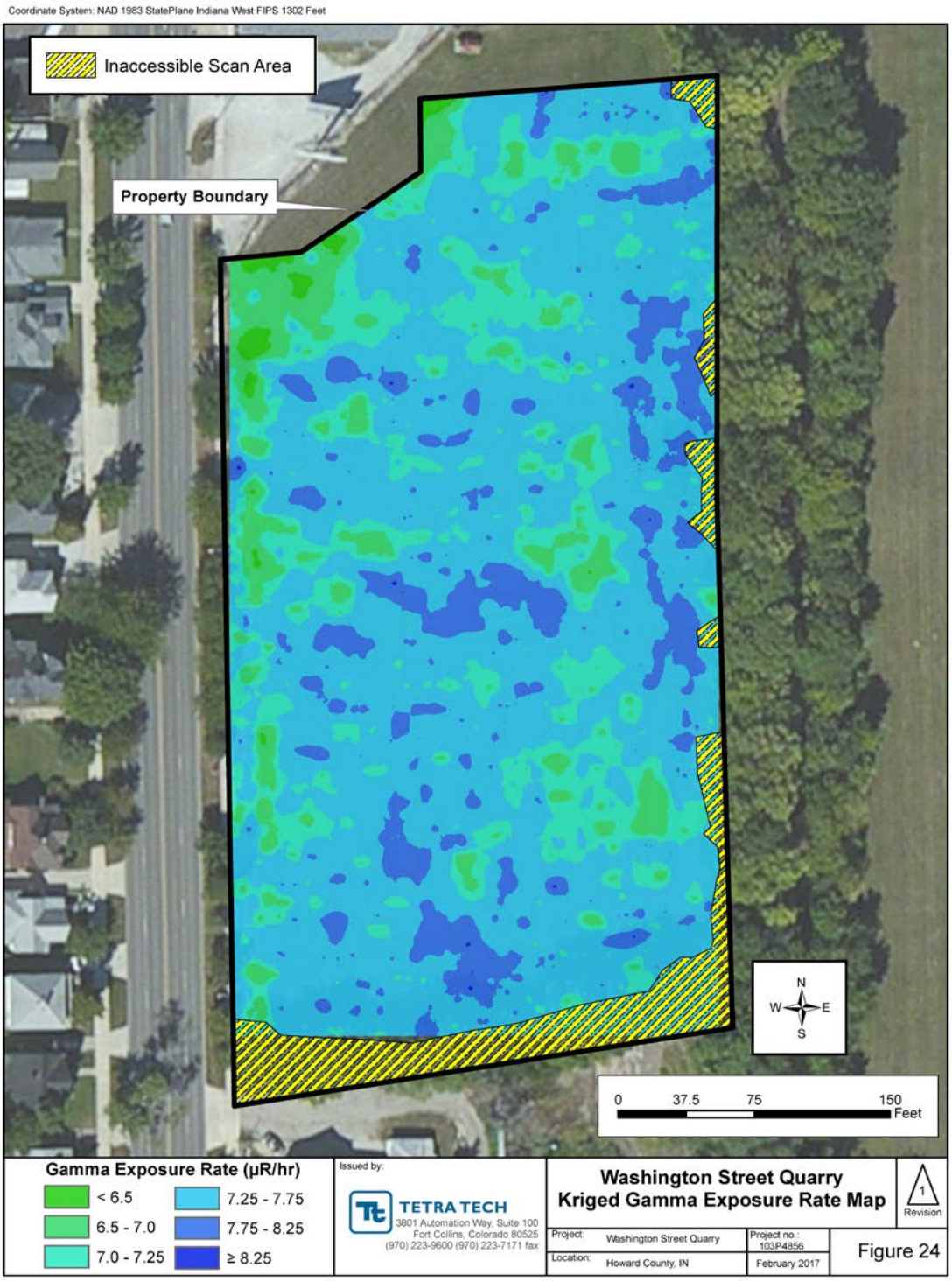

Figure 24 Washington Street Quarry Property Kriged Gamma Exposure Rate Map

An evaluation was performed to assess the statistical distribution of the data collected across the Washington Street Quarry property. Figure 25 presents a normal histogram and probability plot of the gamma exposure rate. The data follows a normal distribution indicating natural terrestrial gamma radiation levels. There were no anomalies (e.g. hot spots) discovered during the comprehensive gamma radiation survey; if there were hot spots detected they would be evidenced in the gamma map or in the distribution analysis. Based on these results it appears there are no areas of concern related to potential gamma emitting radionuclides at the Washington Street Quarry; however, further statistical analysis was performed to compare the data to the background data sets.

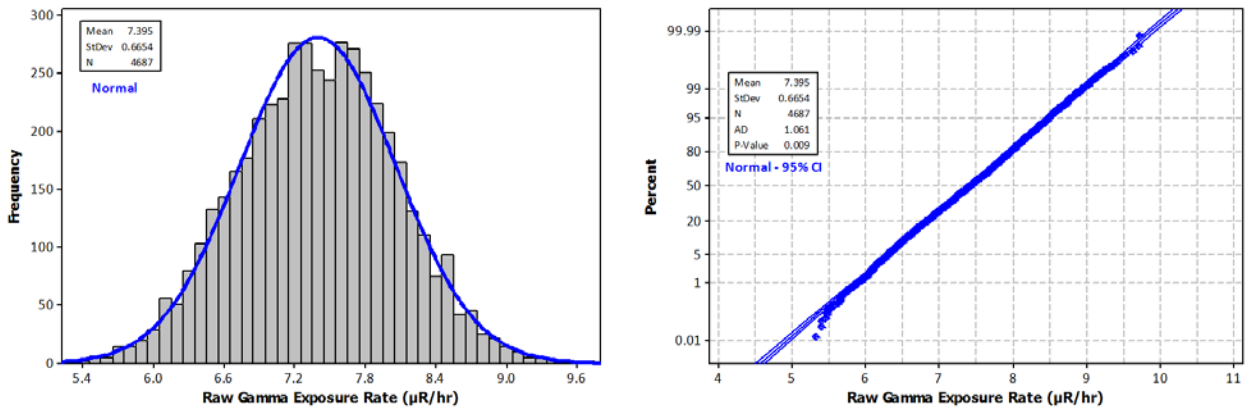

Figure 25 Washington Street Quarry Gamma Exposure Rate –Histogram and Probability Plot

6.2 Comparison of Background Reference Areas

The results of the gamma radiation survey are presented in the preceding subsection and indicate no anomalous readings observed at the site. The average gamma exposure rate at the Washington Street Quarry appears to be within or even lower than the regional background levels measured by Tetra Tech and from the ORAU in 1991. Tetra Tech conducted analysis using ProUCL 5.0 (ProUCL) software. The ProUCL capabilities include two-population hypothesis testing used to perform site versus background comparisons. The two primary two-population hypothesis testing methods used for the comparative background analysis included the Student's t-test and the Wilcoxon-Mann-Whitney (WMW). Both of these tests assume the following null hypothesis (Ho): Ho: The mean (and/or median) of Sample 1 (e.g. the Main Site) is less than or equal to Sample 2 (RBRA). If the data are consistent with the null hypothesis, then the site gamma exposure field is at or below background. For the purposes of this analysis, the WMW test was used to compare the Washington Street Quarry data to each RBRA, and to all of the RBRA data combined. Table 7 provides the results of this statistical test. For the eight RBRAs, the mean/median of the gamma exposure rates collected Washington Street Quarry was lower than the RBRA for 6 of 8 of the RBRAs. The main site data was statistically higher than the mean/median gamma levels measured at Kautz Field 1 and Kautz Field 2. When combining all of the data collected from the RBRAs, it was found that the Washington Street Quarry gamma radiation field is below the background levels. A boxplot showing how the Washington Street Quarry data compares to all of the individual RBRAs is provided in Figure 26. The results of this analysis can be interpreted that the Washington Street Quarry gamma radiation field is within, and on average, lower than the regional background levels. There is no indicating of surficial contamination related to gamma emitting radionuclides. Copies of the ProUCL output data are provided in Appendix D.

Table 7 Summary of ProUCL Output Data for Two Hypothesis Test

Sample 1	Sample 2	Wilcoxon-Mann-Whitney Results
Washington Street Quarry	Foster Park 1	Sample 1 < Sample 2
Washington Street Quarry	Foster Park 2	Sample 1 < Sample 2
Washington Street Quarry	Foster Park 3	Sample 1 < Sample 2
Washington Street Quarry	Kautz Field 1	Sample 1 > Sample 2
Washington Street Quarry	Kautz Field 2	Sample 1 > Sample 2
Washington Street Quarry	Kautz Field 3	Sample 1 < Sample 2
Washington Street Quarry	Harrison Park 1	Sample 1 < Sample 2
Washington Street Quarry	Harrison Park 2	Sample 1 < Sample 2
Washington Street Quarry	All RBRA Data	Sample 1 < Sample 2

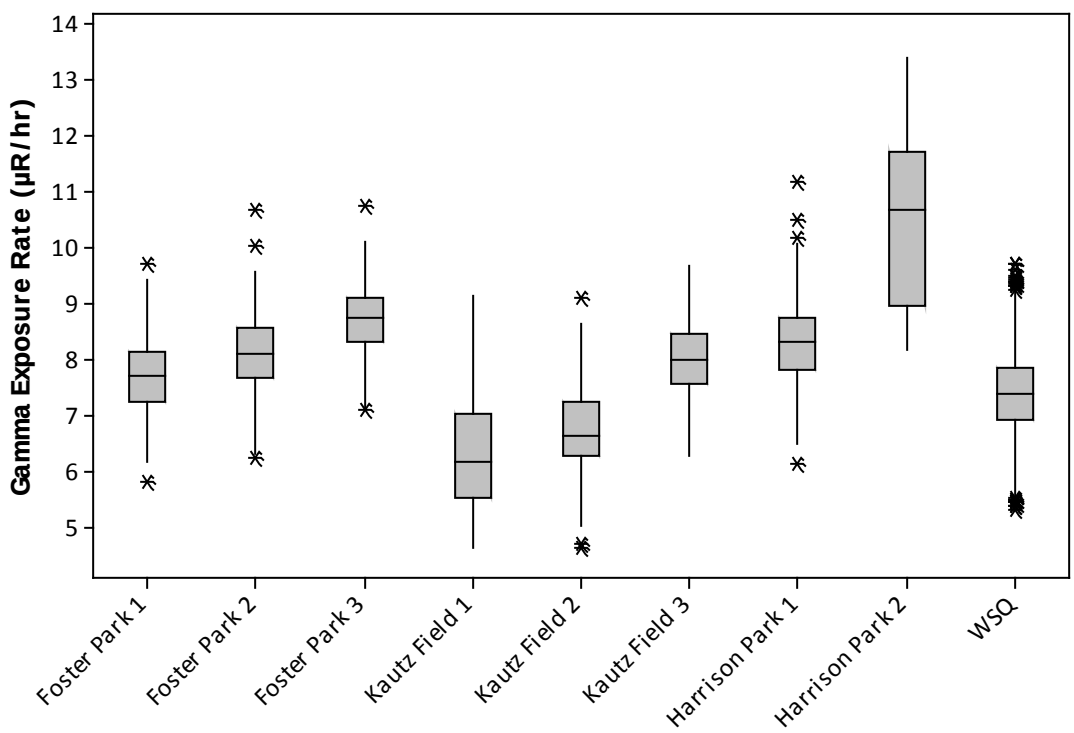

Figure 26 Box Plot of Washington Steeet Quarry versus RBRA Gamma Radiation Levels

6.3 Bicron Cross Calibration Study Results

A cross calibration analysis was conducted in accordance with the methods outlined in Section 3.3.2. This was done strictly for informative purposes in the event future work is done utilizing different instrumentation that can also be cross calibrated to an energy independent system. Similarly, this analysis

would be useful if the site exposure rates were above background levels which is not the case for the WSQ. Table 8 and Figure 27 present the results of the cross calibration study. The locations used for the Bicron/NaI cross calibration study are presented on Figure 28.

Table 8 Summary of Cross Calibration Data

Measurement Location	Average Gamma Exposure (µR/hr[1]) [NaI(Tl)]	Average Dose Rate (µrem/hr[2]) [Bicron]
Bicron 1	8.48	4.44
Bicron 2	6.33	3.33
Bicron 3	11.67	6.17
Bicron 4	4.25	1.94
Bicron 5	7.96	4.46
Bicron 6	9.40	5.38
Bicron 7	6.57	3.10
Bicron 8	7.41	4.40
Bicron 9	7.89	4.46
Bicron 10	8.44	5.18
Bicron 11	5.10	2.67

Notes:
1 µR/hr = microroentgens per hour (collected from NaI(Tl) detector)
2 µrem/hr = microroentgens equivalent man per hour (collected from Bicron detector)

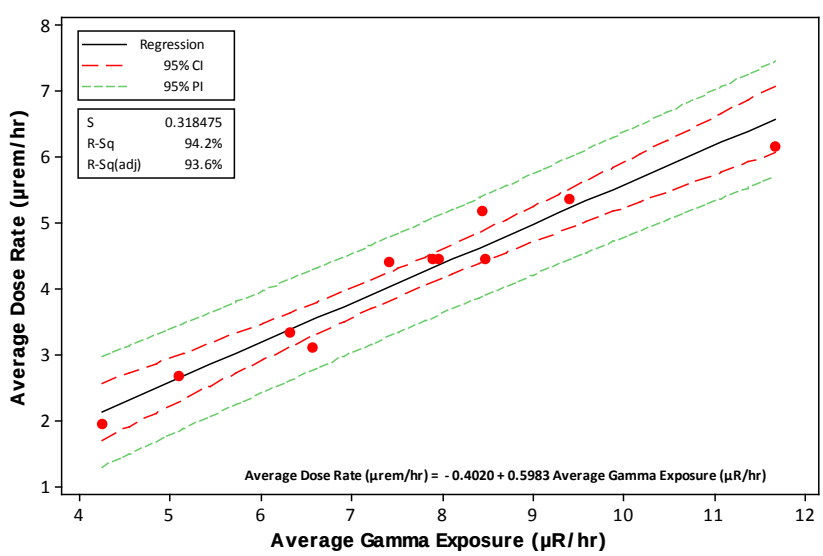

Figure 27 Cross Calibration of Sodium Iodide and Bicron Detectors

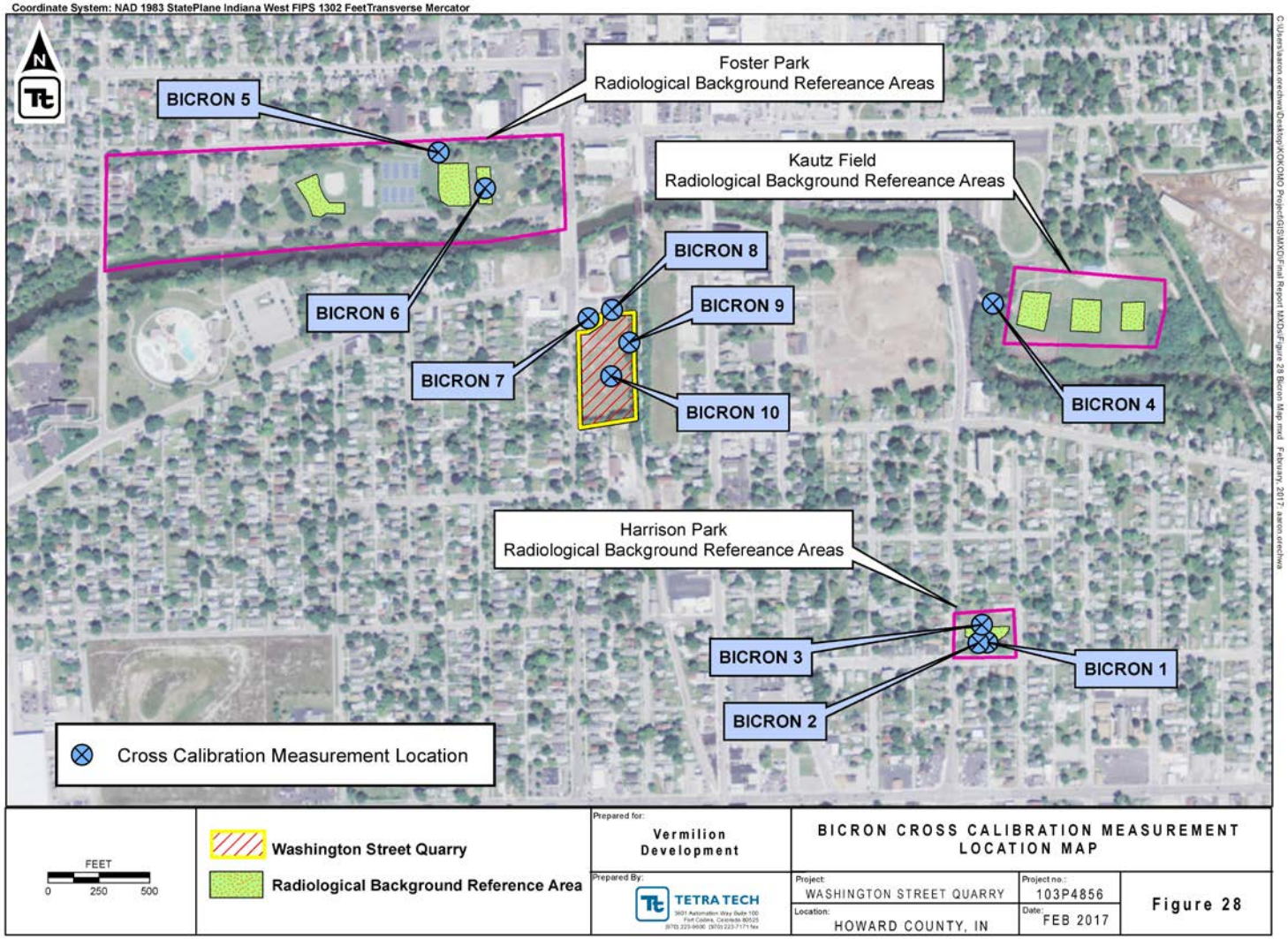

Figure 28 Bicron Cross Calibration Measurement Location Map

7.0 CONCLUSIONS

The Washington Street Quarry, located in Kokomo, Indiana was a historical location for disposal of industrial and low level radioactive waste between the 1960s and 1970s. This site was subject to a much public attention due to the events that took place and the land use practices that occurred. Significant work has been done at the site, as documented from historical references, in order to remove all hazardous materials and properly dispose of the waste. The former owner of the property, Cabot Corporation, spent time and resources to ensure the property was not contaminated prior to transfer to future owners. Cabot hired Bechtel to oversee the cleanup and removal operations at the site. The former owners were required to obtain a Radiological Materials License through the U.S Nuclear Regulatory Commission to properly manage the existing waste stream that was present at one time. In 1991, the Oak Ridge Associated Universities, under an interagency agreement between the U.S. Department of Energy and the U.S. Nuclear Regulatory Agency, led by Timothy Vitkus, a certified health physicist, conducted the Final Status Survey to evaluate the efficacy of the Cabot Corporation's removal efforts in achieving the acceptable site conditions needed to terminate the NRC's license and allow for unrestricted use of the property. The final status survey involved a comprehensive system of methods similar to those found in the more recently developed MARSSIM which included historical site assessments, 100 percent gamma radiation surveys, use of energy dependent exposure rate systems (i.e. HPIC), composite soil samples, and collection of water samples. Tetra Tech conducted a similar type survey during this investigation which included a 100% gamma radiation survey and correlation with an energy dependent system.

The results of the 1991 gamma radiation survey (at a 100 percent level), as indicated in ORAU (1991), indicated the gamma exposure rate measurements collected at accessible regions of the site using 2" x 2" NaI detection systems ranged between 5 µR/hr to 10 µR/hr. In 2016, Tetra Tech conducted a comprehensive gamma radiation survey at all accessible regions of the site utilizing consistent radiation instrumentation (i.e. 2" x 2" NaI scintillation detectors) while also employing a more advanced data collection methodology previously not available during at the time the original survey was conducted. The results of the gamma radiation survey conducted by Tetra Tech showed the raw gamma exposure rates ranged between 5 µR/hr to 10 µR/hr (e.g. precisely 5.32 µR/hr 9.71 µR/hr).

A comprehensive background radiation study was conducted by Tetra Tech. This study involved the collection of ambient radiation data across various radiological background reference areas that met NRC guidance for selection of reference areas. A detailed statistical analysis using approved U.S. Environmental Protection Agency software was performed to compare the data from the Washington Street Quarry and the local reference locations. The results of this analysis showed that the data collected from the site was within the range, and on average lower, when compared to the background radiation levels. Furthermore, a qualitative spatial analysis and quantitative statistical analysis indicated the site radiation levels are within the background limits expected for the region and of a site unimpacted from surficial radiological contamination. This study is limited to the surficial impacts; however, review of historical documentation indicated the subsurface radiological contamination has been addressed.

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APPENDIX A
AUGUST 1990 CABOT LETTER TO NRC; AND ORAU FINAL STATUS SURVEY REPORT

Wayne M. Reiber
Cabot Corporation
950 Winter Street
P.O. Box 9073
Waltham, Massachusetts 02254-9073

August 6, 1991

Ms. Patricia J. Pelke
United States Nuclear Regulatory
Commission, Region III
Material Licensing Division
799 Roosevelt Road
Glen Ellyn, Illinois 60137

Re: Request for Termination of License
and Site Closure
NRC License No. SUC-1538
Cabot Corporation
Washington Street Quarry
Kokomo, Indiana

Dear Ms. Pelke:

In accordance with 10 C. F. R. Section 40.42, Cabot Corporation requests termination of its NRC License No. SUC-1538, covering its activities at the Washington Street Quarry in Kokomo, Indiana. The license's expiration date is August 31, 1991, as extended by request from July 31, 1991. Cabot has terminated all activities involving the materials authorized under the license and thus requests termination of the license.

Attached to this letter are: (1) NRC Form 314 certifying the information concerning the disposition of materials, as required by paragraph 40.42(c)(iv); and the final survey report as required by the Region III staff.

Cabot is requesting this termination prior to the August 9, 1991 fee deadline contained in Revision of Fee Schedules; 100% Fee Recovery Final Rule, 56 Federal Register 31472, 31485 (July 10, 1991) and will have permanently ceased all licensed activities by the September 30, 1991 deadline contained in the same Rule. Therefore, Cabot will not be required to pay the annual fee that was recently assessed for this license. Cabot will send a copy of this letter along with payment invoice to the license fee office specified on the invoice.

Please call me at (617) 622-3761 if you have any questions or if additional materials are needed in order to terminate the license.

Very truly yours,

Wayne M. Reiber
Cabot Corporation

Enclosures

cc: Gerri R. Scoll, Esq.
Dave Freas, Bechtel

BECHTEL FINAL SURVEY REPORT TO CABOT CORPORATION
FOR TERMINATION OF NRC
MATERIALS LICENSE # SUC-1538

BECHTEL
Washington Street Quarry Project
Kokomo, Indiana
Job # 19058

Ron Sands
Prepared by

Roger Healey
Health Services

David H. Lum
Project Manager

Aug. 5, 1991
Date

FINAL SURVEY REPORT FOR TERMINATION OF NRC
MATERIALS LICENSE # SUC-1538

I. Purpose of the Final Survey Report:

The Final Survey Report has been prepared to document events, survey data, and other issues that serve to verify removal of radioactive materials from the Washington Street Quarry (WSQ) project site to an acceptable condition suitable for unconditional release of the site and termination of Nuclear Regulatory Commission (NRC) Materials License SUC-1538.

The contents of this report were discussed with members of the NRC Region III staff to insure the adequacy of the report in its content and purpose. These discussions were held at the NRC Region III office on July 26, 1991 between George M. McCann (Mike), Chief of Licensing Branch; Patricia Pelke, Licensing Branch; and Ron Sands the WSQ site safety & health officer (SSHO) / WSQ radiation safety officer (RSO) from Bechtel.

The report has been organized to present the purpose, discuss the removal actions, discuss the ORAU Survey of Washington Street Quarry and its findings, and identify the holding areas used after the ORAU survey. Also included are discussions of the routine site surveys and periodic drum surveys conducted, surveys of those holding areas which remain accessible, and an accounting of what was collected and what was removed from the site. A report summary and several appendices providing supporting information are also part of this report.

II. Removal Action

WSQ located on Washington Street in Kokomo, Indiana is owned by Cabot Corporation. Cabot had reason to believe that uranium associated with a previous company's project (ACORN project) may have been erroneously disposed of among other industrial debris at the quarry. Cabot contracted with Bechtel to locate, collect and remove the uranium. Limited investigation efforts were made to locate the uranium during the years of 1987 and 1988. In April of 1989 a more concerted effort began to locate and remove the uranium. As the effort moved along, some objects and materials were collected that displayed radiation readings well above background. (The instruments used were Ludlum 2220 scaler/rate meters with 2"x2" sodium iodide detectors.) Early during the removal project it became evident that drums of other, non-radioactive, hazardous materials were present in WSQ. Cabot and Bechtel reassessed the situation and began a rather conservative effort of survey and collection of both radioactive and potentially hazardous materials.

The procedures and precautions for collecting materials was done in a very conservative fashion because of the uncertain potential for types and amounts of hazardous material in the industrial debris encountered. The criteria was as follows:

- Is the material radioactive (determined by 2 times then later 4 times background)?
- Does the material give off organic vapors in excess of 1 ppm?
- Does the material have any physical appearance that sets it apart from the quarry dirt?
- Any other physical observation that in the judgement of the SSHO, that suggests the materials need to be collected?

When any of the above criteria was answered positively, the material was collected into overpack drums and held for later analysis. Materials were intentionally segregated to prevent possible reaction of potentially incompatible chemicals. This lead to a large number of overpack drums, many holding only small quantities of material.

At the completion of excavation, nearly 400 overpacks, 300 drums of wax, 6 compressed gas cylinders, and approximately 55 tons of slightly radioactive grinding wheels had been collected. Samples were collected and laboratory analyses were performed to establish waste streams. Most of the chemically contaminated materials were shipped to incineration facilities, while some were sent to appropriate landfills. The compressed gas cylinders were handled by companies that specialize in their disposal. The radioactive materials were transferred to other companies for subsequent disposal at a U. S. Ecology site or sent directly to the Envirocare facility in Utah. Through discussions with the NRC, it was determined that the grinding wheels were not of regulatory concern under Title 10, Code of Federal Regulations. With that decision in place, all other radioactive materials were removed from WSQ. The specific destinations of the radioactive material transfers are listed on the NRC 314 form.

III. ORAU Survey of Washington Street Quarry

In May, 1990 the entirety of the quarry material had been excavated and surveyed, and the material was placed into its final location. At this time Cabot made request to the NRC for a verification survey of WSQ for which Oak Ridge Associated Universities (ORAU) was assigned. On June 28, 1990 ORAU personnel conducted measurements and sampling at WSQ. Their results and findings were presented to the NRC in a letter from Timothy J. Vitkus of ORAU to Bill Adam of NRC Region III dated August 7, 1990 and verified the acceptable condition of the site to permit back filling operations to begin as allowed in Amendment No. 01 to Materials License Number SUC-1538. The ORAU report can be found in Appendix A of this report.

IV. The Holding Areas Used and their Present Conditions

Various holding areas were used pending shipment of the radioactive wastes (see Appendix B, Map of Holding Areas Used Following ORAU Survey) and they are identified below.

Area 1. Grid square S270W100 - S220W050 Used from June 21, 1990 to December 17, 1990 when the radioactive wastes were relocated as back fill operations progressed. This area has been covered with back fill material.

Area 2. Grid square S150W100 - S100W050 Used from December 17, 1990 to December 28, 1990 when flooding of the holding area required movement of the wastes to a safe location. This area has been covered with back fill material.

Area 3. Grid square S100W180 - S075W180 Used from December 28, 1990 to January 15, 1991 when the wastes were returned to the pre-flood location in Area 3. This area remains accessible for further study.

Area 4. Grid square S150W100 - S100W050 (Same as Area 3) Used from January 15, 1991 to March 1, 1991 when the wastes were relocated as back fill operations moved into this holding area. This area has been covered with back fill material.

Area 5. Grid square S050W060 - S000W025 Used from March 1, 1991 to June 27, 1991 when all wastes had been staged for shipment. This area has been covered with back fill material.

Area 6. Grid square S050W160 - S035W155 Used from June 10, 1990 to June 11, 1990. Used for staging location for the radioactive wastes prior to shipment. This area remains accessible for further study.

Area 7. Grid square S090W210 - S060W195 Used from June 27, 1990 to June 28, 1990. Used for staging location for the radioactive wastes prior to shipment. This area remains accessible for further study.

V. Operational Health Physics and Industrial Hygiene

In view of the unknown character of the radiological hazards present at WSQ and the potential of hazardous chemical, Bechtel and Cabot implemented operational health physics (HP) and industrial hygiene (IH) precautions to insure worker safety, safety of the public and safety of the environment. The operational HP/IH methodology to provide health physics and industrial hygiene coverage through personnel monitoring, bioassay monitoring, monitoring of radiation and chemical levels, and contamination control in compliance with 10CFR20 was used through the end of the excavating effort and was applied to virtually all of the materials handling operations at WSQ. Much of the methodology continued through removal of all materials of concern from WSQ. The operational HP/IH efforts are described below.

Surveys:

A wide variety of surveys were conducted during the excavating and removal phases of work at WSQ. They are outlined below.

1. Pre-cut surveys - A plot of quarry material would be laid out for excavation. The selected area would be surveyed prior to commencement of excavation. The excavation cut would be limited to one foot in depth made by using an excavator to peal back layers several inches thick until the one foot depth had been achieved. The pre-cut surveys consisted of:

    a. A radiological walk over survey using a Ludlum 2220 rate meter with sodium iodide detector looking for any increase in count rate to indicate a possible point source or vein of radioactive material was conducted. If such a reading was found, efforts were made to unearth the source. The criteria for collection of the material was originally set at twice background; however, that was later relaxed to four times background which was also considered a very conservative number based on the instruments used.

    b. An industrial hygiene (IH) walk over survey was conducted using either an HNU or TIP II instrument for detecting organic vapors, and an EXOTOX air monitoring instrument to measure and monitor levels of oxygen, hydrogen sulfide gas, and explosive levels of gas. When the instrumentation indicated the presence of a potential hazardous material, appropriate steps were taken similar to those for the radiological walk over. The criteria was slightly different due to the difference in the natures of the potential hazards.

c. A metal detector / visual walk over was conducted to detect buried drums of material and to look for evidence of possible hazards which may have been missed in the instrument surveys. Whenever a possible hazard was found in this walk over, the follow on investigation incorporated the use of radiological and IH instruments for further evaluation of the hazard as well as the judgement of the site safety and health officer (SSHO) in determining the need to collect the material.

2. Lay-over surveys - Once the material was excavated, it would be spread out into a thin (not exceeding one foot) layer. Radiological, IH, and visual walk over surveys would be conducted of this material using the same criteria as the pre-cut surveys.

3. Final placement surveys - When the quarry material was placed in its final and permanent location through one foot lifts, radiological, IH, and visual walk over surveys would be conducted again also using the pre-cut survey criteria.

4. Work area surveys - When materials were collected, packaged, repackaged or otherwise handled, surveys were conducted in all work areas to detect radiation and/or potential chemical contamination. The information was used with other information to formulate a planned approach to the work and the levels of personal protective equipment (PPE) required. Once work was complete, the work area was surveyed for any residual contamination to verify proper cleanup.

5. Routine site surveys - Routine surveys to verify working levels of radiation, to confirm the absence of contamination in indoor work, break and eating areas, and to insure compliance with appropriate postings were accomplished following direction from NRC Regulatory Guide 8.21. (See Appendix C - Examples of Routine Surveys.)

6. Periodic drum surveys - These were conducted to check the dose rates around the drums as they sat in the various holding areas. Smear surveys were also conducted to verify that no contamination was leaking from the drums. (See Appendix D - Example of Periodic Drum Survey.)

Monitoring:

Monitoring was conducted for contamination control purposes, personnel exposure information, and to meet Kokomo Waste Water Permit requirements. Some of the monitoring was formalized and documented in detail while some was informal and was documented only as directed by the site safety and health plan (SSHP).

1. Personnel dosimetry was used to monitor radiation worker exposures. The TLD results indicated no exposures exceeding 10 mRem in any month during the monitoring period.

2. Bioassay monitoring was conducted quarterly with the collection of urine samples. No uptake of uranium or thorium isotopes was found.

3. Contamination control monitoring was conducted during the excavation phases of the WSQ operations and whenever the overpacks of materials were opened. Personnel radiological monitoring was performed by workers self frisking with a Geiger-Mueller (GM) instrument and by a daily frisk by a qualified HP technician. IH monitoring was conducted by a qualified technician. There were no instances of personnel contamination, nor contamination of any equipment except where some gross spillage of radioactive material occurred in the protected work area. This was detected by simple frisking technique and removed by placing the contaminated items into radioactive waste disposal containers. Further frisking was performed to confirm removal of the contaminants.

4. Perimeter air monitoring was conducted through the collection of particulates onto filters using high volume (hi-vol) air sampling equipment. The filters were periodically changed out and the particulates counted for gross alpha and gross beta emissions and compared to the volume of air sampled. No significant release of radioactivity was measured, and in most cases, results were below the minimum detectable activity (MDA).

5. Effluent water sampling - Because of the influx of ground water, a continuing effort of de-watering was maintained through the excavation and back fill operations at WSQ. Water was pumped from the quarry at a rate of 200 to 600 gallons per minute to keep the quarry from re-flooding The water permit issued by the Wastewater Treatment Plant, City of Kokomo, required collection of water samples three times weekly for measurement of the gross alpha and gross beta activity for each sample. Radioactivity never exceeded the permit levels of 15 pCi/l gross alpha and 1000 pCi/l gross beta.

VI. Environmental Health Physics:

At the outset of the project, the need for environmental health physics (EHP) not a major issue although certain EHP activities were performed. Those activities and other factors used to determine the extent of EHP efforts are listed below.

Factors:

- Perimeter air monitoring was performed from approximately April, 1989 to May, 1991 using particulate filters. Analytical data indicated no significant amount of detectable airborne radioactivity.

- Water samples of the quarry effluents were collected three times weekly and analyzed for gross alpha and gross beta from June, 1989 to May, 1991. No significant amount of waterborne radioactivity was measured.

- Soil samples were collected and analyzed for thoriums and uraniums. The sample collection was limited to soils in the northern third of the quarry. The analyses showed no significant radioactivity.

- The handling of collected radioactive materials resulted in no instances of personnel contamination or contamination of any equipment except where gross spillage of radioactive material occurred in the protected work area. This was detected by simple frisking technique and removed by placing the contaminated items into radioactive waste disposal containers. Further frisking confirmed removal of the contaminants.

- Results of bioassay analysis indicated no uptake of uranium or thorium radionuclides by workers.

- The ORAU Survey of Washington Street Quarry conducted in June, 1990 indicated environmentally acceptable conditions for commencement of back fill operations.

- Collected radioactive materials were containerized in steel drums and maintained in designated holding areas. Sampling and repackaging operations were performed in areas specially prepared for such work. These operations were followed by thorough frisking of the work area and the collection and counting of smears. The frisking and smear survey activities were in addition to the routine surveys.

- The total amount of radioactivity removed from the site was less than 80 mCi and was in the form of objects (turnings, bar stock, etc.) and foundry sand. Approximately 76 mCi was associated with the depleted uranium (DU) determined to offer no smearable contamination. The radioactive objects and sand were spread through approximately 400,000 tons of original quarry material. Their collection and removal left no significant levels of radioactive contamination.

The need for a more comprehensive EHP program is offset by the absence of a significant quantity of radioactive material, the absence of detected waterborne or airborne radioactive contaminants, and the anticipation of the final survey per 10CFR40.42 to verify those conditions. In view of these considerations, no additional effort to conduct environmental health physics was warranted after the radioactive materials were relocated from the WSQ site.

VII. Dose Rate Surveys of the Final Holding Areas

Surveys to measure dose rates at the former locations of holding areas 3, 5, 6, and 7 were conducted on July 15th and 18th, 1991. Dose rates ranged from 4 to 6 microR/hr at all locations including measurements taken at 1 centimeter and 1 meter above the ground surfaces. (See Appendix E - Survey Reports of Accessible Holding Areas; and Appendix F - Certificates of Calibration.)

VIII. Accounting of the Materials Collected and Disposed

All collected radioactive materials (except for the grinding wheels) were placed into separate steel drum overpacks. As more information was compiled on each collected material, efforts were taken to reduce the radioactive waste volume through a variety of methods. Sorting to remove radioactive from non-radioactive components was used. (The non-radioactive portions were disposed of as hazardous waste as a precaution.) Repackaging and consolidation were also used to reduce volume. The original 76 drums of material were reduced to 19 through these efforts.

The collected grinding wheels were stacked along the east, north - east boundary of the quarry and were eventually covered with the back fill dirt imported to WSQ. Based on conversations with the NRC staff of July 12, 1991, the NRC has no regulatory interest in the grinding wheels.

The radioactive materials were reduced to the smallest practical volume achievable prior to removal from WSQ. (See Appendix G - Tabulation of Materials Collected and Their Disposal.) The removal from WSQ was undertaken during the month of June, 1991 and is verified on the NRC 314 form. (See Appendix H.)

IX. Summary of the Final Survey Report

The Final Survey Report has presented the information demonstrating removal of radioactive materials from WSQ. All materials were transferred to appropriate licensees. The site is now suitable for unconditional release and termination of NRC Materials License Number SUC-1538. This report satisfies final survey report requirements imposed by NRC Region III staff.

Appendix A

ORAU Survey of Washington Street Quarry

Oak Ridge Associated Universities
Post Office Box 117
Oak Ridge, Tennessee 37831-0117

Energy/
Environment
Systems Division

August 7, 1990

Mr. Bill Adams
Region III
Nuclear Regulatory Commission
799 Roosevelt Road
Glen Ellyn, Illinois 60137

Subject: SURVEY OF WASHINGTON STREET QUARRY - CABOT CORPORATION
KOKOMO, INDIANA

Attached are the results of measurements and sampling performed June 28, 1990 at Cabot Corporation's Washington Street Quarry in Kokomo, Indiana. As can be seen from the findings, exposures rate levels, with the exception of two noted locations, and radionuclide concentrations in soils and water are in the range of background levels.

Requests for additional information may be referred to me at FTS 626-5073 or (615) 576-5073.

Sincerely,

Timothy J. Vitkus

Timothy J. Vitkus
Project Leader
Environmental Survey and Site
Assessment Program

TJV:jle

cc: D. Tiktinsky, NMSS/6A4
T. Mo, NMSS/6H3
V. Tharpe, NMSS/6H3
C. Haughney, NMSS/6H3
D. Sreniawski, NRC/Reg III

AUG 13 1990

Appendix A
ORAU Survey of Washington Street Quarry

CONFIRMATORY SURVEY
OF THE
CABOT CORPORATION
WASHINGTON STREET QUARRY
KOKOMO, INDIANA

INTRODUCTION

The Cabot Corporation is the present owner of a quarry located at 410 S. Washington Street in Kokomo, Indiana. Originally, limestone was quarried for use as a construction material in and around Kokomo during the late 1800's. The quarry was later allowed to flood and used as a cooling pond for a neighboring steam plant located east of the quarry. For the past several decades, the quarry has been utilized for the disposal of fill dirt, building rubble, and industrial wastes such as foundry sands, wax, steel and furnace refractory. In mid 1967 the previous site owner, Union Carbide's Stellite Division, was performing experimental alloying work with depleted uranium and thorium with on-site burial of solid wastes. The alloy was to be machined to close tolerances for final shipment to an aircraft fabricator. Metal turnings, which resulted from the machining process, were isolated, packaged and shipped to Nuclear Engineering in Moorehead, KY. However, at a later date three to four drums of the depleted uranium turnings that had been left at the site were discovered by Cabot Corporation. Cabot Corporation subsequently buried the drums in the quarry in accordance with an NRC license.

In 1987, site investigations and characterizations were begun on the quarry in order to locate the buried depleted uranium drums.

Prepared by the Energy/Environment Systems Division of Oak Ridge Associated Universities, Oak Ridge, Tennessee, under interagency agreement, (NRC Fin. No. A-9076) between U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

August 8, 1990

Bechtel was chosen as the contractor to manage site restoration and in the spring of 1989 excavation to recover the buried drums began.

Presently, all fill material has been excavated and surveyed. The drums of depleted uranium were unearthed, repackaged and are currently stored on-site, awaiting final disposition. Additional radiological materials, including grinding wheels containing low levels of thorium, as well as chemically hazardous materials were discovered during excavation. These materials were also repackaged and stored on site.

At the request of NRC Region III, the Environmental Survey and Site Assessment Program (ESSAP) of Oak Ridge Associated Universities (ORAU) performed a confirmatory survey of the radiological condition of the quarry.

FACILITY DESCRIPTION

The Washington Street Quarry is located at 410 S. Washington St. near the central business district of Kokomo, Indiana (Figure 1). The quarry covers an area of approximately 3.25 acres and is bounded by Washington St. to the west and rail lines to the east. The northwestern portion of the quarry is at or near street level. The Bechtel office and equipment trailers are staged in this section. Access into the quarry is by a cut and graded access road. The east, south, and west walls of the quarry are sheer with the quarry floor which is 35 to 54 feet below street level. An approximately 1000 ft^2 drum staging area is located within the quarry. The drum staging area contains the chemical and radiological materials that were unearthed during remediation activities. There are also storage piles located against the west wall of the quarry consisting of grinding wheels and excavated drums which contain inert materials.

PROCEDURES

On June 28, 1990, ORAU personnel conducted a confirmatory survey of the Washington Street Quarry.

1. Available historical documentation for the site was reviewed as part of the ORAU survey procedure.

2. Accessible surfaces within the quarry were surface scanned by a 100% walkover survey using NaI(Tl) gamma scintillation detectors coupled to countrate meters with audible indicators. Areas where elevated activity was identified were marked for further investigation.

3. Exposure rate measurements were performed one meter above the ground at six representative on-site locations and one off-site location, using a pressurized ionization chamber. See Table 1 for measurement locations.

4. Five point composite soil samples were collected from each of ten randomly selected grid blocks within the quarry. The existing grid, comprised of 50 ft X 50 ft blocks, established by Bechtel was used as reference. See Figure 2 for sample locations.

5. Soil samples were collected from locations which exhibited elevated activities and from those areas where elevated ambient radiation interfered with gamma scintillation scans. These areas include around the grinding wheel pile and around the section of the drum staging area that contained the excavated radioactive materials.

6. Water samples were collected at the point where seepage ponded near the southeast section of the quarry as well as at a location where water entered the quarry through

fractures in the wall and at a point midway between water entrance and ponding.

7. Samples and measurement data were returned to Oak Ridge, Tennessee for analysis and interpretation.

FINDINGS

Gamma scans within the quarry identified areas of elevated activity in the southeast portion of the drum storage area. The elevated activity noted was attributed to the materials contained within the drums. A composite soil sample was collected from this area to confirm the absence of any significant levels of contaminants. A second area of elevated activity was identified east of the drum storage area. The anomaly was due to the presence of several grinding wheels placed there by Bechtel as equipment supports. The third area was around the grinding wheel storage pile. A composite soil sample was collected from locations in and around this area as well. Two additional areas of elevated activity were identified during gamma scans. Further investigation identified the presence of a buried drum of contaminated residue at grid point S531,W138. The residue was excavated by Bechtel personnel and the area resurveyed. The second location was found at S376,W246. This anomaly was due to a buried grinding wheel which was removed and the area resurveyed. In both cases gamma scintillation measurements fell to twice background levels or less following remediation.

RESULTS

Exposure rate measurements are performed 1 meter above the surface presented in Table 1. General contact gamma radiation levels for the site ranged from 5 μR/h - 10 μR/h. Gamma radiation levels in the vicinity of the drum staging area containing the radioactively contaminated materials and the area

around the grinding wheel pile ranged from 12 μR/h - 36 μR/h. For comparison, area background levels were approximately 8 μR/h. Radionuclide concentrations in soils are summarized in Table 2. Ranges for each nuclide of interest, after remediation of elevated locations, are as follows: uranium-235 ranged from 0.1 ± 0.1 pCi/g to 0.5 ± 0.2 pCi/g, uranium-238 ranged from <1.6 pCi/g to 4.3 ± 1.7 pCi/g, and thorium-232 ranged from <0.6 pCi/g to 2.1 ± 0.6 pCi/g. These concentrations are typical of naturally occurring background levels.

Gross activity in the water samples was 1.0 to 3.9 pCi/l and 4.6 to 7.2 pCi/l for alpha and beta respectively.

SUMMARY

At the request of NRC Region III the Environmental Survey and Site Assessment Program of Oak Ridge Associated Universities performed a verification survey of the Cabot Corporations Washington Street Quarry in Kokomo, Indiana. Two locations were identified as having potentially excessive activity levels. These were remediated and resurveyed with satisfactory post-remedial results. Elevated activity was observed in the vicinity of the grinding wheels. The observed levels are caused by the naturally occurring thorium levels found in the grinding wheels. This has been addressed and documented in a June 19, 1990 report submitted by Bechtel to the NRC Region III. Elevated activity was similarly identified around the radioactive material section of the drum storage pad; originating from the containerized materials. In both of the above instances, soil sample data supported these conclusions. All final measurements and samples with the exception of the vicinity of the drum storage area and the grinding wheel pile, as noted above, were well within the four times background values previously utilized by Bechtel as the action criteria and, with few exceptions, were in the range of typical background levels.

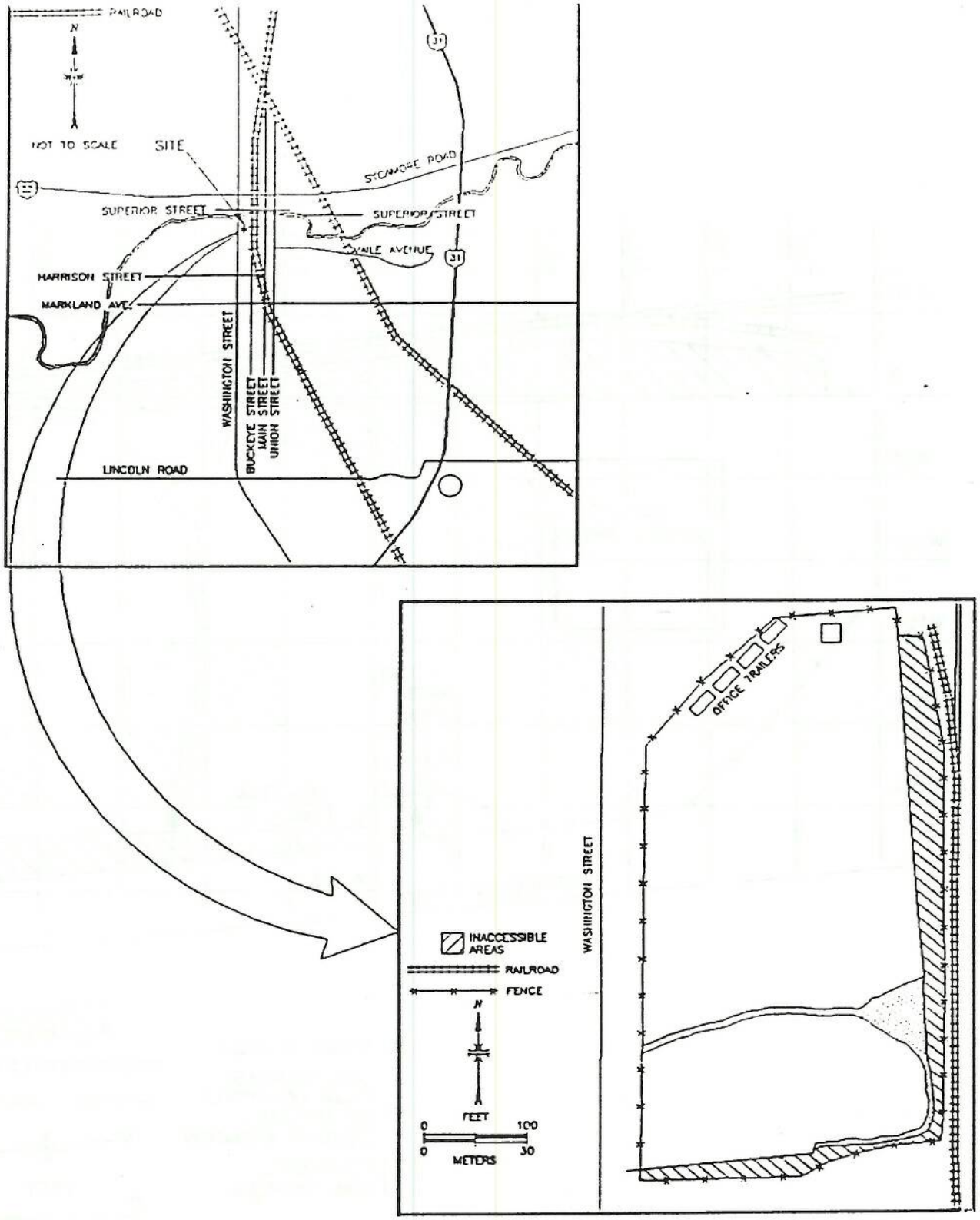


FIGURE 1: Cabot Corporation, Washington Street Quarry

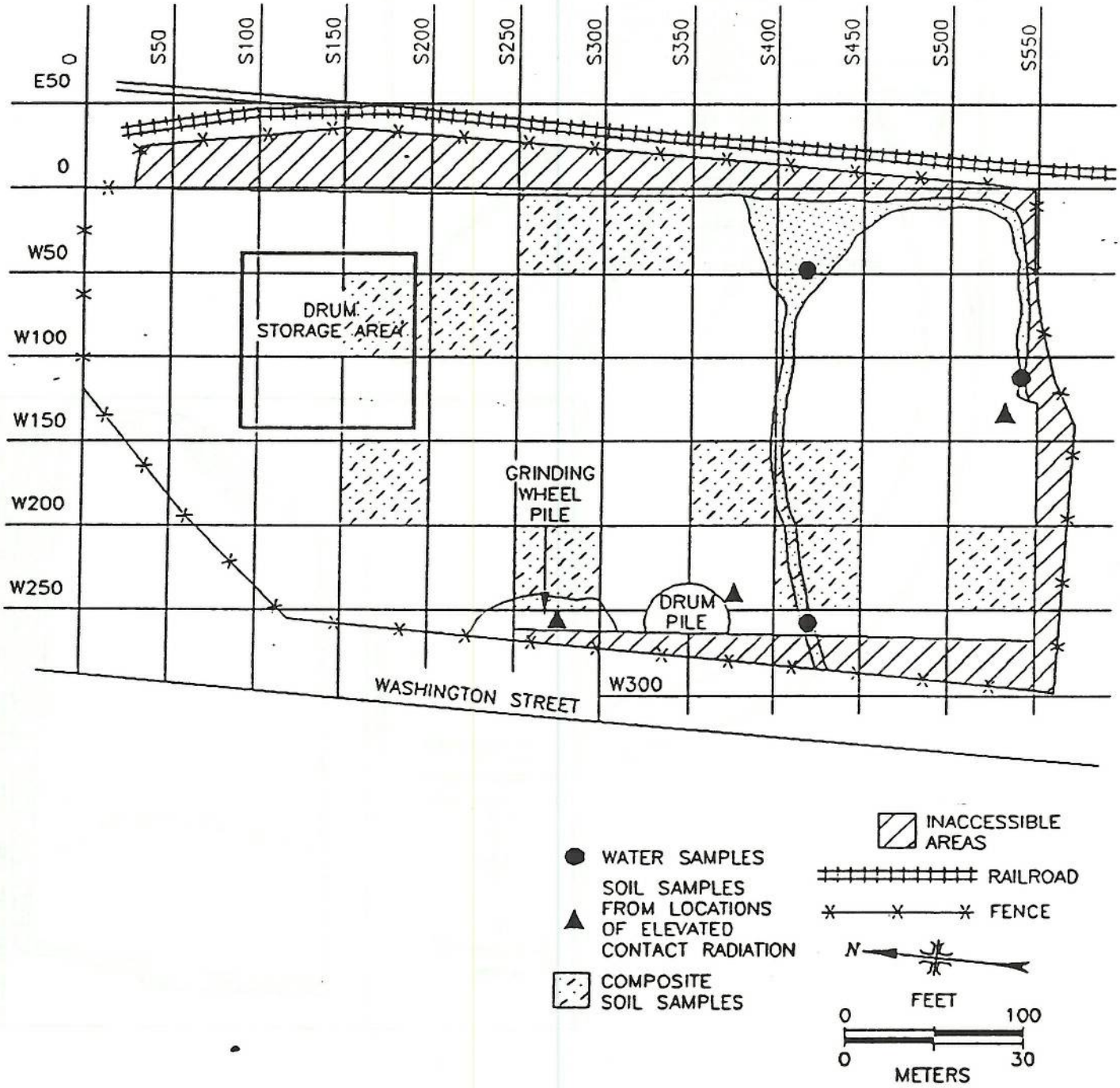


FIGURE 2: Washington Street Quarry Indicating Sampling Locations

TABLE 1

EXPOSURE RATE MEASUREMENTS
CABOT CORPORATION
WASHINGTON STREET QUARRY

Location[a]	Grid Coordinate S	Grid Coordinate W	Exposure Rate (μR/h) at 1 m above surface
1	300	150	9
2	253	246	15
3	300	250	14
4	400	150	9
5	200	50	21
6	200	200	8
7	Hwy 31 (Background)		8

[a]Refer to Figure 2.

TABLE 2

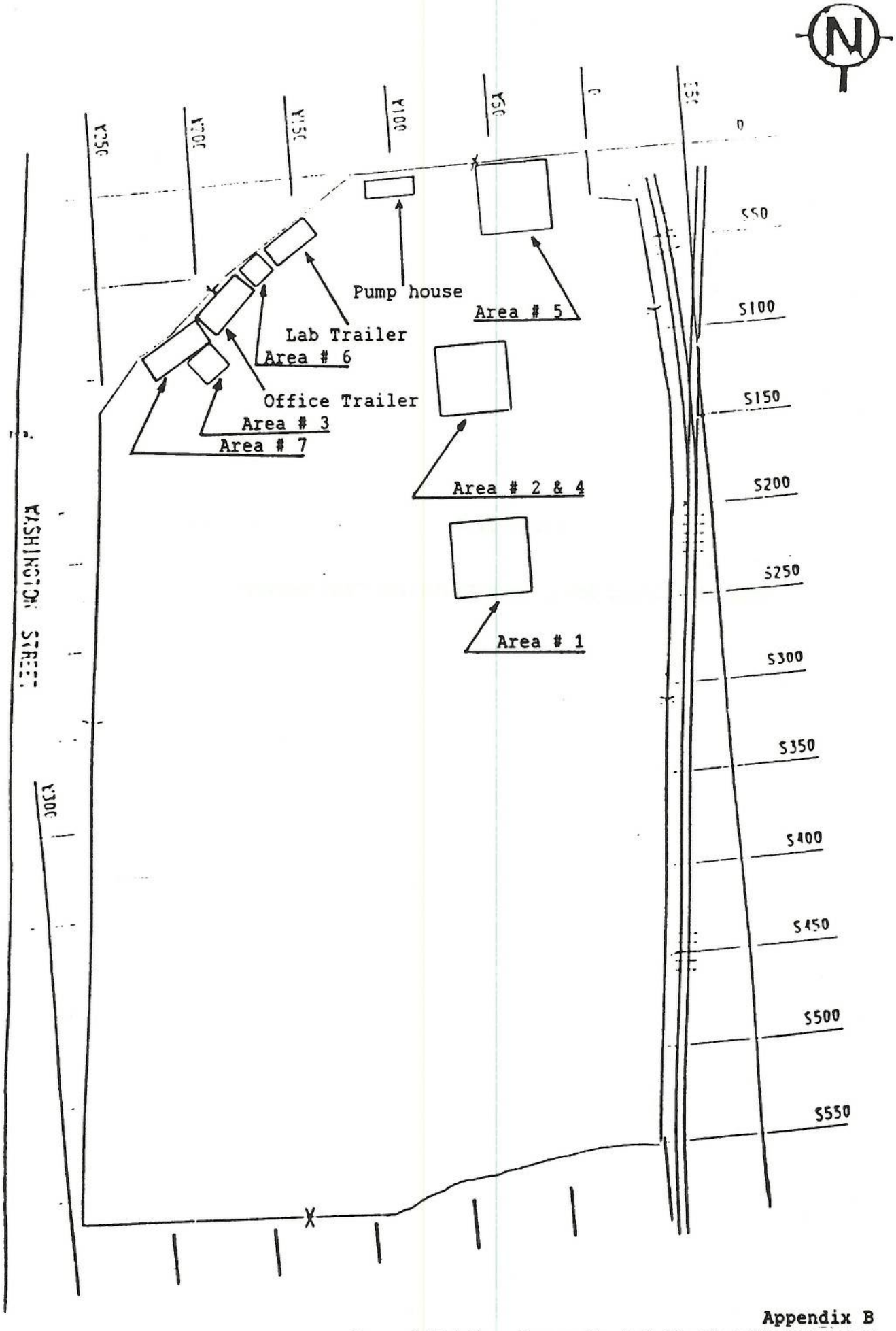
RADIONUCLIDE CONCENTRATIONS IN SOIL
CABOT CORPORATION
WASHINGTON STREET QUARRY
KOKOMO, INDIANA

Sample No.	Location S W	Radionuclide Concentrations (pCi/g) U-235	U-238	Th-232
1[a,c]	531S, 138W	10.4 ± 0.6	34.4 ± 4.0	27.0 ± 1.7
2[b,c]	531S, 138W	0.5 ± 0.2	4.3 ± 1.7	2.1 ± 0.6
3[c]	376S, 246W	0.1 ± 0.1	2.0 ± 1.1	0.9 ± 0.4
4[c]	300S, 250W	0.2 ± 0.1	<1.6	1.0 ± 0.3
5	450S, 250W	0.2 ± 0.1	2.7 ± 1.3	1.1 ± 0.3
6	450S, 250W	0.2 ± 0.1	1.2 ± 0.9	1.0 ± 0.3
7	400S, 200W	0.2 ± 0.1	1.3 ± 1.1	1.0 ± 0.4
8	550S, 250W	0.2 ± 0.1	1.7 ± 1.0	1.2 ± 0.4
9	300S, 250W	0.1 ± 0.1	1.3 ± 1.3	1.0 ± 0.4
10	200S, 200W	0.2 ± 0.1	1.7 ± 0.9	1.0 ± 0.3
11	250S, 100W	0.2 ± 0.1	1.7 ± 1.1	0.9 ± 0.4
12	250S, 100W	0.2 ± 0.1	<1.4	<0.6
13	300S, 50W	0.2 ± 0.1	2.2 ± 1.0	0.8 ± 0.3
14	350S, 500W	0.2 ± 0.1	1.2 ± 0.8	0.7 ± 0.3
15	200S, 100W	0.2 ± 0.1	<1.7	1.2 ± 0.3

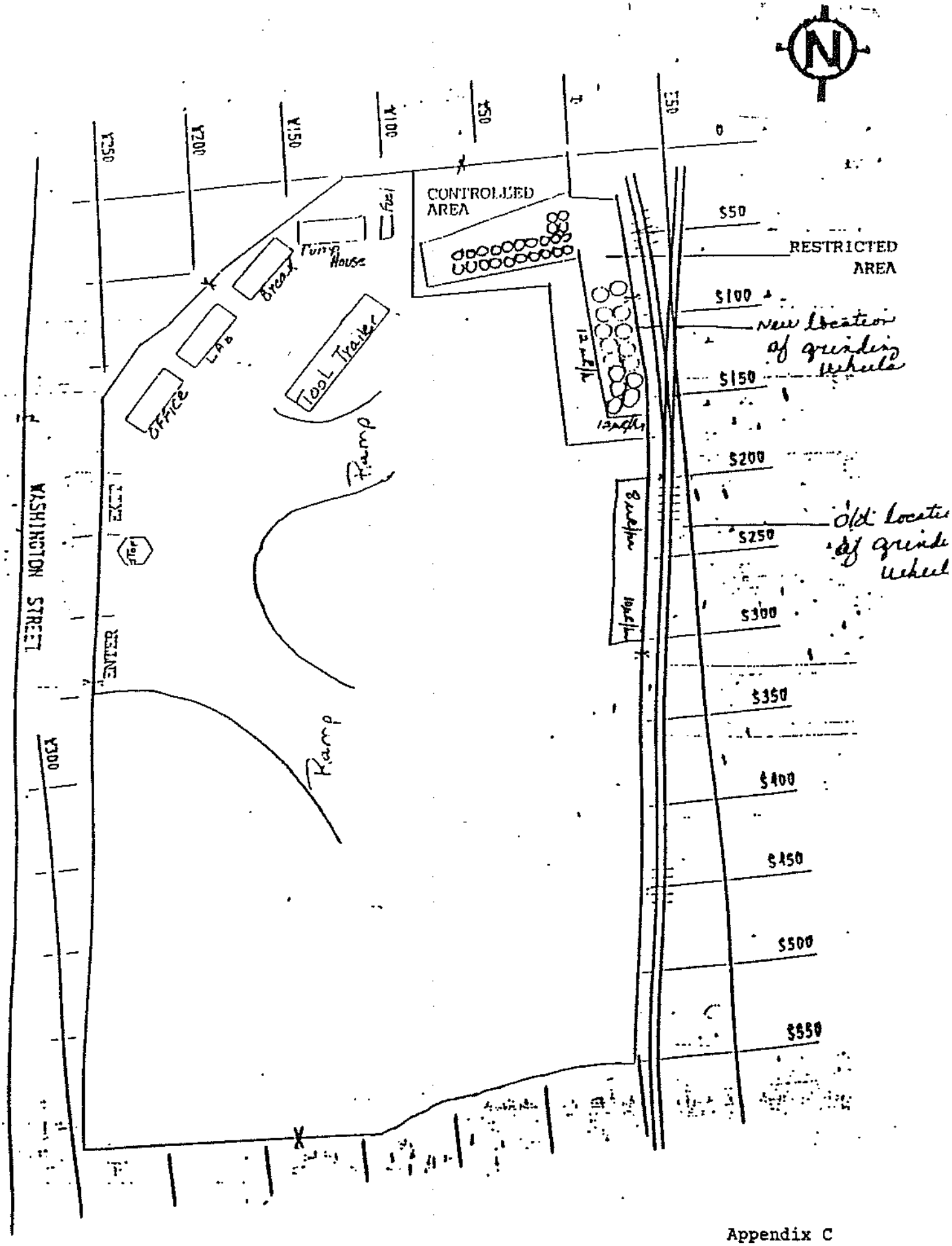
[a]Prior to remediation.
[b]Post remediation sample.
[c]Soil sample from location of elevated contact radiation.

Appendix B

Map of Holding Areas Used Following ORAU Survey



Appendix B
Map of Holding Areas Used Following ORAU Survey



Appendix C
Examples of Routine Site Surveys

Appendix C

Examples of Routine Site Surveys

BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY IH/HP LOG

Page 1 of 2

Date Friday 5 Apr 91

Wind is blowing to N Wind Descriptor:

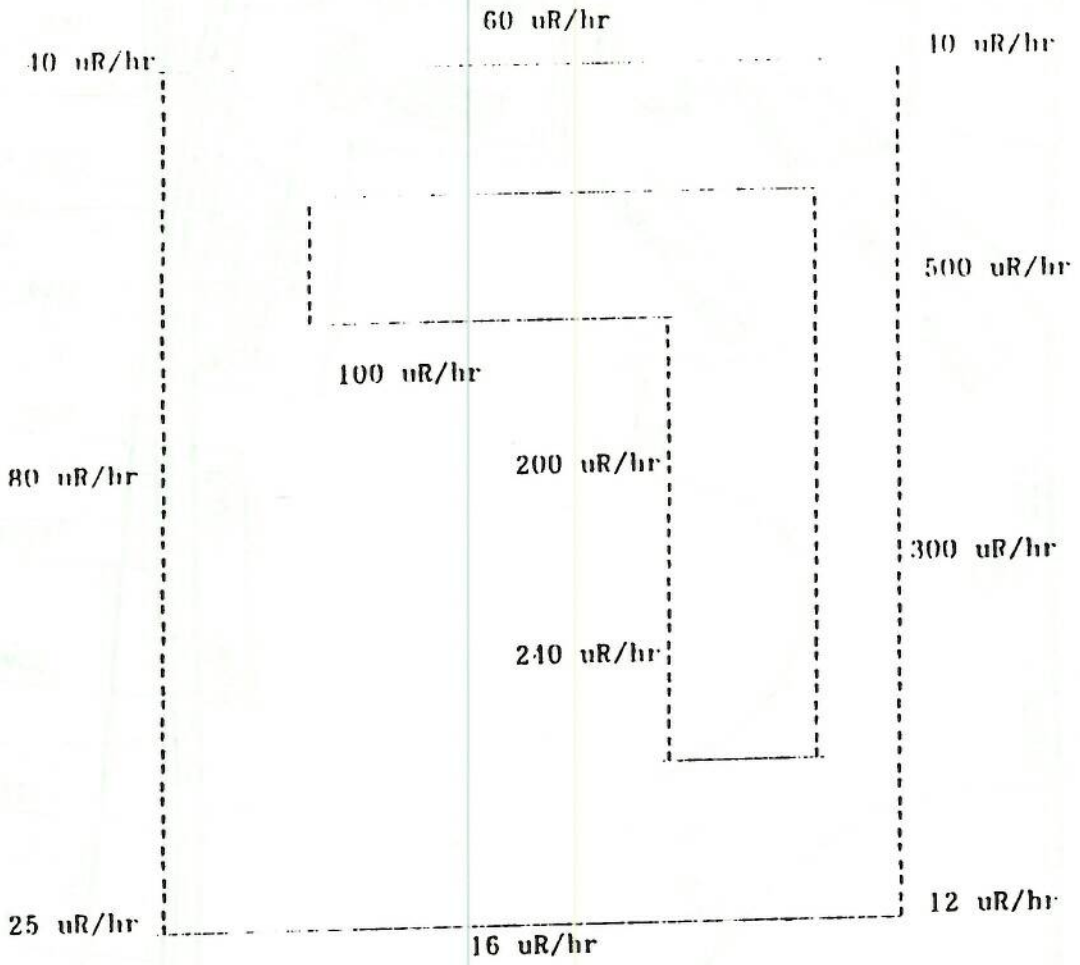
General Weather Description

General Work Description(s): (1) pumping Ops (2) Rad Survey
~~(2) Backfill Op~~

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks
Ludlum 12S	Rad	1600	10uR/hr	Survey to check area
				grinding wheels were
				moved from
				BKg outside trailer
				6 uR/hr

RAD OVERPACK AREA
April 5, 1991

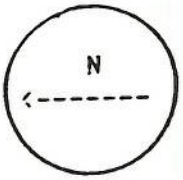


INSTRUMENT USED IN SURVEY: LUDLUM 12 S MICRO R METER SERIAL #71691

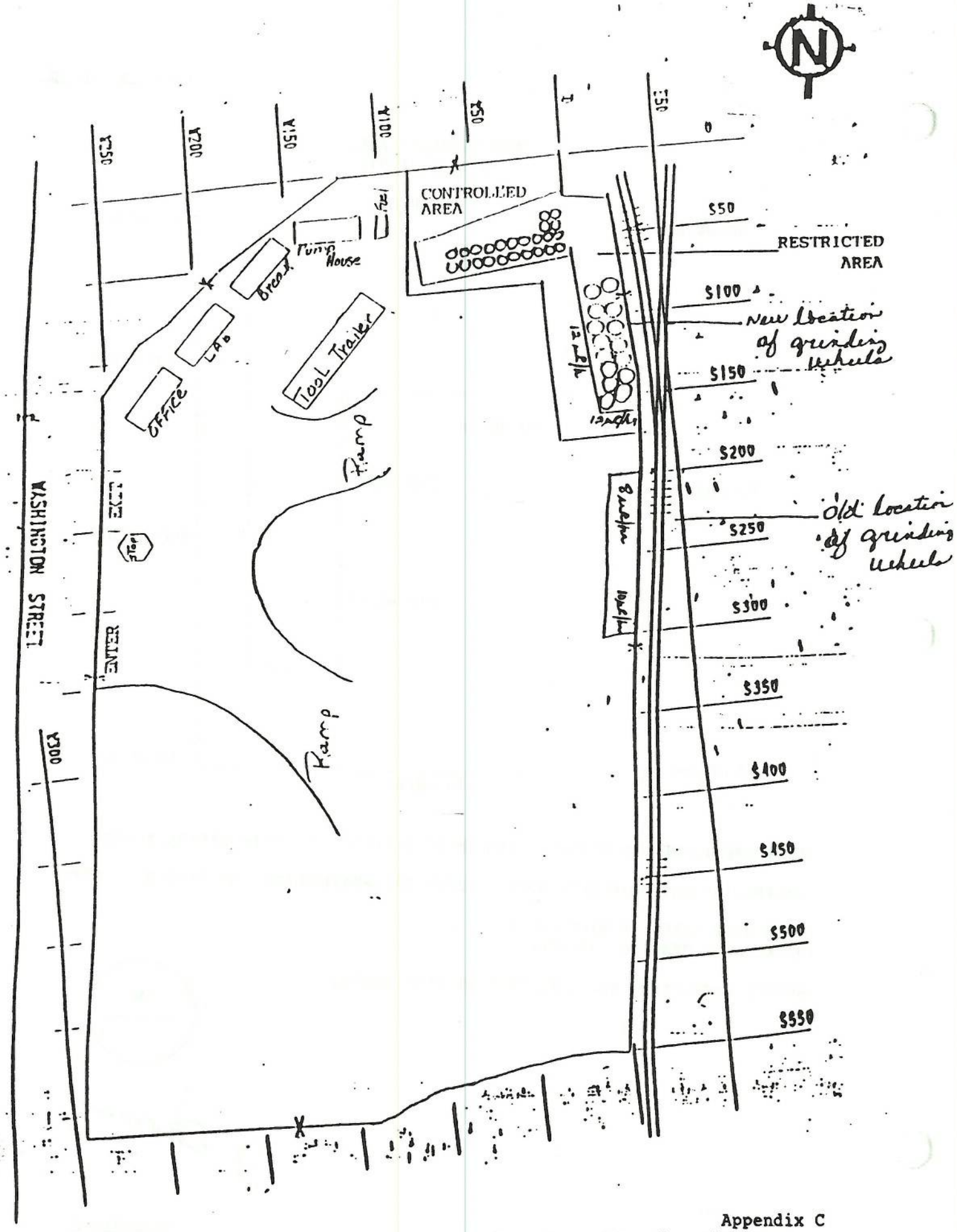
CALIBRATED ON: MARCH 6, 1991 NEXT CALIBRATION DUE: SEPTEMBER 6, 1991

DOSE RATE GIVEN IN MICRO R/hr
BACKGROUND READING: 4uR/hr

SURVEY CONDUCTED: April 5, 1991 BY JUDY THOMAS



J. Thomas



Appendix C
Examples of Routine Site Surveys

BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY IH/HP LOG

Page 1 of 8

Date Monday 8 Apr 91

Wind is blowing to NW Wind Descriptor: Light to None

General Weather Description 80% chance of Rain

General Work Description(s): (1) pumping Ops (2) Backfill Began

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks
Lodlum 12S Micro R Meter	Rad	1000		See Attached Survey

BECHTEL NATIONAL, INC.
Washington Street Quarry Project
410 South Washington Street
Kokomo, Indiana 46901

SMEAR SURVEY RECORD

Date: April 8, 1991

Smears Collected by: Judy Thomas Smears Counted by: Judy Thomas

Smear Number	Smear Location	Gross Alpha (cpm)	Gross Beta/Gamma (cpm)	Counter Eff.
Bkg	Alpha Counter Background	.16	XXXXX	.338 c/d
Bkg	Beta/Gamma Counter Bkg	XXXXX	26.31	.083 c/d

		ALPHA MEASUREMENTS		BETA-GAMMA MEASUREMENTS	
		Gross Alpha (cpm)/100cm	Net Alpha (dpm)/100cm	Gross Beta/Gamma (cpm)/100cm	Net Beta/Gamma (dpm)/100cm
1	LAB TRAILER DESK	.00	0.00	27.00	8.31
2	LAB TRAILER FLOOR	.40	0.71	25.00	0.00
3	BECHTEL TRAILER DOOR	.20	0.12	27.00	8.31
4	BECHTEL TRAILER FLOOR	.20	0.12	27.40	13.13
5	BECHTEL TRAILER FLOOR	.40	0.71	26.40	1.08
6	BECHTEL TRAILER DOOR	.20	0.12	30.20	16.87
7	BECHTEL TRAILER SHELF	.20	0.12	29.20	31.82
8	BECHTEL TRAILER SHELF	.10	0.71	28.60	27.59
9	BREAK ROOM COFFEE POT	.00	0.00	26.20	0.00
10	BREAK ROOM REFRIDGERATOR	.00	0.00	25.10	0.00
11	OFFICE TRAILER FLOOR	.20	0.12	24.00	0.00
12	OFFICE TRAILER DESK	.00	0.00	25.20	0.00
13	OFFICE TRAILER COFFEE	.00	0.00	26.00	3.49
14	OFFICE TRAILER WT.COOLER	.00	0.00	30.00	14.16

SITE WIDE SURVEY

APRIL 8, 1991

SMEARS COUNTED ON:

LUDLUM MODEL 2000 SCALER (ALPHA)

WITH MODEL 43-10 DETECTOR

CALIBRATION DATE NOVEMBER 6, 1990

COUNTER EFFICIENCY 33.8%

LUDLUM MODEL 2200 SCALER RATEMETER (BETA)

WITH MODEL 44-10 DETECTOR

CALIBRATION DATE NOVEMBER 6, 1990

COUNTER EFFICIENCY 8.3%

ALPHA BACKGROUND .16 COUNTS PER MINUTE

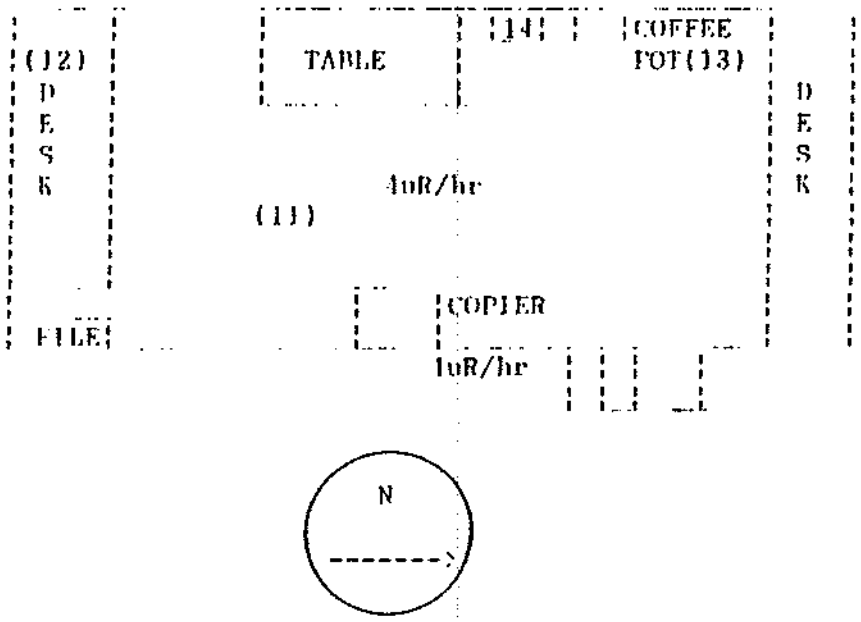
BETA BACKGROUND 26.31 COUNTS PER MINUTE

**********NEXT CALIBRATION DUE MAY 6, 1991**********

SITE WIDE SURVEY

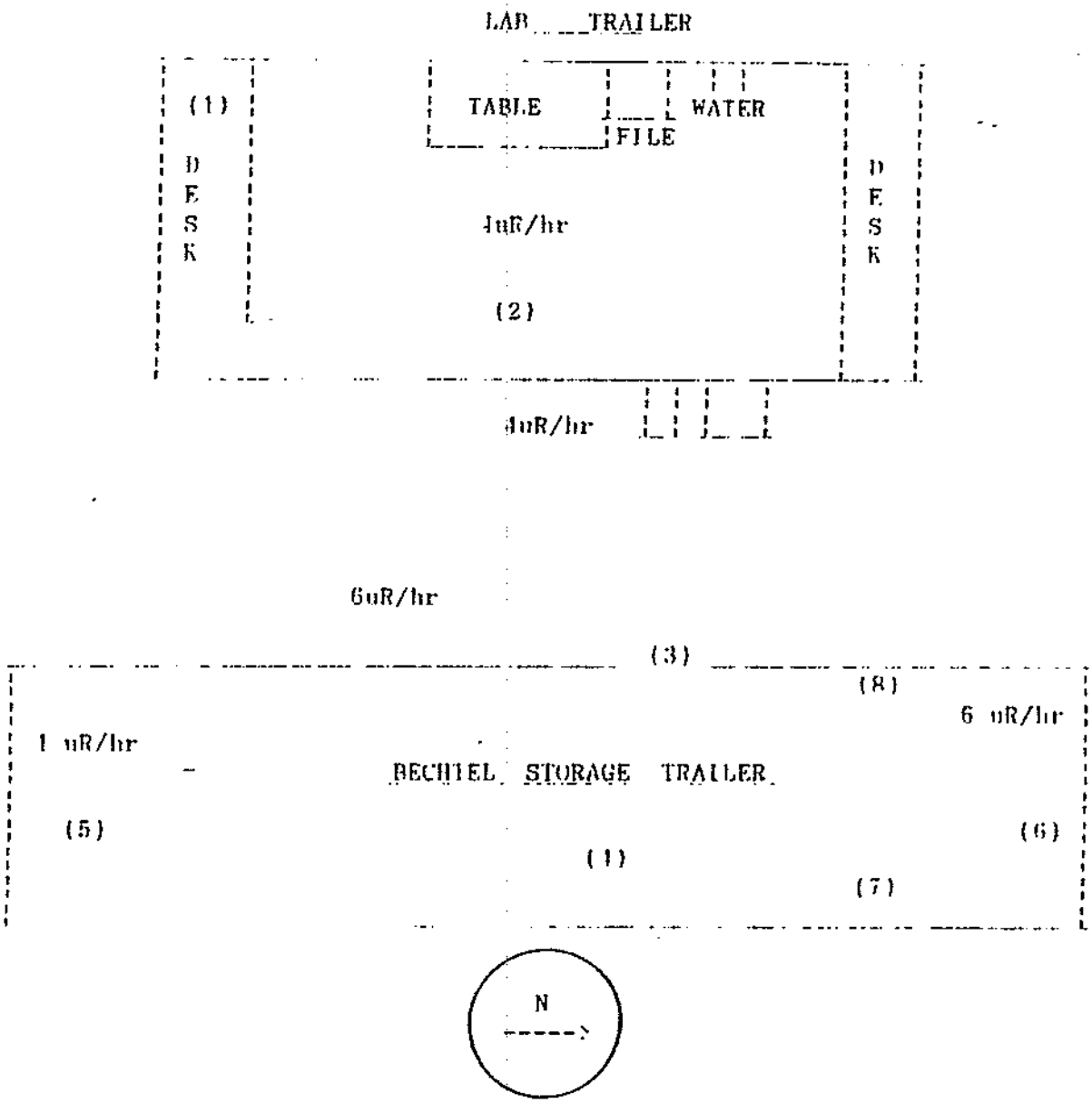
APRIL 8, 1991

OFFICE TRAILER



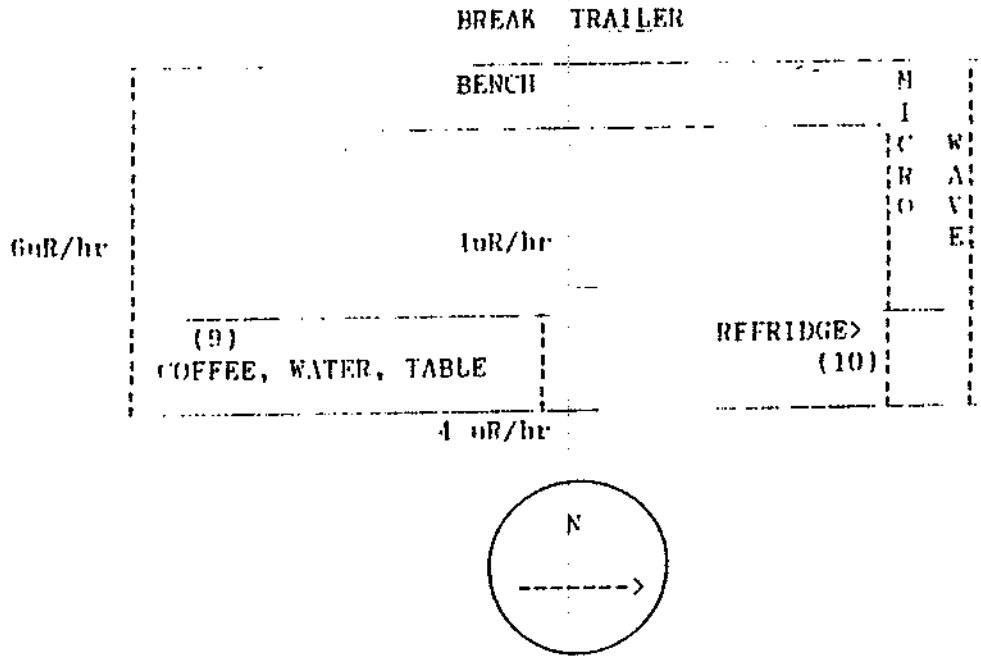
SITE WIDE SURVEY

APRIL 8, 1991

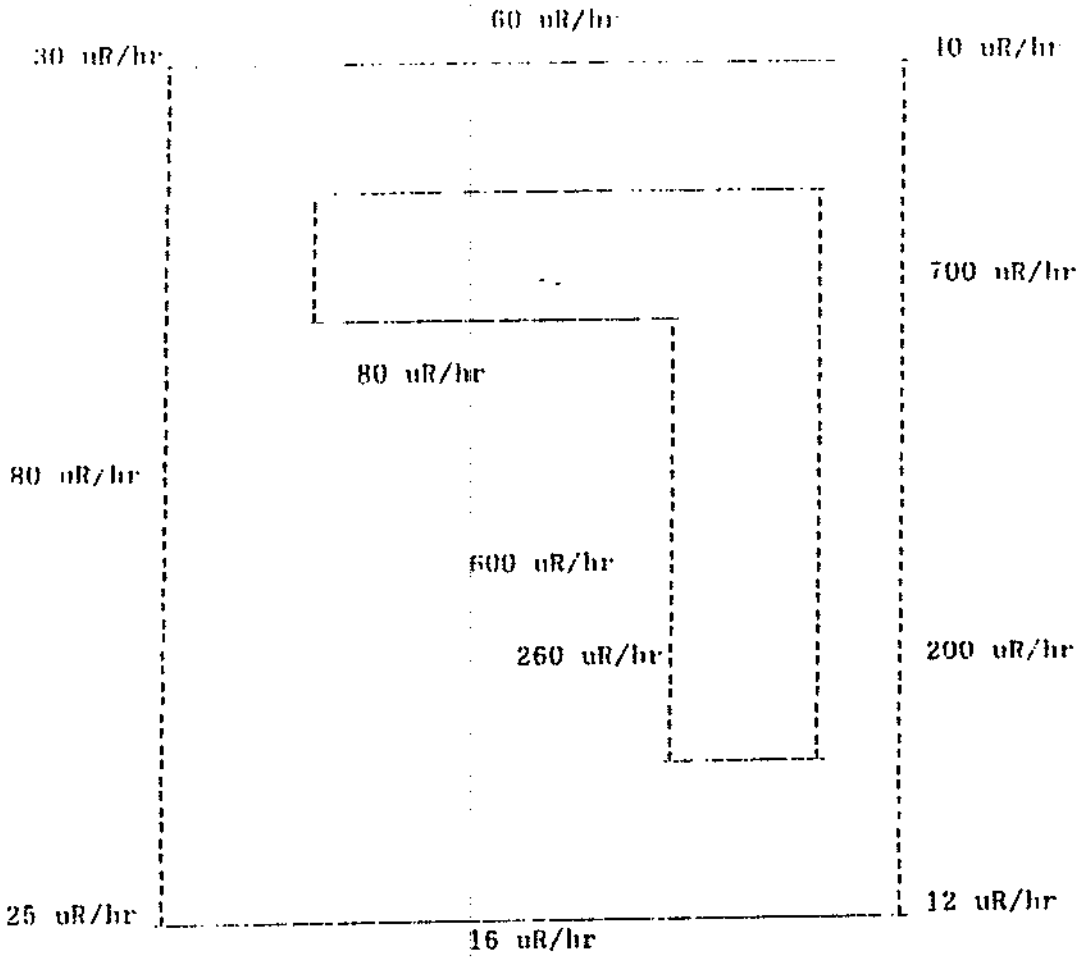


SITE WIDE SURVEY

APRIL 8, 1991



RAD OVERPACK AREA
April 8, 1991

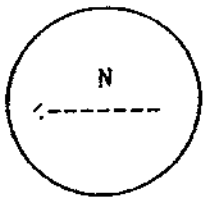


INSTRUMENT USED IN SURVEY: LUDLUM 12 S MICRO R METER SERIAL #71691

CALIBRATED ON: MARCH 6, 1991 NEXT CALIBRATION DUE: SEPTEMBER 6, 1991

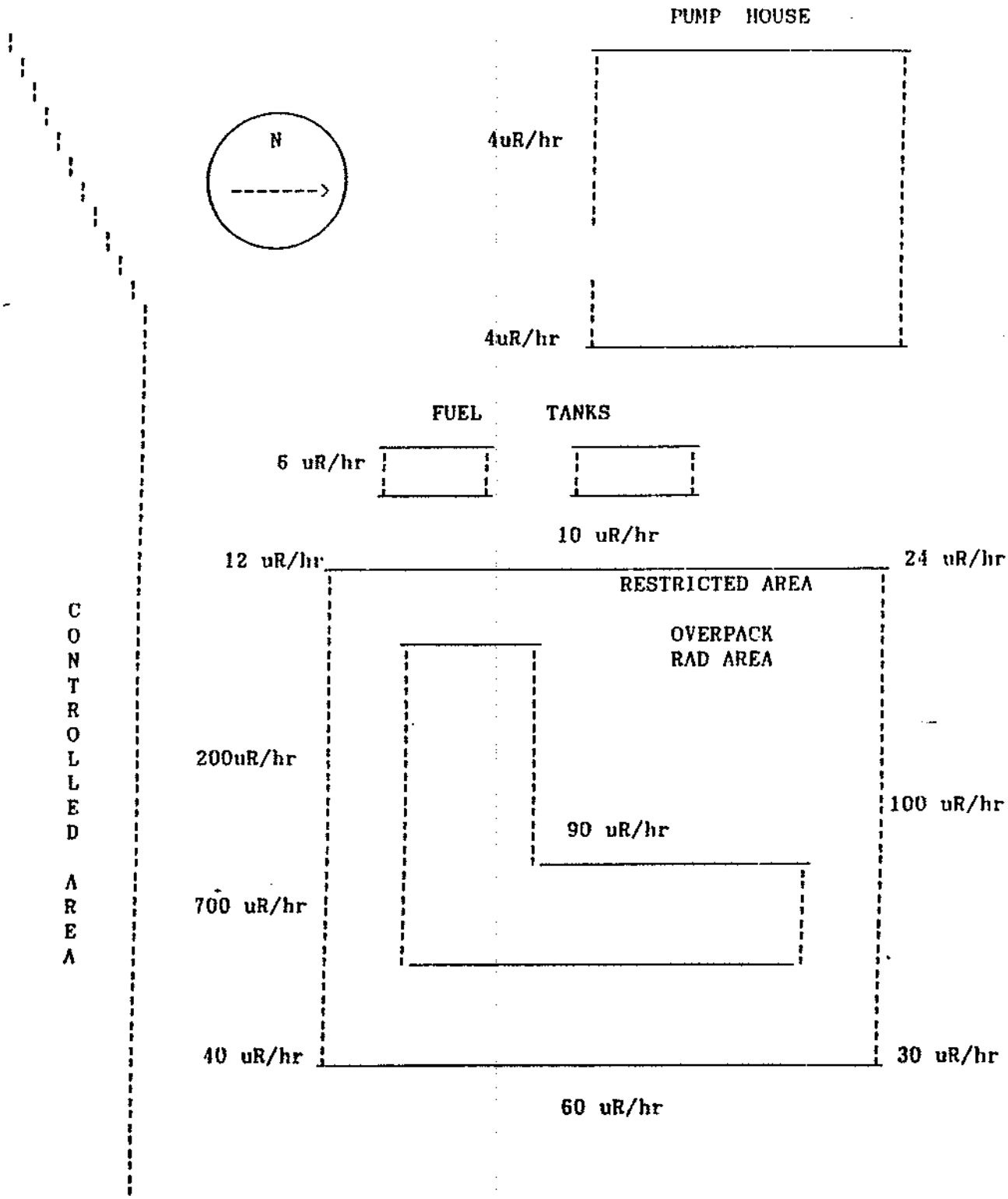
DOSE RATE GIVEN IN MICRO R/hr
BACKGROUND READING: 4uR/hr

SURVEY CONDUCTED: April 8, 1991 BY JUDY THOMAS



SITE WIDE SURVEY

APRIL 8, 1991



BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY HH/HP LOG

Monday
Date 20 May 91

Page 1 of 9

Wind is blowing to____ Wind Descriptor: Light To None

General Weather Description High @ upper 80's

General Work Description(s) (1) Backfill (2) Drum Evaporation (3) Site-Wide Survey

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks
Ludlum 12-S	Rad	1200		See Attached Survey

Appendix C
~~Examples of Routine~~ Site Surveys

BECHTEL NATIONAL, INC.
Washington Street Quarry Project
410 South Washington Street
Kokomo, Indiana 46901

SMEAR SURVEY RECORD

Date: MAY 20, 1991

Smears Collected by: Judy Thomas

Smears Counted by: Judy Thomas

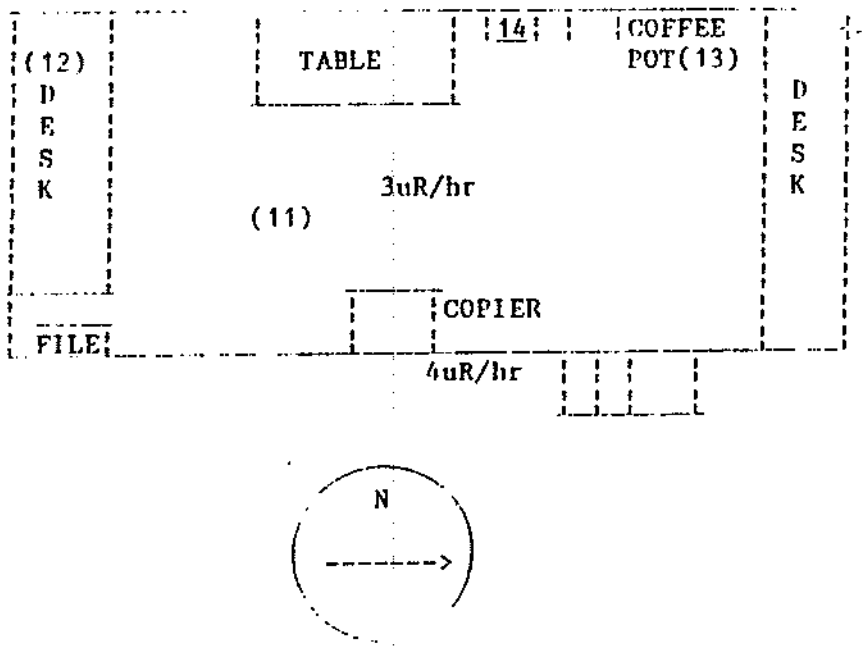
Smear Number	Smear Location	Gross Alpha (cpm)	Gross Beta/Gamma (cpm)	Counter Eff.
Bkg	Alpha Counter Background	.26	XXXXX	.386 c/d
Bkg	Beta/Gamma Counter Bkg	XXXXX	25.44	.081 c/d

		ALPHA MEASUREMENTS		BETA-GAMMA MEASUREMENTS	
		Gross Alpha (cpm)/100cm	Net Alpha (dpm)/100cm	Gross Beta/Gamma (cpm)/100cm	Net Beta/Gamma (dpm)/100cm
1	LAB TRALIER DESK	.00	.00	26.40	11.85
2	BECHTEL TRAILER DOOR	.40	.36	26.40	11.85
3	BECHTEL TRAILER DOOR	.40	.36	24.00	.00
4	BECHTEL TRAILER FLOOR	.40	.36	23.80	.00
5	BECHTEL TRAILER FLOOR	.20	.00	24.60	.00
6	BREAK ROOM COFFEE POT	.40	.36	25.80	.00
7	BECHTEL TRAILER SHELF	.20	.00	25.60	1.98
8	BECHTEL TRAILER SHELF	.20	.00	33.00	93.33
9	BREAK ROOM FLOOR	.20	.00	28.80	41.48
10	BREAK ROOM REFRIGERATOR	.00	.00	21.60	.00
11	OFFICE TRAILER DESK	.00	.00	25.40	.00
12	OFFICE TRAILER COFFEEPOT	.20	.00	24.40	.00
13	OFFICE TRAILER WATER	.00	.00	24.20	.00
14	OFFICE TRAILER FLOOR	.00	.00	26.40	11.85

SITE WIDE SURVEY

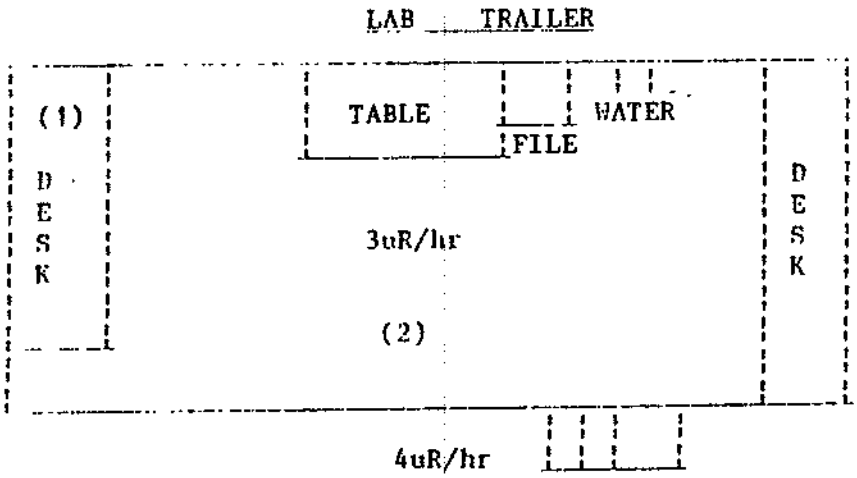
MAY 20, 1991

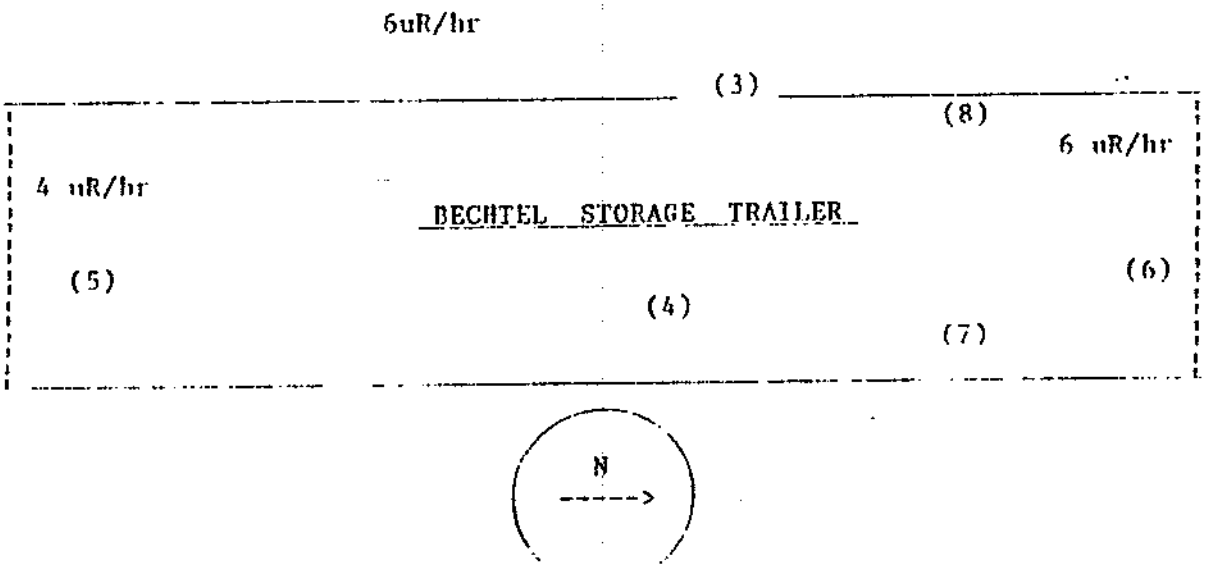
OFFICE TRAILER



SITE WIDE SURVEY

MAY 20, 1991

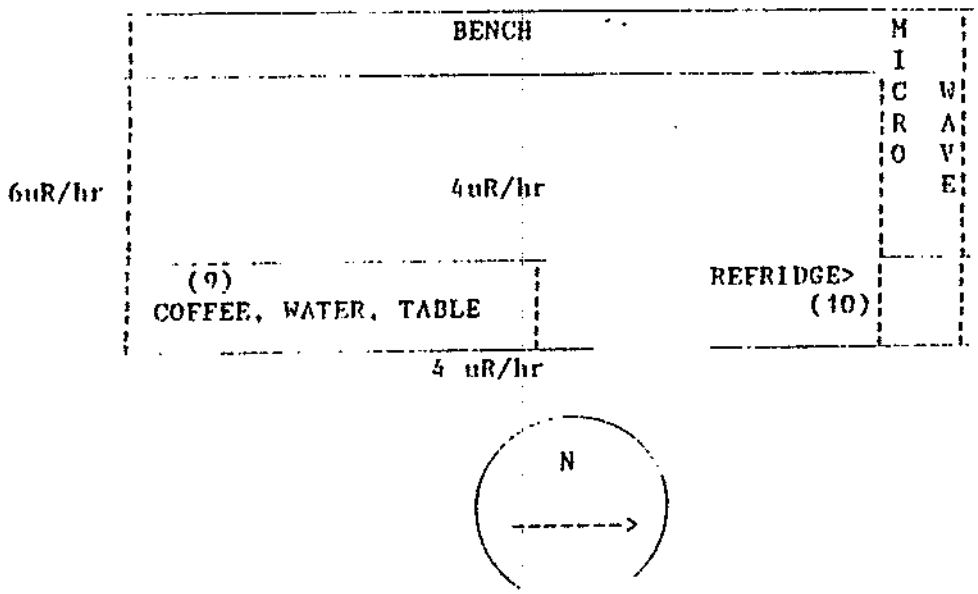




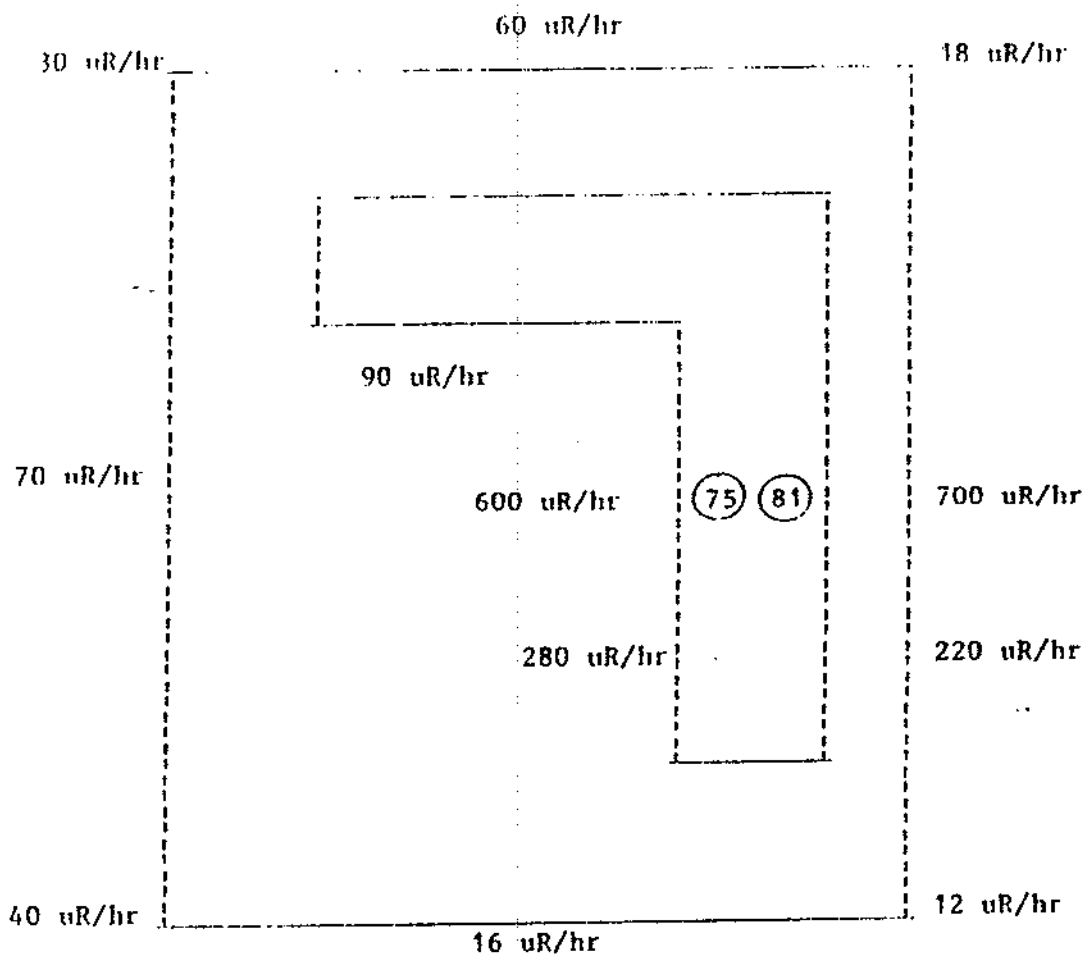
SITE WIDE SURVEY

MAY 20, 1991

BREAK TRAILER



RAD OVERPACK AREA
MAY 20, 1991

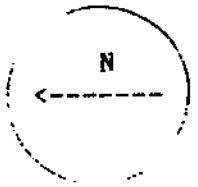


INSTRUMENT USED IN SURVEY: LUDLUM 12 S MICRO R METER SERIAL #71691

CALIBRATED ON: MARCH 6, 1991 NEXT CALIBRATION DUE: SEPTEMBER 6, 1991

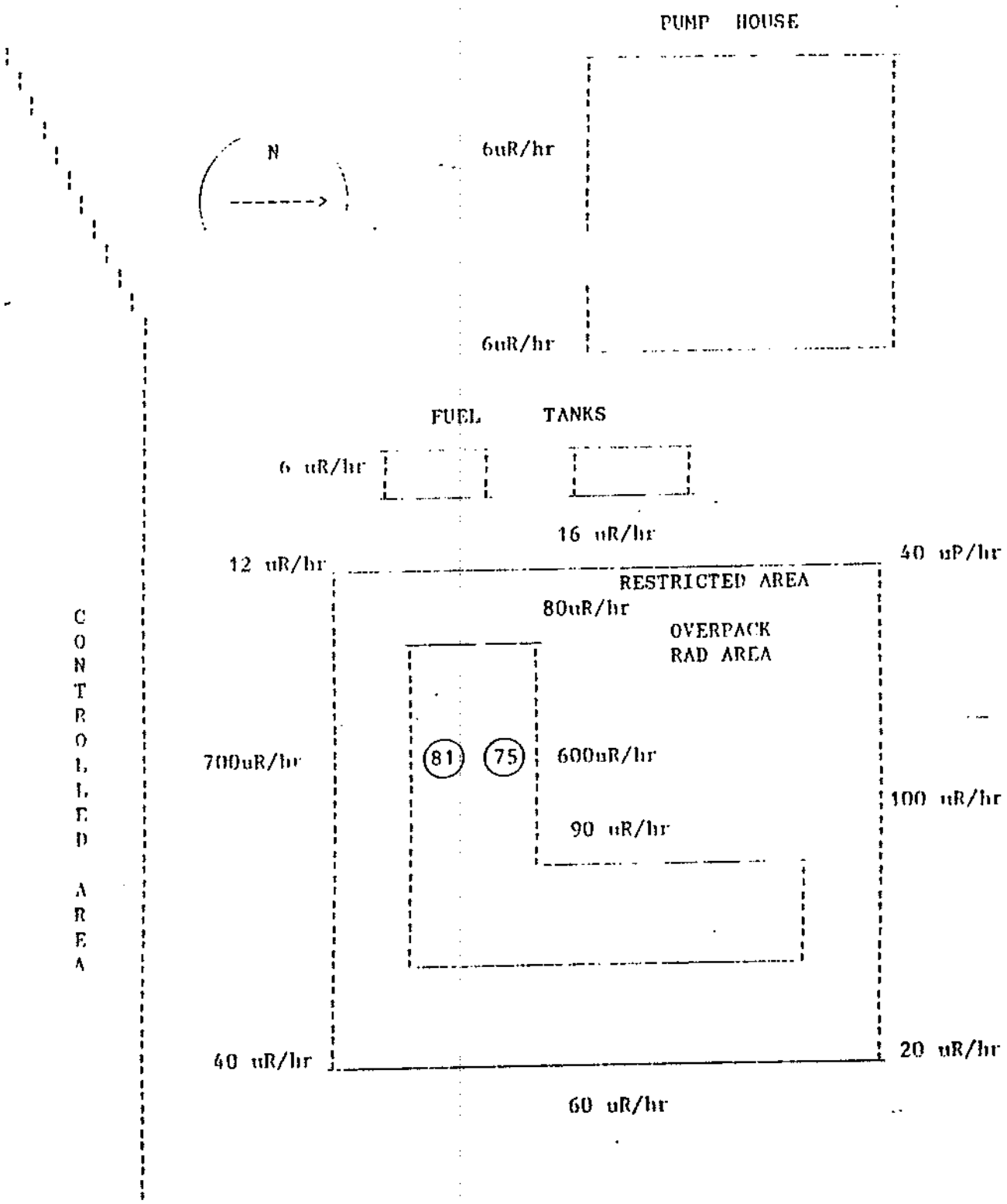
DOSE RATE GIVEN IN MICRO R/hr
BACKGROUND READING: 4uR/hr (PRE AND POST SURVEY)

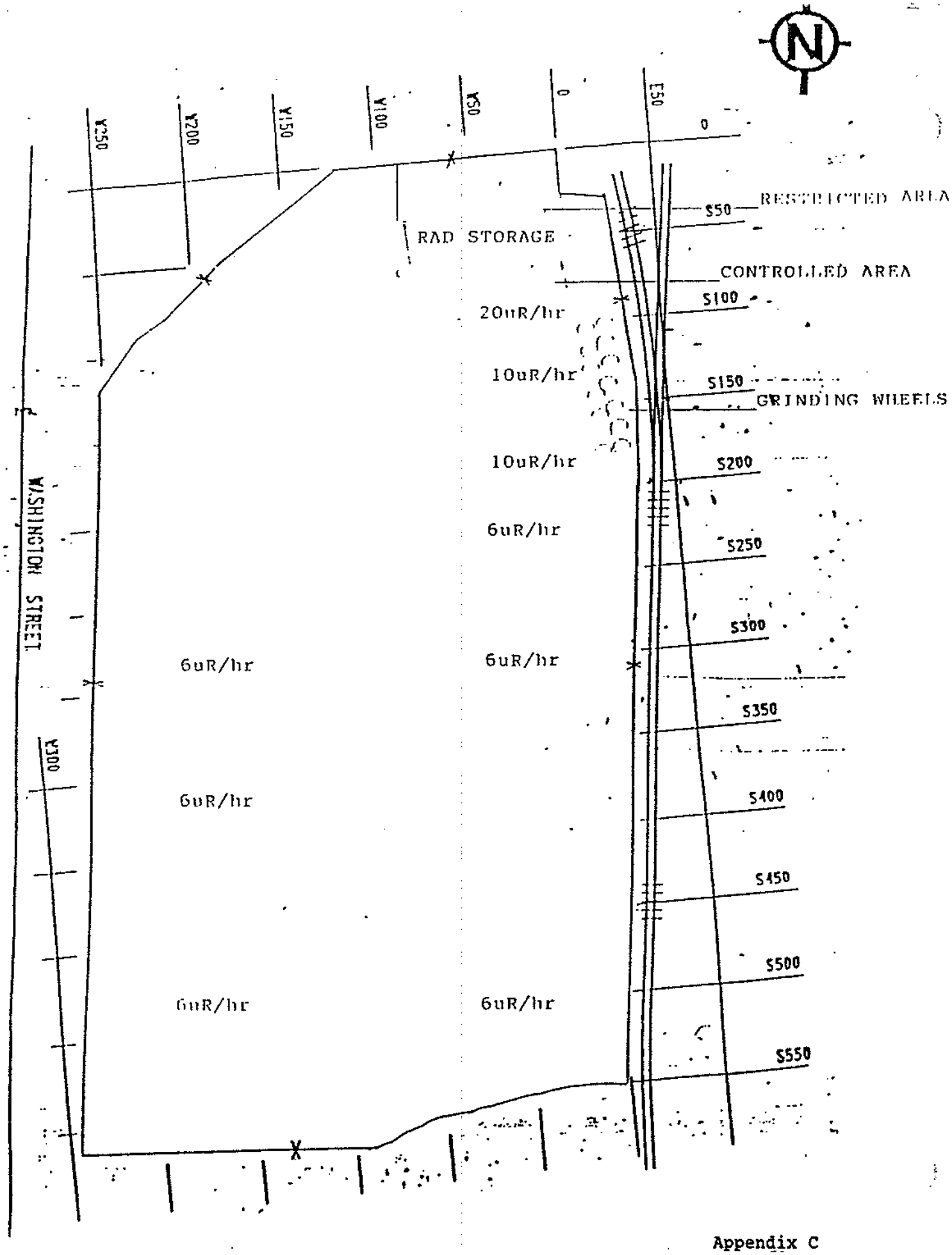
SURVEY CONDUCTED: MAY 20, 1991 BY JUDY THOMAS



SITE WIDE SURVEY

MAY 20, 1991





Appendix C
Examples of Routine Site Surveys

A. MATERIALS DATA

SPECIFIC MATERIAL TRANSFER ACTIONS

Date of Shipment	Materials Shipped	Licensed Recipient and License Number
June 11, 1991	Radioactive Materials, n.o.s. (depleted uranium) -2 drums Radioactive Materials, Limited Quantity, n.o.s. -2 drums	Allied Ecology Services, Inc California Radioactive Materials License Number 2873-60
June 28, 1991	Radioactive Material, LSA, n.o.s. -1 drum	same as above
June 28, 1991	Radioactive Material, LSA, n.o.s. -14 drums	Envirocare of Utah, Inc. Utah Department of Health, Bureau of Radiation Control, Radioactive Material License Number UT2300249

NRC FORM 314
(6-89)
10 CFR 30.36(d)(1)(iv)
10 CFR 40.42(d)(1)(iv)
10 CFR 70.38(d)(1)(iv)

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF DISPOSITION OF MATERIALS

INSTRUCTIONS SEND THE COMPLETED CERTIFICATE TO THE NRC OFFICE SPECIFIED ON THE REVERSE. *(All items MUST be completed—print or type)*

APPROVED BY OMB: 3150-0028
EXPIRES: 4/30/92

ESTIMATED BURDEN PER RESPONSE TO COMPLY WITH THIS INFORMATION COLLECTION REQUEST: .5 HRS. FORWARD COMMENTS REGARDING BURDEN ESTIMATE TO THE RECORDS AND REPORTS MANAGEMENT BRANCH (P-530), U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC 20555, AND TO THE PAPERWORK REDUCTION PROJECT (3150-0028), OFFICE OF MANAGEMENT AND BUDGET, WASHINGTON, DC 20503.

LICENSEE NAME AND ADDRESS

Cabot Corporation
950 Winter Street
P.O. Box 9073
Waltham, MA 02254-9073

LICENSE NUMBER

SUC-1538

LICENSE EXPIRATION DATE

July 31, 1991

THE LICENSEE OR ANY INDIVIDUAL EXECUTING THIS CERTIFICATE ON BEHALF OF THE LICENSEE CERTIFIES THAT:
(Check and/or complete the appropriate item(s) below.)

A. MATERIALS DATA *(Check one and complete as necessary)*

[ ] 1. NO MATERIALS HAVE EVER BEEN PROCURED OR POSSESSED BY THE LICENSEE UNDER THIS LICENSE.

OR

[X] 2. ALL MATERIALS PROCURED AND/OR POSSESSED BY THE LICENSEE UNDER THE LICENSE NUMBER CITED ABOVE HAVE BEEN DISPOSED OF IN THE FOLLOWING MANNER. *(If additional space is needed, use the reverse side or provide attachments.)*

Describe specific material transfer actions and, if there were radioactive wastes generated in terminating this license, the disposal actions, including the disposition of low-level radioactive waste, mixed waste, Greater-than-Class-C waste, and sealed sources, if applicable.

For transfers, specify the date of the transfer, the name of the licensed recipient, and the recipient's NRC license number or Agreement State name and license number.

See attached list

If materials were disposed of directly by the licensee rather than transferred to another licensee, licensed disposal site or waste contractor, describe the specific disposal procedures *(e.g., decay in storage).*

B. OTHER DATA

[X] 1. OUR LICENSE HAS NOT YET EXPIRED; PLEASE TERMINATE IT.

2. WAS A RADIATION SURVEY CONDUCTED TO CONFIRM THE ABSENCE OF LICENSED RADIOACTIVE MATERIALS AND TO DETERMINE WHETHER ANY CONTAMINATION REMAINS ON THE PREMISES COVERED BY THE LICENSE? *(Check one)*

[ ] NO *(Attach explanation)*
[X] YES, THE RESULTS *(Check one)*
  [X] ARE ATTACHED, or
  [ ] WERE FORWARDED TO NRC ON *(Date)*

3. THE PERSON TO BE CONTACTED REGARDING THE INFORMATION PROVIDED ON THIS FORM

NAME: Wayne Reiber

TELEPHONE NUMBER: 617-622-3761

4. MAIL ALL FUTURE CORRESPONDENCE REGARDING THIS LICENSE TO

Cabot Corporation
950 Winter Street
P.O. Box 9073
Waltham, MA 02254-9073

CERTIFYING OFFICIAL

I CERTIFY UNDER PENALTY OF PERJURY THAT THE FOREGOING IS TRUE AND CORRECT.

SIGNATURE

DATE

PRINTED NAME AND TITLE

WARNING: FALSE STATEMENTS IN THIS CERTIFICATE MAY BE SUBJECT TO CIVIL AND/OR CRIMINAL PENALTIES. NRC REGULATIONS REQUIRE THAT SUBMISSIONS TO THE NRC BE COMPLETE AND ACCURATE IN ALL MATERIAL RESPECTS. 18 U.S.C. SECTION 1001 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

Appendix H

NRC 314 Form

Overpack Number	Repackaged Into Drum Number	Repackaged Into Drum Number	Transferred to Materials License Number
48	427		UT2300249
49	368	432	UT2300249
50	370	432	UT2300249
51	365	428	UT2300249
52	370	432	UT2300249
53	365	428	UT2300249
54	429		UT2300249
55	429		UT2300249
56	429		UT2300249
57	430		UT2300249
58	430		UT2300249
60	367	423	UT2300249
61	367	423	UT2300249
62	366	423	UT2300249
63	431		UT2300249
64	368	432	UT2300249
65	431		UT2300249
66	365	428	UT2300249
68	369		2873-60
69	75/81		2873-60
70	75/81		2873-60
71	75/81		2873-60
72	75/81		2873-60
73	75/81		2873-60
74	75/81		2873-60
75			2873-60
76	75/81		2873-60
77	75/81		2873-60
78	75/81		2873-60
79	75/81		2873-60
81	-		2873-60
82	404	433	UT2300249
83	367	423	UT2300249
84	369		2873-60
85	367	423	UT2300249
243	432		UT2300249
255	432		UT2300249
356	432		UT2300249
402	433		UT2300249
403	433		UT2300249
404	433		UT2300249

Grinding wheels (approximately 55 tons) left at WSQ

Licensees to which the materials were transferred:

Allied Ecology Services, Inc., California Radioactive Materials License Number 2873-60

Envirocare of Utah, Inc., Utah Department of Health, Bureau of Radiation Control, Radioactive Material License Number UT2300249

Overpack Number	Repackaged Into Drum Number	Repackaged Into Drum Number	Transferred to Materials License Number
1	421		UT2300249
3	431		UT2300249
4			2873-60
5	422		UT2300249
9	368	432	UT2300249
10	421		UT2300249
13	22		2873-60
14	421		UT2300249
15	422		UT2300249
20	370	432	UT2300249
22			2873-60
23	366/367	423	UT2300249
24	367	423	UT2300249
25	366	423	UT2300249
26	424		UT2300249
27	424		UT2300249
28	370	432	UT2300249
29	366	423	UT2300249
30	371	425	UT2300249
31	367	423	UT2300249
33	371	425	UT2300249
34	368	432	UT2300249
35	367	423	UT2300249
36	368	432	UT2300249
37	367	423	UT2300249
38	426		UT2300249
39			UT2300249
40	370	432	UT2300249
41	427		UT2300249
42	371	425	UT2300249
43	366	423	UT2300249
44	367	423	UT2300249
45	371	425	UT2300249
46	427		UT2300249
47	368	432	UT2300249

Appendix G

Tabulation of Materials Collected and Their Disposition

Instrument Services Inc.

GF Instrument Services, Inc.

CALIBRATION CERTIFICATE

This Certificate will be accompanied by Calibration Charts or Readings where applicable

CUSTOMER INFORMATION		INSTRUMENT INFORMATION	
Customer Name	Bechtel	Instrument Manufacturer	Tudium
Customer Address	410 S. Washington Street Kokomo, IN 46901	Model 2000	Serial Number 64310
		External Probe(s)	Serial # 056217
Customer P.O. #	19058-PO-270	Calibration Method	^{230}MP-1 s/n 298 Th s/n 11623
Work Order #	I-91-04-234		

INSTRUMENT CALIBRATION INFORMATION

Instrument Range	Calibration Standard Value	Instrument Response Before Calib	Instrument Response After Calib	Comment
1 min X0.1	20K CPM	1,995 CPM	1,995 CPM	All Calibrations Bln. + & - 10%
	40K	3,997	3,997	
				HV set at 900 Volts
1 min X1	20K	19,994	19,994	
	40K	39,960	39,960	Input Sensitivity = 10 millivolts
1 min X10	20K	199,967	199,967	^{230}Th Efficiency = 33.7%
	40K	399,937	399,937	

STATEMENT OF CERTIFICATION

We Certify that the instrument listed above was calibrated and inspected prior to shipment and that it met all of the Manufacturers published operating specifications. We further certify that our Calibration Measurements are traceable to the National Institute of Standards and Technology (We are not responsible for damage incurred during shipment or use of this instrument).

Instrument Calibrated by: [illegible] (Signed)

Calibration Date 05-02-91

Re-Calibration Due 11-02-91

I certify that the above information is correct

[illegible] 05-02-91

Administrative Coordinator Date

GP Instrument Services, Inc.

Form IS-23

CALIBRATION CERTIFICATE

This Certificate will be accompanied by Calibration Charts or Readings where applicable

CUSTOMER INFORMATION

Customer Name: Bechtel
Customer Address: 410 S. Washington Street
Kokomo, IN 46901

Customer P.O. #: 19058-PO-270
Work Order #: I-91-04-234

INSTRUMENT INFORMATION

Instrument Manufacturer: Ludlum
Model: 2200 Serial Number: 62818
External Probe(s): 44-40 Serial #: 056218

Calibration Method: ^{99}MP-1 s/n 298
^{99}Tc s/n 1256

INSTRUMENT CALIBRATION INFORMATION

Instrument Range	Calibration Standard Value	Instrument Response Before Calib	Instrument Response After Calib	Comment
1 min X0.1	20K CPM	1,997 CPM	1,997 CPM	All Calibrations Btn. + & - 10%
	40K	3,992	3,992	
				High Voltage - 900 Volts
1 min X1	20K	19,993	19,993	
	40K	39,989	39,989	Input Sensitivity = 55 millivolts
1 min X10	20K	199,924	199,924	Window - OFF
	40K	399,909	399,909	
				Threshold set at 5.0
				Window set at 0
				^{99}Tc Efficiency = 8.1%

STATEMENT OF CERTIFICATION

We Certify that the instrument listed above was calibrated and inspected prior to shipment and that it met all of the Manufacturers published operating specifications. We further certify that our Calibration Measurements are traceable to the National Institute of Standards and Technology (We are not responsible for damage incurred during shipment or use of this instrument)

Instrument Calibrated by: [signature] (Signed)

Calibration Date: 05-02-91
Next Calibration Due: 11-02-91

I certify that the above information is correct

[signature] 05-02-91
Administrative Coordinator Date

Instrument Services Inc.

GP Instrument Services, Inc.

Form IS 23

CALIBRATION CERTIFICATE

This Certificate will be accompanied by Calibration Charts or Readings where applicable

CUSTOMER INFORMATION

Customer Name: Bechtel
Customer Address: 410 S. Washington Street
Kokomo, IN 46901

Customer P.O. #: 19058 PO 255
Work Order #: I-91-02-221

INSTRUMENT INFORMATION

Instrument Manufacturer: Ludlum
Model: 12S
Serial Number: 71691
External Probe(s) Serial #:

Calibration Method: 137MP-1 s/n 298
Cs s/n 107

INSTRUMENT CALIBRATION INFORMATION

	Instrument Range	Calibration Standard Value	Instrument Response Before Calib	Instrument Response After Calib	Comment
1	X1	200 CPM		1.1 uR/hr	All Calibrations Btn. + & - 10%
2		400		2.2	
3					High Voltage = 540 Volts
4	X10	0.015 mR/hr		16	Input set at 40 millivolts
5		0.02		20	
6		0.03		27	200 CPM = 1.1 uR/hr
7					
	X100	0.1		110	
9		0.2		200	
10		0.3		290	
11					
12	X1000	1		1,100	
13		2		2,000	
14		3		2,800	
15					
16					
17					
18					
19					
20					
21					
22					
23					

STATEMENT OF CERTIFICATION

We Certify that the instrument listed above was calibrated and inspected prior to shipment and that it met all of the Manufacturers published operating specifications. We further certify that our Calibration Measurements are traceable to the National Institute of Standards and Technology (We are not responsible for damage incurred during shipment or use of this instrument).

Instrument Calibrated by: [signature] (Signed)

Calibration Date: 03-06-91
Next Calibration Due: 03-06-92

I certify that the above information is correct: [signature]
Administrative Coordinator

03-06-91
Date

~~Appendix F~~
Certificates of Calibration

LUDLUM MEASUREMENTS, INC.
POST OFFICE BOX 810 PH. 915 235-5494
501 OAK STREET FAX NO. (915) 235-4672
SWEETWATER, TEXAS 79556, U.S.A.

CERTIFICATE OF CALIBRATION

CUSTOMER Dechel Inst Co ORDER NO. 70-2239
Mfg. Ludlum Model 123 Serial No. 71691
Mfg. Det. Model Serial No.
Cal. Date 7-10-90 Cal. Due Date 7-10-91 Cal. Interval 1 yr. METERFACE 202-064
Check mark (✓) applies to applicable instr. and/or detector IAW mfg. spec. s. ☑ New Instrument

[ ] Det. (Alpha) Bkgnd. cpm ☐ Det. Oper. V V at MV
T 75 °F RH 60 % Alt 705.8 mm Hg ☑ F/S Resp. ck ☑ Zero Reset ck. ☑ Audio ck. ☑ Meter Zeroed
☑ Bat. ck. (Min. Volt) 2.2 VDC ☐ Bat. Volt VDC Instrument Volt Set 748 V
[ ] Threshold Dial Input Sens. 54 mV. ☐ Input Sens Linearity
[ ] HV Readout (2 points) Ref./Inst. / V Ref./Inst. / V
[ ] Alarm Setting ck. ☐ Window Operation ☐ Background subtract ☑ Mechanical ck.
Repair Instrument Received: ☐ Within Toler. + -10% ☐ 10-20% ☐ Out Toler. ☐ Requiring Repair

COMMENTS:

Gamma Calibration: GM detectors positioned perpendicular to source except for M. 44.9 in which the back of probe faces source.

RANGE MULTIPLIER	REFERENCE CAL. POINT	INSTRUMENT METER READING	INSTRUMENT REC'D "AS FOUND READING"
X 1000	2000 uR/hr ≈ 409 Kcpm	1950 uR/hr	
X "	1000 " ≈ 204 "	1100 "	
X 100	40.9 "	200 "	
X "	20.4 "	100 "	
X 10	4.09 "	20 "	
X "	2.04 "	10 "	
X 1	.409 "	2 "	
X "	.204 "	1 "	
X			
X			
X			

X100, 10, 1 Range(s) Calibrated Electronically

	Reference Cal. Point	Instrument Meter Reading	"As Found Reading"
Digital Readout	/ / / / /	/ / / / /	/ / / / /
Log Scale	/ / / / /	/ / / / /	/ / / / /

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Bureau of Standards, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants, or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of MIL-STD-45662A and ANSI N323-1978.

State of Texas Calibration License No. LO-1963

☑ Cs137 Gamma s/n 1162 s/n G112 ☐ Neutron Am-241 Be s/n T-304

☐ Alpha s/n ☐ Beta s/n ☐ Other

☑ M-500 s/n 57885 ☑ Oscilloscope s/n 709296 ☑ Multimeter s/n A34153

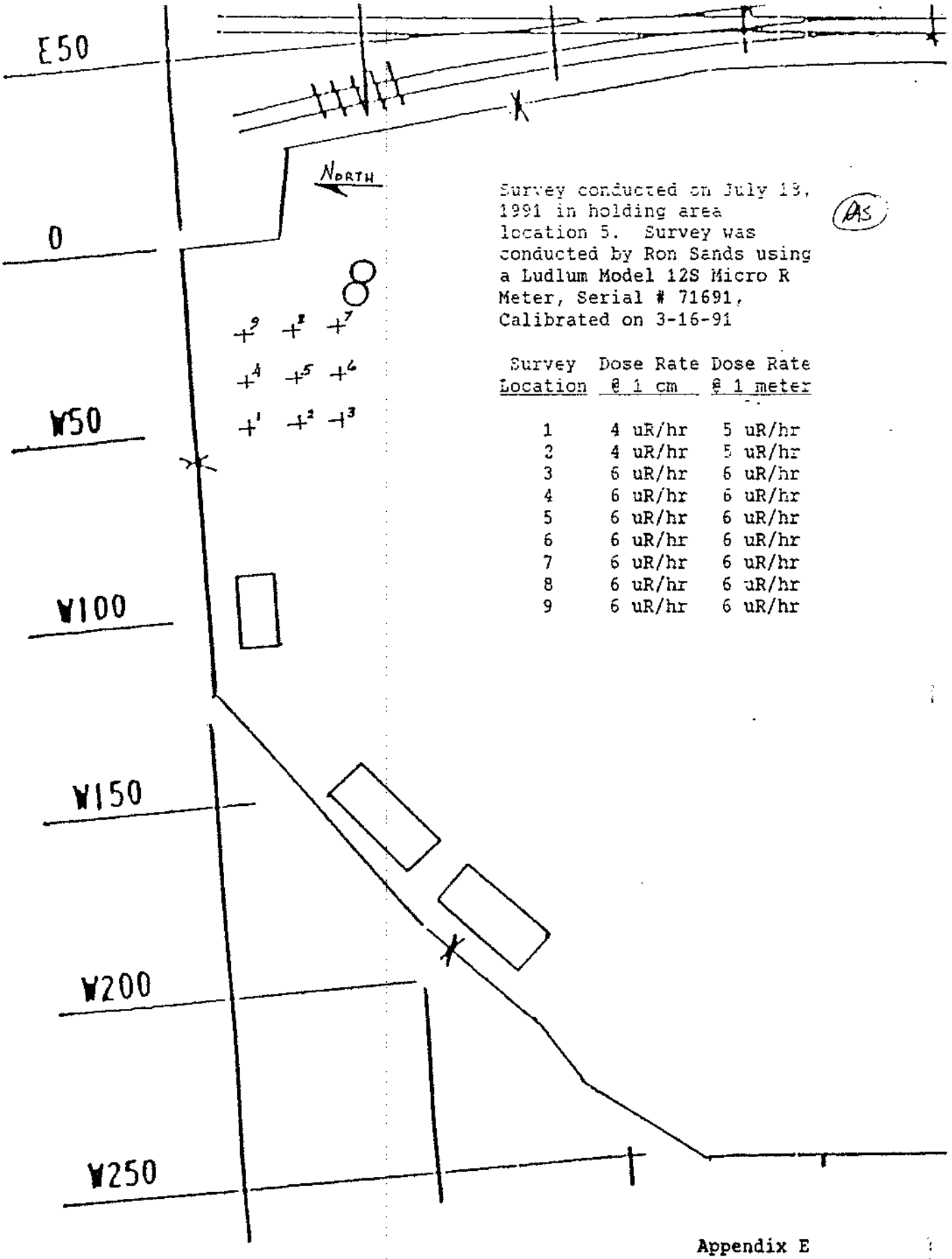
Calibrated By: Thomas A. Rodgers Date 7-10-90

Reviewed By: Larry Bell Date 7-10-90

Form 22 — 6/90

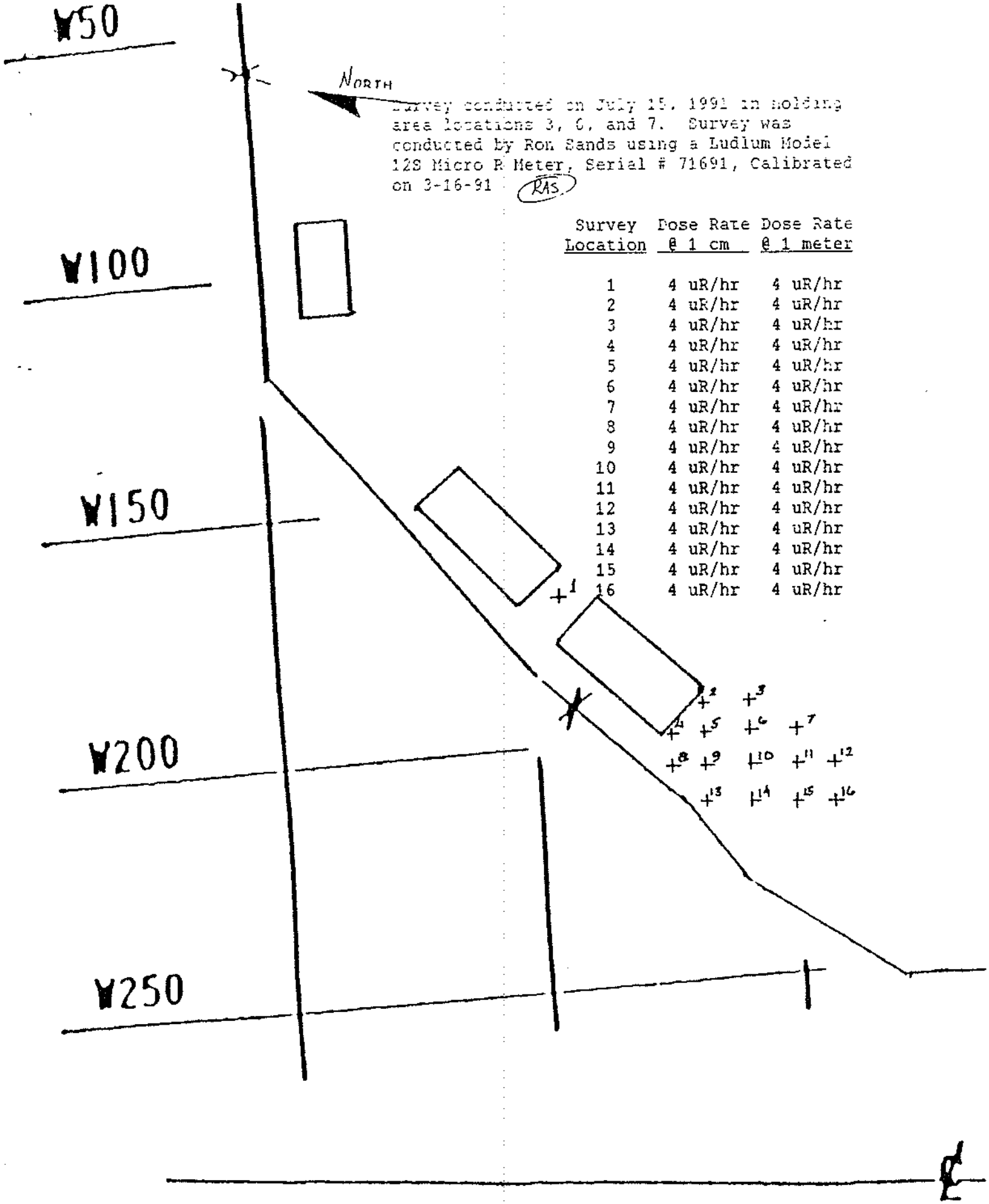
Appendix F

Certificates of Calibration



Survey conducted on July 19, 1991 in holding area location 5. Survey was conducted by Ron Sands using a Ludlum Model 12S Micro R Meter, Serial # 71691, Calibrated on 3-16-91

Survey Location	Dose Rate @ 1 cm	Dose Rate @ 1 meter
1	4 uR/hr	5 uR/hr
2	4 uR/hr	5 uR/hr
3	6 uR/hr	6 uR/hr
4	6 uR/hr	6 uR/hr
5	6 uR/hr	6 uR/hr
6	6 uR/hr	6 uR/hr
7	6 uR/hr	6 uR/hr
8	6 uR/hr	6 uR/hr
9	6 uR/hr	6 uR/hr



Survey conducted on July 15, 1991 in holding area locations 3, 6, and 7. Survey was conducted by Ron Sands using a Ludlum Model 12S Micro R Meter, Serial # 71691, Calibrated on 3-16-91 RAS

Survey Location	Dose Rate @ 1 cm	Dose Rate @ 1 meter
1	4 uR/hr	4 uR/hr
2	4 uR/hr	4 uR/hr
3	4 uR/hr	4 uR/hr
4	4 uR/hr	4 uR/hr
5	4 uR/hr	4 uR/hr
6	4 uR/hr	4 uR/hr
7	4 uR/hr	4 uR/hr
8	4 uR/hr	4 uR/hr
9	4 uR/hr	4 uR/hr
10	4 uR/hr	4 uR/hr
11	4 uR/hr	4 uR/hr
12	4 uR/hr	4 uR/hr
13	4 uR/hr	4 uR/hr
14	4 uR/hr	4 uR/hr
15	4 uR/hr	4 uR/hr
16	4 uR/hr	4 uR/hr

Appendix E

Survey Reports of Accessible Holding Areas

SURVEY OF ENVIROCARE SHIPMENT

JUNE 27, 1991

SMEARS COUNTED ON:

LUDLUM MODEL 2000 SCALER (ALPHA)

WITH MODEL 43-10 DETECTOR

CALIBRATION DATE MAY 2, 1991

COUNTER EFFICIENCY 38.6

LUDLUM MODEL 2200 SCALER RATEMETER (BETA)

WITH MODEL 44-10 DETECTOR

CALIBRATION DATE MAY 2, 1991

COUNTER EFFICIENCY 8.1%

ALPHA BACKGROUND .16 COUNTS PER MINUTE

BETA BACKGROUND 25.42 COUNTS PER MINUTE

**********NEXT CALIBRATION DUE NOVENBER 2, 1991**********

Judy Thomas

BECHTEL NATIONAL, INC.
Washington Street Quarry Project
410 South Washington Street
Kokomo, Indiana 46901

SMEAR SURVEY RECORD

Date: JUNE 27, 1991

Smears Collected by: Judy Thomas

Smears Counted by: Judy Thomas

Smear Number	Smear Location	Gross Alpha (cpm)	Gross Beta/Gamma (cpm)	Counter Eff.
Bkg	Alpha Counter Background	.16	XXXXX	.386 c/d
Bkg	Beta/Gamma Counter Bkg	XXXXX	25.42	.081 c/d

		ALPHA MEASUREMENTS		BETA-GAMMA MEASUREMENTS	
		Gross Alpha (cpm)/100cm	Net Alpha (dpm)/100cm	Gross Beta/Gamma (cpm)/100cm	Net Beta/Gamma (dpm)/100cm
1	OVERPACK #432	.40	.62	23.60	.00
2	OVERPACK #421	.20	.10	29.40	49.14
3	OVERPACK #422	.40	.62	24.80	.00
4	OVERPACK #432	.80	1.65	28.00	31.85
5	OVERPACK #424	.40	.62	25.00	.00
6	OVERPACK #425	1.00	2.18	24.60	.00
7	OVERPACK #426	.00	.00	26.40	12.10
8	OVERPACK #427	.20	.10	29.60	51.60
9	OVERPACK #428	.20	.10	21.80	.00
10	OVERPACK #429	.20	.10	31.20	71.36
11	OVERPACK #369	.00	.00	29.20	46.67
12	OVERPACK #39	.60	1.14	24.60	.00
13	OVERPACK #429	.40	.62	23.40	.00
14	OVERPACK #430	.20	.10	25.00	.00
15	OVERPACK #431	1.00	2.18	27.00	19.51

ENVIROCARE shipment June 28, 1991.
Net Alpha and Beta are well below requirements.
No contamination found.

Appendix D
Examples of Periodic Drum Surveys

BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY ID/HP LOG

Page 1 of 3

Date 27 Jun 91

Wind is blowing to ___ Wind Descriptor:

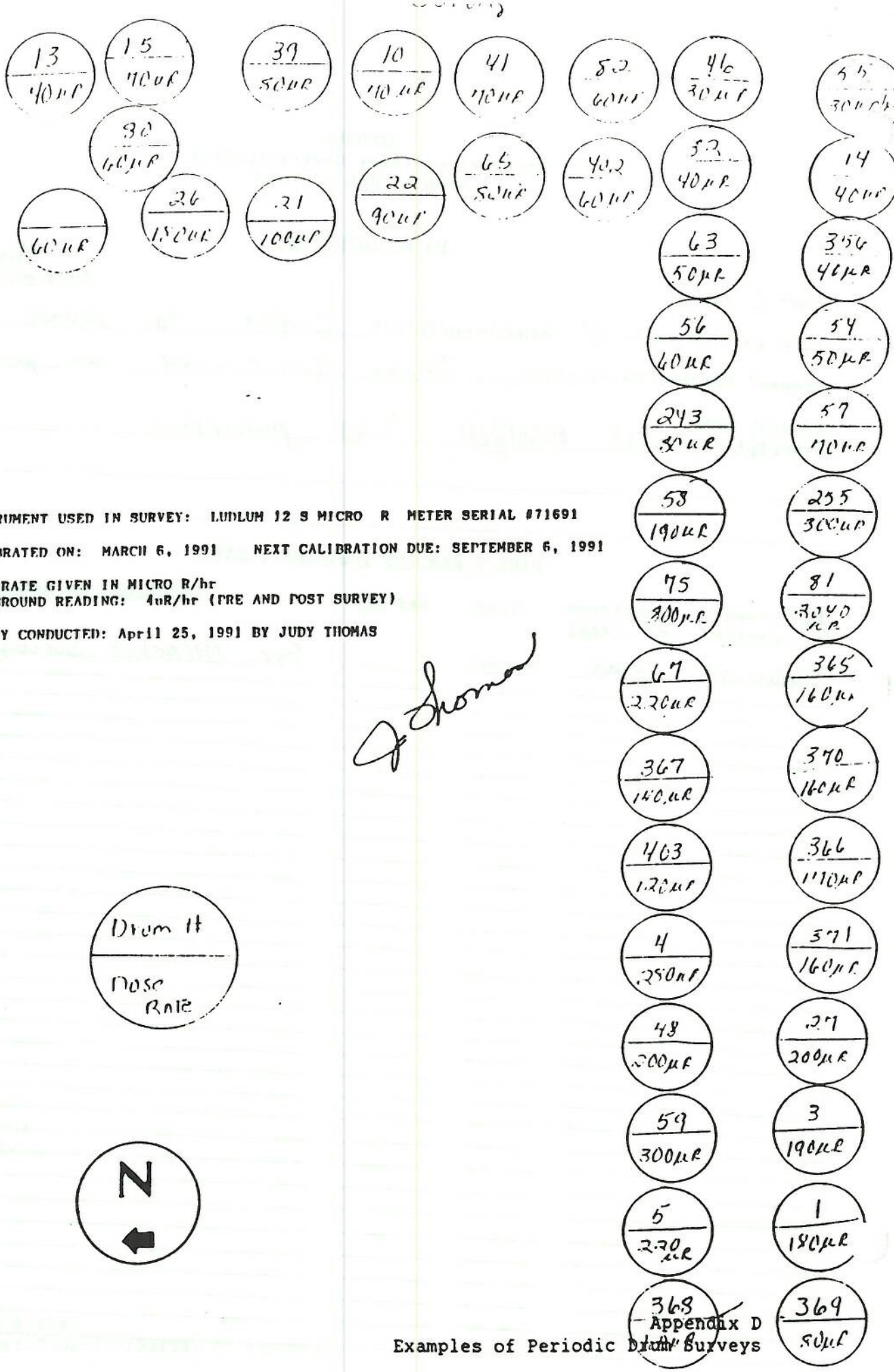
General Weather Description

General Work Description(s): (1) Back fill (2) Smear surveyed waste drums

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks

Appendix D
Examples of Periodic Drum Surveys



INSTRUMENT USED IN SURVEY: LUDLUM 12 S MICRO R METER SERIAL #71691

CALIBRATED ON: MARCH 6, 1991 NEXT CALIBRATION DUE: SEPTEMBER 6, 1991

DOSE RATE GIVEN IN MICRO R/hr
BACKGROUND READING: 4uR/hr (PRE AND POST SURVEY)

SURVEY CONDUCTED: April 25, 1991 BY JUDY THOMAS

J Thomas

Appendix D
Examples of Periodic Drum Surveys

BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY IH/HP LOG

Date Thursday 25 Apr 91

Page 1 of 2

Wind is blowing to N Wind Descriptor: Light to None

General Weather Description Sunny Light wind no precip.

General Work Description(s): (1) Backfill (2) pumping

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks
Ludlum 12S	Rad	1200		See Attached Survey

RAD AREA SURVEY

MARCH 21, 1991

SMEARS COUNTED ON:

LUDLUM MODEL 2000 SCALER (ALPHA)

WITH MODEL 43-10 DETECTOR

CALIBRATION DATE NOVEMBER 6, 1990

COUNTER EFFICIENCY 33.8%

LUDLUM MODEL 2200 SCALER RATEMETER (BETA)

WITH MODEL 44-10 DETECTOR

CALIBRATION DATE NOVEMBER 6, 1990

COUNTER EFFICIENCY 8.3%

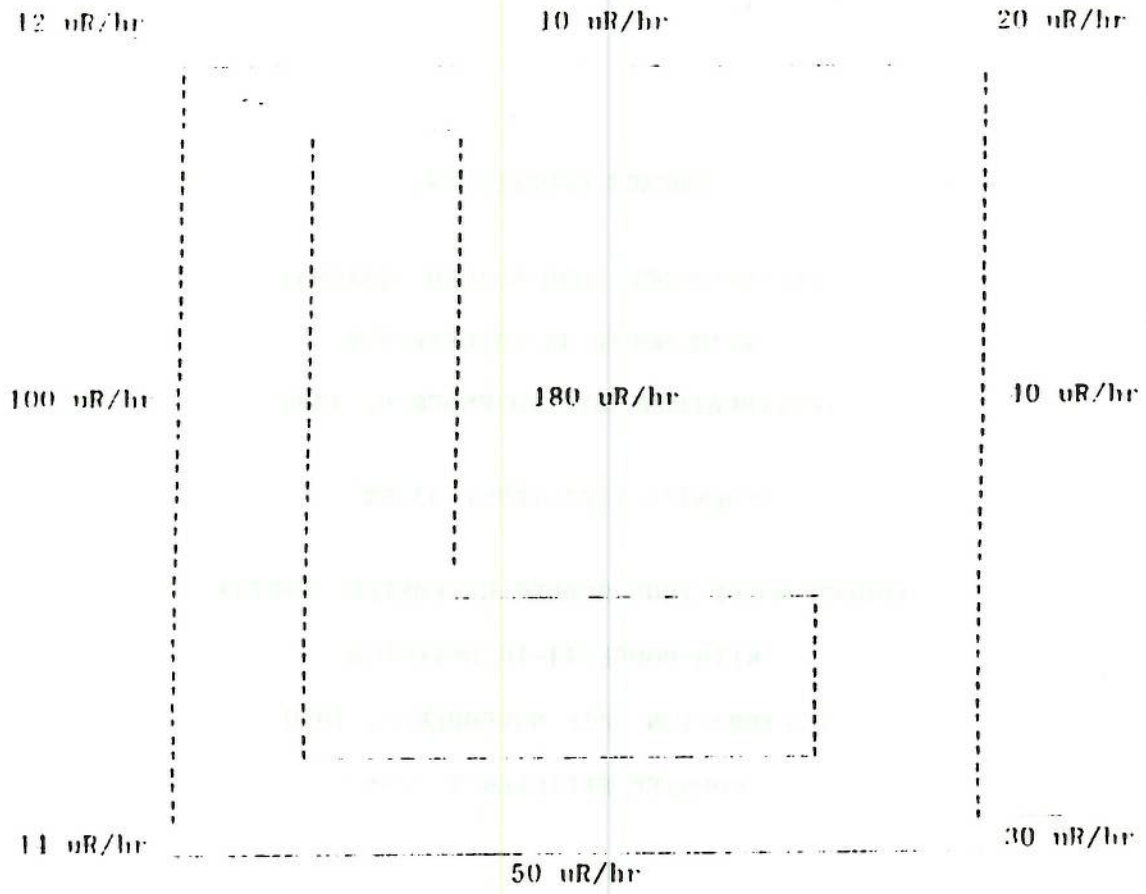
ALPHA BACKGROUND .16 COUNTS PER MINUTE

BETA BACKGROUND 25.71 COUNTS PER MINUTE

**********NEXT CALIBRATION DUE MAY 6, 1991**********

RAD OVERPACK AREA SURVEY

MARCH 21,1991



INSTRUMENT USED IN SURVEY: LUDLUM 12 S MICRO R METER SERIAL # 71691

CALIBRATED ON : MARCH 6, 1991

DOSE RATE GIVEN IN MICRO R/hr

BACKGROUND READING: 6 uR/hr

SURVEY CONDUCTED : MARCH 21, 1991

BECHTEL NATIONAL, INC.
Washington Street Quarry Project
410 South Washington Street
Kokomo, Indiana 16901

SMEAR SURVEY RECORD

Date: MARCH 21, 1991

Smears Collected by: Judy Thomas

Smears Counted by: Judy Thomas

Smear Number	Smear Location	Gross Alpha (cpm)	Gross Beta/Gamma (cpm)	Counter Eff.
Bkg	Alpha Counter Background	.16	XXXXX	.338 c/d
Bkg	Beta/Gamma Counter Bkg	XXXXX	25.71	.083 c/d

		ALPHA MEASUREMENTS		BETA-GAMMA MEASUREMENTS	
		Gross Alpha (cpm)/100cm	Net Alpha (dpm)/100cm	Gross Beta/Gamma (cpm)/100cm	Net Beta/Gamma (dpm)/100cm
1	OVERPACK DRUM NUMBER 1	.40	0.71	29.00	39.64
2	OVERPACK DRUM NUMBER 27	.00	0.00	21.40	0.00
3	OVERPACK DRUM NUMBER 39	.00	0.00	28.40	32.40
4	OVERPACK DRUM NUMBER 55	.00	0.00	28.40	32.40
5	OVERPACK DRUM NUMBER 56	.00	0.00	27.20	17.95
6	OVERPACK DRUM NUMBER 58	.40	0.71	24.20	00.00
7	OVERPACK DRUM NUMBER 67	.20	0.12	29.20	41.16
8	OVERPACK DRUM NUMBER 81	1.00	2.49	21.80	00.00
9	OVERPACK DRUM NUMBER 255	.20	0.12	29.60	16.87
10	OVERPACK DRUM NUMBER 365	.60	1.30	27.40	20.36
11	OVERPACK DRUM NUMBER 366	.40	0.71	25.10	0.00
12	OVERPACK DRUM NUMBER 368	.20	0.12	26.20	5.90
13	OVERPACK DRUM NUMBER 369	.60	1.30	27.20	17.95
14	OVERPACK DRUM NUMBER 371	.10	0.71	26.80	13.13

Appendix D
Examples of Periodic Drum Surveys

BECHTEL
Washington Street Quarry Project
Bechtel Job # 19058

DAILY IH/HP LOG

Page 1 of 4

Date Thursday 31 Mar 91

Wind is blowing to W Wind Descriptor: Light + Breezy

General Weather Description Clear Sunny High in 70's

General Work Description(s): (1) pumping Ops (2) General clean-up
(3) Rad Area Survey

DIRECT READING INSTRUMENT DATA

Instrument or Device	Substance or Agent	Time	Reading	Location and Remarks
Ludlum 12-5			See Attachment	
Micro R Meter				

Appendix D
Examples of Periodic Drum Surveys

Appendix D

Examples of Periodic Drum Surveys

SITE WIDE SURVEY

MAY 20, 1991

SMEARS COUNTED ON:

LUDLUM MODEL 2000 SCALER (ALPHA)

WITH MODEL 43-10 DETECTOR

CALIBRATION DATE MAY 2, 1991

COUNTER EFFICIENCY 38.6

LUDLUM MODEL 2200 SCALER RATEMETER (BETA)

WITH MODEL 44-10 DETECTOR

CALIBRATION DATE MAY 2, 1991

COUNTER EFFICIENCY 8.1%

ALPHA BACKGROUND .26 COUNTS PER MINUTE

BETA BACKGROUND 25.44 COUNTS PER MINUTE

**********NEXT CALIBRATION DUE NOVENBER 2, 1991**********

Appendix C
Examples of Routine Site Surveys

APPENDIX B
STANDARD OPERATING PROCEDURE FOR CONDUCTING GAMMA RADIATION SURVEYS

Radiological Investigation
Standard Operation Procedure –: Gamma Radiation Survey

1.0 PURPOSE

This Standard Operating Procedure (SOP) describes the protocol and methods for performing a continuous mobile gamma radiation survey as part of the Washington Street Quarry radiological investigation. The methods presented in this SOP include equipment operation, survey techniques and instrument calibration requirements.

1.1 Equipment and Materials

Each mobile gamma survey system consists of:

(1) USB compatible laptop or mobile computer installed with Tetra Tech *ScanSystem* software, *GammaViewer* software and a global mapping software installed

(1) Standard backpack (shown on Figure 1)

(2) *USGlobalSat* GPS Receiver with USB Interface

(1) Ludlum 44-10 NaI scintillation detector (shown in Figure 2)

(1) Ludlum 2350-1 data logger (shown in Figure 2)

(1) 4 port USB hub

(1) 3-foot Ludlum coaxial cable

(1) RS232 Serial to USB Converter

(1) Ludlum RS232 data cable

Figure 1 Mobile GPS Integrated Gamma Survey System – Backpack (left) and ATV (rightSample Containers, Preservatives, And Holding Times

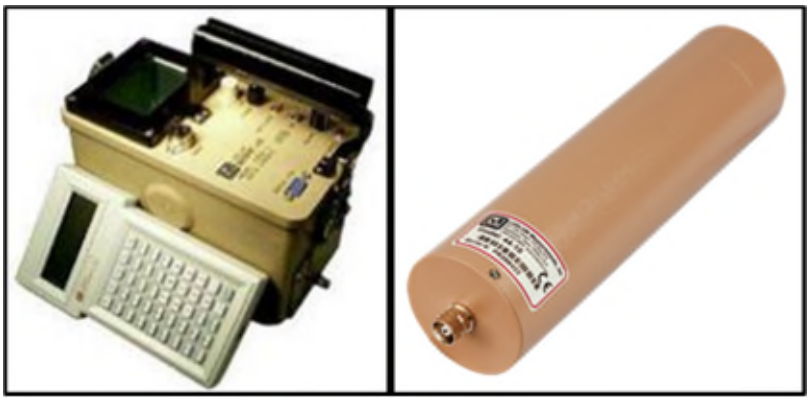


Figure 2 Ludlum 2350-1 Data Logger (left) and Ludlum 44-10 NaI Scintillator

2.0 PROCEDURE

2.1 Backpack and System Set Up

Ensure the 2350-1 data logger has sufficient battery voltage, which is defined as greater than 5.6V. If there is less than 5.6V- place four new D-size batteries correctly without allowing the battery to drop directly into the battery compartment. Connect RS232 serial converter to RS232 port on the Ludlum 2350-1 datalogger. Connect GPS receivers and serial converter to the 4-port USB hub and connect the USB hub to field computer. Open “Device Manager” and note which COMM ports have been assigned to respective USB devices.

2.2 ScanSystem Software Operations

ScanSystem software shall be used to record simultaneous GPS location data and gamma exposure rate date. Upon first launching the program, click the “Configure” button, then the “Disable Ports” function. Assign the correct COMM port ID to the Rad and GPS locations. Select “Enable Ports” and close the window. Next click “Start GPS”. Both GPS and gamma exposure rate data should now be displayed in

real time on the ScanSystem main screen. A screenshot showing ScanSystem menu is shown in Figure 3.

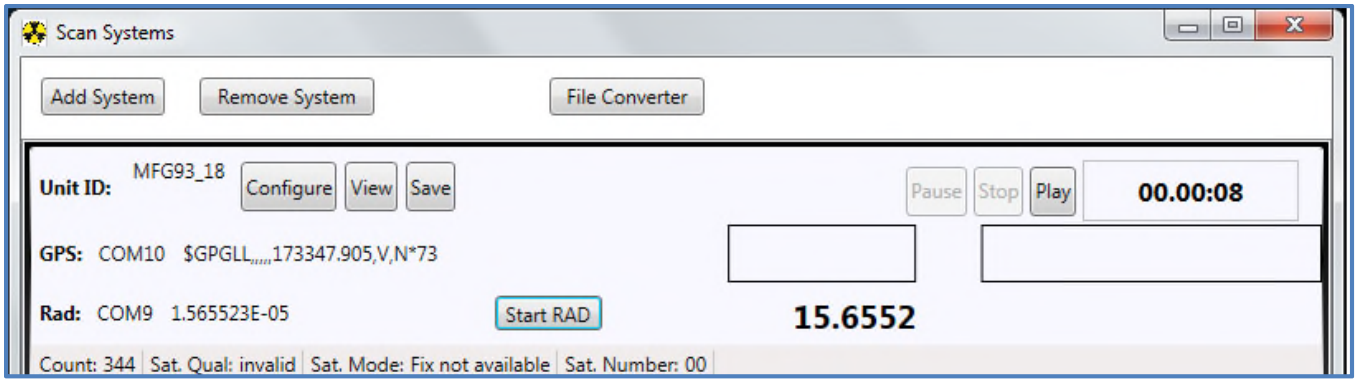


Figure 3 ScanSystem GUI Screenshot.

To log data, click the “Play” button. The software will ask if previous data is to be overwritten (Figure 4). To save data, click “Stop” then the “Save” icon, select a directory and name the text file. Warning: if you select “Overwrite Data” by mistake, you should save a new file with a different name in order to avoid erasing the existing scan data file.

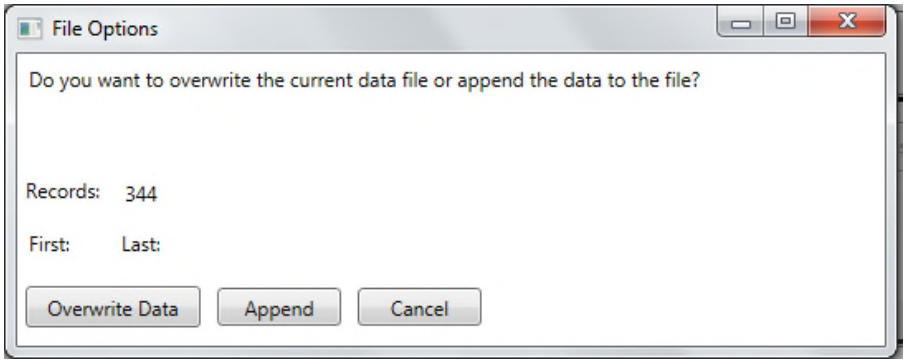


Figure 4 Screenshot of GUI Interface (overwrite screen)

Text file names should include the detector ID, date and time, and project ID. The software will ask if current data is to be cleared from the application at this point (Figure 5). If continuing scanning for the day, do not clear the application. Only clear the application at the beginning of a new scanning day. If the application is cleared by mistake, save a new file and continue to append to the new file.

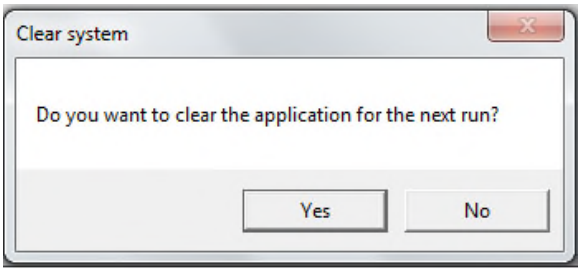


Figure 5 Screenshot of GUI Interface (clear screen)

2.3 Mapping Software Operations

- Mapping software can be used to visually guide operators over their pre-defined survey path. It displays current location overlaid on shapefiles. Shapefiles, as long as properly projected, are supported with different software types. WGS84 datum is preferred to avoid confusion. It is highly recommended to use mapping software with pre-entered transect lines.Geographic coordinates or location of sample, whichever is applicable;

3.0 RECORDS

3.1 Survey Records

Documenting scanning results and observations from the field is very important (NRC, 2000). Surveys shall be recorded as follows:

- Survey information shall be recorded in the field logbook by field personnel.
- Surveys shall be documented in writing. The person performing the survey is responsible for correct and accurate documentation of survey data.
- Surveys shall be documented as they are performed whenever possible in a clear and legible manner using black or blue ink.
- Indicate survey points or sample locations, as applicable, and record the associated measurements. Provide sufficient detail to adequately describe each specific area surveyed.
- The person(s) performing the survey shall sign the survey record.
- Instrument check records shall be included with the survey records in the field logbook.
- All records of surveys shall be maintained in accordance with Sampling and Analysis Plan.

4.0 QUALITY ASSURANCE AND QUALITY CONTROL

All radiological characterization projects conducted by Tetra Tech incorporate specific data quality assurance and quality control (QA/QC) protocols. In general, QA includes qualitative factors that provide confidence in the results, while QC involves quantitative, field evidence that supports the validity of results. Tetra Tech utilizes quality assurance and quality control methods as data quality indicators that are outlined in NRC (2000). The QA/QC survey procedures used by Tetra Tech are industry accepted techniques that ensure the data collected is of the highest quality and reliability.

4.1 Quality Assurance

Calibration refers to the determination and adjustment of the instrument response in a particular radiation field of known intensity (NRC, 2000). Calibration of all radiation detection equipment is the primary method for QA that is used to ensure the data collected is of high quality and reliable. Tetra Tech ensures all instruments used during radiological projects are factory calibrated within 12 months per the

manufacturer's recommendation. Scanned copies of calibration documentation for all instruments shall be included with the final survey report.

4.2 Quality Control

The primary QC method utilized by Tetra Tech includes calibration checks. These checks are measurements performed each time an instrument is used. The specified protocol used on this project involves quantitative calibration checks using a background as well as a known source.

The QC calibration checks that are used include:

- **Daily Checks:** Daily background, field strip, and check source QC measurements that will be conducted in the field at the site. Daily QC measurements will be collected on site at a designated background location selected by the lead field engineer. Control charts are used to present the results.

- **Pre- and Post-survey:** Pre-survey and post-survey background and check source QC measurements that will be performed at a designated location off site. The results are presented in tables, probability plots and histograms.

4.2.1 Daily QC Measurements

Each day prior to performing the gamma radiation survey, instrument comparison QC measurements will be performed for all NaI detectors potentially used to survey the Site. Sets of individual background QC measurements will be compared under the same counting geometries. Under the QA program, factory-calibrated instruments must also meet on-site field test criteria. Data developed using any of the field-qualified instruments are then interchangeable, allowing instrument substitution if needed.

- Field Check Results:

    - For normally distributed data, 99 percent of all measurements are expected to fall within ±3 standard deviations from the mean. Background, field strip, and check source standard deviation values are recalculated twice daily throughout the project. Any instrument with a QC measurement result falling outside ±3 standard deviations from the mean of all QC measurements on the field check control chart require investigation. A detector exceeding control limits on any QC check (background or source check) is replaced with a pre-qualified spare detector and sent back to the manufacturer for evaluation, repair, and recalibration.

    - QC measurements, including a background check and a source check, are performed twice daily during the work for each scanning system in use. These checks are performed outdoors at a specified location.

The Ludlum 2350 datalogger system employs a calibration factor to internally convert detector counts per minute to exposure rate. The calculated exposure rate, directly proportional to the measured count rate, is transmitted by the data logger to the scanning system portable computer. No record of count rate is retained by the system, but count rates can be calculated using the instrument-specific calibration factors.

Daily count rate variations within these limits are functions of several possible variables, including exact placement of detector systems during daily checks, and recent variations in barometric pressure. Low

detector count rates at very low background gamma exposure rates contribute significantly to variability in count rates. Differences in detector internal characteristics, including minor NaI detector crystal issues or photomultiplier tube optical interface variations, can also affect NaI detector readings.

The data should be compiled and input into control charts and analyzed at the end of each day to identify any anomalies with the data. Control charts are used to monitor performance of the radiation detection instruments. A control chart is a graphical plot of measurement results with respect to time and an example control chart is shown below in Figure 6. A control chart of the daily calibration checks for the duration of the project will be included in the final report.

Figure 6 Example of Control Chart

4.2.2 Pre-Survey and Post-Survey QC Measurements

Before and after the gamma survey, field personnel will collect instrument QC measurements at a designated indoor location for each NaI detector that could potentially be utilized for the gamma survey. The purpose of the pre-survey and post-survey QC protocol is to quantify the consistency of readings among the different detection systems. The pre-survey and post-survey calibration checks consist of background and source ^{137}Cs measurements collected at the Tetra Tech office in Fort Collins, Colorado. The average value of the measurements will be compared using the mean, probability plots, and histograms and comparing various statistical measures such as the Anderson-Darling coefficient and the correlation coefficient (R). An example of this analysis is shown in Figure 7 and Figure 8.

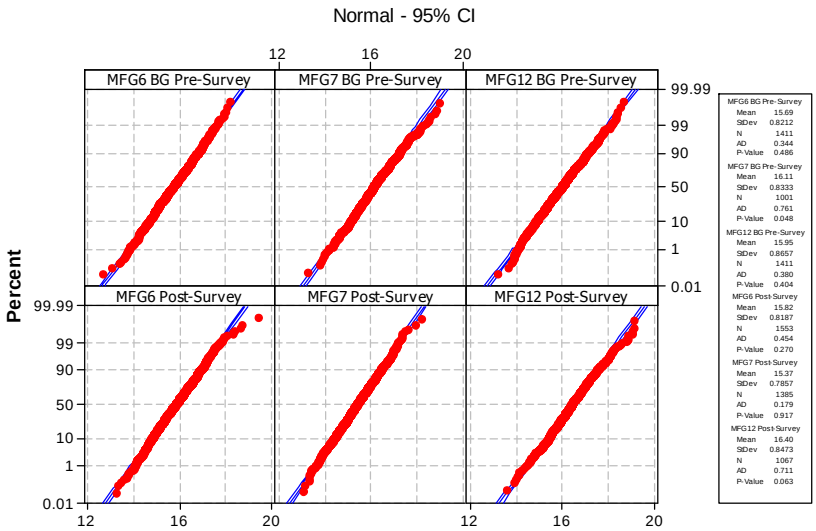


Figure 7 Example of Probability Plot Comparisons

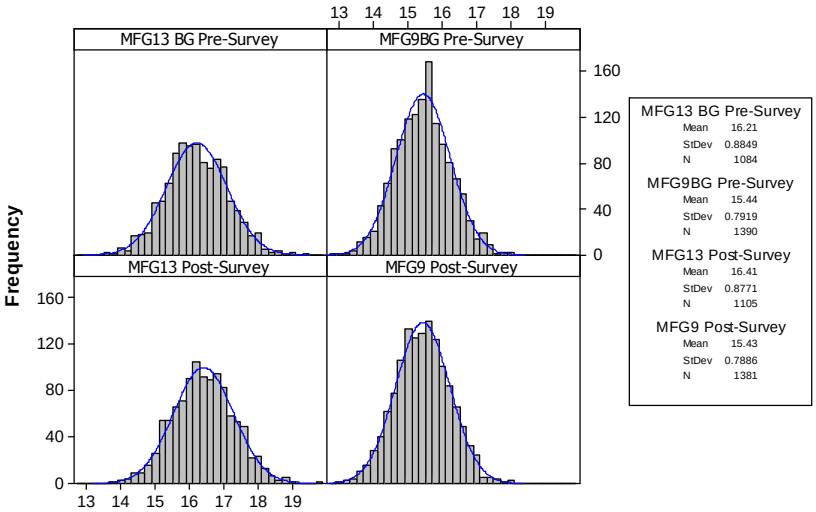


Figure 8 Example of Frequency Histogram Comparisons

5.0 REFERENCES

NRC (U.S. Nuclear Regulatory Commission), 2000. Multi-Agency Radiological Site Survey and Investigation Manual. NUREG-1575, Rev. 1. August 2000 (with 2001 addendum).

APPENDIX C
RADIATION INSTRUMENTATION CALIBRATION DOCUMENTATION

Designer and Manufacturer of Scientific and Industrial Instruments

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
501 Oak Street
325-235-5494
Sweetwater, TX 79556, U.S.A.
☐ 10744 Dutchtown Road
865-392-4601
Knoxville, TN 37932, U.S.A.

CUSTOMER TETRA TECH MFG,INC ORDER NO. 20299557/442127

Mfg. Bicron Model MICRO REM Serial No. B990Y

Mfg. Model Serial No.

Cal. Date 28-Oct-16 Cal Due Date 28-Oct-17 Cal. Interval 1 Year Meterface 0-200µrem/

Check mark ☑ applies to applicable instr. and/or detector IAW mfg. spec. T. 72 °F RH 40 % Alt 709.0 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical ck. ☐ Meter Zeroed ☐ Background Subtract ☐ Input Sens. Linearity
☑ F/S Resp. ck ☑ Reset ck. ☐ Window Operation ☐ Geotropism
☑ Audio ck. ☐ Alarm Setting ck. ☑ Batt. ck. (Min. Volt) _____ VDC
☐ Calibrated in accordance with LMI SOP 14.8 ☑ Calibrated in accordance with LMI SOP 14.9

Instrument Volt Set _____ V Input Sens. _____ mV Det. Oper. _____ V at _____ mV Threshold _____ mV Dial Ratio _____ = _____

☐ HV Readout (2 points) Ref./Inst. _____ / _____ V Ref./Inst. _____ / _____ V

COMMENTS:

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

RANGE/MULTIPLIER	REFERENCE CAL. POINT	INSTRUMENT REC'D "AS FOUND READING"	INSTRUMENT METER READING*
x 1000	150 mR/hr	160	160
x 1000	50 mR/hr	48	48
x 100	15 mR/hr	158	158
x 100	5 mR/hr	48	48
x 10	1500 µR/hr	145	150
x 10	500 µR/hr	45	48
x 1	150 µR/hr	145	150
x 1	100 µR/hr	45	100
x0.1	15 µR/hr	150	150
x0.1			

*Uncertainty within ± 10% C.F. within ± 20%

Range(s) Calibrated Electronically

	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*		REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
Digital Readout				Log Scale			

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978

State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources: Cs-137 S/N: ☐ 059 ☐ 2171CP ☐ 2261CP ☐ 720 ☐ 734 ☐ 781 ☐ 1131 ☐ 1616 ☐ 1696 ☐ 1909 ☐ 1916CP ☐ 2324/2521
☐ 5717CO ☐ 5719CO ☐ 60646 ☐ 70897 ☐ 73410 ☐ E552 ☑ G112 ☑ 2168CP ☐ S-394 ☐ S-1054 ☐ T10081 ☐ T10082 Neutron Am-241 Be ☐ T-304 Ra-226 ☐ Y982

☐ Alpha S/N _____ ☐ Beta S/N _____ ☑ Other Cs-137 201uCi

☐ m 500 S/N _____ ☐ Oscilloscope S/N _____ ☐ Multimeter S/N _____

Calibrator [signature] Title Calibrator Date 28-oct-16

QC'd By [signature] Title FINAL QC Date 28 Oct 16

This certificate shall not be reproduced except in full, without the written approval of Ludlum Measurements, Inc.
FORM C22A 07/25/2016 Page 1 of 1

AC Inst. Only ☐ Passed Dielectric (Hi-Pot) and Continuity Test
☐ Failed: _____

Designer and Manufacturer of Scientific and Industrial Instruments

MFG-12

CERTIFICATE OF CALIBRATION

LUDLUM MEASUREMENTS, INC.
501 Oak Street
325-235-5494
Sweetwater, TX 79556, U.S.A.

☐ 10744 Dutchtown Road
865-392-4601
Knoxville, TN 37932, U.S.A.

CUSTOMER TETRA TECH MFG, INC. ORDER NO. 20285871/433017

Mfg. Ludlum Measurements, Inc. Model 2350-1 Serial No. 134764

Cal. Date 14-Mar-16 Cal Due Date 14-Mar-17 Cal. Interval 1 Year Meterface N/A

Check mark ✓ applies to applicable instr. and/or detector IAW mfg. spec. T. 74 °F RH 31 % Alt 701.0 mm Hg

☐ New Instrument Instrument Received ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

☑ Mechanical check ☐ Input Sens. Linearity

☑ F/S Resp. check ☑ Reset check ☐ Window Operation

☑ Audio check ☑ Alarm Setting check ☑ Battery check (Min. Volt) 4.4 VDC

☑ Ratemeter Linearity check ☑ Integrated Dose check ☑ Recycle Mode check

☑ Data Log check ☑ Overload check ☑ Scaler Readout check Threshold Dial Ratio 100 = 10 mV

☑ Calibrated in accordance with LMI SOP 14.8 ☑ Calibrated in accordance with LMI SOP 14.9

☑ HV Readout (2 points) Ref./Inst. 500 / 501 V Ref./Inst. 2000 / 1999 V

COMMENTS: *Firmware: 37122N21*

I/O Firmware: 37123N05 Calibrated with 39" cable.

Resolution for Cs137≈9.37%

Gamma Calibration: GM detectors positioned perpendicular to source except for M 44-9 in which the front of probe faces source.

	Probe Model	Serial #	High Voltage	Threshold	Units/ Time Base	Dead Time Correction Factor	Calibration Constant	Linearity ±10%*
Detector # 1	LMI44-10	PR139484	900	100	4 / 2	1.382029E-05	5.535037E+10	✓
Detector # 2	LMI44-10	PR139484	900	100	7 / 1	1.382029E-05	1.000000E+00	
Detector # 3	CS137PK	662KEV	601	642	7 / 1	0.000000E+00	1.000000E+00	
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								
Detector #								

Units: 0 -- rad, 1 -- Gray, 2 -- rem, 3 -- Sv, 4 -- R, 5 -- C/Kg, 6 -- Disintegrations, 7 -- Counts, 8 -- Ci/cm sq., 9 -- Bq/cm sq.

Time Base: 0 -- Seconds, 1 -- Minutes, 2 -- Hours

* See attached detector documentation, if applica

Digital Readout	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*	REFERENCE CAL. POINT	INSTRUMENT RECEIVED	INSTRUMENT METER READING*
	400kcpm	400.10 (0)	400.07 (0)	400cpm	40 (0)	40 (0)
	40kcpm	40.02 1	40.02 1	40cpm	4 1	4 1
	4kcpm	4.00	4.00			

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Institute of Standards and Technology, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants or have been derived by the ratio type of calibration techniques. The calibration system conforms to the requirements of ANSI/NCSL Z540-1-1994 and ANSI N323-1978.

State of Texas Calibration License No. LO-1963

Reference Instruments and/or Sources: Cs-137 S/N: ☐ 059 ☐ 2171CP ☐ 2261CP ☐ 720 ☐ 734 ☐ 781 ☐ 1131 ☐ 1616 ☐ 1696 ☐ 1909 ☐ 1916CP ☐ 5105 ☐ 5717CO ☐ 5719CO ☐ 60646 ☐ 70897 ☐ 73410 ☐ E552 ☐ G112 ☐ M565 ☐ S-394 ☐ S-1054 ☐ T10081 ☐ T10082 Neutron Am-241 Be S/N: ☐ T-304 Ra-226 S/N: ☐ Y982

☐ Alpha S/N ☐ Beta S/N ☐ Other

☑ m 500 S/N 289158 ☐ Ra-226 S/N Y982 ☑ Multimeter S/N 93870637

Calibrated By: Jeremy Thompson Date 14-Mar-16

Reviewed By: Donnie Mickos Date 14-Mar-16

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501 Oak Street
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☐ 10744 Dutchtown Road
865-392-4601
Knoxville, TN 37932, U.S.A.

Model 2350 Bench Test Data

Customer TETRA TECH MFG, INC. Date 14-Mar-16 Order #. 20285871/433017

Model 2350-1 Serial No. 134764 Detector 44-10 Serial No. PR139484

Source Cs137 1.5mCi

High Voltage 900 V As Found 900 V. Input 10.00 mV As Found 10 mV.

Cal. Constant 5.535037E+10 as found 5.535037 E+10

Dead Time 1.382029E-05 as found 1.382029 E-05

Alarm Setting: Ratemeter 1000000000.000000 as found 1.0 E+09

Scaler 1000000.000000 as found 1.0 E+06

Integrated dose 1000000000.0000 as found 1.0 E+09

Overload ☐ On ☑ Off as found ☐ On ☑ Off Window 1000 as found 1000

Detector Received: ☑ Within Toler. +-10% ☐ 10-20% ☐ Out of Tol. ☐ Requiring Repair ☐ Other-See comments

Reference Point	"As Found" Readings: Meter Reading	After Adjustment Readings: Meter Reading
2000 μR/hr	1.91 mR/hr	1.91 mR/hr
1500	1.48	1.48
1000	1.02	1.02
500	497 μR/hr	497 μR/hr
200	198	198
150	149	149
100	98.1	98.1

Other

Signature Jeremy Thompson Date 14-Mar-16

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Sweetwater, TX 79556, U.S.A.

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865-392-4601
Knoxville, TN 37932, U.S.A.

Bench Test Data For Detector

Detector 44-10 Serial No. PR139484

Customer TETRA TECH MFG, INC. Order #. 20285871/433017

Counter 2350-1 Serial No. 134764 Counter Input Sensitivity 10.00 mV

Count Time 6 Seconds Distance Source to Detector Surface

Other Cal Constant = 1.000000E+00 Dead Time = 1.382029E-05

High Voltage	Background	Isotope Am241 Size ≈0.77μCi	Isotope Size	Isotope Size	Isotope Size
800	736	12151			
850	744	12243			
*900	754	12211			
950	771	12417			
1000	751	12373			
1050	756	12287			
1100	894	12439			
1150	1387	13611			

Signature Jeremy Thompson Date 14-Mar-16

• *Serving The Nuclear Industry Since 1962* •

Detector Setup Barcodes GENERATED: 3/14/2016 11:45:16 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 1

H900$M
Set High Voltage: 900

W1000$WOFF$P
Set Window: 1000,OFF

F6$H
Set Scaler Count Time: 6

SB2$.
Set Readout Time Base: hours

SL1.382029E-05$X
Set Dead Time: 1.382029E-05

SC5.535037E+10$S
Set Calibration Constant: 5.535037E+10

*MLMI44-10$ *
Set High Detector Model: LMI44-10

NPR139484$E
Set High Detector Serial #: PR139484

J1.000000E+09$V
Set High Ratemeter Alarm: 1.000000E+09

K1000000$H
Set High Scaler Alarm: 1000000

P1.000000E+09$.
Set High Dose Alarm: 1.000000E+09

SP1$7

Save Parameters as: D1

T100$Q
Set Threshold: 100

O40.0$OOFF$6
Set Overload: 40.0,OFF

SU4$F
Set Readout Units: R

SM0$3
Set Readout Range Multiplier: Auto

SVD0$P
Set Display Mode: Normal

SVD1$Q
Set Display Mode: Parameters

SVD2$R
Set Display Mode: Detector

D1$A
Set Active Detector Setup: 1

Detector Setup Barcodes GENERATED: 3/14/2016 11:45:17 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 2

H900$M
Set High Voltage: 900

W1000$WOFF$P
Set Window: 1000,OFF

F6$H
Set Scaler Count Time: 6

SB1$-
Set Readout Time Base: minutes

SL1.382029E-05$X
Set Dead Time: 1.382029E-05

SC1.000000E+00$0
Set Calibration Constant: 1.000000E+00

*MLMI44-10$ *
Set High Detector Model: LMI44-10

NPR139484$E
Set High Detector Serial #: PR139484

J1.000000E+09$V
Set High Ratemeter Alarm: 1.000000E+09

K1000000$H
Set High Scaler Alarm: 1000000

P1.000000E+09$.
Set High Dose Alarm: 1.000000E+09

SP2$8

Save Parameters as: D2

T100$Q
Set Threshold: 100

O40.0$OOFF$6
Set Overload: 40.0,OFF

SU7$I
Set Readout Units: c

SM0$3
Set Readout Range Multiplier: Auto

SVD0$P
Set Display Mode: Normal

SVD1$Q
Set Display Mode: Parameters

SVD2$R
Set Display Mode: Detector

D2$B
Set Active Detector Setup: 2

Detector Setup Barcodes GENERATED: 3/14/2016 11:45:18 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 3

H601$K
Set High Voltage: 601

W40WONL
Set Window: 40,ON

F6$H
Set Scaler Count Time: 6

SB1$-
Set Readout Time Base: minutes

SL0.000000E+00$8
Set Dead Time: 0.000000E+00

SC1.000000E+00$0
Set Calibration Constant: 1.000000E+00

MCS137PK$S
Set High Detector Model: CS137PK

N662KEV$C
Set High Detector Serial #: 662KEV

J1.000000E+09$V
Set High Ratemeter Alarm: 1.000000E+09

K1000000$H
Set High Scaler Alarm: 1000000

P1.000000E+09$.
Set High Dose Alarm: 1.000000E+09

SP3$9

Save Parameters as: D3

T642$.
Set Threshold: 642

O40.0$OOFF$6
Set Overload: 40.0,OFF

SU7$I
Set Readout Units: c

SM0$3
Set Readout Range Multiplier: Auto

SVD0$P
Set Display Mode: Normal

SVD1$Q
Set Display Mode: Parameters

SVD2$R
Set Display Mode: Detector

D3$C
Set Active Detector Setup: 3

Detector Setup Checklist GENERATED: 3/14/2016 11:45:23 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 1

The following list is stored as detector setup D1 in the Model 2350.

I have verified the list below has no discrepancies with the detector settings table: JT

Comments:

User ID	=
High Voltage	= 900 volts
Threshold	= 100
Window	= 1000,OFF
Overload Current	= 40.0 micro amperes
Scaler Count Time	= 6 seconds
Readout Units	= R
Readout Time Base	= hours
Readout Range Multiplier	= Auto
Detector Dead Time	= 1.382029E-05
Detector Calibration Constant	= 5.535037E+10
Detector Model Number	= LMI44-10
Detector Serial Number	= PR139484
Ratemeter Alarm Setting	= 1.000000E+09
Scaler Alarm Setting	= 1000000
Integrated Dose Alarm Setting	= 1.000000E+09
Low Count Alarm Setting	= 0.000000E+00
Operating Batter Voltage	= 6.5 volts

Detector Setup Checklist GENERATED: 3/14/2016 11:45:23 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 2

The following list is stored as detector setup D2 in the Model 2350.

I have verified the list below has no discrepancies with the detector settings table: JT

Comments:

User ID	=
High Voltage	= 900 volts
Threshold	= 100
Window	= 1000,OFF
Overload Current	= 40.0 micro amperes
Scaler Count Time	= 6 seconds
Readout Units	= c
Readout Time Base	= minutes
Readout Range Multiplier	= Auto
Detector Dead Time	= 1.382029E-05
Detector Calibration Constant	= 1.000000E+00
Detector Model Number	= LMI44-10
Detector Serial Number	= PR139484
Ratemeter Alarm Setting	= 1.000000E+09
Scaler Alarm Setting	= 1000000
Integrated Dose Alarm Setting	= 1.000000E+09
Low Count Alarm Setting	= 0.000000E+00
Operating Batter Voltage	= 6.5 volts

Detector Setup Checklist GENERATED: 3/14/2016 11:45:23 AM
Model 2350-1 Serial Number: 134764
Detector Setup Number: 3

The following list is stored as detector setup D3 in the Model 2350.

I have verified the list below has no discrepancies with the detector settings table: JT

Comments:

User ID	=
High Voltage	= 601 volts
Threshold	= 642
Window	= 40,ON
Overload Current	= 40.0 micro amperes
Scaler Count Time	= 6 seconds
Readout Units	= c
Readout Time Base	= minutes
Readout Range Multiplier	= Auto
Detector Dead Time	= 0.000000E+00
Detector Calibration Constant	= 1.000000E+00
Detector Model Number	= CS137PK
Detector Serial Number	= 662KEV
Ratemeter Alarm Setting	= 1.000000E+09
Scaler Alarm Setting	= 1000000
Integrated Dose Alarm Setting	= 1.000000E+09
Low Count Alarm Setting	= 0.000000E+00
Operating Batter Voltage	= 6.5 volts

APPENDIX D
PROUCL STATISTICAL TESTING OUTPUT FORMS

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3				User Selected Options								
4				Date/Time of Computation	12/19/2016 12:00:15 PM							
5				From File	Data_a.xls							
6				Full Precision	OFF							
7				Confidence Coefficient	95%							
8				Substantial Difference	0.000							
9				Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)							
10				Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median							
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Foster Park 1**											
15												
16					**Raw Statistics**							
17					Sample 1 (Main Site)	Sample 2 (Foster Park 1)						
18				Number of Valid Observations	4687	277						
19				Number of Distinct Observations	3724	274						
20				Minimum	5.317	5.826						
21				Maximum	9.712	9.717						
22				Mean	7.395	7.704						
23				Median	7.403	7.705						
24				SD	0.665	0.658						
25				SE of Mean	0.00972	0.0395						
26												
27					**Wilcoxon-Mann-Whitney (WMW) Test**							
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	11469607							
32				Standardized WMW U-Stat	-7.157							
33				Mean (U)	649150							
34				SD(U) - Adj ties	23177							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	1							
37												
38	**Conclusion with Alpha = 0.05**											
39	**Do Not Reject H0, Conclude Sample 1 <= Sample 2**											
40	**P-Value >= alpha (0.05)**											
41												

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3			User Selected Options									
4			Date/Time of Computation	12/19/2016 12:04:05 PM								
5			From File	Data_a.xls								
6			Full Precision	OFF								
7			Confidence Coefficient	95%								
8			Substantial Difference	0.000								
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)								
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median								
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Foster Park 2**											
15												
16				**Raw Statistics**								
17					Sample 1 (Main Site)	Sample 2 (Foster Park 2						
18				Number of Valid Observations	4687	272						
19				Number of Distinct Observations	3724	268						
20				Minimum	5.317	6.251						
21				Maximum	9.712	10.68						
22				Mean	7.395	8.101						
23				Median	7.403	8.098						
24				SD	0.665	0.674						
25				SE of Mean	0.00972	0.0409						
26												
27				**Wilcoxon-Mann-Whitney (WMW) Test**								
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	11276423							
32				Standardized WMW U-Stat	-15.13							
33				Mean (U)	637432							
34				SD(U) - Adj ties	22955							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	1							
37												
38	**Conclusion with Alpha = 0.05**											
39		**Do Not Reject H0, Conclude Sample 1 <= Sample 2**										
40		**P-Value >= alpha (0.05)**										
41												

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3			User Selected Options									
4			Date/Time of Computation	12/19/2016 12:05:29 PM								
5			From File	Data_a.xls								
6			Full Precision	OFF								
7			Confidence Coefficient	95%								
8			Substantial Difference	0.000								
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)								
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median								
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Foster Park 3**											
15												
16				**Raw Statistics**								
17					Sample 1 (Main Site)	Sample 2 (Foster Park 3						
18				Number of Valid Observations	4687	139						
19				Number of Distinct Observations	3724	139						
20				Minimum	5.317	7.111						
21				Maximum	9.712	10.74						
22				Mean	7.395	8.689						
23				Median	7.403	8.741						
24				SD	0.665	0.645						
25				SE of Mean	0.00972	0.0547						
26												
27				**Wilcoxon-Mann-Whitney (WMW) Test**								
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	11040380							
32				Standardized WMW U-Stat	-16.78							
33				Mean (U)	325747							
34				SD(U) - Adj ties	16188							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	1							
37												
38	**Conclusion with Alpha = 0.05**											
39		**Do Not Reject H0, Conclude Sample 1 <= Sample 2**										
40		**P-Value >= alpha (0.05)**										

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3			User Selected Options									
4			Date/Time of Computation	12/19/2016 12:06:36 PM								
5			From File	Data_a.xls								
6			Full Precision	OFF								
7			Confidence Coefficient	95%								
8			Substantial Difference	0.000								
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)								
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median								
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Kautz Field 1**											
15												
16				**Raw Statistics**								
17					Sample 1 (Main Site)	Sample 2 (Kautz Field 1)						
18				Number of Valid Observations	4687	301						
19				Number of Distinct Observations	3724	300						
20				Minimum	5.317	4.643						
21				Maximum	9.712	9.133						
22				Mean	7.395	6.316						
23				Median	7.403	6.183						
24				SD	0.665	0.979						
25				SE of Mean	0.00972	0.0564						
26												
27				**Wilcoxon-Mann-Whitney (WMW) Test**								
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	12129139							
32				Standardized WMW U-Stat	18.06							
33				Mean (U)	705394							
34				SD(U) - Adj ties	24218							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	0							
37												
38	**Conclusion with Alpha = 0.05**											
39		**Reject H0, Conclude Sample 1 > Sample 2**										
40		**P-Value < alpha (0.05)**										

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3			User Selected Options									
4			Date/Time of Computation	12/19/2016 12:09:39 PM								
5			From File	Data_a.xls								
6			Full Precision	OFF								
7			Confidence Coefficient	95%								
8			Substantial Difference	0.000								
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)								
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median								
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Kautz Field 2**											
15												
16				**Raw Statistics**								
17					Sample 1 (Main Site)	Sample 2 (Katuz Field 2)						
18				Number of Valid Observations	4687	244						
19				Number of Distinct Observations	3724	241						
20				Minimum	5.317	4.634						
21				Maximum	9.712	9.093						
22				Mean	7.395	6.78						
23				Median	7.403	6.649						
24				SD	0.665	0.705						
25				SE of Mean	0.00972	0.0451						
26												
27				**Wilcoxon-Mann-Whitney (WMW) Test**								
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	11833934							
32				Standardized WMW U-Stat	12.72							
33				Mean (U)	571814							
34				SD(U) - Adj ties	21680							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	0							
37												
38	**Conclusion with Alpha = 0.05**											
39		**Reject H0, Conclude Sample 1 > Sample 2**										
40		**P-Value < alpha (0.05)**										

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3			User Selected Options									
4			Date/Time of Computation	12/19/2016 12:11:07 PM								
5			From File	Data_a.xls								
6			Full Precision	OFF								
7			Confidence Coefficient	95%								
8			Substantial Difference	0.000								
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)								
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median								
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: Kautz Field 3**											
15												
16				**Raw Statistics**								
17					Sample 1 (Main Site)	Sample 2 (Kautz Field 3)						
18				Number of Valid Observations	4687	210						
19				Number of Distinct Observations	3724	206						
20				Minimum	5.317	6.296						
21				Maximum	9.712	9.667						
22				Mean	7.395	7.993						
23				Median	7.403	8						
24				SD	0.665	0.594						
25				SE of Mean	0.00972	0.041						
26												
27				**Wilcoxon-Mann-Whitney (WMW) Test**								
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	11235376							
32				Standardized WMW U-Stat	-12.13							
33				Mean (U)	492135							
34				SD(U) - Adj ties	20044							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	1							
37												
38	**Conclusion with Alpha = 0.05**											
39	**Do Not Reject H0, Conclude Sample 1 <= Sample 2**											
40	**P-Value >= alpha (0.05)**											

	A	B	C	D	E	F	G	H	I	J	K
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**										
2											
3			User Selected Options								
4			Date/Time of Computation	12/19/2016 12:12:49 PM							
5			From File	Data_a.xls							
6			Full Precision	OFF							
7			Confidence Coefficient	95%							
8			Substantial Difference	0.000							
9			Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)							
10			Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median							
11											
12											
13	**Sample 1 Data: FINAL Main Site**										
14	**Sample 2 Data: Harrison Park 1**										
15											
16				**Raw Statistics**							
17					Sample 1 (Main Site)	Sample 2 (Harrison Park 1)					
18				Number of Valid Observations	4687	241					
19				Number of Distinct Observations	3724	240					
20				Minimum	5.317	6.13					
21				Maximum	9.712	11.16					
22				Mean	7.395	8.302					
23				Median	7.403	8.31					
24				SD	0.665	0.756					
25				SE of Mean	0.00972	0.0487					
26											
27				**Wilcoxon-Mann-Whitney (WMW) Test**							
28											
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**										
30											
31				Sample 1 Rank Sum W-Stat	11190049						
32				Standardized WMW U-Stat	-16.76						
33				Mean (U)	564784						
34				SD(U) - Adj ties	21540						
35				Approximate U-Stat Critical Value (0.05)	1.645						
36				P-Value (Adjusted for Ties)	1						
37											
38	**Conclusion with Alpha = 0.05**										
39	**Do Not Reject H0, Conclude Sample 1 <= Sample 2**										
40	**P-Value >= alpha (0.05)**										

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	A	B	C	D	E	F	G	H	I	J	K
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**										
2											
3				User Selected Options							
4				Date/Time of Computation	12/19/2016 12:14:06 PM						
5				From File	Data_a.xls						
6				Full Precision	OFF						
7				Confidence Coefficient	95%						
8				Substantial Difference	0.000						
9				Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)						
10				Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median						
11											
12											
13	**Sample 1 Data: FINAL Main Site**										
14	**Sample 2 Data: Harrison Park 2**										
15											
16					**Raw Statistics**						
17					Sample 1 (Main Site)	Sample 2 (Harrison Park 2)					
18				Number of Valid Observations	4687	48					
19				Number of Distinct Observations	3724	48					
20				Minimum	5.317	8.178					
21				Maximum	9.712	13.39					
22				Mean	7.395	10.5					
23				Median	7.403	10.67					
24				SD	0.665	1.577					
25				SE of Mean	0.00972	0.228					
26											
27					**Wilcoxon-Mann-Whitney (WMW) Test**						
28											
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**										
30											
31				Sample 1 Rank Sum W-Stat	10989559						
32				Standardized WMW U-Stat	-11.59						
33				Mean (U)	112488						
34				SD(U) - Adj ties	9423						
35				Approximate U-Stat Critical Value (0.05)	1.645						
36				P-Value (Adjusted for Ties)	1						
37											
38	**Conclusion with Alpha = 0.05**										
39	**Do Not Reject H0, Conclude Sample 1 <= Sample 2**										
40	**P-Value >= alpha (0.05)**										

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	A	B	C	D	E	F	G	H	I	J	K	L
1	**Wilcoxon-Mann-Whitney Sample 1 vs Sample 2 Comparison Test for Uncensor Full Data Sets without NDs**											
2												
3				User Selected Options								
4				Date/Time of Computation	12/19/2016 12:25:51 PM							
5				From File	Data_All.xls							
6				Full Precision	OFF							
7				Confidence Coefficient	95%							
8				Substantial Difference	0.000							
9				Selected Null Hypothesis	Sample 1 Mean/Median <= Sample 2 Mean/Median (Form 1)							
10				Alternative Hypothesis	Sample 1 Mean/Median > Sample 2 Mean/Median							
11												
12												
13	**Sample 1 Data: FINAL Main Site**											
14	**Sample 2 Data: ALL RBRAs**											
15												
16					**Raw Statistics**							
17					Sample 1 (Main Site)	Sample 2 (All RBRAs)						
18				Number of Valid Observations	4687	1732						
19				Number of Distinct Observations	3724	1628						
20				Minimum	5.317	4.634						
21				Maximum	9.712	13.39						
22				Mean	7.395	7.67						
23				Median	7.403	7.752						
24				SD	0.665	1.196						
25				SE of Mean	0.00972	0.0288						
26												
27					**Wilcoxon-Mann-Whitney (WMW) Test**							
28												
29	**H0: Mean/Median of Sample 1 <= Mean/Median of Sample 2**											
30												
31				Sample 1 Rank Sum W-Stat	14260170							
32				Standardized WMW U-Stat	-11.91							
33				Mean (U)	4058942							
34				SD(U) - Adj ties	65902							
35				Approximate U-Stat Critical Value (0.05)	1.645							
36				P-Value (Adjusted for Ties)	1							
37												
38	**Conclusion with Alpha = 0.05**											
39	**Do Not Reject H0, Conclude Sample 1 <= Sample 2**											
40	**P-Value >= alpha (0.05)**											

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