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TRANSMITTAL OF OPERABLE UNIT 3 ENGINEERING STUDY REPORTS TO THE U. S. ENVIRONMENTAL PROTECTION AGENCY AND THE OHIO ENVIRONMENTAL PROTECTION AGENCY - (ACTUAL TITLE OF REPORT: ENGINEERING STUDY FINAL REPORTS, OPERABLE UNIT 3)

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DOE-FN EPAS
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FINAL REPORT

Department of Energy

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DOE-0694-96

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Mr. Tom Schneider, Project Manager
Ohio Environmental Protection Agency
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Dear Mr. Saric and Mr. Schneider:

TRANSMITTAL OF OPERABLE UNIT 3 ENGINEERING STUDY REPORTS TO THE U.S. ENVIRONMENTAL PROTECTION AGENCY AND THE OHIO ENVIRONMENTAL PROTECTION AGENCY

Enclosed are the cummulative results of the Operable Unit 3 (OU3) Engineering/Treatability Study Activities for your information. This document consists of numerous engineering studies which were performed for remediation of OU3 waste streams. The Final OU3 Treatability Study Work Plan (TSWP) was approved by the U.S. Environmental Protection Agency (U.S. EPA) on April 13, 1994. The Final OU3 TSWP contained four study-specific appendices which provided test plans for four engineering studies. A summary of each of the studies is provided below:

- Chemical Conversion of Asbestos-Containing Material - As indicated in a letter from the Department of Energy, Fernald Area Office (DOE-FN) to the U.S. EPA and the Ohio Environmental Protection Agency (OEPA), this study was eliminated from the OU3 TSWP (Reference: Letter Number DOE-1588-94, from Jack Craig to James Saric and Tom Schneider, "Operable Unit 3 Treatability Study Work Plan - Addendum," dated June 1, 1994).

- Chemical Leaching - A preliminary chemical leaching study was performed to remove radionuclides from scabbled concrete. Preliminary tests proved the feasibility of this technology. However, the technology was not considered cost effective due to the costs associated with the additional development work required for the treatment and disposal of the wastes generated from the process. The final engineering study report was submitted to DOE-FN on September 12, 1995.

Recycled and Recyclable

- Vitrification of Asbestos-Containing Materials and Vitrification of Mixed Wastes - Funding for these studies was redirected to allow resources to be refocused on remedial projects (Reference: Letter Number DOE-0250-95, from Jack Craig to James Saric and Tom Schneider, "Operable Unit 3 Treatability Study Work Plan - Addendum," dated December 7, 1994).

Several additional engineering studies were identified in a letter from the DOE-FN to the U.S. EPA and the OEPA (Reference: Letter Number DOE-0250-95, from Jack Craig to James Saric and Tom Schneider, "Operable Unit 3 Treatability Study Work Plan - Addendum," dated December 7, 1994) to support OU3 Removal Actions, Hazardous Waste Management Unit (HWMU) closures, Decontamination and Dismantlement (D&D) activities performed during the interim remedial action, and the Department of Energy, Headquarters (DOE-HQ) Technology Development Program activities. A summary of each of the studies discussed in the letter is provided below:

- Recycling of Copper - The study is being performed to determine an effective, least cost method to separate radiologically contaminated asbestos insulation from 1,400 tons of copper wire for subsequent recycle. Test work is being performed on 300 tons of copper wire at Manufacturing Science Corporation (MSC), Oak Ridge, Tennessee. This engineering study is currently ongoing and scheduled for completion in August 1996. The final report will be issued when the project is completed.

- Treatment of Thorium Nitrate - This engineering study supported the Resource Conservation and Recovery Act (RCRA) closure of Thorium Nitrate Tank T-2, which was an OU3 HWMU. The Thorium Nitrate Solidification Final Report Completed Under Removal Action Number 9, submitted to DOE-FN and the EPAs (February 1996), details the completed Thorium Nitrate Solidification Project.

- N-Scan Prompt Gamma Neutron Activation Analysis - This EM-50 PRDA has not been performed, since the technology on which it would be based has not proven reliable in the development process. Therefore, this study will not be demonstrated at the Fernald Environmental Management Project (FEMP).

  Ultrasonic Cleaning of Strategic Metals - A preliminary engineering study was performed to evaluate the effectiveness of ultrasonic cleaning as a decontamination technology for strategic metals. The results of this limited study are being summarized in a white paper which will be issued in March 1996.

Several other engineering studies, which were not initially identified in the OU3 TSWP or in the letter from the DOE-FN to the USEPA and OEPA (Reference: Letter Number DOE-0250-95, dated December 07, 1994, from Jack Craig to James Saric and Tom Schneider, "Operable Unit 3 Treatability Study Work Plan - Addendum"), were performed. These studies are summarized below:

- EET Decontamination of Transite - EET is the owner of a proprietary chemical technology for the extraction of contaminants, including radionuclides, from solid materials. An engineering study was performed at the DOE Piketon Facility (joint demonstration) on transite using EET's TECHXTRACT™ technology. Although the process was successful at decontaminating the test transite, the technology proved to be too labor intensive to be considered cost effective. The final engineering study report was submitted to DOE-FN on October 23, 1995.

- Analysis of Surface Blasting Technologies ("Blast-off" Study) - This engineering study, performed at Florida International University, tested and compared eight surface decontamination technologies on rusted and painted structural steel. The final engineering study report was submitted to DOE-FN on September 12, 1995.

- Transite Characterization Study - This engineering study, performed at the University of Cincinnati Accelerated Life Testing and Environmental Research (ALTER) Facility, investigated whether Fernald transite was surface or volumetrically contaminated with radionuclides and developed methods to measure the contamination depth. Test results indicate that both surface and volumetrically contaminated transite exist at the FEMP. Contamination depth appears to be dependent on the process history of the buildings where samples were taken. Methods to measure radiological contamination depth were also successfully developed. The final engineering study report was submitted to DOE-FN on January 26, 1996.

- Kelly™ Decontamination - The Kelly™ Decontamination System was tested to determine the effectiveness of removing radionuclides and inorganics from concrete. Results indicate that the technology was not effective. The final engineering study report was submitted to DOE-FN on September 28, 1995.

- Plant 7 Steel Recycling - This engineering study, performed by Alaron, Incorporated, Wampum, Pennsylania, investigated grit blasting decontamination and unrestricted reuse of structural steel. The final report is expected to be issued to DOE-FN and the EPAs by the end of March 1996.

- Plant 7 Lead Recycling - This engineering study, performed by Scientific Ecology Group (SEG), Incorporated, Oak Ridge, Tennessee, investigated chemical decontamination of the lead and unrestricted reuse. The final report is expected to be issued to DOE-FN and the EPAs by the end of March 1996.

The original studies performed were labeled as treatability studies, when the true scope of work was to establish the process capabilities for OU3 materials. In this context, these studies are truly proof of process studies and were not needed to support alternative evaluations conducted in the OU3 Remedial Investigation/Feasibility Study (RI/FS) Report. Therefore, since they did not support screening of technologies, they were not included in Final RI/FS Report (February 1996). However, the data obtained was employed in the evaluation of the remedial alternatives for OU3. As noted on the CC list, this document is being placed in the Administrative Record.

If there are any questions, please contact Mr. John Trygier at 648-3154.

Sincerely,

Johnny Reising

FN:Hall

Johnny W. Reising
Fernald Remedial Action
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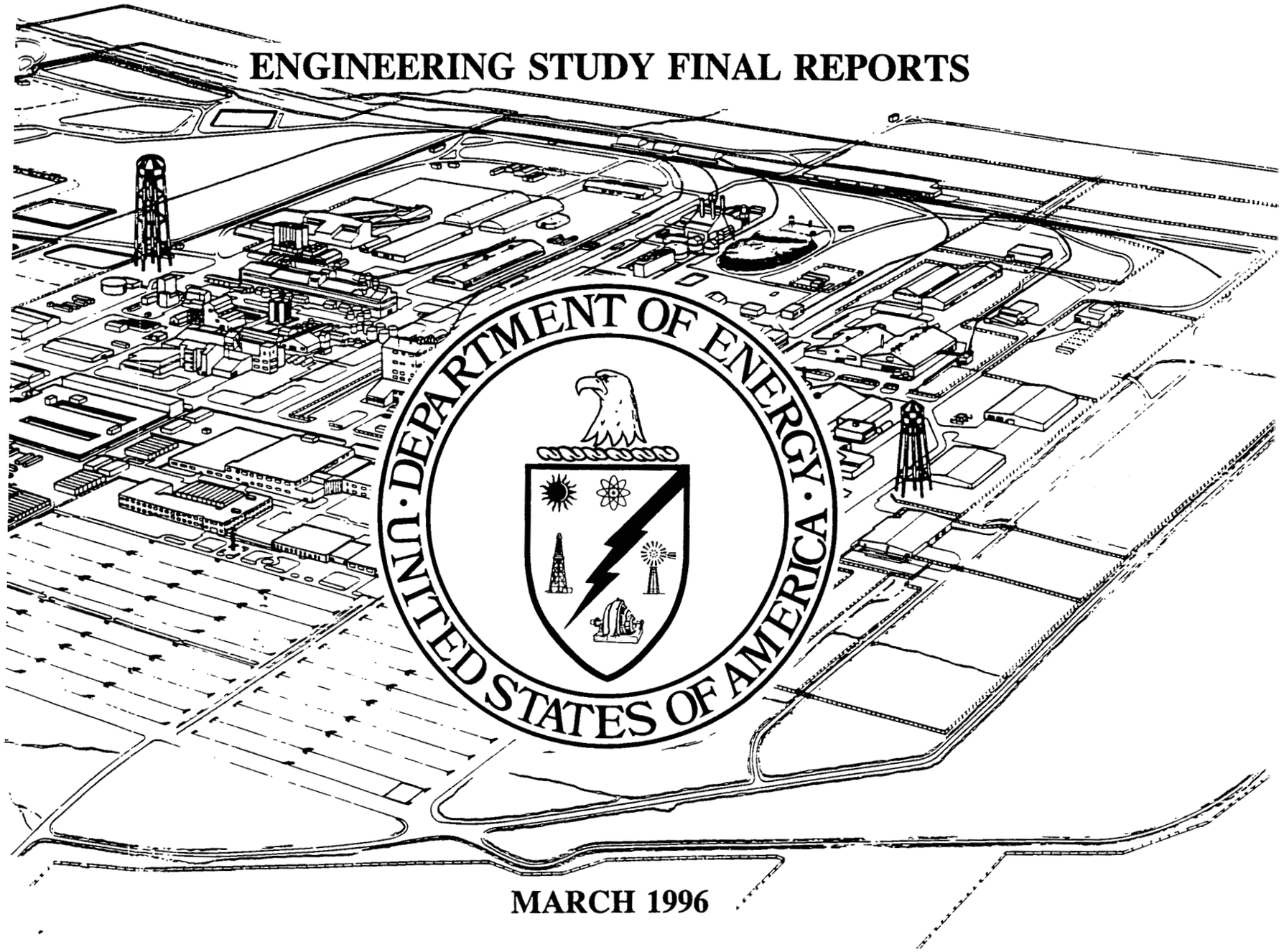
OPERABLE UNIT 3

ENGINEERING STUDY FINAL REPORTS



MARCH 1996

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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Section 1.0

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FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

OPERABLE UNIT 3

CHEMICAL LEACHING PRELIMINARY ENGINEERING STUDY

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Fernald Area Office

Under Contract DE-AC24-920R21972

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EXECUTIVE SUMMARY

At the Fernald Environmental Management Project (FEMP), formerly known as the Feed Materials Production Center (FMPC), the Department of Energy (DOE) is conducting a Remedial Investigation and Feasibility Study (RI/FS) to achieve environmental restoration of the site. Response actions at the FEMP are being conducted according to the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This report describes and evaluates Chemical Leaching as a waste treatment technology for remediation of Operable Unit 3 (OU3) at the FEMP. OU3 consists of the former Fernald Production Area, and production-associated facilities and equipment.

To support the development of remedial alternatives and to estimate waste volumes, OU3 media were grouped into ten main material categories based on physical characteristics (e.g., plastic, asbestos-containing, etc.), anticipated location of contamination (e.g., surface or volumetrically contaminated), and potential for beneficial reuse/recycle (e.g., bulk steel, etc.). Uranium is the principal contaminant of concern, although other radiological and hazardous contaminants are also present or anticipated in OU3 media.

Concrete makes up the largest category, by volume, of contaminated media within OU3. This material category includes poured concrete floors and walls, which may be slightly or heavily reinforced. Concrete was used extensively for paved surfaces such as storage pads, building floors, freestanding poured walls for shielding, building foundations, roofs, columns, equipment pedestals, and shielding.

Residue, from scabbling outdoor concrete surfaces that exhibited high radiation levels, was collected as a primary media for testing in this study. Scabbling of concrete surfaces to remove elevated radiological contamination zones has been an ongoing practice at the FEMP to reduce the exposure to workers according to DOE Order 5480.11, Radiation Protection for Occupational Workers. RI data collected for OU3 indicates that concrete and acid brick contamination is limited to surface and near surface zones. If all OU3 concrete and acid brick surfaces were scabbled and successfully leached, the volume of material requiring disposal at a low level waste (LLW) facility would be less than 1% of the original volume of concrete and acid brick. This recognition provided the driver to evaluate the possibilities of leaching contaminants from cement matrices.

The leaching process uses a chemical leaching agent to extract specific chemical compounds or metals, such as uranium, from insoluble bulk media. The process involves vigorously mixing finely divided solid particles containing the leachable component and the solution containing the leaching agent, under controlled conditions. This allows the desired component to transfer from the solid phase to the liquid phase. The intended separation occurs as the liquid is removed from the solids. This process was used extensively at the FEMP in previous uranium processing work, but not for removing uranium from scabbled concrete, and not to such low levels as required by the present cleanup work.

The purpose of these preliminary tests was to obtain data to assess chemical leaching as a remedial technology in support of the RI/FS and to demonstrate the use of chemical leaching to remove radiological contaminants from concrete. Successful leaching would allow 1) controlled recycling/reuse of the remaining decontaminated bulk volumes of scabbled media, including the option to dispose of decontaminated waste material on-site, and 2) final disposition of a greatly reduced volume of media containing the collected contaminants.

The conclusions reached regarding chemical leaching as a treatment alternative for contaminated concrete and acid brick are listed below:

- Only 0.5 normal (N) sulfuric acid (H_2SO_4) successfully leached uranium (U) and thorium (Th) from scabbled concrete. Although considered a success, the use of sulfuric acid as a leaching agent has the following potential drawbacks:
  - Restrictions on the handling and use of acid reagents,
  - Dissolution of the concrete along with the radiological contaminants,
  - Possible atmospheric emissions,
  - Possible generation of Resource, Conservation, and Recovery Act (RCRA) characteristic wastes,
  - Generation of an additional LLW stream (precipitated U sludge) requiring a secondary process for separation and treatment before disposal,
  - Increased reagent costs (additions of fresh solution are required to compensate for the rise in pH resulting from leaching an alkaline material (concrete)), and
  - Has not been proven effective for the removal of other radiological and chemical contaminants.

- A significant volume reduction in LLW was not achieved.

- Chemical leaching is not effective in reducing the mobility of the contaminants.

- Developing a chemical leaching process that could reduce radiological contamination in concrete by 80 percent is feasible. However, an 80 percent reduction may not be

sufficient to allow the material to be released for unrestricted reuse or recycle. In addition, process development would be costly and time consuming.

- Scabbled concrete contains various U, Th, and other radiological compounds. Each compound has its own physical and chemical properties, and only reacts or dissolves under certain favorable conditions (i.e., at the right pH, temperature, leaching solution). It is unlikely that a single leaching solution, under fixed conditions, would remove all contaminants at once. A multiple stage leaching process would be required to effectively remove the various radiological and chemical contaminants. Variations in the types and amounts of contaminants in the media from different areas of the site would also impact the process.

- Several of the radiological contaminants precipitate out of solution during the leaching process. A secondary process would be required to separate and treat this precipitated sludge. This secondary process would increase development, design, construction, and processing costs, and would generate additional quantities of LLW requiring separation and treatment before disposal.

- Chemical leaching produces a leachate waste stream requiring treatment and disposal.

- Chemical leaching does not provide the anticipated cost savings. The cost of development, construction, operating costs, and secondary waste treatment and disposal for chemical leaching is prohibitive compared to the cost of "box and bury".

- The alkalinity of the concrete tends to neutralize acidic leaching solutions and interferes with their ability to leach radiological compounds.

- Acid brick is chemically different from concrete. Any chemical leaching process developed for concrete would not be applicable to acid brick. Separate development studies would be required for acid brick.

- Scabbling concrete to separate the contaminated fraction from the remainder may actually increase worker health and safety concerns over environmental concerns for the bulk disposal of the material. In situ leaching approaches, if feasible, would be more desireable from a worker health protection standpoint.

In addition, no criteria currently exists to release concrete no matter what reduction in radiological contamination is achieved. Based on test results, chemical leaching is not considered a viable remedial technology option warranting further treatability testing for OU3 media.

1.0 INTRODUCTION

This report describes and evaluates Chemical Leaching as a waste treatment technology for remediation of U.S. Department of Energy's Operable Unit 3 at the Fernald Environmental Management Project. OU3 consists of the former Fernald Production Area, and production-associated facilities and equipment.

The goal of this report is to evaluate chemical leaching for the remediation of concrete and acid brick on the basis of feasibility, effectiveness, and reliability. The information presented in this report supports the analysis presented in the OU3 Feasibility Study Report and the Proposed Plan (PP) and is designed to meet the requirements of the U.S. Environmental Protection Agency's (EPA) "Guide for Conducting Treatability Studies under CERCLA".

1.1 SITE DESCRIPTION

At the FEMP, formerly known as the Feed Materials Production Center[1], the DOE is conducting a Remedial Investigation and Feasibility Study to achieve environmental restoration of the site. Response actions at the FEMP are being conducted in accordance with the requirements of CERCLA.

The FEMP is located on a 1,050-acre site in a rural agricultural area about 18 miles northwest of downtown Cincinnati, Ohio (Figure 1.1). The site is near the villages of Fernald, New Baltimore, New Haven, Ross, and Shandon, Ohio.

The FEMP is a government-owned, contractor-operated federal facility where an Environmental Restoration Management Contract (ERMC) approach is being implemented to manage the restoration activities, with Fernald Environmental Restoration Management Corporation (FERMCO), a wholly owned subsidiary of Fluor Daniel Incorporated, currently serving as the ERMC contractor. The FEMP produced high-purity uranium metal products for the DOE and its predecessor agency, the Atomic Energy Commission, during the period 1952-1989. Thorium was also processed, but on a smaller scale, and is still stored on-site. Production activities were stopped in 1989, and the production mission of the facility was formally ended in 1991. The FEMP was included on the National Priorities List in 1989.

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[1] Throughout this report, the acronym "FEMP" is used for this facility, even though it was known as the FMPC when in operation.

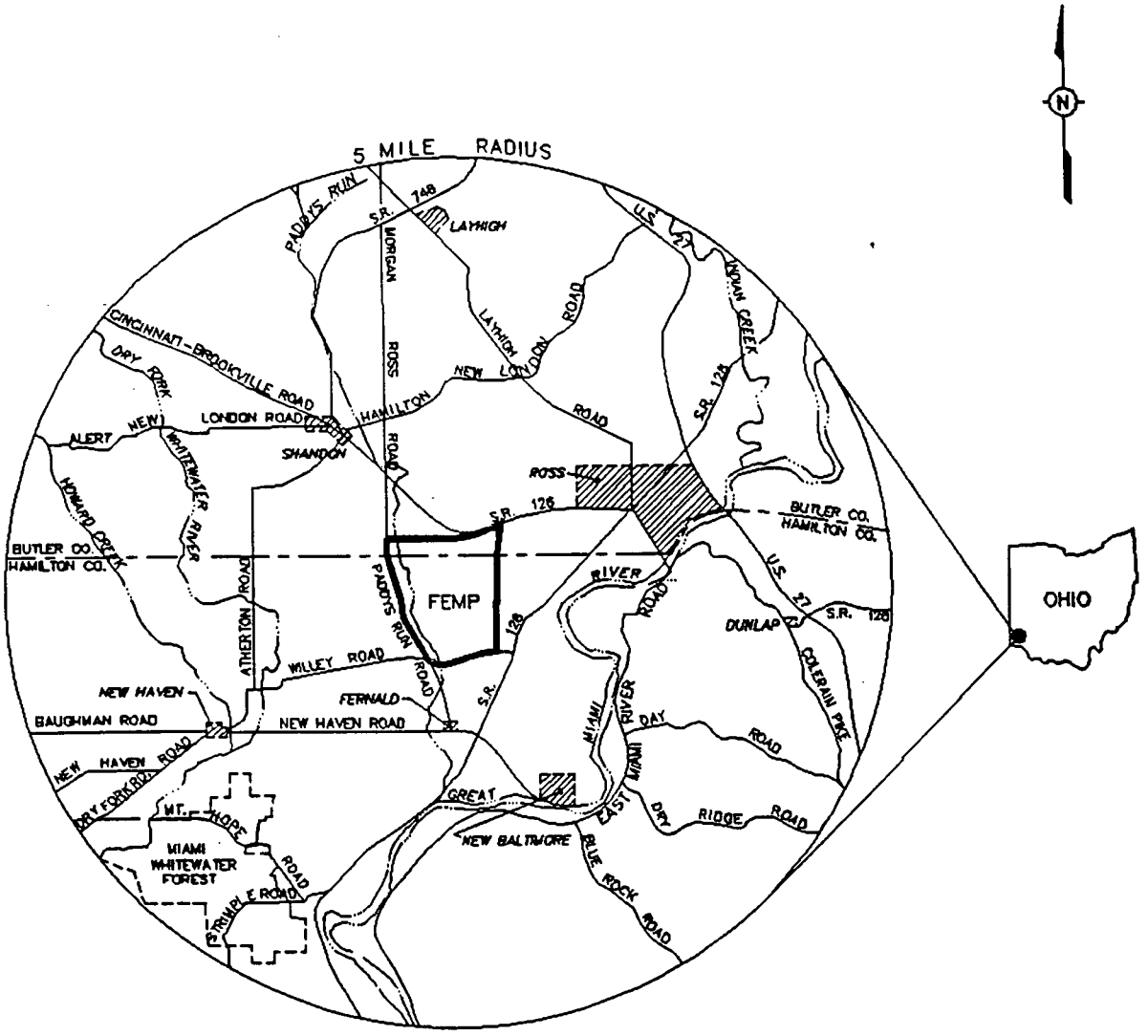


FIGURE 1.1 Location of the FEMP Facility

The current mission of the site is environmental restoration in accordance with the requirements of CERCLA of 1980, as amended by Superfund Amendments and Reauthorization Act (SARA). On July 18, 1986, a Federal Facility Compliance Agreement (FFCA) was signed by the U.S. EPA and the DOE to ensure that environmental impacts associated with past and present activities at the FEMP are investigated and remedial actions are assessed and carried out.

1.1.1 Description of Operable Unit 3

The FEMP is divided into five separate *operable units*. OU3 consists of the former Fernald Production Area and production-associated facilities and equipment. OU3 includes all above- and below-grade improvements, including, but not limited to, all structures, equipment, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, K-65 transfer line, waste water treatment facilities, fire training facilities, scrap metal piles, feedstocks, and coal pile as defined by the *Consent Agreement as Amended under CERCLA Sections 120 and 106(a) in the Matter of: U.S. Department of Energy Feed Materials Production Center, Fernald, Ohio* (EPA 1991).

1.2 WASTE STREAM DESCRIPTION

1.2.1 Waste Matrices

To support the development of remedial alternatives and to estimate waste volumes, OU3 media have been grouped into ten main material categories on the basis of their primary construction materials and characteristics. Although most media fit within the definition of a single category, several media types are identified as being multi-faceted (e.g., mica-coated electrical insulation, ceramic tile containing asbestos). The material categories were based on physical characteristics (e.g., plastic, asbestos-containing, etc.), anticipated location of contamination (e.g., surface or volumetrically contaminated), and potential for beneficial reuse/recycle (e.g., bulk steel, etc.).

Concrete makes up the largest category, by volume, of contaminated media within OU3. This material category includes poured concrete floors and walls which may be slightly or heavily reinforced. Concrete was used extensively for paved surfaces such as storage pads, building floors, free-standing poured walls, building foundations, roofs, columns, equipment pedestals, and shielding. Residue from scabbling outdoor concrete surfaces that had high exposure, was sampled and used for the preliminary chemical leaching tests. Samples from the scabbled concrete were screened into sizes

ranging from 90 microns to 850 microns to determine: (1) the correlation between contamination concentration and particle size, and (2) the most effective leaching solution based on particle size.

1.2.2 Pollutants/Chemicals

Section 2.4 of the OU3 RI/FS Work Plan Addendum (WPA) addresses the nature of contamination present in OU3 media based on the processes and operations performed at the FEMP. A summary of historical information and process knowledge indicating the primary radiological and chemical contaminants of interest for OU3 is presented in the OU3 RI/FS WPA. Section 3 of the UO3 RI/FS Report discusses the characterization of UO3. Appendix A of the OU3 RI/FS Report provides summary tables of OU3 RI data. Uranium is the principal contaminant of concern, although other radiological and hazardous contaminants are also present or anticipated in OU3 media. Chemical leaching was to remove the following radionuclides from scabbled concrete:

- U_3O_8 (which may have various oxidation states of U)
- Enriched U (up to 1.25% U-235), depleted U (down to 0.2%)
- $UO_2(X)_2$ (where X = Cl^{-1}, NO_3^{-1}, SO_4^{-2}, CO_3^{-2}), UO_3
- Depleted and enriched UF_4 (0.2% - 1.25% U-235)
- UF_6, UO_2F_2
- Th, ThF_4, ThO_2 (ceramic and non-ceramic form), Thorium oxalate ($Th(C_2O_2)_2$)
- Ba, Cd, Cr, $BaSO_4$ (ceramic form), Cs, ^{99}Tc

Chemical contaminants of concern were not considered during the initial phase of treatability testing. Later phases of the treatability testing included provisions for testing the effectiveness of chemical leaching for removing chemical contaminants from concrete.

1.3 REMEDIAL TECHNOLOGY DESCRIPTION

Chemical leaching has been used for many years and in many applications, particularly in the non-ferrous mining industry, to concentrate and recover valuable resources from what would otherwise be waste material. Leaching agents are typically solutions (e.g., sodium carbonate/bicarbonate, citric acid, hydrochloric acid) used to extract chemical compounds or metals, such as uranium, from insoluble media. The process involves vigorously mixing finely divided solid particles containing the leachable component and the solution containing the leaching agent, under controlled conditions. This allows the desired component to transfer from the solid phase to the liquid phase and be removed as the liquid is separated from the solids. The chemical leaching process is typically conducted in an agitated vessel, which assures contact of all the contaminated media with the leachate solution. This

process had been used extensively at the FEMP in uranium processing work, but not to remove uranium from scabbled concrete and not to such low levels as required by the present cleanup work. Solids may also be loaded into a column with the leaching agent flowing either up or down the column and contacting the bed of solids. Additional leaching techniques, such as open piles (e.g., mill tailings piles) and in situ ore body leaching do not lend themselves to close environmental control and will not be considered for OU3 work.

Contaminants collected in the leachate can be concentrated further by precipitation, conducted as part of the waste water processing system, The neutralized leachate slurry can be filtered and the contaminants, as filter cake, can be prepared for disposition off-site in the same manner as other LLW filter cakes generated at the FEMP.

Scabbling is a surface removal technique which physically removes up to one-half inch layers of surface material. In accordance with DOE Order 5480.11, Radiation Protection for Occupational Workers, scabbling concrete surfaces has been an ongoing practice at the FEMP to reduce the exposure to workers. RI data collected for OU3 indicates that the contamination in concrete and acid brick is limited to the surface. One concrete location where scabbling was performed required only one-sixteenth to one-eighth inch surface removal to reduce the contamination from 10^5 counts per minute to below detection of the instrument (< 1,000 counts per minute). Scabbled concrete and acid brick residues would potentially contain virtually all of the contamination. If all OU3 concrete and acid brick surfaces were scabbled and successfully leached, the volume of material requiring disposal at a low level waste (LLW) facility would be less than one percent of the original volume of concrete and acid brick.

2.0 CONCLUSIONS AND RECOMMENDATIONS

During Remedy Screening, chemical leaching was evaluated for its applicability and appropriateness to OU3 media and contaminants. Chemical Leaching has been evaluated against three standard EPA guidance criteria: effectiveness; implementability; and cost.

2.1 CONCLUSIONS

This preliminary treatability study evaluated the use of chemical leaching to treat contaminated concrete. This is based on the leachability of uranium from the concrete, and the overall potential reduction of LLW requiring disposal. Results from this study are reported in Section 4.0 of this report. Although treatability testing was limited to concrete, some conclusions relating to chemical leaching of acid brick can be drawn. The conclusions reached regarding chemical leaching as a treatment alternative are as follows:

- Only 0.5N sulfuric acid (H_2SO_4) successfully leached U and Th from scabbled concrete. Although considered a success, the use of sulfuric acid as a leaching agent has the following potential drawbacks:
  - Restrictions on the handling and use of acid reagents
  - Dissolution of the concrete as well as radiological contaminants
  - Possible atmospheric emissions
  - Possible generation of RCRA characteristic wastes
  - Generation of an additional LLW stream (precipitated U sludge) requiring a secondary process for separation and treatment prior to disposal
  - Increased reagent costs (additions of fresh solution are required to compensate for the rise in pH resulting from leaching an alkaline material (concrete))
  - Has not been proven effective for the removal of other radiological and chemical contaminants
- A significant volume reduction in LLW was not achieved.
- Chemical leaching is not effective in reducing the mobility of the contaminants.
- It is feasible to develop a chemical leaching process which could reduce radiological contamination in concrete by 80 percent. However, there is no guarantee that an percent reduction is sufficient to allow the material to be released for unrestricted reuse or recycle. In addition, process development would be costly and time consuming.
- Scabbled concrete contains various U, Th, and other radiological compounds. Each compound has its own physical and chemical properties, and only reacts or dissolves under certain favorable conditions (i.e., at the right pH, temperature, leaching solution). It is unlikely that a single leaching solution, under fixed conditions, would remove all

contaminants at once. A multiple stage leaching process would be required to effectively remove the various radiological and chemical contaminants. Variations in the types and amounts of contaminants in the media from different areas of the site would also impact the process.

- Several of the radiological contaminants tend to precipitate out of solution during the leaching process. A secondary process would be required to separate and treat this precipitated sludge. This secondary process would increase development, design, construction, and processing costs, and would generate additional quantities of LLW requiring separation, treatment and disposal.

- Chemical leaching produces a leachate waste stream requiring treatment and disposal.

- Chemical leaching does not provide the anticipated cost savings. The cost of development, construction, operating costs, and secondary waste treatment and disposal for chemical leaching is prohibitive compared to the cost of "box and bury".

- The alkalinity of the concrete tends to neutralize acidic leaching solutions and interferes with their ability to leach radiological compounds.

- Acid brick is chemically different from concrete. Any chemical leaching process developed for concrete would not prove to be applicable to acid brick. Separate development studies would be required for acid brick.

- Scabbling concrete to separate the contaminated fraction from the remainder may actually increase worker health and safety concerns over environmental concerns for the bulk disposal of the material. In situ leaching approaches, if feasible, would be more desireable from a worker health protection standpoint.

Based on test results, chemical leaching is not considered a viable remedial technology option warranting further treatability testing for OU3 media.

2.2 RECOMMENDATIONS

Although chemical leaching was commonly used at the FEMP to leach uranium during the production years, the technology was never applied to decontaminating concrete or acid brick. Results from testing showed only sulfuric acid effectively removed U and Th from concrete. However, the drawbacks associated with sulfuric acid usage outweigh the benefits. In addition, no criteria currently exists to release concrete no matter what reduction in radiological contamination is achieved.

Although an effective chemical leaching process could be developed, extensive process development would be required to develop a multiple stage process capable of removing a wide range of

radiological and chemical contaminants. A separate process would be required to decontaminate acid brick. Therefore, no additional test work is recommended.

3.0 TREATABILITY STUDY APPROACH

This Preliminary Study was was used to establish the general feasibility of chemical leaching and was performed prior to the treatability study outlined in the OU3 Treatability Study Work Plan (TSWP), approved by U.S. EPA, March 1994. The OU3 TSWP was prepared in accordance with the EPA's Guide for Conducting Treatability Studies Under CERCLA Interim Final (EPA 1988) and Final (EPA 1992). The scope of the study as approved Appendix C in the TSWP was reduced in an effort to reduce costs while determining if the full scope of testing in Appendix C was warranted.

The purpose of treating contaminated materials is to achieve a reduction in risk to the environment and human health. Treatability studies support remedy selection by providing data about potentially promising treatment processes and alternatives. Treatability studies test the effectiveness, performance, and implementability of potential remedial process options on OU3 media and contaminants of concern. Treatability studies are conducted to ensure that selected remedial process options comply with Applicable or Relevant, and Appropriate Requirements (ARARs).

The EPA Guide for Conducting Treatability Studies Under CERCLA (EPA 1992) outlines a three-tiered approach to conducting treatability studies for a Superfund site. The approach includes Remedy Screening, Remedy Selection, and Remedy Design. The remedy screening and remedy selection testing are generally pre-Record Of Decision (ROD) studies and the remedy design studies are generally post-ROD. Remedy screening and remedy selection treatability studies provide the performance and cost data needed to: 1) evaluate potentially applicable treatment alternatives, and 2) select the most applicable remedial alternative for remedial action based on the nine National Contingency Plan (NCP) evaluation criteria. The proposed OU3 treatability study approach is consistent with EPA's phased system for conducting treatability studies.

This preliminary-scale test was used to provide a qualitative evaluation of the potential effectiveness of a process option. Because the primary objective of remedy screening testing is to determine the potential feasibility of a process option, rigorous analytical Quality Assurance/Quality Control (QA/QC) requirements are not generally required. Ordinarily, it is acceptable to specify that remedy screening data be generated at Analytical Support Levels (ASL) A/B. Criteria for defining ASLs are contained in Section 3 of the OU3 TSWP.

3.1 TEST OBJECTIVES AND RATIONALE

The purpose of this preliminary test was to obtain data to assess chemical leaching as a remedial technology and to demonstrate the use of chemical leaching as a viable alternative for the removal of radiological contaminants from concrete. This would allow 1) controlled recycling/reuse of the remaining decontaminated bulk volumes of scabbled media, including the option of disposal of decontaminated waste material on-site, and 2) final disposition of a greatly reduced volume of media containing the collected contaminants. Other study-related objectives included:

- determine whether chemical leaching can effectively remove radiological contaminants from concrete,
- demonstrate a practical, cost effective means of contaminant removal,
- confirm the cost/benefit ratio of performing chemical leaching to bring about a substantial volume reduction of LLW,
- effectively treat and dispose of secondary wastes generated by the process;
- identify the optimum concrete particle size,
- determine the optimum leaching agent, and
- optimize the following process variables:
  - leaching agent concentration,
  - number of extractions required to leach the contaminants,
  - residence time of the media in the leachate, and
  - physical and chemical characteristics of the leaching process (e.g., pH, temperature, agitation of solutions).

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

Chemical leaching was selected as a potential remediation technology for removing radiological from concrete and acid brick. Chemical leaching involves removing contaminants by a chemical process using aqueous leaching solutions. Extracted contaminants may be further concentrated (e.g., precipitation, evaporation) or subjected to alternative treatment processes (e.g., stabilization). Because no release criteria is available, a percent redcution of contaminants wasestablished for the objectives. To warrant further testing, chemical leaching had to reduce uranium and thorium concentrations in concrete by 80 percent and be considered cost-effective.

Leaching solutions commonly used to extract uranium from the test media fall into three categories: carbonates, weak organic acids, and strong acids. Solutions combining various ratios of carbonate and bicarbonate salts of ammonium, potassium, or sodium make up the carbonate category. Weak organic acids may include EDTA, citric acid, and acetic acid. Sulfuric, nitric, and hydrochloric acid are examples of strong acids.

Although the strong acids category would be expected to provide the quickest and most thorough uranium removal, other factors may make these acids less desirable. These factors include: restrictions on the handling and use of acid reagents, probable dissolution of the concrete as well as contaminants, possible atmospheric emissions, and possible generation of RCRA characteristic wastes.

During preliminary testing, various combinations of process variables were tested to determine gross impacts of the variables on the test media. Upon completion of the preliminary phase of lab-scale testing, the results were analyzed and used to determine whether to proceed with additional testing. Variables tested included:

- type of leaching solution (five leaching solutions) - nitric acid, sulfuric acid, hydrochloric acid, acetic acid, sodium bicarbonate, and sodium carbonate/sodium bicarbonate solutions,
- leaching solution concentration,
- concrete particle size - ranged from 850 micrometers (μm) to <90 μm,
- loading ratio - concrete to leaching solution in grams per liter (g/l),
- residence time of each extraction cycle, and
- number of extraction cycles.

Because the heating mantle used could not maintain the leaching solution at a constant elevated temperature, all testing was conducted at ambient temperatures. Concrete samples were placed in two liter beakers with the leaching solution and stirred for at least two minutes to fully wet the solids in the solution. Fifty milliliter (ml) samples of leachate solution were withdrawn and filtered at thirty minute intervals and analyzed for total uranium and thorium. All tests were conducted for a minimum of three hours or until an equilibrium was reached. The time of contact for each leach cycle is an important factor in determining the cost and duration of a leaching operation. To reach maximum efficiency, it was important to minimize the leach period, while still achieving satisfactory results. Solution concentrations vary simply because of the difference in chemical and physical properties of each solution.

Additional leaching solution was added as needed during the tests to correct for pH changes, to replace the volume removed during sampling, or to correct for evaporative losses. Changes in pH resulted from reactions between the leachate and the alkaline concrete. At the end of each leaching test, samples of the leached concrete were collected and analyzed for total U and Th.

3.3 EQUIPMENT AND MATERIALS

Equipment and materials used is this study are listed below.

Table 1 List of Equipment

Equipment Category[1]	Item Description
Instruments	pH digital meter, thermometer (calibrated and traceable), bench-scales, β/γ frisker, ion selective electrode(s)
Filtration Equipment	Vacuum source, filter funnel, filter paper
Dry/Wet Screening Apparatus	Sieve vibrating shaker, standard test sieves (8")
Decontamination Materials	Standard phosphate-free laboratory detergent, potable water from FEMP water system, certified de-ionized organic-free (ASTM Type II) water, steam cleaner, and plastic/aluminum wrap
General Laboratory Equipment	Hot plate, ventilated laboratory hood, stirring apparatus, beakers, plastic containers, balance (calibrated), spatula, reagent storage/dispensing bottles, wash bottles

[1] This equipment list does not include analytical instrumentation for initial or final characterization.

3.4 SAMPLING AND ANALYSIS

3.4.1 Waste Stream

Several radiologically-contaminated areas at the FEMP were decontaminated using an automated chiseling technique, "scabbling", which removes the surface layer and collects the contaminated residues in "knock-out" drums. For the purpose of the treatability study, portions of this residue were collected from a randomly selected drum using (Site CERCLA Quality (SCQ) method K.5 "Drum Sampling". The samples were shipped to the FEMP laboratory in two one-gallon glass containers. The scabbled concrete was mechanically sieved into eight fractions ranging from 850 μm to < 90 μm. Initial screening of each particle size consisted of frisking the scabbled concrete samples for gross contamination levels with a hand-held beta/gamma frisker.

3.4.2 Treatment Process

3.4.2.1 Leachate Sampling and Analysis

For each test, 50-ml samples of leaching solution were collected at thirty minute intervals from the test beaker, filtered, and analyzed for total uranium and thorium. A 250 ml glass bottle was used to collect the leaching solution sample. The sample bottle was immediately sealed and marked. Site chain-of-custody procedures were followed to ensure sample integrity. Fifty ml of fresh leaching solution was added to the test beaker to replace the sample withdrawn. All analytical testing was performed to ASL A and followed approved methods outlined in Appendix G of the SCQ.

3.4.2.2 Leached Concrete Residue Sampling and Analysis

After each test, the residue/solution was filtered to separate the concrete residue from the leaching solution. The concrete residue was thoroughly dried and a sample of approximately 30 grams was collected and analyzed for total uranium and thorium. Site chain-of-custody procedures were followed to ensure sample integrity. All analytical testing was performed to ASL C and followed approved methods outlined in Appendix G of the SCQ.

3.5 DATA MANAGEMENT

A project-specific treatability laboratory notebook was used to provide a complete record of test data collected while conducting experiments by recording all daily laboratory activities and real-time analytical results associated with this project. The notebook was signed out from the facility Quality Control Coordinator (QCC) to the individuals working on the project. At the completion of the project, the laboratory notebook was returned to the facility QCC for retention.

FEMP site-wide data systems provide a centralized, consistent, and flexible repository for data collected/generated under this project. The goal is to provide a centralized data repository for a large quantity of treatability data, of known quality, that satisfy regulatory requirements, project Data Quality Objectives (DQOs), and that can support a wide range of data requests for assessment and reporting in a timely manner. Data which is collected or generated from this treatability study was entered into the data repository.

All data management and reporting followed standard QA/QC protocol. Standard QA/QC protocol, as it applies to testing within the laboratory, adheres to the following guidelines:

- Verification on numerical results - all raw data entries, transcriptions, and calculations are checked,
- Data validation through test for reasonableness - summaries of all test results for individual reports are reviewed to determine the overall reasonableness of data and to determine the presence of any data that may be considered outliers,
- Routine instrument calibration was performed, and
- Use of trained personnel conducting tests - all technicians are trained in the application of standard laboratory procedures for analyses, as well as, in the QA measures implemented for internal QC checks.

3.6 DEVIATIONS

- This preliminary testing was performed prior to the test plan outlined in Appencdix C of the OU3 TSWP. Based on the preliminary data generated, a decision was made to eliminate Phase I through IV of the treatability study.

- Preliminary testing was limited to concrete media only. No acid brick or ABCOV residues were tested. No ABCOV residues were tested due to the project being canceled.

- During testing, leaching solution temperatures above ambient could not be maintained and resulted in leaching solution temperature fluctuations. As a result, the elevated test temperatures were eliminated from preliminary testing.

- Some leach tests were continued past the planned three hours because uranium leaching was still occurring. Leaching time was extended to five hours, and in some cases eight hours, to determine the maximum leachability of the solution.

4.0 STUDY RESULTS AND DISCUSSION

4.1 DATA ANALYSIS OF WASTE STREAM CHARACTERISTICS

4.1.1 Analysis of Waste Stream Characteristics

Concrete makes up the largest volume of contaminated media within OU3. Residue, from scabbling on outdoor concrete surface areas that have had high exposure, were used for the preliminary chemical leaching tests. Uranium (in the form of U_3O_8) is the principal contaminant of concern, although other radiological and hazardous contaminants are also present. During preliminary testing, analysis of the leachate and concrete was limited to U and Th. Later phases of planned treatability testing included provisions for addressing chemical and other radiological contaminants.

4.1.2 Analysis of Treatability Study Data

Although analyses for thorium were performed on both the concrete residues and leachates, thorium levels were usually below the detection limits of the analytical equipment. In most cases, it was not possible to analyze thorium results or to draw definite conclusions about the effectiveness of the chemical leaching technology on removing thorium.

Results of the preliminary tests are summarized in Appendix A. All conversions from parts per million (ppm) to milligrams (mg) were adjusted to account for evaporative losses (leachate samples) or dissolution losses (concrete residue samples). Variations in the Instrument Detection Limit (IDL) for U and Th were also noted. The IDL results vary because the IDL is primarily a function of the sample volume and detector efficiency. Other variables also influence the IDL to a lesser extent. Negative numbers appearing in the Tables indicate the U precipitated out of solution in the form of a sludge. Uranium precipitates as a result of leachate pH changes or the leachate becoming saturated. Changes in pH result from leachate reacting with the alkaline concrete.

Unless otherwise indicated, the U content of the original concrete sample was back-calculated from the "Cumulative U Leached in Solution" and the "Total U in Residue" columns. Since the precipitated sludges were not separated from the concrete residues or analyzed, back-calculating the U content of the original concrete sample can result in the U content of the original sample being understated. Understating the U content of the original concrete sample has the following effects. The incremental and cumulative amounts and percents of U actually leached from the concrete sample are higher than indicated in the Tables because the amount of U present in the precipitated sludge is

unaccounted for. However, the percent (incremental and cumulative) of U actually remaining in the leachate and available for later separation and treatment would be overstated.

Of the nine tests performed, only 0.5N H_2SO_4 successfully leached U and Th from scabbled concrete. Although considered a success, the use of sulfuric acid as a leaching agent has drawbacks. These include:

- Restrictions on the handling and use of acid reagents,
- Dissolution of the concrete, as well as, radiological contaminants,
- Possible atmospheric emissions,
- Possible generation of RCRA characteristic wastes,
- Generation of an additional LLW stream (precipitated U sludge) requiring a secondary process for separation and treatment prior to disposal,
- Increased reagent costs (additions of fresh solution are required to compensate for the rise in pH resulting from leaching an alkaline material (concrete)), and
- Has not been proven effective for the removal of other radiological and chemical contaminants.

Initial testing indicates that a chemical leaching process is feasible. However, scabbled concrete contains various U, Th, and other radiological compounds. Each compound has its own physical and chemical properties, and only reacts or dissolves under certain favorable conditions (i.e., at the right pH, temperature, leaching solution). It is unlikely that a single leaching solution, under fixed conditions, would remove all contaminants at once. A multiple stage leaching process would be required to effectively remove the various radiological and chemical contaminants. Variations in the types and amounts of contaminants in the media from different areas of the site would also impact the process. In addition, several of the radiological contaminants precipitate out of solution during the leaching process. A secondary process would be required to separate and treat this precipitated sludge and would generate additional quantities of LLW requiring separation and treatment before disposal.

Costs associated with a full scale chemical leaching process would include additional process development, facility design and construction, processing/operating costs, disposal of clean concrete residue, secondary waste treatment and disposal, and facility decontamination and decommissioning. These costs would be several orders of magnitude higher than the to cost to "box and bury" contaminated concrete.

4.1.3 Comparison to Test Objectives

One of the goals of this treatability study was to evaluate chemical leaching as a potential remediation technology for OU3 media. Data generated during preliminary testing allowed the performance of chemical leaching to be assessed. Evaluation of the results indicates:

- Only one leaching solution (sulfuric acid) was successful in leaching U and Th,
- A reduction in LLW was not achieved,
- The anticipated cost benefits were not realized, and
- Chemical leaching can not be considered a viable remedial technology for OU3 media.

4.2 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

The Chemical Leaching Treatability Study was conducted according to the overall quality assurance program at the FEMP as described in the SCQ. The SCQ establishes a framework for control of the various sampling and analysis activities. Basic requirements for the development of DQOs, sampling, sample handling and storage, chain-of-custody records, and laboratory and field analyses were followed as specified in the sections and appendices of the SCQ.

Whenever available, standard analytical procedures and methods for inorganic and organic analysis (e.g., SW-846, EPA-600 methods, Scope of Work (SOW) for the Contract Laboratory Program) were followed during the treatability study. These procedures and methods were in accordance with the requirements of Appendix G of the SCQ. The radiological methods were in accordance with the performance based criteria listed in Appendix G of the SCQ. All laboratory analyses were performed to ASLs A/B.

5.0 REFERENCES

E. Kornelson, V. M. McNamara and J. C. Ingles. 1959. "Recovery of Uranium from an Acid Leach Liquor, Using an Ion Exchange Resin and Sodium Carbonate and Bicarbonate as Eluting Agents." Mines Branch Research Report R 33. Department of Mines and Technical Surveys, Ottawa, Canada.

APPENDIX A

7580

CHEMICAL LEACHING PRELIMINARY TEST DATA

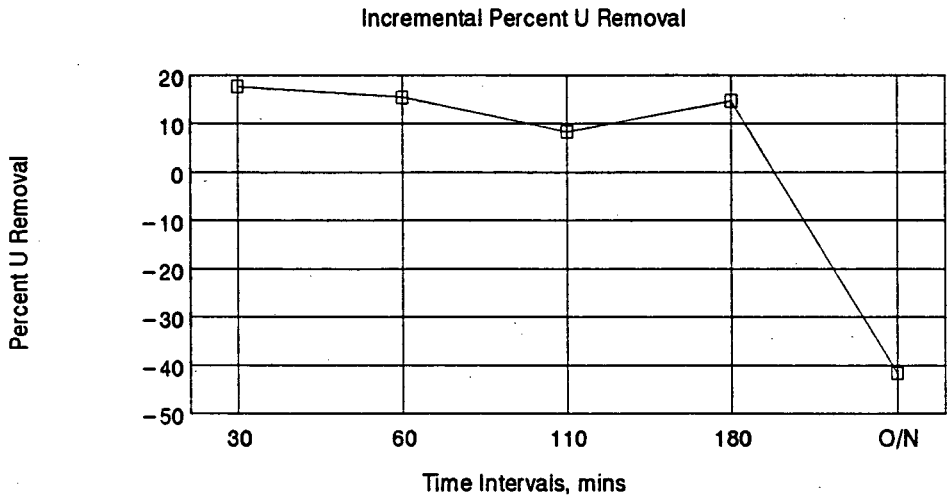
Chemical solution: 15g/l Sodium bicarbonate
Solution volume: 1 liter
Loading Ratio: 264g/l
Scabbled concrete size: < 150 Micron
Scabbled concrete mass: 264 g

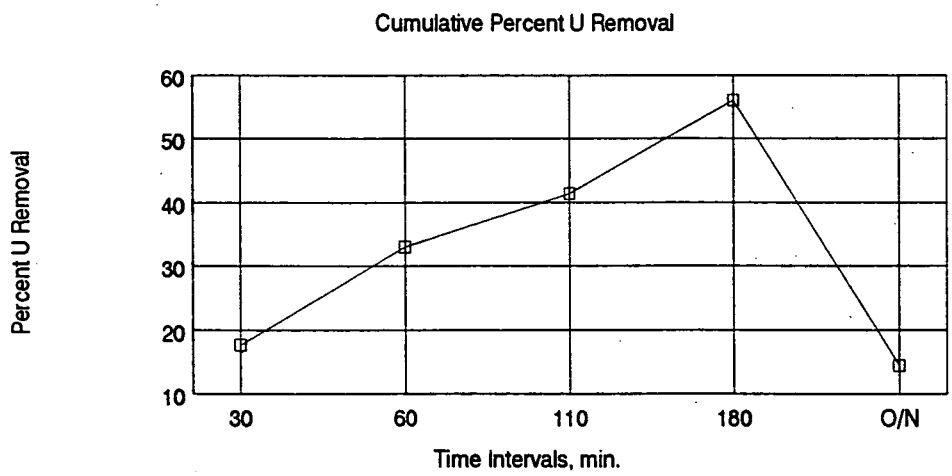
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
C1	30	<45 (1)	72	59.8	17.6	59.8	17.6	170	Sodium Bicarbonate
C2	60	<45 (1)	140	52.2	15.4	112.0	33.0	200	Sodium Bicarbonate
C3	90	<45 (1)	170	28.3	8.3	140.3	41.3	175	Sodium Bicarbonate
C4	120	<45 (1)	190	49.8	14.7	190.0	56.0	0	Sodium Bicarbonate
C5	Overnight (O/N)	<45 (1)	49	−141.0	−41.5	49.0	14.4	0	

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
Cs	Overnight	87.8	1100	290.4

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 339.4





CHEMICAL LEACHING PRELIMINARY TEST DATA

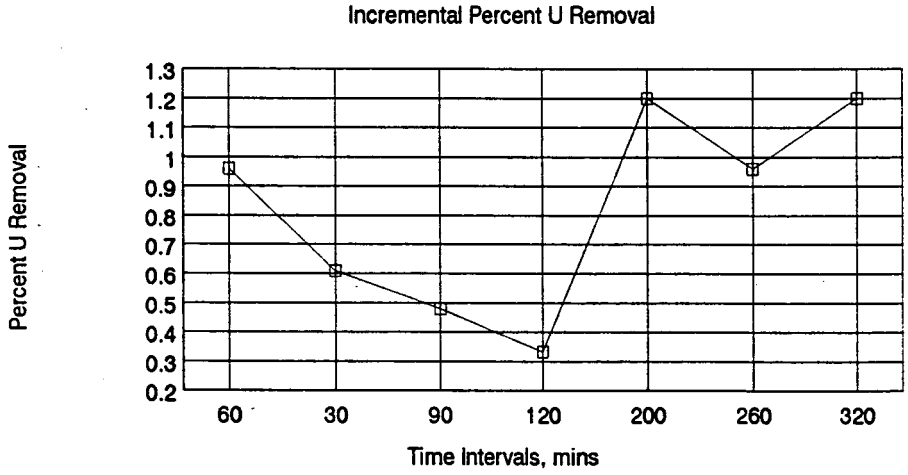
Chemical Solution: 42g/l Sodium Bicarbonate
Solution Volume: 1 liter
Loading Ratio: 264.4g/l
Scabbled concrete size: < 250 Micron
Scabbled concrete mass: 264.4g

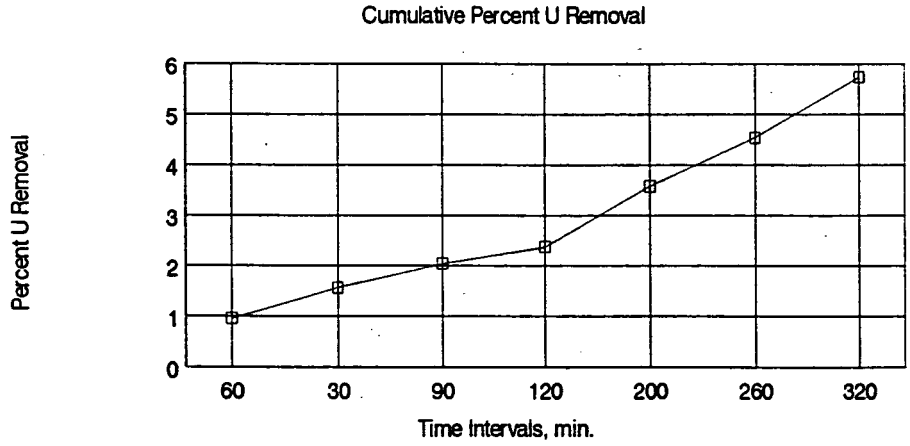
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
5BC-1	30	<45[1]	5.2	4.6	1.0	4.6	1.0	120	Sodium Bicarbonate
5BC-2	60	<45[1]	8.5	2.9	0.6	7.5	1.6	120	Sodium Bicarbonate
5BC-3	90	<45[1]	11.1	2.3	0.5	9.8	2.0	120	Sodium Bicarbonate
5BC-4	120	<45[1]	12.9	1.6	0.3	11.4	2.4	120	Sodium Bicarbonate
5BC-5	200	<45[1]	19.4	5.7	1.2	17.1	3.6	120	Sodium Bicarbonate
5BC-6	260	<45[1]	24.6	4.6	1.0	21.6	4.5	120	Sodium Bicarbonate
5BC-7	320	<45[1]	31.1	5.7	1.2	27.4	5.7	120	Sodium Bicarbonate

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
5BC-S	320	94	1700	449.5

Footnote:
[1] IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 476.8





CHEMICAL LEACHING PRELIMINARY TEST DATA

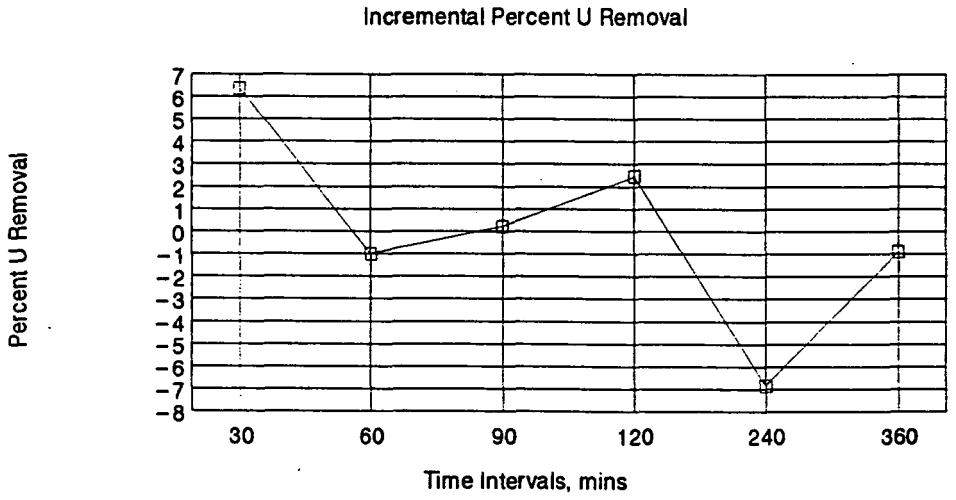
Chemical solution: 0.5N Nitric Acid
Solution volume: 0.5 liter
Loading Ratio: 500g/l
Scabbled concrete size: < 450 Micron
Scabbled concrete mass: 250 g

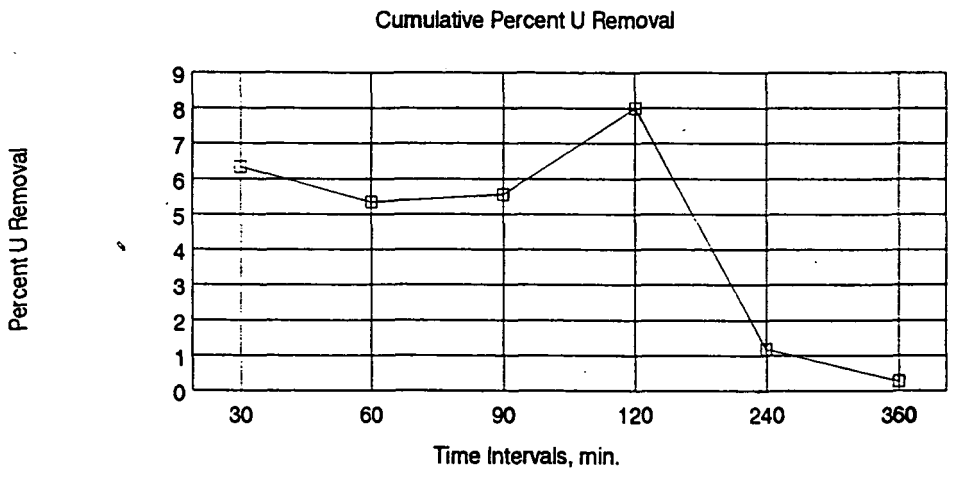
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
5NA-1	30	<45 (1)	30.3	11.5	6.3	11.5	6.3	120	Nitric Acid
5NA-2	60	<45 (1)	25.5	-1.8	-1.0	9.7	5.3	120	Nitric Acid
5NA-3	90	<45 (1)	26.5	0.4	0.2	10.1	5.6	120	Nitric Acid
5NA-4	120	<45 (1)	38.2	4.4	2.5	14.5	8.0	120	Nitric Acid
5NA-5	240	<45 (1)	5.6	-12.4	-6.8	2.1	1.2	120	Nitric Acid
5NA-6	360	<45 (1)	<1 (2)	-1.6	-0.9	0.5	0.3	0	Nitric Acid

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
Cs	Overnight	48	1020	180.9

Footnote:
(1) IDL for Th
(2) IDL for U
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 181.4





CHEMICAL LEACHING PRELIMINARY TEST DATA

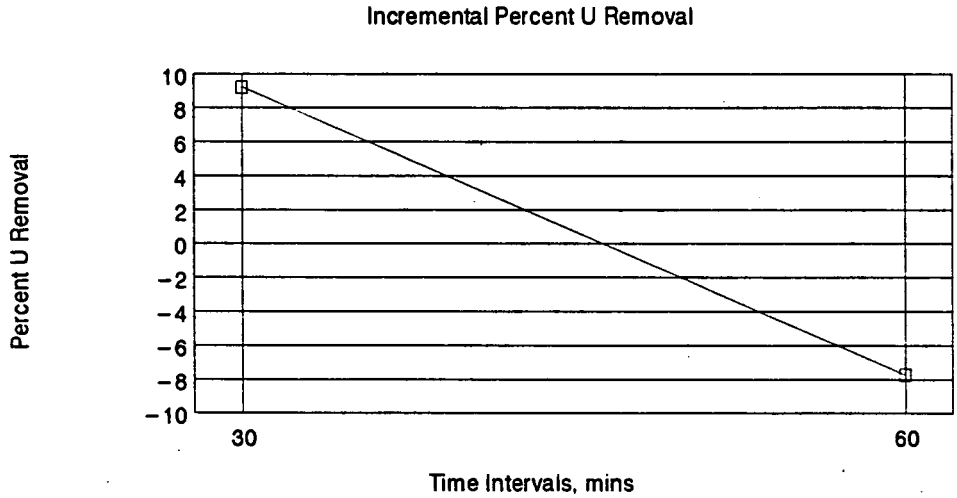
Chemical Solution: 3.925N Nitric Acid
Solution Volume: 0.1 liter
Loading Ratio: 1000g/l
Scabbled concrete size: < 425 Micron
Scabbled concrete mass: 100 g

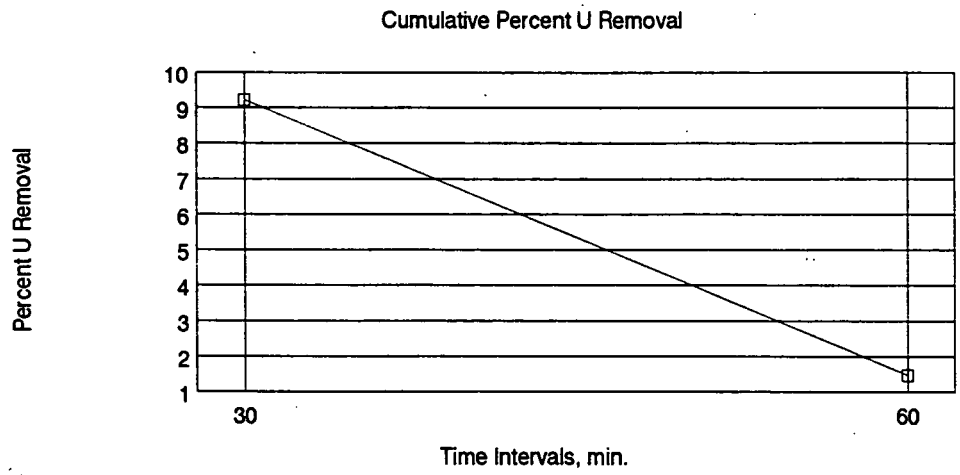
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
2-N-4	30	<45 (1)	120	10.0	9.2	10.0	9.2	17	Nitric Acid
2-N-5	60	<45 (1)	20	-8.4	-7.7	1.6	1.5	20	Nitric Acid

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
2-NS-1	Original	<45 (1)	1080	108.0
2-NS-2	30	<45 (1)	960	96.0
2-NS-3	60	53	830	83.0

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 108.0





CHEMICAL LEACHING PRELIMINARY TEST DATA

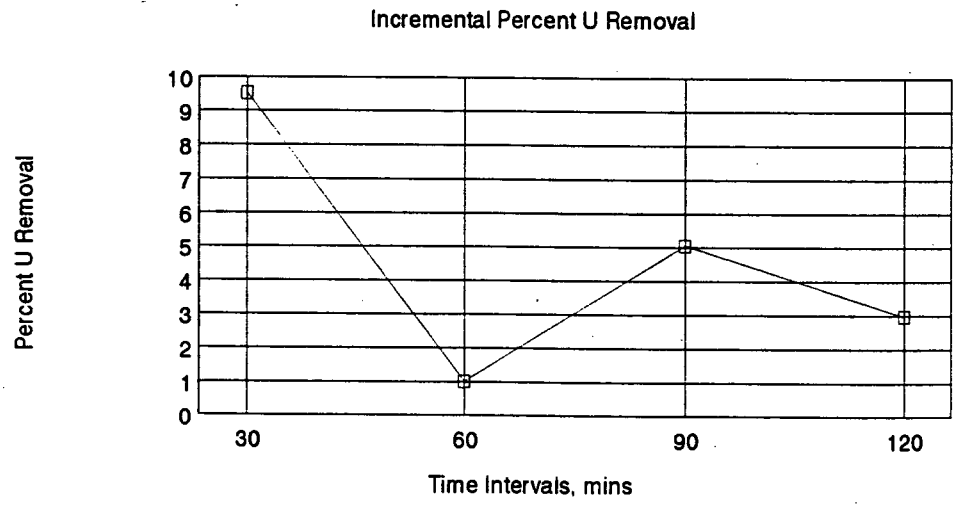
Chemical solution: 15g Sodium Bicarbonate/45g Sodium Carbonate
Solution volume: 1 liter
Loading Ratio: 281g/l
Scabbled concrete size: < 250 Micron
Scabbled concrete mass: 281 g

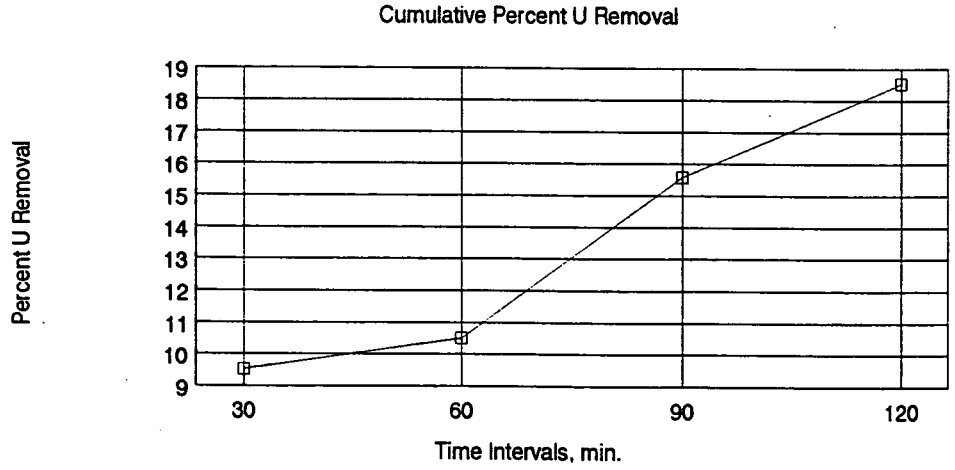
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
BC/C-1	30	<45 (1)	68	56.4	9.5	56.4	9.5	170	Bicarb./Carb.
BC/C-2	60	<45 (1)	78	6.0	1.0	62.4	10.5	200	Bicarb./Carb.
BC/C-3	90	<45 (1)	112	30.0	5.1	92.4	15.6	175	Bicarb./Carb.
BC/C-4	120	<45 (1)	110	17.6	3.0	110.0	18.5	0	Bicarb./Carb.

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
BC/C-S	120	88	1719	483.0

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 593.0





CHEMICAL LEACHING PRELIMINARY TEST DATA

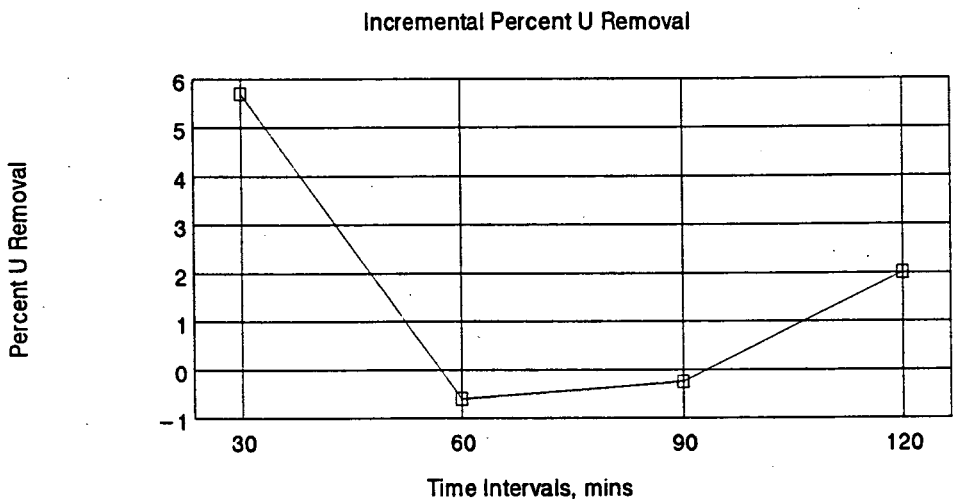
Chemical Solution: 0.5N Acetic Acid
Solution Volume: 0.4 liter
Loading Ratio: 500g/l
Scabbled concrete size: < 425 Micron
Scabbled concrete mass: 200 g

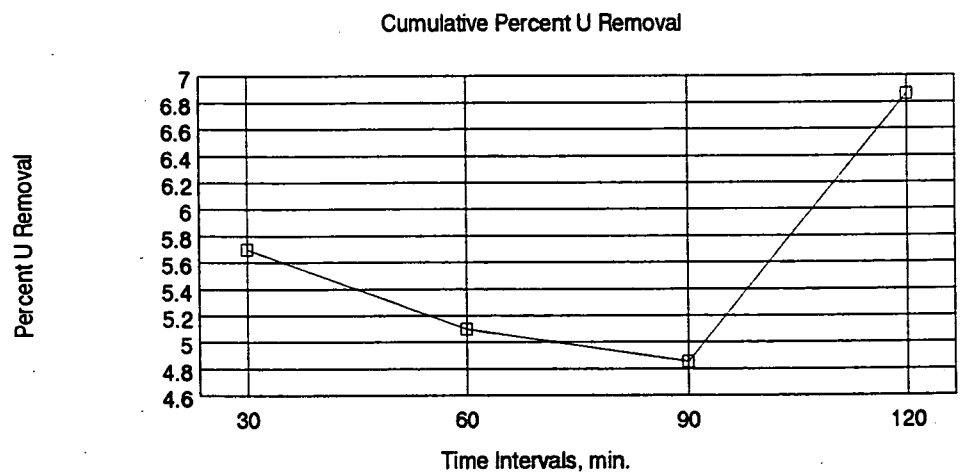
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
A-1	30	<45 (1)	28	9.3	5.7	9.3	5.7	68	Acetic Acid
A-2	60	<45 (1)	26	-1.0	-0.6	8.3	5.1	80	Acetic Acid
A-3	90	<45 (1)	24	-0.4	-0.2	7.9	4.9	70	Acetic Acid
A-4	120	<45 (1)	28	3.3	2.0	11.2	6.9	0	Acetic Acid

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
A-S	120	24.5	760	152.0

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 163.2





CHEMICAL LEACHING PRELIMINARY TEST DATA

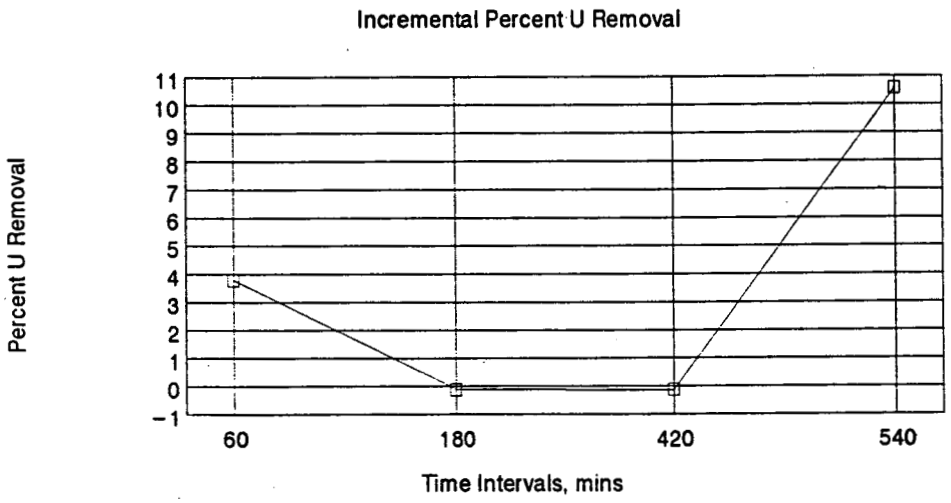
Chemical solution: 15g Sodium Bicarbonate/45g Sodium Carbonate
Solution volume: 1 liter
Loading Ratio: 281.36g/l
Scabbled concrete size: < 90 Micron
Scabbled concrete mass: 281.36 g

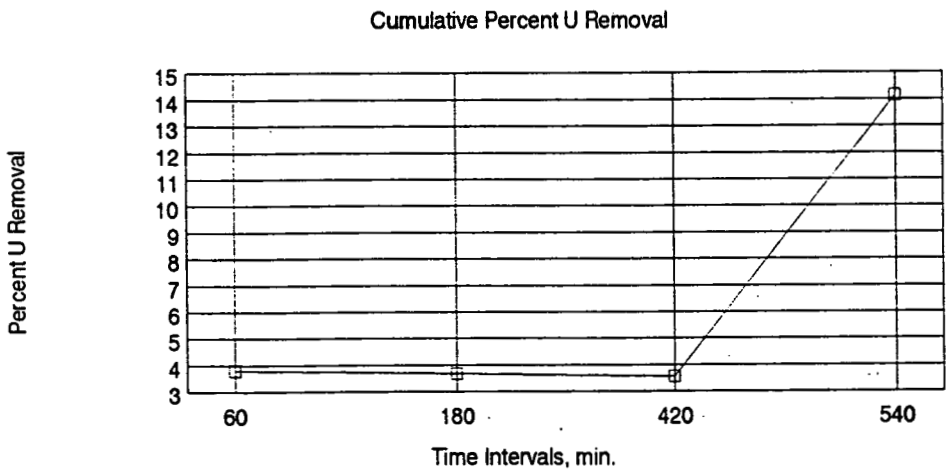
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
P1	60	<45 (1)	35	23.6	3.8	23.6	3.8	325	Bicarb./Carb.
P2	180	<45 (1)	31	−0.7	−0.1	22.9	3.7	260	Bicarb./Carb.
P3	420	<45 (1)	30	−0.7	−0.1	22.2	3.6	260	Bicarb./Carb.
P4	540	<45 (1)	110	65.8	10.6	88.0	14.1	200	Bicarb./Carb.

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
PS	540	<18 (1)	1900	534.6

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 622.6





CHEMICAL LEACHING PRELIMINARY TEST DATA

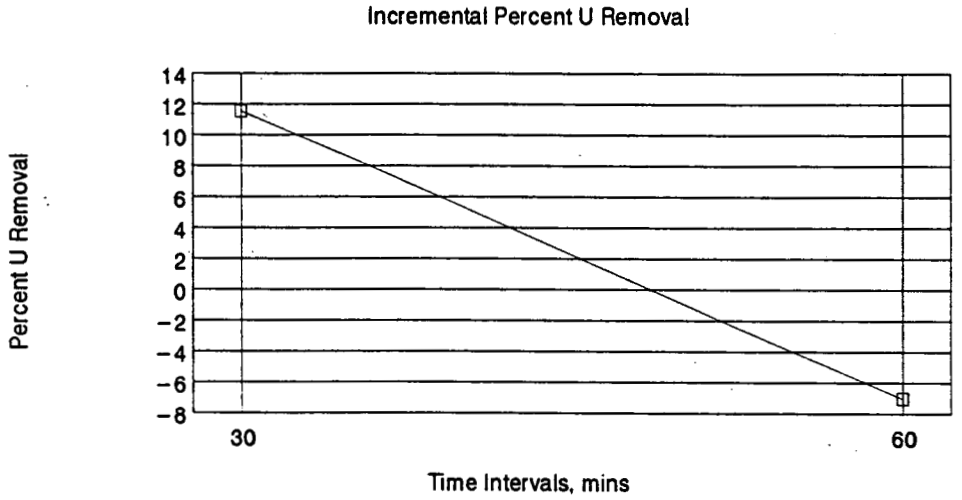
Chemical Solution: 8.75N Nitric Acid
Solution Volume: 0.1 liter
Loading Ratio: 1000g/l
Scabbled concrete size: < 425 Micron
Scabbled concrete mass: 100 g

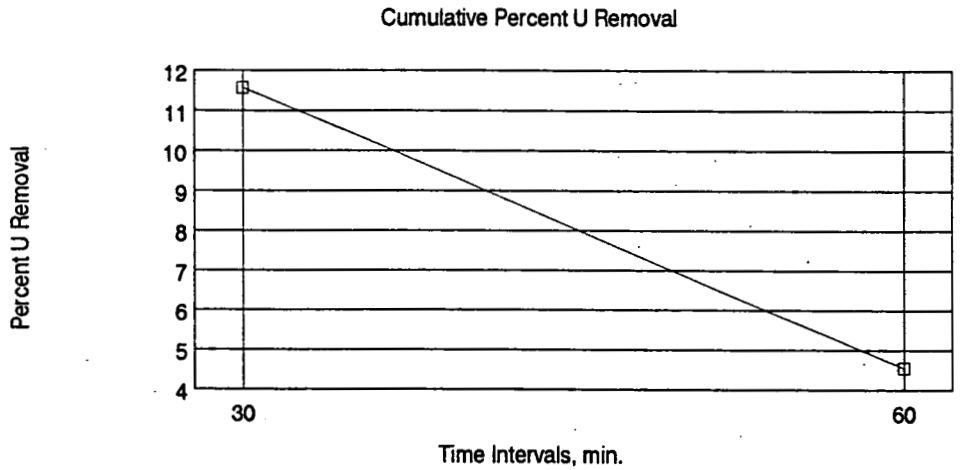
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
1-N-4	30	<45 (1)	152	12.6	11.6	12.6	11.6	17	Nitric Acid
1-N-5	60	<45 (1)	62	-7.7	-7.0	5.0	4.6	20	Nitric Acid

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
1-NS-1	Original	<45 (1)	1090	109.0
1-NS-2	30	54	860	86.0
1-NS-3	60	<45 (1)	730	73.0

Footnote:
(1) IDL for Th
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 109.0





CHEMICAL LEACHING PRELIMINARY TEST DATA

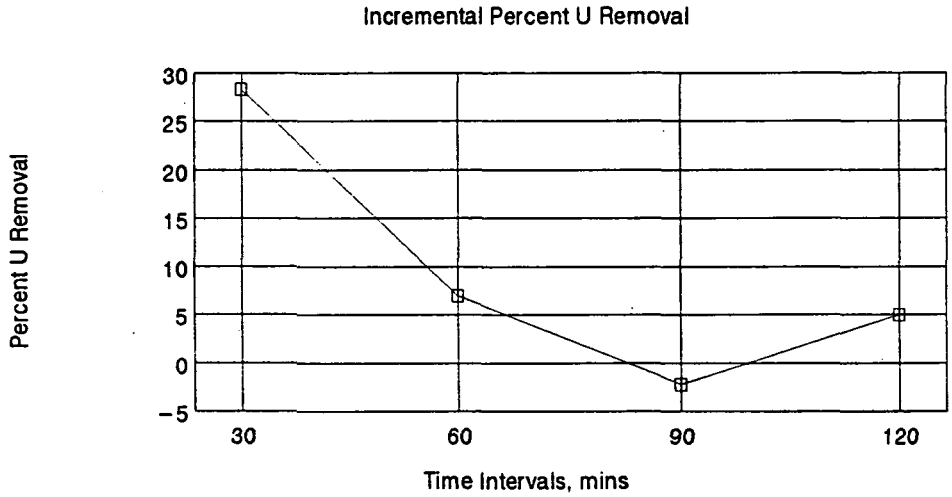
Chemical Solution: 0.5N Sulfuric Acid
Solution Volume: 0.4 liter
Loading Ratio: 500g/l
Scabbled concrete size: < 250 Micron
Scabbled concrete mass: 200 g

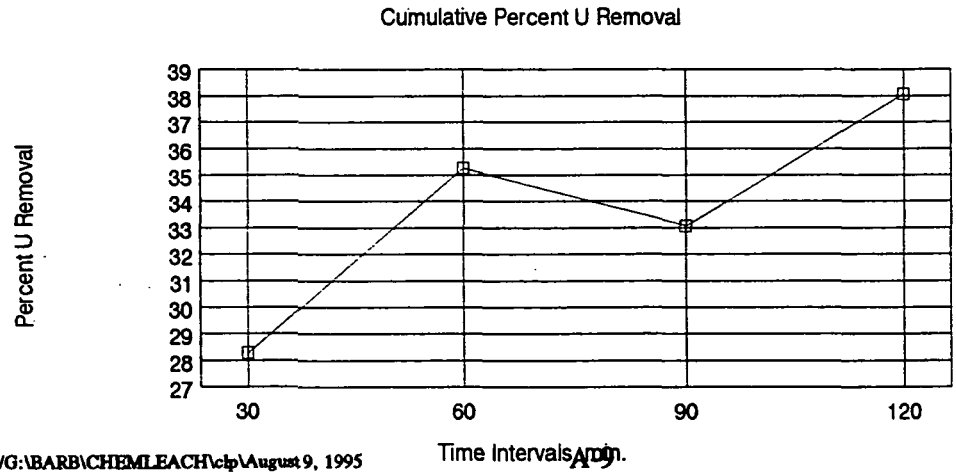
Leachate Sample	Time Interval (min.)	Total Th (ppm)	Cumulative Total U in Soln. (ppm)	Incremental U Leached (mg)	Incremental % U Leached	Cumulative U Leached (mg)	Cumulative % U Leached	Make-up Soln added (ml)	Soln Type
SF-1	30	<45 (1)	170	56.4	28.3	56.4	28.3	68	Sulfuric Acid
SF-2	60	<45 (1)	220	14.0	7.0	70.4	35.3	80	Sulfuric Acid
SF-3	90	<45 (1)	200	-4.4	-2.2	66.0	33.1	70	Sulfuric Acid
SF-4	120	<45 (1)	190	10.0	5.0	76.0	38.1	0	Sulfuric Acid

Concrete Residue Sample	Time Interval (min.)	Total Th (ppm)	Total U (ppm)	Total U (mg)
SF-S	Original	56.2	998	199.6
SF-3R	90	<18 (1)	197	39.4
SF-4R	120	<18 (1)	<11 (2)	<2.2

Footnote:
(1) IDL for Th
(2) IDL for U
Where IDL = Instrument detection limit

Original U Content of Concrete Sample (mg): 199.6





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Section 2.0

KELLY DECONTAMINATION

OF

CONCRETE ENGINEERING STUDY

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EXECUTIVE SUMMARY

At the Fernald Environmental Management Project (FEMP), formerly known as the Feed Materials Production Center (FMPC), the Department of Energy (DOE) is conducting a Remedial Investigation and Feasibility Study (RI/FS) to achieve environmental restoration of the site. Response actions at the FEMP are being conducted in accordance with the requirements of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This report describes and evaluates the Kelly™ Decontamination System for use during the interim remedial action of Operable Unit 3 (OU3) at the FEMP. OU3 consists of the former Fernald Production Area, production-associated facilities, and equipment.

Concrete makes up the largest volume of contaminated material within OU3. This material category includes poured concrete floors and walls, which may be slightly or heavily reinforced. Concrete was used extensively for paved surfaces such as storage pads, building floors, free-standing poured walls for shielding, building foundations, roofs, columns, equipment pedestals, and shielding.

A Kelly™ Decontamination System was utilized to clean high contamination concrete areas. The Kelly™ Decontamination System incorporates a steam cleaner and a vacuum to remove the contaminants, plus a high efficiency particulate air (HEPA) filter unit to prevent the release of radioactive particles during decontaminating operations. This system was tested on a contaminated concrete surface to determine its effectiveness in decontaminating radionuclides and inorganics, which includes Resource Conservation and Recovery Act (RCRA) hazardous metals.

The conclusions reached regarding the Kelly™ Decontamination System as a treatment alternative are described below.

- The process does not appear to significantly reduce levels of inorganic (including RCRA hazardous metals) contamination. In fact, the process appears to increase the mobility of these contaminants in concrete.
- The process does not appear to significantly reduce levels of fixed and removable radiological contamination in concrete.
- A significant reduction in the volume of concrete requiring LLW disposal was not achieved.
- The equipment is identified by the vendor as being portable. However, actual field tests indicate that the equipment is bulky and hard to physically move.

- Since the equipment must be transported through clean areas to get to other contaminated areas requiring decontamination, the equipment must be decontaminated after each job. Decontamination is difficult due to the equipment configuration, accessories (hoses, brushes, etc.) and parts (electrical cords, wheels, etc.). This limits the mobility of the equipment.

- The equipment requires a 480 volt power source, which is not available in all areas where the equipment is intended for use.

1.0 INTRODUCTION

This report describes and evaluates the Kelly™ Decontamination System as a technology for remediation of U.S. Department of Energy's Operable Unit 3 at the Fernald Environmental Management Project. OU3 consists of the former Fernald Production Area, production-associated facilities, and equipment. The goal of this report is to evaluate the Kelly™ Decontamination System as a decontamination technology for the removal of inorganics (including RCRA hazardous metals) and radiological contamination on concrete.

1.1 SITE DESCRIPTION

At the FEMP, formerly known as the Feed Materials Production Center[1], the DOE is conducting a Remedial Investigation and Feasibility Study to achieve environmental restoration of the site. Response actions at the FEMP are being conducted in accordance with the requirements of CERCLA.

The FEMP is located on a 1,050-acre site in a rural agricultural area about 18 miles northwest of downtown Cincinnati, Ohio (Figure 1.1). The site is near the villages of Fernald, New Baltimore, New Haven, Ross, and Shandon, Ohio.

The FEMP is a government-owned, contractor-operated federal facility where an Environmental Restoration Management Contract (ERMC) approach is being implemented to manage the restoration activities, with Fernald Environmental Restoration Management Corporation (FERMCO), a wholly owned subsidiary of Fluor Daniel Incorporated, currently serving as the ERMC contractor. The FEMP produced high-purity uranium metal products for the DOE and its predecessor agency, the Atomic Energy Commission, during the period 1952-1989. Thorium was also processed, but on a smaller scale, and is still stored on-site. Production activities were stopped in 1989, and the production mission of the facility was formally ended in 1991. The FEMP was included on the National Priorities List (NPL) in 1989.

The current mission of the site is environmental restoration in accordance with the requirements of CERCLA of 1980, as amended by Superfund Amendments and Reauthorization Act (SARA). On July 18, 1986, a Federal Facility Compliance Agreement (FFCA) was signed by the U.S. EPA and the DOE

[1] Throughout this report, the acronym "FEMP" is used for this facility, even though it was known as the FMPC when in operation.

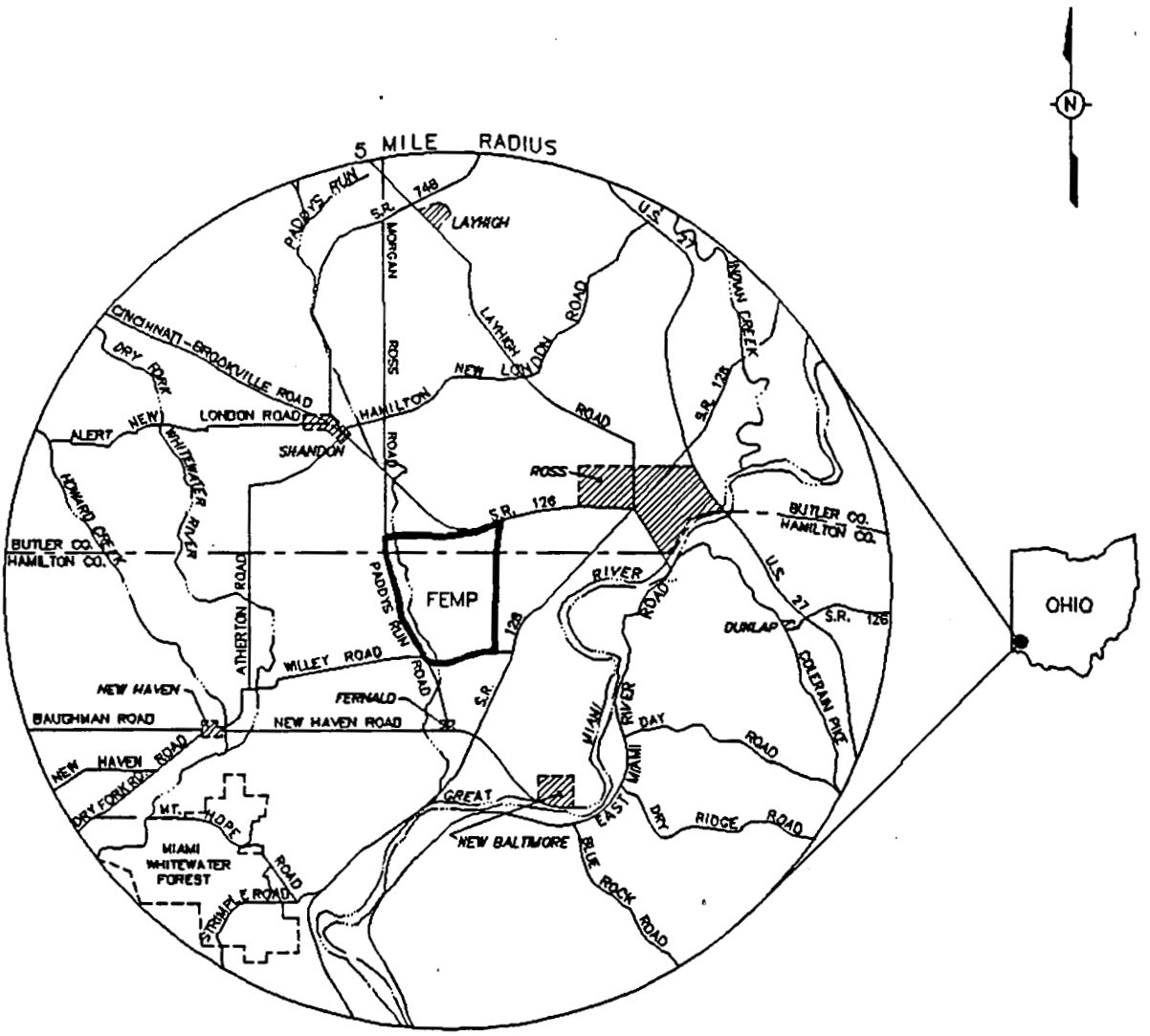

FIGURE 1-1 Location of the FEMP Facility

to ensure that environmental impacts associated with past and present activities at the FEMP are investigated and remedial actions are assessed and carried out.

1.1.1 Description of Operable Unit 3

The FEMP is divided into five separate *operable units*. OU3 consists of the former Fernald Production Area and production-associated facilities and equipment. OU3 includes all above- and below-grade improvements, including, but not limited to, all structures, equipment, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, K-65 transfer line, waste water treatment facilities, fire training facilities, scrap metal piles, feedstocks, and coal pile as defined by the *Consent Agreement as Amended under CERCLA Sections 120 and 106(a) in the Matter of: U.S. Department of Energy Feed Materials Production Center, Fernald, Ohio* (EPA 1991).

1.2 WASTE STREAM DESCRIPTION

1.2.1 Waste Matrices

To support the development of remedial alternatives and to estimate waste volumes, OU3 materials have been grouped into ten main categories on the basis of their primary construction materials and characteristics. Although most materials fit within the definition of a single category, several material types are identified as being multi-faceted (e.g., mica-coated electrical insulation, ceramic tile containing asbestos). The material categories were based on physical characteristics (e.g., plastic, asbestos-containing, etc.), anticipated location of contamination (e.g., surface or volumetrically contaminated), and potential for beneficial reuse/recycle (e.g., bulk steel, etc.).

Concrete makes up the largest volume of contaminated material within OU3. This material category includes poured concrete floors and walls which may be slightly or heavily reinforced. Concrete was used extensively for paved surfaces such as storage pads, building floors, free-standing poured walls, building foundations, roofs, columns, equipment pedestals, and shielding.

1.3 REMEDIAL TECHNOLOGY DESCRIPTION

The Kelly™ Decontamination System has been utilized in industry for many years. The advantage of this system is that it incorporates a steam cleaner and a vacuum to remove the contaminants, plus a high efficiency particulate air (HEPA) filter unit to prevent the release of radioactive particles during decontaminating operations.

The Kelly™ Decontamination System uses a spray-vacuum cleaning technique for general decontamination, combining a low-volume, pressurized spray of super heated water with a HEPA-filtered wet vacuum system. The five major components of the Kelly™ Decontamination System are the main unit, vacuum power unit, demister/HEPA filter, cyclone liquid separator, and spray-vacuum tools. Each component is described below.

Main Unit - This unit supplies the super heated water under pressure to the decontamination tools. The unit contains both input and output water filters, pressure and flow rate monitors, a temperature controller, and the necessary safety devices. Normal system output pressure is between 250 and 300 pounds per square inch (psi) with water temperatures up to 300°F.

Vacuum Power Unit - This unit provides the source of vacuum for the decontamination tools by using a positive displacement liquid ring vacuum pump driven by a 10 horse power (HP) motor. The pump is rated at 187 cubic feet per minute (cfm) at negative pressures up to 10 inches of mercury. This pump uses water as the cooling and sealing medium and is designed for the high input humidity conditions of the airstream.

Demister/HEPA Filter Unit - This unit contains a high efficiency demister and high capacity HEPA filter in a patented Bag-in, Bag-out stainless steel housing. The unit is located upstream of the Vacuum Power Unit to prevent any release of radioactive particles during decontamination operations with the spray-vacuum tools.

Cyclone Liquid Separator - A lightweight, portable cart with a stainless steel cyclone-type separator removes from the waste water any large particles or trash vacuumed up during system operation. A peristaltic pump constantly drains the waste water from the separator vessel to allow continuous operation and to limit the build-up of radiation levels.

Spray Vacuum (Decon) Tools - Built entirely of stainless steel, these tools contain the properly sized spray nozzles inside a vacuum shroud supported by roller bearing wheels.

Spray Vacuum/Brush Tool - A pneumatically actuated nylon brush is inclosed inside of a vacuum shroud. The shroud is made of stainless steel and utilizes the steam, vacuum, and the brush to remove contaminants from surfaces.

According to the operating manual, the Kelly™ Decontamination System is most effective when operated at pressures between 225 and 285 pounds per square inch (psi) with water temperatures between 250°F and 275°F. The flow rate can vary from 0.4 to 3.0 gallons per minute (gpm), depending on the type of tool.

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2.0 CONCLUSIONS AND RECOMMENDATIONS

The Kelly™ Decontamination System was evaluated for its applicability and appropriateness to OU3 materials and contaminants. The Kelly™ Decontamination System has been evaluated against three standard EPA guidance criteria: effectiveness; implementability; and cost.

2.1 CONCLUSIONS

This engineering study evaluated the use of the Kelly™ Decontamination System to treat OU3 contaminated concrete. Results from this study are reported in Section 4.0 of this report. The conclusions reached regarding the Kelly™ Decontamination System as a treatment technology are as follows:

- The process does not appear to significantly reduce levels of inorganic (including RCRA hazardous metals) contamination in concrete. In fact, the process appears to increase the mobility of these contaminants.
- The process does not appear to significantly reduce levels of fixed and removable radiological contamination in concrete.
- A significant reduction in the volume of concrete requiring LLW disposal was not achieved.
- The equipment is identified by the vendor as being portable. However, actual field tests indicate that the equipment is bulky and hard to physically move.
- Since the equipment must be transported through clean areas to get to other contaminated areas requiring decontamination, the equipment must be decontaminated after each job. Decontamination is difficult due to the equipment configuration, accessories (hoses, brushes, etc.) and parts (electrical cords, wheels, etc.). This limits the mobility of the equipment.
- The equipment requires a 480 volt power source, which is not available in all areas where the equipment is intended for use.

2.2 RECOMMENDATIONS

Based on the test results, the Kelly™ Decontamination System is not considered a viable concrete decontamination technology warranting further engineering testing for OU3 materials. Therefore, no additional test work or purchase of this equipment is recommended.

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3.0 ENGINEERING STUDY APPROACH

This Engineering Study was performed in accordance with the OU3 Treatability Study Work Plan (TSWP), approved by U.S. EPA, March 1994. The OU3 TSWP was prepared in accordance with the EPA's Guide for Conducting Treatability Studies Under CERCLA Interim Final (EPA 1988) and Final (EPA 1992).

The purpose of treating contaminated materials is to achieve a reduction in risk to the environment and human health. Engineering studies support remedy selection by providing data about potentially promising treatment processes and alternatives. Engineering studies test the effectiveness, performance, and implementability of potential remedial process options on OU3 materials and contaminants of concern. Engineering studies are conducted to ensure that selected remedial process options comply with Applicable or Relevant, and Appropriate Requirements (ARARs).

The EPA Guide for Conducting Treatability Studies Under CERCLA (EPA 1992) outlines a three-tiered approach to conducting engineering studies for a Superfund site. The approach includes Remedy Screening, Remedy Selection, and Remedy Design. The remedy screening and remedy selection testing are generally pre-Record Of Decision (ROD) studies and the remedy design studies are generally post-ROD. These engineering studies provide the performance and cost data needed to select the most applicable technologies for remedial action. The proposed OU3 engineering study approach is consistent with EPA's phased system for conducting engineering studies.

In general, remedy screening tests provide a qualitative evaluation of the potential effectiveness of a process option. Because the primary objective of remedy screening testing is to determine the potential feasibility of a process option, rigorous analytical quality assurance/quality control (QA/QC) requirements are not generally required. Ordinarily, it is acceptable to specify that remedy screening data be generated at analytical support levels (ASL) A/B. Criteria for defining ASLs are contained in Section 3 of the OU3 TSWP.

Remedy screening testing was used to establish the general feasibility of using the Kelly™ Decontamination System to decontaminate concrete and to determine if remedy selection testing was warranted.

3.1 TEST OBJECTIVES AND RATIONALE

Technologies for cleaning concrete are being tested because large volumes of contaminated concrete exist at the FEMP which require disposal at a low level waste disposal facility. The purpose of this test is to evaluate the effectiveness of the Kelly™ Decontamination System as an in-situ decontamination method during the OU3 interim remedial action and to determine if the purchase of additional systems is warranted.

To be considered successful, the Kelly™ Decontamination System must effectively remove radiological and chemical contaminants (e.g., uranium, RCRA hazardous metals, etc.), must be mobile in order to be easily moved from one location to another, and must be cost effective. If the concrete can be decontaminated to meet the On-Property Disposal Facility Waste Acceptance Criteria (WAC), then disposal costs would be significantly reduced compared to off-site disposal. If the reduction in disposal costs is greater than the cost of the processing and equipment, then the technology would be considered cost effective. In addition, decontaminating the concrete would reduce health risks and lower personal protective equipment (PPE) requirements for workers.

The specific objectives of the testing included:

- determining the effectiveness of the Kelly™ Decontamination System in removing fixed and removable radiological contamination on concrete surfaces;
- determining the effectiveness of the Kelly™ Decontamination System in removing organics and inorganics, including RCRA hazardous metals contamination, in and on concrete to below regulatory limits;
- evaluating the portability of the equipment;
- determining the effectiveness of the Kelly™ Decontamination System in removing contamination from below the concrete surface to a depth of 1/2"; and
- determining the cost effectiveness of the Kelly™ Decontamination System compared to other disposition options.

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

The Machining Area in Plant 9 was chosen as the location to test the Kelly™ Decontamination System. Preliminary radiological surveys indicated levels of contamination greater than 1 million (M) disintegrations per minute (DPM)/100 cubic centimeters (cm^2) Beta-Gamma (fixed and removable) in the area where two lathes were used during production. These lathes were used for outer diameter turning

of uranium ingots. The lathes have been removed, leaving a considerable amount of radioactive contamination in the area. Lubricants used during the turning operation have embedded the uranium contamination in the concrete. Process knowledge and RI data also indicate the presence of RCRA hazardous metals in the area. The test was conducted on approximately a 10 feet X 20 feet section of concrete and consisted of the following phases.

Phase 1 - Field screening and intrusive concrete sampling prior to cleaning with the Kelly™ Decontamination System.

Phase 2 - Cleaning the concrete floor using the Kelly™ Decontamination System.

Phase 3 - Field screening and intrusive concrete sampling after cleaning the concrete with the Kelly™ Decontamination System.

Phase 1 was a semi-quantitative/quantitative investigation to determine the nature of chemical and radiological contamination in the "High Contamination Area" in Plant 9. The semi-quantitative data consisted of field screening to determine radiological activity levels, and identify the presence of RCRA Metals (Ag, As, Ba, Cd, Cr, Hg, Pb, and Se) and organics in the area.

Based on the field screening results, a Sampling Plan was developed to indicate the locations for intrusive sampling. Concrete chips taken by intrusive sampling provided quantitative data of radiological and inorganic, including RCRA, contamination. Intrusive sampling was performed to determine if the equipment was effective in removing contamination to a depth of one half inch.

Field surveys were taken in accordance with SP-P-35-23, *Radiological Surveys*, and EP-CRU3-006, *Operation of the XRF Analyzer*. The concrete chips were collected using procedure EP-CRU3-020, *Sampling Hard Solids*.

In Phase 2, the test area was sub-divided into two 10 feet x 10 feet sections. One sub-section was decontaminated using the spray-vacuum method and the other sub-section was decontaminated by using the spray-vacuum/brush method. Decontamination of the Plant 9 concrete was performed by the Hazwat workers in the Remediation Support Operations (RSO) group in accordance to Standard Operating Procedure (SOP) 20-C-015, *Operating the Kelly™ Decontamination System*.

The Kelly™ Decontamination System was operated within the parameters recommended by the manufacturer for optimum performance. In the spray-vacuum mode of operation, the equipment was operated at approximately 272 psi, 260°F, and 1.75 gpm. In the spray-vacuum/brush mode, the equipment was operated at approximately 255 psi, 275°F, and 1.3 gpm Both methods incorporated two passes on the concrete surface with the spray vacuum tools. No detergents were used for this test.

Phase 3 was a semi-quantitative/quantitative investigation to determine the efficiency of the Kelly™ Decontamination System in removing the radiological and chemical contaminants in the same two 10 feet x 10 feet areas that was surveyed in Phase I. The semi-quantitative data consisted of field screening to determine radiological activity levels, and identify the presence of RCRA Metals (Ag, As, Ba, Cd, Cr, Hg, Pb, and Se) and organics in the area.

Quantitative data were obtained by analyzing the concrete chip samples obtained by intrusive sampling after decontamination. The chip samples were taken next to the two sample points identified in Phase I.

The operation of the Kelly™ Decontamination System did not produce a secondary waste requiring characterization. All of the water and vapor extracted from the concrete was disposed of in the FEMP sump system, along with any contaminants extracted. Disposal of this waste stream in the FEMP sump system is allowable since the sump system is used to treat similar waste streams to meet regulatory requirements.

3.3 EQUIPMENT AND MATERIALS

Equipment and materials used is this study are discussed below.

3.3.1 Field Screening Equipment and Procedures

The following is an equipment list required to perform the operation of the XRF, which is covered under FEMP Procedure EP-CRU3-006, Operation of the Portable X-Ray Fluorescence (XRF) Analyzer:

- Spectrace 9000 Portable X-Ray Fluorescence Analyzer with probe, interface cable, and pure element check samples;
- Sample cups;
- Herculite sheeting;
- Sample cup O-ring;
- Flat-bladed screwdriver;
- Mylar film;
- XRF probe lab stand;
- Vinyl tape;

- Stainless steel scoop or trowel;
- Lint-free wipes;
- Non-Radiological Field Screening Logbook; and
- Indelible ink pen.

The following is an equipment list required to perform the operation of the PID, which is covered under FEMP Procedure EP-CRU3-030, Operation of the Photo-Ionization Detector (PID):

- Portable Photoionization Detector (PID);
- Sample Probe;
- Battery and battery charger;
- AC battery charger adaptor;
- Zero-zero air cylinder with regulator;
- Calibration kit;
- Span gas cylinder with regulator;
- Sample bag with fitting attachment;
- Lint free wipes;
- Methanol solution;
- Two 9/16" wrenches;
- Phillips-head screwdriver;
- Ambient air thermometer;
- Non-Radiological Field Screening Logbook; and
- Indelible ink pen.

The following is an Equipment List required to perform the radiological surveys under FEMP Procedure RC-RDA-010, Radiological Contamination Surveys:

- Beta/gamma G-M probe;
- Alpha scintillation probe;
- Tennelec Automatic Low Background Counting System; and
- Smear paper.

3.3.2 Intrusive Sampling Equipment and Procedures

The following is an Equipment List required to perform the sampling of concrete, which is covered under FEMP Procedure EP-CRU3-020, Sampling of Hard Solids:

- Disposable latex gloves;
- Herculite sheeting;
- Hammer, bushing tool and stainless steel chisel;
- Rotary hammer drill with core bit;
- Scoop or trowel made of Teflon, stainless steel or PVC;
- One Teflon, stainless steel or PVC collection container for each sample location;
- Metric scale;
- Sample labels;
- Custody tape;
- Synthetic ice and ice chest with internal thermometer;

- Large and small plastic bags;
- Dust containment system;
- Lint-free wipes;
- Large stainless steel spoon;
- Sample container;
- Leather gloves;
- Intrusive Sampling Field Logbook;
- Indelible ink pen;
- Glass or stainless steel measuring cup;
- Crushing container;
- HEPA vacuum; and
- Sample jar label.

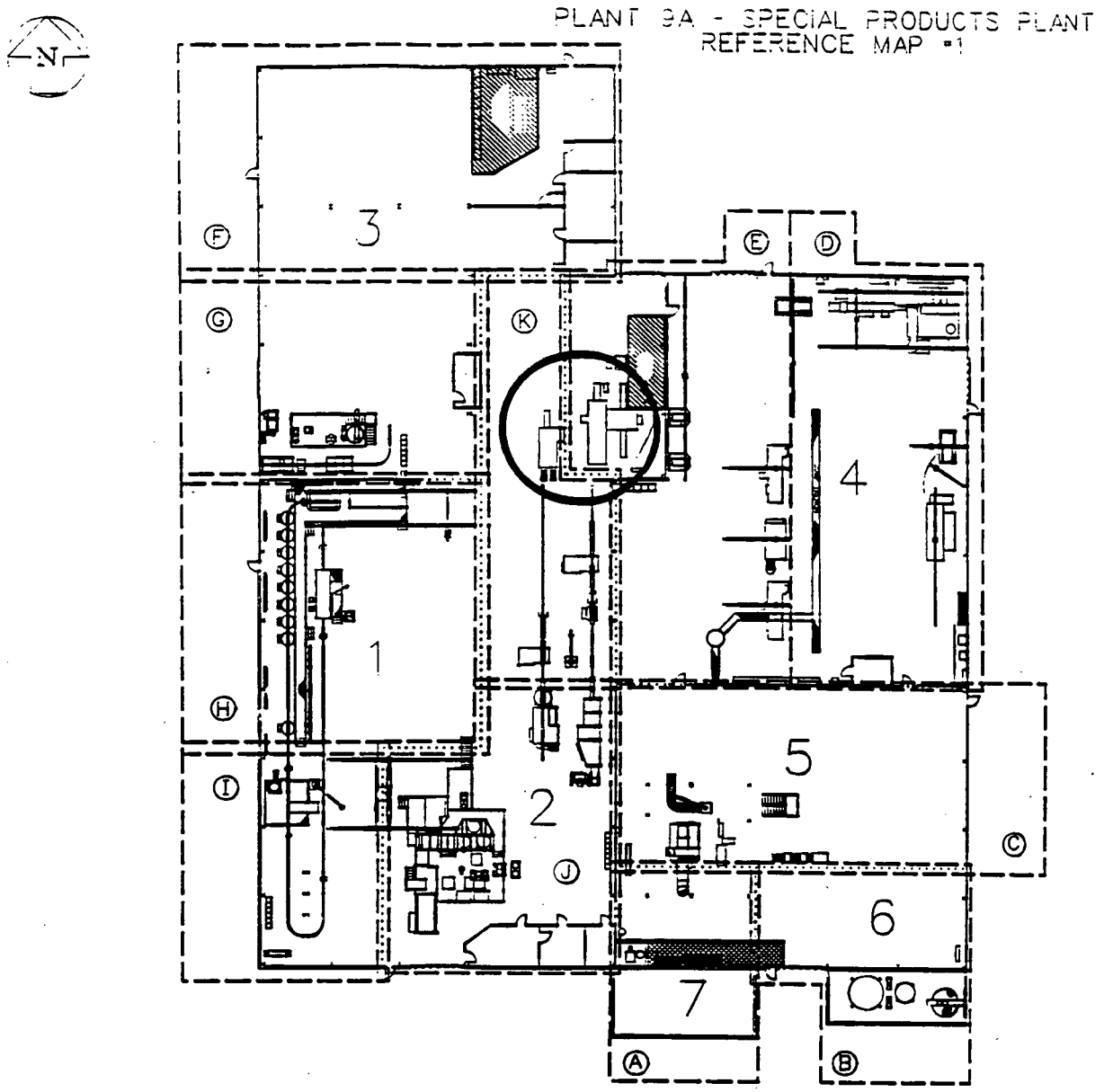
3.3.3 Kelly™ Decon System Equipment and Procedures

The following is an Equipment List required to perform the cleaning of concrete with the Kelly™ Decon System, which is covered under FEMP Procedure SOP 20-C-015, Operating the Kelly™ Decontamination System :

- Main unit;
- Liquid ring vacuum pump;
- Demister/HEPA filter unit;
- Cyclone liquid separator;
- Spray-vacuum (decon) tools;
- Spray gun;
- Spray wands;
- Steam hose;
- Vacuum hose, 3 inch;
- Vacuum hose, 2-1/2 inch;
- Fresh water supply hose;
- Waste water discharge hose;
- Main unit reservoir drain hose;
- Vacuum unit water supply hose;
- Metal storage containers on casters;
- Power supply cords, 480-Volt, 3 phase;
- Extension cord for waste water pump;
- Power supplies, 460-volt, 3 phase, 60 Amp;
- Grounded power supply, 115-volt;
- Decontamination agent, EPA approved;
- Process water supply; and
- White filter bags for Cyclone Liquid Separator.

3.4 SAMPLING AND ANALYSIS

Figure 3-1 shows the layout of Component 9A, Special Products Plant and the circled area shows where the field tests were performed.



PROCESS 1 - URANIUM PRODUCTION AND DERBY CLEANING
PROCESS 2 - ENRICHED URANIUM CASTING
PROCESS 3 - ZIRNLO DECLADDING
PROCESS 4 - URANIUM MACHINING
PROCESS 5 - HEAT TREATING (HISTORICAL PROCESS-
CURRENTLY DUST COLLECTOR)
PROCESS 6 - SCRAP METAL PICKLING (HISTORICAL PROCESS-
CURRENTLY DUST COLLECTOR)
PROCESS 7 - BRIQUETTING (HISTORICAL PROCESS-
CURRENTLY DUST COLLECTOR)

····· - PROCESS AREA BOUNDARIES
—— - FIGURE BOUNDARIES

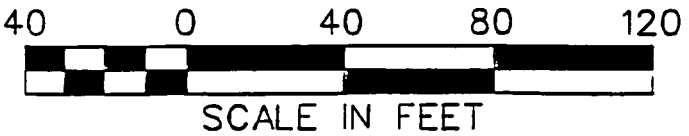


FIGURE 3-1 Plant 9A - Special Products Plant Reference Map #1

Field screening and intrusive sampling were performed in accordance with the OU3 RI/FS Work Plan Addendum (WPA) Sampling and Analysis Plan (SAP). All of the analytical testing performed followed approved methods outlined in the Sitewide CERCLA Quality Assurance Project Plan (SCQ).
To support the above approach, ASLs B and C were required. The field screening portion using the XRF and beta/gamma frisker, and the intrusive sampling for radiological constituents were ASL B. The intrusive sampling for TAL Inorganics was ASL C.

3.4.1 Field Screening

Field screening data collected were semi-quantitative in nature and was performed to determine the nature of chemical and radiological contamination.

Initial field screening of the two 10 feet x 10 feet sections of concrete in Plant 9 consisted of radiological swipe samples (Figure 3-2) collected from a grid pattern to determine radiological activity levels. Swipe samples were analyzed using a Tennelec. A portable X-Ray Fluorescence (XRF) Analyzer was used to identify the presence of any RCRA Metals (Ag, As, Ba, Cd, Cr, Hg, Pb, and Se). The XRF was used at six locations where visible contamination (such as oil, grease, etc.) occurred (Figure 3-3). All screening points were measured from a fixed object for the purpose of relocating those points after the area has been cleaned. A Photo-Ionization Detector (PID) was also used to indicate the presence of any organics in the area.

Results from the field screening were used to determine intrusive sampling point locations.

3.4.2 Intrusive Sampling

Quantitative data was collected from intrusive samples. Prior to cleaning the floor with the Kelly™ Decontamination System, two concrete chips samples were taken (RI/FS samples 9A-048 and 9A-049 - Figure 3-2). The two highest radiological and/or chemical contamination areas found during field screening were chosen for intrusive sampling. Chip samples were taken at a depth of 1/2 inch in the concrete floor using a rotary hammer drill with a core bit, chisel, or a bushing tool attachment. The material was broken into pieces no greater than 3/8 inch in diameter and were sent to a FEMP approved off-site lab and analyzed for radionuclides and target analyte list (TAL) inorganics for the purpose of this test.

Plant 9 Test Area
Radiological Smear Screening Locations

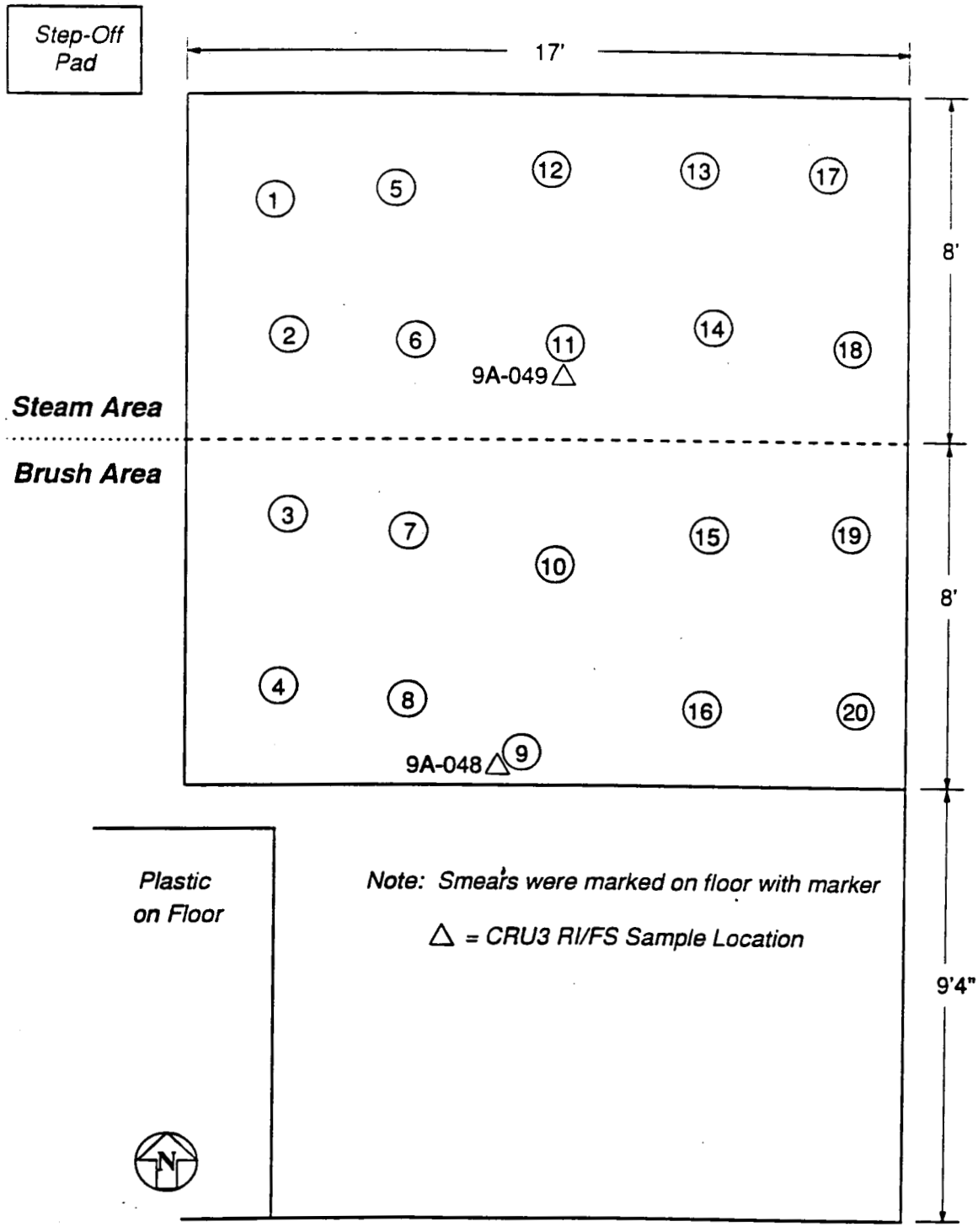


Figure 3-2 Plant 9 Test Area - Radiological Smear Screening Locations

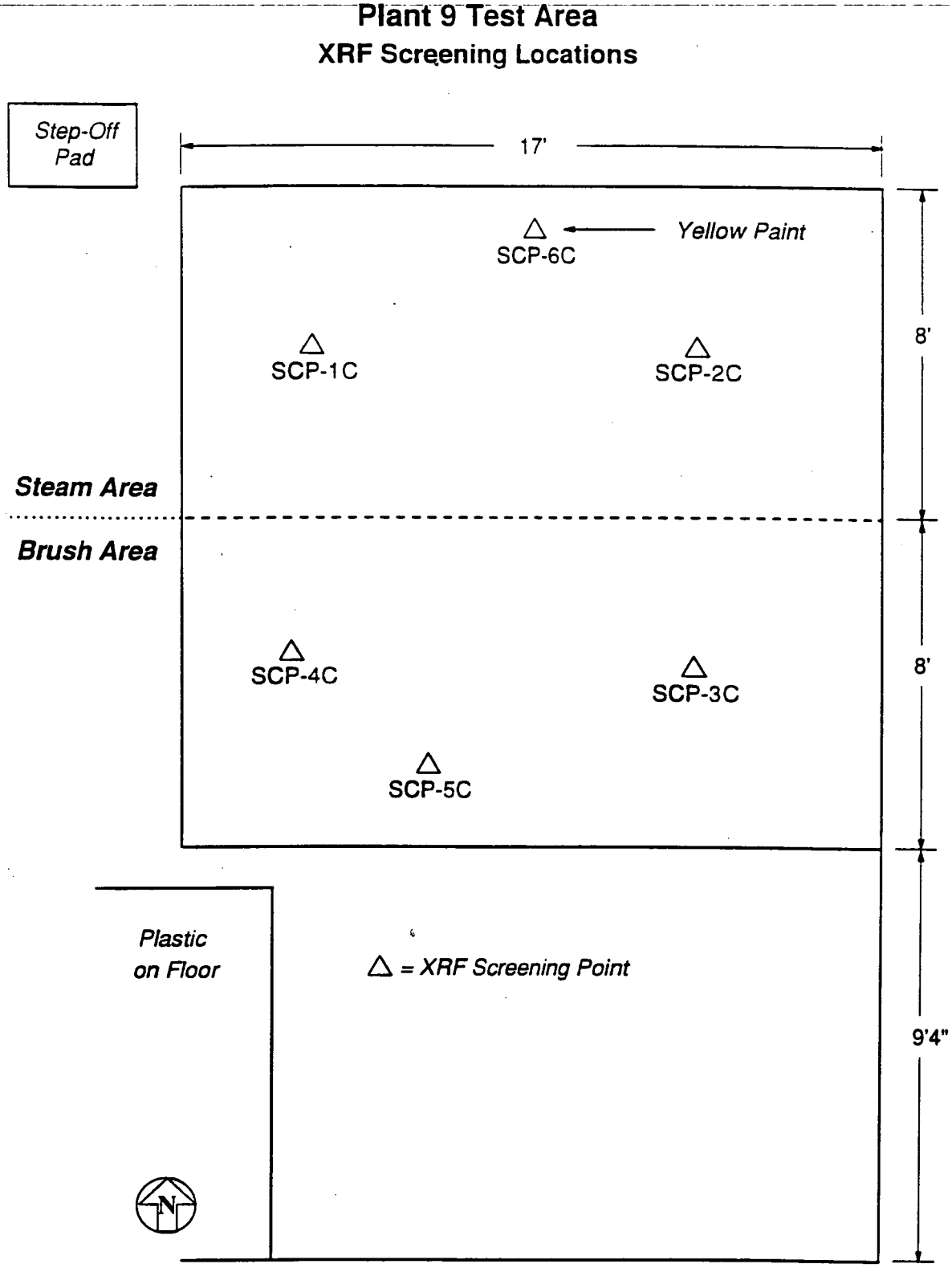


Figure 3-3 Plant 9 Test Area - XRF Screening Locations

After the test area was cleaned using the Kelly™ Decontamination System, field screening and intrusive samples (RI/FS samples 9A - 050 and 9A-051) samples were collected using the same methods and analyses identified during waste stream sampling (Section 3.4.1). Intrusive samples of the concrete were collected adjacent to the initial samples (RI/FS samples 9A - 048 and 9A-049).

3.5 DATA MANAGEMENT

All field screening and intrusive sampling were performed in accordance with the SCQ and the decontamination of concrete followed the guidelines stated in FERMCO SOP 20-C-015, Operating the Kelly™ Decontamination System.

Because this was considered to be a remedy screening test, the analytical results were not data validated. If the Kelly™ Decontamination System had proven to be a favorable method of decontaminating concrete, then additional testing with more rigorous QA/QC would have been recommended.

Radiological field screening information for this project was recorded in the CRU3 RI/FS Radiological Field Screening Logbook. Chemical field screening information for this project was recorded in the CRU3 RI/FS Chemical Field Screening Logbook. Daily activities and real-time analytical results were recorded in these documents and are stored in the CRU3 RI/FS files. Field activities for intrusive sampling were recorded in the CRU3 RI/FS Intrusive Sampling Logbook. The logbook is located in the CRU3 RI/FS files. The analytical results from the intrusive sampling are stored in the CRU3 RI/FS files. Field activities for the operation of the Kelly™ Decontamination System were recorded in the RSO Supervisor's logbook. This logbook is stored within the RSO organization.

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4.0 STUDY RESULTS AND DISCUSSION

4.1 ANALYSIS OF ENGINEERING STUDY DATA

4.1.1 Smear Samples

Table 1 shows the results of the smear samples taken in the test area before and after decontamination. Results are presented for both removable, and fixed and removable contamination. A t-test was performed on the data to investigate the differences between the means. Analysis of the test results shows a statistically significant decrease in removable radiological contamination at the 99% confidence level. However, analysis of the fixed and removable beta/gamma contamination data shows no statistically significant decrease in contamination resulting from the use of the Kelly™ Decontamination System.

At this time, no radiological criteria has been established for unrestricted reuse/recycle of decontaminated concrete. Although a decrease in levels of removable radiological contamination were observed, the final results are not anticipated to be low enough to allow unrestricted reuse/recycle of the concrete.

4.1.2 XRF Data

Table 2 shows the XRF results for the test. No cadmium, mercury, or selenium was detected at any of the sample locations. The presence of chromium in the SP6 sample can be attributed to sampling over an area of yellow paint. Two chromium results (high and low) are listed in Table 2 because a portable XRF was used. The portable XRF uses three sources (isotopes) in the probe. Normally, the contaminant being measured responds to only one of the three sources in the probe. In the case of chromium, the chromium responds to two sources and gives two readings (high and low). However, the chromium-low reading is the more accurate of the two results.

Results for the remaining RCRA metals are inconclusive. The data shows both increases and decreases in contamination levels for each metal. Although XRF analyses were performed in the same grid area and at approximately the same point before and after cleaning, it was difficult to pinpoint and reanalyze the first sampling point. Because of this, the XRF analyses are more qualitative than quantitative, indicating only the presence of RCRA metals.

4.1.3 PID Data

No organics were detected.

4.1.4 Radiological and Inorganic Data

Table 3 shows a comparison of radiological and Toxicity Characteristic Leaching Procedure (TCLP) leaching results. Samples 9A-048 and 9A-049 were concrete chips collected by intrusive sampling before cleaning with the Kelly Decontamination System. Samples 9A-050 and 9A-051 were concrete chips collected by intrusive sampling after cleaning with the Kelly equipment. Analytical results for the samples collected were averaged before and after the cleaning.

Average results from the radiological and TCLP leaching analyses were compared before and after cleaning. Although a statistical analysis could not be performed due to limited data, a general trend was observed. In virtually every instance, TCLP leaching results were higher after cleaning had been performed. Only the levels of magnesium showed a decrease (28%). Increases in the TCLP leaching results ranged from 40% to more than 2000%. The highest increases observed (more than 1000%) were for aluminum, antimony, beryllium, cadmium, mercury, and thallium. Increases between 100% and 1000% were observed for arsenic, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, vanadium, and zinc. Increases in levels for barium, calcium, and potassium were all below 100%. However, results for all RCRA hazardous metals were below regulatory limits.

The increase in metals leachability is assumed to be the result of physical changes in the concrete resulting from the cleaning. The Kelly Decontamination System has dissolved significant amounts of calcium in the concrete matrix which is easily leached during the TCLP analysis. Calcium binds, or fixes, metal and radiological contaminants within the concrete matrix. When the calcium (or binding agent) is dissolved, other contaminants are more easily leached.

Results for radiological contaminants were inconclusive. Seven of the eighteen analytes had one or more results near or below detection limits. For the other radiological contaminants, the contaminants were present in such small amounts or the results varied so much, that analysis of the results becomes unreliable. Analysis of the data to determine if these results were statistically significant could not be performed due to the limited number of samples collected. As a result, no definite conclusions could be drawn about the equipment effectiveness for removing radiological contamination. However, it appears that the Kelly equipment provides little, if any, overall reduction in fixed or removable radiological contamination levels.

The On-Property Disposal Facility WAC for Technicium-99 (Tc-99) in concrete is the most restrictive criteria for on-property burial. This WAC is mass based, not concentration based. Although the data shows a decrease in Tc-99, this data is not considered reliable due to the limited number of samples collected and the variation seen in other radiological data. Therefore, no reliable mass reduction estimates for Tc-99 could be performed.

From the analysis of the results, it does not appear that the Kelly Decontamination System reduces fixed or removable radiological contamination levels. In addition, use of this system to clean concrete causes a change in the concrete which allows stabilized metals fixed within the concrete matrix to be more easily leached.

4.1.5 Equipment Mobility

From discussions with operating personnel using the equipment and observations by engineering personnel, the equipment is bulky and hard to physically move. The equipment must also be decontaminated before moving it to other contaminated areas for use. This is because the equipment must pass through uncontaminated areas to reach its next destination. Decontamination is difficult due to the equipment configuration, accessories (hoses, brushes, etc.) and parts (electrical cords, wheels, etc.). This limits the mobility of the equipment. The equipment also requires a 480 volt power source to operate, which is not available in all areas where the equipment is intended for use.

4.1.6 Cost

Costs associated with the Kelly™ Decontamination System include capital costs for equipment, plus operating and maintenance (O&M) costs (labor, decon, supplies/chemicals). Since capital costs alone for the Kelly™ Decontamination System are approximately $250,000 and the process did not achieve the desired decontamination results during testing, the system itself is not considered cost effective for remediation of OU3 materials.

4.1.7 Comparison to Test Objectives

The objectives of this engineering study were to evaluate the Kelly™ Decontamination System as a potential remediation technology for OU3 concrete material based on its effectiveness to remove surface and volumetric contamination, cost, and mobility. Data generated during remedy screening field tests allowed the effectiveness and mobility of the equipment to be assessed. Although a reliable determination regarding the effectiveness of the equipment to remove Tc-99 could not be made, sufficient data exists

to evaluate the equipment as a remediation technology. Based on results of the field testing and cost analysis, the Kelly™ Decontamination System is not considered a viable remediation technology warranting further testing.

APPENDIX A

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TABLE 1

FIELD SCREENING
SMEAR SAMPLE RESULTS

	Removable Contamination (dpm/100 cm2)		Fixed & Removable Contamination (dpm/100 cm2)	
Sample #	Before Decon	After Decon	Before Decon	After Decon
1	25 K	3 K	60 K	60 K
2	25 K	4 K	60 K	70 K
3	50 K	15 K	40 K	60 K
4	30 K	12 K	200 K	250 K
5	50 K	20 K	500 K	450 K
6	30 K	100 K	600 K	400 K
7	25 K	20 K	200 K	500 K
8	30 K	16 K	500 K	400 K
9	60 K	16 K	1000 K	250 K
10	40 K	12 K	500 K	800 K
11	50 K	3 K	800 K	250 K
12	60 K	6 K	200 K	450 K
13	50 K	5 K	200 K	400 K
14	50 K	4 K	500 K	450 K
15	40 K	3 K	600 K	500 K
16	60 K	8 K	200 K	700 K
17	30 K	3 K	150 K	150 K
18	25 K	2 K	60 K	60 K
19	20 K	3 K	50 K	50 K
20	40 K	4 K	300 K	400 K
Average	39.5 K	12.95 K	336 K	332.5 K

TABLE 2

FIELD SCREENING
XRF RESULTS

Sample Number		Ag (ppm)	As (ppm)	Ba (ppm)	Cd (ppm)	Cr-Hi (ppm)	Cr-Lo (ppm)	Hg (ppm)	Pb (ppm)	Se (ppm)	U (ppm)
SP1	Before Decon	ND	ND	198	ND	ND	ND	ND	430	ND	6772
SP1	After Decon	ND	ND	308	ND	ND	ND	ND	5615	ND	6197
SP2	Before Decon	148	ND	169	ND	ND	ND	ND	173	ND	6825
SP2	After Decon	ND	ND	214	ND	ND	ND	ND	267	ND	4505
SP3	Before Decon	ND	ND	145	ND	ND	ND	ND	389	ND	19288
SP3	After Decon	ND	ND	66	ND	ND	ND	ND	ND	ND	33007
SP4	Before Decon	ND	ND	140	ND	ND	ND	ND	206	ND	9031
SP4	After Decon	ND	ND	245	ND	ND	ND	ND	112	ND	1858
SP5	Before Decon	125	ND	60	ND	ND	ND	ND	ND	ND	40696
SP5	After Decon	107	ND	113	ND	ND	ND	ND	ND	ND	38977
SP6	Before Decon	193	2300	181	ND	13000	11000	ND	19800	ND	4851
SP6	After Decon	143	ND	144	ND	ND	ND	ND	267	ND	3824

ND = Non-Detect

TABLE 3

ANALYTICAL RESULTS

	Before Decontamination		After Decontamination	
Sample Number	9A-048	9A-049	9A-050	9A-051
Sample Analysis	Total Rad * pCi/g	Total Rad * pCi/g	Total Rad * pCi/g	Total Rad * pCi/g
Plutonium-238	<.14	<.13	<.16	<.15
Plutonium-239/240	0.47	0.6	0.63	0.15
Thorium-228	0.81	1.9	1.8	0.76
Thorium-230	0.36	0.71	0.91	0.48
Thorium-232	0.17	0.17	0.19	0.17
Uranium-234	1700	1900	2300	290
Uranium-235/236	110	99	140	14
Uranium-238	1200	1400	1800	200
Americium-241	<.3	<.43	0.36	<.15
Neptunium-237	0.6	0.84	0.73	<.12
Polonium-210	<1.6	0.97	<3.8	<2.2
Total Uranium (mg/g)	5000	6500	8500	780
Cesium-137	<.15	<.037	0.29	0.025
Radium-226	0.33	0.32	0.32	0.33
Radium-228	0.37	0.28	0.29	0.25
Lead-210	2.8	4.9	<1.7	3.9
Strontium-90	<.27	0.54	0.47	<.26
Technetium-99	280	61	450	30

	Before Decontamination		After Decontamination			
Sample Number	9A-048	9A-049	9A-050	9A-051		
Sample Analysis	TCLP Leaching ug/l	TCLP ** Leaching ug/l	TCLP Leaching ug/l	TCLP ** Leaching ug/l	Difference	% Change
Aluminum	69.30		779.00		(709.70)	(1,024.10)
Antimony	40.80		500.00		(459.20)	(1,125.49)
Arsenic	4.40		33.00		(28.60)	(650.00)
Barium	344.00		530.00		(186.00)	(54.07)
Beryllium	0.50		10.00		(9.50)	(1,900.00)
Cadmium	2.20		40.00		(37.80)	(1,718.18)
Calcium	1,531,000.00		2,150,000.00		(619,000.00)	(40.43)
Chromium	7.70		30.00		(22.30)	(289.61)
Cobalt	7.80		60.00		(52.20)	(669.23)
Copper	13.40		97.90		(84.50)	(630.60)
Iron	28.10		256.00		(227.90)	(811.03)
Lead	4.70		20.00		(15.30)	(325.53)
Magnesium	88,000.00		63,500.00		24,500.00	27.84
Manganese	1,020.00		2,400.00		(1,380.00)	(135.29)
Mercury	0.07		2.00		(1.93)	(2,757.14)
Nickel	15.90		100.00		(84.10)	(528.93)
Potassium	20,100.00		35,900.00		(15,800.00)	(78.61)
Selenium	6.50		30.00		(23.50)	(361.54)
Silver	4.60		40.00		(35.40)	(769.57)
Sodium	26,800.00		NR			
Thallium	2.40		40.00		(37.60)	(1,566.67)
Vanadium	11.40		30.00		(18.60)	(163.16)
Zinc	84.10		299.00		(214.90)	(255.53)
Cyanide	NR		NR			

* Blank corrected
** TCLP leaching not performed.

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EET DECONTAMINATION

OF

TRANSITE ENGINEERING STUDY

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EXECUTIVE SUMMARY

At the Fernald Environmental Management Project (FEMP), formerly known as the Feed Materials Production Center (FMPC), the Department of Energy (DOE) is conducting a Remedial Investigation and Feasibility Study (RI/FS) to achieve environmental restoration of the site. Response actions at the FEMP are being conducted in accordance with the requirements of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This report describes and evaluates the Environmental Extraction Technologies, Inc. (EET) TECHXTRACT™ Decontamination System for use during the interim remedial action of U.S. DOE Operable Unit 3 (OU3) at the FEMP. OU3 consists of the former Fernald Production Area, production-associated facilities, and equipment.

Asbestos-containing materials (ACM) are wide-spread and have been heavily utilized at the FEMP over the years. The list of known ACM include transite wall and roof panels, some floor tiles, pipe insulation, and loose insulation. Due to the porosity of transite and insulation, contamination is assumed to have migrated throughout the depth of the material. Transite is a trade name for an asbestos-cement composite material composed of primarily portland cement and chrysotile (asbestos) fibers. Transite has been widely used on-site as the interior and exterior structural skin of buildings.

EET is the owner of a proprietary chemical technology for the extraction of contaminants from solid materials. EET's TECHXTRACT™ technology is designed to extract a variety of contaminants, including radionuclides, polychlorinated biphenols (PCBs), and heavy metals, from the surface and substrate of materials such as transite. The TECHXTRACT™ process involves the sequential application of up to three proprietary solutions. The solution is sprayed onto a surface and allowed to dwell for a period as determined by EET. The surface is then scrubbed between each chemical application, and finally rinsed with water and vacuumed. The solution chemistry is designed to achieve a high degree of permeation and penetration into the media being treated and to break chemical bonds holding the contaminants in the pores.

The conclusions reached regarding the EET TECHXTRACT™ Decontamination System as a treatment alternative for the decontamination of transite are described below.

- The technology is effective in reducing surface alpha and beta/gamma activity levels to below 1,000 disintegrations per minute (dpm)/100 square centimeters (cm^2) alpha and below 5000 dpm/100 cm^2 beta/gamma;

- Painted surfaces reduce the effectiveness of this technology. Removing painted surfaces prior to decontamination may generate a Resource, Conservation and Recovery Act (RCRA) waste requiring treatment and disposal.

- The technology is not cost effective based on comparisons to burial in the on-property disposal facility.

- The process is slow and labor intensive. Several applications of the chemical solutions are required to decontaminate transite surfaces. Scrubbing of the surface is also required between solution applications.

- The process generates little waste. For the 7 to 8 liters of solution used during the tests, only 1-1 1/2 liters were recovered as waste.

- No conclusions can be made regarding the effectiveness of the technology on volumetrically contaminated transite.

Based on the test results, further engineering testing for the EET TECHXTRACT™ Decontamination System is not warranted for transite. Therefore, no additional test work is recommended.

1.0 INTRODUCTION

This report describes and evaluates the EET TECHXTRACT™ Decontamination System as a technology for remediation of U.S. Department of Energy's Operable Unit 3 at the Fernald Environmental Management Project. OU3 consists of the former Fernald Production Area, production-associated facilities, and equipment. The goal of this report is to evaluate the EET TECHXTRACT™ Decontamination System as a chemical decontamination technology for the removal of RCRA hazardous metals and radiological contamination on transite.

1.1 SITE DESCRIPTION

At the FEMP, formerly known as the FMPC[1], the DOE is conducting a Remedial Investigation and Feasibility Study to achieve environmental restoration of the site. Response actions at the FEMP are being conducted in accordance with the requirements of CERCLA.

The FEMP is located on a 1,050-acre site in a rural agricultural area about 18 miles northwest of downtown Cincinnati, Ohio (Figure 1.1). The site is near the villages of Fernald, New Baltimore, New Haven, Ross, and Shandon, Ohio.

The FEMP is a government-owned, contractor-operated federal facility where an Environmental Restoration Management Contract (ERMC) approach is being implemented to manage the restoration activities, with Fernald Environmental Restoration Management Corporation (FERMCO), a wholly owned subsidiary of Fluor Daniel Incorporated, currently serving as the ERMC contractor. The FEMP produced high-purity uranium metal products for the DOE and its predecessor agency, the Atomic Energy Commission, during the period 1952-1989. Thorium was also processed, but on a smaller scale, and is still stored on-site. Production activities were stopped in 1989, and the production mission of the facility was formally ended in 1991. The FEMP was included on the National Priorities List (NPL) in 1989.

The current mission of the site is environmental restoration in accordance with the requirements of CERCLA of 1980, as amended by Superfund Amendments and Reauthorization Act (SARA). On July 18, 1986, a Federal Facility Compliance Agreement

[1] Throughout this report, the acronym "FEMP" is used for this facility, even though it was known as the FMPC when in operation.

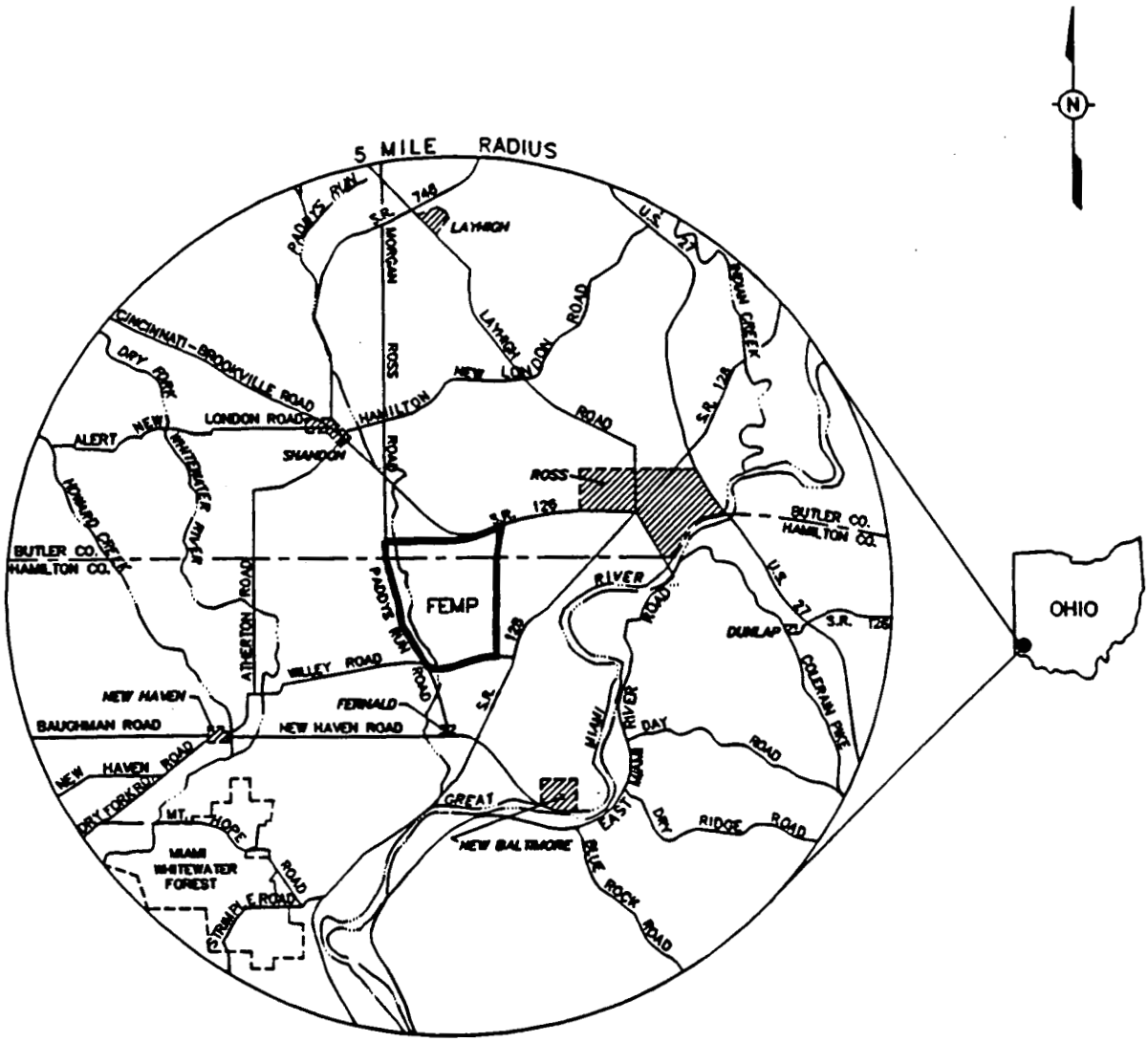

FIGURE 1.1 Location of the FEMP Facility

(FFCA) was signed by the U.S. Environmental Protection Agency (EPA) and the DOE to ensure that environmental impacts associated with past and present activities at the FEMP are investigated and remedial actions are assessed and carried out.

1.1.1 Description of Operable Unit 3

The FEMP is divided into five separate *operable units*. OU3 consists of the former Fernald Production Area and production-associated facilities and equipment. OU3 includes all above- and below-grade improvements, including, but not limited to, all structures, equipment, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, K-65 transfer line, waste water treatment facilities, fire training facilities, scrap metal piles, feedstocks, and coal pile as defined by the *Consent Agreement as Amended under CERCLA Sections 120 and 106(a) in the Matter of: U.S. Department of Energy Feed Materials Production Center, Fernald, Ohio* (EPA 1991).

1.2 WASTE STREAM DESCRIPTION

1.2.1 Waste Matrices

To support the development of remedial alternatives and to estimate waste volumes, OU3 materials have been grouped into ten main categories on the basis of their primary construction materials and characteristics. Although most materials fit within the definition of a single category, several material types are identified as being multi-faceted (e.g., mica-coated electrical insulation, ceramic tile containing asbestos). The material categories were based on physical characteristics (e.g., plastic, asbestos-containing, etc.), anticipated location of contamination (e.g., surface or volumetrically contaminated), and potential for beneficial reuse/recycle (e.g., bulk steel, etc.).

Asbestos-containing materials are wide-spread and have been heavily utilized at the FEMP over the years. The list of known ACM include transite wall and roof panels, some floor tiles, pipe insulation, and loose insulation. Due to the porosity of transite and insulation, contamination is assumed to have migrated throughout the depth of the material.

Transite is a trade name for an asbestos-cement composite material composed of primarily portland cement and chrysotile (asbestos) fibers. Transite has been widely used on-site as the interior and exterior structural skin of buildings. The exterior panels are usually corrugated

sheets, while interior skins are usually flat sheets. Corrugations help to withstand heavy service conditions and forms a weather seal when lapped over other structural or insulation panels. Transite is formed by hydraulically pressing together uncured, thin asbestos-cement sheets to form a hard, durable material. The final product has an approximate density of 112 pounds per cubic feet (lb/ft^3), and is usually 3/8 inch thick, 42 inches or 48 inches wide, and either 48 or 96 inches long.

1.3 REMEDIAL TECHNOLOGY DESCRIPTION

EET is the owner of a proprietary chemical technology for the extraction of contaminants from solid materials. EET's TECHXTRACT™ technology is designed to extract a variety of contaminants, including radionuclides, PCBs, and heavy metals, from the surface and substrate of materials such as concrete, steel, brick, and transite.

EET's process involves the applications of up to three solutions (specific solutions are proprietary). One solution is sprayed onto a surface at a time and allowed to dwell for a period as determined by EET. Additional solutions are then used as deemed necessary by EET. The surface is scrubbed between each chemical application. At the end of the decontamination period, the surface is rinsed with water and vacuumed. The solution chemistry is designed to achieve a high degree of permeation and penetration into the media being treated and to break chemical bonds holding the contaminants in the pores.

2.0 CONCLUSIONS AND RECOMMENDATIONS

During Remedy Screening, the EET TECHXTRACT™ Decontamination System was evaluated for its applicability and appropriateness to OU3 materials and contaminants. The EET TECHXTRACT™ Decontamination System has been evaluated against three standard EPA guidance criteria: effectiveness; implementability; and cost.

2.1 CONCLUSIONS

This engineering study evaluated the use of the EET TECHXTRACT™ Decontamination System to treat OU3 contaminated transite. Results from this study are reported in Section 4.0 of this report. The conclusions reached regarding the EET TECHXTRACT™ Decontamination System as a treatment technology are described below.

- The technology is effective in reducing surface alpha and beta/gamma activity levels to below 1,000 disintegrations per minute (dpm)/100 square centimeters (cm^2) alpha and below 5000 dpm/100 cm^2 beta/gamma;
- Painted surfaces reduce the effectiveness of this technology. Removing painted surfaces prior to decontamination may generate a Resource, Conservation and Recovery Act (RCRA) waste requiring treatment and disposal.
- The technology is not cost effective based on comparisons to burial in the on-property disposal facility.
- The process is slow and labor intensive. Several applications of the chemical solutions are required to decontaminate transite surfaces. Scrubbing of the surface is also required between solution applications.
- The process generates little waste. For the 7 to 8 liters of solution used during the tests, only 1-1 1/2 liters were recovered as waste.
- No conclusions can be made regarding the effectiveness of the technology on volumetrically contaminated transite.

2.2 RECOMMENDATIONS

Based on the test results, no further engineering testing of the EET TECHXTRACT™ Decontamination System is warranted on transite. Therefore, no additional test work is recommended.

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3.0 ENGINEERING STUDY APPROACH

This Remedy Screening Engineering Study was performed in accordance with the OU3 Treatability Study Work Plan (TSWP), approved by U.S. EPA, March 1994. The OU3 TSWP was prepared in accordance with the EPA's Guide for Conducting Treatability Studies Under CERCLA Interim Final (EPA 1988) and Final (EPA 1992).

The purpose of treating contaminated materials is to achieve a reduction in risk to the environment and human health. Engineering studies support remedy selection by providing data about potentially promising treatment processes and alternatives. Engineering studies test the effectiveness, performance, and implementability of potential remedial process options on OU3 materials and contaminants of concern. Engineering studies are conducted to ensure that selected remedial process options comply with Applicable or Relevant, and Appropriate Requirements (ARARs).

The EPA Guide for Conducting Treatability Studies Under CERCLA (EPA 1992) outlines a three-tiered approach to conducting engineering studies for a Superfund site. The approach includes Remedy Screening, Remedy Selection, and Remedy Design. The remedy screening and remedy selection testing are generally pre-Record Of Decision (ROD) studies and the remedy design studies are generally post-ROD. Remedy screening and remedy selection engineering studies provide the performance and cost data needed to: 1) evaluate potentially applicable treatment alternatives, and 2) select the most applicable remedial alternative for remedial action. The proposed OU3 engineering study approach is consistent with EPA's phased system for conducting engineering studies.

In general, remedy screening tests provide a qualitative evaluation of the potential effectiveness of a process option. Because the primary objective of remedy screening testing is to determine the potential feasibility of a process option, rigorous analytical quality assurance/quality control (QA/QC) requirements are not generally required. Ordinarily, it is acceptable to specify that remedy screening data be generated at analytical support levels (ASL) A/B. Criteria for defining ASLs are contained in Section 3 of the OU3 TSWP.

Remedy screening testing was used to establish the general feasibility of using the EET TECHXTRACT™ Decontamination System to decontaminate transite and to determine if remedy selection testing was warranted.

3.1 TEST OBJECTIVES AND RATIONALE

Technologies for cleaning transite are being tested because large volumes of contaminated transite exist at the FEMP which require disposal. The purpose of this test is to evaluate the effectiveness of the EET TECHXTRACT™ Decontamination System as a decontamination method for transite during the OU3 interim remedial action.

To be considered successful, the EET TECHXTRACT™ Decontamination System must effectively remove radiological and chemical contaminants (e.g., uranium, RCRA hazardous metals, etc.) and must be cost effective. If the decontaminated transite meets the On-Property Disposal Facility WAC, then disposal costs would be significantly reduced compared to off-site disposal. If the reduction in disposal costs is greater than the cost of the process, then the technology would be considered cost effective.

The specific objectives of the testing included:

- removing radiological contamination on the surface of transite to below 1,000 disintegrations per minute (dpm)/100 square centimeters (cm^2) alpha;
- removing radiological contamination on the surface of transite to below 5,000 dpm/100 cm^2 beta/gamma;
- removing RCRA hazardous metals to below regulatory levels; and
- determine the cost effectiveness of the system.

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

Plant 8, designated as the Recovery Plant, is located in the former FEMP production area. One 4-foot by 8-foot transite panel, located in the Motor Control Room at Plant 8, was identified based on radiological screening, for the chemical decontamination testing. This transite panel had a layer of paint on the surface, which is typical of transite at the FEMP. Once the panel was removed, it was transferred to Building 12D (Maintenance) where it was cut in half. One half of the panel was used for the test. The other half of the transite panel

was discarded. Almost all of the contamination was confined to the bottom half of the test panel. One initial sample was removed and analyzed for baseline characterization.

The transite panel was then transported to Martin Marietta Energy Systems (MMES) facility in Portsmouth, Ohio for chemical decontamination. The paint on the surface of the transite was not removed prior to decontamination, since surface removal would not be performed during full scale decontamination and dismantlement (D&D) operations at the FEMP. The transite panel was divided into nine subsections which were surveyed between reagent applications for alpha and beta/gamma radioactivity using Ludlum 12 Geiger-Muller (GM) counters. Application of up to three solutions, described as solutions 0100, 0200, and 0300 (specific chemicals used in each solution are proprietary) were applied to the transite surface using an atomizer or spray bottle. Each application was scrubbed on the transite surface and allowed to dwell for a period of time, as determined by the EET representative, before rinsing the surface with water. The rinse water was collected with a wet/dry vacuum for containerization as waste. Tables A-1 and A-2 in Appendix A summarize the actual test conditions used.

Following treatment, the transite panel was returned to the FEMP, where an additional transite grab sample was collected and analyzed for final characterization. Results of the testing were used to determine the technology effectiveness.

3.3 EQUIPMENT AND MATERIALS

Equipment and materials used is this study consisted of a spray bottle, scrub brush, wet vacuum, and proprietary chemicals.

3.4 SAMPLING AND ANALYSIS

All of the analytical testing performed followed approved methods outlined in the FEMP Sitewide CERCLA Quality Assurance Project Plan (SCQ). To support the above approach, ASL B was required.

3.4.1 Field Preparation

Radiological scanning was performed on the entire transite panel in accordance with FERMCO procedure, SPP-35-023. The area of the transite panel exhibiting the highest beta/gamma

reading was at the bottom of the panel and was identified using a hand-held Geiger-Mueller instrument. A triangular sample from the bottom of the panel was collected for baseline characterization by Remediation Support Operation (RSO) personnel.

Environmental Field Operations (EFO) personnel at FERMCO reduced the transite sample by crushing, using an electric rotary hammer with a bushing attachment and high efficiency particulate air (HEPA) equipped dust containment device per FEMP procedure EP-CRU3-020 "Sampling Hard Solids". The transite was reduced to a maximum size of one-half inch. A minimal amount of water was used during the sample reduction process to reduce dusting. This sampling activity and sample preparation were performed at the FEMP in the containment area of Building 12D, Maintenance Building.

The initial sample collected was analyzed for the eight RCRA hazardous metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver), total and isotopic uranium (U) and thorium (Th), radium-226/228 (Ra-226/228), and technetium-99 (Tc-99). This analysis was performed prior to treatment as a baseline characterization. An alpha-beta screen was also performed in order to ship the samples to MMES for decontamination testing.

3.4.2 Treatment Process

After decontamination, the transite panel was returned to the FEMP by MMES and transported to Building 12D. One final sample was collected by EFO personnel from the panel at a point adjacent to the initial sample. The sample was crushed as described in Section 3.4.1 and analyzed for the eight RCRA hazardous metals, total and isotopic U and Th, Ra-226/228, and Tc-99.

3.5 DATA MANAGEMENT

The data management plan was implemented so information collected during the investigation was properly managed following completion of field activities. Sampling teams recorded daily activities in the Field Activity Log (FAL) and were completed in accordance with the requirements specified in Appendix B of the FEMP SCQ.

Analytical data was entered into the FEMP Site-Wide Environmental Database (SED) by Analytical Data Management. Manual, double keyed, data entry was performed and the

entered data was compared to the original data sheets. Any corrections were initialed and dated. Hard-copy documents are kept in permanent storage in the CERCLA/RCRA Unit 3 (CRU3) RI/FS project files and the electronic database is permanently archived in a neutral ASCII file format. Field and analytical data were validated.

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4.0 STUDY RESULTS AND DISCUSSION

4.1 ANALYSIS OF ENGINEERING STUDY DATA

4.1.1 Technology Effectiveness

Initial averaged readings for fixed alpha and fixed beta/gamma radioactivity were 1,769 and 20,556 dpm/100 cm^2 respectively. Surface alpha activity levels were reduced to below 1000 dpm/100 cm^2 in one application and surface beta/gamma activity levels were reduced below 5000 dpm/100 cm^2 in four applications. Table A-1 in Appendix A summarizes alpha (A) and beta/gamma (B/G) results for each of the nine test subsections after each decontamination cycle. Tables A-3 and A-4 show average alpha and beta/gamma results, respectively, after each decontamination cycle in graphical form.

The process appears to be effective in removing radiological contaminants from the transite surface tested. Painted areas do pose a problem in applying this technique, as communicated by EET and observed during testing of other, non-FERMCO materials. Removal of paint before decontamination may generate a RCRA regulated waste which would also require treatment and disposal. During testing, the painted surface of the transite was gradually eroded as the chemical solutions were applied. However, the painted surface was never completely removed.

Testing was limited to surface decontamination. While no definite conclusions can be drawn regarding the effectiveness of the technology on volumetrically contaminated transite, results of analytical testing on the crushed transite (Table A-5) show no apparent volumetric decrease in radiological or RCRA metal contamination resulting from the EET decontamination process. Whether a volumetric reduction in contaminants would have been achieved on unpainted transite is unknown.

4.1.2 Implementability

Use of the EET technology involves several applications of proprietary chemical solutions which are allowed to dwell on the contaminated surface prior to scrubbing, rinsing with water, and vacuuming the residue. The technology is slow and labor intensive, and would be difficult and costly to implement on a large scale.

During testing, the chemical solutions were allowed to dwell on the transite surface for a total of approximately nineteen hours to reduce alpha radiation levels to below 1000 dpm/100 cm^2. To reduce beta/gamma radiation levels to below 5000 dpm/100 cm^2, the solutions were allowed to dwell on the transite surface for a total of approximately eighty hours. However, these dwell times include four occasions when the solutions were allowed to dwell overnight on the transite surface. It is unknown whether the solutions continued decontaminating the transite during the entire overnight periods or whether the decontaminating action diminishes over a period of time. If so, dwell times required to reduce alpha and beta/gamma radiation levels on the transite surface could be less than testing indicated.

4.1.3 Cost Effectiveness

When this engineering test was started, no on-property disposal facility WAC existed. Based on the WAC currently being developed, FEMP transite will not require decontamination for on-property disposal. Therefore, the EET TECHXTRACT™ Decontamination System can not currently be considered cost effective. If the proposed on-property WAC is modified, the cost effectiveness of this technology will be reassessed.

4.1.4 Comparison to Test Objectives

One of the goals of this engineering study was to evaluate the EET TECHXTRACT™ Decontamination System as a potential remediation technology for OU3 transite material. Data generated during remedy screening allowed the performance of the technology to be assessed. All other test objectives were met during the course of this testing.

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5.0 REFERENCES

Davenport, D., T. Houk, 1995, *Evaluation of the TechXtract™ Surface Decontamination Process*, POEF-MMES-04, Prepared by Martin Marietta for Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio.

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APPENDIX A

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TABLE A-1

FERNALD TRANSITE

APPLICATION	DATE	START TIME	STOP TIME	1-A	1-B/G	2-A	2-B/G	3-A	3-B/G	4-A	4-B/G	5-A	5-B/G	6-A	6-B/G	7-A	7-B/G	8-A	8-B/G	9-A	9-B/G	NOTE
INTIAL	12\20\94	1230		2.0 K	35 K	2.4 K	30 K	3.2 K	30 K	3.2 K	25 K	600	10 K	960	10 K	800	5 K	1600	30 K	960	10 K	
0300	12\20\94	1405	1409																			
0200	12\20\94	1416	1423																			
0200	12\20\94	1435	1440																			
0300/0200 Rinse & Vacuum	12\20\94	1750	1800																			
0300	12\20\94	1800	1805																			
0200	12\20\94	1825	1828																			
0300/0200 Rinse & Vacuum	12\21\94	0945	1010																			
0300	12\21\94	1325	1328																			
0200	12\21\94	1341	1343																			
0300/0200 Rinse & Vacuum	12\21\94	1537	1540																			
RAD SURVEY	12/21/94	1345		640	10 K	400	10 K	<400	5 K	640	5 K	<400	5 K	<400	10 K	400	5 K	480	20 K	<400	5 K	
0100	12\21\94	1543	1546																			
0100 Rinse & Vacuum	12\22\94	0945	0957																			
RAD SURVEY	12/27/94	1100		400	5 K	<400	5 K	<400	<5 K	<400	<5 K	<400	10 K	<400	5 K	<400	5 K	<400	10 K	<400	5 K	
0300	12\27\94	1300	1309																			
0200	12\27\94	1324	1331																			
0200	12\27\94	1455	1503																			
0300	12\28\94	0853	0854																			
0200	12\28\94	0909	0914																			
0300/0200 Rinse & Vacuum	12\28\94	1015	1027																			
RAD SURVEY	12/28/94	1400		<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	5 K	<400	5 K	<400	5 K	<400	5 K	<400	<5 K	
0100	12\28\94	1421	1423																			
0100 Rinse & Vacuum	12\29\94	0930	1005																			
RAD SURVEY	12/29/94	1335		<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	
RAD SURVEY	1/04/95	1430		<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	<400	<5 K	

TABLE A-2 Surface #6 (Fernald Transite)

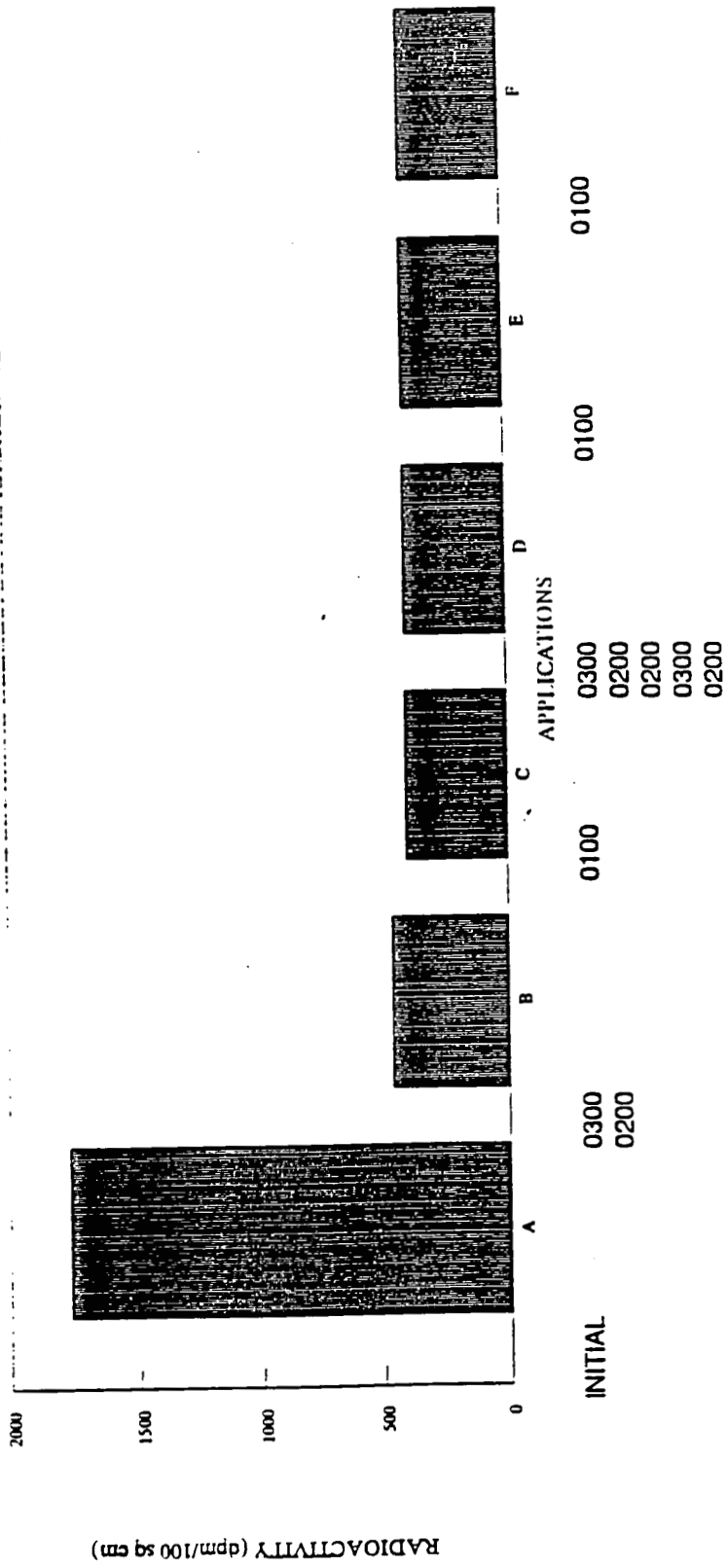
Date	Activity	Time	Recommended Dwell Time	Actual Dwell Time	Comments
12/20/94	Baseline Survey	1230	N/A	N/A	Predecontamination survey. Sampling event 0.
	0300	1405-1409	10 minutes	10 minutes	
	0200	1415-1423	N/A	20 minutes	
	0200	1435-1440	90 minutes	195 minutes	
	Rinse & Vacuum	1750-1800	N/A	N/A	Rinse solution: 90% Water - 10% EET Formula 0300.
	0300	1800-1805	10 minutes	25 minutes	
	0200	1825-1828	Overnight	Overnight	At night ambient temperatures were below freezing.
12/21/94	Rinse & Vacuum	0945-1010	N/A	N/A	Rinse solution: 90% Water - 10% EET Formula 0300.
	Survey	1345	N/A	N/A	Sampling event 1.
	0300	1325-1328	10 minutes	16 minutes	
	0200	1341-1343	90 minutes	116 minutes	
	Rinse & Vacuum	1537-1540	N/A	N/A	Rinse solution: 90% Water - 10% EET Formula 0300.
	0100	1543-1546	Overnight	Overnight	

TABLE A-2 Surface #6 (Fernald Transite) (CONT'D)

Date	Activity	Time	Recommended Dwell Time	Actual Dwell Time	Comments
12/22/94	Rinse & Vacuum	0945-0957	N/A	N/A	Rinse solution: 100% water.
	Survey	1400	N/A	N/A	Survey before Christmas break. Sampling event 2a.
12/27/94	Survey	1100	N/A	N/A	Survey after Christmas break. Sampling event 2b.
	0300	1300-1309	10 minutes	24 minutes	
	0200	1324-1331	60 minutes	94 minutes	
	0200	1458-1503	Overnight	Overnight	
12/28/94	0300	0853-0854	10 minutes	16 minutes	
	0200	0909-0914	90 minutes	66 minutes	
	Rinse & Vacuum	1015-1027	N/A	N/A	Rinse solution: 100% water.
	Survey	1400	N/A	N/A	Sampling event 3.
	0100	1421-1423	Overnight	Overnight	
12/29/94	Rinse & Vacuum	0930-1005	N/A	N/A	Rinse solution: 100% water.
	Survey	1335	N/A	N/A	Sampling event 4.
01/04/95	Survey	1430	N/A	N/A	Final survey to verify results. Sampling event 5.

TABLE A-3 FERNALD TRANSITE

X-705A EET DECON DEMONSTRATION (ALPHA)



ALL RADIOACTIVITY DATA IS AN AVERAGE OF ALL NINE SURVEY POINTS

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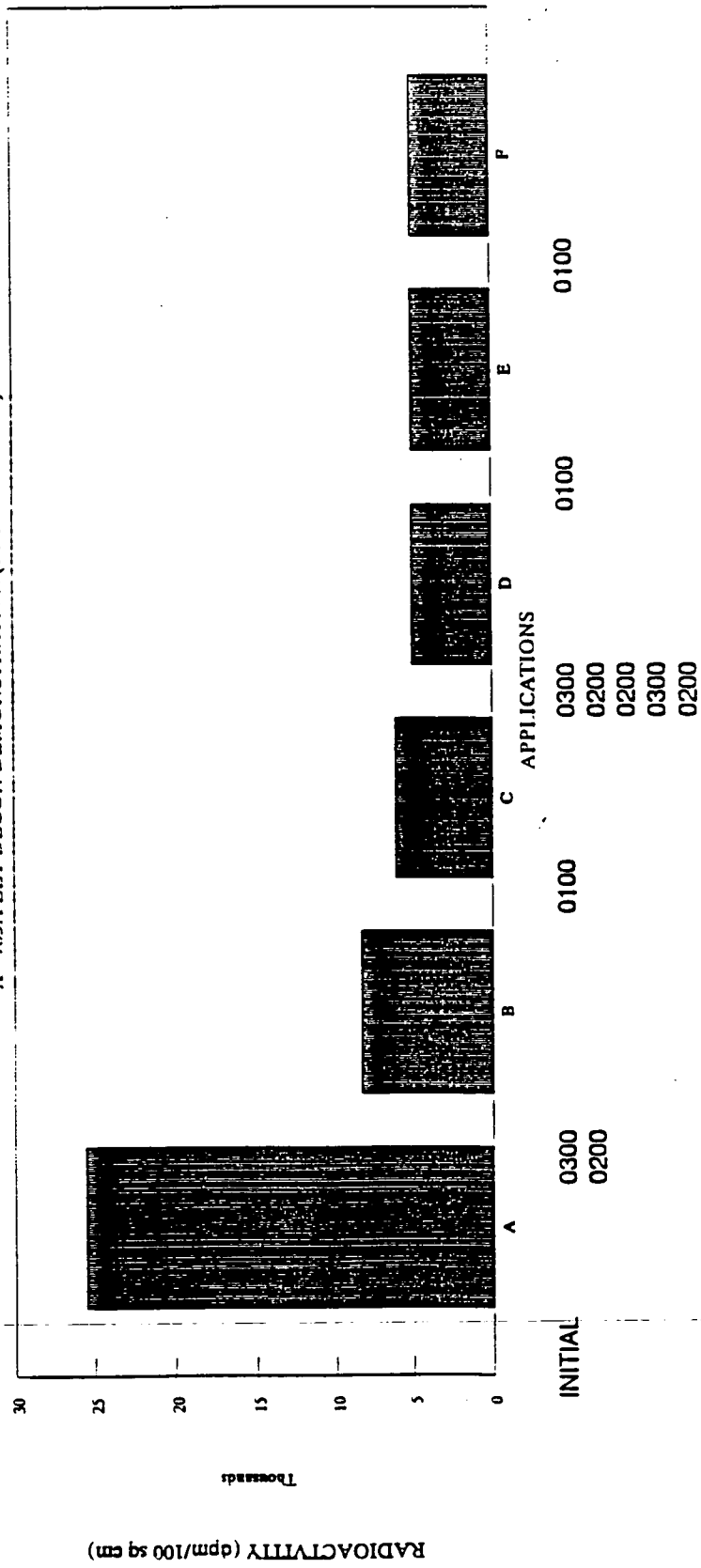
TABLE A-4 FERNALD TRANSITE

X-705A EET DECON DEMONSTRATION (BETA-GAMMA)



ALL RADIOACTIVITY DATA IS AN AVERAGE OF ALL NINE SURVEY POINTS

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TABLE A-5

ANALYTICAL RESULTS

	Before Decon		After Decon	
Alpha (pCi/g)	8.6		12	
Beta (pCi/g)	20		15	U
Th (ppm)	45	U*	45	U
U (ppm)	18.5		19.6	
U-236 (pCi/g)	0.5		ND**	
U-234 (pCi/g)	8.6		ND	
U-235 (pCi/g)	0.39		ND	
U-238 (pCi/g)	6.22		ND	
Ra-226 (pCi/g)	0.65		0.71	
Ra-228 (pCi/g)	0.78	U	0.76	U
Tc-99 (pCi/g)	4.7	U	4.9	U
Th-228 (pCi/g)	0.32		0.3	
Th-230 (pCi/g)	0.95		1	
Th-232 (pCi/g)	0.28		0.3	
Ar (mg/kg)	2.3		2.4	
Ba (mg/kg)	120		121	
Cd (mg/kg)	1.2	U	1.2	U
Cr (mg/kg)	112		112	
Pb (mg/kg)	36		34.4	
Hg (mg/kg)	0.14		0.23	
Se (mg/kg)	0.28		0.39	
As (mg/kg)	2.1	U	2.2	

* Undetected
** Not Determined

TREATABILITY STUDY REPORT

FOR

THORIUM NITRATE (TN)

Prepared by Chem-Nuclear Systems, Inc.

June 16, 1995

☒ APPROVED
☐ APPROVED AS NOTED
☐ NOT APPROVED RESUBMIT

SIGNED [illegible] DATE 7/24/95

This approval does not relieve the vendor of the obligation to meet specifications and all other terms and conditions of the subcontract or purchase order.

PROJECT TN Solidification

INTRODUCTION

In an effort to remove an estimated 6,500 gallons of TN waste from the Department of Energy's Fernald facility, the Fernald Environmental Restoration Management Corporation (FERMCO) commissioned Chem-Nuclear Systems, Inc. (CNSI) to perform a treatability study on the cementitious solidification of TN. FERMCO Purchase Order 95SP002666-000-00, as revised, contained the Scope of Work (SOW) and was issued to initiate this study.

FERMCO provided CNSI with an initial 500 ml. sample of TN. The sample was a composite of tank T2's contents. Appendix A contains the initial information provided by FERMCO with the sample.

OBJECTIVE

The objective of this study was to develop a cementitious solidification formula which would maximize waste loading and sufficiently bind hazardous constituents (RCRA metals) to meet federal limits. The final waste form was required to meet the Nevada Test Site (NTS) Waste Acceptance Criteria (WAC). Additionally, in the interest of both cost and production efficiency, the formula would be compatible with the UNH process equipment if possible. Specific monitoring requirements were included by FERMCO in the SOW.

CNSI APPROACH

CNSI intended that the thorium in the waste liquid be converted to thorium compounds by treatment with 25% sodium hydroxide (NaOH) and pozzolanic cement (P-cement). NaOH addition would be controlled, with temperature monitoring and agitation, until the pH reached 1.5 to 2. This level would allow the liquid waste to be transferred to a cement mixer without adverse reaction between the liquid and the steel of the mixer.

Following completion of the NaOH addition, P-cement would be added to form a smooth pourable paste. P-cement for this study was a mixture of 40% by weight Class "F" flyash and 60% by weight portland cement.

Solidified samples would be sealed and placed in an oven at 150 °F. Several days of cure under these conditions simulates the heat effects expected in larger masses of actual product.

TEST FORMULA DEVELOPMENT

In order to utilize the same processing system planned for UNH, the decision was made to use the same chemicals required in UNH processing. The specific quantities of each chemical were to be determined through testing. NaOH would be used to raise the pH to a level of between 1.5 - 2.0. P-cement would be added until a pourable "lean" mix was obtained. The PCP cups would be capped, marked and placed in the curing oven for a minimum of three days.

Additional samples were to be prepared identical to the first with the exception of P-cement. The quantity of P-cement added to the mix would be increased by 20% to obtain a "medium" mix. The mix would be thicker but would still be pourable from a cement mixer.

Actual preparation of the test formulas resulted in some unexpected results. The test samples were found to undergo a thixotropic reaction where they transformed from a fluid to a solid in an extremely short amount of time and then reverted back to a fluid.

The thixotropic reaction presented a serious problem with respect to full scale processing using the UNH system. The materials rapid phase change with little or no warning precluded its use in a cement mixer for two reasons. The first reason is that of safety; a full batch that suddenly goes solid could unbalance the mixer and result in it's overturning. Secondly, while the lab test samples reverted to a fluid with continued stirring there is know way of knowing if the rotation of the mixer drum will provide sufficient agitation to bring about the change from solid to fluid.

Discussions between the CNSI and FERMCO chemist led to the theory that the particle size of the binder was related to the reaction rate. The fine particles of cement resulted in a large surface area which fueled the rapid solidification reaction. Since coarse cement is not readily available it was decided to utilize a coarse magnesium oxide (MgO) as the binder. It was thought that a 40 to 80 mesh MgO would probably be the best size. Since MgO hydrates at a lower pH than portland cement, the use of granular MgO would not be as likely to promote the initial gel reaction.

A second sample was required to complete testing using MgO since 80% of the first sample was consumed in the initial TN testing using P-cement.

TEST FORMULA PROCESSING

Appendix B contains summary tables detailing the 20 test formulas. Appendix C contains the logsheets and data sheets for the TN testing. This data includes the information obtained from real time monitoring of the solidifications. The various parameters monitored are discussed below:

pH

The pH concern with the solidification process is two-fold. Initially, the pH must be raised to a level sufficient to prevent damage to the steel components of the cement mixing system. The target pH for this is a minimum of 1.5 to 2. The second concern is the pH required for the cement to set and cure. Sample pH was monitored while initial neutralization was accomplished. Once the sample pH was raised to approximately 2 pH monitoring was discontinued.

Temperature

Temperature is also a parameter of concern during solidification. The chemical reactions which occur during neutralization and solidification can generate large amounts of heat in a very short time. The curing process of cement is also an exothermic reaction generating heat.

Lab testing indicates that the heat generated by the various neutralization reactions would increase temperature in each case approximately 50-60 °F.

Density

The density of the test solidification final product ranged from 56.1 lb/ft^3 to 124.1 lb/ft^3.

NO_x Emission

NO_x emissions were not monitored during TN testing as a result of UNH testing. NO_x was not detected during UNH testing and since the UNH had a higher free acid content, and therefore a greater likelihood of generating NO_x, it was felt to be unnecessary. However, monitoring and atmospheric protection will be required during initial operations until definitive data is obtained.

TEST FORMULA RESULTS

Three samples were selected from the P-cement formulas based upon their final appearance. The three samples selected all complied with the NTS WAC. There was no free liquid and all samples were solid free standing monoliths. Even though MgO testing yielded several successful solidification formulas, a sufficient level of confidence was not obtained with respect to processing in a cement mixer. The three P-cement samples were sent to DATA CHEM Laboratories for TCLP analysis.

Observations of the final products for all 20 samples are contained in Appendix C. The table below details observations of the 3 samples selected for TCLP analysis.

SAMPLE	OBSERVATIONS
TN-3	No liquid; light gray color; very hard with no penetration when probed
TN-4	No liquid; light gray color; very hard with no penetration when probed.
TN-8	No liquid; dark gray color; solid but soft enough to penetrate when probed; surface chunked when probed; condensation on PCP cup lid (sample was never placed in oven)

The three samples passed TCLP and the laboratory test results can be found in Appendix D. The table below lists the concentration (ppm) of RCRA metals present in the waste stream and the concentration of RCRA metals in the final solidified product, both in ppm.

WASTE STREAM	RCRA METAL	INITIAL CONCENTRATION (ppm)	TCLP RESULTS (PPM)
TN-3	Cadmium	1.42	ND
"	Chromium	3.77	0.03
TN-4	Cadmium	1.42	ND
"	Chromium	3.77	0.08
TN-8	Cadmium	1.42	ND
"	Chromium	3.77	0.1

The following table lists waste loading as a volume percentage of liquid waste to final product:

SAMPLE	WASTE VOLUME (ml)	FINAL VOLUME (ml)	WASTE LOADING (%)
TN-3	50	140	35.7
TN-4	50	120	41.7
TN-8	50	130	38.5

CONCLUSION

A successful cementitious solidification formula has been developed for use on FERMCO's TN liquid waste. However the formula is not compatible with the equipment to be used for UNH processing. Use of the formula results in a final product which exceeds the requirements of NVO-325 and provides reasonable waste loading.

A full scale processing system which utilizes the formula is easily achievable using technology and equipment currently available. The solidification will be performed "in-container" utilizing 55 gallon solidification drums.

Due to the time constraints of the project and the additional costs associated with further testing, CNSI recommends proceeding with "in-container" processing utilizing 55 gallon drums. Drums are compatible with the waste stream in it's final form and CNSI has successfully performed drum solidification on other solidification projects. The use of 55 gallon drums is acceptable with the NTS WAC. Of the three solidification formulas which were tested TN-4 would be the formula of choice due to it's higher waste loading.

APPENDIX A

FERMCO TN DATA SUMMARY

(1 PAGE)

Thorium Nitrate Data Summary
Tank T-2

05-Apr-95 7580

Chemical Analysis

Analyte	Results	Units	Notes
Matrix			Liquid
pH	<1		
Normality	0.72	N	
% Acid	2.73	w/w	Nitric Acid Basis
Nitrates		g/l	
Density @ 20 C	1.661	g/ml	
Cadmium	1.42	ppm	
Chromium	3.77	ppm	

Measured Tank T-2 Radioisoptopic Inventory

Isotope	Concentration (Lab Analysis)	Units	Tank Inventory (Ci)
Uranium 232	13000	pCi/l	0.000
Uranium 233	1400000	pCi/l	0.034
Uranium 234	1400000	pCi/l	0.034
Uranium 235	260	pCi/l	0.000
Uranium 236	410	pCi/l	0.000
Uranium 238	4700	pCi/l	0.000
Thorium 232	41000000	pCi/l	1.010
Thorium 230	10450000	pCi/l	0.257
Thorium 228	37500000	pCi/l	0.924
Total Thorium	373.9	g/l	N/A
Plutonium 238	7100000	pCi/l	0.175
Plutonium 239	550000	pCi/l	0.014
Potassium 40	<1700	pCi/l	0.000
Cesium 137	<130	pCi/l	0.000
Neptunium 237	<190	pCi/l	0.000
Manganese 54	<140	pCi/l	0.000
Antimony 125	<300	pCi/l	0.000
Cesium 134	<110	pCi/l	0.000
Cobalt 60	<180	pCi/l	0.000
Zinc 65	<330	pCi/l	0.000
Ruthenium 106	<1100	pCi/l	0.000
Barium 133	<130	pCi/l	0.000
Cobalt 57	<67	pCi/l	0.000
Cesium 144	<520	pCi/l	0.000
Measured Total			2.449

Theoretical Thorium - 232 Decay Products in the 6500 Gallons in T-2

Decay Daughter	Mass in T-2	Activity in T-2 (Ci)
Radium - 228	3.18 mg	0.922
Actinium - 228	0.39 ug	0.922
Thorium - 228	1.01 mg	0.877
Radium 224	5.18 ug	0.877
Radon - 220	0.89 ng	0.877
Polonium - 216	2.37 pg	0.877
Lead - 212	22.3 ng	0.877
Bismuth - 212	5.85 ng	0.877
Thallium - 208	0.99 ng	0.315
Polonium - 212	0.44 ng	0.562
Theoretical Activity		7.983

EXHIBIT K

APPENDIX B

TN TESTING SUMMARY TABLES

(2 PAGES)

SUMMARY REPORT OF TN TREATABILITY STUDY

	TEST NUMBER									
	TN-1	TN-2	TN-3	TN-4	TN-5	TN-6	TN-7	TN-8	TN-9	TN-10
Waste Volume (ml)	50	50	50	50	50	50	50	50	50	50
Initial Temp. (°F)	67	67	67	63	63	63	64	62	67	60
Initial pH	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5
Water (ml)	0	50	50	0	50	50	0	50	0	0
25 % NaOH (g)	7.6	7.6	7.6	47.5	7.6	7.6	0	7.6	7.6	7.6
50 % NaOH (g)	0	0	0	0	0	0	35.4	0	0	0
Maximum Temp. (°F)	85	79	79	86	78	78	156	73	90	84
Final pH	1.5-2.0	1.5-2.0	1.5-2.0	Note 2	1.5-2.0	1.5-2.0	Note 2	1.5-2.0	1.5-2.0	1.5-2.0
TSP (g)	0	0	0	0	0	3.1	0	0	0	0
P-40 (g)	58.7	60.7	72	52.2	0	62.4	21.7	60.7	0	0
RPB (g)	0	0	0	0	37	0	0	0	0	0
P-100 (g)	0	0	0	0	0	0	0	0	103.7	90
MMP30-MgO (g)	0	0	0	0	0	0	0	0	0	46.6
Maximum Temp. (°F)	Note 1	Note 1	109	110	Note 1	Note 1	Note 1	107	86	80
Final Vol. (ml)	100	130	140	120	100	150	100	130	115	115
Final Mass (g)	131.7	183.9	177.2	165.2	89.9	201.6	127.1	196.8	221	225.9
Density (g/ml)	1.32	1.41	1.27	1.38	0.90	1.34	1.27	1.51	1.92	1.96
"on contact" C.W. (mR/hr)	1.5	1.4	1.4	1.7	1.3	1.3	1.5	1.6	1.5	1.6
"1 foot" (mR/hr)	0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1

Note 1 – Not observed due to the final product being unacceptable for production purposes.
Note 2 – Final pH >3; litmus paper unable to provide accurate indication above 3 due to chemical interference.

RPB – Rhone Poulanc Binder; 60% MgOH + 40% Flyash

000115

7580

(...\tn1-sum.wk1)

SUMMARY REPORT OF TN TREATABILITY STUDY

	TEST NUMBER									
	TN-11	TN-12	TN-13	TN-14	TN-15	TN-16	TN-17	TN-18	TN-19	TN-20
Waste Volume (ml)	50	50	50	50	50	50	50	50	50	50
Initial Temp. (°F)	67	66	64	64	60	62.5	64.5	69	70	71
Initial pH	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5	0-0.5
25 % NaOH (g)	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Maximum Temp. (°F)	89	88.5	88	87	84	86	Note 3	92	92.5	93
Final pH	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0	1.5-2.0
P-100 (g)	0	75	75	75	90	90	90	90	90	90
MMP30-MgO (g)	80	60	40	0	45	40	40	40	0	0
Premier 98HB-MgO (g)	0	0	0	40	0	0	0	0	0	0
Huber 100 - MgO (g)	0	0	0	0	0	0	0	0	40	40
Maximum Temp. (°F)	136	124	119.5	108.5	117.5	123.5	117	Note 4	126.5	122
Final Vol. (ml)	90	115	105	110	125	120	125	110	120	120
Final Mass (g)	168.4	221.1	203	203.7	224.6	218.6	219.4	218.6	217.9	218.5
Density (g/ml)	1.87	1.92	1.93	1.85	1.8	1.82	1.76	1.99	1.82	1.82
"on contact" C.W. (mR/hr)	1.7	1.5	1.7	1.6	1.4	1.5	1.6	1.6	1.6	1.6
"1 foot" (mR/hr)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

** Not observed.

Note 3 – Not measured. NaOH was added to waste and the solution was set aside to cool to ambient in order to study the effects of lower initial temperature on the final reaction.

Note 4 – Not measured. MgO was mixed for two minutes following addition and then capped and set aside.

APPENDIX C

TN TREATABILITY STUDY LOG & DATA SHEETS

(37 PAGES)

TN TREATABILITY

7580

LOG SHEET

DATE: 4-19-95

PAGE: 1 DATE OF: 10 ~~19~~

LOCATION: BW TEST LAB

TIME:	ACTIVITY
1033	JOHN CARLSON AND JOE PATTON IN LAB.
1040	50 ml TN IN GRADUATED CYLINDER IS 148g, GRADUATED CYLINDER IS 65g.
	148g - 65g = 83g WASTE
	83g ÷ 50ml = 1.66 g/ml ⇒ CONSISTENT w/ REPORTED DENSITY
N-1 1042	50ml TN @ 67°F, pH = 0-0.5
1044	COMMENCE ADDING 25% NaOH → NaOH DROPLETS FORM WHITE PRECIPITATE WHICH DISSOLVES WITH TIME/AGITATION.
1047	5.6g NaOH ADDED, pH = 0.5, T = 83°F, WHITE PRECIP.
1049	7.6g NaOH ADDED (TOTAL), pH = 1.5-2.0, T = 85°F, WHITE PRECIP.
1052	CONTINUED AGITATION → WHITE PRECIP. GONE, pH = 1.5-2.0. FREE ACID GONE, TN ITSELF BUFFERING NaOH.
1057	BEGIN ADDING P-CEMENT, P-CEMENT LUMPS UP AND BECOMES GRAINY.
1100	SAMPLE SOLIDIFIED AFTER ADDING 58.7g OF P-CEMENT. CHANGE FROM FLUID → SOLID VERY QUICK. SAMPLE LABELLED TN-1, CAPPED.
1120	50ml TN ADDED TO 50ml WATER. T = 70°F, pH = 0.-0.5
1125	ADD 7.6g NaOH → WHITE PRECIP, T = 79°F.
1126	ADD P-CEMENT, P-CEMENT STILL GRAINY WHEN MIXED.
1129	46.2g P-CEMENT ADDED, T = 121°F.
1130	ADD 14.5g P-CEMENT. SAMPLE QUICKLY PASSED FROM LIQUID TO NICE PASTE TO FIRM MIX (NOT POURABLE)
1132	SAMPLE HAS REVERTED TO A PASTE FOLLOWING AGITATION AFTER NOTICING A CHANGE IN SAMPLE SURFACE. THE SURFACE LOOKED WETTER THAN IT WAS @ 1130 WHEN IT WENT SOLID.
1133	POURABLE PASTE, CAPPED TN-2
N-3 1141	50ml TN ADDED TO 50ml WATER, T = 70°F
1143	ADDED 7.6g NaOH, T = 79°F
1147	ADDED 40g P-CEMENT T = 109°F
1152	w/o AGITATION MATERIAL SETTLED, IMMEDIATELY SUSPENDED w/ AGITATION.
1155	ADDED 5g P-CEMENT → FLUID
1157	ADDED 5g P-CEMENT → FLUID TO SOLID AND BACK TO FLUID
1159	ADDED 5g P-CEMENT → FLUID
1203	ADDED 17g P-CEMENT → FLUID, NO THICKENING, POURABLE. CAPPED TN-3.

SUMMARY:

TN TREATABILITY 7580

LOG SHEET

DATE: 4-19-95 PAGE: 2 ~~DATE~~ OF: 10

LOCATION: BW TEST LAB

TIME:	ACTIVITY
1400	INSPECT SAMPLES, TN-1 NOT CHECKED.
	TN-2 → NO LIQUID, NOT POURABLE, CONSISTENCY OF JELL-O
	TN-3 → NO LIQUID, NOT POURABLE, CONSISTENCY OF JELL-O(+)
TN-4 1406	50 ml TN T = 63 °F pH = 0-0.5
1409	ADDING NaOH
1411	10.2 g NaOH ADDED, pH = 2.0 T = 88 °F
1416	STILL ADDING NaOH, pH = 2.5 T = 94 °F
1422	40.2 g (TOTAL) OF NaOH ADDED, pH = 3.0 T = 96 °F → WHITE PRECIP SLOWLY REDISSOLVING
1430	47.5 g (TOTAL) NaOH ADDED, pH > 3.0 T = 86 °F (COLD ROOM, SMALL SAMPLE)
	WHITE PRECIP, NOT VISIBLY REDISSOLVING BUT STILL LOOSE AND PUMPABLE.
1434	ADD P-CEMENT
1439	52.2 g P-CEMENT ADDED. SAMPLE THICKENED AND THEN THINNED TO POURABLE FLUID.
	CAPPED TN-4.
TN-5 1455	50 ml TN + 50 ml H_2O + 7.6 g NaOH ; T = 74 °F
1458	ADD RPB → MIXES SMOOTHLY (NOT GRAINY), GRADUAL TEMP ↑
1500	INSTANT ROCK - NO LIQUID, NO WARNING ; 37 g RPB ADDED, CAPPED TN-5
[illegible] 1515	50 ml TN + 50 ml H_2O + 7.6 g NaOH
1520	T = 72 °F ADDING T32A → NOT MIXING VERY WELL, NOT DISSOLVING.
1530	DISSOLVE T32A IN H_2O AND ADDED TO WASTE → FORMED MILKY FLUID.
1536	ADDED 62.4 g P-CEMENT, THICKENED TO GEL AND THEN THINNED TO FLUID.
	CAPPED TN-6.
TN-7 1630	50 ml TN, T = 64 °F
1632	ADD 50% NaOH
1633	T = 104 °F 6.4 g 50% NaOH ADDED.
1635	15.4 g (TOTAL) 50% NaOH ADDED, T = 134 °F
1637	T = 156 °F, 35.4 g 50% NaOH ADDED (TOTAL) → SAMPLE THICKENED RAPIDLY
	TO THE CONSISTENCY OF GRITS.
1641	ADD 21.7 g P-CEMENT → SAMPLE TOO THICK TO POUR. CAPPED TN-7
1650	SAMPLES TN-1 THROUGH TN-7 PLACED IN OVEN (150 °F).

SUMMARY :

TN TREATABILITY

LOG SHEET

DATE: 4-20-95 PAGE: 3 DATE OF: 10 ~~19~~

LOCATION: BW TEST LAB

TIME: ACTIVITY

1020	INSPECT TN-1 THROUGH TN-7
	SAMPLE / DESCRIPTION / EST. VOLUME / COLOR
	TN-1 / SET / HARD / 125-150 ml / MED GRAY
	TN-2 / FAIRLY HARD/DIFFICULT TO PENETRATE / 130 ml / DARK GRAY
	TN-3 / HARD/SLIGHT DIMPLE / 140 ml / DARK GRAY
	TN-4 / HARD/SLIGHT DIMPLE / 120 ml / LIGHT GRAY
	TN-5 / DID NOT SET / N/A / OFF WHITE
	TN-6 / SOFT WET PASTE / 150 ml / DARK GRAY
	TN-7 / FIRM, DRY, RESISTS PENETRATION / 90 ml / DARK GRAY
1036	SAMPLES RETURNED TO OVEN.
N-8 1050	50 ml TN + 50 ml H_2O + 7.6 g NaOH + 60.7 g P-CEMENT
	T_i = 62°F, T_{NaOH} = 73°F pH = 1.5-2.0, @ ~50 g P-CEMENT MIX THICKENED AND WITHIN 1 MIN (W/STIRRING) MIX WAS FLUID.
1055	CAPPED TN-8 AND SET ON TOP OF OVEN. THIS SAMPLE IS TO CHECK FORMULA'S ABILITY TO SET W/O HEAT FROM OVEN (SIMULATE SMALLER CONTAINER, I.E. 55 GALLON DRUM)
1100	SCE&G SHUT OFF POWER TO THE SITE.
1600	POWER RESTORED TO SITE.
1607	INSPECT TN-8 → NO LIQUID, SETTING UP.
TN-9 1610	50 ml TN + 7.6 g NaOH T_i = 67°F, T_f = 90°F, pH_f = 1.5-2.0
1615	ADD P-100 T_i = 86°F, NO TEMP INCREASE
1623	ADDED 103.7 g P-100, T = 82°F → SAMPLE COOLING TO AMBIENT ∴ P-100 NOT REACTIVE. SAMPLE CONSISTENCY OF SYRUP → WOULD SUSPEND 40-80 MESH MgO.
1625	CAPPED TN-9 AND SET ON TOP OF OVEN.

SUMMARY :

TN TREATABILITY

LOG SHEET

7580

DATE: 5-3-95 PAGE: 4 DATE OF: 10/19

LOCATION: BW TEST LAB

TIME:

ACTIVITY

0930 AT LAB TO SELECT UP TO 5 SAMPLES FOR TCLP TESTING.

SAMPLE	DESCRIPTION	VOL	RAD LEVEL	COLOR
TN-1	HARD, GRAINY, CHUNKS ON TOP DUE TO RAPID SET, NO LIQUID	N/A	N/A	LIGHT GRAY
TN-2	NO LIQUID, FIRM BUT EASILY PENETRATED	N/A	N/A	DARK GRAY
TN-3	NO LIQUID, VERY HARD	140 ml	1.4 mR/HR O.C. (CW) 0.1 mR/HR @ 1 FT	LIGHT GRAY
TN-4	NO LIQUID, VERY HARD	120 ml	1.7 mR/HR O.C. (CW) <0.1 mR/HR @ 1 FT	LIGHT GRAY
TN-5	SOLID BUT CRUMBLES EASILY, NO LIQUID	N/A	N/A	OFF WHITE
TN-6	SOLID (CLAY LIKE), NO LIQUID, EASILY PENETRATED	N/A	N/A	DARK GRAY
TN-7	SOFT, EASILY CRUMBLES, NO LIQUID	N/A	N/A	DARK GRAY
TN-8	HARD BUT COMPRESSABLE, NO LIQUID, CONDENSATION ON LID, PROBING WITH ROD CAUSES SLIGHT PENETRATION AND CHUNKING OF SURFACE.	130 ml	1.6 mR/HR O.C. (CW) 0.1 mR/HR @ 1 FT	DARK GRAY
TN-9	LIQUID LAYER ON TOP w/ P-100 SETTLED ON BOTTOM, STIRRING SAMPLE RETURNED IT TO SYRUP CONSISTENCY	N/A	N/A	N/A
50 ml TN LIQUID		50 ml	2.4 mR/HR O.C. (CW) <0.1 mR/HR @ 1 FT	CLEAR

RAD SURVEYS PERFORMED w/ E-120 # 5892, CAL DUE 5/30/95.

1000 SELECTED TN-3, TN-4, TN-8 FOR TCLP TESTING.

1030 TCLP SAMPLES PACKAGED FOR SHIPMENT TO DATA CHEM LAB IN UTAH.

1100 COMPLETED PACKAGING SAMPLES, PLACED REST OF SAMPLES ON BENCH FOR FUTURE RETURN TO FERMCO.

1430 COMPLETED SHIPPING PW/ SAMPLES SHIPPED VIA FEDEX.

SUMMARY :

TN TREATABILITY

7580

LOG SHEET

DATE: 5-9-95 PAGE: 5 DATE OF: 10 / 11

LOCATION: BW TEST LAB

TIME:	ACTIVITY
1100	JOHN CARLSON / JOE PATTON IN LAB, INSPECT TN-9.
	TN-9 CONSISTENCY OF PUDDING → SLIGHT LIQUID ON TOP, P-100 ON BOTTOM.
	RETURNED TO FLUID FOLLOWING STIRRING → P-100 INERT IN TN.
TN-9 CONT'D 1110	TN-9 @ 60 °F, ADD 7g OF MARTIN MARIETTA PRILL 30 MgO (MMP30)
1112	T = 60.5 °F, ADD ADDITIONAL 17g MMP30. (24g TOTAL)
1114	T = 62 °F, NOTICABLE THICKENING OF SAMPLE.
1118	T = 62 °F, ADD ADDITIONAL 9.8g MMP30 (33.8g TOTAL)
1119	T = 62.5 °F
1120	POUR SAMPLE FROM ONE CUP TO ANOTHER → VERY THICK, SLOW FLOW, DROPPED IN LUMPS, RECOMMEN LESS P-100 OR LARGER MgO.
TN-10 1130	50 ml TN, pH = 0-0.5, T = 60 °F → LAST OF FIRST TN SAMPLE.
1133	ADD 7.6g NaOH → USUAL WHITE PRECIP.
1134	T = 84 °F, WHITE PRECIP ALMOST GONE, AS USUAL. pH = 1.5-2.0.
1139	ADDING P-100 (90g)
1141	P-100 MIXED IN, LIGHT SYRUP CONSISTENCY
1143	ADD MMP30
1144	SAMPLE VERY POURABLE AFTER 34.3g MMP30
1146	46.6g (TOTAL) MMP30 ADDED, T = 80 °F, VERY POURABLE
1150	CAPPED TN-10.
1200	OUT OF LAB.
1440	JC/JP IN LAB → BEGIN USE OF SECOND TN SAMPLE.
TN-11 1447	50 ml TN pH = 0, T = 67 °F
1450	ADD 7.6g NaOH T_f = 89 °F
1452	ADDING MMP30
1454	80g MMP30 ADDED, T = 89.5 °F
1456	CONTINUE AGITATION, T = 95 °F
1458	CONTINUE AGITATION, T = 115.5 °F
1459	SAMPLE IS SOLID, VERY GRANULAR T = 136 °F → NO GOOD FOR MIXER. CAPPED TN-11
TN-12 1520	50 ml TN + 7.6g NaOH, T_i = 66 °F T_f = 88.5 °F
1523	T = 87 °F ADD 75g P-100
1524	T = 84 °F
1527	T = 84 °F ADD 60g MMP30 IN 30 SECONDS
1529	T = 85.5 °F

SUMMARY :

TN TREATABILITY

LOG SHEET

7580

DATE: 5-9-95

PAGE: 6 DATE OF: 10 / 11

LOCATION: BW TEST LAB

TIME:

ACTIVITY

TN-12 CONT'D	1531	T = 88.5 °F (MORE FLUID THAN TN-10)
	1533	T = 94 °F
	1535	T = 105 °F
	1537	T = 119.5 °F
	1539	T = 124 °F SAMPLE BEGAN THICKENING 30 SECONDS EARLIER, SAMPLE NOW SOLID – NOT POURABLE.
	1540	CAPPED TN-12.
TN-13	1600	50 ml TN @ 64 °F + 7.6 g NaOH. T_f = 88 °F
	1605	ADD 75 g P-100
	1607	ADD 40 g MMP30 IN 6 SECONDS T_i = 82 °F
	1609	T = 84.5 °F
	1611	T = 87 °F
	1613	T = 91.5 °F
	1615	T = 100.5 °F
	1617	T = 113.5 °F
	1619	T = 118 °F
	1621	T = 119.5 °F
	1623	T = 119 °F
	1625	T = 118 °F → VERY POURABLE, WATERY, PERFECT IF IT GOES HARD.
TN-14	1630	50 ml TN @ 64 °F + 7.6 g NaOH T_f = 87 °F
	1632	ADD 75 g P-100
	1634	ADD 40 g PREMIER 98 HB (12x40) MgO IN 3 SECONDS. T_i = 83 °F FEELS MORE GRANULAR WHILE STIRRING.
	1636	T = 87.5 °F
	1638	T = 89.5 °F
	1640	T = 92 °F
	1642	T = 94.5 °F
	1644	T = 96.5 °F
	1646	T = 99 °F
	1648	T = 101.5 °F
	1650	T = 103.5 °F
	1652	T = 105.5 °F
	1654	T = 107 °F
	1656	T = 108 °F
	1658	T = 108.5 °F
	1700	T = 108.5 °F
	1702	T = 108 °F VERY POURABLE, CAPPED TN-14.
	1704	TN-9, 10, 11, 12, 13, 14 IN OVEN (150 °F). OUT OF LAB.

SUMMARY:

TN TREATABILITY

7580

LOG SHEET

DATE: 5-10-95

PAGE: 7 OF: 10 ~~11~~

LOCATION: BW TEST LAB

TIME:

ACTIVITY

0945 JC/JP IN LAB TO INSPECT SAMPLES

SAMPLE	DESCRIPTION
TN-9	MOSTLY DRY, WET ON ONE SIDE, QUITE HARD < 1/2 ml SYRUPY LIQUID, EVAPORATING w/ LID OFF PCP CUP.
TN-10	SIMILAR TO TN-9, SOFT PASTY LAYER ON TOP (1/16" - 1/8" THICK), SYRUPY LIQUID (pH 9-10) PRESENT, EVAPORATING w/LID OFF PCP CUP.
TN-11	NO LIQUID, VERY HARD
TN-12	NO LIQUID, VERY HARD 115 ml VOL, 223.9 g NET
TN-13	~15 ml FREE LIQUID + SOFT TOP LAYER → 25 % HARD BOTTOM LAYER → 75 %
TN-14	30-40 ml FREE LIQUID + SOFT LAYER ON TOP → 50 % HARD BOTTOM LAYER → 50 %

CHECKED 2ND TN SAMPLE DENSITY

283.7 g GROSS − 117.7 g (GRADUATED CYLINDER) = 166 g WASTE

166 g WASTE ÷ 100 ml WASTE = 1.66 g/ml ⇒ OK

1015	50 ml TN @ 60 °F
1016	ADD 7.6 g NaOH
1017	T_f = 84 °F
1021	ADD 90 g P-100
1027	T = 79.5 °F ADD 45 g MMP30 IN 8 SECONDS
1029	T = 81.5 °F
1031	T = 83.5 °F
1033	T = 85.5 °F
1035	T = 89.5 °F
1037	T = 96 °F SAMPLE APPEARANCE UNCHANGED FROM 1027 APPEARANCE.
1039	T = 105.5 °F
1040	T = 114 °F
1043	T = 117.5 °F
1045	T = 115 °F MIX THICKENED TO A SOLID w/IN 30 SECONDS. CAPPED TN-15.
1058	50 ml TN + 7.6 g NaOH → SAMPLE SET ASIDE TO COOL TO AMBIENT TO CHECK AFFECT OF STARTING TEMP.

SUMMARY :

TN TREATABILITY

7580

LOG SHEET

DATE: 5-10-95 PAGE: 8 DATE OF: 10 / 4

LOCATION: BW TEST LAB

TIME:

		ACTIVITY
N-16	1104	50 ml TN @ 62.5 °F + 7.6 g NaOH T_f = 86 °F
	1108	ADD 90 g P-100
	1111	T = 84.5 °F, ADD 40 g MMP30 (30 SECOND ADD TIME)
	1113	T = 86 °F
	1115	T = 88.5 °F
	1117	T = 92.5 °F
	1119	T = 99 °F
	1121	T = 109.5 °F
	1123	T = 119.5 °F
	1125	T = 123.5 °F
	1127	T = 123.5 °F
	1129	T = 121 °F SAMPLE HAS THICKENED TO A SOLID. CAPPED TN-16
N-17	1335	SAMPLE PREPARED AT 1058 IS @ 64.5 °F → ADD 90 g P-100
		↳ COOLED w/ICE.
	1337	T = 71 °F → TEMP ↑ DUE TO P-100 BEING AT ROOM TEMP (72 °F)
		ADD 40 g MMP30 IN 15 SECONDS - INITIAL MIX A LITTLE STIFFER DUE TO LOWER TEMP.
	1339	T = 75.5 °F
	1341	T = 77.5 °F
	1343	T = 79 °F
	1345	T = 82 °F
	1347	T = 85.5 °F
	1349	T = 90.5 °F
	1351	T = 98 °F
	1353	T = 107.5 °F
	1355	T = 114 °F
	1357	T = 117 °F
	1359	T = 117 °F
	1400	T = 116 °F SAMPLE THICKENED TO SOLID. CAPPED TN-17
N-18	1417	50 ml TN @ 69 °F + 7.6 g NaOH T_f = 92 °F
	1419	ADD 90 g P-100
	1422	T = 91 °F, ADD 40 g MMP30 IN 25 SECONDS
	1424	T = 94 °F, STOPPED STIRRING, CAPPED AND SET ASIDE.
N-19	1445	50 ml TN @ 70 °F + 7.6 g NaOH T_f = 92.5 °F AC OFF
	1448	ADD 90 g P-100
	1450	T = 92 °F ADD 40 g HUBER 100 IN 30 SECONDS
	1452	T = 94 °F
	1454	T = 98 °F
	1456	T = 106.5 °F
	1458	T = 116 °F
	1500	T = 123.5 °F
	1502	T = 126 °F
	1504	T = 126.5 °F
	1506	T = 126 °F
	1508	T = 125 °F
	1510	T = 123 °F
	1512	T = 120.5 °F
	1514	T = 119.5 °F

SUMMARY :

000125

TN TREATABILITY

LOG SHEET

DATE: 5-10-95

PAGE: 9

DATE OF: 7580 10/4

LOCATION: BW TEST LAB

TIME:

ACTIVITY

CONT'D	1516	T= 117.5°F
	1518	T = 115 °F BEGINNING TO THICKEN
	1519	SAMPLE THICKEN TO A SOLID. CAPPED TN-19.
N-20	1528	50 ml TN @ 71°F + 7.6 NaOH T_f = 93°F
	1531	ADD 90 g P-100
	1533	T=91.5°F ADD 40 g HUBER 100 IN 20 SECONDS
	1535	T= 93.5°F
	1537	T= 97.5°F
	1539	T= 107 °F
	1541	T= 114.5°F
	1543	T= 120 °F
	1545	T= 122 °F
	1547	T= 121.5°F
	1548	T= 121.5 °F STOPPED MIXING, SAMPLE VERY FLUID. CAPPED TN-20
	1549	TN-15 THROUGH TN-20 IN OVEN (140°F) OUT OF LAB.

SUMMARY :

TN TREATABILITY

LOG SHEET

DATE: 5-17-95

LOCATION: BW TEST LAB

TIME:

PAGE: 10 7580 DATE OF: 10/4

ACTIVITY

0930 ENTERED LAB TO PERFORM FINAL INSPECTION AND PACKAGE SAMPLES FOR RETURN TO FERMCO.

SAMPLE	DESCRIPTION	VOLUME (ml)	MASS (g)	RAD LEVELS (OC/1FT IN mR/HR)	COLOR
TN-1	CRUMBLY	~100 ml	131.7 g	1.5/0.1	LIGHT GRAY
TN-2	HARD	130 ml	183.9	1.4/<0.1	MEDIUM GRAY
TN-5	CRUMBLY	~100 ml	89.9	1.3/<0.1	WHITE
TN-6	CLAY LIKE	150 ml	201.6	1.3/<0.1	DARK GRAY
TN-7	CRUMBLY	~100 ml	127.1	1.5/0.1	MEDIUM GRAY
TN-9	HARD	115 ml	221	1.5/0.1	DARK GRAY
TN-10	HARD	115 ml	225.9	1.6/<0.1	DARK GRAY
TN-11	HARD AND GRAINY	90 ml	168.4	1.7/<0.1	WHITE
TN-12	HARD	115 ml	221.1	1.5/<0.1	DARK GRAY
TN-13*	HARD, FREE LIQUID ON TOP	~105 ml	203	1.7/<0.1	DARK GRAY
TN-14*	HARD, FREE LIQUID ON TOP	~110 ml	203.7	1.6/<0.1	DARK GRAY
TN-15	HARD	125 ml	224.6	1.4/<0.1	DARK GRAY
TN-16	HARD	120 ml	218.6	1.5/<0.1	DARK GRAY
TN-17	HARD	125 ml	219.4	1.6/<0.1	DARK GRAY
TN-18*	HARD, 2-3 ml FREE LIQUID ON TOP	110 ml	218.6	1.6/<0.1	DARK GRAY
TN-19	HARD	120 ml	217.9	1.6/<0.1	DARK GRAY
TN-20*	HARD, SOFT SURFACE LAYER (~1/16")	120 ml	218.5	1.6/<0.1	DARK GRAY

* ADDED ADDITIONAL DRY P-CEMENT TO SOLIDIFY FREE LIQUID.
MASS = WASTE MASS (GROSS - 24.1 g FOR PCP CUP/LID w/o TAPE & STICKERS)

1100 COMPLETED INSPECTING & PACKAGING TN SAMPLES FOR SHIPMENT TO FERMCO.

1445 COMPLETED SHIPPING PW/ SAMPLES SHIPPED VIA FEDEX TO FERMCO.

SUMMARY:

SURROGATE WASTE CHARACTERIZATION

WASTE FORM T2 (THORIUM NITRATE) CLEAR LIQUID

SURROGATE WASTE CONSTITUENTS AND QUANTITY:

FREE ACID CONTENT	0.72 N
U-233,234	1.4×10^6 pCi/l EACH
TH-232	4.1×10^7 pCi/l
TH-230	1.0×10^7 pCi/l
TH-228	3.8×10^7 pCi/l
PU-238	7.1×10^6 pCi/l

PHYSICAL PARAMETERS

pH: 0-0.5

SPECIFIC GRAVITY: 1.661

TEMPERATURE: SEE LOGSHEETS

% SOLIDS (IF APPLICABLE): NONE VISIBLE

OTHER PROPERTIES:

PREPARED BY: Scott A. [illegible] DATE: 5-29-95

WASTE FORM IDENTIFICATION: TN-1

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %50

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-40 → 58.7g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH = ~2.0, ADD P-40, SEAL PCP CUP AND PLACE IN OVEN (~150°F) FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 c HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-2

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %38.5

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): H_2O - 50 ml ; 25% NaOH - 7.6 g ; P-40 → 60.7 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD H_2O, ADD NaOH TO RAISE pH ~2.0, ADD P-40 SEAL PCP CUP AND PLACE IN ~150 °F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-3

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %35.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): H_2O - 50 ml; 25% NaOH - 7.6g; P-40 → 72g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD H_2O; ADD NaOH TO RAISE pH = ~2.0; ADD P-40 AND SEAL PCP CUP, PLACE IN ~150 °F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-4

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %41.7

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 47.5g ; P-40 → 52.2 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH > 2.0, ADD P-40 AND SEAL PCP CUP, PLACE IN ~150 °F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-5

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %50.0

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): H_2O - 50 ml; 25% NaOH - 7.6 g; RPB - 37 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD H_2O, ADD NaOH TO RAISE pH ~2.0, ADD RPB AND SEAL PCP CUP, PLACE IN ~150 °F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-6 7580

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %33.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): H_2O - 50 ml ; 25% NaOH - 7.6 g ; T32A - 3.1 g ; P-40 → 62.4 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD H_2O, ADD NaOH TO RAISE pH ~2.0, ADD T32A, ADD P-40 AND SEAL PCP CUP, PLACE IN ~150 °F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-7

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-19-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %50.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 50% NaOH - 35.4 g ; P-40 → 21.7 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH > 2.0, ADD P-40 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-8

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4-20-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %38.5

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): H_2O - 50 ml; 25% NaOH - 7.6 g; P-40 → 60.7 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD H_2O, ADD NaOH TO RAISE pH ~ 2.0, ADD P-40 AND SEAL PCP CUP,

~~PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.~~ * THIS SAMPLE NOT PLACED IN OVEN TO SIMUL USING DRUMS VICE B-25 BOXES.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-9

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 4/20/95 & 5/9/95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %43.5

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 103.7g ; MMP30 - 33.8g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES: ✓ (1) NO:____

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

(1) SEE LOGSHEET FOR COMMENTS

~~ABBY SPECIMEN PREPARATION~~

7580

WASTE FORM IDENTIFICATION: TN-10

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-9-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %43.8

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6 g ; P-100 → 90 g ; mmP30 - 46.6 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES: (1) NO:____

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

(1) SEE LOGSHEET FOR COMMENTS

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-11

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-9-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %55.6

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; MMP30 - 80g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

WASTE FORM IDENTIFICATION: TN-12

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-9-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %43.8

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% $NaOH$ - 7.6g; P-100 → 75g; MMP30 - 60g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD $NaOH$ TO RAISE pH ~2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

AREA SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-13

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-9-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %47.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g; P-100 - 75g; MMP30 - 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES: ✓ NO:____

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-14

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-9-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %45.5

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 75g ; PREMIER 98 HB - 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~ 2.0, ADD P-100, ADD PREMIER 98 HB AND CAP PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES: ✓ NO:____

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-15

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %40.0

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 90g ; MMP30 - 45g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~ 2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

WASTE FORM IDENTIFICATION: TN-16

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %41.7

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 90g ; MMP30 - 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~ 2.0, ADD P-100, AND MMP30 AND SEAL PLP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-17

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %40.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25 % NaOH - 7.6 g ; P-100 → 90 g ; MMP30 - 40 g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

ABBR SPECIMEN PREPARATION

WASTE FORM IDENTIFICATION: TN-18

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %45.5

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 90g ; MMP30 - 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD P-100, ADD MMP30 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A
NOT TESTING FOR COMPRESSIVE STRENGTH.
5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES: ✓ NO:____

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

TEST SPECIMEN PREPARATION

7580

WASTE FORM IDENTIFICATION: TN-19

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %41.7

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25% NaOH - 7.6g ; P-100 → 90g ; HUBER 100 → 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~2.0, ADD P-100, ADD HUBER 100 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

WASTE FORM IDENTIFICATION: TN- 20

NOTEBOOK REFERENCES: TN TREATABILITY LOGSHEETS

DATE PREPARED: 5-10-95 PREPARED BY: CARLSON/JOHNSON

PORTION OF WASTE INCORPORATED IN SOLIDIFIED PRODUCT WT. %__ VOL. %41.

COMPOSITION OF (SURROGATE) WASTE: 50 ml DIRECT FROM TN SAMPLE BOTTLE

COMPOSITION OF SOLIDIFICATION FORMULA (INCLUDING ADDITIVES AND MODIFIERS): 25.% NaOH - 7.6g ; P-100 → 90g ; HUBER 100 - 40g

PREPARATION OF TEST SPECIMENS: (INCLUDE CURE PROTOCOL AND TEMPERATURE: ADD NaOH TO RAISE pH ~ 2.0, ADD P-100, ADD HUBER 100 AND SEAL PCP CUP, PLACE IN ~150°F OVEN FOR MINIMUM OF 3 DAYS.

SHAPE AND DIMENSIONS OF SPECIMEN:

1. CYLINDER 2" DIAMETER X 4" LENGTH (ALL TESTS EXCEPT LEACHABILITY).

2. TRUNCATED CONE, TOP DIAMETER 7.5 cm, BOTTOM DIAMETER 7.0 cm HEIGHT 6.0 cm. (LEACHABILITY ONLY) VOLUME: 250cc SURFACE AREA: 220 cm^2.

~~INITIAL COMPRESSIVE STRENGTH OF THREE CYLINDERS AFTER 28 DAY CURE:~~

~~CYLINDER 1:_____ CYLINDER 2: _____ CYLINDER 3: _____~~

N/A NOT TESTING FOR COMPRESSIVE STRENGTH. 5-29-95

~~INITIAL COMPRESSIVE STRENGTH OF TEN CYLINDERS PREPARED FROM THIS BATCH:~~

~~CYLINDER 4:_____ CYLINDER 5:_____ CYLINDER 6:_____ CYLINDER 7:_____~~

~~CYLINDER 8:_____ CYLINDER 9:_____ CYLINDER 10:_____ CYLINDER 11:_____~~

~~CYLINDER 12:_____ CYLINDER 13:_____~~

~~AVERAGE COMPRESSIVE STRENGTH:_____ ± _____~~

FREE LIQUID OBSERVED AFTER CURE OF LEACH SPECIMEN? YES:____ NO: ✓

OTHER OBSERVATIONS: SEE TN TREATABILITY LOGSHEETS FOR ADDITIONAL INFORMATION.

WASTE FORM LEACHABILITY TEST LOG

SAMPLE IDENTIFICATION:_____ NOTEBOOK REFERENCE:_____

NUCLIDE:_____
A_0:_____
LEACH TEST STARTED:_____
FREE LIQUID:_____

Interval Number	Amount Leached a_n µCi	$\frac{a_n}{A_o}$	Cum. $\frac{a_n}{A_o}$	Int. Time $(\Delta t)_n$ Sec.	Cum. Time $\Sigma(\Delta t)_n$ Sec.	$A=\left[\frac{\frac{a_n}{A_o}}{(\Delta t)_n}\right]^2$	$T=\left(\frac{\sqrt{\Sigma(\Delta t)_n}+\sqrt{\Sigma(\Delta t)_{n-1}}}{2}\right)^2$	$D=\pi(A)(T)(1.2913)^*$	LIX (-log D)	Est. LIX if Cum. $\frac{a_n}{A_o} > .20^{**}$
1										
2										
3										
4										
5										
6										
7										
								AVERAGE OF ALL LIX VALUES:		

*Produce of $(V/S)^2$ For Particular Test Block Used By CNSI, $(250\ cm^3/220\ cm^2)^2 = 1.2913$

**In ANS-16.1 Determine Shape Factor, "G", From Table I For L/d = 1; then $D = \frac{Gd^2}{\Sigma(\Delta t)n}$ (d = 6.6 cm.)

Calculated Values: Correlation Coefficient:_____
Confidence Range:_____

Comments/Observations:_____

DATE:_____ ANALYST:_____

N A

FERMCO PERFORMING TCLP

5-29-95

2580

000149

LEACH TEST CALCULATION SHEET

SAMPLE IDENTIFICATION: _____
INTERVAL NUMBER: _____
SAMPLE DATE (HOUR & DAY): _____
ANALYSIS DATE: _____
VOLUME OF LEACHATE SAMPLE: _____
COUNT TIME (MINUTES): _____
ANALYST: _____

	Sr-85	Cs-137	Co-60
COUNTS DISPLAYED:	_____	_____	_____

DEAD TIME RANGE DISPLAYED: _____%

Sr-85 Leached (a_n) = Sr-85 Counts_____ X 6.70 X 10^{-6} X $e^{.0107(\text{Days})}$*

_____ = _____ μCi

_____(Efficiency Sr-85)

Cs-137 Leached (a_n) = Cs-137 Counts_____ X 7.77 X 10^{-6}

N A _____ = _____ μCi

_____(Efficiency Cs-137)

Co-60 Leached (a_n) = Co-60 Counts _____ X 6.61 X 10^{-6}

_____ = _____ μCi

_____(Efficiency Co-60)

*NOTE 1: Because of the short half-life for Sr-85 (about 65 days), the time in days between sample analysis and analysis of the nuclide source material must be factored into determination of (a_n). This correction may be normally omitted for Cs-137 and Co-60 with respective half-lives of 30 and 5 years.

NOTE 2: The above equations for determining (a_n) values from observed counts are simplified to avoid repetitive calculations. The following test variables must be maintained at the stated levels for these equations to be valid.

Volume of undiluted leachate analyzed = 15 cc
Total volume of leachate = 2200 cc
Count time (EG&G Multi-channel Analyzer) = 10 minutes (Live Time)

NOTE 3: The CNSI Leach Laboratory is thermostatically controlled to 73 ± 2°F.

FERMCO PERFORMING TCLP

000150

BIODEGRADATION EXPOSURE TEST LOG

WASTE FORM IDENTIFICATION: _____

SPECIMEN TYPE: _____

NOTEBOOK REFERENCES: _____

SAMPLES EXPOSED BY: _____

DATE SHIPPED TO VENDOR: _____

COMPRESSIVE STRENGTH RESULTS

AFTER BIOLOGICAL EXPOSURE

SAMPLE	BREAK STRENGTH (LBS)	COMPRESSIVE STRENGTH (psi)
A		
B	N/A	
C		

AVERAGE COMPRESSIVE STRENGTH: _____ ± _____

DATE _____ ANALYST _____

VENDOR OBSERVATIONS: _____

_____

SAMPLES NOT BEING ANALYZED PAW 10 CFR 61

AFTER FUNGAL EXPOSURE

SAMPLE	BREAK STRENGTH (LBS	COMPRESSIVE STRENGTH (psi)
A		
B		
C		

AVERAGE COMPRESSIVE STRENGTH: _____ ± _____

DATE _____ ANALYST _____

VENDOR OBSERVATIONS: _____

_____

5-29-95

10E08[R] RADIATION EXPOSURE TEST LOG

WASTE FORM IDENTIFICATION: _____

SPECIMEN TYPE: _____

NOTEBOOK REFERENCES: _____

SAMPLES IRRADIATED BY: _____

DATE SHIPPED TO VENDOR: _____

CERTIFIED TOTAL DOSAGE APPLIED: _____

COMPRESSIVE STRENGTH RESULTS

AFTER IRRADIATION

SAMPLE	BREAK STRENGTH (LBS)	COMPRESSIVE STRENGTH (psi)
A	N/A	
B	SAMPLES	
C	NOT BEING	

ANALYZED IAW 10 CFR 61

AVERAGE COMPRESSIVE STRENGTH BEFORE IRRADIATION: _____ ± _____

DATE _____ ANALYST _____

VENDOR OBSERVATIONS: _____

_____

5-29-95

THERMAL C' G TEST LOG

FREEZER: -40°C. for 3 Hours*
OVEN: +60°C. for 3 Hours
*Condition samples of ambient temperature for at least one hour after removal from inside freezer and/or oven.

DATE	CYCLE NO.	FREEZER PROBE TEMP. °C		OVEN TEMP. °C		DATE	CYCLE NO.	FREEZER PROBE TEMPERATURE °C		OVEN TEMP. °C	
		Start	Finish	Start	Finish			Start	Finish	Start	Finish
	01						16				
	02						17				
	03						18				
	04						19				
	05						20				
	06						21				
	07						22				
	08						23				
	09						24				
	10						25				
	11						26				
	12						27				
	13						28				
	14						29				
	15						30				

N/A
SAMPLES NOT BEING TESTED SAW 10 CYCLES
5-29-95

COMMENTS AND OBSERVATIONS:_____

BREAK STRENGTH_____LBS COMPRESSIVE STRENGTH____psi
_____LBS _____psi
Ave. _____LBS Ave. _____psi +/- _____

DATE_____ ANALYST_____ DATE_____ ANALYST_____

000153

2580

000154

WATER IMMERSION TEST LOG

ASTE FORM_____ SPECIMEN TYPE_____

OTEBOOK REFERENCE_____ WATER TYPE_____

DATE	TOTAL IMMERSION TIME, DAYS	SPEC.	INITIAL WEIGHT (DRY) gms	FINAL WEIGHT (WET) gms	WEIGHT CHANGE %	BREAK STRENGT Hpsi	COMPRESSIVE STRENGTH, lbs	ANALYST
		A						
		B						
		C						
		D						
		E						
		F						
		G						
		H						
		I						
		J						
		K						
		L						

N/A SAMPLES NOT BEING ANALYZED TAW 10-5-92

5-29-95

OMMENTS AND OBSERVATIONS:_____

AVERAGE COMPRESSIVE STRENGH BEFORE IMMERSION:_____ +/- _____

AFTER 90 DAYS:_____ +/- _____

AFTER 120 DAYS:_____ +/- _____

AFTER 150 DAYS:_____ +/- _____

AFTER 180 DAYS:_____ +/- _____

ATE:_____ ANALYST:_____

APPENDIX D

TCLP TEST RESULTS

(6 PAGES)

DATA CHEM LABORATORIES
A Sorenson Company

FORM A (TYPE I)
SINGLE METHOD ANALYSES

Form RLIMS63A-V1.0
05099518523445

SAMPLE ANALYSIS DATA SHEET

S9543039

Date Printed.....: 09-MAY-95 18:52
Client Sample Name: 2000151332 |TM-3
DCL Sample Name...: MXS 03559

Client Name.....: FERMCO
Client Ref Number....: Contract 8434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Matrix.....: CODE Z
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☐ As Received ☐ Dried

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2AZ

DCL Preparation Group: G954404J
Date Prepared.....: 05-MAY-95 00:00
Preparation Method...: 1311/3015
Aliquot Weight/Volume: Not Applicable
Net Weight/Volume....: 203.5
Date TCLP Prepared...: 04-MAY-95 00:00

DCL Analysis Group: G954404J
Analysis Method...: 6010
Instrument Type...: ICP
Instrument ID.....:
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Arsenic	08-MAY-95 00:00	0.5	ND			5.0
Barium	08-MAY-95 00:00	0.02	0.71			100
Cadmium	08-MAY-95 00:00	0.01	ND			1.0
Chromium	08-MAY-95 00:00	0.02	0.03			5.0
Lead	08-MAY-95 00:00	0.1	ND			5.0
Selenium	08-MAY-95 00:00	0.3	ND			1.0
Silver	08-MAY-95 00:00	0.02	ND			5.0

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FORM A (TYPE I)
SINGLE METHOD ANALYSES

SAMPLE ANALYSIS DATA SHEET

7580

Form RLIM363A-V1.0
05099500385199
Page 6

S954303D

Date Printed.....: 09-MAY-95 00:38
Client Sample Name: 2000151332 |TW-3
DCL Sample Name...: MXS 03559

Client Name.....: FERMCO
Client Ref Number....: Contract #434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Matrix.....: CODE E
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☒ As Received ☐ Dried

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2BE

DCL Preparation Group: G954404H
Date Prepared.....: 08-MAY-95 00:00
Preparation Method...: 1311
Aliquot Weight/Volume: 50mL
Wet Weight/Volume....: 203.5
Date TCLP Prepared...: 04-MAY-95 00:00

DCL Analysis Group: G954404H
Analysis Method...: 7470
Instrument Type...: CVAA
Instrument ID.....: AAS-CVE
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Mercury	08-MAY-95 00:00	0.0002	ND		2	0.2

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SAMPLE ANALYSIS DATA SHEET

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05099518523445
Page 10

5954303B

Date Printed.....: 09-MAY-95 18:52
Client Sample Name: 2000151334 |TM-4
DCL Sample Name...: MXS 03560

Client Name.....: FERMCO
Client Ref Number....: Contract #434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Matrix.....: CODE E
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☐ As Received ☐ Dried

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2AE

DCL Preparation Group: G954404J
Date Prepared.....: 05-MAY-95 00:00
Preparation Method...: 1311/3015
Aliquot Weight/Volume: Not Applicable
Net Weight/Volume....: 191.5
Date TCLP Prepared...: 04-MAY-95 00:00

DCL Analysis Group: G954404J
Analysis Method...: 6010
Instrument Type...: ICP
Instrument ID.....:
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Arsenic	08-MAY-95 00:00	0.5	ND			5.0
Barium	08-MAY-95 00:00	0.02	0.56			100
Cadmium	08-MAY-95 00:00	0.01	ND			1.0
Chromium	08-MAY-95 00:00	0.02	0.08			5.0
Lead	08-MAY-95 00:00	0.1	ND			5.0
Selenium	08-MAY-95 00:00	0.3	ND			1.0
Silver	08-MAY-95 00:00	0.02	ND			5.0

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FORM A (TYPE I)
SINGLE METHOD ANALYSES

SAMPLE ANALYSIS DATA SHEET

Form RLIMS63A-V1.0
05099500385199
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S954303F

Date Printed.....: 09-MAY-95 00:38
Client Sample Name: 2000151334 |TM-4
DCL Sample Name...: MXS 03560

Client Name.....: FERMCO
Client Ref Number....: Contract #434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Matrix.....: CODE E
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☒ As Received ☐ Dried

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2BE

DCL Preparation Group: G954404H
Date Prepared.....: 08-MAY-95 00:00
Preparation Method...: 1311
Aliquot Weight/Volume: 50mL
Net Weight/Volume....: 191.5
Date TCLP Prepared...: 04-MAY-95 00:00

DCL Analysis Group: G954404H
Analysis Method...: 7470
Instrument Type...: CVAA
Instrument ID.....: AAS-CVE
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Mercury	08-MAY-95 00:00	0.0002	ND		2	0.2

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FORM A (TYPE I)
SINGLE METHOD ANALYSES

SAMPLE ANALYSIS DATA SHEET

Form RLIMS63A-V1.0
0509951852344 5
Page 11

8954303C

Date Printed.....: 09-MAY-95 18:52
Client Sample Name: 2000151335 |TB-8
DCL Sample Name...: MXS 03561

Client Name.....: FERMCO
Client Ref Number....: Contract #434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Matrix.....: CODE E
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☐ As Received ☐ Dried

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2AE

DCL Preparation Group: G954404J
Date Prepared.....: 05-MAY-95 00:00
Preparation Method...: 1311/3015
Aliquot Weight/Volume: Not Applicable
Net Weight/Volume....: 223.1
Date TCLP Prepared...: 04-MAY-95 00:00

DCL Analysis Group: G954404J
Analysis Method...: 6010
Instrument Type...: ICP
Instrument ID.....:
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Arsenic	08-MAY-95 00:00	0.5	ND			5.0
Barium	08-MAY-95 00:00	0.02	1.7			100
Cadmium	08-MAY-95 00:00	0.01	ND			1.0
Chromium	08-MAY-95 00:00	0.02	0.10			5.0
Lead	08-MAY-95 00:00	0.1	ND			5.0
Selenium	08-MAY-95 00:00	0.3	ND			1.0
Silver	08-MAY-95 00:00	0.02	ND			5.0

000160

0020

DATA CHEM LABORATORIES
A Sorenson Company

FORM A (TYPE I)
SINGLE METHOD ANALYSES

SAMPLE ANALYSIS DATA SHEET

S954303G

Client Name.....: FERMCO
Client Ref Number....: Contract #434287 - Mixed Waste
Sampling Site.....: Not Provided
Release Number.....: F5030

Date Received.....: 04-MAY-95 00:00
DCL Client Group.....: MX-0185-2BE

DCL Preparation Group: G954404H
Date Prepared.....: 08-MAY-95 00:00
Preparation Method...: 1311
Aliquot Weight/Volume: 50mL
Net Weight/Volume....: 223.1
Date TCLP Prepared...: 04-MAY-95 00:00

Date Printed.....: 09-MAY-95 00:38
Client Sample Name: 2000151335 |TW-8
DCL Sample Name...: MXS 03561

Matrix.....: CODE E
Date Sampled.....: 03-MAY-95 00:00
Reporting Units...: mg/L
Report Basis.....: ☒ As Received ☐ Dried

DCL Analysis Group: G954404H
Analysis Method...: 7470
Instrument Type...: CVAA
Instrument ID.....: AAS-CVE
Column Type.....: Not Applicable

Analytical Results

Analyte	Date Analyzed	PQL	Result	Flag	Dilution	Regulatory Limit
Mercury	08-MAY-95 00:00	0.0002	ND		2	0.2

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FINAL REPORT
FEMP/SUB-098
UC-706

ANALYSIS OF POTENTIAL SURFACE BLASTING DECONTAMINATION TECHNOLOGIES FOR STRUCTURAL STEEL

M.A. Ebadian, Ph.D. & L.E. Lagos
Principal Investigators

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FEMP/SUB-098
UC-706

ANALYSIS OF POTENTIAL SURFACE BLASTING DECONTAMINATION TECHNOLOGIES FOR STRUCTURAL STEEL

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Fernald Field Office

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ABSTRACT

During the decontamination and dismantlement (D&D) activities at the Fernald Environmental Management Project (FEMP) approximately 15,041 tons of contaminated structural steel will be generated from the D&D of approximately 200 buildings and other structures. The majority of the structural steel is considered to be radiologically contaminated. The D&D activities require the treatment of the structural steel to reduce occupational and environmental radiological exposures during dismantlement. Treatment technologies may also be required for possible recycling. Many proven commercial treatment technologies are available. These treatment processes vary in aggressiveness, safety requirements, secondary waste generation, and capital, operating and maintenance costs. Choosing the appropriate technology to meet the decontamination objectives for structural steel is a difficult process. A single information source comparing technologies in the areas of safety, cost, and effectiveness is not currently commercially available to perform a detailed analysis. This study presents comparable data related to operation, maintenance, cost, health and safety aspects of seven prominent commercially available blasting technologies for nuclear decontamination. The technologies include: ultra high pressure water (< 55,000 psi and ≥ 15,000 psi), high pressure water (< 15,000 psi and > 1,000 psi), carbon dioxide (CO_2) pellets, sponge, steel grit, wet ice, and plastic. Soda blasting, an emerging blasting technology, was also included in the study.

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1 INTRODUCTION

During the decontamination and dismantlement (D&D) activities at the Fernald Environmental Management Project (FEMP) approximately 15,041 tons of contaminated structural steel will be generated from the D&D of approximately 200 buildings and other structures. The majority of the structural steel will be considered to be radiologically contaminated.

The Fernald site is owned by the Department of Energy (DOE). It is a contractor-operated federal facility that produced high-purity uranium metal products for the DOE and its predecessor agency, the Atomic Energy Commission, from 1952 to 1989. Thorium bearing ores were also processed at the FEMP, but on a smaller scale. Production activities ceased in 1989, and the production mission of the facility was formally ended in 1991. The FEMP was included on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List in 1989. The current mission of the site is environmental restoration according to the requirements of CERCLA.

The D&D activities require the treatment of the structural steel to reduce occupational and environmental radiological exposures during dismantlement. Treatment technologies may also be required for possible recycling. Many proven commercial treatment technologies are available. These treatment processes vary in aggressiveness, safety requirements, secondary waste generation, capital, and operating and maintenance costs. Choosing the appropriate and most effective technology to meet the decontamination objectives for structural steel is a difficult process. A single information source comparing technologies in the areas of safety, cost, and effectiveness is not currently commercially available to perform a detailed analysis.

The two primary decontamination objectives are: 1) a reduction in the surface contamination levels to reduce potential personnel and environmental exposure and 2) the reduction of surface contamination levels to meet DOE Order 5400.5 for unrestricted use. Decontamination objectives are developed on project and/or site specific basis. The decontamination of steel in the majority of the cases is surface cleaning or the removal of surface coating and/or rust removal. The decontamination technology will be required to perform a surface cleaning or achieve a white metal surface or some point in between. This engineering study was tailored to meet the decontamination

objectives of the FEMP and was also designed to be applicable to other environmental restoration sites.

2 CONCLUSIONS

The purpose of the study was to provide a source of comparable data for structural steel nuclear decontamination using commercially available blasting technologies. The tables shown in Appendix 9.2 provide the conclusion to the study. It can be concluded from this study that all technologies demonstrated positive and negative aspects related to their operation that need to be considered before any technology can be implemented at a specific site. The field engineer should be aware of the benefits and limitations that each technology has to offer. For example, technologies that used a closed vacuum system such as steel grit and plastic media, had the advantage of collecting and recycling the media, as well as, the removed surface with minimum exposure to the operator or the surrounding area. However, the production rates for these closed systems were slower compared to open systems such as ultra high pressure water, CO_2, sponge, soda, or wet ice. On the other hand, these open systems had high production rates, but the secondary waste stream was not recovered or collected, and the operator and the surrounding area were exposed to this waste stream. The correct solutions to meet the decontamination objectives are site specific. The data collected in Appendix 9.2 is intended to represent the factors that are required to make this site specific conclusions. A unit/operating cost was developed based on the results of this study along with some assumptions that are listed in Section 5.3 item 6. It is important to note that waste disposal costs are not included in this unit/operating cost value. Within each technology class, a group of sub categories exists. These individual subcategories offer technology variations that may improve the overall technology viability to achieve the individual decontamination objectives. These technological differences are not discussed in this study. It is left to the reader to research and review these technological differences. Table 6 presents the subcategory tested as part of this engineering study.

3 ENGINEERING STUDY APPROACH

3.1 Test Objective

The objective of this test was to perform a comparative analysis of commercially available structural steel decontamination blasting technologies applicable to the D&D of the FEMP structures and assess applicability to other environmental restoration sites. The basis for this comparative analysis included:

- determining the quantities of structural steel for each standard shape at the FEMP;
- determining the predominant surface conditions/types of structural steel at the FEMP;
- defining the end point achieved;
- determining the types of blasting technologies to be tested; and
- determining the effectiveness, implementability, and cost of utilizing the various technologies.

3.1.a. Determining the Quantities of Structural Steel for each Standard Shape at the FEMP.

The FEMP operates a Site-wide Waste Information, Forecasting, and Tracking System (SWIFTS) database that manages information concerning site-wide wastes. A subset of this database is the information related to Operable Unit 3 (OU3), above ground structures. The database contains all necessary information to obtain the quantities of structural steel in the forms of I-beams, plates, channels, and angles per process area as defined by the OU3 Work Plan Addendum (WPA). Because the quantity of I-beams and plates found at the FEMP are greater than the quantity of channels and angles, and the

standard channels and angles are a subset of the I-beam geometry, the channels and angles were excluded from this study.

3.1.b. Determining the Predominant Surface Conditions/Types of Structural Steel at the FEMP.

Using the OU3 WPA defined process areas, visual inspections were performed in each of the main process buildings (18 buildings were inspected) to determine the surface condition (no rust, light rust, rust, heavy rust) and paint specification (3000G, 3000C, 3000F, 3000H, 3000N) in each process area. The data presented in Figures 3.1.b.1 and 3.1.b.2 represent the two main classifications of structural steel found at the FEMP that are I-beams and plates. Figures 3.1.b.1 and 3.1.b.2 represent the quantity of plates in square feet or I-beams in linear feet and rust condition versus paint type found at the FEMP.

The review of the data consisted of choosing the largest quantity of steel within each geometry and the most common paint type. The data presented in Figures 3.1.b.1 and 3.1.b.2 yield the combination of two geometries (I-beam and plate) and two surface conditions (paint and rust). These geometries and conditions were developed as surrogate materials. The following surrogates were developed and tested to obtain the information presented in Sampling and Analysis Section:

- I-beam using 3000G specification;
- I-beam with rust;
- plate using 3000H specification; and
- plate with rust.

standard channels and angles are a subset of the I-beam geometry, the channels and angles were excluded from this study.

3.1.b. Determining the Predominant Surface Conditions/Types of Structural Steel at the FEMP.

Using the OU3 WPA defined process areas, visual inspections were performed in each of the main process buildings (18 buildings were inspected) to determine the surface condition (no rust, light rust, rust, heavy rust) and paint specification (3000G, 3000C, 3000F, 3000H, 3000N) in each process area. The data presented in Figures 3.1.b.1 and 3.1.b.2 represent the two main classifications of structural steel found at the FEMP that are I-beams and plates. Figures 3.1.b.1 and 3.1.b.2 represent the quantity of plates in square feet or I-beams in linear feet and rust condition versus paint type found at the FEMP.

The review of the data consisted of choosing the largest quantity of steel within each geometry and the most common paint type. The data presented in Figures 3.1.b.1 and 3.1.b.2 yield the combination of two geometries (I-beam and plate) and two surface conditions (paint and rust). These geometries and conditions were developed as surrogate materials. The following surrogates were developed and tested to obtain the information presented in Sampling and Analysis Section:

- I-beam using 3000G specification;
- I-beam with rust;
- plate using 3000H specification; and
- plate with rust.

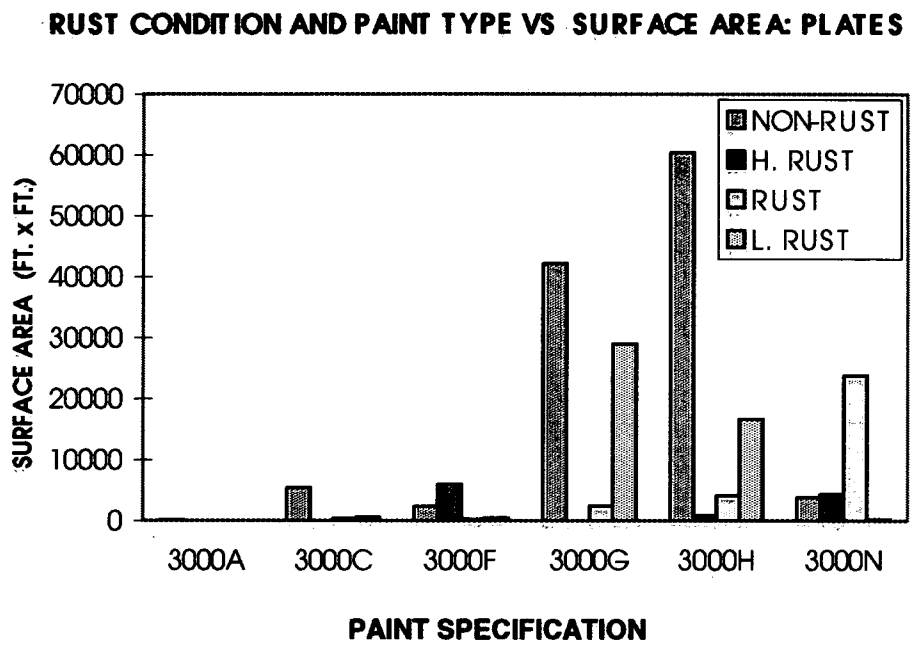

Figure 3.1.b.1

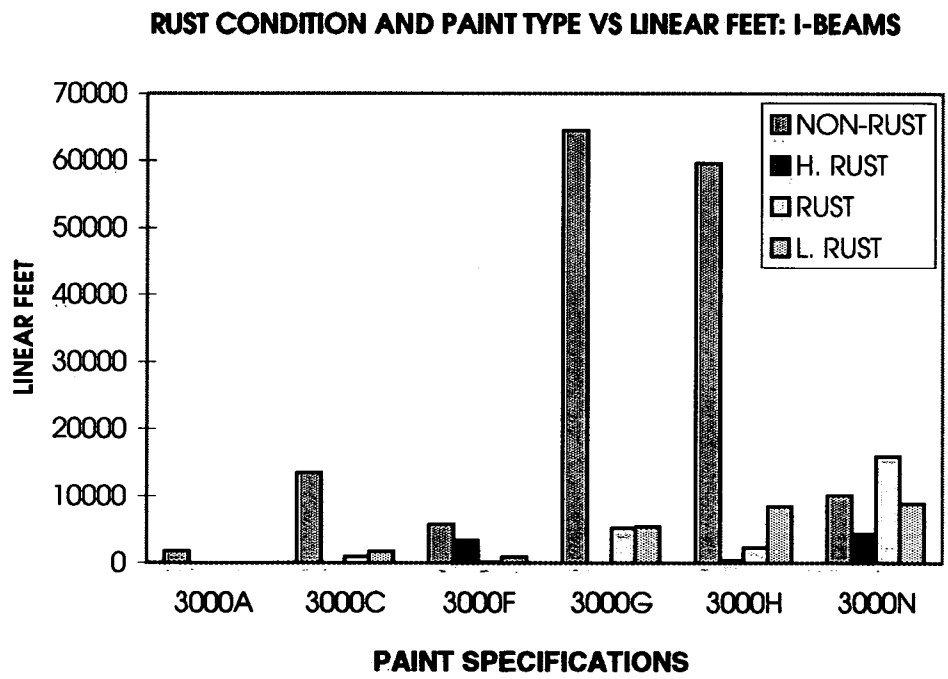

Figure 3.1.b.2

The 3000G and 3000H paint specifications are summarized below.

General Specifications (3000G). Field application of this painting was used for general specifications, unless acid resistant or solvent resistant paint was specified. All structural steel surfaces, including rivets and scarred areas, were coated with red lead primer, such as Dutch Boy® No. 51, or approved equal, before the field coat was applied. The field coat consisted of one coat of dust type, Pittsburgh® Metalleaf Aluminum Paint, Dupont® Aluminum, or approved equal, applied in strict accordance with the manufacturer's instructions. The coverage was not more than 500 sq. ft. per gallon.

Hydrofluoric Acid Atmospheres (3000H). Field application of this painting was for the process area that has hydrofluoric acid atmospheres, or for the process area related with hydrofluoric acid. All rust, loose scale, and foreign matter was removed. All structural steel surfaces, including rivets and scarred areas, were then cleaned with aromatic solvents, such as Prufcoat® 55T, before the field coating was applied. Oil-like distillates, such as kerosene, were not used. The temperature was not less than 40°F. After all surfaces had been prepared, the specified coatings were then mixed, thinned, and applied in strict accordance with the manufacturer's recommendations, which were considered as part of the surface condition's specifications. All structural steel surfaces, including rivets and scarred areas, were coated with one coat of Prufcoat® Solvent No. 55T. The field coat consisted of two coats of Standard Prufcoat®.

3.1.c Comparing the End Point Achieved to the Decontamination Objectives.

To ensure the results of this test were applicable to the different decontamination objectives and to other environmental restoration sites, the technologies were employed in the most efficient manner as determined by the vendor. The end point achieved was compared to a set of established surface finish standards. A surface end-point definition for different surface conditions was then given based on the review of the specifications of the Steel Structures Painting Council, USA, and the National Association of Corrosion Engineers, USA. These specifications do not apply to the removal of radiological contamination. These specifications are as follows:

Solvent Cleaned Surface. The solvent cleaned surface shall be free of all visible oil, grease, dirt, dust, drawing and cutting compounds, and other detrimental contaminants from the steel surface. The solvent cleaned surfaces may still have rust, rust scale, or mill scale.

Brush-Off Cleaned Surface. The brush-off cleaned surface shall be free of all visible oil, grease, dirt, dust, base mill scale, loose rust, and loose paint (i.e., tightly adhered particles that cannot be removed by lifting with a dull putty knife).

Commercially Cleaned Surface. A commercial cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products, and other foreign matter, except for staining. Staining shall be limited to no more than 33 percent of each square inch of the surface area and may consist of light shadows, slight streaks, or minor discolorations caused by rust stains, mill scale stains, or previously applied paint stains. Slight residues of rust and paint may also be left in the bottom of pits if the original surface is pitted.

Cleaned Near-White Metal Surface. A cleaned near-white surface, when viewed without magnifications, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products and other foreign matter, except for staining. Staining shall be limited to no more than five percent of each square inch of the surface area and may consist of light shadows, slight steaks or minor discolorations caused by rust stains, mill scale stains, or previously applied paint stains.

Cleaned White Metal Surface. A cleaned white surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products, and other foreign matter. The surface should have a slightly roughened gray white, uniform metallic color.

For most technologies the above end-point description did not apply, so a new set of end-point descriptions was created.

Removed Surface. A cleaned surface where paint coatings and loose rust were removed, leaving a surface free of oil, grease, dirt, or dust. There were different degrees of cleanness under this definition. These degrees of cleanness varied according to the number of coatings/rust removed. If all the conditions under a particular grade have not been met the end point was defaulted to the next lesser grade. These various degrees of cleanness were:

Grade A : This degree of cleanness grade described a surface where 80% or greater of the finish coating surface had been removed.

Grade B : This degree of cleanness grade described a surface where 80% or greater of the finish coat and 80% or greater of the sub-primer/sub coat had been removed.

Grade C : This degree of cleanness described a surface where 80% or greater of the finish coat and 80% or greater of the sub primer/sub coat and 80% of the red oxide primer had been removed.

Grade D: This degree of cleanness grade describes a surface where 80% of the loose rust had been removed from the surface.

3.1.d Determining the Types of Technologies to be Tested.

Established databases were used for categorizing and performing the initial screening of technology types. These databases include:

- DOE/EM-0142P Decommissioning Handbook,
- Final Operable Unit 3 Treatability Study Work Plan for the Fernald Environmental Management Project,
- ORNL/M-2751 Oak Ridge National Laboratory Technology Logic Diagram,

- EGG-WTD-11104 Idaho National Engineering Laboratory Decontamination and Decommissioning Technology Logic Diagram,
- Oak Ridge K-25 Site Technology Logic Diagram,
- The Environmental Protection Agency Vendor Information System for Innovative Treatment Technologies (VISITT), and
- Alternative Treatment Techniques Information Center (ATTIC) database.

These databases provided a screening based on the applicability of a technology to a given material and contaminant. Considering this review, the following commercially available blasting technologies were tested:

- ultra high pressure water (< 55,000 psi and ≥ 15,000 psi);
- high pressure water (< 15,000 psi and > 1,000 psi);
- carbon dioxide (CO_2) pellets;
- sponge;
- steel grit;
- ice; and
- plastic.

Emerging blasting decontamination technology companies were also invited to demonstrate their technologies. The test parameters remained consistent for the emerging technologies, however the emerging technology companies were not monetarily compensated to perform the testing. One soda blasting technology company chose to participate in the study.

3.1.e Surrogate Selection and Preparation.

The decontamination of steel in the majority of the cases consists of surface cleaning or removing a coating and/or rust. The percentage of steel that will require the removal of base metal is a negligible concern at the FEMP. These assumptions allow the use of surrogate materials to simulate the largest structural steel decontamination problems at the FEMP. The surrogates consisted of W6 x 9 I-beams cut at 10 feet, and 1/4" minimum thick steel plates cut at 4ft x 4ft. The I-beams were prepared and coated using the 3000G specification. I-beams that exhibited rust conditions consistent with that found at the FEMP were also prepared/collected. The steel plates were prepared and coated using the 3000H specification. Steel plates that exhibited rust conditions consistent with that found at the FEMP were also prepared/collected. A vendor was procured to prepare and paint the I-beams and plates meeting the required specifications. The remaining I-beams and plates were procured through a scrap dealer or a structural steel manufacturer/distributor. The option to procure steel and allow it to oxidize until resembles the desired "rust" condition was also used. It is estimated that 2.6 tons of I-beams and 8.2 tons of plate were used to perform the tests.

The original 3000G and the 3000H specifications were converted into year 1995 specifications. The conversions of the original paint specifications lead to the following specifications.

<u>I-beam Specification (3000G Equivalent)</u> 1) Prepare metal according to the M.A.B. technical data and application instructions. 2) Apply Rust-O-Lastic Anti-Corrosive Primer 3 mils wet to obtain 1 1/2 mils dry film thickness. 3) Wait 24 hours then apply finish coat of Rust-O-Lastic finish coating at 3 mils wet to obtain 1 1/2 mils dry film thickness.

<u>Plates Specification (3000H Equivalent)</u> 1) Prepare metal according to the M.A.B. technical data and application instructions. 2) Apply Plymastic at 8 mils wet to obtain 7 mils dry film thickness. 3) Wait 24 hours then apply finish coat of Plythane 880 coating at 3 mils wet to obtain 1 1/2 mils dry film thickness.

The following figures represent the four surrogates used in this study. Painted plate is shown in Fig 3.1.e.3, a rusted plate is shown in Fig. 3.1.e.4, a painted I-beam is shown in Fig 3.1.e.5, and a rusted I-beam is shown in Fig. 3.1.e.6

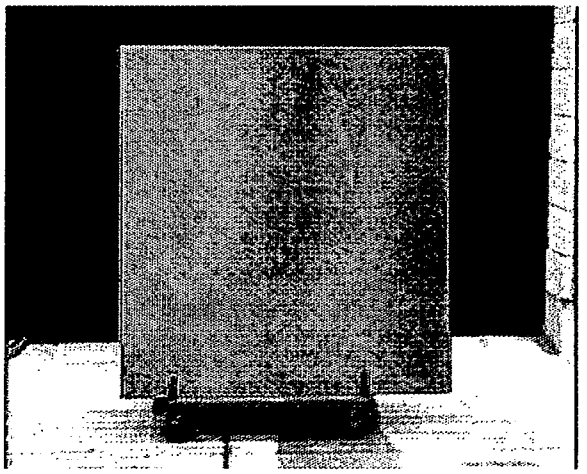

Figure 3.1.e.3 Painted Plate

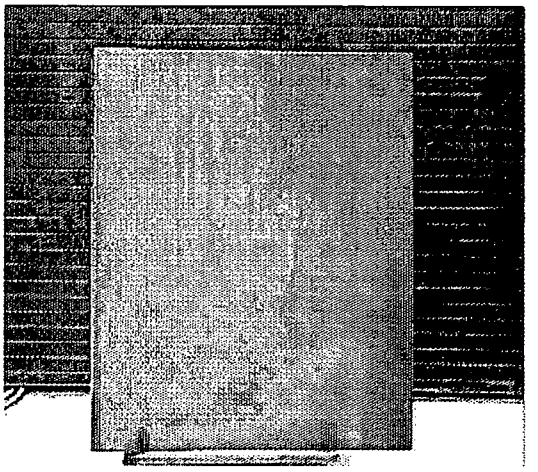

Figure 3.1.e.4 Rusted Plate

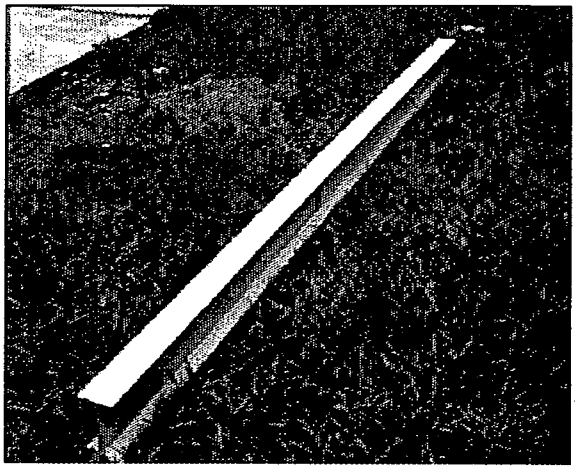

Figure 3.1.e.5 Painted I-beam

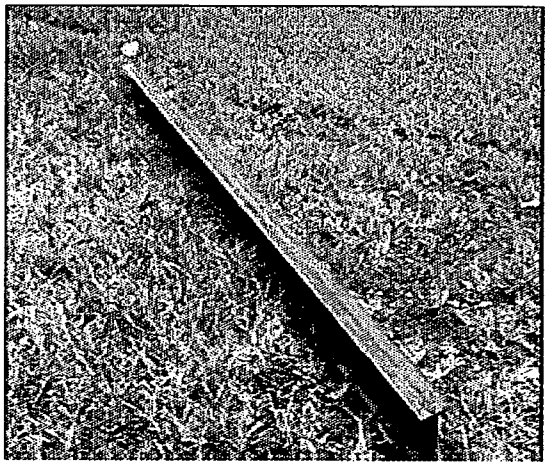

Figure 3.1.e.6 Rusted I-beam

3.2 Experimental Design and Procedures

The testing of the selected technologies was conducted under the Hemispheric Center for Environmental Technology (HCET) at the campus of Florida International University (FIU) in Miami, Florida. Each technology was tested for a minimum of four hours of actual operating time for each surrogate. This operating time provided sufficient time to collect the operational and safety information required for each technology. Additional data was collected on the capital costs, maintenance costs, and equipment staging/destaging costs. The experimental design consisted of the following factors:

- methods of obtaining technology vendors;
- test location and utility parameters; and
- data requirements.

3.2.a Methods of Obtaining Technology Vendors.

The request for qualifications of prospective bidders was advertised in the *Commerce Business Daily* (CBD). The advertisement identified the type of work to be contracted and the minimum qualifications for bidders. Qualified and interested bidders were asked to submit an expression of interest. The purpose of the advertisement was to pre-qualify prospective bidders by evaluating their response to the request to determine if they would indeed meet the qualification standards. The qualifications for the bidders included the number of years of work experience in nuclear decontamination, and references of previous work performed using the proposed technology.

Following the bid opening, the bids were reviewed to ensure that the lowest apparent bidder was responsive and responsible. Determination of responsiveness was based on proper completion of bid forms and the acknowledgment of any amendments to the invitation for bid. The lowest apparent bidder was deemed responsible if this bidder

possessed the capability and experience as required in the solicitation to perform the test in a safe and timely manner at the bid price.

3.2.b Test Location and Utilities Provided.

The tests were performed under HCET at the campus of FIU. The area available for testing consisted of an enclosure 10 feet x 16 feet x 10 feet high. The enclosure was equipped with a ventilation system maintaining 0.1 inches of water negative pressure at 10 air exchanges per hour. The enclosure was equipped with instrumentation to measure sound levels, oxygen depletion, and other potential health and safety concerns. The enclosure was capable of collecting any secondary waste generated.

The following utilities were available for use by the technology vendors:

- 60 psi, 60 gpm portable water supply;
- 90 psi, 30-40 cfm compressed air supply;
- 240 volt, 30 amp, 110 volt, 15 amp single phase; and
- 250 volt, 300 amp three phase electrical supply.

3.2.c Data Requirements.

General Information

General information included:

- Technology description
- Equipment requirements

Cost Information.

Cost information included:

- Capital cost for the purchase of equipment
- Utility cost
- Maintenance cost
- Unit/operating cost

Operational Data

The operational data included:

- Production rates
- End point achieved
- Labor classification
- Limitations
- Utility requirements
    - Power consumption calculations
    - Utility requirements
- Environmental conditions
- Secondary waste management
    - Physical condition of secondary waste
    - Quantity of media used
    - Volume of secondary waste
    - Characteristics of media
    - Weight of secondary waste
- Equipment portability
- Measurement of fuel used
- Operation/maintenance requirements

Implementation Data

The implementation data included:

- Level of training required
- Availability of equipment and supplies
- Health and safety concerns

3.3 Test Equipment and Materials

FIU supplied:

- enclosure and ventilation system;
- surrogate/material handling equipment;
- utilities as stated in "Test location and utilities provided";
- surrogate material;
- personnel monitoring instrumentation;
- project oversite; and
- sample and data collectors.

The technology vendor was required to supply the following as part of the subcontract:

- all equipment and support equipment required;
- trained operators;
- job safety analysis for each technology;
- operating procedures;
- blast media and other materials;
- project manager;
- information required to complete data requirements section;

- transportation of all equipment, materials personnel to FIU; and
- Per diem for all vendor personnel.

3.4 Sampling and Analysis

Information was collected from commercial experience, vendor information, and field testing. Time studies were conducted to collect some of the operational data. The end point condition was then compared to the given standards to document the end point achieved. Field measurements were taken to document secondary waste generation, potential personnel exposure, and other measurable data requirements. Documentation provided by the vendors and interviews with the vendors provided other pertinent information. Table 3.4.1 presents the data requirements and the sample collection method.

The technology vendor was responsible for determining and providing information to FIU-HCET related to the estimated quantity of secondary waste that was generated and the characterization of that waste. The vendors were provided with the material safety data sheets on the paint products used in the development of the surrogates, to aid in the characterization determination. FIU-HCET was responsible for the management and disposal of the generated waste.

Table 3.4.1 - Data Requirements.

Data Requirements	Sample Collection Method
GENERAL INFORMATION	
Technology description	vendor supplied, field inspection
Equipment requirements	vendor supplied, field verification
COST DATA	
Capital cost for the purchase of equipment	vendor supplied
Utility cost	vendor supplied, measurement of fuel used, gallons of water used (flow meter), electric meter calculation
Maintenance cost	vendor supplied
Unit/operating cost	vendor supplied, generated from operational data calculations
OPERATIONAL DATA	
Production rates	time studies
End point achieved	comparison to known standards
Labor classification	vendor supplied, field verification
Limitations	vendor supplied, field inspection
Utility requirements	vendor supplied, field verification
Power consumption calculations	field calculation
Utility requirements	field inspection
Environmental conditions	vendor supplied, field inspection
Secondary waste management	vendor supplied, field inspection
Physical condition of secondary waste	field observation
Quantity of media used	field calculation
Volume of secondary waste	field calculation
Characteristics of media	media material safety data sheet
Weight of secondary waste	field measurement
Equipment portability	vendor supplied, field verification
Measurement of fuel used	field calculation
Operation/maintenance requirements	vendor supplied, field verification
IMPLEMENTATION DATA	
Level of training required	vendor supplied
Availability of equipment and supplies	vendor supplied, verification
Health and safety concerns	vendor supplied

4 DEVIATIONS

A single beginning surface condition for each surrogate was the requirement stated in the test plan. This goal was achieved in all but one of the surrogates, as a sufficient quantity of rusted plate was not able to be purchased. New plates were therefore purchased and left to rust to obtain the forth surrogate. However, the rusting process yielded an inconsistent beginning surface condition. The beginning surface conditions for the rusted steel plate was tracked and then used to see if this inconsistency had an impact on the end point achieved. Results indicated no significant difference between the end point condition of one plate and the end point condition of another plate using the same technology.

5 TECHNOLOGY TABLE DEFINITIONS

5.1 Table 1 Technology Overview:

This table is presented to show an overall summary for each technology. Each technology is described in terms of how the technology works and in terms of the equipment used. Capital equipment and cost are also described as well as the benefits and limitations for each technology.

1. Technology

Established databases were used for categorizing and performing the initial screening of technology types. These databases provided a screening based on the applicability of a technology to a given material and contaminant. These databases include:

- DOE/EM-0142P Decommissioning Handbook,
- Final Operable Unit 3 Treatability Study Work Plan for the Fernald Environmental Management Project,
- ORNL/M-2751 Oak Ridge National Laboratory Technology Logic Diagram,
- EGG-WTD-11104 Idaho National Engineering Laboratory Decontamination and Decommissioning Technology Logic Diagram,
- K-2073 Oak Ridge K-25 Site Technology Logic Diagram,
- The Environmental Protection Agency Vendor Information System for Innovative Treatment Technologies (VISITT), and
- Alternative Treatment Techniques Information Center (ATTIC) database.

Based on this review, the following commercially available blasting technologies will be tested:

- ultra high pressure water (< 55,000 psi and ≥ 15,000 psi);
- high pressure water (< 15,000 psi and > 1,000 psi);
- carbon dioxide (CO_2) pellets;
- sponge;
- steel shot;
- ice; and
- plastic.

The study also collected data using the same test conditions for soda blasting technology.

2. Description

The description section provides an introduction to the broad technology category. Details such as the description of the media used, how the media is propelled, description of vacuum system (if used), and the process by which the paint/contaminant is removed are provided.

3. Capital Equipment

The capital equipment section details the major equipment requirements to operate the specific vendor technology as listed in Table 6. Containment systems and ventilation systems that may be required to support these technologies are not discussed in the table.

4. Capital Cost

These costs represent cost figures presented by the technology vendors in the middle of calendar year 1995. Air compressor costs were obtained from a local equipment vendor in Miami, Florida.

5. Benefits

The Benefits section was obtained from performing a literature search of the individual technologies and through field demonstrations. If a conflict existed between published information and the field demonstrations the data observed in the field testing were used. The Benefits section provides an overall look at the potential benefits. The data presented on the attached tables should be used to determine site specific benefits.

6. Limitations

The Limitations section was obtained from performing a literature search of the individual technologies and through field demonstrations. If a conflict existed between published information and the field demonstrations the data observed in the field testing were used. The Limitations section provides an overall look at the potential limitations. The data presented on the attached tables should be used to determine site specific limitations.

Table 6 discusses the specific vendor equipment used in each of the technologies tested. The results presented may differ if a different technology vendor was used.

5.2 Table 2 Operational Parameters:

This table described the operational parameter collected during the duration of this test for each technology. The data described here was observed and measured for all technologies. Vendors information was also used and verified by field measurements.

1. Technology

(See Table 1 Definitions)

Surrogate Type The decontamination of steel in the majority of the cases consists of surface cleaning or removing a coating and/or rust. The percentage of steel requires the removal of base metal is a negligible concern at the FEMP. These assumptions allow the use of surrogate materials to simulate the largest structural steel decontamination problems at the FEMP. The surrogates consist of W6 x 9 I-beams and 1/4 inch thick steel plates. The I-beams were prepared and coated using a 3000G equivalent specification as described in the following paragraph. I-beams that exhibit rust conditions consistent with that found at the FEMP were also prepared/collected. The steel plates were prepared and coated using a 3000H equivalent specification as described in the following paragraph. Steel plates that exhibit rust conditions consistent with that found at the FEMP were also prepared/collected.

I-beam Specification (3000G Equivalent) 1) Prepare metal according to the M.A.B. technical data and application instructions. 2) Apply Rust-O-Lastic Anti-Corrosive

Primer 3 mils wet to obtain 1 1/2 mils dry film thickness. 3) Wait 24 hours then apply finish coat of Rust-O-Lastic finish coating at 3 mils wet to obtain 1 1/2 mils dry film thickness.

Plates Specification (3000H Equivalent) 1) Prepare metal according to the M.A.B. technical data and application instructions. 2) Apply Plymastic at 8 mils wet to obtain 7 mils dry film thickness. 3) Wait 24 hours then apply finish coat of Plythane 880 coating at 3 mils wet to obtain 1 1/2 mils dry film thickness.

2. End Point Achieved

To ensure the results of this test are applicable to the different decontamination objectives and to other environmental restoration sites, the technologies will be employed in the most efficient manner as determined by the vendor. The end point achieved will be compared to a set of established surface finish standards. A surface end-point definition for different surface conditions has been given based on the review of the specifications of the Steel Structures Painting Council, USA, and the National Association of Corrosion Engineers, USA. These specifications do not apply to the removal of radiological contamination.

Solvent Cleaned Surface. The solvent cleaned surface shall be free of all visible oil, grease, dirt, dust, drawing and cutting compounds, and other detrimental contaminants from the steel surface. The solvent cleaned surfaces may still have rust, rust scale, or mill scale.

Brush-Off Cleaned Surface. The brush-off cleaned surface shall be free of all visible oil, grease, dirt, dust, base mill scale, loose rust, and loose paint (i.e., tightly adhered particles that cannot be removed by lifting with a dull putty knife).

Commercially Cleaned Surface. A commercial cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products, and other foreign matter, except for staining. Staining shall be limited to no more than 33 percent of each square inch of the surface area and may consist of light shadows, slight streaks, or minor discolorations caused by rust stains, mill scale stains, or previously applied paint stains. Slight residues of rust and paint may also be left in the bottom of pits if the original surface is pitted.

Cleaned Near-White Metal Surface. A cleaned near-white surface, when viewed without magnifications, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products and other foreign matter, except for staining. Staining shall be limited to no more than five percent of each square inch of the surface area and may consist of light shadows, slight steaks or minor discolorations caused by rust stains, mill scale stains, or previously applied paint stains.

Cleaned White Metal Surface. A cleaned white surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint and oxides, corrosion products, and other foreign matter. The surface should have a slightly roughened gray white, uniform metallic color.

For most technologies the above end-point description did not apply, so a new set of end- point descriptions were created.

Removed Surface. A cleaned surface where paint coatings and loose rust were removed. Leaving a surface free of oil, grease, dirt, or dust. There were different degrees of cleanness under this definition. These degrees of cleanness varied according to the number of coatings/rust removed. If all the conditions under a particular grade have not been met the end point was defaulted to the next lesser grade. These various degrees of cleanness were:

Grade A: This degree of cleanness grade described a surface where 80% or greater of the finish coating surface had been removed.

Grade B: This degree of cleanness grade described a surface where 80% or greater of the finish coat and 80% or greater of the sub-primer/sub coat had been removed.

Grade C: This degree of cleanness described a surface where 80% or greater of the finish coat and 80% or greater of the sub primer/sub coat and 80% of the red oxide primer had been removed.

Grade D: This degree of cleanness grade describes a surface where 80% of the loose rust had been removed from the surface.

3. Production Rate

The vendor operated a technology for four continuous hours of operation for each surrogate. The production rate was calculated by measuring and calculating the square feet cleaned and dividing by four hours. The four hours consisted of all factors associated with the vendor operation of the technology. This includes: operating time, minor maintenance activities (such as cleaning a nozzle or changing a vacuum head), and equipment adjustment. Material handling aspects of switching the surrogates is not included in the four hours of operation. The result is four production rates; one for each surrogate per technology.

4. Volume of Secondary Waste

The secondary waste was collected and segregated for each surrogate for each technology. The waste was placed in a known container volume and the volume was calculated. No effort was made to compact the material. The value obtained was divided by four to obtain a cubic feet per hour value. For the CO_2 pellet blasting technologies the amount of paint chips/rust is estimated. The amount of water used for the water blasting technologies is included in the volume calculations.

5. Weight of Secondary Waste

The secondary waste was collected and segregated for each surrogate for each technology. The waste was placed in a container and placed on a scale to determine the weight. The value obtained was divided by four to obtain a pounds per hour value. For the CO_2 pellet blasting technologies the amount of paint chips/rust is estimated. The amount of water used for the water blasting technologies is included in the weight calculations. The factor of 7.42 pounds per gallon was used to determine the weight of the water and paint chips/rust for the water blasting technologies.

6. Physical Condition of Secondary Waste

The physical condition of the secondary waste provides a visible observation of the condition of the secondary waste. These observations include: fine power with no observable difference from the media and the paint/rust removed, paint chips, small pieces of media mixed with paint/rust, etc.

7. Labor Classification

Standard labor classifications are used to determine the individuals required. These classifications are equipment operator and blast technician. This labor also represents the minimum number of people required to operate the equipment. The extrapolation of the labor required to operate the equipment in contaminated environment is not included.

5.3 Table 3 Utility/Media Requirements:

This table described the utility required by each technology, also the amount of fuel, power, and media used was measured and recorded for each technology. The data described here was observed and measured for all technologies. Vendors information was also used and verified by field measurements. An unit/operating cost was developed and calculated based on the results of this study along with some assumptions that are listed in Section 5.3 item 6.

1. Technology

(See Table 1 Definition)

2. Measurement of Fuel Used

The number of gallons of fuel used during the four hours operating time is measured and is divided by four to obtain the gallons per hour value.

3. Quantity of Media Used

The number of pounds or gallons of media used during the four hour operating time is measured and is divided by four to obtain the pounds/gallons per hour value.

The operational techniques used during the sponge blasting field testing did not allow for the segregation of the media for each surrogate employed. The total amount of spent sponge was calculated for all four surrogates. A percentage based on square feet blasted per surrogate and the total square footage blasted was used to determine the quantity of media used for each surrogate.

4. Power Consumption Calculations

Using the voltage and amperage values for the electric motors and dividing by four provide the kilowatt per hour value. A value of eight cents per kilowatt-hour is used to develop the dollars per hour value.

5. Utility Requirements

The types of utilities required to operate the technology is discussed. The utilities used during the field testing are shown. In many cases optional power sources are available for each type of equipment. Utilities to operate the containment and ventilation system or any support equipment is not shown in the tables.

6. Unit/Operating Cost

The following factors are included in the calculation of the unit/operating cost. Labor (@ $22.00 per hour), media ($/pound as given by each technology vendor), utilities ($

1.10/gallon for diesel fuel or $ .08 per kilowatt-hour), and the production rate (square feet/hour). A unit/operating cost is calculated for each surrogate per technology. Factors dealing with waste management or support services are not included in the unit/operating cost calculation. The cost figures are estimated as of July 1995.

5.4 Table 4 Operation/Maintenance Requirements:

This table provides information on the operation and maintenance requirements for each technology. This information is intended to give the reader an idea of the various equipment required by each technology, as well as, the equipment portability, operational maintenance and availability. The environmental conditions while the technology was being demonstrated were observed and recorded.

1. Technology

(See Table 1 Definition)

2. Environmental Conditions

The environmental conditions provide a description of the environment created by the operation of the technology within the enclosure. These descriptions include: no visible emissions, water fog created in enclosure, visible air turbulence, etc.

3. Equipment Portability

Equipment portability is broken down into four categories. These categories include: one person can move, requires two people to move, requires forklift to move, or is trailer mounted.

4. Operational/Maintenance Requirements

The operational/maintenance requirements provide an account of the types of operational and maintenance activities performed during the four hour operating time. This description provides for cleaning of nozzles, changing of vacuum heads, allowing mist to clear to see surrogate, equipment adjustments, etc.

5. Availability of Equipment and Supplies

Availability of equipment and supplies was obtained from the individual technology vendors. Long lead procurement items are differentiated from equipment and supplies that are off-the-shelf items.

5.5 Table 5 Health and Safety Concerns:

This table describes information indicating some of the potential health and safety hazards related to each technology. These health and safety aspects were observed during the duration of each test. Appendix 9.1 represents a sample of the method used for data collection from each vendor. Each vendor was required to complete this table and the information was verified during the test.

1. Technology

(See Table 1 Definition)

2. Health and Safety Concerns

The health and safety concerns associated with the operation and minimum maintenance of the equipment is discussed. No effort is made to extrapolate the potential health and safety concerns associated with working with hazardous material removal, confined space work, or other external factors not demonstrated during the field testing. This information was provided from the vendors and from observing the field testing.

3. Sequence of Basic Job Steps

The steps require by the specific technology from set up stage to dismantling of equipment. This information was provided from the vendors and from observing the field testing.

4. Potential Accident or Hazards

A description of potential for accidents or hazards related to the operation of a specific technology. This information was provided from the vendors and from observing the field testing.

5. Recommended Safe Job Procedure

A description of recommendations to avoid the above potential accidents or hazards. This information was provided from the vendors and from observing the field testing.

6. Training

The level of training required includes the type and hours required to operate and provide minimal maintenance to the equipment. Other training associated with accessing an

environmental restoration site, radiological worker training or other support training is not discussed. The information presented in the level of training required was obtained from the technology vendors.

5.6 Table 6 Technology Vendor Participants:

This table provides the list of vendors that participated in this study. The company name, the technology used, and the product name is provided.

1. Company name

The name of the company performing the technology.

2. Technology

(See Table 1 Definition)

3. Product Name

The product name of the blast unit used during the blasting process.

6 TECHNOLOGY RECOMMENDATIONS

The intent of this section is to review the operation of each of the technologies tested and make recommendations on ways to improve the technology based on the test results. It is important to note that some of the recommended changes may improve the system in one area of operation but may adversely impact the technologies ability to excel in an other area.

Ultra high pressure water (< 55,000 psi and ≥ 15,000 psi)

In order to apply this technology in a radiological environment, a specially designed enclosure would be needed to collect the secondary waste water. This waste water can be collected and treated for later release or reuse. This specially designed enclosure would also need an adequate air exchange system to keep good visibility inside the enclosure. Adequate personal protection equipment (PPE) would have to be used, since water splashed all over the enclosure and on the operator. This technology was able to generate very high production rates on painted surfaces as well as rusted surfaces. This high production rates were comparable with other technologies such as sponge, soda, wet ice, and CO_2 . The secondary waste water generated was much less than the water generated by high pressure water.

High pressure water (< 15,000 psi and > 1,000 psi)

This technology would also require a specially designed enclosure to capture and treat the amount of water generated as secondary waste. This water can be collected and treated for later release or reuse. Demands on the operator for this technology were very high due to the great amount of back pressure at the nozzle; a system where the operator's fatigue is reduced would be preferable for this type of coating/rust removal. This system had a very easy set-up procedure, it was composed of a trailer mounted heavy duty water pump, connecting hoses, and a gun nozzle. The entire system was set-up in a matter of minutes. Furthermore, the only utility needed to operate this system was a water supply

that can be connected to the system by using a regular garden hose. The components of this system and set-up time were very similar to the ultra high pressure water system.

Carbon dioxide (CO_2) pellets

A good ventilation system was imperative for the use of this technology not only for visibility purposes but also for safety purposes, since CO_2 depleted the oxygen concentration in the enclosure. As the CO_2 pellets interact with the metal surface, the steel surface cools decreasing the ability of this technology to remove the surface. A device that keeps a high temperature differential would increase production rates. Even though this open system did not capture and collected the secondary waste, the system generated the least amount of secondary waste since the waste was only composed of removed paint chips or rust dust. This system generated high production rates and minimal secondary waste, but an enclosure would have to be provided to contain the waste and filter out airborne particles specially when working with contaminated material.

Sponge

This technology would also require a specially designed enclosure to capture and treat the amount of sponge media generated as secondary waste. This enclosure would need a grated floor where the sponge media can be collected and recycled without the intervention of an operator. An automatic recyclable system would be ideal in a situation where the material being blasted is radiologically contaminated. Adequate PPE would also be required, since the media is propelled all over the enclosure after it bounds off the surface. Since this process used no water, a potential for dust generation was great specially when the media was recycled too many times. There was definitely a linear relationship between the amount of times the media was recycle and the amount of dust generated inside the enclosure. The media degraded to a point where it started to become dust. This degradation would cause a potential for airborne particles and a hazard specially where radionuclides are present. Nevertheless, production rates for this system were very high and by using an open blast system the two types of geometries did not affected the production rate for this technology.

Steel grit

Production rates for this technology could be improved by increasing the size of the nozzles used in the blasting process on flat surfaces. For instance, a five-inch nozzle would cover a larger area than the two-inch nozzle used on the various surrogates for this test; but by increasing the nozzle size, the accessibility to some surfaces may be limited. A combination of various nozzle sizes can be used to cover all types of surfaces, but time would be lost in interchanging different nozzles and shrouds. Even though this technology had a low production rate, this vacuum system was able to remove the painted surfaces and rusted surfaces and collect the secondary waste. This waste and media mix were separated and the media was recycle and reuse. This made this system very attractive since the exposure to the operator was very low. The system can work very well under an environment where radionuclides are present.

Wet Ice

This technology would also require a specially designed enclosure or sump system to capture and treat the amount of water generated as secondary waste. This water can be collected and treated for later release or reuse. A good ventilation/filtering system would be required to keep adequate visibility inside the enclosure. Since water splashed all around the enclosure, adequate PPE would be needed to protect the operator, especially in a radioactive environment. Water was generated as part of the secondary waste, but the amount of water generated was much less than the water generated by ultra high pressure water or by high pressure water.

Plastic

Production rates for this technology could be improved by increasing the size of the nozzles used in the blasting process on flat surfaces. Shrouds surrounding the nozzle

should be used to prevent the media from escaping the nozzle area. A stronger vacuum system could do a better job at collecting the media before it escapes the nozzle/shroud area. Even though this technology had a low production rate, this vacuum system was able to remove the painted surfaces and rusted surfaces and collect the secondary waste. This waste and media mix were separated and the media was recycle and reuse. This made this system very attractive since the exposure to the operator was very low. The system can work very well under an environment where radionuclides are present.

Soda

This technology had very high production rates compared to ultra high pressure water, sponge, and CO_2. Airborne particulates generated during coating stripping may contain toxic elements from the coating being removed. A good ventilation/filtering system would be required to removed the particulate cloud that forms as the blast medium strikes the surface. This would also provide adequate visibility inside the enclosure. Since airborne particulates were visible all around the enclosure, adequate PPE would be needed to protect the operator, especially in a radioactive environment.

7 LESSONS LEARNED

The study did not specify a given endpoint that a technology was required to meet. The vendors were asked to optimize all the operating parameters and achieve the optimal end point condition. This optimal end point condition varied among the technologies as expected. This request to optimize the operating parameters was an unusual request from the vendors perspective. After discussions with the vendors the intent of optimizing the technology was met.

The enclosure constructed and used during the execution of this project was designed to provide a containment to control the secondary waste generated and provide a ventilated environment. The design did not allow for resistance to projectiles from the various types of media. The inner wall became deteriorated to the point were pieces had to be removed and new interior panels were installed. The deterioration of the inner wall did not cause a breach in containment.

The initial ventilation system in the enclosure did not adequately perform to the design specifications. Supplemental ventilation was added to meet the design requirements.

A material transportation cart was used to load and unload the surrogates in and out of the enclosure. This system worked well for many of the technologies employed, however some of the technologies exerted a large force on the surrogate surface causing the cart to move. A rack was deigned and installed to stabilize the surrogates when the circumstances required the additional support.

During the initial bid process to acquire the vendors to perform the study the question was asked by one vendor whether one beam was being cleaned or was the technology to be operated for four hours of actual operating time. This question was not asked by any other vendor and was considered an isolated case. During the field testing of the technologies it was observed

that the scope of work was not read by the people in the field or the scope of work was not understood. It is recommended to have an alignment meeting with each vendor to ensure that the full scope of work is understood and is agreed upon by all vendors.

Of the four types of surrogates required obtaining enough rusted steel plate with a consistent surface condition proved to be very difficult. A scrap dealer had the quantity of rusted I beams required and the surface condition was consistent. The painted surrogates were purchased from a professional painting contractor according to the paint specifications. The plates were purchased new and left outdoors to rust. The surface achieved was inconsistent from plate to plate. The beginning surface condition was noted for each plate; the ending surface conditions were compared between rusted plates to determine any variations. The inconsistent beginning surface condition did not appear to change the production rates or the end point achieved for the technologies tested.

The inspection of the surrogates after the completion of the testing in some cases yielded an inconsistent ending surface condition. A consensus was reached by the group to determine the predominant ending surface condition.

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APPENDICES

APPENDIX A

JOB SAFETY ANALYSIS

9.1 Job Safety Analysis

Attached is an example of the job safety analysis forms completed by the individual technology companies.

FEMP

JOB SAFETY ANALYSIS

JOB:			DATE: Rev. 0
JOB TITLE:	DEPARTMENT:	SECTION/GROUP:	
SUPERVISOR:	ANALYSIS BY:	REVIEWED BY:	APPROVED BY:
REQUIRED AND/OR RECOMMENDED PERSONAL PROTECTIVE EQUIPMENT: SAFETY GLASSES W/ RIGID SIDE SHIELDS, STEEL TOED SHOES, HARD HAT			

SEQUENCE OF BASIC JOB STEPS	POTENTIAL ACCIDENT OR HAZARDS	RECOMMENDED SAFE JOB PROCEDURE
1.		

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APPENDIX B

DATA TABLES

Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
CO2	This technology has a refrigerated liquid CO2 supply and a system for converting the liquid to the solid media used to perform coating removal. Compressed liquid is allowed to expand in a pressure-controlled chamber where the temperature drops from about -37oC (-35oF) to about -78oC (-109oF). It causes a mixture of CO2 vapor and solid CO2 snow to form. The snow is collected, compressed, and extruded through a die to produce pellets of a selected size and hardness as needed for the specific coating removal operation. In an open blast system the CO2 pellets remove the coating by a combination of impact, embrittlement, thermal contraction, and gas expansion. The frozen CO2 pellets provide thermal shock, or cracking. They cryogenically sever the bond between the substrate and coating. When the CO2 pellets sublime upon impact, the expanding gas can help remove the coating. The air pressure blows the coating fragments off the substrate. A liquid nitrogen system with a heat exchanger is used to propel the CO2 pellets. This nitrogen propellent system is used in place of an air compressor.	Basic system with blasting unit, blasting nozzle, heat exchanger, hoses, and nitrogen bottles	$89,000.00	CO2 media vaporize, leaving only the volume of dry coating residue waste	As containment surface cools production rates decreases
		Pelletizer (HP-500 extruder)	$54,000.00	Eliminates water use	Ventilation system required to avoid potentially dangerous CO2 concentrations in the containment area
				Has a clean and well-defined coating removal pattern	Possible worker exposure to extreme cold
				Can selectively remove individual coating layers	Operators wear respiratory and eye protection equipment for protection from rebounding particulate
				Pre-or post-stripping cleanup requirements typically are minimal	Operators wear hearing protection due to high noise levels from blasting equipment
				No separation/recycling system needed	Rebounding pellets may carry coating debris and contaminate the work area or workers
				No media disposal costs incurred	Large local temperature drops can occur but are confined mainly to the surface layer
				Benign to most substrates; surface damage minimal for a	There is potential hazard from compressed air and/or high

Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
				steel surface	velocity CO2 pellets
				No size limitations on parts to be stripped	High humidity can cause the dry ice pellets to clog the lines and the nozzle
				This open blast system was able to reach interior corners, end corners and thin metal edges.	Low temperature can cause condensation on substrate
					Non-automated system fatigues workers because of cold, weight, and thrust of blast nozzles
					Can operate at 50 ft away from delivery unit
					Technology was able to remove

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
High H2O	High-pressure water blasting removes coatings with a stream of water projected from specially designed nozzles at pressures of 3,000 psig to 15,000 psig. Heavy-duty pumps, typically in the 15 to 600 hp range, supply water at high pressure. The water is sprayed through a nozzle or system of rotating nozzles onto the coated surface. The coating is removed by the impact of the water stream. The stripping action can be supplemented by presoftening with an alcohol solvent or by including soft or hard abrasives in the water stream.	Basic system (10,000 psig)	$61,400.00	The technology has a high stripping rate	Nozzle reaction forces are substantially increasing operator fatigue
		tool box, standard replacement parts, various nozzle configurations, and extra hoses	$15,000.00	Water can be recycled, but needs to be separated from paint chips.	A system must be available to collect, filter, and recycle stripping water containing coating debris
				There are no size limitations on parts to be stripped	Workers must be protected from direct impingement of water jet due to extreme danger from <10,000 psig water jet
				Water encapsulates contaminants thereby reducing airborne contamination	A misapplied water jet will damage the substrate
				System can be adjusted to remove individual coating layer	Water can enter cavities
				No special media is required	Operators wear respiratory and eye protection from rebounding media and airborne particles
				Systems are modular and require minimal setup time	Operators wear hearing protection due to high noise levels from blasting equipment
				This open blast system was able to reach interior corners,	Significant wastewater may be generated

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
				end corners and thin metal edges.	
					Stripping rate vary significantly with type of coating to be removed
					Nozzle gun is heavy which imposes a high level of fatigue on the operator
					Can operate at 500 ft away from delivery unit
					Technology was able to remove loose rust surface only

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Plastic	This process uses compressed air or centrifugal wheels to project plastic media at the surface. The sharp-faceted particles fracture on impact, leaving new sharp edges to allow continued use for stripping. In general, the plastic media are selected to be harder than the coating. In typical applications, the air pressure measured in the range from 10 to 60 psig. The higher pressures remove coating faster but also are more likely to induce substrate damage. A vacuum system is used to collect the media and removed surfaces.	Total equipment	$70,000.00	The technology has a low stripping rate on painted surfaces	Spent media contain coating chips and may be a hazardous waste
		with blast room	$160,000.00	Eliminates water use	Operators wear respiratory and eye protection from rebounding media and airborne particles
		Air compressor (600 cfm)	$49,322.00	Can selectively remove individual coating layers	Operators wear hearing protection due to high noise levels from blasting equipment
				Often done with recyclable thermoplastic media	Media may cause metal substrate damage such as reducing resistance to metal fatigue, hiding and causing of surface cracks, and buckling
				Fully automated robotics systems available	More aggressive media may damage substrate
				System provides aggressive removal action	Media has potential for high disposal costs if spent media are hazardous and cannot be recycled
				No size limitations on parts to be stripped	Media has flammable characteristics
				Systems are modular and require minimal setup time	Subsystems are needed for media recovery and recycling and dust collection and control
				Special fittings can be adapted to reach interior corners, end corners, and thin metal edges.	There is a possible explosive hazard from dust

Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
					Can operate at 50 ft away from delivery unit Technology was able to remove loose rust surface only.

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Soda	Compressed air advances the sodium bicarbonate medium from a pressure pot to a nozzle where the medium combines with a stream of water. The blast medium and water mixture, accelerated to several hundred miles per hour, collides with the coated surface and shatters into a very fine particulate. The water helps control the dust produced when the media impacts on the coating and prohibits heat buildup in the substrate.	Delivery unit	$3,700.00	High stripping rate	The sodium bicarbonate medium cannot be recycled for stripping
		Air compressor (300 cfm)	$27,676.00	Can selectively remove individual coating layers	Operators wear respiratory and eye protection due to rebounding media and airborne particulate
				In some applications, bicarbonate stripping can reduce prewashing and masking of the surface needed prior to stripping	Airborne particulates generated during coating stripping may contain toxic elements from the coating being removed. An exhaust ventilation system should be used during blasting to remove the particulate cloud that forms as the blast medium strikes the surface
				Use of water dissipates the heat generated by the abrasive process and reduces the amount of dust in the air	Operator wear hearing protection due to very high noise levels from blasting equipment
				No size limitations on parts to be stripped	Slug discharge of bicarbonate (over about 3,000 ppm) can adversely affect the operation of an anaerobic digester
				Sodium bicarbonate and water residue on surface of metal creates a protection that prevents the metal to corrode	Additional water is needed to dilute the paste like secondary waste created by water stream, soda, and removed coating

Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
				Systems are modular and require minimal setup time	Can operate at 250 ft away from delivery unit
				This open blast system was able to reach interior corners, end corners and thin metal edges.	Technology was able to remove loose rust surface only.

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Sponge	This technique cleans by an open blasting system with various grades of foam-cleaning media. The sponges are made of a water based urethane matrix. During surface contact, the sponges expand and contract, exposing the embedded abrasive and creating a scrubbing effect. Then the sponge recoils and collapses around the contaminant, trapping the contaminant/dust within the sponge matrix. The feed unit is pneumatically powered and propels the sponges against the surface being cleaned. The sifter unit consist of a series of progressively finer screens used to remove debris from the sponges. Residue from the sifter unit must be properly disposed of. The wash unit is a portable closed-cycle centrifugal unit that launders the sponges, usually in three to five cycles. The evaporator unit reduces the volume of contaminated wastewater from the wash unit before disposal.	Delivery unit with hoses and gun	$27,000.00	Media can absorb liquids i.e. oils	High potential exposure to dust, hazardous byproducts
		Air compressor (250 cfm and 120 psig)	$30,114.63	Aggressive system for coating removal	Operators wear respiratory and eye protection from rebounding media and airborne particles
				Media is recyclable	Operators wear hearing protection due to high noise levels from blasting equipment
				Various grades of media are available to adapt to different surface conditions	Spent media contain coating chips and may be a hazardous waste
				No size limitations on parts to be stripped	Media may cause metal substrate damage
				Eliminates the use of water	Potential high disposal costs if spent media is hazardous and cannot be recycled.
				Can selectively remove individual coatings.	Spent media contain coating chips and may be a hazardous waste
				Fully developed systems are available that include the automatic recycle of the sponge media	Requires subsystem for media recovery and recycling and dust collection and control
				Systems are modular and require minimal setup time	If media is recycled too many times, the dust level increases dramatically

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
				This open blast system was able to reach interior corners, end corners and thin metal edges.	Collection system required to contain media
					Can operate at 75 ft away from delivery unit

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Steel Grit	Compressed air carries the media to a nozzle which accelerates the media and impinges the surface. The media scraps the coating, rust and contamination from the surface. A vacuum system which surrounds the nozzle removes the media, and surface removed. The vacuum system separates the usable media from the remaining debris and is reused in the system. The vacuum system may be powered bycompressed air or electricity. Many systems can operate a single nozzle or multiple nozzle increasing production rates. Various grades and types of media are available to tailor the media to the surface conditions. Media type and surface begin removed can dramatically change the amount of secondary waste to be managed.	Delivery unit with hoses and gun	$34,110.00	Shrouds capture the majority of the media and airborne contamination	Media becomes part of waste
		Air cooler/dryer	$12,079.00	Shrouds may be changed to adapt to different surface geometries	Can damage delicate substrate
		Air compressor (750 cfm and 125 psig)	$44,800.00	Eliminates water use	Operators wear hearing protection due to high noise levels from blasting equipment
				No size limitations on parts to be stripped	Substrate must be dry before blasting can be performed
				Minimal radioactive airborne contamination	Shrouds limit the nozzle accessibility to all surfaces
				Systems are modular and require minimal setup time	Can operate at 180 ft away from delivery unit
				Systems can be adapted to remove a single layer of paint or to a near white metal finish	
				Multiple nozzles can be used on a single machine, depending on model used, therefore increasing production rates.	
				A variaty of accessories and attachments can be adapted to the nozzle to cover interior corners, end corners and thin metal edges.	

Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Ultra High	Ultra high-pressure pumps supply water to a system of rotating nozzles or single nozzle that spray the water stream onto the coated or rusted surface. The coating is removed by the kinetic impact of the water stream. The contamination as well as the coating is flushed away from the surface. Water systems are able to reach and flush convoluted surfaces. Standard potable water supply is required with a capacity up to ten gallons per minute. Part of the water supply is used to cool machinery. For the removal of secondary waste, a system is needed to collect and separate the debris from the secondary water. Both need to be treated.	Basic system (35,000 psi)	160,000.00	The technology has a high stripping rate	Coating debris sludge may be a hazardous waste
		tool box, standard replacement parts, various nozzle configurations, and extra hoses	$70,000.00	Water can be recycled	Waste water and residue disposal requirements will depend on the toxicity of the coating and pigments being removed
		Air compressor (35scfm 90psi)	$27,676.00	Waste water stream is normally compatible with waste water treatment plants available at many installations	A system must be available to collect, filter, and recycle stripping water containing coating debris
				There are no size limitations on parts to be stripped	Workers must be protected from direct impingement of water jet due to extreme danger from water jet
				Water encapsulates contaminants thereby reducing airborne contamination	A misapplied water jet will damage a delicate substrate
				System can be adjusted to remove individual coating layer	Water can enter cavities
				No special media is required	Operators wear respiratory and eye protection from rebounding media and airborne particles
				Nozzle reaction forces are minimal reducing operator	Operators wear hearing protection due to high noise

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
				fatigue	levels from blasting equipment
				Low flow rate	Flash rusting may occur on cleaned steel surfaces
				Systems are modular and require minimal setup time	Can operate at 100 ft away from delivery unit
				This open blast system was able to reach interior corners, end corners and thin metal edges.	Technology was able to remove loose rust surface only

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
Wet Ice	Compressed air carries the media to a nozzle which accelerates the media and impinges the surface. The media scraps the coating, rust and contamination from the surface. A vacuum system which surrounds the nozzle removes the media, and surface removed. The vacuum system separates the usable media from the remaining debris and is reused in the system. The vacuum system may be powered by compressed air or electricity. Many systems can operate a single nozzle or multiple nozzles increasing production rates. Various grades and types of media are available to tailor the media to the surface conditions. Media type and surface begin removed can dramatically change the amount of secondary waste to be managed.	Delivery unit	150,000.00	Uses less water volume than water technologies	System may not be aggressive enough to remove most coatings
		Air compressor (200 psi 400 cfm)	$40,000.00	Water encapsulates contamination as well as surface begin removed	Waste water treatment system is required to minimize the amount of secondary waste generated
		Cooler	$5,000.00	Operators wear respiratory and eye protection from rebounding media and airborne particles	Distance from main unit to nozzle must be minimal.
				Operators wear hearing protection due to high noise levels from blasting equipment	Compressed air stream may generate additional airborne if system is not operated properly.
				Containment does not require monitoring for gas buildup	Flash rusting may occur if steel is not treated
				No special media is required	If shrouds are used visibility as well as accessibility are minimized
				Operates at moderate temperatures	Many components are required to be set up to make the system operational
				This open blast system was able to reach interior corners, end corners and thin metal edges.	Ice must be managed to ensure an adequate supply is available for nozzle system
					Removed painted surface, but not the red-oxide primer.

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Table 1 Technology Overview

22-Aug-95

Technology	Description	Capital Equipment	Capital Cost	Benefits	Limitations
					Technology was able to remove loose rust surface only. Can operate at 200 ft away from delivery unit

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Table 2 Operational Parameters

22-Aug-95

Technology	Surrogate Type	End Point Achieved	Production Rate	Volume of Secondary Waste	Weight of Secondary Waste	Physical Condition	Labor Classification
CO2	painted plate	grade C	12.0 sq. ft/hr	0.008 ft3/hr	0.24 lbs/hr	Paint chips	1 operator/maintenance engineer at the CO2 blaster
	painted I-beam	grade C	11.5 sq. ft/ hr	0.003 ft3/hr	0.09 lbs/hr	Paint chips	
	rusted plate	grade D	144.0 sq. ft/ hr	0.012 ft3/hr	N/A	Rust powder	1 blast technician at the nozzle
	rusted I-beam	grade D	115.0 sq. ft/ hr	0.009 ft3/hr	N/A	Rust powder	
High H2O	painted plate	grade B	8.8 sq. ft/ hr	112 ft3/hr	6970 lbs/hr	Paint chips mixed with water stream	1 operator/maintenance engineer at the water blaster
	painted I-beam	grade B	14.4 sq. ft/hr	112 ft3/hr	6970 lbs/hr	Paint chips mixed with water stream	
	rusted plate	grade D	36.0 sq. ft/ hr	112 ft3/hr	6970 lbs/hr	Rust powder mixed with water stream	1 blast technician at the nozzle
	rusted I-beam	grade D	40.3 sq. ft/ hr	112 ft3/hr	6970 lbs/hr	Rust powder mixed with water stream	
Plastic	painted plate	grade C	1.2sq. ft/hr	0.25 ft3/hr	13.75 lbs/hr	Fine powder with	2 operator/maintenance engineers rotating on blasthead
	painted I-beam	grade C	9.1 sq. ft/hr	0.19 ft3/hr	12.5 lbs/hr	no observable	
	rusted plate	grade D	28.0 sq. ft/hr	0.49 ft3/hr	8.75 lbs/hr	difference from	
	rusted I-beam	grade D	13.6 sq. ft/hr	0.7513 ft3/hr	10 lbs/hr	media and paint/rust removed	

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Table 2 Operational Parameters

22-Aug-95

Technology	Surrogate Type	End Point Achieved	Production Rate	Volume of Secondary Waste	Weight of Secondary Waste	Physical Condition	Labor Classification
Soda	painted plate	grade C	24.0 sq. ft/hr	5.8 ft3/hr	361 lbs/hr	Powder paint mixed with water	1 operator/maintenance engineers rotating on blasthead
	painted I-beam	grade C	23.0 sq. ft/hr	5.0 ft3/hr	311 lbs/hr	Powder paint mixed with water	
	rusted plate	grade D	48.0 sq. ft/hr	4.8 ft3/hr	299 lbs/hr	Powder rust mixed with water	1 blast technician at the nozzle
	rusted I-beam	grade D	28.8 sq. ft/hr	4.8 ft3/hr	299 lbs/hr	Powder rust mixed with water	
Sponge	painted plate	commercial	32.0 sq. ft/hr	688.2 ft3/hr	228.1 lbs/hr	Small pieces of	1 operator/maintenance engineers rotating on blasthead
	painted I-beam	commercial	12.0 sq ft/ hr	258.1 ft3/hr	85.5 lbs/hr	media mixed with	
	rusted plate	commercial	36.0 sq. ft/ hr	774.3 ft3/hr	256.6 lbs/hr	paint/rust	2 blast technicians rotating at the nozzle
	rusted I-beam	commercial	18.2 sq ft/ hr	391.4 ft3/hr	129.7 lbs/hr		
Steel Grit	painted plate	near-white	11.6 sq. ft/hr	0.02 ft3/hr	2.1 lbs/hr	Fine powder with	1 blast technician per nozzle
	painted I-beam	near-white	14.6 sq. ft/hr	0.02 ft3/hr	2.4 lbs/hr	no observable	
	rusted plate	near-white	19.5 sq ft/ hr	0.02 ft3/hr	1.8 lbs/hr	difference from	1 operator/maintenance engineer to check equipment monitors
	rusted I-beam	near-white	14.6 sq ft/ hr	0.02 ft3/hr	2.1 lbs/hr	media and paint/rust removed	

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Table 2 Operational Parameters

22-Aug-95

Technology	Surrogate Type	End Point Achieved	Production Rate	Volume of Secondary Waste	Weight of Secondary Waste	Physical Condition	Labor Classification
Ultra High H2O	painted plate	grade C	62.0 sq. ft/hr	32.0 ft3/hr	1992 lbs/hr	Powder paint mixed with water	1 operator/maintenance engineer at the water blaster
	painted I-beam	grade C	57.5 sq. ft/hr	32.0 ft3/hr	1992 lbs/hr	Powder paint mixed with water	
	rusted plate	grade D	112.0 sq. ft/hr	32.0 ft3/hr	1992 lbs/hr	Rust powder mixed with water	1 blast technician at the nozzle
	rusted I-beam	grade D	78.0 sq. ft/hr	32.0 ft3/hr	1992 lbs/hr	Rust powder mixed with water	
Wet Ice	painted plate	grade B	5.2 sq. ft/hr	3.2 ft3/hr	200 lbs/hr	Paint chips mixed with water stream	1 operator/maintenance engineers rotating on blasthead
	painted I-beam	grade C	8.5 sq. ft/hr	3.2 ft3/hr	200 lbs/hr	Paint chips mixed with water stream	
	rusted plate	grade D	72.0 sq. ft/hr	3.2 ft3/hr	200 lbs/hr	Rust powder mixed with water	1 blast technician at the nozzle
	rusted I-beam	grade D	64.0 sq. ft/hr	3.2 ft3/hr	200 lbs/hr	Rust powder mixed with water	

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Table 3 Utility / Media Requirements

22-Aug-95

Technology	Measurement of Fuel Used	Quantity of Media Used	Power Requirements	Utility	Unit/ Operating Cost
CO2	190 gal/hr	100 lbs/hr	N/A	liquid nitrogen	$94.67 /hr
High H2O	5 gal/hr	16 gal/min (water)	N/A	water supply of 16 gpm at 85 psi, diesel fuel	$52.46 /hr
Plastic	1.25 gal/hr	11 lbs/hr	N/A	diesel fuel, 460 volts	$73.19 /hr
Soda	7.81 gal/hr	68.8 lbs/hr	N/A	diesel fuel	$100.15 /hr
Sponge	10 gal/hr	43.8 lbs/hr	N/A	diesel fuel	$86.66 /hr

Table 3 Utility / Media Requirements

22-Aug-95

Technology	Measurement of Fuel Used	Quantity of Media Used	Power Requirements	Utility	Unit/ Operating Cost
Steel Grit	14.1 gal/hr	6.25 lbs/hr	N/A	diesel fuel	$63.98 /hr
Ultra High	5.5 gal/hr	7 gal/min (water)	N/A	water supply of 7 gpm at 85 psi, diesel fuel	$51.68 /hr
Wet Ice	18 gal/hr	200 lbs/hr	6.6 kw/hr	diesel fuel, water supply of 0.4 gpm, 3 phase power 220 V, 60 amp	$66.01/hr

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Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
CO2	CO2 gas and Nitrogen propellent fill enclosure Oxygen is depleted inside enclosure Visibility is limited Surface removed is found through out the enclosure The surface of the surrogate and nozzle reach cold temperatures Strong air currents are needed to remove air from enclosure Operators are directly exposed to CO2 gas due to oxygen depletion	Delivery unit	Trailer mounted	Maintenance tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through first or second tier blasting service companies

Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
High H2O	Water mist fills enclosure, reducing visibility Strong air currents are needed to remove air from enclosure Water back splash hits all sides of enclosure Surface removed is captured in back splash Strong back pressure on operator If the surrogate is not fastened, the water stream force can move it Operators are exposed to water back splash Surface removed is found through out the enclosure	Delivery unit	Trailer mounted	Mechanical tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through first or second tier blasting service companies

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Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
Plastic	Small amount of plastic is found in enclosure	Delivery unit	Forklift	Maintenance tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through 24 hr delivery
	Vacuum system captures plastic and surface removed	Blast room	Trailer mounted		
	Misapplied nozzle will propel plastic out of housing	Air compressor	Trailer mounted		
Soda	Media (soda) fills the air of enclosure	Delivery unit	One person	Maintenance tasks range from simple to mid-level of difficulty	One to two weeks backorder
	Strong air currents are needed to removed air from enclosure	Air compressor	Trailer mounted		
	Cloud of media falls over operator				

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Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
Sponge	Strong air currents are needed to remove air from enclosure	Delivery unit	Two person	Maintenance tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through 24 hr delivery
	Sponge rebound hits all sides of enclosure	Air compressor	Trailer mounted		
	Operators are exposed to sponge rebound				
	Surface removed and sponge is found through out the enclosure				
	As sponge breaks down and surface is removed a dusty environment is created				
Steel Grit	Small amount of grit is found in enclosure	Delivery unit	Forklift	Maintenance tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through 24 hr delivery
	Vacuum system captures grit and surface removed	Dryer/cooler	Forklift		
	Misapplied nozzle will propel grit out of housing	Air compressor	Trailer mounted		

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Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
Ultra High H2O	Water mist fills enclosure Strong air currents are needed to remove air from enclosure Water back splash hits all sides of enclosure Surface removed is captured in back splash Water stream force can move surrogate Operators are exposed to water back splash Visibility is limited Surface removed is found through out the enclosure	Delivery unit Air compressor	Trailer mounted Trailer mounted	Mechanical tasks range from simple to complex.	Equipment and accessories are readily available through first or second tier blasting service companies

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Table 4 Operation/Maintenance Requirements

22-Aug-95

Technology	Environmental Conditions	Equipment	Equipment Portability	Operational Maintenance	Availability
Wet Ice	Water mist fills enclosure, reducing visibility	Delivery unit	Forklift	Maintenance tasks range from simple to mid-level of difficulty	Equipment and accessories are readily available through 24 hr delivery
	Strong air currents are needed to remove air from enclosure	Air compressor	Trailer mounted		
	Water back splash hits all sides of enclosure	After-cooler	One person		
	Surface removed is found through out the enclosure				
	Operators are exposed to water back splash				

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Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
CO2	Oxygen depletion caused by CO2 around operator's area. Therefore high air exchanges are needed to remove air from enclosure. By removing the air, good visibility can be kept inside enclosure therefore minimizing potential for accidents.	Set up of blast equipment.	Safety gear to be worn.	Prejob briefing and disciplinary actions.	Cryogenic safety
		Set up of area or equipment to be cleaned.	Use proper lifting techniques.	Proper lifting techniques.	Industrial safety
		Run nitrogen hose to blast area.	Keep isolated from traffic area, rope off area.	Safe traffic area control and proper isolation zone.	Operation of equipment (pressure supply, equipment lineup, and ice supply)
		Stage equipment to be cleaned.	Make sure exhaust is properly vented to the outside.	Proper ventilation out of building.	Equipment maintenance (pressure supply, blasting unit, and nozzle assembly)
		Set up HEPA units.	Inspect cords and power supply. Set O2 monitor and run all seams.	Proper inspection and tag out procedure.	
		Test engineering controls; i.e. HEPA units, light, O2 monitor, nitrogen shut off valves.	Insure proper closure of all seams.	Proper dress out procedure.	
		Prejob breifing.	Breathing hazards, skin contamination.	Proper use of CO2 gun and breathing equipment.	
		Blast technicians dress out.	Proper lifting and contamination control.	Proper lifting procedure and storage of clean parts.	
		Clean equipment/ parts.	Proper storage of equipment.	Proper contamination control.	
		Remove equipment/parts from blast enclosure.			
		Have above inspected for acc			

Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
High H2O	High pressure can cause serious injury to operator. Due to the extreme back pressure at the nozzle, high air exchanges are needed to remove air from enclosure. Also by removing the air, good visibility cab be kept inside enclosure therefore minimizing potential for accidents.	Set up of blast equipment.	Safety gear to be worn.	Prejob briefing and disciplinary actions.	Equipment safety
		Set up of area or equipment to be cleaned.	Use proper lifting techniques.	Proper lifting techniques.	Industrial safety
		Run water and air supply hoses as needed.	Keep isolated from traffic area, rope off area.	Safe traffic area control and proper isolation zone.	Operation of equipment (pure water sources and pressure delivery system)
		Stage equipment to be cleaned.	Check all cords and ducting for breaks, shock, and escape of contaminant.	Electrical safety and ducting inspection.	Equipment maintenance (prime mover, intensifier system, and blasting gun)
		Test engineering controls; i.e. pumps, ventilation, lighting.	Improper closing of seams.	Dress out procedure.	
		Prejob breifing/ appropriate permits.	Breathing hazard, skin contamination, cutting self by improper gun use.	Safe handling of high pressure blasting equipment. Insure proper use of breathing equipment.	
		Blast technicians dress out.	Lifting and contamination control.	Proper lifting procedure and storage of clean parts.	
		Clean equipment/parts.	Lifting, contamination control, proper storage.		
		Remove equipment/parts from blast enclosure.			
		Have above checked for acceptance.			

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Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Plastic		Set-up. Remove equipment from demonstration vehicle.	Back strain, crushed feet, pinched hands.	Use fork lift.	Equipment safety
		Operation. Abrasive blasting of beam sections.	Breathing small particles of dust. Contamination and debris in eyes.	Safety Shoes.	Start-up procedures
		Tear down.		Hard Hats.	Normal operating procedures
				Safety Glasses.	Machine and equipment maintenance
				Use Ventilation 5,000 cfm.	
				Use proper blast equipment protective clothing.	

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Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Soda	Good ear protection is needed due to very high sound level inside enclosure. High air enchanges are needed to keep good visibility inside enclosure to minimize potential for accidents. Sodá and water mix should be washed down with additional water to prevent slipping of operator due to the slipping nature of mix.	Equipment Inspection	Improper hook-up, worn component failure	Visual inspection of equipment and safety devices and hookup to power source.	Equipment safety
		System start-up	Unauthorized personnel in work area. Erratic operation	Personal protective equipment utilized. Proper function of system.	Start-up procedures
		Production blasting	Excessive build-up of spent media. Operator fatigue.	Wash the work area down as required. Operator rotation at 15 minute intervals.	Normal operating procedures
		Shut down	Dead man override. Power source not deactivated	Instruction and supervision.	Machine and equipment maintenance
				Shut off utilities and drain the system. Clean the work area.	

Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Sponge		Equipment setup	Chicago fitting -not secure-causing hoses to whip around causing accident	Safety pin all Chicago fittings so hoses do not separate.	Air supply requirements, including hose size
		Abrasive blasting	inhalation of dust	Personal safety equipment: coveralls, leather gloves, full face respirator hearing protection	Start-up procedures
			foreign body in eye		Hook-up procedures
			skin abrasion		Normal operating procedures
			hearing loss		Machine and equipment maintenance
					Safety procedures

Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Steel Grit		Connect air hoses from compressor.	Hose blowing off	Make sure all connections are tight and safety pins are clipped into blast hose.	Air supply requirements, including hose size
		Connect vacuum/ blast hoses.	Kinked trigger line would turn blast on or if trigger is not locked.	Make sure trigger is locked	Functional description of the LTC Vacuum Blasting Machine
		Start compressor and open air valves.	Loud noise, eye hazard.	Open valves starting at compressor and work towards machine, double check hose connections.	Start-up procedures
		Turn on machine.		Make sure blast heads are pointed away from people, and trigger lines are not kinked.	Hook-up procedures
		Start blasting.		Ear plugs, safety glasses.	Normal operating procedures
					Machine and equipment maintenance
					Safety procedures

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Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Ultra High H2O	Ultra high pressure water stream can cause serious injury to operator at close distances. Appropriate air exchanges are needed to keep good visibility inside enclosure therefore minimizing potentials for accidents. Rubber mat should be used to prevent operator from slipping.	Set up of blast equipment.	Safety gear to be worn.	Prejob briefing and disciplinary actions.	Equipment safety
		Set up of area or equipment to be cleaned.	Use proper lifting techniques.	Proper lifting techniques.	Industrial safety
		Run water and air supply hoses as needed.	Keep isolated from traffic area, rope off area.	Safe traffic area control and proper isolation zone.	Operation of equipment (pure water sources and pressure delivery system)
		Stage equipment to be cleaned.	Check all cords and ducting for breaks, shock, and escape of contaminant.	Electrical safety and ducting inspection.	Equipment maintenance (prime mover, intensifier system, and blasting gun)
		Test engineering controls; i.e. pumps, ventilation, lighting.	Improper closing of seams.	Dress out procedure.	
		Prejob breifing/appropriate permits.	Breathing hazard, skin contamination, cutting self by improper gun use.	Safe handling of high pressure blasting equipment. Insure proper use of breathing equipment.	
		Blast technicians dress out.	Lifting and contamination control.	Proper lifting procedure and storage of clean parts.	
		Clean equipment/parts.	Lifting, contamination control, proper storage.		
		Remove equipment/parts from blast enclosure.			
		Have above checked for acceptance.			

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Table 5 Health and Safety Concerns

22-Aug-95

Technology	Health and Safety Concerns	Sequence of Basic Job Steps	Potential Accident or Hazards	Recommended Safe Job Procedure	Training
Wet Ice		Verify that all services are available- compressed air, water power (electric)	Hoses may get damaged, wire or cable changed.	Electrical cable to unit. Disconnect switch within sight of unit for emergency purposes.	Basic refrigeration
		Ensure all connections are secure.	Slipping, tripping, or falling due to wet floor or unstable footing.	Electrical circuits are equipped with fuses or thermal overload devices.	Introduction to CIB
		Energize system.		Blasting may be discontinued by releasing trigger or engaging pause switch at Ice Blast unit.	Field system operation
		Slowly pressurize system with compressed air.		Air system is equipped with safety blow-off valve.	Schematic drawing discussion
		Turn on water supply.		Refigeration system equipped with standard thermal overload protection devices.	System shutdown and secure
		After cool down cycle, begin blasting.			

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Table 6 TECHNOLOGY VENDOR PARTICIPANTS

22-Aug-95

Company Name	Technology	Product Name
A.R.C.		
	Wet Ice	Iceblast
AEA O'DONNELL, INC.		
	Sponge	Sponge Jet
BARTLETT		
	Plastic	Plasblast
CHURCH & DWIGHT		
	Soda	Armex
ICESOLV		
	CO2	TOMCO
	High H2O	10K Hydrolazer
	Ultra High H2O	ADMAC
LTC AMERICAS		
	Steel Grit	LTC 1050Pn

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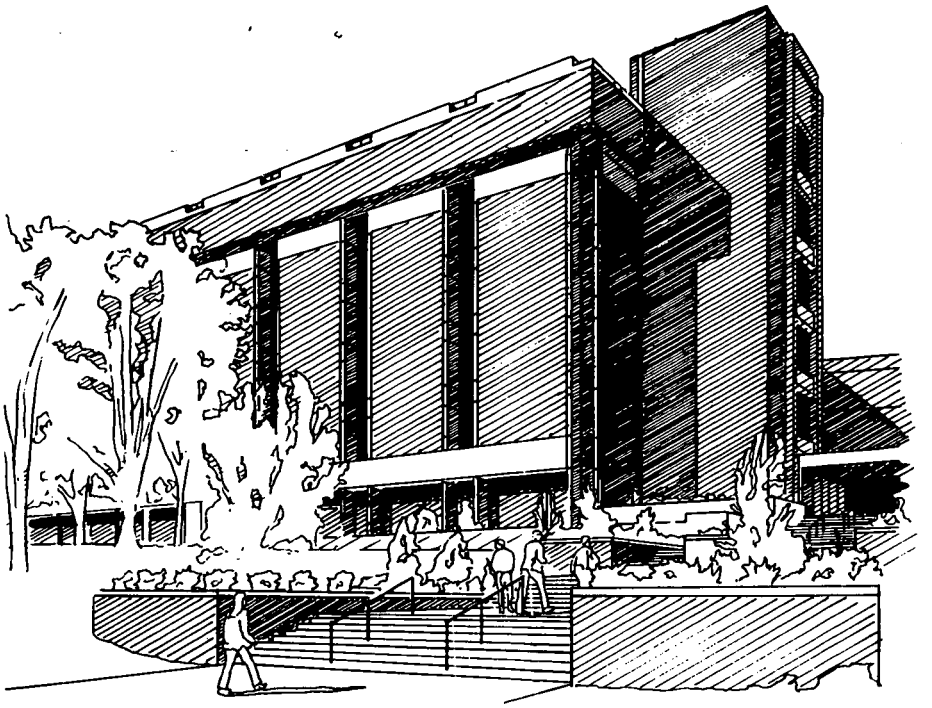

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ALTER

Accelerated Life Testing and Environmental Research

TRANSITE CHARACTERIZATION TREATABILITY STUDY

Final Report
Submitted to:

FERNALD ENVIRONMENTAL REMEDIATION MANAGEMENT COMPANY OF OHIO

November 1995

000250

University of Cincinnati - College of Engineering

Transite Characterization Treatabiliy Study
Final Report

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1.0 INTRODUCTION

A typical decontamination and decommissioning concern for both Department of Energy (DOE) facilities and nuclear power industry facilities is accurately determining the depth to which radiological contamination has penetrated building materials. The optimal means of decontaminating or disposing of such materials will often be dependent on this penetration depth. The building material of primary concern in this study is transite, an asbestos-cement material used for both internal and external walls at process buildings at the DOE Fernald site. Transite was used extensively as building panels at DOE sites prior to the implementation of asbestos-controlling regulations. Uranium processing at the Fernald site has resulted in the radiological and chemical contamination of these panels. In the current era of remediation, prior to the disposal of these transite panels, the multiple concerns of toxic (asbestos containing) and radioactive/chemical (process contaminated) waste must be addressed. Such a mixed waste is much more costly to dispose of than singularly contaminated waste. It is therefore desirable to minimize the amount of mixed wastes. In the case of transite, surface decontamination might be able to restore the bulk of the material to the simpler toxic waste form. The viability of decontamination hinges on the distribution of the contamination through the thickness of the transite panels. Consequently, characterizing this contamination distribution is the first step in the disposal of the transite. Note: the term " contamination distribution" will be used in this report to indicate the distribution of contamination through the thickness of transite samples, and does not refer to the distribution of contamination on the surface of the samples unless specifically mentioned.

The University of Cincinnati was contracted by Fernald Environmental Restoration Management Company (FERMCO) to develop a methodology to determine the depth of radiological contamination for transite samples from the Fernald site to ascertain the feasability of decontamination. This methodology development was to include a review of potential techniques and analysis of Fernald transite samples using one or a few of the most promising techniques identified by this review. In addition, an analysis of the metals contamination was requested. The penetration of lead through the thickness of transite was of particular interest as windows and doors were hung using lead washers and casings.

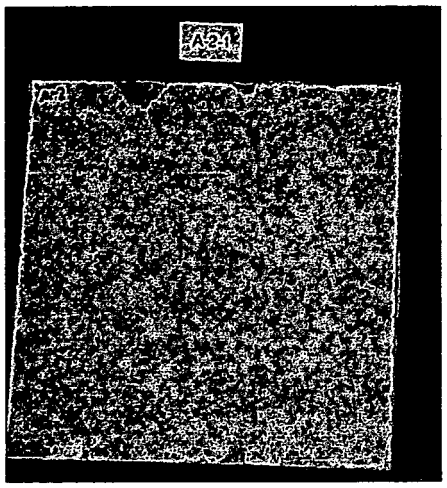
The potential exists for a variety of destructive and non-destructive techniques to be used to characterize the contamination distribution through the thickness of transite. Destructive methods primarily involve a sequential layer removal and subsequent analysis of the exposed

surfaces. Such destructive techniques are very limiting due to the difficulties in handling radiologically contaminated asbestos made friable by the destructive process and due to the resulting constraints on sample size. Consequently, a non-destructive technique capable of being implemented on site is preferred, as this would bypass some difficulties in handling, and would minimize reliance on inferential statistics by allowing a much larger scale sampling plan.

2.0 TRANSITE SAMPLES

Transite is the brand name of an asbestos-cement construction material consisting of chrysotile asbestos (magnesium silicate) and portland cement. Manufacturing consisted of multiple layers of material bonded in a hydraulic press to form composite laminar panels. At the Fernald site, these panels typically have the dimensions of 4'x10' and are either flat or corrugated in form. The flat panels have a nominal thickness of 1/4" whereas the corrugated panels have a nominal thickness of 3/8". In general, the flat panels were used for internal walls and the corrugated panels were used for external walls. Transite was chosen as a building material for its strength and ability to resist moisture, heat, and corrosion. It has a density of about 100 lbs/ft^3 or 1.6 g/cm^3.

The samples used in this study to develop a methodology for determining the contamination distribution were taken from two different buildings at the Fernald site with very different process histories, representing extreme cases. One was Building 7, a dry limited use area where very little process contamination occurred, and the other was Building 2, a wet process extensive use area where more process contamination occurred. Initially, 3 groups or blocks of panels (A, B, and C) were taken from these buildings for analysis. Each of these groups consisted of 6 panels of approximately 10"x10". Group A were flat panels from the interior of building 7A. Group B were corrugated panels from the exterior of Building 7. Group C were flat panels from the interior of Building 2. Examples of the panels from these three groups are shown in Figure 2–1. Each panel was further labeled 1 through 6 in each group, resulting in panels A1 through A6, B1 through B6, and C1 through C6. Furthermore, these panels were subdivided into 9 samples each, a through i. For example, panel C5 was divided into approximately 3"x3" squares C5a through C5i, as shown in Figure 2–2. Each of these samples represents the basic unit of analysis. This presumes a certain degree of contamination homogeneity while allowing sufficient area for practical application of analytic methods.



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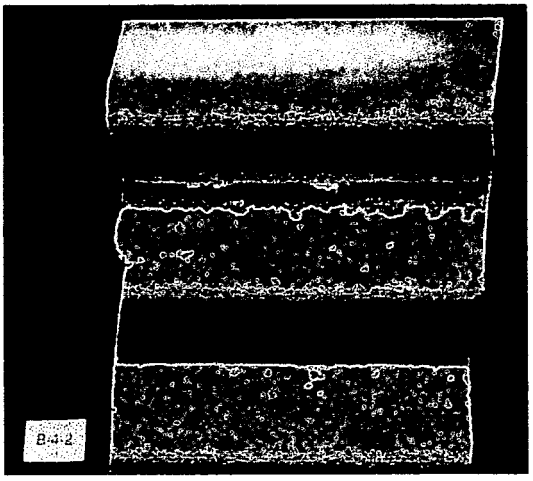

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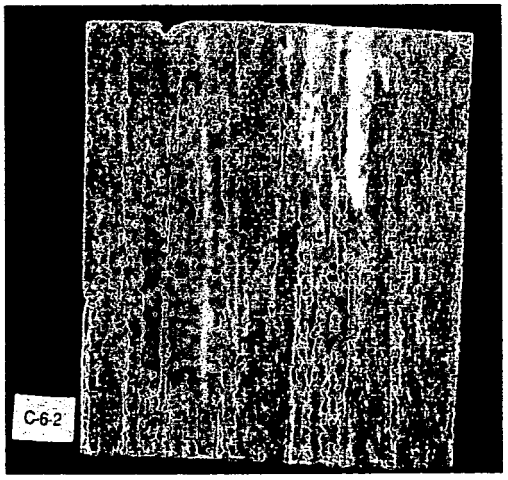


(c)

Figure 2–1: Examples of transite panels from a) Group A (Building 7 – Interior), b) Group B (Building 7 – Exterior), and c) Group C (Building 2 – Interior).

C5a	C5b	C5c
C5d	C5e	C5f
C5g	C5h	C5i

Figure 2–2 Sample labeling

3.0 TECHNIQUES INVESTIGATED

After developing a set of criteria for which a technique must meet in order to be useful for transite characterization, as many techniques as possible were identified and evaluated. These techniques can be grouped into three categories based on the ability of the technique to provide information about the contamination distribution in the sample: 1) destructive techniques which require destroying the sample to provide any information, 2) non-destructive techniques which only provide information about the surface of the sample and therefore require destructive analysis to determine the contamination distribution, and 3) non-destructive techniques which directly provide information about the contamination distribution. As previously noted, entirely non-destructive techniques (category 3) are preferred. The following techniques were considered in an attempt to provide an encompassing range of possibilities while still remaining within the realm of desired criteria. Such criteria consist of minimizing cost, ability to perform in-house, time constraints, quantitative or qualitative nature of the results, ability to measure contamination penetration distribution, accuracy, and precision. A more complete description of each technique, including benefits and limitations, is presented in Appendix A.

3.1 NEUTRON ACTIVATION ANALYSIS (NAA)

Activation analysis consists of first activating the sample and then measuring the resultant induced activity. Activation is the process whereby an element is converted to an unstable state, creating a radioactive material. In the case of Neutron Activation Analysis (NAA), activation is accomplished using a high neutron flux which can penetrate deeply and relatively uniformly. The target material captures the incident neutrons and becomes unstable. The subsequent decay of the target material can be measured with a high resolution gamma-ray detector such as a high-purity germanium (HPGe) detector. The measured spectrum is characteristic of the material, allowing identification of its constituent isotopes. No direct depth information is provided by standard NAA and a large source of neutrons (typically a research reactor) is required. While means of providing depth information can be envisioned, including the gamma-ray spectroscopy technique discussed in section 3.9, most would result in using destructive analysis with NAA (category 1 and possibly 3).

3.2 PROTON INDUCED X-RAY EMISSION (PIXE)

An energetic proton beam is created and directed onto the target. This results in the target atom inner electron shell becoming excited. In returning to the stable ground state, the target atom gives up the excitation energy in the form of an X-ray which has an energy characteristic of that element. Typically, a lithium-drifted silicon (Si(Li)) solid-state detector is used to detect these X-rays and the resultant spectrum allows elemental identification. The quantity of a particular element in a sample is determined based on the assumption that the peak area is proportional to the amount of that element in the sample. In general, PIXE is a non-destructive technique used for surface or near-surface analysis and requires a proton accelerator. Consequently, PIXE would require destructive analysis to provide definitive information about the contamination distribution in transite samples (category 2).

3.3 ATOMIC ABSORPTION SPECTROMETRY (AAS)

A parallel beam of photons is created by a hollow cathode atomic spectral lamp. The beam passes through an atomized sample of the material of interest. The sample will attenuate the continuum of radiation at frequencies corresponding to the target atom resonance transition energies. The attenuated product radiation passes through a monochromator that filters through the range of frequencies characteristic of the element of interest. Finally, a detector measures the resultant radiation intensity. This method is normally based on analyzing for a single element dependent on the monochromator. It is destructive (category 1) and provides no depth information although it does result in a measure of the concentration.

3.4 X-RAY FLUORESCENCE (XRF)

Similar to PIXE in outcome, the source of incident radiation with X-ray fluorescence is high energy photons such as gamma-rays and X-rays. Again, this incident radiation causes vacancies in the inner electron shells of the target material. The resultant transition of electrons to fill these desirable, low potential positions results in the release of X-rays that are characteristic of the element. A high energy resolution detector, such as a HPGe detector which is able to discern the adjacent photopeaks, measures the resultant spectrum to identify the material. This technique works best with a homogeneous solid material, and primarily provides surface or near surface information. Consequently, XRF would require destructive analysis to provide definitive information about contamination penetration depth (category 2).

3.5 BACKSCATTER SPECTROSCOPY

A source, such as a Van deGraaf accelerator, that can provide a beam of collimated and monoenergetic particles directs these particles onto a very flat and thin target material. Most of the particles will pass through the target while a few will be backscattered. A detector placed at very large angles (> 160^0) measures the energy of these backscattered particles. A kinematic analysis based on knowledge of the initial and final energies and angle of scattering indicates the mass of the target atoms. Quantitative analysis is subsequently performed through knowledge of the scattering cross section of the material and number of scatters. This technique requires an extremely uniform surface and would require destructive analysis to provide contamination penetration depth information (category 2).

3.6 INDUCTIVELY COUPLED SPECTROSCOPY (ICP) - ATOMIC EMISSION SPECTROSCOPY (AES) AND MASS SPECTROSCOPY (MS)

An inert gas, usually Argon, is inductively coupled with a high frequency electrical field. The resulting ionization of the circulating gas creates a very high temperature controlled plasma. A sample of the material of interest is dissolved, dissociated, and atomized before injection into the plasma. This results in the material atoms being excited and emitting light at frequencies that are unique to the material. The intensity and wavelength of the light is then measured by either an emission spectrometer or a mass spectrometer. Quantitative analysis is based on the intensity when compared to a standard sample. This method requires that the sample be in a solution capable of being atomized and provides no direct depth information (category 1).

3.7 ULTRAVIOLET (UV) FLUORESCENCE

When uranium is exposed to an oxygen containing environment, such as air, uranyl ions (UO_2^{+2}) are formed. These ions fluoresce visible green light when exposed to ultraviolet (UV) light. The concentration of contamination is proportional to the intensity at which the material fluoresces. The presence of uranium contamination can be determined qualitatively by direct observation. Image analysis, through the use of standards to determine relative intensities, could likely produce quantitative results. However, such a quantitative analysis would require extremely consistent photography. This method, developed by UC ALTER in 1992, provides only surface information (category 2), but it is very quick, simple, and inexpensive.

3.8 AUTORADIOGRAPHY

Autoradiography differs from typical radiography only in that the source of radiation is provided by the sample itself and a separate radioactive source is not required. Typical radiography also involves capturing the image of the sample on a photographic plate based on the attenuation of the radiation from the separate source by the intervening sample, while autoradiography captures the actual pattern and intensity of contamination from the sample. The only requirements are film and a means of handling the light sensitive media for exposure purposes. Since autoradiography also provides a spatial representation of contamination, it can be used for comparison to the UV photography results for verifying which regions contain uranium contamination. The greatest drawback to autoradiography is the lengthy time requirement which can be as much as several days for sufficient exposure. Autoradiography provides surface or near surface information and would require destructive analysis to determine the contamination distribution through the thickness of the transite panels (category 2).

3.9 GAMMA-RAY SPECTROSCOPY

While providing spectral data from a source of gamma-rays using a detector and multi-channel analyzer is not a new concept, using such data with a knowledge of the source material attenuation coefficient to determine the contamination penetration distribution is a pioneering application of the existing technology. The greatest advantage of this technique is the ability to obtain penetration data directly without having to remove layers of the material destructively (category 3). In order to obtain sufficient photopeak areas for analysis, some samples may require lengthy counting times on the order of days, depending on the degree of contamination. A HPGe detector is recommended for high energy resolution to discern adjacent photopeaks.

4.0 TECHNIQUES USED

To determine the contamination distribution in transite panels, the following were determined the most appropriate methods, in accordance with the considered criteria, allowing use of current in-house equipment to minimize cost while providing sufficient accuracy and precision in a timely manner. The techniques include ICP for metals analysis and autoradiography, UV fluorescence, and gamma-ray spectroscopy for radiological characterization. Of these, the only technique to directly provide information about the contamination penetration distribution through the thickness of the sample is the gamma-ray spectroscopy. This novel non-destructive technique initially required the use of other techniques to provide verification. In order for the other destructive techniques to provide information about the contamination penetration distribution, successive layers of material must be removed to allow analysis at the various depths. One possible concern with using the destructive techniques to verify the non-destructive technique is that the latter provides a continuous distribution while the former provides data at discrete thicknesses. However, the random nature of the thickness of layer removal and a sufficiently large number of data points ensure that interpolation between analysis depths is valid for comparison.

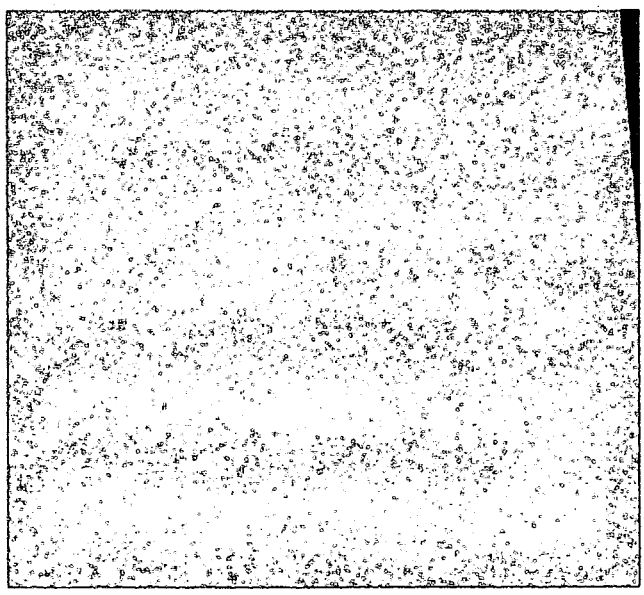
4.1 DESTRUCTIVE RADIOLOGICAL TECHNIQUES

Converting the surface analysis provided by UV fluorescence and autoradiography into a form that reveals the contamination distribution in the depth of the transite requires the removal of layers. Figure 4-1 shows examples of UV fluorescence and autoradiograph results. Also, the data provided by these techniques is essentially qualitative and verification of the non-destructive method requires a comparison with a quantitative distribution. This quantitative data is provided by a Geiger-Mueller (GM) beta/gamma ($\beta - \gamma$) survey meter with measurements at each depth analyzed. A 3'x 2'x 4' high efficiency particulate air (HEPA) filtered glove box containment built specifically for this project (see Figure 4-2) was used to deal with the unique challenge of the neccessary creation of friable radioactive asbestos resulting from layer removal. Samples of transite are placed in the containment along with an 18" belt sander , 1" micrometer, and double bagged $\beta - \gamma$ survey meter with a circular probe. Measurements of contamination are conducted in-situ using the $\beta - \gamma$ survey meter. Measurements of thickness are performed with the micrometer at the positions indicated by Figure 4–3.

Each sample is then placed in a vise attached to a wooden base inside the containment such that about half of the sample thickness extends above the top of the vise. The belt sander with rough grit sandpaper is applied to remove layers of material. Applying the sander in a variety of directions maximizes even removal. The thickness of the layer removed is dependent on both the amount of pressure applied manually and the amount of time spent sanding. Through meticulous sander control and technique, it is possible to remove a fairly even layer with a minimum thickness of approximately 0.01". The variation in the thickness measured by the micrometer at the eight positions is a measure of the evenness.

Before and after each of these layer removals, the sample is analyzed with the Geiger-Mueller detector, UV photography, and autoradiography. The detector is used in the glove box by placing the probe, which is about the same size as the sample, on the sample face and obtaining a visually averaged reading from the meter face on slow response. For the UV photography, the sample is placed in a light box equipped with ultraviolet fluorescent bulbs which emit light at a 254 nanometer (nm) wavelength. A 35 millimeter (mm) camera is attached to the viewport with 200 speed film, and the exposure is of 4 second duration. For comparative purposes, consistent settings and development are crucial. Different levels of contamination result in varied intensity hues and shades of iridescent green. Optically scanning the image into a digital format allows some image enhancement to emphasize the actual contamination. Correct interpretation of the UV images often requires comparison to the equivalent autoradiograph. The autoradiographs are produced using standard X-ray imaging film with a central polymeric base coated on both sides with a thin emulsion covered with an anti-scratch layer. Two triple closure light-tight boxes were constructed for film storage and sample exposure. The film is placed in direct contact with a sample and stored in one of the boxes for an exposure time of either 24 or 48 hours, depending on the contamination level. It has been empirically determined that a Geiger-Mueller detector reading of about 1000 counts per minute (cpm) or greater can be exposed for 24 hours with a sufficient image. Lesser activity requires a 48 hour exposure. Consistent developing is provided by a standard automated developer. One concern with this method of layer removal was the possibility of cross-contamination between subsequent layers due to removal by abrasion. The results have indicated that this effect is negligible through well resolved contamination pattern images (from the autoradiography and UV photography results) and the consistent decrease in activity with layer removals of varying thickness.

(a)



(b)

Fig. 4–1: Example of results from a) UV photography and b) autoradiography of a transite sample. The dark areas in b) correspond to regions with relatively high radiological contamination and have associated dark green regions in a).

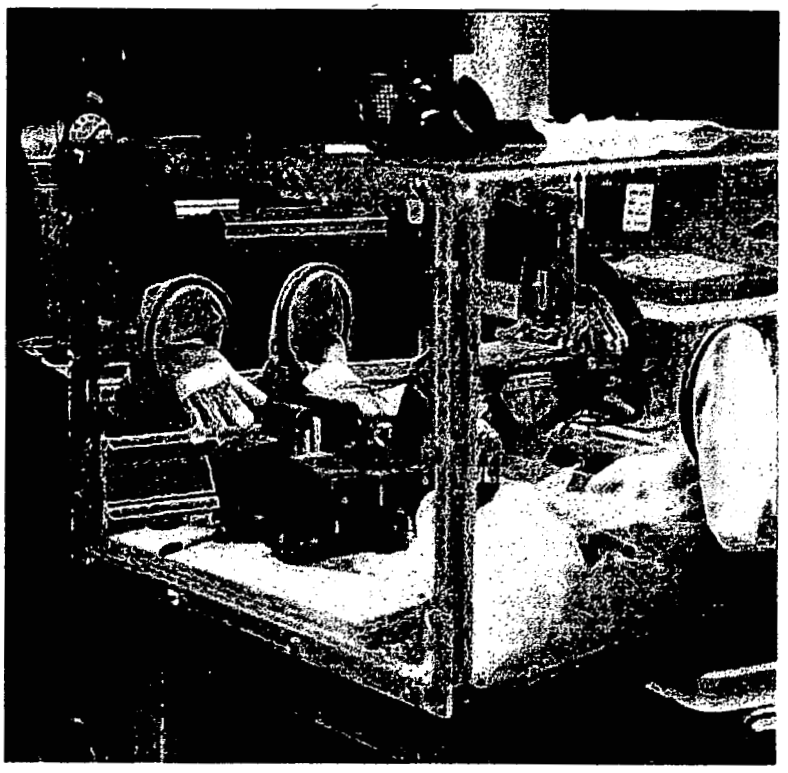


Fig. 4–2: HEPA Filtered Glove Box for Destructive Transite Analyses.

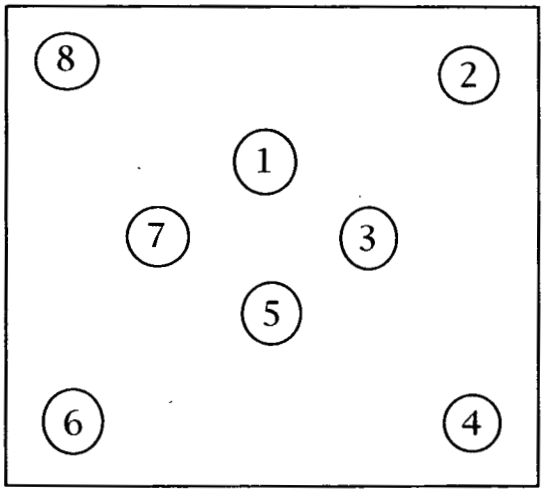


Figure 4–3 - Thickness Measurement Locations

4.2 NON-DESTRUCTIVE RADIOLOGICAL TECHNIQUE

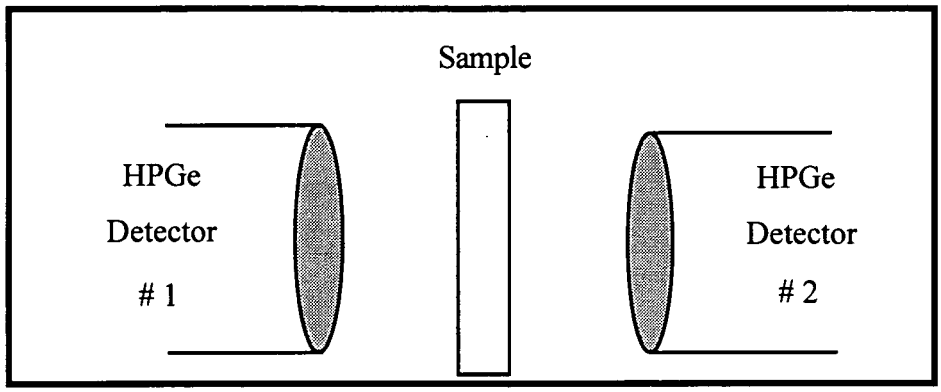
A non-destructive method of measuring the contamination penetration distribution, which is based on measuring the gamma-ray spectra from both sides of the sample, is proposed and validated in this study. In conjunction with knowledge of the gamma-ray linear attenuation coefficient of the sample material and proper diffusion or leaching models representative of how the material was contaminated, the ratio of photopeak areas at several energies from these spectra can be used to infer the most-probable distribution of the contamination. Figure 4–4 illustrates the implementation of this technique. A HPGe detector provides sufficient energy resolution to discern all of the photopeaks of interest. Comparing the measured ratio of the respective photopeak areas from both sides of the panel (Figure 4–4b) over a range of energies to computer-generated ratios for possible contamination distributions allows determination of the most-probable distribution (Figure 4–4c). While discussion of this technique in this study is focused on its use with Fernald transite, the technique can be used with any material for which gamma-ray spectra can be acquired on both sides of the sample.

4.2.1 Computational Techniques

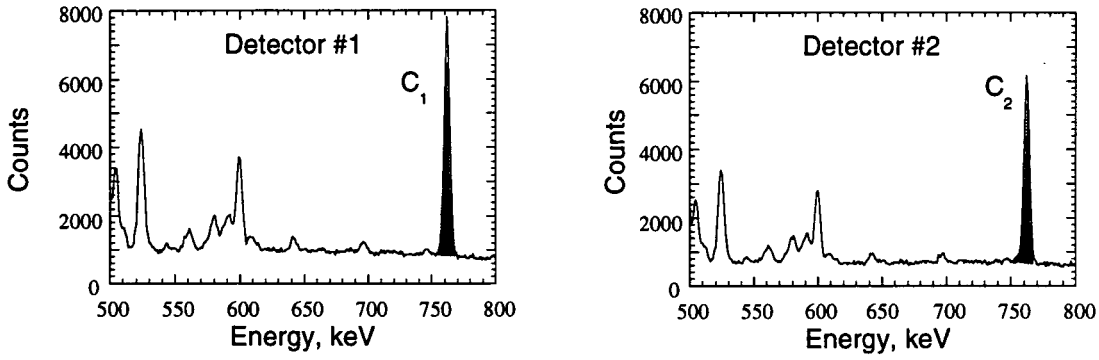
4.2.1.1 Mathematical Representation of the Detector Responses

The number of gamma-rays detected from some spatially extended source will vary as the geometric or material conditions of the medium change. Detecting gamma rays from both sides of radiologically contaminated planar samples as in the currently proposed technique presents such a situation. Fortunately, the point kernel technique has been a widely and successfully used for modeling such radiation transport problems. In the point kernel technique, the fundamental assumption is that the extended radiation source can be regarded as consisting of differential isotropic point sources. Additionally, the effect of the radiation from the whole source at the points of interest (the detectors in this method) can be obtained by summation of the contributions from the individual differential sources that comprise the entire source region. In most practical applications, the assumption that the original nuclear radiation is emitted isotropically is physically valid when considering effects on a macroscopic scale.

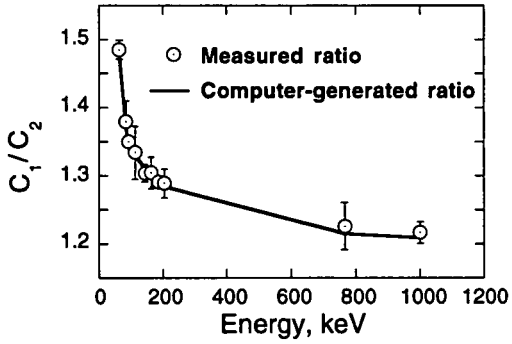
In this application, only full-energy gamma rays are considered. This implies that only the uncollided gamma-ray flux reaching the detectors from the source is considered. Consequently, the computational complexity of the technique is greatly simplified and no generality is lost since only photopeak count rates are being considered. Additionally, it has been assumed that the contamination distribution is uniform in the *x-y* plane on both sides, but not in the z direction.



a



b



c

Figure 4–4 Demonstration of the gamma-ray spectrometry technique using two detectors to determine the contamination penetration distribution in the sample; a) shows the sample-detector geometry; b) the gamma-ray spectra recorded by the detectors and one of the full-energy peaks; c) shows the relationship of measured response ratios as a function of gamma-ray energy compared to the computer-generated ratios.

Furthermore, the term contamination distribution will be used to refer only to the variation in the z direction (the thickness of the sample). In the z direction, the contamination has been assumed to penetrate through a certain thickness. Therefore, the transite panels are assumed to be a finite volumetric radiation source with some kind of contamination distribution in the z direction.

When a detector is set before a finite planar volumetric source, the response of the detector, $f(E)$,to the source at a particular energy E can be written as:

$$\phi(E) = \iiint_{v_s} dv \iint_{s_d} ds\, g(z)\, f(x,y,z,r,\theta,E), \tag{4–1}$$

$$f(x,y,z,r,\theta,E) = \frac{S_0\, r\, e^{-\mu(E)\, z\, \rho/(a+t-z)}}{4\pi\, \rho^2}, \tag{4–2}$$

and

$$\rho = (x^2 + y^2 + r^2 + (a+t-z)^2 - 2r(x^2+y^2)^{1/2} \cos(\tan^{-1}\frac{y}{x} - \theta))^{1/2}, \tag{4–3}$$

where:

x,y,z,r,θ are coordinates

$\phi(E)$ is the uncollided gamma-ray current reaching the detector surface;

$f(x,y,z,r,\theta,E)$ is the kernel function;

$g(z)$ is the unknown source distribution function in z direction;

$\mu(E)$ is the linear attenuation coefficient of the source material;

E is the gamma-ray energy;

S_0 is the source strength, particles per unit volume per unit time;

v_s is the source volume;

s_d is the detector surface area;

t is the sample thickness;

a is the distance between the source surface and detector surface;

Consequently, the response ratio $R(E)$ for a finite volumetric source at energy E can be written as:

$$R(E) = \frac{\phi_1(E)}{\phi_2(E)} = \frac{\iiint_{v_s} dv \iint_{s_d} ds\, g(z)\, f_1(x,y,z,r,\theta,E)}{\iiint_{v_s} dv \iint_{s_d} ds\, g(z)\, f_2(x,y,z,r,\theta,E)}, \tag{4–4}$$

where$\phi f_1(E)$ and $\phi_2(E)$ are the uncollided gamma-ray currents over the surfaces of two detectors. Due to the relative coordinates, the forms in kernel functions ϕ_1 and ϕ_2 will be slightly different.

Let $C(E)$ be the detector count rate, then $C(E)= e\phi(E)$, where e is a constant accounting for the detection efficiency. For two identical detectors symmetrically positioned on both sides of the source, e is approximately equal. Consequently, the detector response ratio $R(E)$ can be expressed as:

$$R(E) = \frac{\phi_1(E)}{\phi_2(E)} = \frac{C_1(E)}{C_2(E)}, \qquad (4\text{–}5)$$

where $C_1(E)$ and $C_2(E)$ are the count rates for two detectors, respectively.

Note that surface contamination is the limiting case of a volumetric distribution with the penetration depth approaching zero. Therefore, the mathematical expression for a surface source is similar to that of a volumetric source.

The major complication in solving the integral equation (4–4) for $g(z)$ is that the solution strongly depends upon the conditions of the kernel functions ϕ_1 and ϕ_2, function R as it varies with energy, and the relations of ϕ_1, ϕ_2, R, and g. When the kernel functions are nonlinear functions, as in our case, and function R is also a nonlinear function, it is difficult to obtain the solution using either analytical or numerical methods. In some situations, no solutions exist. However, if the unknown distribution function $g(z)$ can be constrained to a properly chosen mathematical expression in terms of physically valid assumptions, equation (4–4) can be efficiently and dependably solved. On the basis of this fundamental idea, resolving equation (4-4) becomes possible and, as it will be shown later, this is an efficient approach for determining the contamination distribution. In the computation process, the Gauss-Legendre integration method is used for multidimensional integrals.

4.2.1.2 Diffusion in Solid Materials

To select potential unknown distribution functions $g(z)$ in equation (4–4), the manner in which the sample was contaminated should be considered to obtain the proper analytical models. One common situation which may occur when solid materials are radiologically contaminated is the process of diffusion transport, during which the radioactive particles migrate into the material. Although there are different models describing diffusion phenomena with various considerations for different diffusion mechanisms (such as the bulk diffusion model, bulk diffusion with partial fixation model, bulk diffusion with linear adsorption model, and some empirical models which emphasize different diffusion mechanisms and conditions), all can be generalized into a fundamental form. The major differences in such models are reflected by the expression of the diffusion coefficient parameter. In general, if only considering the cumulative contamination effect, the lumped parameter (or effective diffusion coefficient) can be used. The diffusion

process is described by transport theory and can be used to obtain the theoretical solution given specific initial and boundary conditions.

Generally, the one dimensional, time-dependent problem is represented by Fick's second law and can be written as:

$$\frac{\partial J}{\partial z} = -\frac{\partial c}{\partial t}, \tag{4–6}$$

where J is the flux of particles, and c is the concentration of diffusion species. In a homogeneous system, equation (4–6) can further be reduced to:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial z^2}, \tag{4–7}$$

where D is the diffusion coefficient or diffusivity of the sample material.

For some specific initial conditions and boundary conditions, equation (4–7) can be solved analytically. For the case of Fernald transite, two special cases are considered herein. Other cases, and possibly other models (such as leaching), may be more appropriate for different contamination scenarios.

4.2.1.2.1 Instantaneous Contamination Exposure

If the diffusing species is deposited as a "thin" layer, or an instantaneous contamination, on the surface of the sample, the initial condition is:

$$c(z,0)=s_0\,\delta(z), \tag{4–8}$$

where δ is the Dirac delta function, defined by:

$$\delta(z) = \begin{cases} 0, & z \neq 0 \\ 1, & z = 0 \end{cases}, \tag{4–9}$$

and

$$\int_0^{+\infty} c\,dz = s_0, \tag{4–10}$$

where s_0 is the quantity of diffusing particles deposited per unit area. Under these conditions, the analytical solution to equation (4–7) is:

$$c(z,t) = (s_0 / 2(\pi Dt)^{1/2})\,exp(-z^2 / 4Dt). \tag{4–11}$$

Equation (4–11) is the Gaussian distribution function and Figure 4–5 shows the contamination penetration profile at two different times. Note the total amount of contamination remains constant at s_0, while the penetration depth increases with time.

4.2.1.2.2 Constant Surface Contamination Exposure

If the sample is being continuously exposed to a constant concentration of the diffusing species, a different situation arises. In this case, with initial condition:

$$c(z,0) = c_0 , \tag{4–12}$$

and boundary condition:

$$c(0,t) = c_s , \tag{4–13}$$

the analytical solution is:

$$\frac{c - c_s}{c_0 - c_s} = erf\left(\frac{z}{2\sqrt{Dt}}\right) , \tag{4–14}$$

where, "*erf*" indicates the error function:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-u^2}\, du \quad . \tag{4–15}$$

Since the transite panels were not radiologically contaminated when the buildings were constructed, c_0 represents the material background concentration which is approximately zero compared to the contamination concentrations. Therefore, equation (4–14) can be further simplified as:

$$c(z,t) = c_s\, erfc(z / 2(Dt)^{1/2}), \tag{4–16}$$

where "*erfc*" is the complementary error function (*erfc*=1-*erf*). c_s has the physical meaning of concentration of the constant source of the diffusing species at the surface of sample. Figure 4–6 shows the contamination penetration profile at two different times. Again the surface activity or contamination remains constant with time, while the penetration depth increases with time.

Equations (4–11) and (4–16) are the analytical solutions of equation (4–7) for a planar geometry. These distribution functions have been simplified into the following formats to consistently represent the contamination distribution function *g(z)* in the detector response ratio equation (4–4).

$$g(z) = S_{01}\, exp(-\lambda_1 z^2) , \tag{4–17}$$

and

$$g(z) = S_{02}\, erfc(\lambda_2 z) , \tag{4–18}$$

where it is assumed that effective diffusion coefficient D and time t are constant for a specific point in time. Therefore, S_0 represents the lump parameter of $S_{01}=s_0/2(pDt)^{1/2}$, $S_{02}=c_s$, and λ

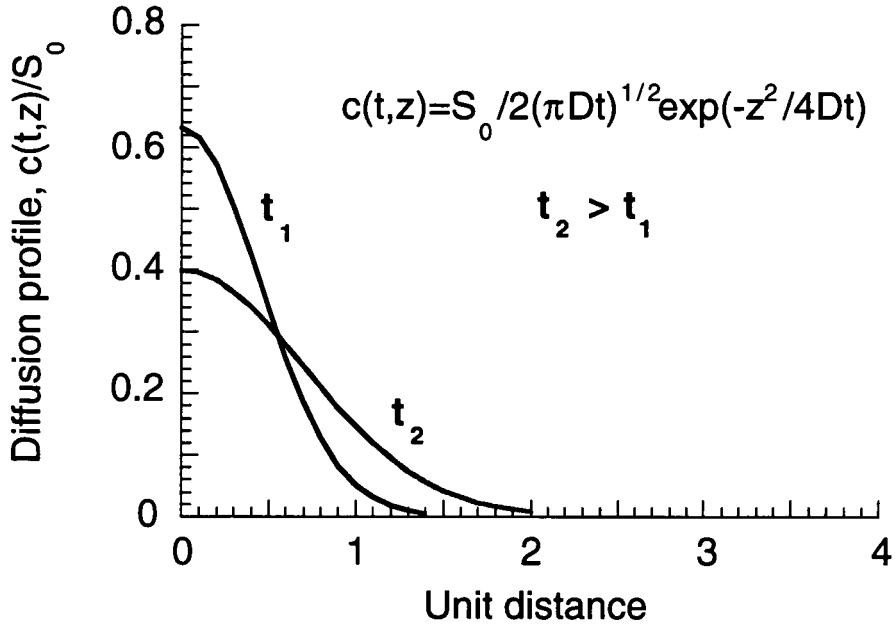


Figure 4–5 Contamination distribution (Gaussian distribution) through thickness of sample due to instantaneous contamination exposure using diffusion model at two times, t_1 and t_2, after the exposure.

represents $\lambda_1 = 1/4Dt$, $\lambda_2 = 1/2(Dt)^{1/2}$. Both parameters ($S_0$ and λ) are expressed by the diffusion coefficient and duration of time since the initial exposure to contamination.

A major objective in developing this non-destructive technique is to predict the possible contamination distributions that may occur in the transite panels by using computer simulation of the experimental measurement. Such simulation provides insight into how the radiation is attenuated due to the different geometry and photon energies, and uses these characteristic differences to evaluate the contamination distribution. Furthermore, this simulation not only performs the calculations to resolve the equation (4–4) when the distribution function $g(z)$ is given, but also generates the optimum parameters to predict the most probable contamination distribution , such as the λ and S parameters in the diffusion model. These optimum parameters are determined using a least-squares fit.

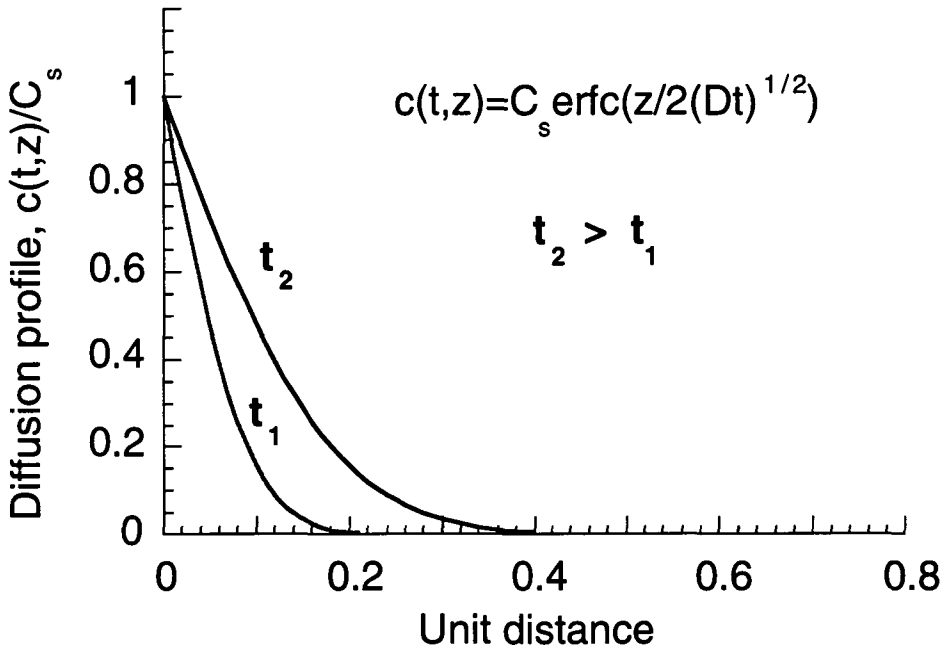


Figure 4–6 Contamination distribution (complimentary error function) through thickness of sample due to constant contamination exposure using diffusion model at two times, t_1 and t_2, after the initial contamination.

4.2.2 Distinguishing Spatial Distributions

4.2.2.1 Detector Responses to Surface and Volumetric Sources

The potential exists for both sides of Fernald transite panels to be radiologically contaminated. In almost all cases, this situation occurs. Consequently, the contamination will penetrate into the material from both sides. If the penetration depth is small, the material may be considered surface contaminated and could possibly be decontaminated. If the contamination has penetrated deeply into the material, it must be considered volumetric and could be distributed through the panel thickness in any of a nearly infinite number of distributions. Therefore, two problems should be considered: first, identifying whether the contamination is distributed on the surface only or is volumetric; and second, determining the contamination penetration depth along with the contamination distribution within the panel.

To address these two problems, two fundamental parameters which are used in the analysis are introduced. The first parameter is the *response ratio* which is defined as C_1/C_2, where C_1 and C_2 are the photopeak counting rates in detectors 1 and 2, respectively, at a particular energy. This ratio is used to reflect the difference in gamma-ray attenuation for the two sides and analytically corresponds to equation (4–4). The second parameter is the *boundary condition ratio* which is defined as S_2/S_1, where S_1 is the surface activity of the more contaminated side (hot side), and S_2 is the surface activity of the less contaminated side (cold side). This ratio presents the relationship of the boundary contamination levels on the two surfaces of a transite panel. By choosing the hot and cold sides as sides 1 and 2, respectively, the boundary condition ratio will always be less than or equal to unity ($S_2/S_1 \leq 1$). The response ratio, however, depends upon the geometry and gamma-ray energy.

4.2.2.2 Contamination on One Side

Some situations may exist where only one side of the transite panel is contaminated. This is represented by S_2 being equal to zero. If the measurement geometry is arranged as illustrated in Figure 4–7, the response ratio as a function of gamma-ray energy will always be greater than unity ($C_1/C_2 \geq 1.0$) and vary depending on the contamination distribution.

The different contamination distributions, shown in Figure 4–8a, will generate the corresponding detector response ratios shown in Figure 4–8b. It should be noted that any contamination distribution approaches the behavior of a surface source as the penetration depth approaches zero. This is illustrated in Figs. 4–8a and 4–8b by volumetric source 1 (VS1) , and the surface source (SS). Different penetration depths will result in different response ratios (C_1/C_2) as a function of energy as shown in Figure 4–8b. These differences permit the quantitative analysis and distinguish the different source distributions. For example, if given a set of measured response ratios (C_1/C_2) for a transite panel, one can compare this data with the computed results to identify which distribution is most probable.

4.2.2.3 Contamination on Two Sides

When both sides of a transite panel are contaminated, the boundary condition ratio (S_2/S_1) becomes non-zero and the analysis is more complicated. The recommended measurement geometry for this technique when contamination exists on two sides is shown in Figure 4–9.

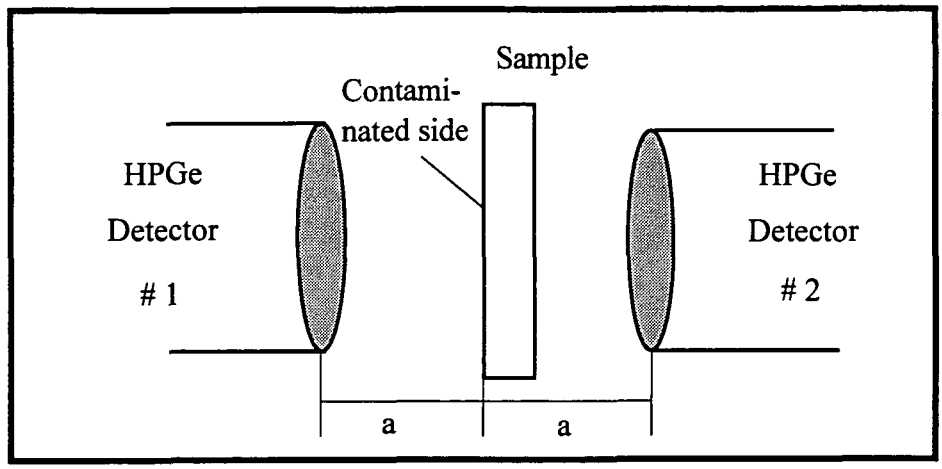


Figure 4–7 Sample-detector geometry for samples contaminated on one side only.

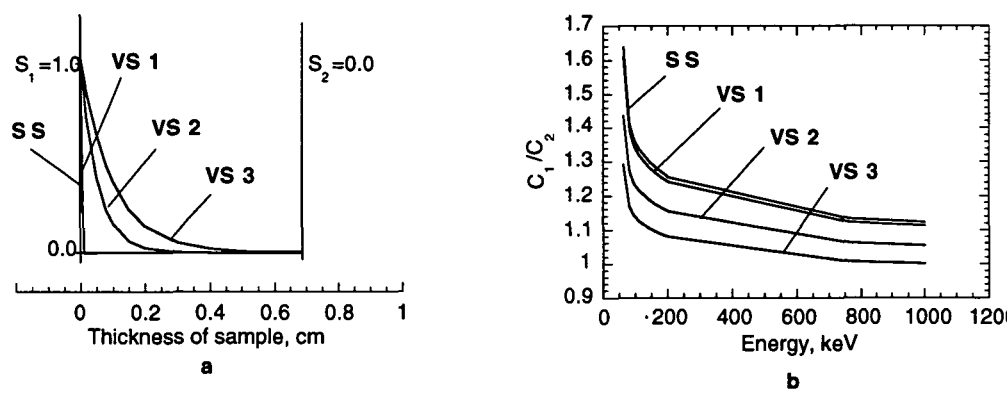


Figure 4–8 a) Configuration of different contamination distributions used to model transite panels contaminated on one side only. b) Corresponding response ratios (C_1/C_2) for surface and volumetric sources shown in (a) for transite panels contaminated on one side only. (SS is surface source, VS is volumetric source.)

The following analytical techniques were used to determine contamination distribution for such cases:

- When $S_2 \neq S_1$ and the boundary condition ratio (S_2/S_1) is known, a comparison between the measured data and the computed data is possible to determine the most likely distribution within the panel. For example, assume $S_2/S_1=0.15$ for the geometry in Figure 4–9. Several possible contamination distributions with this boundary condition ratio are shown in Figure

4–10a. However, each distribution will contribute differently to the response ratio, as shown in Figure 4–10b. When the proper distribution model is selected, such as selecting diffusion model equation (4–9) adapted for a two-sided case, then comparing these simulated results with the measured data, the true distribution can be identified.

- When $S_2 \neq S_1$ and the boundary condition ratio (S_2/S_1) is unknown, we may use relationships obtained by computer simulation to evaluate the maximum and minimum boundary condition ratios. This is accomplished by using the measured response ratios. Referring to Figure 4–11, the measured ratios R_1 and R_2 at energies 64 keV and 1001 keV, intersect with the simulated surface source results at points of 2 and 4, respectively. The vertical line formed by these points corresponds to the maximum possible ratio $(S_2/S_1)_{max}$ of approximately 0.30. If the shape of the distribution *g(z)* is known, as shown in Figure 4–11, the ratio S_2/S_1 can be determined by intersection points 1 and 3, and is approximately 0.15. Otherwise, when ratio S_2/S_1 is known, the distribution function *g(z)* can be determined by measured response ratios R_1 and R_2. Note that the minimum boundary condition occurs when S_2/S_1 is zero. If R_1 and R_2 are known and $S_2/S_1=0$, the distribution *g(z)* can be determined and provides the other limiting case. Furthermore, this case produces the maximum penetration depth of the contamination from the hot side of the panel. If S_2/S_1 is larger than zero, then the penetration depth of the contamination from the hot side will be smaller, and there will be some contamination on the cold side.

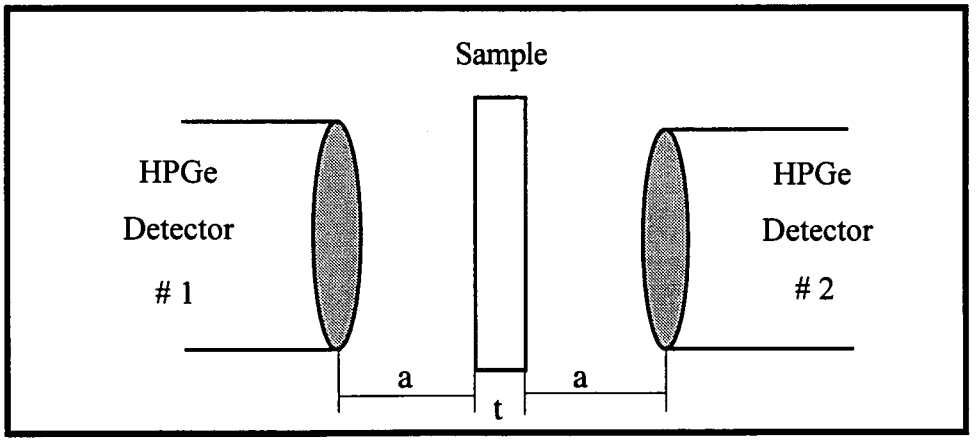


Figure 4–9 Sample-detector geometry for transite panels contaminated on two sides

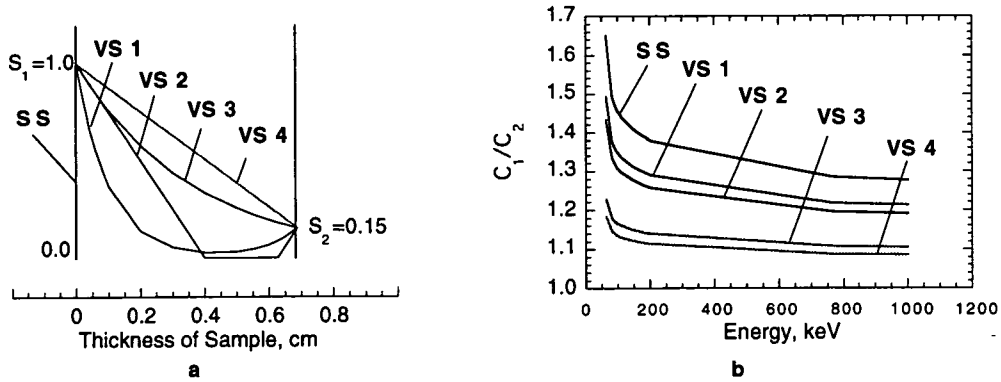


Figure 4–10 a) Configuration of different contamination distributions in transite panels when S_2/S_1=0.15. b) Response ratios (C_1/C_2) for different contamination distributions shown in (a) when S_2/S_1=0.15. (SS means surface source, VS means volumetric source.)

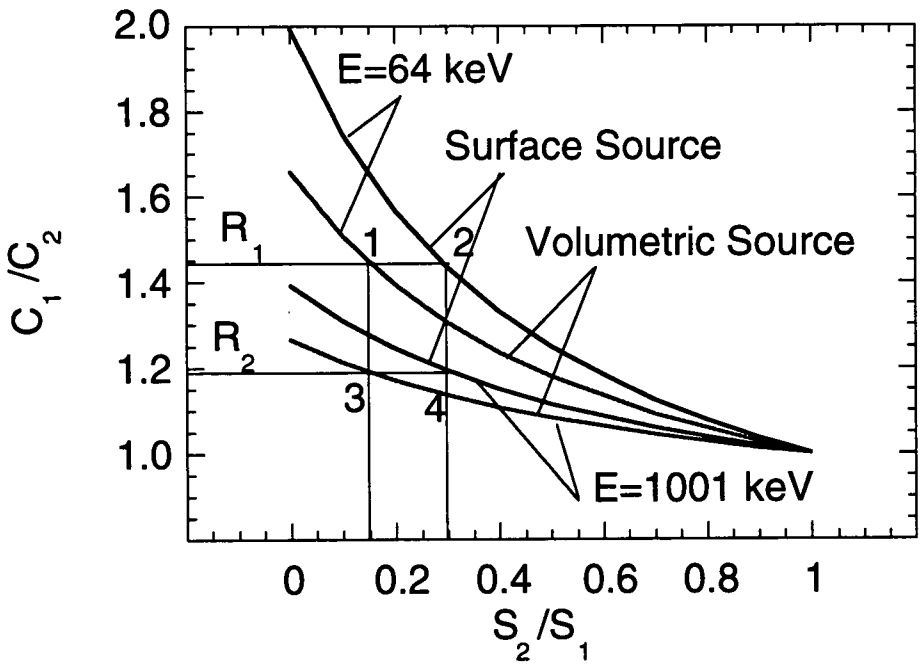


Figure 4–11 Relationship of response ratio (C_1/C_2) and boundary condition ratio (S_2/S_1) (surface and volumetric sources for E=64 and 1001 keV).

4.2.3 Technique Requirements

Implementing this technique requires both significant experimental response ratio data and the significant material and geometric input data for the simulation. Knowledge of the gamma-ray linear attenuation coefficient as a function of energy and material is required to perform the computer simulations. As a result, the linear attenuation coefficient of transite was measured over the energy range of interest. These measurements were performed using a HPGe detector with standard gamma-ray sources (Cd-109, Am-241, and Eu-152) and multiple transite panels to provide variable thicknesses.

The accuracy of this technique increases with the number and energy range of detector response ratios used. As seen in Figs. 4–8b, 4–10b, and 4–11, the response ratio varies most significantly at low energies. Consequently, it is desirable to use as many response ratios as possible in the low energy region. Furthermore, choosing the gamma-ray energies for recording response ratios must be considered carefully. For the Fernald transite panels, it was first necessary to note that the contamination is primarily from uranium processing, thus the radionuclides on the transite panels are primarily Uranium (U)-235, U-238, and their daughters. Due to the relatively short period of time (short compared to uranium and uranium daughter half-lives) that the contamination has been on the transite panels (5-40 years), the number of gamma-ray energies to choose from is limited. More precisely, U-235 will likely be in equilibrium with daughter Thorium (Th)-231, but may not be in equilibrium with Protactinium (Pa)-231 and its daughters; and U-238 will likely be in equilibrium with daughters Th-234 and Pa-234m, but may not be in equilibrium with U-234 and its daughters. These restrictions are due to the relatively long half-lives of Pa-231 and U-234, respectively. Thus, gamma-ray energies were chosen only from those radionuclides which were believed to be in equilibrium with U-235 and U-238. Table 4–1 lists the resulting energies and radionuclides chosen for analysis of the Fernald transite panels.

To obtain the most accurate response ratios, a HPGe detector is recommended. Although the technique calls for two detectors, only one HPGe detector is actually required. With one detector, an experimental arrangement similar to that shown in Figure 4–9 is achieved by turning the sample over and carefully controlling the geometric conditions. Furthermore, the high energy resolution of a HPGe detector is necessary to ensure that all counts are associated with the correct full-energy gamma-ray peak.

Table 4–1 Gamma-ray energies and associated radionuclides at which response ratio should be recorded for Fernald transite panels

Energy, keV	Radionuclide
63.29	Th-234
84.21	Th-231
92.80	Th-234
112.81	Th-234
143.76	U-235
163.35	U-235
185.72	U-235
205.31	U-235
766.62	Pa-234m
1001.22	Pa-234m

4.3 METALS CHARACTERIZATION TECHNIQUES

Metals contamination of transite was measured indirectly by performing leach tests and directly by digestion of the transite surface layer. The following provides a description of the methods used. Results of the analyses are provided in Section 5.3

4.3.1 Leaching Procedure

Transite panels were identified as A, B, or C series, corresponding to Building 7 interior flat panels, Building 7 exterior corrugated panels, and Building 2A interior flat panels, respectively. Building 7 interior panels (A series) were used for the initial metals analysis.

Samples were prepared by cutting transite panel A6 into approximately 4 in. by 4 in. squares. Panels were dry cut in a sealed glove box using a tile saw. Final dimensions of panel A6 samples are summarized in Table 4–2. The volume and surface area was calculated for each cut sample to determine the required amount of leachant.

The procedure developed for this study is similar to the ANS 16.1 leach test. To provide more aggressive leaching, without the destruction of the samples, the following changes were incorporated into the standard leach test: 1) the strength of the acetic acid leachant was increased from 0.04M to 0.4M and 2) the leachant was stirred continuously for all leach intervals.

Table 4-2 Sample dimensions for transite panel A6

SAMPLE A6b

LENGTH	mm	in	THICKNESS	mm	in
1	103.09	4.059	1	6.14	0.242
2	99.99	3.937	2	6.68	0.273
3	103.32	4.068	3	6.13	0.240
4	99.88	3.932	4	5.84	0.231
AVG(1&3)	103.21	4.064	AVERAGE	6.20	0.247
AVG(2&4)	99.94	3.935			
SURFACE AREA (cm ^ 2)			231.46		
LEACHANT VOLUME REQ'D (mL)			2315		

SAMPLE A6c

LENGTH	mm	in	THICKNESS	mm	in
1	100.10	3.941	1	6.21	0.244
2	103.04	4.057	2	6.6	0.260
3	99.87	3.932	3	6.14	0.242
4	102.51	4.036	4	6.23	0.245
AVG(1&3)	99.99	3.937	AVERAGE	6.30	0.248
AVG(2&4)	102.78	4.047			
SURFACE AREA (cm ^ 2)			231.62		
LEACHANT VOLUME REQ'D (mL)			2316		

SAMPLE A6e

LENGTH	mm	in	THICKNESS	mm	in
1	95.42	3.757	1	5.35	0.211
2	100.05	3.939	2	5.57	0.219
3	95.17	3.747	3	5.46	0.215
4	99.97	3.936	4	5.33	0.210
AVG(1&3)	95.30	3.752	AVERAGE	5.43	0.214
AVG(2&4)	100.01	3.938			
SURFACE AREA (cm ^ 2)			211.81		
LEACHANT VOLUME REQ'D (mL)			2118		

SAMPLE A6f

LENGTH	mm	in	THICKNESS	mm	in
1	95.07	3.743	1	5.08	0.200
2	102.38	4.031	2	5.74	0.225
3	95.22	3.749	3	5.41	0.213
4	102.36	4.030	4	5.33	0.210
AVG(1&3)	95.15	3.746	AVERAGE	5.39	0.212
AVG(2&4)	102.37	4.031			
SURFACE AREA (cm ^ 2)			216.53		
LEACHANT VOLUME REQ'D (mL)			2165		

The leach vessels were constructed of unreactive polypropylene. To maximize the surface exposed to the leachant solution, samples were suspended on an inert stand.

At the end of each leaching interval, the specimen was removed from the used leachant and placed into fresh leachant. The leachate was sampled and completely replaced after cumulative leach times of 2, 7, and 24 hours from initiation of the test. Subsequent leachate sampling and replacements were made at cumulative leach times of 48, 72, and 121 hours. Spent leachate was analyzed through ICP spectroscopy. Prior to ICP analysis, the spent leachate was acid digested according to method USEPA SW-846:3051 (Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils). ICP analysis was performed according to method USEPA SW-846:6010A (Inductively Coupled Plasma - Atomic Emission Spectroscopy).

4.3.2 Surface Digestion

Abraded material from the surface of the transite panels was digested and analyzed for total extractable lead, uranium, and barium content. Approximately 30 grams of dry, abraded transite material taken from the glove box was provided in a single 250 milliliter (ml) high density polyethylene (HDPE) container from which all analytical samples were taken. The container was manually and randomly sampled to obtain 24 dry transite samples, labeled M1 through M24. Each sample consisted of approximately one-half (0.5 +/-) grams of dry transite material.

Transite samples were placed in separate 100 ml PFA-lined pressure vessels to which 10 ml of trace-metal grade nitric acid was added for digestion. Sample digestion was carried out in a Questron Q45 EnviroPrep microwave digester. The sample digestion procedure followed USEPA SW-846, Method 3051.

Once digestion was completed, samples were analyzed for total extractable lead, uranium, and barium content using a Perkin-Elmer Optima 3000 Inductively Coupled Plasma - Atomic Emission Spectrometer. The preparation, calibration, and measurement of each analyte followed USEPA SW-846, Method 6010A. Calibration was carried out using a stock 10,000 microgram/liter multi-element standard produced by SPEX Chemical Division of Metuchen, NJ. Three replicate readings were carried out for each analyte of each sample. The measured concentrations presented, based on 100 ml volume, are the arithmetic average of the three replicate readings for each analyte. These concentrations were then converted to analyte concentrations as milligrams of analyte per kilogram of dry transite solids.

5.0 RESULTS

5.1 RADIOLOGICAL CHARACTERIZATION RESULTS BASED ON DESTRUCTIVE TECHNIQUES

Quantitative measurements with the Geiger-Mueller (G-M) detector allow the determination of a contamination penetration distribution. This method also has a lower threshold of detection than the qualitative techniques of UV photography and autoradiography. Below approximately 300 to 500 cpm on the G-M detector, no contamination was visible under UV excitation nor after a 48 hour autoradiography exposure. It is possible that with a much longer exposure time, the autoradiography could theoretically match or better this threshold, but would be impractical for most applications.

Prior to performing any destructive analysis, the original uncut 10"x10" panels were surveyed with portable β–γ and alpha (α) detectors in each quadrant of both sides in order to determine an initial external contamination level. Figure 5–1 is a sample of this data. The shaded areas indicate the panel orientation such that data from appropriate quadrants can be compared when thepanel is flipped. The remainder of this initial survey data is presented in Appendix B.

Table 5–1 is a sample of the β-γ count rate data collected using a G-M detector during the destructive layer removal. Figure 5–2 illustrates these results. Data for all other samples analyzed using this technique are presented in Appendix C. Figures 5–3 through 5–6 illustrate the qualitative results collected using UV photography and autoradiography after each layer removal.

5.2 RADIOLOGICAL CHARACTERIZATION RESULTS BASED ON NON-DESTRUCTIVE TECHNIQUE

5.2.1 Linear Attenuation Coefficient of Transite

The measurements of transite attenuation coefficients were performed by using a HPGe detector with clean transite samples and three standard radiation sources. The major consideration in choosing the standard radiation sources is ensuring that the range of gamma-ray energies should

cover the expected range of full-energy peaks for the transite sample. The measured linear attenuation coefficients of transite are listed in Table 5–2 and are shown in Figure 5–7.

Samples from interior of Plant 7

Sample A-1 Measurement Date: 10/21/94

A-1	
β–γ 100 cpm α 10 cpm	β–γ 100 cpm α 5 cpm
β–γ 110 cpm α 10 cpm	β–γ 110 cpm α 10 cpm

Side 1* – Painted

A-1	
β–γ 90 cpm α 0 cpm	β–γ 90 cpm α 0 cpm
β–γ 80 cpm α 0 cpm	β–γ 90 cpm α 0 cpm

Side 2 – Painted

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure 5–1 Example of initial survey data

Table 5–1 Example of layer removal results based on geiger-mueller detector β-γ measurements

original thickness: 0.257 inches

Sample C5a - side1

Total Thickness Removed (inches)	Activity (cpm)
0	19000
0.022	1200
0.032	500
0.046	100
0.057	80
0.074	50 (background)

Sample C5a - side2

Total Thickness Removed (inches)	Activity (cpm)
0	3500
0.008	700
0.029	300
0.049	100
0.058	50 (background)

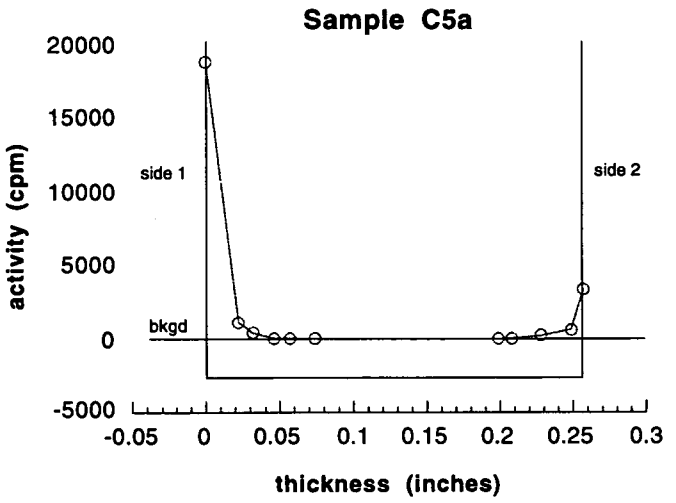
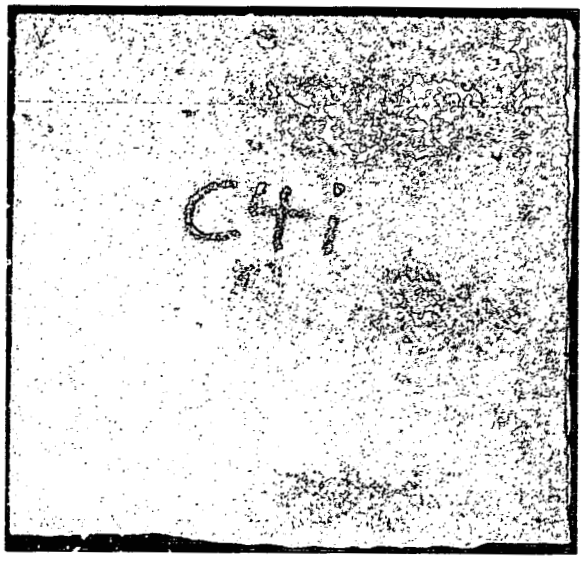
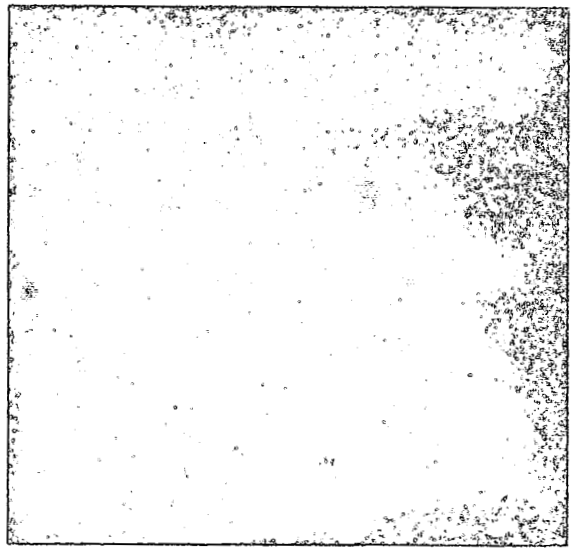


Figure 5–2 Example of contamination penetration distribution for sample C5a



(a)

(b)

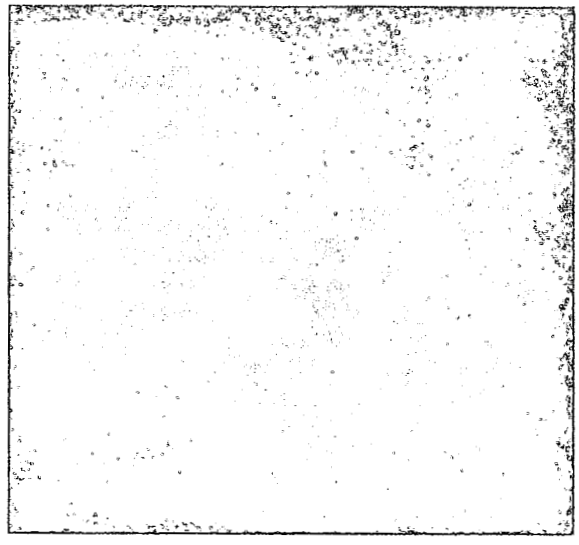


(c)

Figure 5–3: Sample C4i prior to destructive analysis (20000 cpm) photographed under (a) ambient light and (b) UV light and (c) after a 24 hour autoradiographic exposure.

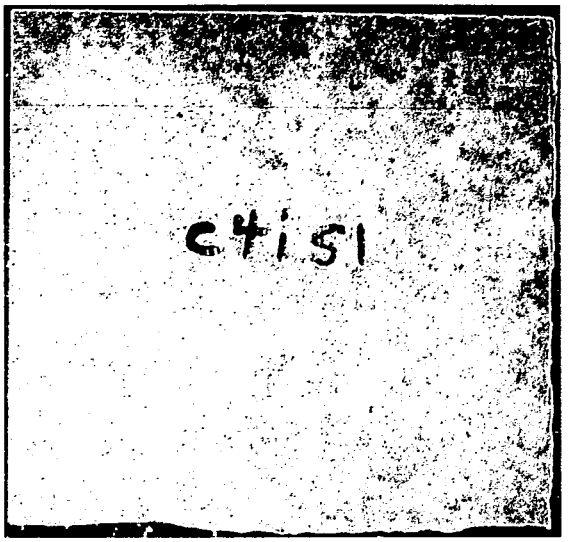
(a)

(b)

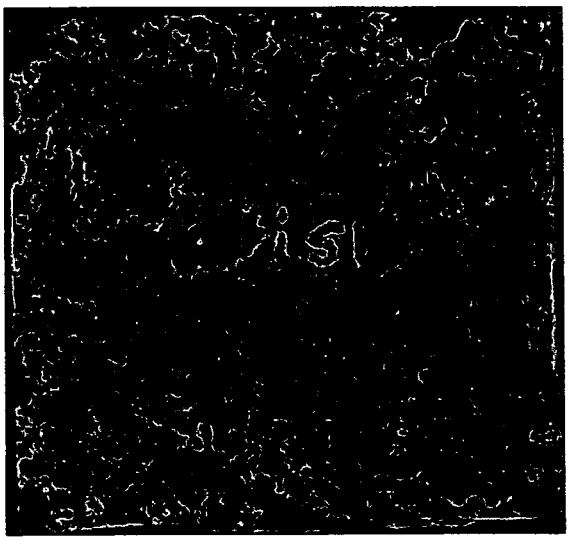


(c)

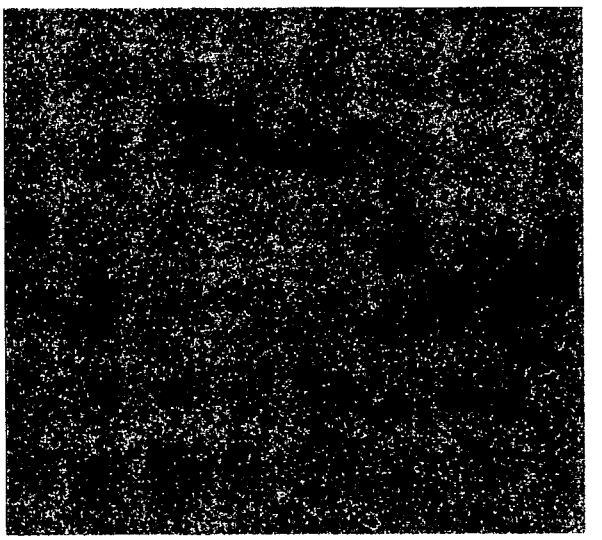
Figure 5–4: Sample C4i after one layer removal (19000 cpm), photographed under (a) ambient light and (b) UV light and (c) after a 24 hour autoradiographic exposure.



(a)



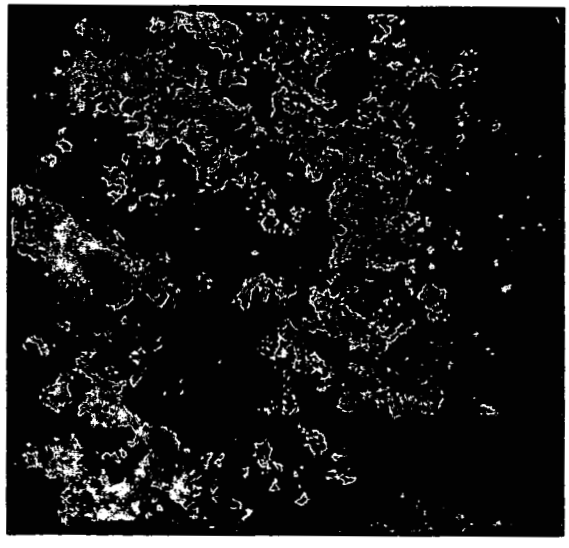
(b)



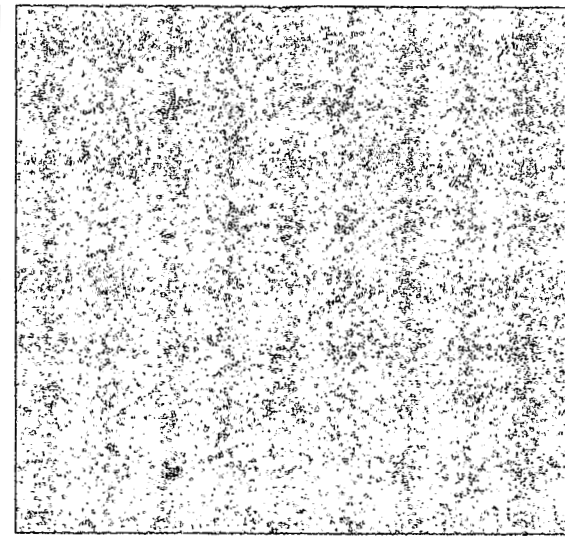
(c)

Figure 5–5: Sample C4i after two layer removals (3300 cpm) photographed under (a) ambient light and (b) UV light and (C) after a 24 hour autoradiographic exposure.

(a)

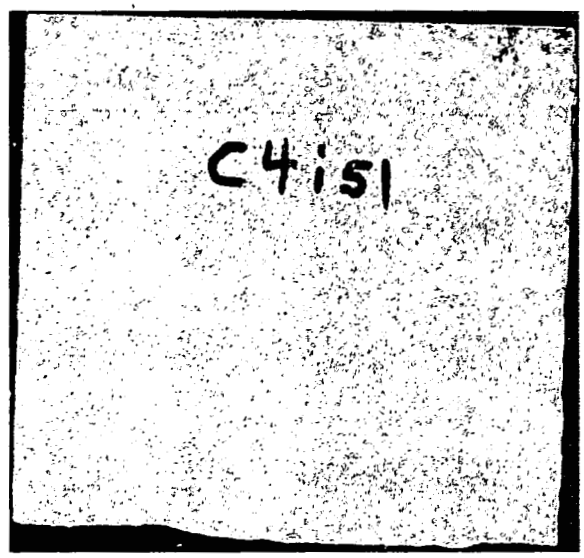


(b)

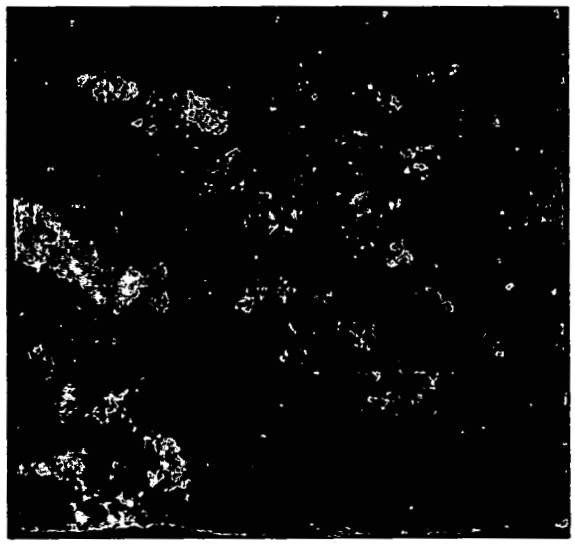


(c)

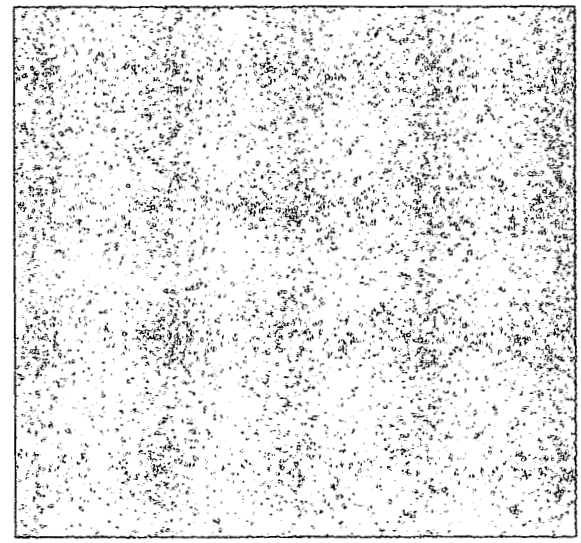
Figure 5–6: Sample C4i after three layer removals (300 cpm) photographed under (a) ambient light and (b) UV light and (c) after a 48 hour autoradiographic exposure.



(a)



(b)



(c)

Figure 5–6a: Sample C4i after 4 layer removals (210 cpm) photographed under (a) ambient light and (b) UV light and (c) after a 48 hour autoradiographic exposure.

Table 5–2 Linear attenuation coefficients of transite

Gamma-ray Energy (keV)	Linear Atten. Coeff. (cm^{-1})	Standard Deviation(σ)	Standard Source
59.53	0.62711	0.035	Am-241
88.05	0.37256	0.021	Cd-109
121.63	0.30455	0.010	Eu-152
244.63	0.22768	0.024	Eu-152
344.06	0.20117	0.011	Eu-152
410.88	0.19682	0.056	Eu-152
443.75	0.19992	0.046	Eu-152
778.66	0.13177	0.023	Eu-152
867.81	0.14106	0.039	Eu-152
963.81	0.12041	0.030	Eu-152
1085.58	0.13128	0.034	Eu-152
1111.80	0.12282	0.0264	Eu-152
1407.7	0.09764	0.020	Eu-152

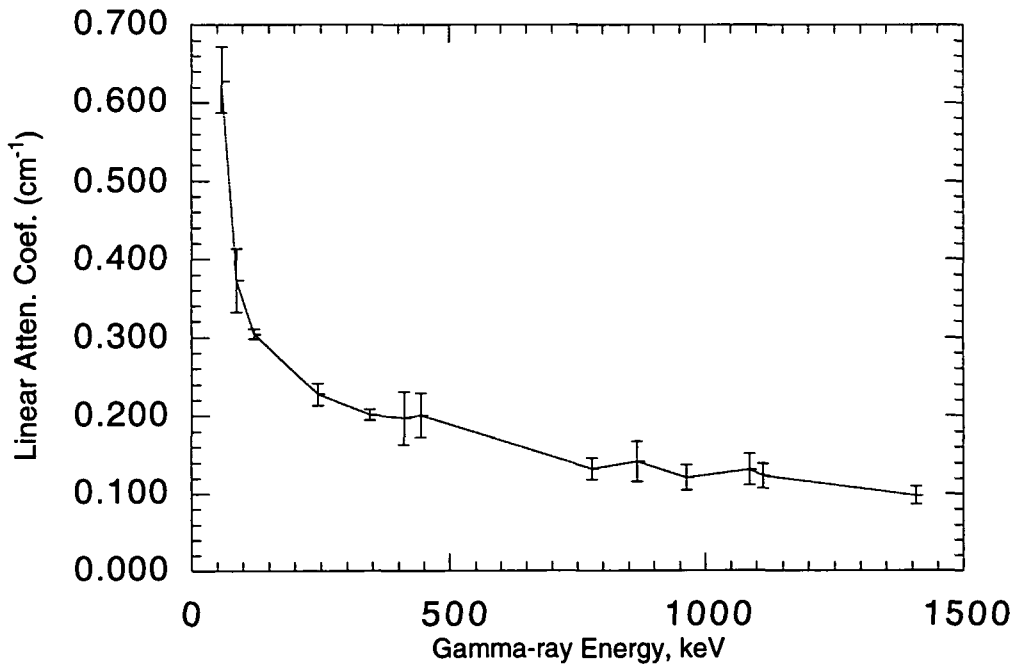


Figure 5-7 Linear attenuation coefficients of transite

5.2.2 Technique Validation

To simulate the contamination of Fernald transite panels, the complementary error function equation (4–18) (the diffusion transport solution for the constant contamination case) can typically be assumed. While some of the Fernald transite was almost continuously exposed to contaminants, most of the transite was exposed more discretely. However, these discrete (or instantaneous) exposures were repeated frequently enough over time to approximate a continuous exposure. This assumption of continuous exposure is certainly not rigorous, but is likely a good approximation. Based on equation (4–18), considering contamination on both sides of a sample, and normalizing the contamination level on the hot side to unity, the predicted contamination distribution can be expressed as:

$$g(z) = erfc(\lambda_1 z) + R_B\, erfc(\lambda_2 (t - z)) \quad , \qquad (5\text{–}1)$$

where λ_1 and λ_2 are the lumped effective diffusion coefficient and diffusion exposure time for side 1 and 2, respectively, R_B is the boundary condition ratio, t is the thickness of transite panel, and z is the distance from the hot surface. Based on the experimental data, the simulation performs a chi-squared (χ^2) minimization with λ_1, λ_2, and R_B as fit parameters to determine the most probable contamination distribution.

As mentioned previously, the choice of an appropriate model is essential to accurately predicting the actual contamination distribution. This choice should be achieved by using physically valid assumptions in terms of analyzing the actual conditions under which the sample was contaminated. For Fernald transite, the diffusion transport theory can be used as a reasonable assumption. In other cases, the choice of models might differ.

To demonstrate the ability of this technique, a series of Fernald transite samples were used in the measurement geometry shown in Figure 4-9. For one such sample, C5a, the measured boundary condition ratio was $S_2/S_1 = 0.184 \pm 0.0535$ (as measured using a G-M detector). The measured response ratios are listed in Table 5–3 and Table 5–4, and shown in Figure 5–8 for two different spacings a=4.0 cm and a=7.1 cm, respectively. Note the sensitivity of the technique to small changes in the sample-detector geometry as indicated by the two different spacings. This sensitivity allows the computer program to accurately predict the contamination distribution based on the measured response ratios. In order to use the measured response ratio data to generate a contamination distribution using the computer simulation program, it was assumed that the distribution in the transite sample was represented by equation (5–1). With these conditions, the computationally predicted contamination distribution for a = 4.0 cm spacing is

$g(z) = erfc(22z) + 0.195\ erfc(22(t-z))$ and produces response ratios similar to the measured data, as shown in Figure 5–9. These gamma-ray spectroscopy technique results were verified using the destructive G-M detector technique results in order to establish the actual or true contamination distribution for sample C5a. The measured layer removal results are shown and compared to the best fit distribution of $g(z)= erfc(22z) + 0.195erfc(22(t-z))$ in Figure 5-10. The results for all other samples analyzed using this gamma-ray spectroscopy technique, along with the comparison to the G-M detector results, are presented in Appendix D.

Note, one fundamental assumption made in order to implement this technique is that the contamination distribution is uniform in the *x-y* plane throughout the sample. Actually, the Fernald transite samples were nonuniformly contaminated with randomly distributed contamination (as indicated by autoradiography) on the surfaces of both sides. Nevertheless, the computer-generated distribution accurately predicts the contamination distribution as measured using the destructive technique. These results imply that the technique is insensitive to the assumption of a uniform distribution in the *x-y* plane. Therefore, the proposed technique is not limited by the uniform contamination exposure case.

Table 5–3 Measured response ratios (C_1/C_2) for C5a (a=4.0 cm)

Energy, keV	C_1	C_2	Ratio(C_1/C_2)	σ
63.91	42226	28435	1.4805	0.01417
84.60	17157	12497	1.3794	0.03042
93.11	209302	155066	1.3498	0.0035279
113.24	8886	6661	1.3340	0.04905
144.09	36945	28331	1.3040	0.01321
163.56	15722	12051	1.3046	0.02270
185.54	188186	145789	1.2908	0.004821
205.35	14697	11403	1.2889	0.02118
765.35	5841	4765	1.2258	0.03452
1001.00	15564	12795	1.2164	0.01578

Where, C_1 is the net photopeak area for detector 1;
C_2 is the net photopeak area for detector 2.

Table 5–4 Measured response ratios (C_1/C_2) for C5a (a=7.1 cm)

Energy, keV	C_1	C_2	Ratio(C_1/C_2)	σ
63.91	41539	29618	1.4025	0.01340
84.60	17467	13175	1.3258	0.02953
93.11	209305	159248	1.3143	0.00508
113.24	9637	7575	1.2722	0.03651
144.09	37653	30367	1.2399	0.01335
163.56	16626	13476	1.2337	0.02331
185.54	188966	152397	1.2399	0.00463
205.35	15126	12327	1.2271	0.02529
765.35	9157	7907	1.1581	0.02389
1001.00	15826	13740	1.1518	0.01452

Where, C_1 is the net photopeak area for detector 1;
C_2 is the net photopeak area for detector 2;

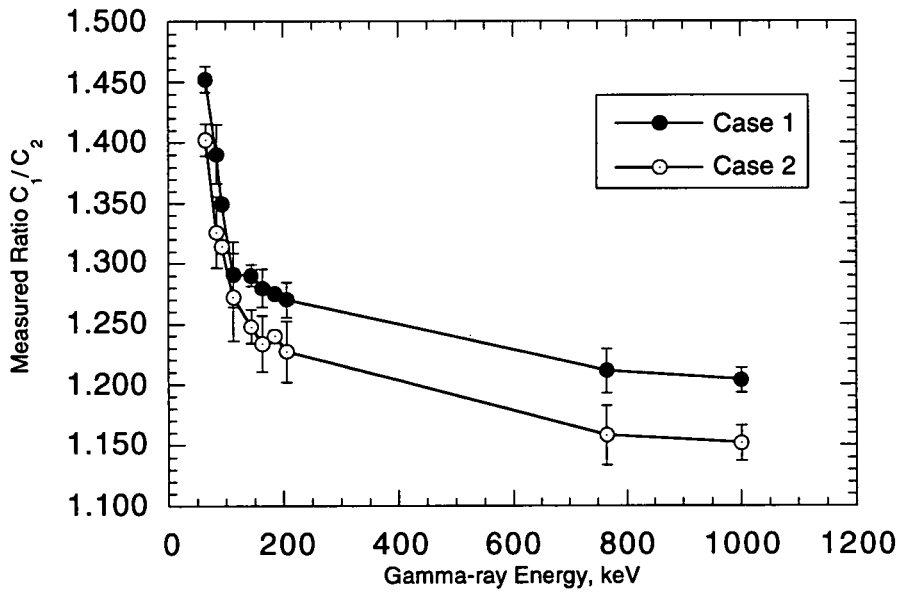


Figure 5–8 Gamma-ray spectroscopy technique measured response ratios as a function of γ–ray energy for Case 1 (a=4.0 cm) and Case 2 (a=7.1 cm) for Sample C5a.

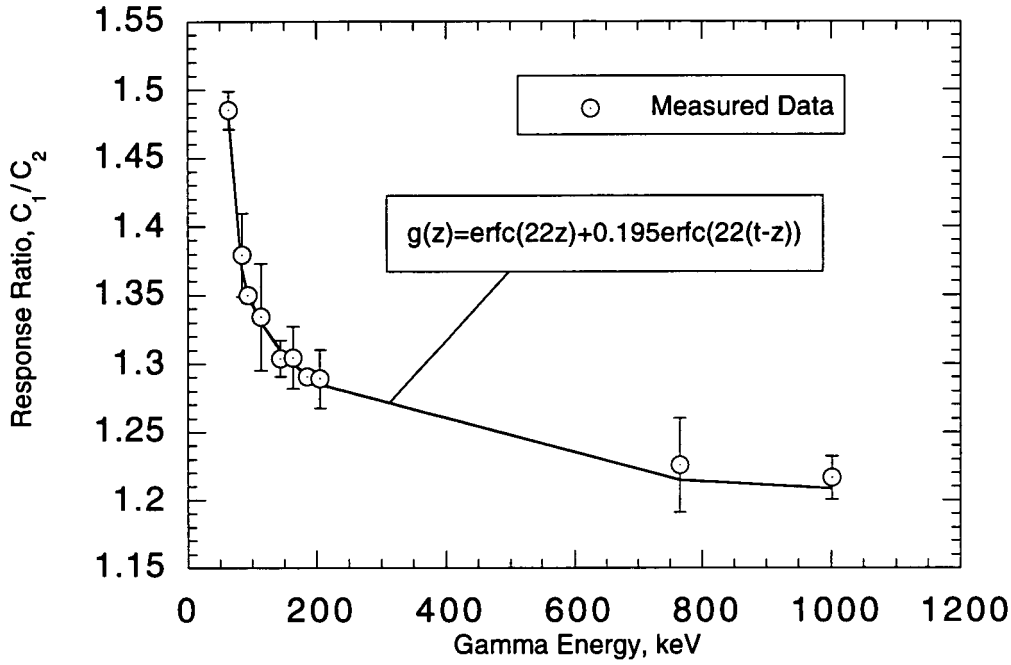


Figure 5–9 Comparison of gamma-ray spectroscopy technique measured response ratios and the computed response ratios for Case 1 (*a*=4.0 cm) for Sample C5a.

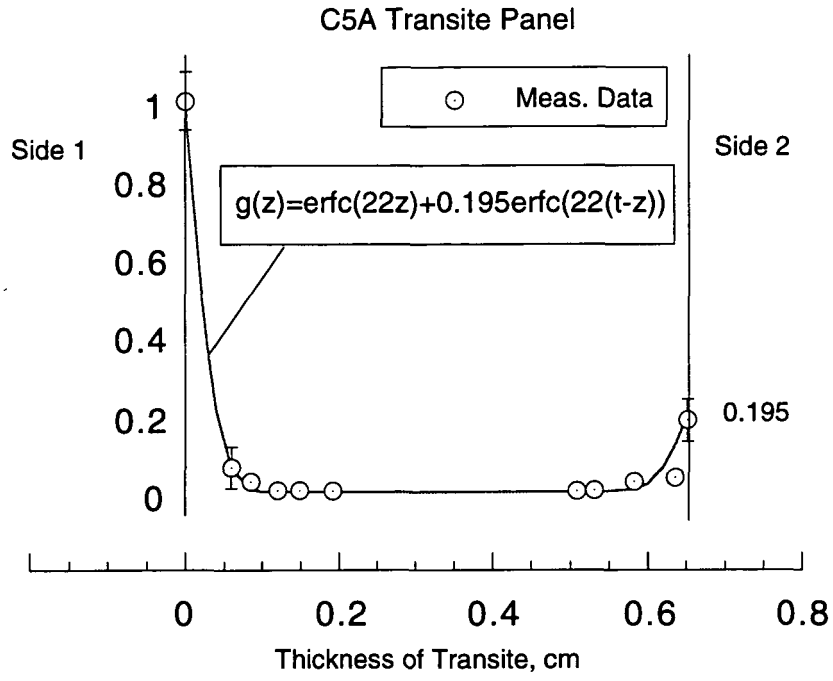


Figure 5–10 Comparison of destructive G-M detector technique measured contamination distribution and the distribution predicted by the gamma-ray spectroscopy technique for transite sample C5a.

5.3 METALS CHARACTERIZATION RESULTS

5.3.1 Metals Characterization Results - Leach Testing

Figures 5.11 through 5.14 depict results from the static leach tests on A6 transite samples. The principal contaminant of concern is lead; barium, chromium and uranium are also quantified. Results from the ICP metal analyses are listed in Tables 5.5 through 5.8.

Lead, chromium and uranium results indicate a peak release of contaminants following the 24 and 48 hour leach intervals. Subsequent leach intervals show decreased amounts of contaminants released. Barium results indicate a peak release after the first leach interval and decreased releases for each interval thereafter. Variations among samples A6b, A6c, A6e, and A6f are considered minimal. Following 121 hours of leaching, the maximum

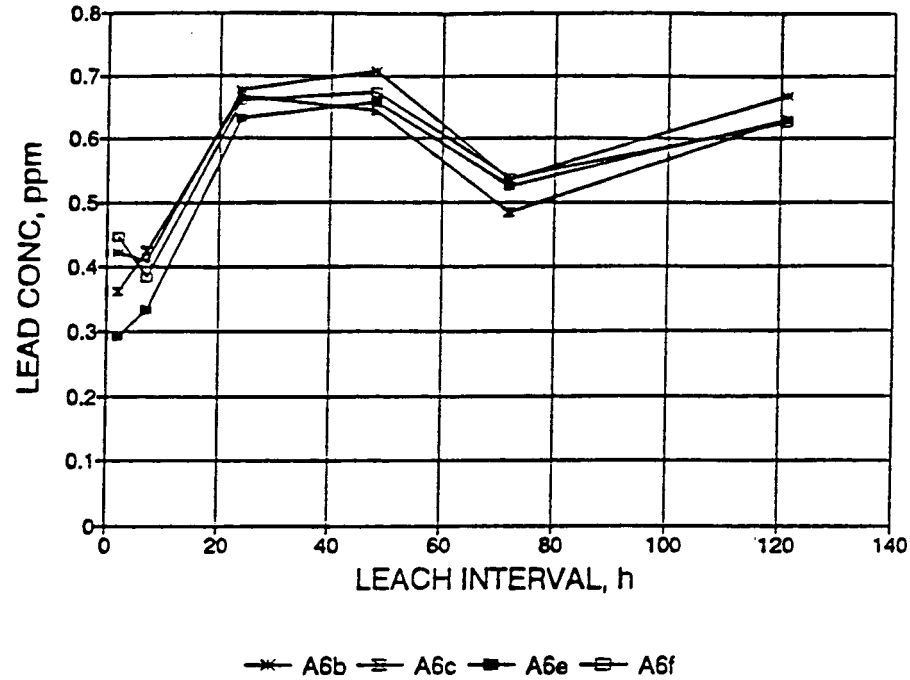
cumulative amounts of lead, barium, chromium, and uranium are 0.67 ppm, 0.35 ppm, 0.19 ppm and 1.92 ppm, respectively.

5.3.2 Metals Characterization Results - Surface Digestion

A total metals analysis was performed to determine the total amount of contamination in the surface layer of the transite. Lead was the principal contaminant of concern. Barium and uranium analyses were also performed.

Results of the digestion of surface transite are provided in Table 5.9. These results represent total surface extractable metals.

While these numbers for lead contamination seem large, it is important to note that very little of this lead appears leachable (see Section 5.3.1). To produce these results, contaminated surface material was sanded off of the transite samples then digested in concentrated nitric acid at 200° C and 200 psi. Also, the final concentration (calculated) is based on the surface abraded material and not the complete sample.



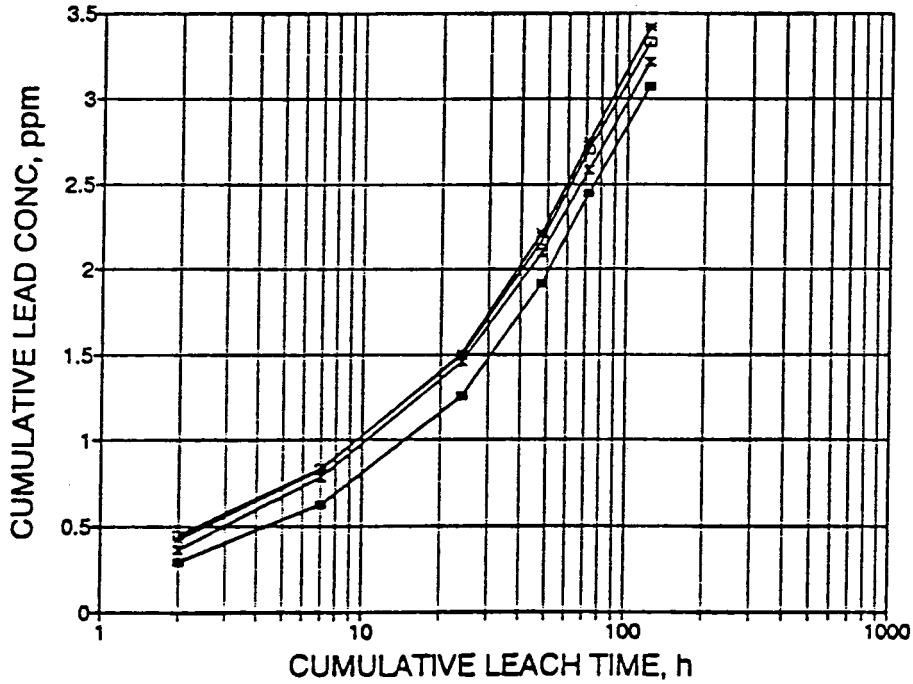
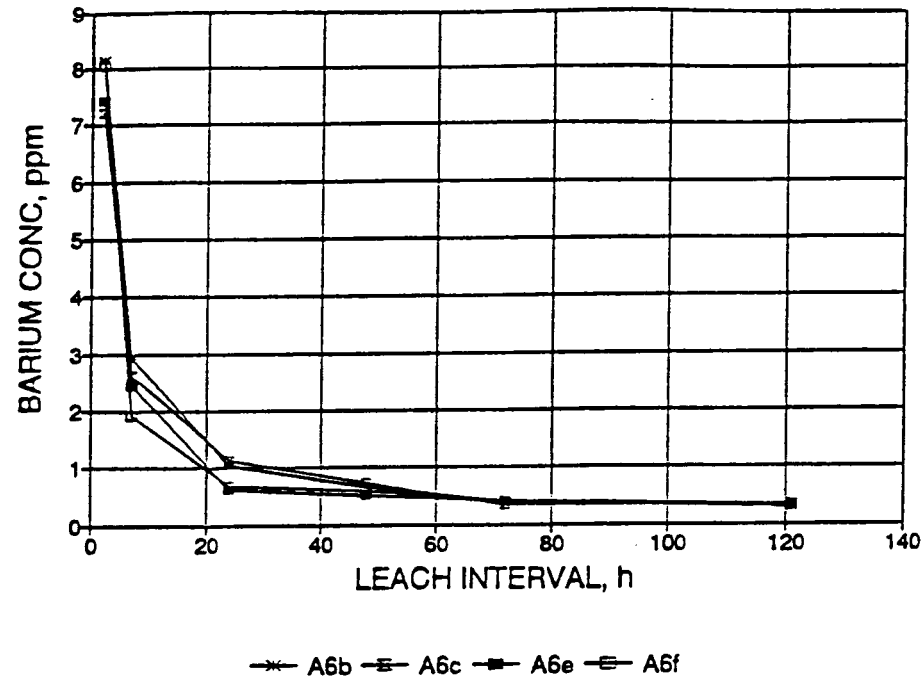


Figure 5-11 Leached lead from A6 transite samples



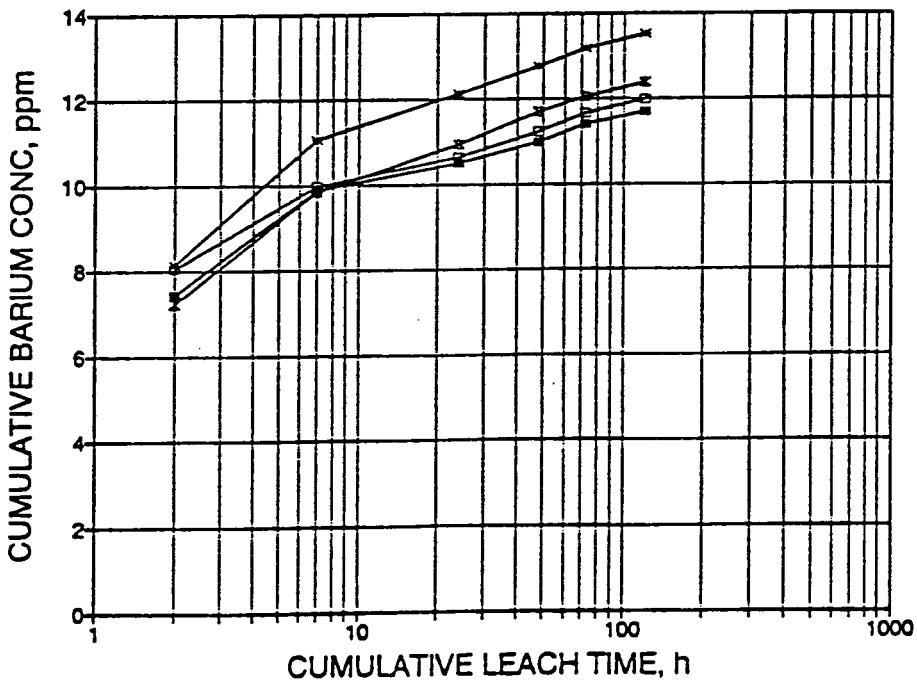
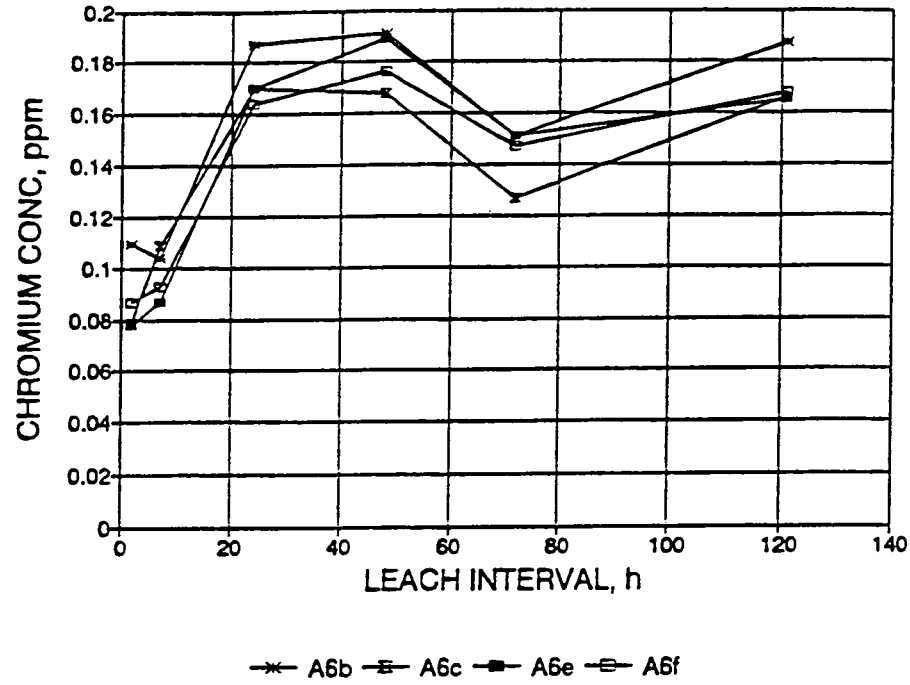


Figure 5-12 Leached barium from A6 transite samples



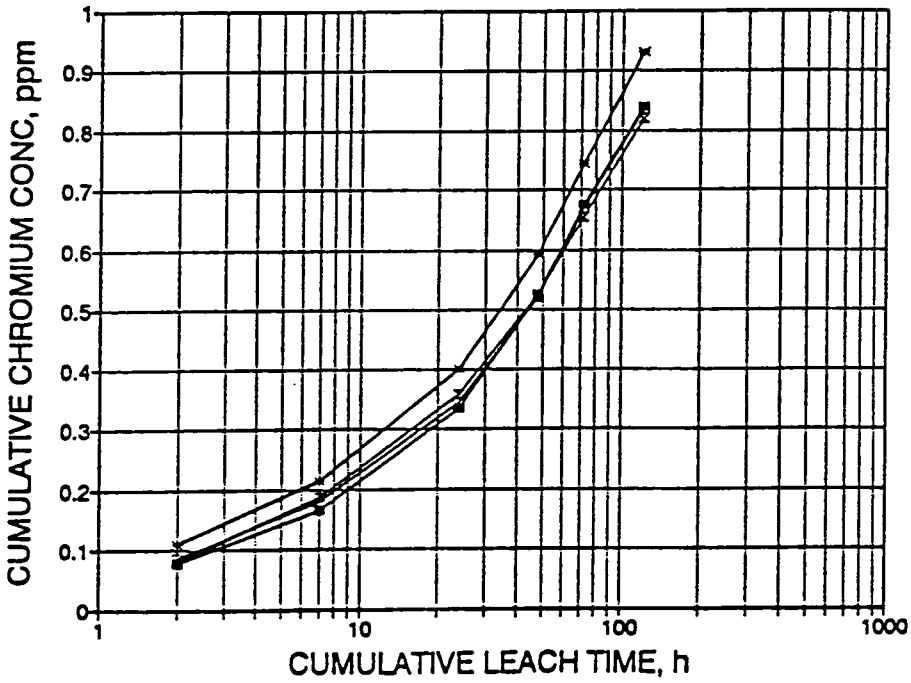
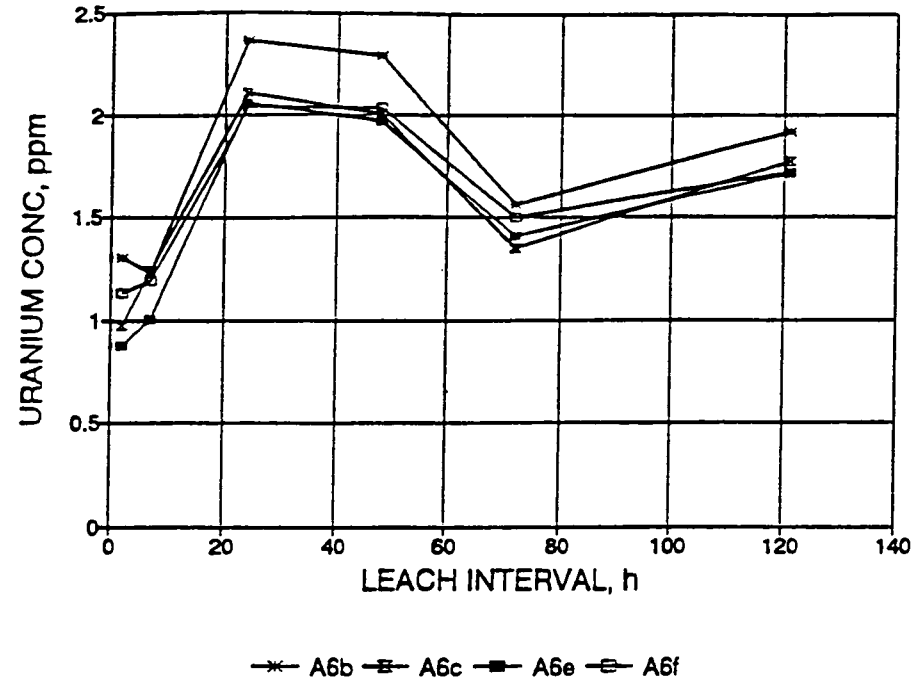


Figure 5-13 Leached chromium from A6 transite samples



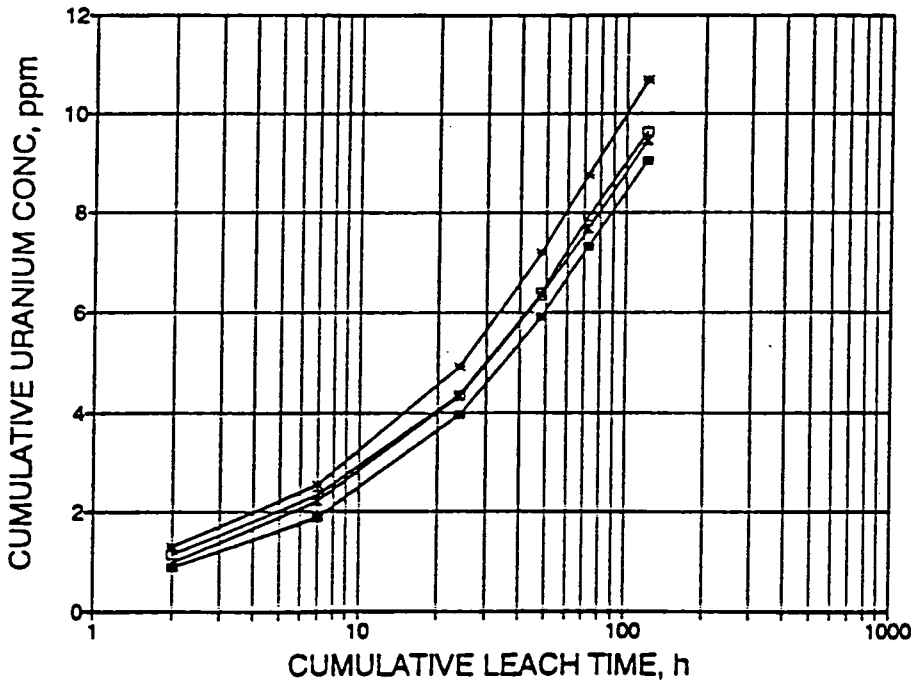


Figure 5-14 Leached uranium from A6 transite samples

Table 5-5A Lead conc, ppm

TIME, h	SAMPLE									
	A6b	SD	A6c	SD	A6e	SD	A6f	SD	CONTROL	SD
2	0.422	0.0065	0.362	0.012	0.293	0.0064	0.448	0.004	0.009	0.009
7	0.409	0.0082	0.425	0.0173	0.334	0.007	0.385	0.0038	0.023	0.0065
24	0.677	0.0086	0.669	0.0084	0.632	0.0105	0.660	0.0107	0.008	0.0108
48	0.708	0.0108	0.644	0.0067	0.659	0.0087	0.674	0.0028	0.016	0.0033
72	0.535	0.0077	0.484	0.0065	0.525	0.0097	0.537	0.0061	0.022	0.0048
121	0.668	0.0043	0.630	0.0067	0.631	0.0063	0.625	0.0064	0.013	0.0109

Table 5-5B Cumulative lead conc. ppm

TIME, h	SAMPLE			
	A6b	A6c	A6e	A6f
2	0.422	0.362	0.293	0.448
7	0.831	0.787	0.627	0.833
24	1.508	1.456	1.259	1.493
48	2.216	2.1	1.918	2.167
72	2.751	2.584	2.443	2.704
121	3.419	3.214	3.074	3.329

Table 5-6A Barium conc. ppm

TIME, h	SAMPLE									
	A6b	SD	A6c	SD	A6e	SD	A6f	SD	CONTROL	SD
2	8.153	0.0287	7.218	0.0164	7.433	0.021	8.047	0.0376	0.007	0.000
7	2.913	0.0069	2.611	0.0067	2.442	0.0144	1.916	0.0052	0.032	0.0001
24	1.044	0.0007	1.124	0.0097	0.621	0.001	0.682	0.0044	0.032	0.0022
48	0.666	0.0183	0.743	0.0112	0.499	0.0039	0.597	0.0051	0.028	0.0001
72	0.394	0.0019	0.347	0.004	0.399	0.0026	0.417	0.0035	0.032	0.0001
121	0.349	0.0028	0.342	0.0038	0.299	0.0016	0.320	0.0019	0.029	0.0003

Table 5-6B Cumulative barium conc, ppm

TIME, h	SAMPLE			
	A6b	A6c	A6e	A6f
2	8.153	7.218	7.433	8.047
7	11.066	9.829	9.875	9.963
24	12.11	10.953	10.496	10.645
48	12.776	11.696	10.995	11.242
72	13.17	12.043	11.394	11.659
121	13.519	12.385	11.693	11.979

Table 5-7A Chromium conc. ppm

TIME, h	SAMPLE									
	A6b	SD	A6c	SD	A6e	SD	A6f	SD	CONTROL	SD
2	0.11	0.0026	0.079	0.0025	0.078	0.0035	0.087	0.0017	0.011	0.0042
7	0.104	0.0013	0.109	0.0017	0.087	0.0009	0.093	0.0028	0.022	0.0018
24	0.187	0.0018	0.170	0.004	0.17	0.0042	0.164	0.0041	0.012	0.0028
48	0.191	0.0045	0.168	0.0031	0.189	0.0022	0.176	0.0006	0.016	0.0044
72	0.151	0.0032	0.127	0.002	0.151	0.0065	0.147	0.0007	0.014	0.0015
121	0.187	0.0032	0.166	0.0078	0.165	0.0047	0.168	0.0007	0.015	0.0008

Table 5-7 B Cumulative chromium conc. ppm

TIME, h	SAMPLE			
	A6b	A6c	A6e	A6f
2	0.11	0.079	0.078	0.087
7	0.214	0.188	0.165	0.18
24	0.401	0.358	0.335	0.344
48	0.592	0.526	0.524	0.52
72	0.743	0.653	0.675	0.667
121	0.93	0.819	0.84	0.835

Table 5-8A Uranium conc. ppm

TIME, h	SAMPLE									
	A6b	SD	A6c	SD	A6e	SD	A6f	SD	CONTROL	SD
2	1.306	0.002	0.976	0.0037	0.877	0.0139	1.133	0.0057	-0.009	0.007
7	1.235	0.0093	1.238	0.0132	1.004	0.0064	1.190	0.0089	-0.145	0.0063
24	2.365	0.0303	2.106	0.0091	2.058	0.0317	2.041	0.0162	-0.138	0.003
48	2.289	0.0314	2.002	0.0323	1.971	0.0188	2.036	0.0209	-0.131	0.0048
72	1.562	0.0128	1.349	0.0075	1.41	0.0064	1.503	0.0024	-0.094	0.0008
121	1.918	0.0084	1.772	0.006	1.713	0.0114	1.720	0.0015	-0.115	0.0045

Table 5-8B Cumulative uranium conc. ppm

TIME, h	SAMPLE			
	A6b	A6c	A6e	A6f
2	1.306	0.976	0.877	1.133
7	2.541	2.214	1.881	2.323
24	4.906	4.32	3.939	4.364
48	7.195	6.322	5.91	6.4
72	8.757	7.671	7.32	7.903
121	10.675	9.443	9.033	9.623

Table 5-9 Transite sample analysis
19 September 1995

Digestion: Method 3051 USEPA SW-846
Analysis: Method 6010A USEPA SW-846

Sample ID	Vessel #	Transite dry weight (grams)	final sample volume (mL)	average measured Pb conc. [ug/L]	average measured U conc. [ug/L]	average measured Ba conc. [ug/L]	replicates	final Pb concentration (calculated) [mg/kg solids]	final U concentration (calculated) [mg/kg solids]	final Ba concentration (calculated) [mg/kg solids]
M1	1	0.55	100.0	2112.1	32989.3	827.4	3	384.0	5998.1	150.4
M2	2	0.52	100.0	2402.3	38279.8	1002.8	3	462.0	7361.5	192.8
M3	3	0.52	100.0	2332.4	38094.9	920.4	3	448.5	7325.9	177.0
M4	4	0.54	100.0	2370.4	38313.9	879.8	3	439.0	7095.2	162.9
M5	5	0.53	100.0	2373.5	38973.1	917.5	3	447.8	7353.4	173.1
M6	6	0.55	100.0	2467.2	40032.9	950.6	3	448.6	7278.7	172.8
M7	7	0.53	100.0	2078.3	32848.1	778.7	3	392.1	6197.8	146.9
M8	8	0.51	100.0	2222.2	38088.1	851.4	3	435.7	7468.3	166.9
M9	9	0.51	100.0	2349.2	38062.0	844.4	3	460.6	7463.1	165.6
M10	10	0.53	100.0	2227.1	35534.7	822.8	3	420.2	6704.7	155.2
M11	11	0.54	100.0	2317.5	37766.1	875.5	3	429.2	6993.7	162.1
M12	12	0.51	100.0	2161.4	35595.3	882.9	3	423.8	6979.5	173.1
M13	1	0.58	100.0	2673.7	43831.6	1023.9	3	461.0	7557.2	176.5
M14	2	0.52	100.0	2143.2	34667.5	873.2	3	412.2	6666.8	167.9
M15	3	0.52	100.0	2271.1	36122.8	918.7	3	436.8	6946.7	176.7
M16	4	0.56	100.0	2233.1	35934.5	916.1	3	398.8	6416.9	163.6
M17	5	0.54	100.0	1959.6	31148.6	806.0	3	362.9	5768.3	149.3
M18	6	0.52	100.0	2392.3	39468.8	1038.0	3	460.1	7590.2	199.6
M19	7	0.50	100.0	2123.8	34507.9	856.4	3	424.8	6901.6	171.3
M20	8	0.51	100.0	2339.9	37143.0	934.1	3	458.8	7282.9	183.2
M21	9	0.54	100.0	2056.7	33176.9	834.8	3	380.9	6143.9	154.6
M22	10	0.59	100.0	2180.1	33985.6	847.3	3	369.5	5760.3	143.6
M23	11	0.52	100.0	2298.5	36577.4	964.5	3	442.0	7034.1	185.5
M24	12	0.53	100.0	2388.7	36969.8	921.6	3	450.7	6975.4	173.9

6.0 CONCLUSIONS

The results indicate the degree to which a given sample can be labeled as surface or volumetrically contaminated by showing a contamination penetration distribution. These distributions adhere closely to what is predicted by diffusion theory given the appropriate initial conditions. The subtle and gross variations of the distributions are derived from the differences in these initial conditions, the primary of which is the process exposure history of the sample. Given the primary concern of determining whether the transite can be decontaminated such that the bulk of the material is at or below background contamination levels, a key characteristic of interest is the depth to background or the depth of material that potentially requires removal. Should this characteristic be too great, decontamination may not be viable for a given method of removal. Figure 6.1 shows the number of sides of samples that were analyzed to have contamination down to a certain depth. The majority of the samples had a background depth of approximately 0.055 inches, all of which had a high level contamination process history (Building 2- extensive use wet process). With an average total initial thickness of 0.259 inches and contamination on both sides of all samples, this represents about 40% of the total material. For samples with a much lower contamination process history (Building 7- limited use dry process), the background depth was only approximately 0.010 inches which would represent about 8% of the total material. These results apparently suggest that radiological contamination may penetrate more deeply into transite panels when the contaminants are deposited by a wet process. Consequently, the viability of decontamination is illustrated to be heavily dependent on the process history. However, the ultimate decision as to whether decontamination is a viable option inherently depends on the capability of the decontamination technique, the regulatory definitions of what constitutes surface and volumetric contamination (as yet undefined to our knowledge), and a cost-benefit analysis along with a knowledge of the contamination distribution, methods for which we have developed the ability to determine. On the other hand, it is apparent that some Fernald transite panels could be more easily decontaminated than others due to the contamination penetration depth which is correlated to the process history. For example, the decontamination technique requirements would be much less demanding to decontaminate samples like those analyzed from Building 7 interior than those analyzed from the interior Building 2. Such conclusions should not be generalized to an entire building without more information and sample analysis due to the potential for localized areas of high contamination.

The UV photography technique proved to be a good qualitative tool for quickly analyzing the samples. Using a series of standard sources along with extremely consistent imaging, it would likely be possible to obtain quantitative data through digital image processing. For this study, the autoradiographs were used as a reference to provide a gross, qualitative indication of what aspects of the UV image corresponded to contamination. The autoradiographs were not limited by extraneous background imaging (visual noise), as the UV images were, since exposure of the film resulted only from radiation produced by the contamination. The threshold of detection was slightly better for the autoradiographs than for the UV photographs. However, autoradiography required lengthy exposure time, on the order of days. Autoradiography could also possibly be quantitative through image analysis.

A new gamma-ray spectrometry based technique to evaluate the radiological contamination penetration depth for planar samples has been described and validated. This technique provides a qualitative and quantitative method to identify whether the radiological contamination is surface or volumetric. The technique predicts possible contamination distributions that may occur inside the samples non-destructively through the process of measuring response ratios and the boundary condition ratio, and a subsequent computer simulation using these data and corresponding geometric and material properties to obtain the predicted distributions. If the conditions under which the samples were contaminated are taken into consideration with reasonable assumptions, this technique produces satisfactory results. The value of this technique is its concept of using gamma-ray spectrometry without destroying the samples and that the computer simulations produce a reasonable representation of the actual contamination distribution.

While this study has focused on the characterization of Fernald transite, other radiologically contaminated materials could also be characterized using these techniques. As long as gamma-ray spectra can be acquired from two opposing sides, a range of photopeak energies are available, and the assumption of uniform contamination across the surface is not restrictive, the non-destructive gamma-ray spectrometry technique can be used. To accurately predict the contamination distribution for a particular sample, a reasonably accurate knowledge of the manner in which the sample was contaminated is also required. In lieu of this knowledge, the destructive techniques can be used to establish appropriate mathematical representations of the contamination distribution. In any case, the destructive techniques should likely be used on a few samples from any new set of building material samples to confirm the results of the non-destructive technique. This recommendation will be necessary until the non-destructive technique has been further validated for a broader set of contaminants and contamination

scenarios. However, it is envisioned that at some point the non-destructive technique will accurately predict the contamination distributions without the need for any destructive measurements for confirmation. These techniques are well-suited for analyzing transite samples from other DOE sites. While the non-destructive technique and the destructive G-M and autoradiography techniques are applicable for any radiological contaminant that emits beta particles and gamma-rays, the UV photography technique is not applicable unless uranium or other contamination that fluoresces under UV excitation is present. Nontheless, the techniques developed in this project would require minor modifications, if any, to be useful for analyzing transite or other building material samples from other DOE sites for the contamination distribution through the thickness of the samples.

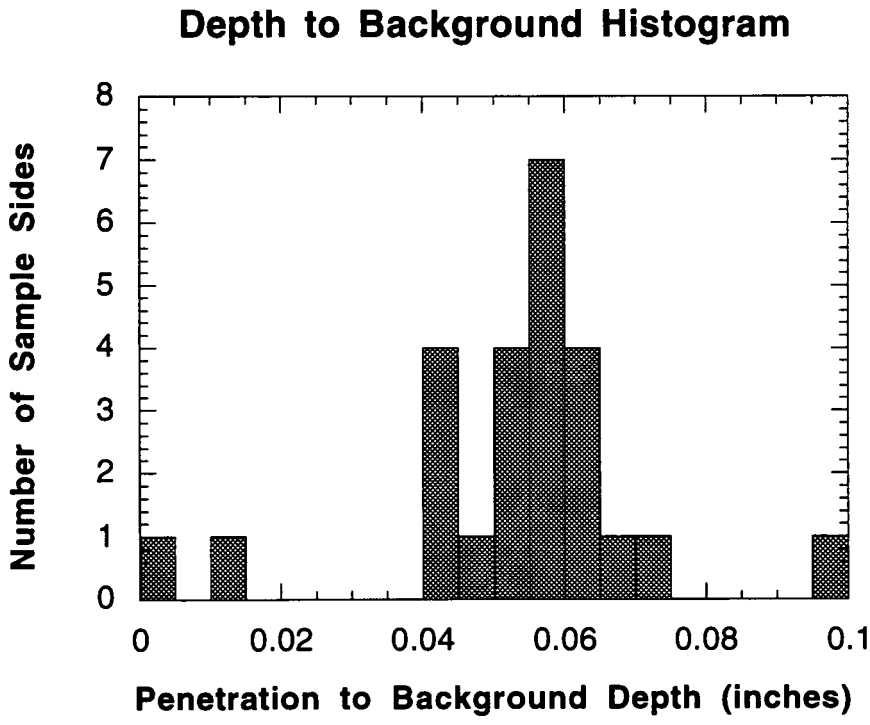


Figure 6–1 Histogram illustrating the background depth distribution for sample sides analyzed

Appendix A

RADIOLOGICAL TECHNIQUES INVESTIGATED

A.1 ACTIVATION ANALYSIS

Activation analysis is an important experimental technique arising as a by-product of the nuclear energy program developed during the last quarter century. It involves the production of radioactive nuclides from stable elements present in the sample under investigation. Each of these radioactive nuclides has characteristic properties including type, intensity and energy of the emitted radiations and half-life. These characteristics can be identified using relatively simple equipment with excellent sensitivity for quantitative estimation.

Activation analysis consists of two main steps:

- Activation of the sample
- Study of the induced radioactivity

A.1.1 Method

In principle, activation analysis may be based on any artificially induced nuclear reaction. We may distinguish three main possibilities:

- First, the energy given to a nucleus by bombardment with energetic gamma-ray quanta or electrons may be used to promote emission of nuclear particles or translation of nuclei into excited states.
- Second, heavier particles, such as protons (as in proton induced x-ray excitation (PIXE) or proton induced gamma-ray excitation (PIGE)), deuterons, and other nuclei may be accelerated by electrical means and used to bombard the sample. Such particles may be incorporated in the nucleus, altering its mass, charge, and radioactive status, or may bring about an internal rearrangement resulting in the emission of other nuclear particles. Electrically-charged projectiles may be furnished with any desired energy using particle accelerators, but have the disadvantage that they penetrate the sample short distances. Though this property can be turned to advantage in the analysis of surface layers. (Furthermore, the energy of the bombarding particles is largely transformed into heat without inducing any nuclear reactions.)

- Third, nuclear reactions of the kind desired for activation analysis are most generally induced by neutron bombardment. Neutrons may be used to produce radioactive nuclides from almost every element. In general, neutrons have good penetration, allowing a homogeneous activation of the entire sample.

The optimum nuclear reaction is chosen with the following considerations in mind:

- Production of large activity should occur within a reasonable irradiation time.
- The radioisotope produced should have a reasonable half-life ($T_{1/2}$>1min).
- The type and energy of the radiation emitted by the radioisotope should not present great counting difficulties.
- A minimum number of interfering reactions should be involved.

If the constituents of the sample are completely unknown, one starts with neutron irradiation because neutrons are absorbed by almost all isotopes. If the composition of the sample is known, then the best reaction for identification of the isotope of interest should be chosen. The "optimum nuclear reaction" depends not only on the isotope and the bombarding particles, but also on the composition of the sample that is being analyzed.

A.1.2 Advantages

The distinctive advantages of activation analysis are as follows:

- The ultimate sensitivity is excellent for nearly every element and is, for many elements, better than can be obtained by any other technique.
- Non-destructive analysis is often possible.
- The method has high sensitivity.
- It is generally possible to analyze for several elements in a single sample at a time.
- Requires a sample with very small mass.
- Provided that no pre-irradiation chemical manipulation is attempted, the technique is free from blank errors caused by the use of contaminated reagents.
- Activation analysis allows the opportunity to distinguish between different isotopes of an element.
- Provides results rapidly.

A.1.3 Photon Activation

Photon activation complements neutron and charged-particle activation. (Photons are better than neutrons in certain cases.) For example, photons are preferred if the product of the neutron activation is an isotope that has a very short half-life or emits only low-energy betas or low-energy X-rays. The cross-section for photonuclear reactions are generally smaller than those for neutrons and charged particles. The reactions most easily induced by photons are of the form (γ, γ'), (γ,p) and (γ,n) reactions.

A.1.4 Activation with Charged Particles (and Proton Induced X-ray Emission, PIXE)

Such projectiles have very limited range in solid matter and it is, therefore, not possible to achieve uniform irradiation unless an extremely thin sample is used. A further difficulty arises because the energy spectrum of a beam of charged particles changes with depth of penetration into the analytical sample. It is not possible, therefore, to make calculations on the basis of a constant cross-section, as can normally be done for neutron and photon activation.

- These reactions have a threshold.
- Protons, deuterons and alpha particles are the most commonly used.
- See Section A.2.

A.1.5 Activation with Neutrons (Neutrons Activation Analysis, NAA)

Instrumental Neutron Activation Analysis (INAA) is a widely used technique for multi-element analysis of environmental, geological, and biological samples. The identification and quantitative determination of activation products in INAA is conventionally achieved using high resolution gamma ray spectrometry (100-300 keV).

A.1.6 The Reactions:

Although charged particles and gamma rays may be used as bombarding particles, neutrons are, by far, the most frequently utilized for irradiation of samples. A neutron, in motion as a certain distance from the nucleus, may deviate from its original path under the action of attractive forces and then continue moving in this altered direction. This type of neutron interaction is called potential scattering. If the neutron approaches sufficiently close to the nucleus, it can be caught due to the action of nuclear forces, penetrating the nucleus and forming a compound nucleus.

The compound nucleus can decay to a state of lower energy by the emission of one or more particles, for example a proton, alpha particle, triton, two neutrons, protons and neutrons, etc. Designation of these reactions are as follows: (n,p) (n,α) (n,t) (n,2n) (n,pn) (n,3n)...

A.1.6.1 Thermal neutron reactions

The most commonly used reaction is the (n, γ) reaction, in which the excited nucleus passes to a lower energy state by emission of a gamma ray. This reaction takes place with almost all isotopes and has no threshold. In general, the (n, γ) cross section is higher for thermal neutrons than for fast neutrons. The reactions of this type (n, γ) are called radiative captures. This type of reaction is advantageous, especially in the determination of trace amounts of an element. This reaction type is only excluded in the case of several light elements (atomic number,Z<8). Typical cross sections for (n, γ) reaction are about of 0.1-100 barns, whereas the majority of applicable reactions of the (n,p) or (n,α) type have activation cross sections on the order of 1-100 millibarns.

A.1.6.2 Fast neutron reactions

Other neutron interactions are (n, α), (n,p) and (n,2n) reactions. Except for a few exothermic (n, α) reactions, the others have a threshold; therefore, they can be induced by fast neutrons only. The activation with fast neutrons usually involves the analysis of light elements which either do not form radioactive nuclides after reaction with thermal neutrons or, if they do, cannot be analyzed with sufficient sensitivity.

A.1.7 Neutron Velocity

One can roughly separate neutrons into 2 classes: fast neutrons, which have energy higher than 0.5 megaelectron volts (MeV) and slow neutrons, which have less energy. A more precise classification of neutrons is as follows: Thermal (energy of about 0.025 eV), epithermal (energy of about 0.2 eV), cadmium (0.4 eV), epicadmium (0.6 eV), slow (1-10 eV), resonance (1-300 eV), medium (500 eV-0.5 MeV), fast (energy above 0.5 MeV), and ultra-fast (above 20 MeV).

A.1.8 Sources of Neutrons

Being uncharged particles, neutrons can not be accelerated. However they can be moderated. Neutron sources include reactors, accelerators, and isotopic sources. Nuclear reactors are by far the most frequently used irradiation facilities. They provide high flux (an upper limit of about

10^{18} neutrons/cm^2-sec, primarily thermal neutrons). Fast neutrons in the kiloelectron volts (keV) range are also available, but at lower flux levels.

Accelerators produce fast neutrons as a product of the charged-particle (d,t) reaction. The maximum flux provided by a neutron generator is on the order of 10^{12} neutrons/cm^2-sec.

Neutrons with an average energy of about 2.5 MeV are produced by the (d,d) reaction. This reaction offers a neutron flux on the order of 10^9 neutrons/cm^2-sec. It is important to note that both the (d,d) and (d,t) reactions produce essentially monoenergetic neutrons.

Isotopic neutron sources are based on (α,n) and (γ,n) reaction and on spontaneous fission (^{252}Cf). All produce fast neutrons.

A.1.9 Disadvantages

- Change in neutron flux during passage through the sample: If the mass of the sample is too great or if it contains certain elements, changes in the flux can occur. These changes may occur in the total neutron flux or in the energy spectrum of the penetrating neutrons or in both.
- The most important factor causing changes is the absorption of neutrons inside the sample (self-absorption). This factor increases with increased sample mass and with an increase in the number of elements present which have a high absorption cross-section.
- Scattering is another factor to be considered, though it typically produces a small uncertainty. (Neutrons may deviate from their original direction because of a collision with atoms in the sample and thus the number of neutrons reaching the internal layers is decreased).
- Another source of uncertainty in activation analysis is the possibility of a reaction that produces the same isotope as the one being counted through the bombardment of a different isotope in the sample.

A.1.10 Detector Used

To detect the gamma rays produced in NAA a high-purity germanium (HPGe) detector is used, due to its excellent energy resolution some 15 times better than that of a thallium-activated sodium iodide (NaI(T1)) scintillator detector.

A.1.11 Use of X-Ray Emitters in Activation Analysis:

A number of authors have investigated the application of X-ray and low energy photon spectrometry (10-200 keV) in activation analysis. The use of X-ray spectrometry has been widely used as an analytical technique where gamma ray spectrometry fails to give satisfactory results. The possibility of using X-ray spectrometry in the activation analysis is based on the property of a number of nuclides to decay after neutron capture by the emission of characteristic X-rays. The latter are due to the different nuclear process and as such, may be divided into three groups:

- those due to internal conversion, X-rays of the parent element (Z)
- those due to electron capture, X-rays of the element (Z-1)
- those due to the beta decay followed by internal conversion, X-rays of the element (Z+1)

The X-rays from all three groups decay according to the half-life of the parent element (Z).

The technique of X-ray spectrometry is attractive since it presents several advantages which are a result of basic properties of X-rays. For example, the precise measurement of the energy of the emitted X-ray permits the unambiguous identification of the element due to the direct correlation between an element and its characteristic X-rays. Furthermore, the limited number of peaks in the X-ray spectrum of each element permits the analysis of many elements in a single spectrum. Finally, the reduced sensitivity of the Si(Li) and planar Ge photon detectors used for the measurement of X-rays, eliminates the interference of Compton scattered high energy gamma rays. As a result, the background is considerably lowered and the peak-to-background ratio much increased.

Habib and Minski introduced the concept of 'advantage factor' (AF) (i.e., the ratio of X-ray to gamma ray sensitivity for a particular isotope). The use of X-ray spectrometry is recommended in those cases where AF is significantly greater than unity.

A.1.12 Interference with the Measurement of X-Rays

Possible interferences with the measurement of X-rays obtained following neutron activation may be due to the discrete x-rays and low energy gamma rays, secondary X rays, and beta particles.

A.1.12.1 Discrete X-rays

Due to the direct relationship between the atomic number of an element and the energy of its characteristic X-rays, the interference with the measurement of these X-rays will result chiefly from X-rays emitted by neighboring elements in the Periodic Table. Another possible source of interference is the L shell X-rays emitted by elements with high atomic numbers that have the same energy as the K shell X-rays of an element with a lower atomic number, or vice versa.

The possibility of distinguishing two elements with close X-ray energies in the same spectrum will depend on the resolution of the detector. In other words, for two neighboring elements in the Periodic Table, the difference between the energy of the K_1 X-rays of one element and that of K_2 X-rays of its immediate predecessor should be greater than the resolution of the detector in order to distinguish the two.

A.1.12.2 SecondaryFluorescent X-rays

Strong beta or gamma rays from the radioactive sample may interact with major elements present in the sample or materials in the vicinity of the detector and induce fluorescent X-rays. Generally the intensity of the X-rays and gamma rays obtained by NAA are too low to produce fluorescent X-rays in sufficient yield to interfere with the measurement. The possibility of secondary fluorescent X-rays must be taken into account only when very long irradiations are carried out or if one of the main components of the matrix is known to produce especially strong gamma or beta radiation following neutron activation.

A.1.12.3 Beta Particles

The beta particles emitted from an irradiated sample are another serious source of interference in X-ray spectrometry. These beta particles may produce a high background which completely obscures the X-ray peaks obtained from trace amounts of low and medium Z elements making their quantitative determination practically impossible. The interference of beta particles may be overcome by use of plastic absorbers or by the deflection of beta particles by magnetic fields (the intensity of the magnetic field depends on the beta energy and the source to detector distance).

The measurement of X-rays produces very satisfactory results for U (L X-rays) and Ba, Sm, Tb and Ta), with a flux of 1.5×10^{13} n/cm^2-sec and with a HPGe detector.

A.1.13 Case of Uranium

Sensitivity:

The sensitivity of neutron activation analysis in determination of Uranium by the (n,γ) reaction with a thermal neutron flux of 10^{13}n/cm^2-s for a maximum irradiation time of one hour is about 10^{-10} gram. Activated ^{238}U is a short-lived nuclide (^{239}U half life: 23.54 minutes) and emits low energy gamma-rays (74.6 keV) and beta particles.

Detection Limit: 0.1-1 ppm

AF of ^{238}U = 1.4 (not enough to use X-rays, because of the interference applicable for X-rays).

A.2 PROTON INDUCED X-RAY EMISSION (PIXE)

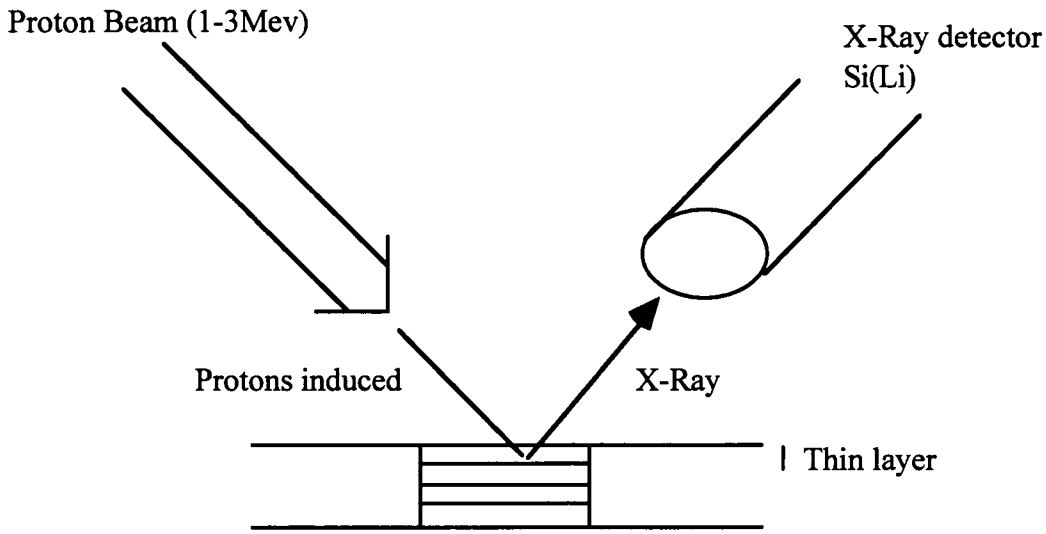


Figure A–1 Schematic diagram of PIXE technique

PIXE analysis can be used to:

- Identify the atomic species in the target from the energies of the characteristic peaks in the X-ray emission spectrum.

- Determine the amount of a particular element present in the target from the intensity of its characteristic emission spectrum. (This normally requires a knowledge of ionization cross-sections, fluorescence yields, and absorption coefficient.)

A.2.1 Method

When an energetic (MeV) proton impinges on a target atom there is a high probability, typically of the order of hundreds of barns (1 barn = 10^{-24} cm^2), that an inner-shell will be excited and removed from a target atom. The excited target atom seeks to regain a stable energy state by reverting to its original electron configuration. In so doing, the electronic transition which takes place may be accompanied by electromagnetic radiation in the form of X-rays, characteristic of the excited atom. The emission consists of K, L, M, ... lines produced by electron transitions to the K, L, M shells of the target atom. The elements present can be identified by the corresponding characteristic X-ray energy (peaks recorded in spectrum).

Elemental quantitative analysis by PIXE based on the assumption that there is an unambiguous relationship between the number of characteristic X-rays of a particular element observed and the amount of this element present in the target sample. PIXE is done mainly in laboratories which have access to a proton accelerator (usually Van de Graaf or Cyclotron). The typical geometry used in PIXE analysis is shown in Figure A–1.

The energy dispersive Si(Li) detectors have high count rate ability and a resolution high enough to distinguish between the X-rays of adjacent elements.

A.2.2 Characteristics

PIXE is essentially a near-surface method. The best results are obtained by PIXE when thin samples are used, thickness less than about 1 mg/cm^2 (or approximately 10 mm). However, thick samples can be investigated by the analyses, but are invariably more complicated and the resulting sensitivity is poorer than with a thin target. Higher proton energies must be used in order to increase the penetration depth of the particle.

It is difficult to obtain a good spatial resolution with PIXE. However, PIXE can be combined with other techniques to get a depth profiling. (Example: Rutherford Backscattering).

Protons provide better sensitivity over the whole Periodic Table than heavier projectiles of the same energy per nucleon.

A.2.3 Advantages

In contrast with a number of other chemical and physical spectrometric techniques, PIXE:

- High sensitivity for all elements, except the lightest ones (X<10).
- Capable of multi-elemental analysis.
- Practically all elements can be covered in a single experimental run.
- Need very short experimental time (typically between 5 and 20 minutes per sample.
- Good concentration sensitivity.
- The basic advantage of characteristic X-ray analysis arises from the relative simplicity of the characteristic X-ray emission spectra.
- The intrinsic capability for analysis without destructively interfering with the specimen.
- Requires only very small samples.
- Background effects are in almost all cases lower than those for comparable X-ray techniques using electrons, and photons.
- Cheaper in comparison with neutron activation analysis per sample analyzed.

A.2.4 Disadvantages

- Inability to determine lightest elements (but coupled with PIGE, can cover the whole Periodic Table).
- Difficult to provide depth information.
- Decreased sensitivity if the elements are too concentrated.
- Decreased sensitivity if the elements are too heavy (interferences between peaks).

A.2.5 Detection Limits and Sensitivity

PIXE is a method of high sensitivity. The average detection limits for trace elements are typically as low as 0.1-1 parts per million (ppm), as shown in Figure A–2.

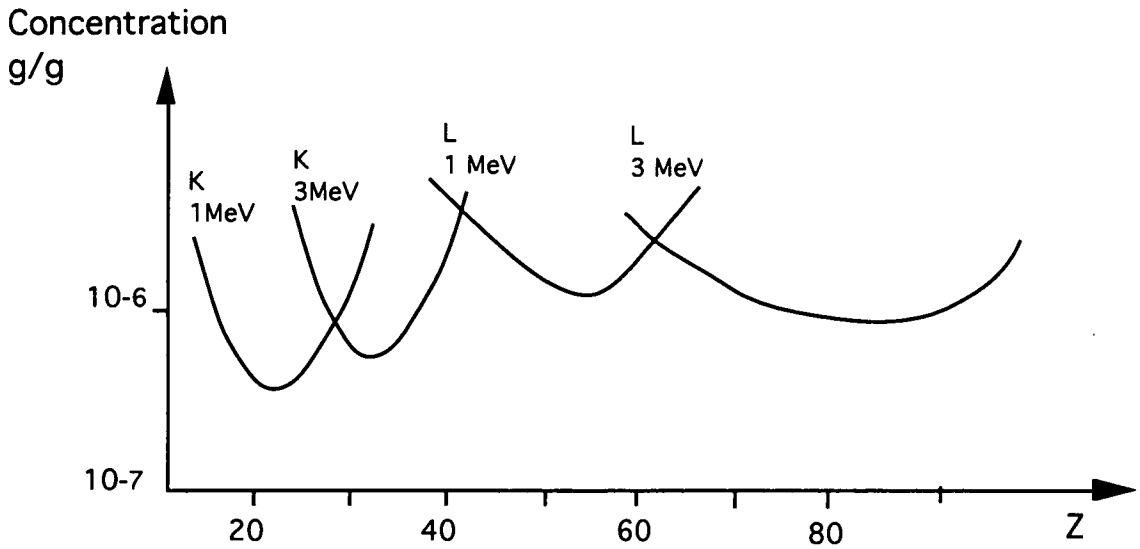


Figure A–2 Theoretical minimum detectable concentration calculated for all elements.

For high Z elements (beyond an atomic number of about 40), good elemental separation is provided by PIXE using the L X-ray lines rather than the K X-rays.

Optimum beam energy:

- The proton energy should be chosen according to the elemental region of interest. The lowest detection limit obtainable for a given range of elements depends on the energy of the proton.
- For heavy elements, we can increase the proton beam energy, however with a high concentration of several heavy elements in a sample, there is often interference between peaks, causing the sensitivity to deteriorate. One solution to this problem is to increase the beam energy so the cross-section for K X-ray production increases, thus making it possible to also use the K X-ray peaks for analysis of the heavy elements

The sensitivity can be improved by increasing the count time.

A.2.6 Proton Elastic Scattering Analysis (PESA)

Due to the degree of attenuation of softer X-rays by matter, X-ray analysis of the lightest elements is made difficult to impossible for practical sample loading. Proton elastic scattering analysis proves to be a useful compliment to PIXE since it has almost identical sample requirements and is also nondestructive. With modern commercially available solid state proton

detectors and 16 MeV incident protons, it is possible to resolve the light elements up through chlorine.

Two other advantages to the use of 16 MeV protons are their smaller specific energy loss (allowing the use of thicker samples) and relative freedom from resonant behavior of the excitation function.

Unfortunately, the nuclear scattering cross sections are approximately 1000 times smaller than the atomic cross sections for PIXE. The effect of this lower efficiency is greatly counterbalanced by the lower backgrounds for PESA spectra.

A.2.7 Conclusion

These methods are fast, have a broad-range, are absolute, are subject to automation, and are well-suited for samples having areas of a few square millimeters and thicknesses of 1 mg/cm^2. Samples of uniform density are most convenient; however, non-uniform samples may be analyzed by using a uniform proton beam.

A.3 ATOMIC ABSORPTION SPECTROMETRY

Techniques commonly referred to as atomic spectrometry usually include atomic emission, atomic absorption, and atomic fluorescence spectroscopy. These involve valence electron transitions yielding radiation with wavelengths in the ultraviolet-visible region of the spectrum.

A.3.1 Atomic Spectra

An electron of an atom at its lowest energy state, the ground state, can absorb a quantum of energy ($+\Delta E$) and undergo transition to a low-lying excited state. Emission occurs when this quantum of energy is released ($-\Delta E$) and the electron returns to the ground state (Figure A–3). A transition to and from the ground state is called a resonance transition. Resonance lines are the most useful analytical lines for atomic absorption spectrometry.

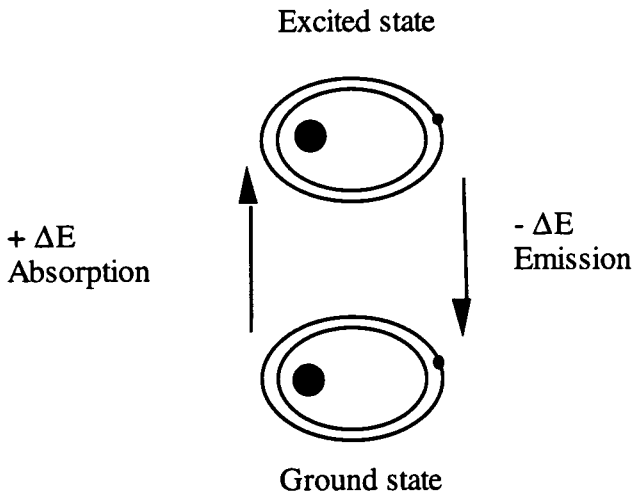


Figure A–3 Relationship between emission and absorption of energy by a valence electron

A.3.2 Basic Concept

When a parallel beam of continuous radiation of intensity I_0 passes through a cell containing atomic species of an element, the transmitted radiation I will show a frequency distribution as given in Figure A4. The atomic species is said to possess an absorption line at frequency v_0, where v_0 is the frequency at the center of the line.

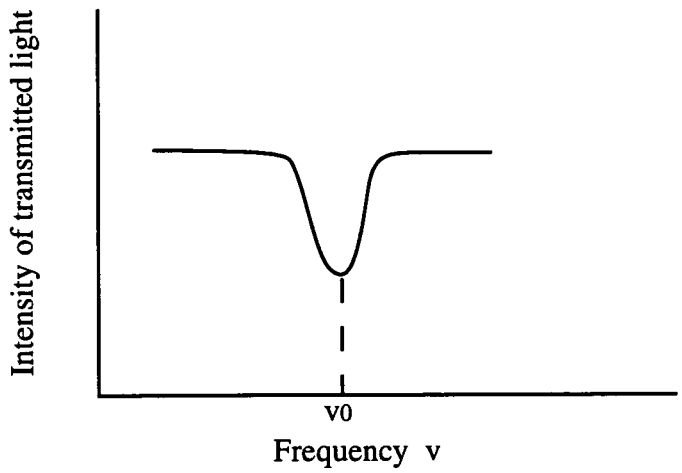


Figure A–4 Intensity attenuation at characteristic frequency

A.3.3 Experimental Method

Since atoms are only able to absorb radiation within a very narrow frequency interval, certain demands must be placed upon the radiation source. Although continuum radiation sources afford a high total illumination intensity, the illumination intensity in the interval of interest of about 0.5 ppm to 5 ppm is nevertheless too weak. For this reason, one recommends that the radiation source used for absorption measurements should emit the spectrum of the element to be quantified. With such an arrangement the required resonance line merely has to be separated from the spectral lines of the same element by means of a monochromator.

The spectrum of the element (usually a single element) under study is emitted from a hollow cathode lamp. This beam, consisting largely of resonance radiation, is electronically or mechanically pulsed. Analyte atoms are produced thermally in the atom reservoir. Ground state

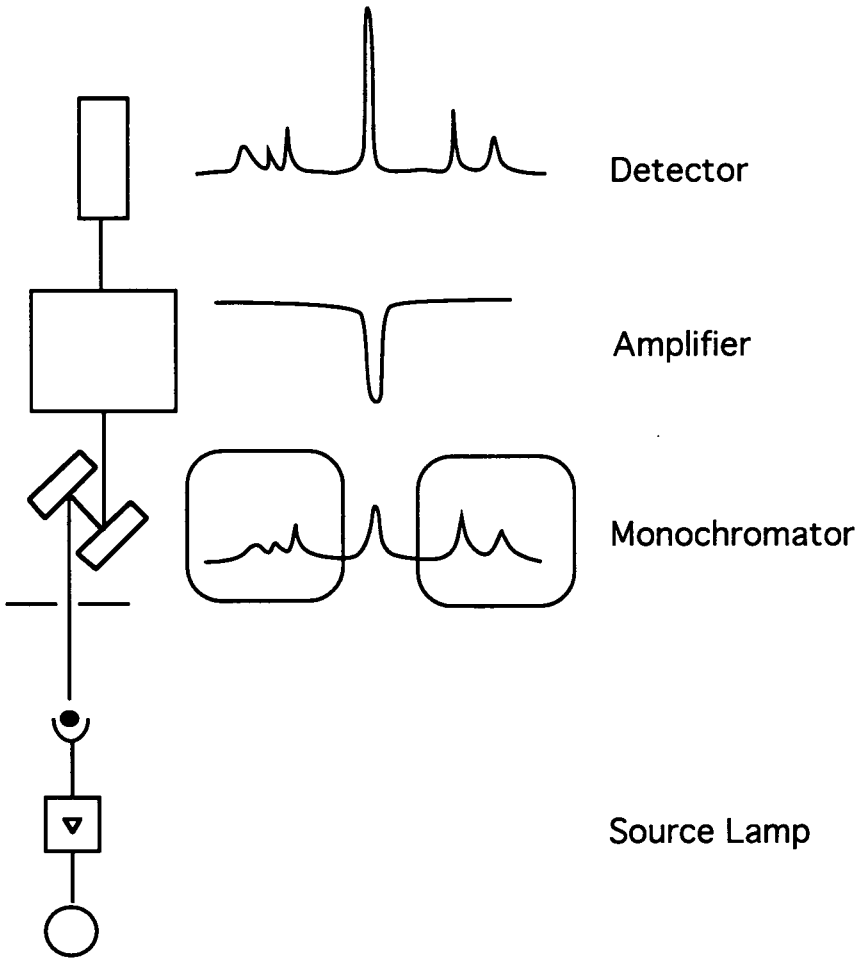


Figure A–5 Atomic absorption spectrometry equipment diagram

atoms, which predominate under the experimental conditions, absorb a portion of resonance radiation from the lamp corresponding to the concentration of this element, reducing the intensity of the incident beam. Lines that do not occur in absorption are not attenuated. After dispersion of the radiation in a monochromator, the resonance line is separated by the exits lit and all other lines are masked. The detector 'sees' only the resonance line, whose attenuation is then displayed.

A.3.4 Instrumentation

The general construction of an atomic absorption spectrometer is simple. The most important components are:

- A radiation source, which emits the spectrum of the analyte element. Hollow-cathode atomic spectral lamps are the most common radiation sources for atomic absorption spectroscopy. These lamps can produce resonance radiation of narrow line width, typically <10 angstroms (Å), for most elements that can be quantified by atomic absorption.
- An atomizer, in which the atoms of the sample to be analyzed are formed. It produces free ground-state atoms of the element of interest. A variety of commercial atomizers are available for use with AA equipment, the most common being flames and furnaces.
- A monochromator for the spectral dispersion of the radiation with an exit slit for selection of the resonance line. Because of the simplicity of the spectrum emitted by most radiation line sources, the monochromator in atomic absorption spectroscopy need not be of high resolution required for emission work.
- A detector permitting measurement of radiation intensity, followed by an amplifier, and a readout device to record the intensity.

A.3.5 Advantages

- Simple spectra

A.3.6 Disadvantages

- Destructive method
- No depth information (only total amount)
- Better with just one element

A.3.7 Case of Uranium

Uranium can be determined in a nitrous oxide/acetylene flame at the 351.5 nm resonance line with a characteristic concentration of 50 mg/l and a detection limit of about 30 mg/l. The resonance lines at 358.5 nm and 356.7 nm exhibit better sensitivity, but a less favorable signal to noise ratio.

A.3.8 Interferences

A.3.8.1 Atomic Spectral Interferences

This type of problem occurs when the radiation being measured is attenuated by substances other than the atoms of interest. Atomic spectral interference occurs when the absorption profile of another element overlaps that of the analyte within the spectral linewidth of the atomic emission line of the source. Because of the narrow width of atomic emission lines, atomic spectral interference causes very few problems.

A.3.8.2 Nonspecific Interferences

Nonspecific interference occurs due to molecular absorption or light scattering in the atomizer. These effects, seldom encountered in flames except in work near the detection limit, are very serious problems in most work with electrothermal atomizers.

A.3.8.3 Chemical Interferences

Chemical interference occurs when the analyte is contained in a chemical compound that is not broken down by the flame or furnace. This results in a lower concentration of 'free' analyte atoms than would occur in the absence of the interference. Atomic absorption can only occur by free atoms.

In work with flames, chemical interferences can be minimized either by using a higher temperature flame and/or through addition of a releasing agent.

A.3.8.4 Ionization Interferences

In atomic absorption, the flame should ideally be an absorption cell in which the sample is atomized and only atoms at the ground state are produced. Although the number of excited atoms at normal flame temperatures is always considerably lower than the number of atoms in the ground state, many practical examples are known in which the emission of the flame

interferes with absorption measurements in this type of instrument. To eliminate this interference due to flame emission, virtually all atomic absorption spectrometers currently operate with a chopped or pulsed radiation system instead of a direct current. The radiation beam is modulated either electrically or mechanically at a fixed frequency and the amplifier electronics are tuned to the same frequency. In this system, only the radiation from the primary source having the modulation frequency is amplified, while the emission from the flame, which is not modulated, is neglected. Accordingly, spectral interferences caused by emission of sample atoms in the flame are practically negligible in such a system. Elements that commonly present a problem are cesium, rubidium, potassium, and sodium.

A.4 X-RAY FLUORESCENCE (XRF)

X-ray fluorescence is an application of X-ray emission spectrometry using X-ray and gamma-ray sources for excitation. X-ray fluorescence is described as an incident beam of photons which impinges on specimens and results in the fluorescence emission of X-rays characteristic of the elements present.

A.4.1 History of this Method

The excitation of characteristic X-rays using a radioisotope source was first reported in 1966. By that time, several measurement techniques had been developed and analysis was proven feasible. Also a range of sealed, radioisotope, low-energy X-ray and gamma ray sources and a few instruments, were commercially available. These techniques are based on detection and low resolution energy selection of characteristic X-rays using ordinary scintillation or proportional counters, and the use of filters for discriminating between X-rays from adjacent elements. An event of more general significance is the recent availability of lithium-drifted silicon and high-purity detectors (Si(Li) and HPGe detectors), whose energy resolution is good enough to resolve K X-rays from the adjacent elements down to sodium.

A.4.2 X-rays Fluorescence System Basic Concepts

Primary radiation is incident on the sample where it interacts to produce vacancies in the inner atomic shells, which then de-excite to produce the characteristic X-rays of interest which are then defined by a collimator or silt arrangement and are absorbed by an appropriate detector. These X-rays from the sample are then detected, and their energies are measured by a detector spectrometer. The detector spectrometer converts the energy of the incident X-ray into a voltage pulse whose amplitude is proportional to that energy. A multichannel analyzer is used to accumulate a histogram of the pulse amplitude spectrum. The energy resolution of the detector is more than adequate to separate X-ray lines from elements of adjacent atomic number. The area under the individual characteristic X-ray peaks in the spectrum is proportional to the concentration of the various elements in the sample.

A radioisotope X-ray fluorescence analyzer consists of the following basic components:

- A sealed radioisotope excitation source.
- A detection system which selects the energy of characteristic X-rays excited and measures their intensity.

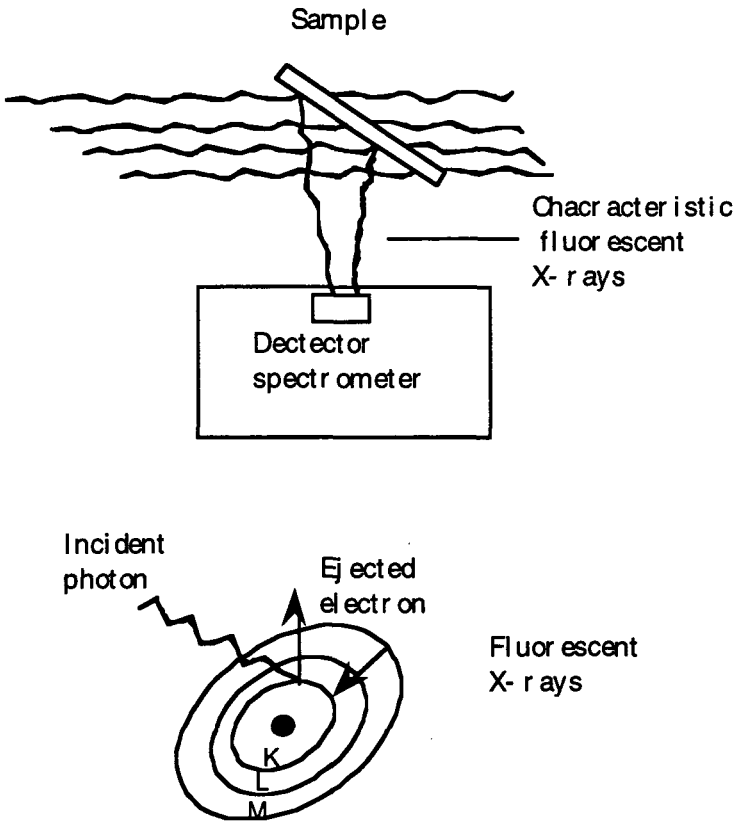


Figure A–6 Schematic of the X-ray fluorescence technique

- An electronic amplification and a read out system whose output can be correlated with the elements present in the specimen and their concentration.

X-ray photons incident on the sample interact either by the photoelectric effect to produce the desired inner shell atomic vacancies in the elements of interest or by scattering mainly from the atoms in the low atomic number substrate. These scattered X-rays constitute an unwanted background that determines the detection limit for the fluorescence measurement.

A.4.3 Sources

Alpha, beta, gamma, and X-ray emitting isotopes have all been used as sources to excite characteristic X-rays.

The most widely used excitation method is by primary or secondary gamma or X-ray sources, preferably those that emit one or a few spectral lines rather than a high proportion of continuous radiation. But characteristic X-rays can be excited by radiation; from an X -ray tube or a radioactive source. Each method has its own problems and advantages.

The major advantage of the preferred sources is that they excite characteristic X-rays efficiently with minimum background in the energy region of interest. It is preferred to use monoenergetic X-ray excitation sources (especially source-target assemblies) rather than broadband excitation, which distribute the scattered radiation over the entire range of energies. The main advantages of radioisotope sources are that they are small and are independent of any external power. The most important limitation of radioisotopes as excitation sources for XRF is their low intensity of primary radiation (10^{-6} to 10^{-7} less than conventional X-ray tubes). The probability of producing fluorescent excitation of an element is greatest when the incident X-ray energy just exceeds the binding energy of the electrons in the appropriate shells. This probability falls off rapidly with increasing excitation energy. This implies that very low energy characteristic X-rays are not efficiently produced by monochromatic radiation of high energy, thus limiting the range of elements that can be sensitively measured with a single exciting energy. In some case, such as the analysis for very light elements ($Z<20$), the use of continuum excitation may give better sensitivity than monochromatic excitation. An X-ray tube is typically chosen as the primary excitation source because of its higher output compared to generally available radioisotope sources. X-ray tubes offer the advantages of being large, high speed, and having stable power supply, but are also costly and less compact.

Bremsstrahlung emitters are secondary sources excited by beta particles. Bremsstrahlung spectra are continuous and have similar shapes to spectra emitted by X-ray tubes. Their main disadvantage is the continuous scattered background which accompanies excitation of characteristic X-rays.

Direct excitation by beta particles has two major disadvantages; excitation of Bremsstrahlung background in the specimen and backscatter of a large proportion of the incident beta particles.

Excitation by alpha emitters becomes efficient below about 2 keV and complements X-ray and gamma-ray excitation.

The criteria of a good source are:

- A simple line spectrum at an appropriate energy below 150 keV.

- No high energy beta or gamma radiation.
- Half life of at least one year.
- Specific activity high enough to yield a source emission of 10^7 to 10^8 photons/s from 1 cm^2 surface.

The resolving energy required of the energy selection apparatus varies from virtually none, for certain very simple measurements, to several hundred when complex groups of K and L X-rays have to be resolved.

A.4.4 Conditions

It is assumed that the specimen is homogeneous, flat, and infinitely thick with respect to the X-ray fluorescence emission. But XRF has found wide application in the analysis of thin films. Depending on the nature of the specimen being irradiated by a beam of X-rays. (i.e., pure element, binary, or multi-element system), the emitted characteristic radiation may be the result of more than one process:

A.4.4.1 Primary Fluorescence

Some K level electrons are ejected directly after interaction, with the incident beam photons.

A.4.4.2 Secondary Fluorescence

Some K level electrons are ejected indirectly; some incident beam photons eject K level electrons, leading to the emission of photons, which in turn have enough energy to eject target level electrons. This process is called the process of enhancement.

A.4.4.3 Tertiary Fluorescence

The realization that an element enhancing another may already be enhanced by a third element results in an additional component of fluorescent emission.

In multi-element specimens, some emitted X-ray lines are likely to be the result of enhancement by more than one element. In the absence of enhancement effects, the emitted intensity is a function of:

- The intensity emitted by the pure element.
- The concentration of the element in the specimen.
- The total mass absorption coefficient.

A.4.5 Advantages

- Requires very small samples.
- Non destructive analysis.
- Simple method.
- Better relative sensitivity for heavier elements than NAA.
- Low costs (lower than PIXE and NAA, but more expensive than ICP-AES).
- Greater depth of analysis.

A.4.6 Disadvantages

- Poor results with highest elements (covers elemental analysis from Aluminum to Uranium).
- Mostly used on solid samples.
- Requires homogeneous solid sample (it is better to analyze heterogeneous solid samples, after dissolution, by ICP-AES).
- Can be slow, particularly for trace determination, because it needs a longer counting time.

A.5 ULTRAVIOLET LIGHT AND RADIOGRAPHY METHODS

An inspection of the remaining transite surface by observing the ultra-violet light emitted by activated uranyl ion phosphorescence may be used as an indicator of local contamination. Samples of transite containing uranium and thorium isotopes were viewed under short-wave length (254 nm) ultraviolet light to determine:

- whether the specimens contain fluorescent species on the surface,
- whether the appearance under UV changes with depth by removing sample layers.

One control specimen with no uranium or thorium content showed no fluorescence. Samples containing radioactive contamination emit bright yellow-green fluorescence from a number of discrete, specific sources. This method is mainly qualitative, but when coupled with imaging software can be quantitative.

A.5.1 Basic Concepts

The term 'fluorescence' as commonly used refers to the emission of light (usually in the visible range) from a material in response to the absorption of incident energy, which is commonly

ultraviolet light. The emission of light is caused by energy released when the electrons in the excited material return to their ground state (true fluorescence), or when the spins of excited electrons return to ground state (fluorescence). The term 'luminescence' properly includes both phenomena, and whether a particular atom or molecule will absorb and re-emit radiant energy depends on its unique atomic structure. As cataloged by several authors, many uranium and thorium compounds emit radiant energy in the visible range upon absorbing ultraviolet light. While there is evidence to suggest that it is actually phosphorescence rather than fluorescence, the latter term is in common use when describing uranium and thorium behavior.

Not all species fluoresce under UV excitation, nor do all uranium and thorium compounds fluoresce. Uranium and thorium are key constituents of radioactive waste and many compounds of these elements fluoresce under ultraviolet light. (Frondel lists 82 fluorescent uranium and thorium compounds.) One of the most common of such fluorescent species, the most colorful and well-documented fluorescent species, which is known to fluoresce an intense yellow-green under short-wave length (254 nm), is the uranyl ion (UO_2+^2) under UV light. The uranyl ion is present in all fluorescing uranium compounds. While the uranyl ion will fluoresce weakly under ordinary or long wave length ultraviolet light (365 nm wavelength), the yellow-green fluorescent emission is far more intense under short-wave length UV incident radiation (254 nm).

This fluorescence may be useful in identifying fluorescent species in radioactive wastes. This can be useful since uranium and thorium compounds are not necessarily distinguishable by visual inspection of a mixed waste.

A.5.2 Experimental Procedure

The procedure is very simple. The sample of transite is viewed under the short wave length (254 nm) ultraviolet light. The specimen containing uranium or thorium emits bright yellow-green fluorescence from a number of discrete, specific points. These point sources are on the order of 1 to 5 mm in diameter and are non-uniformly distributed. Fluorescence is readily observed against the dark non-fluorescent background, other non-fluorescent background, or other non-fluorescent materials present, and specimens with higher measured radioactivity show a larger number of fluorescent point sources. One can also use a camera and filter and take photos useful for later study.

This method is a near surface method, but one can use it to determine the depth profiling of uranium in the samples by removing successive layers of sample between two ultraviolet light exposures.

A.5.3 Advantages

- Simple method both in execution and in interpretation.
- Fast method.

A.5.4 Disadvantages

- Gives relative intensities.
- Low sensitivity.
- Surface method.
- No quantitative determination.

A.5.5 Coupling

A.5.5.1 Imaging Software

This method is just a qualitative method, but it may be possible, by coupling with imaging software, to scan the photo into a computer, digitize the picture, and analyze the image. This can produce a correspondence between the colors and the intensities obtained with the UV method, and quantify the concentration of uranium contained in the samples.

A.5.6 Radiograph

Radiographs can be used to confirm the presence of radioactivity in the sample. The radiograph is sensitive to the short range radiation (α and β particles).

A.5.6.1 Experimental procedure

The samples have to be manipulated under a safety light. The sample side being studied is placed against the film in a dark place. After a specified time, the film is developed. The film appears dark where it received beta and alpha particles emitted by the uranium atoms and their daughters present in the sample. In this way, the position of the uranium atoms present on the sample's surface can be directly deduced.

A.5.6.2 Advantages/Disadvantages:

The radiograph's sensitivity is not higher than that of the UV method. In fact, the sensitivity of this method depends on the time of irradiation of the film. For a sample containing a few atoms that emit radioactive particles, a long exposure time is needed, on the order of hours or days, for the film to be sufficiently irradiated. This method can be lengthy, especially for samples with low activity. For example, the lowest sensitivity for an exposure of 48 hours is around 500 counts per minute (cpm) over a 3"x3" area.

The sensitivity for an exposure of 24 h is twice that (around 1000 cpm).

A.6 BACKSCATTERING SPECTROMETRY

A.6.1 Basis

Both in its concept and in its elementary execution, Rutherford scattering is a simple experiment. A beam of monoenergetic and collimated alpha particles impinges perpendicularly on a target. When the sample that constitutes the target is thin, almost all of the incident particles reappear at the far side of the target with some slightly reduced energy and only slightly altered direction. The few alpha particles that are lost undergo large changes in energy and direction, and changes due to close encounters of the incident particles scattered backward by angles of more than 90° from the incident direction can be detected. This is the situation that is used in the analytical technique called Rutherford backscattering spectrometry.

A.6.1.1 Background

Charged particles are generated in an ion source. Their energy is then raised to several MeV by an accelerator. The high-energy beam that passes through a series of devices which collimate or focus the beam and filter it for a selected type of particle and energy. The beam then enters the scattering chamber and impinges on the sample to be analyzed. Some of the backscattered particles impinge on the detector, where they generate an electrical signal. This signal is amplified and processed with fast analog and digital electronics. The final stage of the data

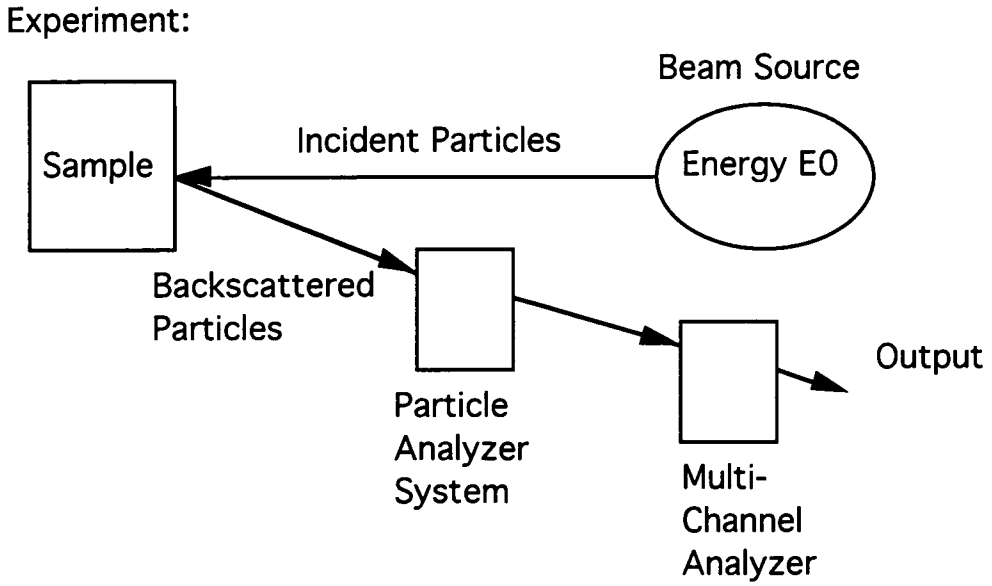


Figure A–7 Backscattering spectrometry geometry

acquisition usually is to store the signals in the form of a spectrum, hence the name backscattering spectrometry.

A.6.1.2 Specifications and properties

- The Backscatter Spectroscopy system has only 3 elements: the beam, the detector and the vacuum pump. The requirements of the vacuum are quite modest by today's standard: 10^{-5} Torr expedient and 10^{-6} Torr is quite adequate.

- The source generates a beam of collimated and monoenergetic particles of energy E_0. The projectile energy E_0 must be much larger than the binding energy of the atoms in the target. Chemical bonds are of the order of 10 eV, so that E_0 should be very much larger than that. Chemical bonds and binding energy are not the same. The angular effect of the elastic backscattering factor decreases as the scattering angle increases, up to 180°, so that large scattering angles are usually preferable, i.e. $\theta>160°$. To maximize count rate, the detector can be located close to the sample. A distance of 10–15 cm between the detector and the target has been found quite sufficient for a 25 mm^2 detector.

  A typical case is a monoenergetic 10 MeV H+ ion beam with a current of 10 to 100 nanoamperes (nA) in a 1 mm^2 area, with scattering through $\theta=170°$. These particles

impinge on the sample which is the object to be analyzed. Almost all of the incident particles are absorbed within the sample. A few (much less than one in 10^4) are scattered back out of the sample. Of these, a small fraction are incident on the area defined by the aperture of an analyzing system.

The scattered particles are analyzed with a solid-state detector located about 10 cm from the target and with a solid angle between 3 and 4 milliSteradians. The detector resolution is between 15 and 20 keV, and the multichannel analyzer is set up with a channel width between 3 and 5 keV.

- The collision then must be an elastic one. The phenomenon is similar to the collisions of two hard spheres and can be solved exactly. Nuclear reactions and resonances must be absent. With a H+ beam, nuclear effects can appear even below 1 MeV; with He+, they begin to appear at 2 to 3 MeV. Several elements have just one stable isotope (for example gold), whereas several others have more than one stable isotope. Sometimes the different signals from the different isotopes cannot be distinguished because the energy resolution of the detection system is too coarse.

- Scratches, cavities, dust particles and any other surface non-uniformities can drastically modify the spectrum, if present in sufficient amounts (even if they are of a sub-micron size). The lateral uniformity of a sample must therefore be assured on the surface as well as in depth.

A.6.2 Accelerator

Many commercially available accelerators can be used for backscattering spectrometry. The most widely used available electrostatic accelerator is the Van de Graaf generator.

A.6.3 Advantages

- Compared to other methods-for example, neutron activation analysis or secondary ion mass spectroscopy - backscattering spectrometry is not very sensitive. However, backscattering spectrometry is capable of quantitative measurements without recourse to standards.

- One of the advantages of this method is that the spectrum can be interpreted rather easily.

- The increase in sensitivity for heavy elements is an asset for the detection of these elements, but a severe limitation for the detection of light elements.

- Two elements of similar mass cannot be distinguished when they appear together in a sample.

- One of the main applications of backscattering spectrometry is the analysis of thin films and layered structures. With spectra analysis of thick samples, only the surface is clearly recognizable as the high-energy edges of the signals in the spectrum.

A.6.4 Four Basic Physical Concepts Enter into Backscattering Spectrometry

- Energy transfer from a projectile to a target nucleus in an elastic two-body collision. This process leads to the concept of the kinematic factor and the capability of mass perception.

- Likelihood of occurrence of such a two-body collision. This leads to the concept of scattering cross section and to the capability of quantitative analysis of atomic composition.

- Average energy loss of an atom moving through a dense medium. This process leads to the concept of stopping cross section and to the capability of depth perception..

- Statistical fluctuation in the energy loss of an atom moving through a dense medium. This process leads to the concept of energy straggling and to a limitation in the ultimate mass and depth resolution of backscattering spectrometry.

A.7 INDUCTIVELY COUPLED PLASMA ATOMIC EMISSION SPECTROMETRY (ICP - AES)

The development of ICP technology began in 1942. The plasma possesses three important characteristics which can be exploited and used as vaporization cells and free atom reservoirs for analytical AES:

- high gas temperature
- capability of being sustained in a noble environment
- freedom from contamination

These characteristics have been used and now the Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES) has become one of the most advanced techniques for elemental analysis. ICP-AES is an elemental analysis technique using spectra emitted by free atoms or ions generated within a source such as an ICP.

A.7.1 Basic Concept

The ICP-AES is a conventional spectroscopy technique; its unique properties derive from the particular excitation source, the ICP.

The method is based on AES coupled with an ICP source. The ICP source produces a stream of high energy ionized gas known as a plasma by inductively coupling an inert gas (most commonly argon) with a high-frequency field. The resulting plasma has an internal temperature up to 10,000 K which dissolves, dissociates, atomizes, and excites the elements present when a sample is injected through its center. This results in the emission of light of unique frequencies from the constituent element(s). The light emitted from the plasma is proportional to the concentration of the elements in the sample. The light is transferred to an emission spectrometer which has the capability of separating the unique frequencies into discrete wavelengths (each wavelength or frequency being associated with an element in the sample). The intensity of light is measured at a wavelength which is unique to that element. The fundamental assumption in quantitative analysis is that the intensity of a line emitted within an excitation source is directly proportional to the concentration of the atoms of the emitter which are present in the discharge. The electronics of the spectrometer calculate the correlation and quantify the results. The presence of a background or residual impurity in standards causes deviation from linearity.

A.7.2 Basic Elements of the ICP-AES

The basic elements of an ICP-AES instrument are the source, optics, detector, and processor.

A.7.2.1 Source

The source produces the emission spectra characteristic of the elements present in a sample. Under ideal conditions the excitation source should:

- excite lines of all elements of interest

- provide constant excitation conditions over a period of time corresponding to the sample excitation
- provide reproducible excitation conditions from sample to sample
- provide sufficient line intensity to achieve the required detection limit
- provide a low spectral background

One source with these characteristics is the ICP. By definition, a plasma is simply a very hot gas in which a significant fraction of the atoms or molecules are ionized. This ionized nature means that a plasma reacts in a number of ways when subjected to electromagnetic influences. The hot plasma ionizes a portion of the incoming flow of non ionized gas so that the process is repeated continuously. Most commonly, a sample is introduced into the ICP in the form of an aqueous aerosol produced by pneumatic or ultrasonic nebulization. As aerosol droplets produced by pneumatic or ultrasonic nebulization enter the base of the plasma discharge and progress up through the aerosol channel, a variety of processes take place. The aerosol droplets that are passed into the plasma by the spray chamber are dissolved to yield a solid salt particle. The salt particles produced are subsequently vaporized to yield gas-phase molecular species. Then molecular dissociation yields free atoms (atomization) that may, given sufficient excitation energy, lose an electron to form free ions (ionization).

A.7.2.2 Optics

The spectrometer optically collects light from the source (plasma) and separates the spectral details of the elements present in a sample for measurement. The primary function of the spectrometer is to isolate light from the various wavelengths corresponding to emission lines of the different analyte elements and to differentiate this light from the plasma background emission. The better the resolution, the less likely that adjacent lines will overlap.

A.7.2.3 Detector

The light detector is generally a photomultiplier tube with associated electronics. The photomultiplier tube produces a current that is proportional to the intensity of the corresponding elemental spectrum. The intensity must be averaged over the measuring time.

A.7.2.4 Processor

A computer system is used to calculate, calibrate, analyze, and store the analytical data generated during analysis.

A.7.3 Sample Preparation by Dissolution and Digestion Methods

All samples have to be in solution form for ICP-AES analysis. Traditionally, samples can be divided into a solution or liquid state, inorganic solid, and solids containing a high proportion of organic matter. The most common dissolution procedures for solid sample are:

- to heat the sample in a gas (thermal decomposition or pyrolysis)
- to treat the sample with liquids such as water, acids, organic solvents, etc.
- to form a melt or a flux by fusion with a salt or salts (fusion with ammonium salts, peroxides, borates, perchlorates, etc.).

The normally very long drawn-out process of dissolution can be accelerated by making the sample into a fine particle size, adding a catalyst, or using ultrasonic agitation. The sample is then introduced, reduced to atomic vapor, and quantified by the intensity of the light emitted by excited atoms and ions.

A.7.4 Detection Limit

The detection limits (the lowest concentration of analyte which gives rise to a detectable signal) are generally very low for most elements falling within the range 1-100 μg/l. It is recommended that an analyte should be present in the sample at a concentration approximately ten times that of its detection limit before a reasonably precise determination can be made. To attain reasonable accuracy, a long integration period of 3 to 5 seconds and frequent recalibration are recommended. A judicious choice of analyte wavelength allows the analyst to assure detection of the selected analyte and minimize or avoid spectral interferences from the plasma background and the sample matrix. For example, for uranium the best wavelength is 385.96 nm with a detection limit around 100 μg/l and a standard concentration around 500 μg/l. The wavelength can also be used with a detection limit around 200 μg/l and the same standard concentration.

A.7.5 Interferences

Not a single analytical technique can be claimed as free of interferences for quantitative analysis. ICP-AES is no exception to this claim. Some of the common interferences which can affect an analysis follows.

A.7.5.1 Chemical and Physical Interference

The ICP is relatively free from chemical interferences due to the high operating temperature of the argon plasma, which is enough to cause dissociation of most chemical bonds and compounds to the atomic state.

A.7.5.2 Ionization Interference

This interference arises from donation of electrons from concomitant species in the sample, which alter the atom or ion concentration of the species being determined.

A.7.5.3 Spectral or Background Interference

This interference is due to light emission at the analyte wavelength by the excitation source or some component of the sample (e.g., a spectral interference occurs when the spectrometer is set to measure the emission of an element at a particular wavelength, and another element is also present in the sample and has an emission line very close to the analyte wavelength).

Interference effects are generally small and easily manageable..

A.7.6 <u>Advantages</u>

- Covers most of the periodic table elements (rare earth elements, refractory elements),
- Encompasses all concentration levels,
- Sensitivity (increase detection limits). Excellent detection for many light elements, but less effective for heavy elements, such as lead or uranium,
- Speed,
- Accuracy and precision (around 1%),
- Convenience unequaled by any other elemental analytical technique,
- No chemical interferences,
- Minimum inter-element effects,
- Simultaneous analysis of 20-40 elements,
- Needs a small volume of solution and consequently a small quantity of rock, mineral, etc.

A.7.7 <u>Disadvantages</u>

- No depth analysis,
- Destructive method,
- It's conventional form requires the analyte to be in solution.

A.8 INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS)

ICP-MS is an alternative use of ICP, as a source of ions, for mass spectrometry. The original concept of ICP-MS was developed from a requirement, expressed in 1970, for the next generation of multi-element analytical instrument systems needed to follow the then rapidly developing technique of ICP-AES. ICP-MS was introduced in commercial form in 1983.

After a survey of available and emerging techniques, it was concluded that atomic mass spectrometry was the only basic spectrometric technique that potentially had the wide element coverage, element specificity, and relatively uniform sensitivity across the periodic table essential to provide a viable successor.

A.8.1 Basic Concept

The bases are the same for ICP-AES, just the optics used are different. The classic spectrometer is replaced by a mass spectrometer. The plasmas used at present for ICP-MS are essentially those developed for AES, and do not necessarily represent the optimum choice for ion source applications.

A.8.2 Detection Limits

A detection limit around 50 mg/l is obtained for many elements in solution in real samples and around a mg/g in a solid. In extreme cases, the detection of an element at or even below these levels may be achieved on examination of a spectrum, because of the ability of the eye to recognize the shape of a very small peak in the presence of background. The detection limit for uranium in a solid is around 0.02 mg/g (6 mg/g for XRF).

Although detection limits for AAS, ICP-AES and XRF have now reached a plateau, the detection limits reported here for the ICP-MS may be improved in the future.

A.8.3 Advantages

- Qualitative and quantitative method
- The instrumental background is extremely small, typically a few ions per second

- Can count individual ions (very low concentration range, typically two orders of magnitude lower than ICP-AES)
- Extreme simplicity of the spectra obtained: spectra contain peaks mainly from singly charged ions
- Excellent detection over the complete Periodic Table, especially good for heavy elements

A.8.4 Disadvantages

- Instrument tends to saturate at high ion currents (restrict the range)
- More expensive than ICP-AES
- Slower operation than ICP-AES

A.8.5 Interferences

This technique suffers from the same interferences as the ICP-AES, because sample introduction constraints are similar.

- Interface effects: this term may be used to describe any perturbation in the detected ion signal caused during the transmission of the sample from ICP tailflame into the first vacuum stage of the mass spectrometer.
- Matrix effects: these effects are more serious in ICP-MS than ICP-AES.
- Doubly ionized species: elements with low second ionization energy can partly be doubly ionized. This effect is less important in new systems.
- Polyatomic ion interference: interferences may be produced in the sample itself.

These interferences are produced from different acids, some of which are used in dissolution procedure for geological samples.

Appendix B

INITIAL SURVEY DATA FOR ALL PANELS

Samples from interior of Plant 7

Sample A-1 Measurement Date: 10/21/94

A-1 β–γ 100cpm α 10 cpm	β–γ 100 cpm α 5 cpm
β–γ 110cpm α 10 cpm	β–γ 110 cpm α 10 cpm

Side 1 – Painted

A-1 β–γ 90cpm α 0 cpm	β–γ 90 cpm α 0 cpm
β–γ 80cpm α 0 cpm	β–γ 90 cpm α 0 cpm

Side 2 – Painted

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample A-2 Measurement Date: 10/21/94

A-2 β–γ 70 cpm α 0 cpm	β–γ 60 cpm α 0 cpm
β–γ 70 cpm α 0 cpm	β–γ 60 cpm α 0 cpm

Side 1 – Painted

A-2 β–γ 70cpm α 10cpm	β–γ 50 cpm α 5 cpm
β–γ 100 cpm α 15cpm	β–γ 70 cpm α 10 cpm

Side 2 – Unpainted

Comments: Left part of Side 2 appears to have been wet at some point

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–1 Initial survey data for panels A–1 and A–2 (shaded areas indicate panel orientation)

Samples from interior of Plant 7

Sample A-3 Measurement Date: 10/21/94

A-3	
β–γ 100 cpm α 0 cpm	β–γ 100 cpm α 5 cpm
β–γ 160 cpm α 0 cpm	β–γ 120 cpm α 5 cpm

Side 1 – Painted

A-3	
β–γ 60cpm α 15cpm	β–γ 100 cpm α 30cpm
β–γ 240 cpm α 40cpm	β–γ 120 cpm α 50cpm

Side 2 – Unpainted

Comments: Side 2 has large chip in upper left corner,

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample A-4 Measurement Date: 10/21/94

A-4	
β–γ 60cpm α 5 cpm	β–γ 80cpm α 0 cpm
β–γ 70cpm α 0 cpm	β–γ 70cpm α 0 cpm

Side 1 – Painted

A-4	
β–γ 130 cpm α 0 cpm	β–γ 130 cpm α 0 cpm
β–γ 140 cpm α 0 cpm	β–γ 130 cpm α 0 cpm

Side 2 – Painted

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–2 Initial survey data for panels A–3 and A–4 (shaded areas indicate panel orientation)

Samples from interior of Plant 7

Sample A-5 Measurement Date: 10/21/94

A-5 β–γ 90cpm α 0 cpm	β–γ 150 cpm α 5 cpm
β–γ 110 cpm α 0 cpm	β–γ 150 cpm α 0 cpm

Side 1 – Painted

A-5 β–γ 80cpm α 0 cpm	β–γ 100 cpm α 0 cpm
β–γ 60cpm α 5 cpm	β–γ 70cpm α 0 cpm

Side 2 – Painted

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample A-6 Measurement Date: 10/21/94

A-6 β–γ 270 cpm α 0 cpm	β–γ 180 cpm α 0 cpm
β–γ 140 cpm α 0 cpm	β–γ 110 cpm α 0 cpm

Side 1 – Painted

A-6 β–γ 130 cpm α 5 cpm	β–γ 180 cpm α 5 cpm
β–γ 80cpm α 10cpm	β–γ 110 cpm α 10cpm

Side 2 – Unpainted

Comments: Looks to be a separate panel that was bolted on all 4 corners and thus was not cut specifically for this project nor should it be expected to be similar to the others

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–3 Initial survey data for panels A–5 and A–6 (shaded areas indicate panel orientation)

Samples from exterior of building 7

Sample B-1

Measurement Date: 10/25/94

B-1	
β–γ 150 cpm α 0 cpm	β–γ 150 cpm α 0 cpm
β–γ 400 cpm α 0 cpm	β–γ 700 cpm α 30cpm

Side 1 – unpainted

B-1	
β–γ 500 cpm α 20cpm	β–γ 550 cpm α 20cpm
β–γ 400 cpm α 30cpm	β–γ 650 cpm α 30cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Sample B-2

Measurement Date: 10/25/94

B-2	
β–γ 100 cpm α 0 cpm	β–γ 50cpm α 0 cpm
β–γ 600 cpm α 0 cpm	β–γ 250 cpm α 0 cpm

Side 1 – unpainted

B-2	
β–γ 400 cpm α 50cpm	β–γ 500 cpm α 20cpm
β–γ 500 cpm α 30cpm	β–γ 500 cpm α 30cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Figure B–4 Initial survey data for panels B–1 and B–2 (shaded areas indicate panel orientation)

Samples from exterior of building 7

Sample B-3 Measurement Date: 10/25/94

B-3	
β–γ 70cpm α 10cpm	β–γ 250 cpm α 40cpm
β–γ 70cpm α 10cpm	β–γ 200 cpm α 40cpm

Side 1 – unpainted

B-3	
β–γ 650 cpm α 10cpm	β–γ 550 cpm α 20cpm
β–γ 350 cpm α 50cpm	β–γ 500 cpm α 50cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Sample B-4 Measurement Date: 10/25/94

B-4	
β–γ 1.4k cpm α 40cpm	β–γ 70cpm α 10cpm
β–γ 1.5k cpm α 40cpm	β–γ 120 cpm α 20cpm

Side 1 – unpainted

B-4	
β–γ 450 cpm α 20cpm	β–γ 500 cpm α 20cpm
β–γ 800 cpm α 40cpm	β–γ 1.1k cpm α 50cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Figure B–5 Initial survey data for panels B–3 and B–4 (shaded areas indicate panel orientation)

Samples from exterior of building 7

Sample B-5 Measurement Date: 10/25/94

B-5	
β–γ 70cpm α 0 cpm	β–γ 1.8k cpm α 20cpm
β–γ 70cpm α 0 cpm	β–γ 1.1k cpm α 0 cpm

Side 1 – adhesive

B-5	
β–γ 600 cpm α 0 cpm	β–γ 700 cpm α 0 cpm
β–γ 600 cpm α 20cpm	β–γ 550 cpm α 30cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Sample B-6 Measurement Date: 10/25/94

B-6	
β–γ 1.5k cpm α 50cpm	β–γ 1.4k cpm α 20cpm
β–γ 150 cpm α 40cpm	β–γ 100 cpm α 20cpm

Side 1 – unpainted

B-6	
β–γ 400 cpm α 20cpm	β–γ 600 cpm α 30cpm
β–γ 350 cpm α 30cpm	β–γ 800 cpm α 40cpm

Side 2 – paint stripes

Comments: corrugated

Background Activity	
β–γ	70 cpm
α	0 cpm

Figure B–6 Initial survey data for panels B–5 and B–6 (shaded areas indicate panel orientation)

Samples from interior of building 2A

Sample C-1 Measurement Date: 10/26/94

C-1 β–γ 15k cpm α 600 cpm	β–γ 13k cpm α 700 cpm
β–γ 11k cpm α 500 cpm	β–γ 13k cpm α 400 cpm

Side 1 – unpainted

C-1 β–γ 2.5k cpm α 300 cpm	β–γ 2kcpm α 800 cpm
β–γ 2.5k cpm α 400 cpm	β–γ 2.5k cpm α 400 cpm

Side 2 – liquid stains

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample C-2 Measurement Date: 10/26/94

C-2 β–γ 9kcpm α 800 cpm	β–γ 1kcpm α 300 cpm
β–γ 8kcpm α 500 cpm	β–γ 1kcpm α 400 cpm

Side 1 – unpainted

C-2 β–γ 1.5k cpm α 400 cpm	β–γ 1.5k cpm α 500 cpm
β–γ 2.5k cpm α 600 cpm	β–γ 3.5k cpm α 700 cpm

Side 2 – liquid stains

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–7 Initial survey data for panels C–1 and C–2 (shaded areas indicate panel orientation)

Samples from interior of building 2A

Sample C-3 Measurement Date: 10/26/94

C-3	
β–γ 11k cpm α 800 cpm	β–γ 10k cpm α 700 cpm
β–γ 10k cpm α 700 cpm	β–γ 10k cpm α 1.1k cpm

Side 1 – unpainted

C-3	
β–γ 2kcpm α 300 cpm	β–γ 2kcpm α 300 cpm
β–γ 3kcpm α 500 cpm	β–γ 4.5k cpm α 700 cpm

Side 2 – unpainted

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample C-4 Measurement Date: 10/26/94

C-4	
β–γ 25k cpm α 1.3k cpm	β–γ 25k cpm α 1.1k cpm
β–γ 25k cpm α 900 cpm	β–γ 25k cpm α 900 cpm

Side 1 – unpainted

C-4	
β–γ 15k cpm α 4kcpm	β–γ 4kcpm α 1.4k cpm
β–γ 15k cpm α 2kcpm	β–γ 8kcpm α 1.5k cpm

Side 2 – unpainted

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–8 Initial survey data for panels C–3 and C–4 (shaded areas indicate panel orientation)

Samples from interior of building 2A

Sample C-5 Measurement Date: 10/26/94

C-5	
β–γ 20k cpm α 900 cpm	β–γ 15k cpm α 1.1k cpm
β–γ 18k cpm α 1.2k cpm	β–γ 15k cpm α 1kcpm

Side 1 – unpainted

C-5	
β–γ 6kcpm α 1.2k cpm	β–γ 15k cpm α 5kcpm
β–γ 10k cpm α 1kcpm	β–γ 18k cpm α 6kcpm

Side 2 – unpainted

Background Activity	
β–γ	50 cpm
α	0 cpm

Sample C-6 Measurement Date: 10/26/94

C-6	
β–γ 18k cpm α 800 cpm	β–γ 13k cpm α 900 cpm
β–γ 15k cpm α 900 cpm	β–γ 12k cpm α 1.1k cpm

Side 1 – unpainted

C-6	
β–γ 20k cpm α 4kcpm	β–γ 6kcpm α 2kcpm
β–γ 20k cpm α 2kcpm	β–γ 8kcpm α 1kcpm

Side 2 – unpainted

Background Activity	
β–γ	50 cpm
α	0 cpm

Figure B–9 Initial survey data for panels C–5 and C–6 (shaded areas indicate panel orientation)

Appendix C

RADIOLOGICAL CHARACTERIZATION SAMPLE SPECIFIC RESULTS BASED ON DESTRUCTIVE ANALYSIS TECHNIQUES

Table C–1 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample A3c

original thickness: 0.252 inches

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	110
0.005	70 (background)

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	220
0.006	120
0.010	90
0.013	70 (background)

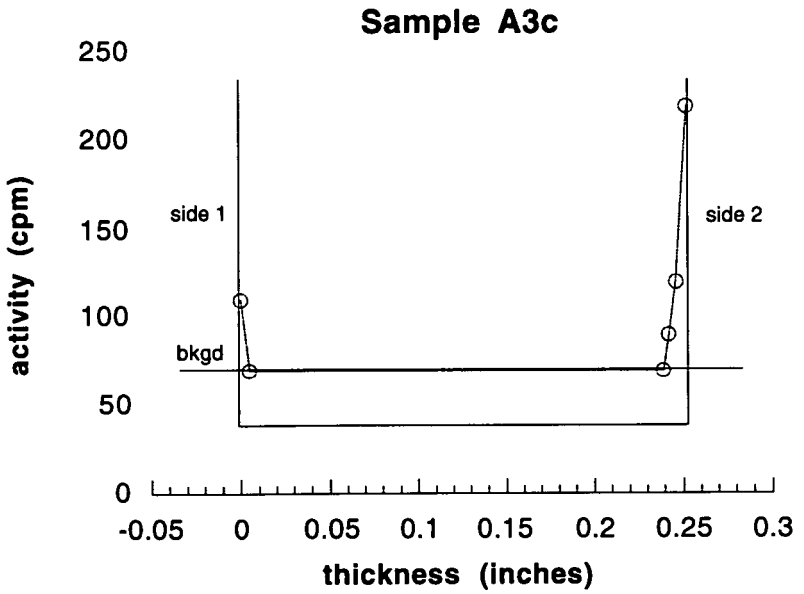


Figure C–1 Graph of the contamination penetration distribution for sample A3c

Table C–2 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample A3e

side 2

original thickness: 0.251 inches

Total Thickness Removed(inches)	Activity (cpm)
0	130
0.067	50 (background)

Table C–3 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C4b

original thickness: 0.261 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	8000
0.006	4000
0.009	3000
0.013	1000
0.019	600
0.031	240
0.047	130
0.055	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	23000
0.012	12000
0.023	2400
0.026	900
0.034	240
0.041	120
0.053	70 (background)

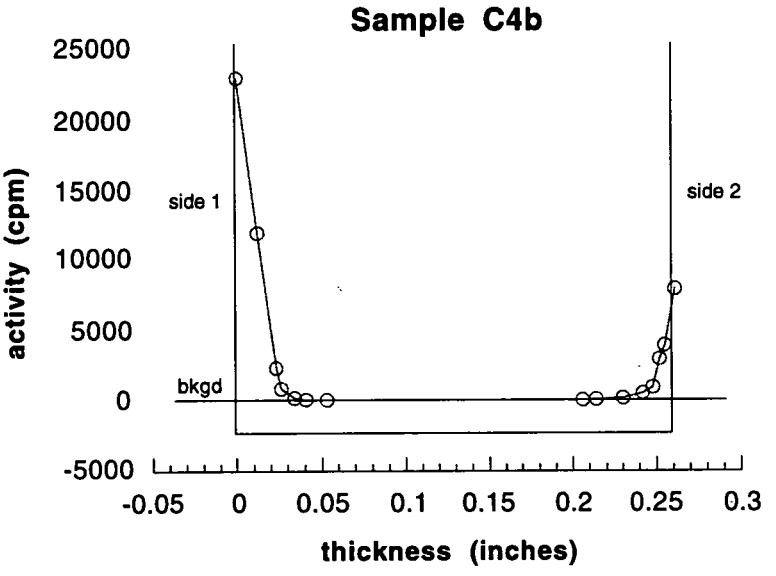


Figure C–2 Graph of the contamination penetration distribution for sample C4b

Table C–4 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C4e

original thickness: 0.260 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	6000
0.005	4000
0.010	1400
0.016	900
0.023	700
0.033	300
0.043	130
0.054	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	20000
0.015	17000
0.026	1700
0.031	400
0.033	200
0.045	120
0.060	70 (background)

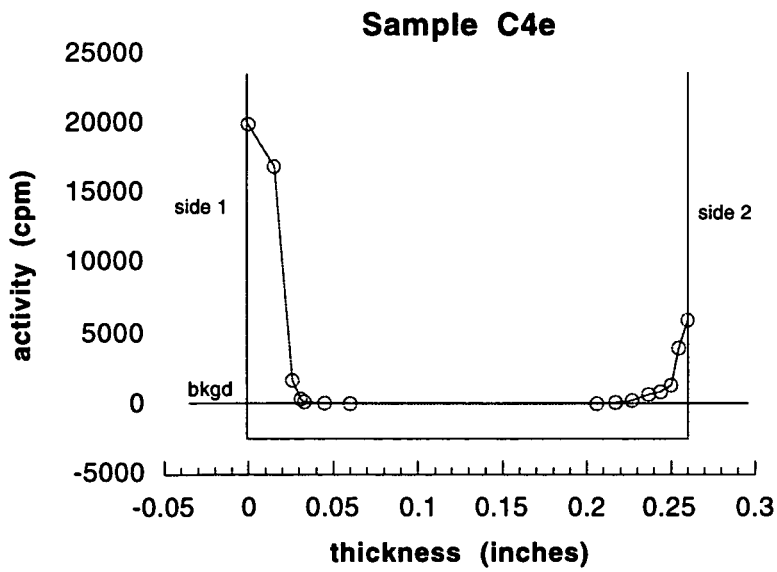


Figure C–3 Graph of the contamination penetration distribution for sample C4e

Table C–5 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5b

original thickness: 0.257 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	4000
0.004	1600
0.008	1000
0.015	700
0.024	350
0.037	180
0.046	120
0.055	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	13000
0.013	5000
0.022	300
0.026	200
0.030	170
0.035	120
0.043	70 (background)

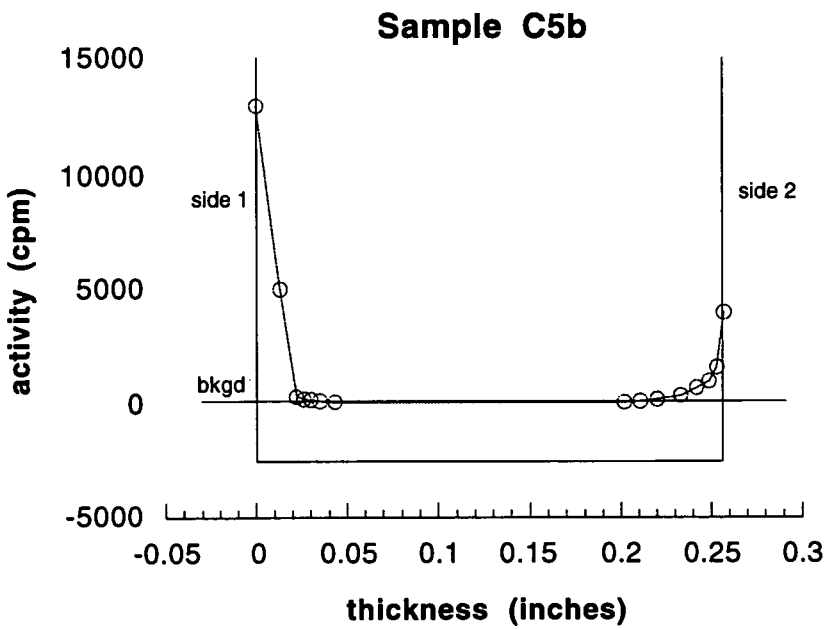


Figure C–4 Graph of the contamination penetration distribution for sample C5b

Table C–6 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5c

original thickness: 0.259 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	5000
0.007	1700
0.012	800
0.019	600
0.031	300
0.039	220
0.050	110
0.061	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	11000
0.014	1700
0.019	300
0.025	180
0.034	130
0.044	70 (background)

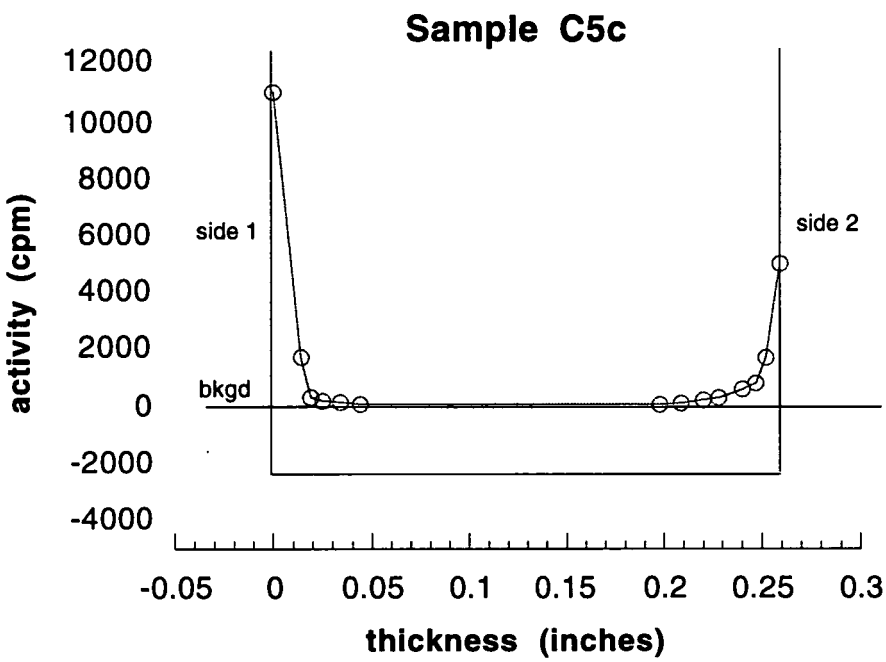


Figure C–5 Graph of the contamination penetration distribution for sample C5c

Table C–7 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5d

original thickness: 0.259 inches

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	18000
0.011	15000
0.017	6000
0.024	700
0.029	240
0.037	130
0.058	70 (background)

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	6000
0.004	4500
0.006	3100
0.009	1900
0.016	900
0.028	400
0.045	140
0.060	70 (background)

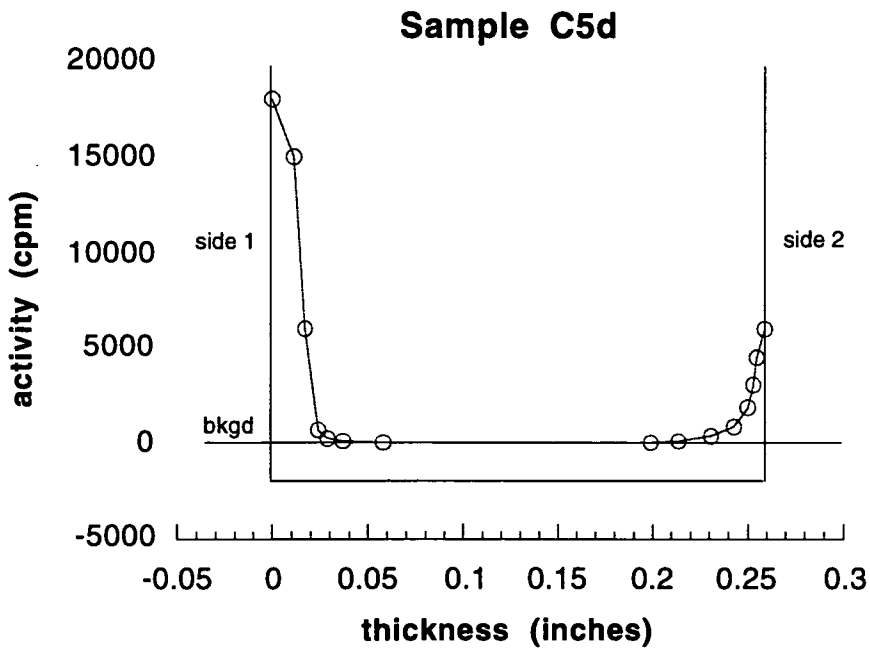


Figure C–6 Graph of the contamination penetration distribution for sample C5d

Table C–8 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5e

original thickness: 0.258 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	7000
0.007	2100
0.011	1100
0.020	500
0.028	400
0.038	350
0.051	210
0.061	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	13000
0.018	500
0.024	240
0.028	180
0.039	120
0.058	70 (background)

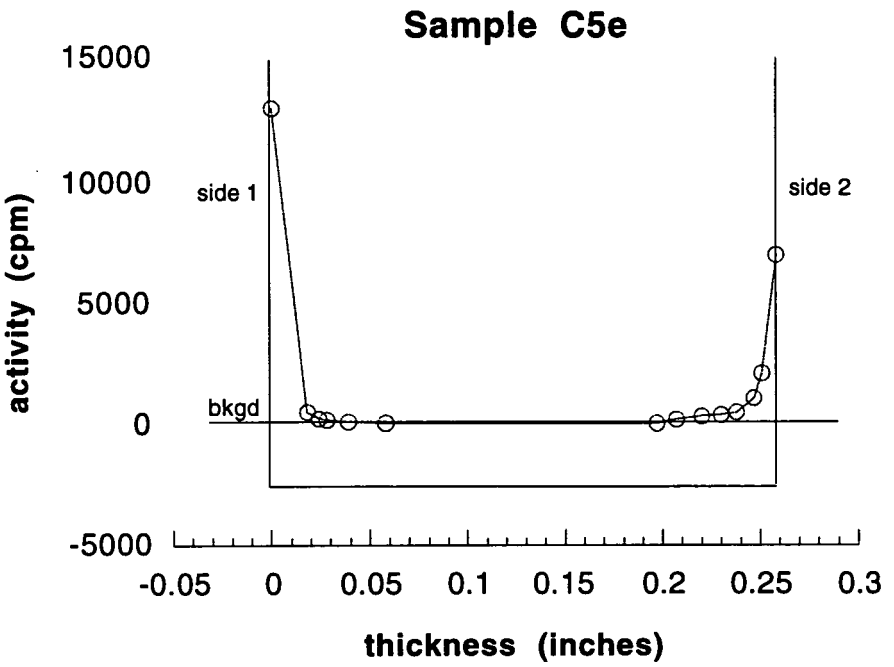


Figure C–7 Graph of the contamination penetration distribution for sample C5e

Table C–9 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5f

original thickness: 0.258 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	6000
0.007	1600
0.012	1000
0.024	500
0.033	280
0.044	180
0.059	120
0.064	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	11000
0.021	1100
0.032	280
0.039	190
0.049	140
0.059	70 (background)

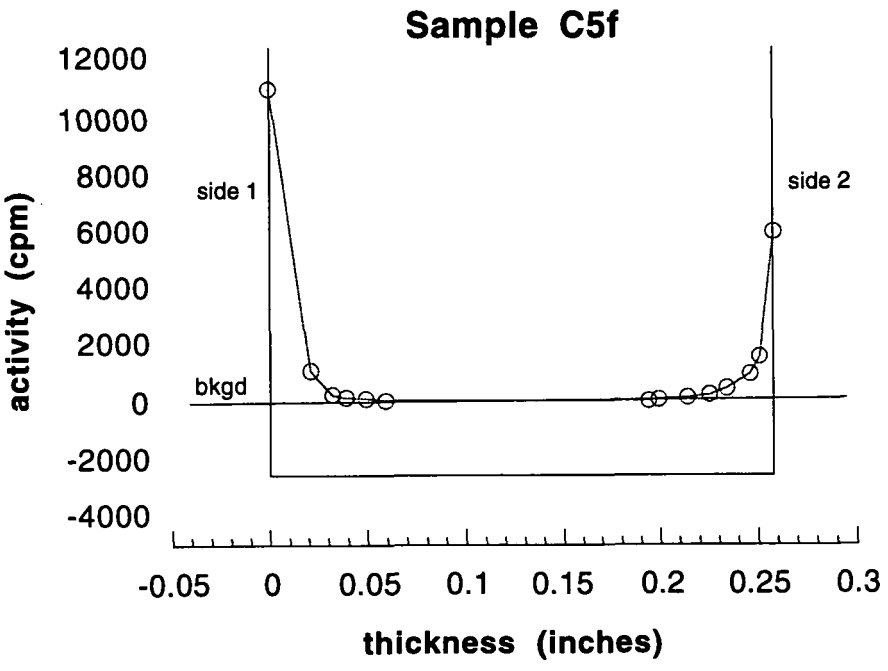


Figure C–8 Graph of the contamination penetration distribution for sample C5f

Table C–10 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5g

original thickness: 0.258 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	13000
0.006	5000
0.009	1400
0.013	700
0.022	360
0.031	280
0.039	170
0.049	130
0.059	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	17000
0.009	12000
0.019	1300
0.029	180
0.035	110
0.042	70 (background)

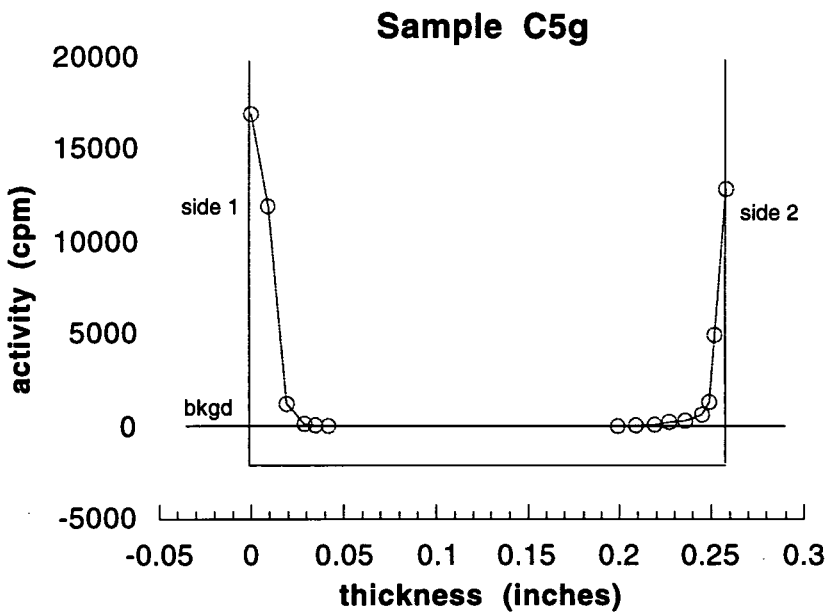


Figure C–9 Graph of the contamination penetration distribution for sample C5g

Table C–11 Layer removal results based on geiger-mueller detector $\beta - \gamma$ measurements for sample C5h

original thickness: 0.260 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	15000
0.005	7000
0.008	4000
0.011	2000
0.016	1000
0.051	240
0.074	140
0.096	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	13000
0.012	8000
0.017	2100
0.021	500
0.026	200
0.033	120
0.048	70 (background)

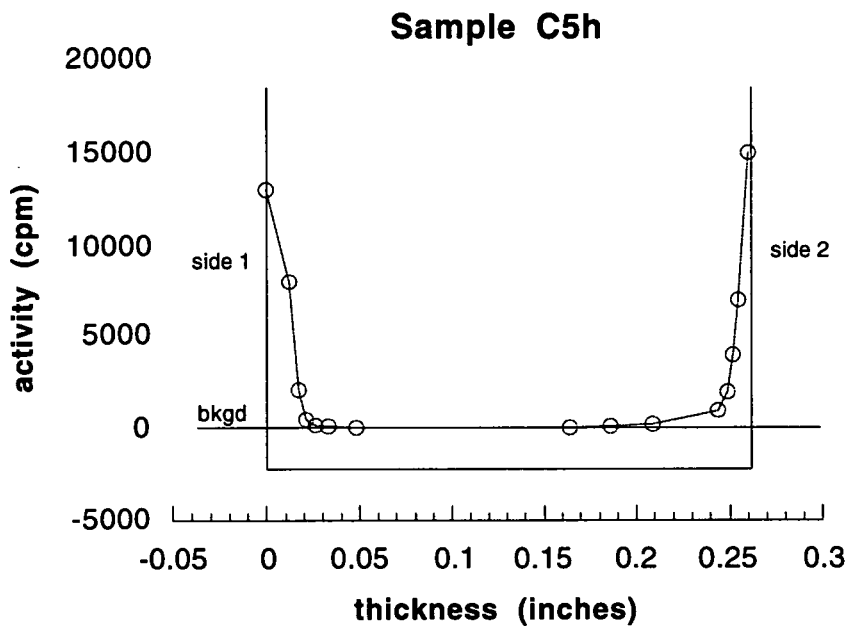


Figure C–10 Graph of the contamination penetration distribution for sample C5h

Table C–12 Layer removal results based on geiger-mueller detector
$\beta - \gamma$ measurements for sample C5i

original thickness: 0.258 inches

side 2

Total Thickness Removed (inches)	Activity (cpm)
0	17000
0.005	3000
0.009	1100
0.015	700
0.022	400
0.034	270
0.041	190
0.050	140
0.063	70 (background)

side 1

Total Thickness Removed (inches)	Activity (cpm)
0	12000
0.010	3400
0.020	360
0.026	200
0.035	130
0.041	70 (background)

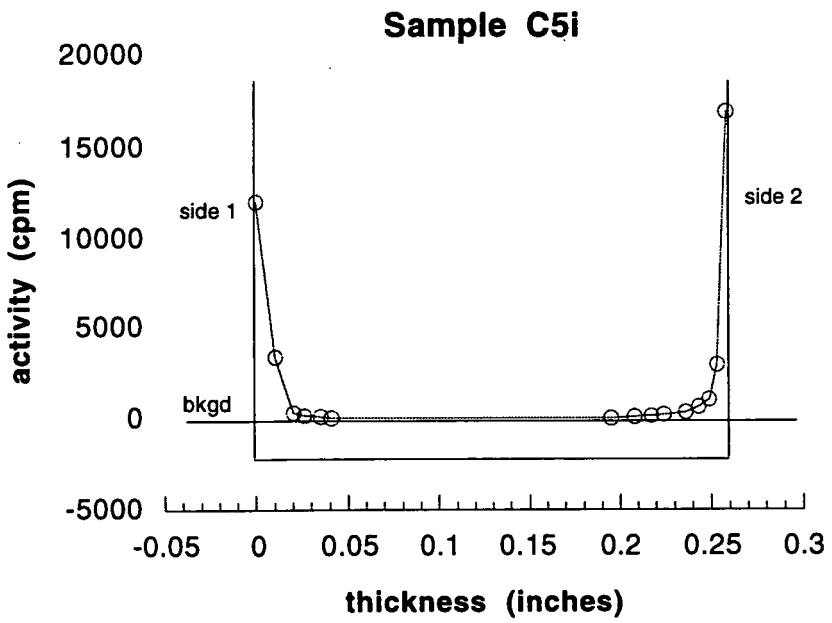


Figure C–11 Graph of the contamination penetration distribution for sample C5i

Appendix D

RADIOLOGICAL CHARACTERIZATION SAMPLE SPECIFIC RESULTS BASED ON GAMMA-RAY SPECTROSCOPY TECHNIQUE

D.1 PREDICTED CONTAMINATION DISTRIBUTIONS

D.1.1 Sample C5d

Sample C5d is of dimension: 8.5 cm by 8.5 cm by 0.657 cm. The measured response ratios are listed in Table D–1 and shown in Figure D–1 for spacing a=4.0 cm.

In order to compare the measured data with simulated data, it was assumed that the distribution in the transite sample was the error complementary function, and that the boundary condition ratio S_2/S_1=0.33 ± 0.058 (as measured using a G-M detector). With these conditions, the predicted distribution $g(z) = erfc(12z) + 0.34erfc(12(t-z))$ produces response ratios similar to the measured data, FigureD–1.

D.1.2 Sample C5e

Sample C5e is of dimension: 8.5 cm by 8.5 cm by 0.654 cm. The measured response ratios are listed in Table D–2 and shown in Figure D–2 for spacing a=7.1 cm.

In order to compare the measured data with computed data by the computer simulation program, it was assumed that the distribution in the transite sample was the error complementary function, erfc(z). The measured boundary condition ratio is S_2/S_1=0.54 ± 0.1 (as measured using a G-M detector). With these conditions, the predicted distribution $g(z) = erfc(27z) + 0.53erfc(27(t-z))$ produces response ratios similar to the measured data, Figure D–2.

D.1.3 Sample C5f

Sample C5f is of dimension: 8.5 cm by 8.5 cm by 0.655 cm. The measured response ratios are listed in Table D–3 and shown in Figure D–3 for spacing a=4.0 cm.

In order to compare the measured data with computed data by computer simulation program, it was assumed that the distribution in the transite sample was the error complementary function, erfc(z). The measured boundary condition ratio is S_2/S_1=0.538 ± 0.0873 (as measured using a G-M detector). With these conditions, the predicted distribution $g(z) = erfc(18z) + 0.555erfc(18(t-z))$ produces response ratios similar to the measured data, Figure D–3.

Table D–1 Measured response ratio (C_1/C_2) for C5d (a=4.0 cm)

Energy, keV	C_1	C_2	Ratio (C_1/C_2)	σ
63.91	83796	64619	1.3063	0.009840
84.60	36620	29454	1.2433	0.01985
93.11	476180	385261	1.2353	0.003178
113.24	21874	18346	1.1979	0.02264
144.09	88242	73044	1.2080	0.008082
163.56	39667	33039	1.2006	0.01370
185.54	447395	381041	1.1741	0.002771
205.35	35796	30461	1.1751	0.01274
765.35	11908	13494	1.1332	0.02154
1001.00	33766	38100	1.1284	0.009145

Where, C_1 is the photopeak area for detector 1;
C_2 is the photopeak area for detector 2.

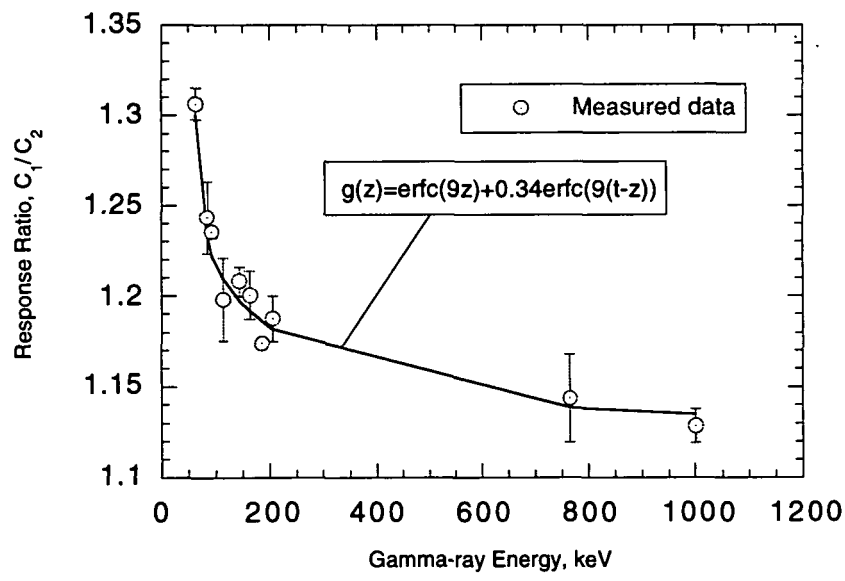


Figure D–1 Comparison of measured data and the computed data for transite sample C5d.

Table D–2 Measured response ratios (C_1/C_2) for C5e (a=7.1 cm)

Energy, keV	C_1	C_2	Ratio (C_1/C_2)	σ
63.91	35610	30683	1.1605	0.01150
84.60	14597	12864	1.1347	0.02591
93.11	176798	157472	1.1227	0.004523
113.24	8539	7675	1.1126	0.03145
144.09	29478	26487	1.1129	0.01212
163.56	12981	11699	1.1096	0.02036
185.54	162788	148305	1.0977	0.004205
205.35	12444	11393	1.0922	0.01938
765.35	4666	4360	1.0701	0.03536
1001.00	13883	13022	1.0661	0.01413

Where, C_1 is thephotopeak area for detector 1;
C_2 is thephotopeak area for detector 2.

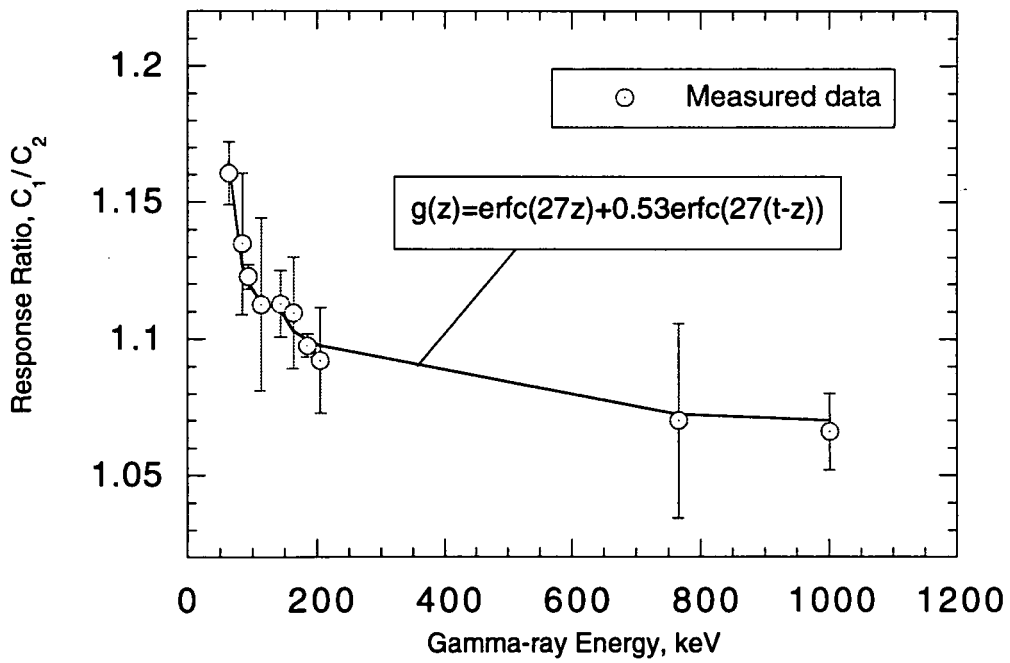


Fig D–2 Comparison of measured data and the computed data for transite sample C5e.

Table D–3 Measured response ratio (C_1/C_2) for C5f (a=4.0 cm)

Energy, keV	C_1	C_2	Ratio (C_1/C_2)	σ
63.91	52152	43646	1.1948	0.00984
84.60	22246	19228	1.1569	0.02134
93.11	302864	265726	1.1397	0.003518
113.24	14348	13157	1.1160	0.02529
144.09	53142	47858	1.1305	0.00921
163.56	23837	21237	1.1224	0.01611
185.54	285393	256941	1.1107	0.003253
205.35	22519	20282	1.1099	0.01512
765.35	7534	6853	1.0993	0.02957
1001.00	24462	22639	1.0805	0.01102

Where, C_1 is the photopeak area for detector 1;
C_2 is the photopeak area for detector 2.

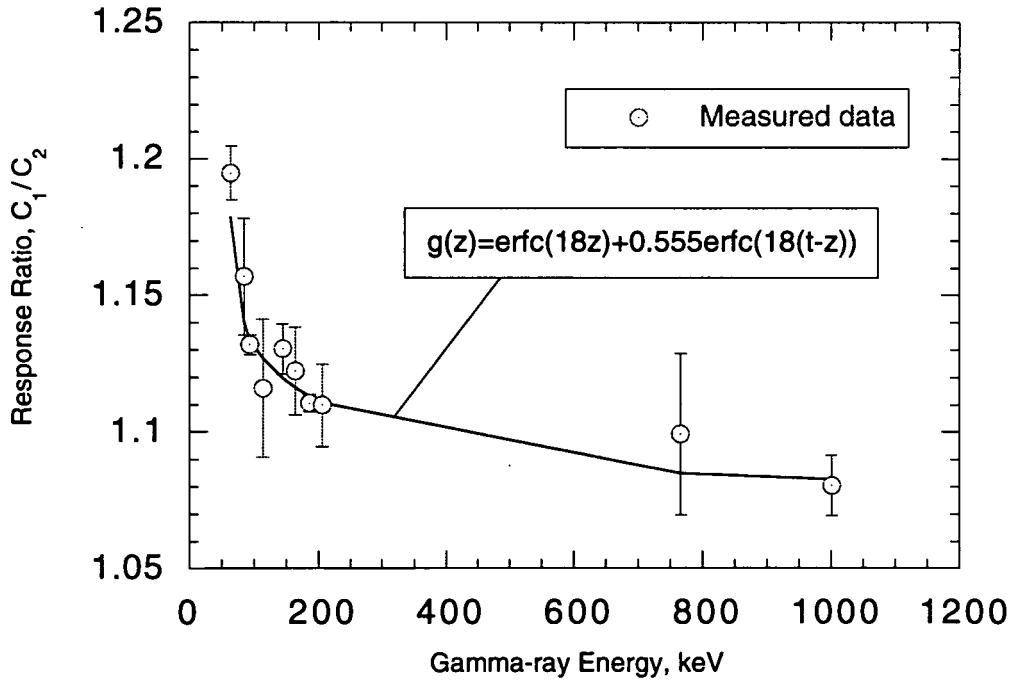


Figure D–3 Comparison of measured data and the computed data for transite sample C5f.

D.2 VERIFICATION BY LAYER REMOVAL MEASUREMENT

D.2.1 Sample C5a

In order to verify these results, a destructive layer removal technique was used to measure the actual decontamination distribution for sample C5a. The measured layer removal results are shown and compared to the best fitted distribution of $g(z)= erfc(22z) + 0.195erfc(22(t-z))$ in Figure D–4.

D.2.2 Sample C5f

Sample C5f was destructively analyzed to verify the gamma-ray spectroscopy technique. The measured layer removal results are shown and compared to the predicted distribution in Figure D–5. The predicted distribution is determined with distribution function $g(z)=erfc(9z) + 0.34erfc(9(t-z))$. Comparing the layer removal and the predicted results, it appears that the predicted distribution on side-2 is significantly different from the layer removal results. This was observed for other samples as well, and is likely due to the choice of equal constants $\lambda_1= \lambda_2$, which assumes the two sides were similarly exposed to the contamination. Actually the two sides were exposed differently. Therefore, it is suggested that the constants λ_1 and λ_2 should be considered separately when this occurs.

D.2.3 Sample C5d

Sample C5d was destructively analyzed to verify the gamma-ray spectroscopy technique. The measured layer removal results are shown and compared to the predicted distribution in FigureD–6. Note that the layer removal results have boundary ratio S_2/S_1=0.33 which is in the range of the measured ratio S_2/S_1=0.33 ± 0.058. The predicted distribution is of the form $g(z)=erfc(9z) + 0.34erfc(9(t-z))$. The difference between the predicted and measured distributions appears significant. These differences could be due to the uncertainties of the gamma-ray spectrum analyses, especially the choice of regions of interest (ROIs) for the full-energy peaks. Other potential sources for the differences include the uncertainty of the destructive measurements.

D.2.4 Sample C5e

Sample C5e was destructively analyzed to verify the gamma-ray spectroscopy technique. The measured layer removal results are shown and compared to the predicted distribution in Figure D–7. The predicted distribution is of distribution form with $g(z)=erfc(27z) + 0.53erfc(27(t-z))$.

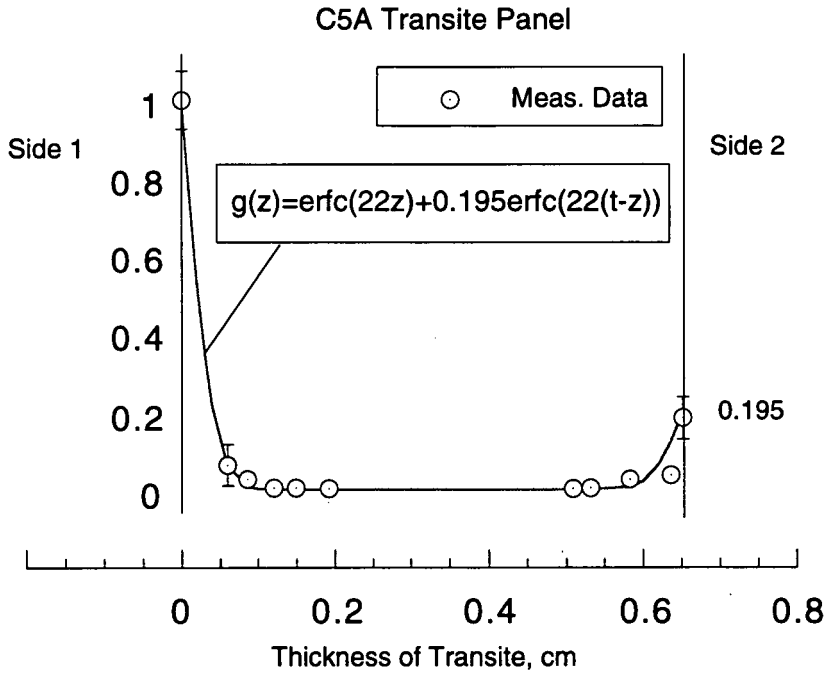
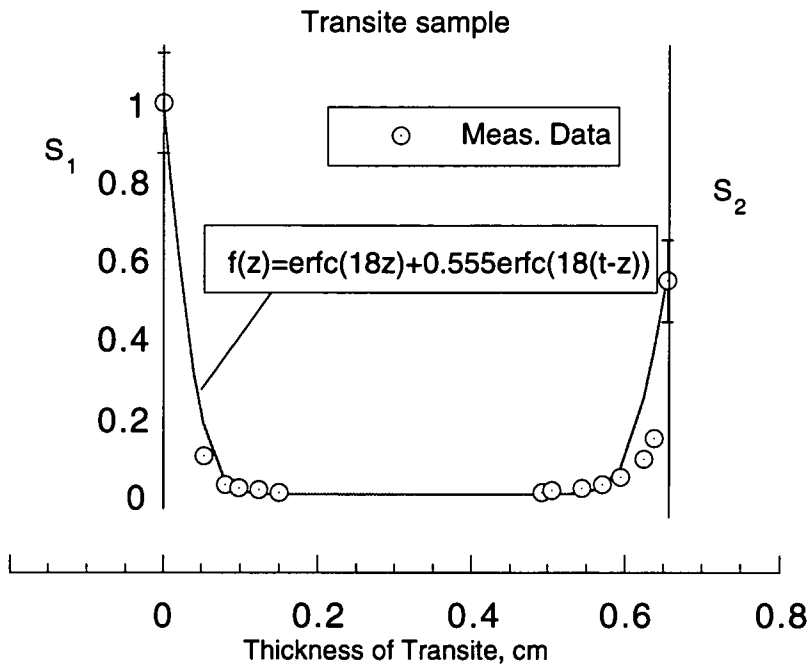


Figure D–4 The comparison of measured distribution by layer removal and the predicted distribution for transite sample C5a



FigureD–5 The comparison of measured distribution by layer removal and the predicted distribution for transite sample C5f.

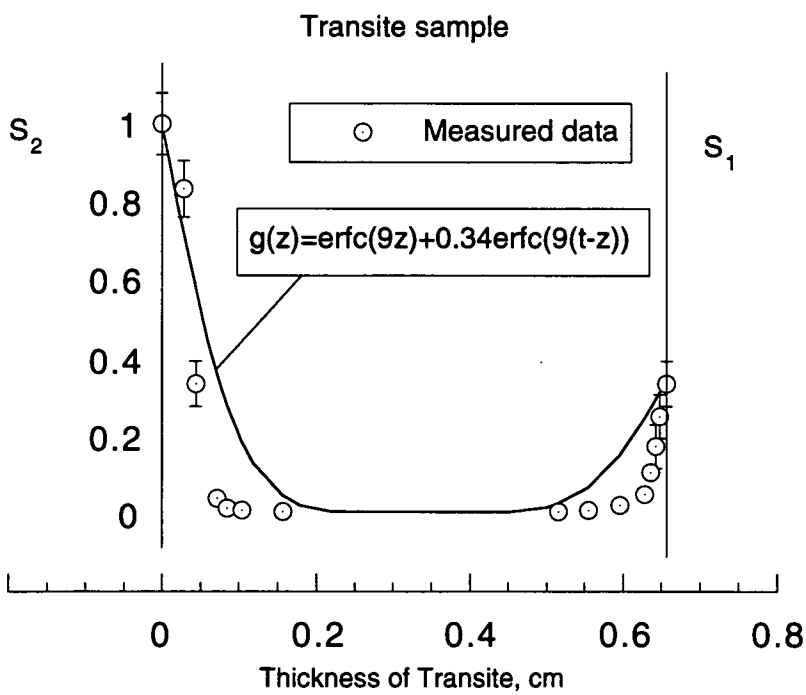


Figure D–6 The comparison of measured distribution by layer removal and the predicted distribution for transite sample C5d

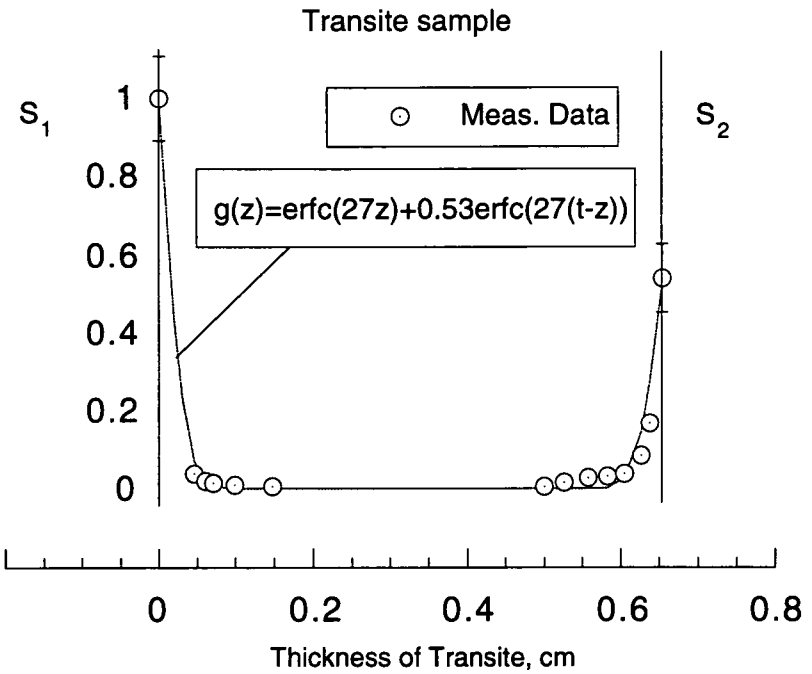


Figure D–7 Comparison of measured data by layer removal and predicted distribution for transite sample C5e.

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Section 7.0