FINAL REPORT

VOLUMETRIC LEAD ASSAY

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Prepared for:

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ACRONYMS

BEGe	Broad Energy Germanium
CMST-CP	Characterization, Monitoring, and Sensor Technology Crosscutting Program
D&D	Deactivation and Decommissioning
DOE	U.S. Department of Energy
DOE-EM	U.S. Department of Energy-Environmental Management
DOE-OST	U.S. Department of Energy-Office of Science and Technology
FIU	Florida International University
FIU-HCET	Florida International University's Hemispheric Center for Environmental Technology
FY00	Fiscal Year 2000
HCET	Hemispheric Center for Environmental Technology
INEEL	Idaho National Engineering and Environmental Laboratory
ISOCS	In-situ object counting system
pCi	Pico Curie
RCRA	Resource Conservation and Recovery Act

NOMENCLATURE

psi	pounds per square inch
ft	foot
V	volt
Amp	ampere

EXECUTIVE SUMMARY

Lead in the form of shot, bricks, plates, and sheeting was and is used as shielding at all DOE sites to reduce worker exposure from gamma emitting radionuclides. Lead forms can become surface contaminated during their use in radioactive areas. They can also become volume contaminated as a result of being formed from surface contaminated lead or as a result of activation in shielding conditions. At many of the DOE sites, for example, Idaho National Engineering and Environmental Laboratory (INEEL), lead is present in far greater quantities than needed for emergency use. Resource Conservation and Recovery Act (RCRA) requires lead to be managed as a hazardous waste if it is no longer providing its intended use. Lead contaminated with radioactive materials must be treated as mixed waste. Disposal of mixed waste is very expensive.

Most of the lead is not expected to be radioactively contaminated. If it can be demonstrated that a significant part of the lead is not contaminated, then instead of disposing it as mixed waste, it can be recycled as a scrap metal, earning revenue, thus providing a significant saving on disposal costs. The traditional contamination survey techniques are not effective in surveying the internal volume of lead forms due to the self-shielding attributes of lead. Current characterization techniques for determining internal volume contamination, requiring physical samples to be extracted from the interior volume of lead items, and laboratory analysis are expensive, time-consuming, and do not provide 100 % lead item sampling and do not meet the DOE's mission of accelerated, safe, and cost-effective cleanup.

An alternative method for characterization and handling of large quantities of lead is proposed. Initially, it is intended for lead bricks. Later, its application can be extended to other lead forms. The method is based on an automated system requiring minimum amount of manpower, thus reducing exposure of human beings to radiation or to airborne lead particles. The system consists of a robotic gripper that picks up lead bricks from a stack and places them on a conveyor. Lead is characterized by a gamma spectrometer using Broad Energy Germanium detectors. In-Situ Object Counting System software is used for determination of the counting efficiency for lead items. Detectors scan the bricks for contamination, and if found radioactive, the bricks are pushed on to a separate container. The contaminated bricks are then dumped as mixed waste, and the uncontaminated ones are collected in a separate container for reuse.

Cost-benefit analysis of an automated system was performed. The cost analysis is based on managing 1,000,000 lbs of lead bricks under three different scenarios: 1) the work for characterization and disposal of lead is given to a contractor; 2) FIU is the prime contractor; and 3) no characterization is performed, and all bricks are disposed of as radioactive waste. For each option two cases were considered: case 1, 50% of the lead bricks are assumed contaminated, and case 2, 20% of the bricks are contaminated. For each of the two cases, cost saving obtained if the characterization and disposal are performed by a contractor or by FIU over disposal of the entire quantity, without characterization, as waste is performed. The analysis shows that for 20% contaminated bricks a maximum saving of \$3,162,200 occurs if characterization is performed by FIU. It is estimated that with the assay time of 1.5 minutes for each brick weighing 60 pounds, the time needed to assay 1 million pounds of lead bricks will be 70 working days if the system is run 6 hours per day.

1.0 INTRODUCTION

The United States Department of Energy (DOE) continually seeks safer and more cost-effective remediation technologies for use in the decontamination and decommissioning (D&D) of its nuclear facilities. Decommissioning a nuclear facility generates an enormous amount of waste with very low level of contamination. At many of the DOE facilities, large quantities of metal are present, which need to be disposed of in a cost-effective way. Of particular concern is lead. Resource Conservation and Recovery Act (RCRA) requires lead to be managed as a hazardous waste if it is no longer providing its intended use. The Idaho National Engineering and Environmental Laboratory (INEEL) has more than 7 million pounds of lead in different forms. The INEEL has established an emergency reserve volume of 131 tons (about 300,000 pounds) of lead, which is in storage for emergency use in a radiological emergency requiring shielding. This volume is exempt from RCRA requirements. Volume greater than this amount that appears to be in storage and is not providing its intended purpose may be considered by a regulator to be in non-compliance. An exemption within RCRA allows lead to be managed as product if a recycling program is shown to be in place. An effective recycling program, which is moving lead to the scrap metal industry, must be in place to prevent potential Notices of Violation. DOE orders require materials that have been in radiological control areas be certified to have "NO DOE RAD ADDED" contamination before they can be recycled.

Lead in the form of shot, bricks, plates, and sheeting was and is used as shielding at all DOE sites to reduce worker exposure from gamma emitting sources. Lead forms can become volume-contaminated as a result of being formed from surface-contaminated lead or as a result of activation in shielding conditions. Because of the self-shielding attributes of lead (resulting from its high density and high atomic number), traditional contamination survey techniques are not effective in surveying the internal volume of lead forms. Current characterization techniques for determining internal volume contamination require physical samples to be extracted from the interior volume of lead items and laboratory analysis. This characterization technique is time-consuming, increases personal lead exposure, delays lead disposition determinations, increases lead laboratory sample management, increases analysis data management, does not provide 100 % lead item sampling, costs \$300 per sample, does not validate surface survey results, and impedes recycling because of the above problems. In view of these difficulties in assessing contamination by conventional methods of sampling and analysis and in view of potential Notices of Violation, the DOE is in urgent need for cost-effective and efficient methods for performing volumetric radioassay of lead in different forms.

This report describes a system for handling and radioassay of lead, consisting of a robot, a conveyor, and a gamma spectrometer. The report also presents a cost-benefit analysis of options: radioassay and recycling lead vs. disposal as waste.

2.0 TECHNOLOGY NEED

Identification No.	Need Title
ID-3.1.45	Volumetric Radioassay of Lead Sheet, Plate, Shot, and Irregular Shapes for "NO DOE RAD ADDED" Determinations
ID-7.2.16	Field Screening of Lead (shot, bricks, sheeting) for Radionuclide Contamination
AL-00-01-10-DD	Accelerated Real-Time Volumetric Radioassay of Lead Forms
SR00-4007	Characterization of Volumetric Contaminated Surfaces

There are more than seven million pounds of shielding lead in INEEL buildings, emergency shielding reserve storage, mixed waste storage, and in the operation surge storage. Approximately one million pounds has been identified as radiologically contaminated and placed into storage. The remaining lead still remains in operational and deactivated buildings or facilities and is awaiting decommissioning. A large percentage of this lead is not expected to be radiologically surface or volume contaminated.

There is a need for volumetric lead radioassays to determine whether millions of pounds of lead shielding, in storage at DOE sites, is free for release into recycling scrap metal industries. Much of this lead is believed not to be radiologically contaminated and will require some kind of field screening method so as to quantify how much of the lead is not contaminated and subject to release. Because of the self-shielding attributes of lead, traditional contamination survey techniques are not effective in surveying the internal volume of lead forms. Current characterization techniques for determining internal volume contamination require physical samples to be extracted from the interior volume of lead items and laboratory analysis. This characterization technique is time-consuming, increases personal lead exposure, delays lead disposition determinations, increases lead laboratory sample management, increases analysis data management, does not provide 100 % lead item sampling, costs \$300 per sample, does not validate surface survey results, and impedes recycling because of the above problems.

The DOE requires a system with the following specifications:

- The system shall measure volumetric contamination.
- The system shall require no drilling of the lead.
- The system shall detect volumetric contamination with Cs-137 at a level of 1 pCi/g in a 30-second count.
- The system shall detect gamma-ray emitters other than Cs-137 at a sensitivity range of 1 pCi/g.
- The system shall validate surface survey results and prevent a potential release of contaminated lead to the scrap metal industry.
- The methodologies for each of the requested lead forms shall be developed by the end of FY01.

- The total cost for identifying the techniques specific for each lead form shall not exceed \$40,000. Alternatively, the cost of assay, including the instrumentation and labor, and disposal of only the fraction of the lead determined to be contaminated and recovery of revenue from the recycling of uncontaminated lead shall be less than the cost of disposal of the entire quantity of lead as a mixed waste (RCRA plus radioactive).

3.0 PROJECT TASKS

The following tasks and milestones were scheduled for completion during FY00.

Task 1. Specific Review and Quantification of DOE Volumetric Lead Assay Needs
With the enormous quantities of lead shielding material stored at many DOE sites, there is a need to conduct an overall assessment of how much is actually contaminated, so as to recycle the uncontaminated portion. This review will of course cut down on disposal costs. It is believed that most of the stored shielding material is not contaminated and needs to be quantified.

Information about the quantities of lead at INEEL was collected and is presented in Table 1.

Task 2. Performance and Evaluation of Current Characterization Technologies
FIU-HCET will select characterization technologies currently in use at DOE facilities storing lead. This will be done through review of commitment documents such as remediation plans and through direct interactions with the individuals responsible for the restoration and remediation activities. Vendors will also be evaluated at FIU-HCET.

Information about the survey instruments used for measurement of contamination was obtained from INEEL. A sodium iodide (TI) based gamma radiation measuring system was developed at INEEL for volumetric surveying of lead bricks. Best efforts to get a copy of the report on this instrument were not successful. So FIU-HCET procured a gamma spectrometric system using broad energy germanium (BEGe) detectors and gained experience with this system and evaluated it. This system was used along with in-situ object counting software (ISOCS) for identification and quantitative assessment of radionuclides. FIU-HCET also procured a sodium iodide based detector, which can be run on the same electronic system as the BEGe detector.

Task 3. Technology Performance and Uncertainties
A description of the technical specifications and the applicability of each technology to the site needs will be reported. This technical evaluation will identify gaps and uncertainties (if any) of the technologies with respect to their DOE mission. Identification of these uncertainties and solutions to reduce these as well as issues such as technology accuracy, reliability, failure rates, and extents will be dealt with explicitly. The occupational safety factor will also be assessed.

As stated in task, a BEGe based system was evaluated for its performance. Using this system along with ISOCS, activity of standard 10 cm x 10 cm Cs-137 and Co-60 sources placed at a distance was determined and found to match with the reference value (Fig. 3). This system also detects the small quantity of naturally occurring radionuclides present in materials, such as lead bricks and lead wool or building materials (Figs. 4-5).

Task 4. Recommendations of Technologies for System Integration

FIU-HCET's CMST program will perform systems' integration as the most cost-effective means of adapting commercial technologies to DOE's needs.

An integrated system composed of a robot, a conveyor, and BEGe detector based gamma spectrometric system was recommended. The sodium iodide system will be used when the gamma energy lines are well separated and also for comparison with the INEEL method.

Task 5. System Design of Modules

Delivery of a system design will identify the most appropriate technologies' combination that addresses DOE site users' needs.

A system design with cost comparison of various alternatives was performed and is presented.

Task 6. Year-End Report

A year-end report consisting of the work performed and combining all results and studies in a comprehensive report will be prepared.

This is the FY00 Year-End Report. Because of DOE's moratorium on disposal of radioactively contaminated metal to the scrap metal industry, this project on radioassay of lead will not continue in FY01. Therefore, this year-end report will be the final report on the project.

4.0 PROJECT MILESTONES

C013-M1	Preliminary Report on Evaluation of Results, and Initial Design to allow Determination of Building Full System and Deploying at DOE sites	Due Date: June 1, 2000
C013-M2	Report on Evaluation of HCET and Commercial Radiation Sensor Systems and Design of Optimal Radioassay Lead System	Due Date: September 6, 2000

Both project milestones were completed on time.

5.0 TECHNOLOGY SUMMARY

Lead is present in large quantities in DOE facilities. At INEEL alone more than 7 million pounds of lead is present. A significant fraction (more than 50%) of lead is estimated not to be contaminated. Unless it is demonstrated to be free from contamination, lead must be assumed contaminated and disposed of as a mixed waste. Disposal of large quantities of lead is expensive and poses an environmental hazard. It also does not take advantage of recycling, which would provide monitoring dividends during the disposition of lead.

Cost-benefit analysis of an automated system, requiring a minimum amount of manpower and thus reducing exposure of human beings to radiation or to airborne lead particles, was performed. The system segregates uncontaminated lead from contaminated lead and thus makes it available for reuse. The system consists of a robotic gripper that picks up lead bricks from a stack and places them on a conveyor. BEGe based detectors mounted on the conveyor scan the bricks for contamination, and if found radioactive, the bricks are pushed on to a separate container. The contaminated bricks are then dumped as mixed waste, and the uncontaminated ones are collected in a separate container for reuse.

BEGe spectrometer with ISOCS is used for identification of gamma emitting radionuclides and for determination of their activities. The ISOCS software performs calculation of counting efficiency of objects of different shapes (planes, cylinders, boxes, spheres, etc.) placed at different distances from the detector, thus dispensing with the need for calibration with sources of identical configurations.

The time taken for placing a brick on the conveyor is 1.5 minutes. During this time, scan of the previously placed brick is completed. It is estimated that at a scanning rate of one brick of 60 pounds in 1.5 minute, the time needed to assay 1 million pounds of lead bricks will be 70 working days if the system is run 6 hours per day.

Various scenarios with different percentages of uncontaminated lead bricks are considered, and estimates of the projected savings are made.

6.0 BENEFITS

The development of a real-time volumetric radioassay will provide the following:

- Fast and inexpensive determination of lead available for reuse and not requiring disposal. NO DOE RAD ADDED lead determination will not only save on the cost of disposal but also provide revenue due to recycling of lead.
- Low occupational exposure to lead.
- Accelerated disposition of entire difficult radioactive lead waste stream.

7.0 CAPABILITIES/LIMITATIONS

FIU-HCET has built and used a system for in-situ decontamination and characterization of large-bore pipes. The characterization system uses a gamma spectrometric system with four BEGe detectors on a conveyor and an in-situ object counting system (ISOCS) software. The detectors are arranged so that two detectors are above and two below the pipe, which moves on the conveyor at a preset speed. The radioassay trailer will be useful as a test bed for this project and will be similar to the expected final lead assay system design. Instead of running a large number of large-bore pipes on a conveyor belt through a radioassay trailer to determine if the pipes are clean, the characterization system will convey lead bricks and other lead forms through to determine whether there is any radioactivity added to the lead material. FIU-HCET personnel were first familiarized with the operation of the gamma spectrometric system and use of ISOCS software for pipe characterization and performed measurements on pipes at a nuclear power plant. Its use was evaluated for determination of NO DOE RAD ADDED for recycling.

Limitations on radioassay of lead are its high density and high atomic number; it also exists in different forms and provides self-shielding. Presence of radionuclides inside thick lead materials, particularly TRU, makes their detection difficult because of the low amounts (and low energy) of gamma rays emitted in the radioactive decay process.

8.0 ACCOMPLISHMENTS

- Reviewed technologies for handling large quantities of lead.
- Procured a sodium iodide (TI) spectrometric system for comparison with DOE method. Also procured a BEGe based gamma spectrometric system with ISOCS for identification of various multiple peaks in the gamma spectrum and for calculation of counting efficiency for different source configurations.
- Received a list of the quantity of lead in different forms available at INEEL. The information has recently been compiled.
- Used BEGe gamma spectrometer with conveyor system and ISOCS system for radioassay of large bore pipes. Evaluated the usefulness of this system for lead assay.
- Performed design of the automatic lead assay system composed of a robot, conveyor, and detection system.
- Performed cost-benefit analysis of the different options for characterization of lead for contamination, recycling the uncontaminated lead, and disposing as waste only the contaminated lead as against disposal of all lead as radioactive waste.

9.0 SYSTEM OPERATION

The system consists of a set of four BEGe detectors, a conveyor, and a gantry robot to lift lead bricks from the pallet and place them on the conveyor.

OPERATION STEPS

- The lead bricks are stacked near the gantry robot.
- The gantry robot picks a lead brick one at a time from the pallet and places it on the conveyor.
- The lead brick then moves along the conveyor to BEGe detector chamber, which detects the brick for radioactivity.
- If the brick is radioactive, a sensor placed on the conveyor activates the product pusher, which pushes the brick into a container.
- If the brick is not radioactive, the sensor does not activate the product pusher, and therefore the lead brick moves to the end of the conveyor and falls into another container.
- Time for one lead brick to run through this system is 1.5 minutes.

The above-mentioned operation can be better understood with the help of Fig. 1.

Schematic for Volumetric Lead Assay System

Fig. 1 Volumetric lead assay system, showing a robotic system, conveyor, characterization system, and lead collection containers.

10.0 SYSTEM SPECIFICATIONS

A number of vendors and their products for various system components (conveyor, robot and gamma spectrometer) were considered. Those considered to meet the requirements of low cost and good performance were selected and are described in this report.

CONVEYOR SYSTEM FROM SHUTTLEWORTH, INC.

The lead bricks are loaded onto the conveyor system individually from the gantry robot at a rate of one brick every 30 seconds. The system is designed to convey lead bricks to the blade stop on Unit #1, where the customer's supplied equipment will detect the block's radioactivity.

If the brick is radioactive, a sensor placed on the conveyor activates the product pusher, which pushes the brick into a container. If the brick is not detected for radioactivity, the sensor won't activate the product pusher, and therefore the lead brick moves to the end of the conveyor and falls into another container.

Fig. 2 Lead characterization system with details.

Mechanical specifications of the conveyor

Conveyor Type:	Slip-Torque, Aluminum Side Rail, Chain Driven, Spec 1041
Roller Diameter:	Standard Pitch, 21 mm
Rollershaft Center:	22.7 mm
Roller Type:	Solid Black Low Friction
Guiderail:	Low Profile Plastic, Spec. 3081
Support Style:	Extruded Aluminum

PNEUMATIC SPECIFICATIONS OF THE CONVEYOR

All pneumatic devices are provided with a 4-way, 5-port solenoid operated valve, installed and piped to the pneumatic device using polyethylene tubing. A filter/regulator unit is provided. If more than one pneumatic device is supplied, the devices will be piped to a common point using polyethylene tubing. All exhaust ports are vented to atmosphere. Pneumatic device and header layout diagrams will be provided, if applicable.

ELECTRICAL SPECIFICATIONS OF THE CONVEYOR

All electrical devices will be installed and terminated to the control panel. Control logic will be included. A non-dimensioned component layout, wiring schematic, software documentation, and panel layout will be provided with the system. The system will be wired according to Shuttleworth, Inc. standard wiring practices and the National Electrical Code.

GANTRY ROBOT FROM PARKER HANNIFIN CORPORATION, DAEDAL DIVISION

The gantry robot, which is placed in front of the conveyor, picks lead bricks from the pallet and places them on the conveyor one at a time. Time to pick one lead brick and place it on the conveyor is approximately 30 seconds. The Robotic System consists of

- HLE Linear Drive Module
- Vertical Drive Module
- Cable System Management
- Home Position Sensors
- Travel Limit Sensors
- Gear Reducers
- Structural Frame
- Servo Motor System
- Robotic Arms for lifting the lead bricks.

GERMANIUM DETECTORS FROM CANBERRA, INC.

The following are the accessories with the broad energy germanium detectors:

- ISOCS Characterization for new CI Detectors
- Flanged Big Mac
- Remote detector chamber
- MAC fill device
- Dewar (30 liter)
- Detector frame and Assembly

- Inspector 2000 DSP portable MCA and accessories
- Genie-2000 Software and accessories
- Genie-2000 Interactive peak fit
- IBM Computer and accessories
- Liquid Nitrogen.

11.0 COST ANALYSIS

This section provides a cost analysis that compares the costs of using a new approach (radioassaying, recycling/ disposing lead bricks) with the baseline method of disposing all bricks as radwaste. The cost analysis is based on managing 1,000,000 lbs of lead bricks under three different scenarios. Three options (option A, option B and option C) are considered. Option A is giving the contract for characterization and disposal of lead to any contractor. In option B, FIU-HCET is the prime contractor. In option C, all bricks are disposed of as radioactive waste. For each option two cases were considered –(case 1 and case 2). In case 1, 50% of the lead bricks are assumed contaminated. In case 2, 20% of the bricks are contaminated. Option A, which is giving the contract characterization and disposal of lead to any contractor, nets a saving of \$1,650,550 if 50% of the bricks are contaminated and a saving of \$2,940,550 if 20% of the bricks are contaminated. Option B, where FIU-HCET is the prime contractor, nets a saving of \$1,872,200 if 50% of the bricks are contaminated and a saving of \$3,162,200 if 20% of the bricks are contaminated. Option C, where all bricks are disposed off as radwaste, does not have a saving. Considering that the system is run 6 hrs per day and the weight of the lead brick is 60 lbs. (12-inch x 4-inch x 3 -inch brick), then the number of days to assay all bricks is 70 days. This is calculated by taking into consideration the time for one lead brick to run through the system is 1.5 minutes.

The schematic cost structure and profit margin calculation for this system can be found in Appendix A. The operating costs and the costs of various equipments can be found in Appendix B.

COST ANALYSIS CONCLUSION

Option A:

If 50% of bricks are contaminated= net savings of	\$1,650,550
If 20% of bricks are contaminated= net savings of	\$2,940,550

Option B:

If 50% of bricks are contaminated= net savings of	\$1,872,200
If 20% of bricks are contaminated= net savings of	\$3,162,200

Option C:

Cost of disposing all lead bricks	\$4,000,000
Option C does not save anything.	

APPENDIX A

SCHEMATIC COST STRUCTURE AND PROFIT MARGIN FOR VOLUMETRIC LEAD ASSAY SYSTEM

OPTION A: GIVING THE CONTRACT TO ANY CONTRACTOR

Bricks to be detected for contamination:	1,000,000 lbs
Weight of one brick: 60 lbs	
Therefore, total number of bricks =	$1,000,000/60 = 16,700$ bricks
Number of hours the system is run per day: 6 hours =	360 minutes
Worst case time for one lead brick to run through the system:	1.5 minutes
Therefore, number of bricks assayed per day =	$360/1.5 = 240$ bricks/day
Number of days to assay all bricks: $16,700/240 =$	70 days

Costs

Cost of the four detectors	\$221,650
Cost of the conveyor system	\$ 45,000
Cost of the robotic system	\$ 45,000
Miscellaneous and maintenance expenses	\$ 10,000
Labor cost for characterization (APPENDIX B)	\$ 44,800
Labor cost for system assembly and testing (APPENDIX B)	\$ 32,000
Cost of filling liquid nitrogen	\$ 1,000

Total Equipment and Operating Costs **\$399,450**

CASE 1. 50% OF BRICKS ARE CONTAMINATED

Option 1: Characterize, dispose contaminated bricks and recycle uncontaminated bricks.

Cost of disposing lead bricks	\$4.00/pound
Cost of selling uncontaminated lead bricks	\$0.30/pound
Cost of shipping bricks = \$0.10/pound	

Cost of disposing 500,000 lbs contaminated bricks = $500,000 \times \$4 = \$2,000,000$

Cost of shipping 1,000,000 lbs contaminated bricks = $1,000,000 \times \$0.10 = \$100,000$

Recovery of costs by selling 500,000 lbs uncontaminated bricks = $500,000 \times \$0.30 = \$150,000$

Total cost of disposing= $\$2,000,000 + \$100,000 - \$150,000 = \$1,950,000$

Total equipment and operating costs = \$399,450

Total costs= \$1,950,000 + \$399,450 =\$2,349,450

Option 2: All bricks are disposed as radioactive waste

Cost of disposing lead bricks 1,000,000 lbs x \$4.00 = \$4,000,000

Therefore, Net Saving by using Option 1 as against Option 2 = \$4,000,000 - \$2,349,450 = \$1,650,550

CASE 2. 20% OF BRICKS ARE CONTAMINATED
Option 1: Characterize, dispose contaminated bricks and recycle uncontaminated bricks.

Cost of disposing lead bricks =	\$4.00/pound
Cost of selling uncontaminated lead bricks =	\$0.30/pound
Cost of shipping bricks =	\$0.10/pound

Cost of disposing 200,000 lbs contaminated bricks = 200,000 x \$4 = \$800,000

Cost of shipping 1,000,000 lbs of contaminated bricks = 1,000,000 x \$0.10 = \$100,000

Recovery of costs by selling 800,000 lbs uncontaminated bricks = 800,000 x \$0.30 = \$240,000

Total cost of disposing = \$800,000 + \$100,000 - \$240,000 = \$660,000

Total equipment and operating costs = \$399,450

Total costs = \$660,000 + \$399,450 = \$1,059,450

Option 2: All bricks are disposed as radioactive waste

Cost of disposing lead bricks 1,000,000 lbs x \$4.00 = \$4,000,000

Therefore, net saving by using Option 1 as against Option 2 = \$4,000,000 - \$1,059,450
= \$2,940,550

Schematic Cost Structure and Profit Margin for Volumetric Lead Assay System

OPTION B: FIU-HCET IS PRIME CONTRACTOR

FIU-HCET has four detector systems that amount to a savings of \$221,650. So, the cost of buying new systems is reduced.

Bricks to be detected for contamination: 1,000,000 lbs

Weight of one brick: 60 lbs

Therefore 1,000,000/60 = 16,700 bricks

Option 2: All bricks are disposed as radioactive waste

Cost of disposing lead bricks 1,000,000 lbs x \$4.00 = \$4,000,000

Therefore, Net Saving by using Option 1 as against Option 2 = \$4,000,000 - \$2,127,800
= \$1,872,200

CASE 2. 20% OF BRICKS ARE CONTAMINATED

Option 1: Characterize, dispose contaminated bricks and recycle uncontaminated bricks.

Cost of disposing lead bricks = \$4.00/pound

Cost of selling uncontaminated lead bricks = \$0.30/pound

Cost of shipping bricks = \$0.10/pound

Cost of disposing 200,000 lbs contaminated bricks = 200,000 x \$4 = \$800,000

Cost of shipping 1,000,000 lbs contaminated bricks = 1,000,000 x \$0.10 = \$100,000

Recovery of costs by selling 800,000 lbs uncontaminated bricks = 800,000 x \$0.30 = \$240,000

Total cost of disposing \$800,000 + \$100,000 - \$240,000 = \$660,000

Total equipment and operating costs = \$177,800

Total costs = \$660,000 + \$177,800 = \$837,800

Option 2: All bricks are disposed as radioactive waste

Cost of disposing lead bricks 1,000,000 lbs x \$4.00 = \$4,000,000

Therefore, Net Saving by using Option 1 as against Option 2 = \$4,000,000 - \$837,800
= \$3,162,200

OPTION C: ALL BRICKS ARE DISPOSED AS RADWASTE

Bricks to be disposed: 1,000,000 lbs

Cost of disposing lead bricks = \$4.00/pound

Cost of disposing lead bricks 1,000,000 lbs x \$4.00 = \$4,000,000

COST ANALYSIS SUMMARY

Option A:

If 50% of bricks are contaminated= net savings of **\$1,650,550**

If 20% of bricks are contaminated= net savings of **\$2,940,550**

Option B:

If 50% of bricks are contaminated= net savings of **\$1,872,200**

If 20% of bricks are contaminated= net savings of **\$3,162,200**

Option C:

Cost of disposing all lead bricks =**\$4,000,000**

Option C does not save anything.

APPENDIX B

FOUR DETECTORS AND ACCESSORIES QUOTED BY CANBERRA

Item	Description	Quantity	Unit Price	Extended Total
1	Broad Energy Germanium Detectors	4	\$33,000	\$132,000
2	ISOCS Characterization for new CI Detectors	1	\$7,500	\$7,500
3	Flanged Big Mac	4	\$1,250	\$5,000
4	Remote detector chamber (4" neck)	4	\$1,000	\$4,000
5	MAC fill device	1	\$500	\$500
6	Dewar (30 liter)	4	\$700	\$2,800
7	5cm Side Shield for detectors	4	\$4,000	\$16,000
8	5cm Back Shield for detectors	4	\$1,600	\$6,400
9	Detector frame and Assembly	4	\$7,200	\$28,800
10	Inspector 2000 DSP portable MCA and accessories	1	\$9,000	\$9,000
11	Genie-2000 Software and accessories	1	\$3,150	\$3,150
12	Genie-2000 Interactive peak fit for review results of automatic peak search, add/delete peaks, modify fit regions and graphic display of fits & residuals	1	\$500	\$500
13	IBM Computer and accessories	1	\$6,000	\$6,000
Total				\$221,650

CONVEYOR SYSTEM AND ITS ACCESSORIES QUOTED BY SHUTTLEWORTH

Mechanical Specifications

Conveyor type:	Slip-Torque, Aluminum Side Rail, Chain Driven, Spec 1041
Roller diameter:	Standard Pitch, 21 mm
Rollershaft center:	22.7 mm
Roller type:	Solid Black Low Friction
Guiderail:	Low Profile Plastic, Spec. 3081
Support style:	Extruded Aluminum

PNEUMATIC SPECIFICATIONS

PNEUMATIC SUPPLY ONLY:

All pneumatic devices are provided with a 4-way, 5-port solenoid operated valve, installed and piped to the pneumatic device using polyethylene tubing. A filter/regulator unit is provided. If more than one pneumatic device is supplied, the devices will be piped to a common point using polyethylene tubing. All exhaust ports are vented to atmosphere. Pneumatic device and header layout diagrams will be provided, if applicable.

Total Price of the Conveyor System and its Accessories as provided by Shuttleworth = \$45,000

Robotic System and its Accessories as Quoted by Parker Hannifin Corporation

The Robotic System consists of

- HLE Linear Drive Module
- Vertical Drive Module
- Cable System Management
- Home Position Sensors
- Travel Limit Sensors
- Gear Reducers
- Structural Frame
- Servo Motor System
- Robotic Arms for lifting the lead bricks.

Total Cost of the Robotic System as provided by Parker Hannifin Corporation = \$45,000

Labor Cost for Characterization

Taking into consideration that 2 persons would be working together for 70 days until the whole operation is completed

Number of working hours per person per day = 8 hrs x 2 persons = 16 hrs for two persons

Pay per hour per person = \$40/hr = \$40 x 16 hrs for two persons = \$640/day = \$44,800 for the 70 days period for 2 persons

Therefore, Total Labor Cost for Two persons for the 70-day period = \$44,800

Labor Cost for System Assembly and Testing

Taking into consideration that 4 persons would be working together for 25 days for system assembling and testing

Number of working hours per person per day = 8 hrs x 4 persons = 32 hrs for four persons per day

Pay per hour per person = \$40/hr = \$40 x 32 hrs for four persons = \$1,280/day = \$32,000 for the 25-day period for 4 persons

Therefore, Total Labor Cost for System Assembly and Testing = \$32,000

Maintenance and Miscellaneous Expenses

Taking into consideration that 16 hrs of maintenance would be needed for the whole operation period of 70 days

Pay per hour taking into consideration all benefits = \$40/hr = 16 hrs x \$40 = \$640

Other expenses such as electricity, air-conditioning, additional equipment, spare parts, cost of buying new equipment if old equipment doesn't function, service charges, etc. = \$9360

Therefore, Total Maintenance and Miscellaneous Expenses = \$9360 + \$640 = \$10,000

Cost of Filling Liquid Nitrogen and Expenses Involved in Filling

Cost of Filling Liquid Nitrogen per week = \$50/week

Number of weeks the system will run = 14 weeks

Therefore, Total Cost = \$50 x 14 = \$700

Operating and other expenses such as service charge, spare parts = \$300

Therefore, total cost of filling liquid nitrogen = \$700 + \$300 = \$1000

APPENDIX C

CONTACT INFORMATION

Conveyor System

Shuttleworth Inc.

10 Commercial Road
Huntington, IN 46750-9044
Tel: 219 356 9044
Fax 219 359 7810
URL: www.shuttleworth.com

Robotic System

Parker Hannifin Corporation

Daedal Division
1140 Sandy Hill Road
Irwin, PA 15642
Tel: 1 800 245 6903
URL: www.daedalpositioning.com

Detectors

Canberra Industries

800 Research Parkway
Meriden, CN 06450
Tel: 203 238 2351
Toll Free: 1 800 243 4422
FAX: 203 235 1347
URL: www.canberra.com

Table 1
Inventory of Lead at INEEL

Contaminated and uncontaminated lead (excess + in use) = 7,217,844 lbs.

Contaminated (excess + in use) = 2,943,071 lbs.

Amount of contaminated excess lead = 1,785,295 lbs.

Type and quantity of contaminated excess lead at INEEL

Type of Lead	Quantity of Contaminated Excess Lead (lb)
Shot	94,298
Bricks	100,531
Chunks/Chips	15,339
Sheet	36,680
Wool	208
Bulk	765,829
Cask	292,139
Other	480,271

Table 2
Summary of contamination values for unrestrictive free release

Nuclide	REMOVABLE (dpm/100 cm²)	TOTAL (FIXED+REMOVABLE) (dpm/100 cm²)
U-natural, U-235, U-228 and associated decay products	1,000 alpha	5,000 alpha
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-129	20	500
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-125, I-126, I-131, I-133	200	1,000
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above. Includes mixed fission products containing Sr-90	1,000 beta-gamma	5,000 beta-gamma
Tritium organic compounds, surfaces contaminated by HT, HTO and metal tritide	10,000	*10,000

Notes:

- The values in this table apply to radioactive contamination deposited on, but not incorporated into the interior of the contaminated item. Where contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for the alpha and beta-gamma emitting nuclides apply independently.
- a. The amount of removable radioactive material per 100 cm² of surface area should be determined by swiping the area with dry filter or soft absorbent paper while applying moderate

pressure and then assessing the amount of radioactive material on the swipe with an appropriate instrument of known efficiency.

- b. For objects with a surface area less than 100cm², the entire surface should be swiped, and the activity per unit area should be based on the actual surface area. Except for transuranics, Ra-228, Ac-227, Th-228, Th-230, Pa-231, and alpha emitters, it is not necessary to use swiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual contamination levels are below the values for removable contamination.
3. The levels may be averaged over 1 square meter provided the maximum activity in any area of 100 cm² is less than three times the values in the table.

Table 3
List of instruments used by INEEL technicians

Type of Measurement	Instrument	Efficiency
Beta/Gamma Contamination	Ludlum Model 2A with attached HP260 or HP210 (shielded) GM detector	25-30% for Cesium, 4-Pi, Near Contact 10-15% for Cobalt, 4-Pi, Near Contact 30+% Strontium, 4-Pi, Near Contact
Alpha Contamination	NE Electra with attached 100 sq. cm scintillation detector	15% for Cesium-137, 4-Pi, Near Contact Dual Mode: 16-18% for Plutonium-239, 4-Pi, Near Contact Alpha Only Mode with AP5 100cm ² scintillation detector attached: 22-25% for plutonium-239, 4-Pi, Near Contact Thorium 230 (used for U-328) 1-2% less than Plutonium-239
Swipes for loose alpha and beta/gamma contamination	Tennelec LB-5100 or Protean MPC-9400	N/A

Fig. 3 Gamma spectrum obtained by placing a Co-60 standard source at a distance from the BEGe detector, showing Co-60 peaks, in addition to natural background radionuclides.

Fig. 4 Gamma spectrum obtained by placing a 12"x 4"x2" thick lead brick at a distance from the BEGe detector, showing natural background radionuclides.

Fig. 5 Gamma spectrum obtained by placing 8"x8"x0.25" thick lead wool at a distance from the BEGe detector, showing natural background radionuclides.