INNOVATIVE TECHNOLOGY

Summary Report

DOE/EM-0585

Copper Cable Recycling Technology

Deactivation and Decommissioning Focus Area

Prepared for

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Office of Science and Technology

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INNOVATIVE TECHNOLOGY
Summary Report

Copper Cable Recycling Technology

OST/TMS ID 2958

Deactivation and Decommissioning Focus Area

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Large-Scale Demonstration and Deployment Project
Idaho Falls, Idaho

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Introduction

The United States Department of Energy (DOE) continually seeks safer and more cost-effective technologies for use in deactivation and decommissioning (D&D) of nuclear facilities. The Deactivation and Decommissioning Focus Area (DDFA) of the DOE's Office of Science and Technology (OST) sponsors large-scale demonstration and deployment projects (LSDDPs). At these LSDDPs, developers and vendors of improved or innovative technologies showcase products that are potentially beneficial to the DOE's projects and to others in the D&D community. Benefits sought include decreased health and safety risks to personnel and the environment, increased productivity, and decreased costs of operation.

The Idaho National Engineering and Environmental Laboratory (INEEL) generated a list of statements defining specific needs and problems where improved technology could be incorporated into ongoing D&D tasks. One such need is to reduce the volume of waste copper wire and cable generated by D&D.

Deactivation and decommissioning activities of nuclear facilities generates hundreds of tons of contaminated copper cable, which are sent to radioactive waste disposal sites. The Copper Cable Recycling Technology separates the clean copper from contaminated insulation and dust materials in these cables. The recovered copper can then be reclaimed and, more importantly, landfill disposal volumes can be reduced. The existing baseline technology for disposing radioactively contaminated cables is to package the cables in wooden storage boxes and dispose of the cables in radioactive waste disposal sites. The Copper Cable Recycling Technology is applicable to facility decommissioning projects at many Department of Energy (DOE) nuclear facilities and commercial nuclear power plants undergoing decommissioning activities.

The INEEL Copper Cable Recycling Technology Demonstration investigated the effectiveness and efficiency to recycle 13.5 tons of copper cable. To determine the effectiveness of separating out radioactive contamination, the copper cable was coated with a surrogate contaminant. The demonstration took place at the Bonneville County Technology Center in Idaho Falls, Idaho (see Figure 1).

Figure 1. RADOS Copper Cable Recycling Technology provided by NUKEM and installed for the demonstration tests at the INEEL.

Nukem Nuclear Technologies Corporation (NUKEM) has exclusive access to this Copper Cable Recycling Technology developed by its international affiliate, RADOS of Stuttgart, Germany. RADOS and the Gundremmingen Nuclear Power Plant developed the technology in Stuttgart. The RADOS Copper Cable Recycling Technology has been used in Europe to successfully recover many tons of contaminated copper for free release and reuse. Nukem Nuclear Technologies is the United States licensee of the technology and is based in Columbia, South Carolina. RADOS, of Stuttgart, Germany, is a specialty subcontractor to NUKEM and provided the equipment for the demonstration.

The Technology

Baseline

The baseline technology at the INEEL is to remove contaminated cable from a facility being decommissioned, size and package cables in waste containers, and then transport it to the Radioactive Waste Management Complex (RWMC) for disposal as low-level waste. This practice could be reduced or eliminated if copper recycling were to become the baseline for disposition of contaminated cable. The baseline process for noncontaminated cable includes removing the cable from decommissioned facilities, loading the cables into a dump truck, and transporting it to the INEEL Central Facilities Area (CFA) Excess Yard where it is sold as scrap. Because our waste generators at the INEEL do not pay disposal fees at the RWMC, and we have relatively low volumes of contaminated copper cable in our surplus facilities, our potential for recycle and cost savings is moderate. Large savings could be realized, however, at other DOE sites where larger amounts of cable are available and where waste disposal fees are charged.

Innovative Technology

The Copper Cable Recycling Technology alternative to disposal of radioactively contaminated copper wire and cable should be considered as a means of recovering valuable resources, reducing costs, and reducing the generation and storage of waste. Dust and insulation granules that result from cable recycling can be used as void filler in existing waste boxes, thus eliminating all impact from cable materials on waste disposal sites. For example, boxes containing large-diameter piping and valves or radioactively contaminated concrete typically have large void volumes that can be filled with the insulation material. Both insulation and dust could be used as void filler, assuming contamination content and radiation levels are compatible with existing waste acceptance criteria. Based on cost estimates obtained from local copper recycling vendors, the resale value of copper processed by the NUKEM Copper Cable Recycling Technology is much higher than for nonprocessed copper cable.

Key Results

Key results of the demonstration are summarized below. Section 3 of this report describes these results in detail.

- Overall volume of waste was reduced by 80%
- The Copper Cable Recycling Technology can be easily transported and set up at customer locations.
- The process can provide clean copper for recycle and reuse.
- Cost reductions and accelerated schedules are possible with large volumes of cable.

The benefits of the Nukem Copper Cable Recycling Technology include ease of transport and set up of the equipment in remote locations, as demonstrated by transporting the equipment from Germany to the INEEL using two twenty-foot sea-land containers. Following its shipment from Germany, the technology/equipment was assembled and demonstrated at the Bonneville County Technology Center.

Additional benefits from the Copper Cable Recycling Technology include the following:

- Reduction in waste volume
- Cost reduction resulting from lower storage, treatment, and disposal expenses
- Recovery of a valuable resource
- Easier and safer handling and processing with copper granules than with long lengths of cable
- Capability of processing many types and sizes of cable

- Proven technology
- Transporability.

Contacts and Other Sources of Information

Technical

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Cost Analysis

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Web Site

The INEEL LSDDP Internet web site address is http://id.inel.gov/lsddp

Licensing

Nukem Nuclear Technologies, based in Columbia, South Carolina, is the exclusive United States Licensee of this Copper Cable Recycling Technology. RADOS, of Stuttgart, Germany, is a specialty subcontractor to NUKEM and provided the Copper Cable Recycling Technology for the demonstration.

Permitting

No permitting activities were required to support this demonstration other than an INEEL required Job Safety Analysis (JSA). However, treatment of contaminated cable at an existing nuclear facility would require confirmation that operation of the process can be performed within the existing safety basis of the facility

Other

All published Innovative Technology Summary Reports are available on the OST Web site at www.em.doe.gov/ost under “Publications.” The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST reference number for the NUKEM Copper Cable Recycling Technology is 2958.

SECTION 2
TECHNOLOGY DEMONSTRATION

Overall Process

Thirteen and one-half tons of copper cable removed during demolition of INEEL facilities were processed at the demonstration site. Figure 2 shows some of the cable used in the demonstration. (In this report, the term *copper cable* refers to the complete makeup of the cable, including the individual strands of copper wire and associated insulation material; this should not be confused with the term *copper wire,* which refers to the individual copper conductors that are a component of copper cable.) This total amount of cable was divided into two parts to allow demonstrations using noncontaminated cable and demonstrations using surrogate-contaminated cable. Sizing and preparation of the cable was completed prior to receipt of the Nukem equipment. The copper recycling equipment was capable of processing up to a maximum of six tons of insulated copper cable per day. It can process cable ranging from small individual strands of wire up to large (two inches in diameter) power cables, in random lengths or coils. Before feeding the cable into the processor, however, it must be sized to a maximum length of about 30 inches.

All activities and operations taking place during the demonstration of the surrogate-contaminated cable were conducted as if the input were actually radiologically contaminated. This included generating appropriate documents, using personal protective equipment (PPE), monitoring, and maintaining environmental and air controls. All personnel associated with operation of the equipment were assumed to be radiation workers trained to a level commensurate with the radiation levels typically experienced in handling radioactively contaminated cables.

Prejob and postjob debriefings were conducted to collect observations, concerns, and opinions of operators, sampling personnel, industrial hygiene and safety personnel, and other support personnel.

Objective

The objective of the field demonstration was to assess the effectiveness of the NUKEM Copper Cable Recycling Technology in separating uncontaminated copper from its contaminated insulation and providing separate output streams for uncontaminated copper, contaminated insulation, and contaminated dust products. The technology was evaluated for efficiency, reliability, and potential for cost and schedule savings compared to the current baseline at the INEEL. The demonstration provided sufficient data to develop a cost benefit analysis for fair and independent comparison of the potential benefits of the NUKEM technology over the baseline technology. These benefits can be evaluated by the end-user based on the changing value of copper and the changing costs of alternative disposal methods, and in terms of local conditions.

Figure 2. Excess copper cable used in the demonstration.

Technology and Operation

The NUKEM Copper Cable Recycling Technology demonstration treated input ranging from small telephone wire to 2.5-inch cable. The process consists of shredding, grinding, separating, and filtering. After sizing to appropriate lengths, the wire/cable was placed on the conveyor piece by piece (cables can be fed as rings or as short pieces) to feed into the shredder (see Figure 3). The larger cables were cut into approximately 30-inch lengths to facilitate ease of handling and provide a constant feed rate into the shredder. The speed at which the cables were fed was determined by the amperage draw of the shredder/grinder motors. Operators observed an amperage meter located on the side of the conveyor during the process to regulate the feed rate. If the current exceeded the system limit, it was necessary to reduce or stop the feed until the amperage lowered back within the operating range.

Figure 3. Placing cables on the conveyor to the shredder.

The grinder is a horizontal shaft with grinding blades placed on the circumference of the shaft, which granulate the copper wire, filler/strengthening fibers, and the insulation material covering the copper wire. During the grinding, most of the contamination is removed from the insulation by strong mechanical sheer tension in the grinder.

Contaminated dust generated by the grinding process is then filtered through a three-stage process to prevent release of airborne contamination. A special NUKEM design prevents rebinding of contaminated dust to the insulation material. The dust filters and the off-gas filter are encapsulated and monitored for particulate buildup and cleaned or replaced as required. The dust filters did not require replacement or cleaning during the processing of 13.5 tons of cable. Larger amounts, however, would require changing the filters. The frequency depends on the amount and types of cables processed.

Dust materials result from the inner fillers and fibers used in multiconductor cables. The relatively lighter insulation and dust granules float on a layer of air above a sieve, while the heavier copper fraction is separated by controlling the sieve.

Output from the 13.5 tons (U.S.) of insulated wire and copper cable used in the demonstration were four waste boxes of dust, five waste boxes of insulation and ten 55-gallon drums of clean copper. Figure 4 shows insulation granules coming from the process. Figure 5 shows collected dust material. Figure 6 shows the copper granule product. Figure 7 shows sections of cable with the copper and insulation material products.

Simulated chemical contaminants and a phosphorescent powder were used to contaminate a portion of the cable tested. At the conclusion of the demonstration, a black light was used to examine the HEPA filters and the area around the filters to determine the effectiveness of the system in separating the phosphorescent powder from the copper. No phosphorescent powder was found in the HEPA filters or in the filter housings. Some powder was found in the prefilters, on the conveyor, and in areas where the cable came in contact during the feed process into the equipment.

Figure 4. Insulation granules

Figure 5. Dust particulate.

Figure 6. Copper granules.

Figure 7. Before and after processing.

All personnel involved in setup and operation of the equipment reviewed the operational procedure for the technology. NUKEM personnel held a review with the INEEL and Bonneville County Technology Center (BCTC) personnel and covered each step of the procedure as required during the prejob briefings. These operational steps were followed during setup, operation, and disassembly of the equipment. Personnel followed all safety guidelines established in the INEEL Job Safety Analysis.

Data were collected during training, setup, operations, maintenance, decontamination, and demobilization activities.

Site

The NUKEM technology was tested in Idaho Falls, Idaho at the Bonneville County Technology Center, where the equipment was assembled on the East Side of the BCTC on a 50 x 50-ft concrete pad approximately 50 ft from the building. An enclosed high bay area was used for staging the cable, drums, and all associated equipment. This area remained accessible during the recycling demonstration to allow moving cable and processed materials into and out of the facility.

Table 1 summarizes the operational parameters and conditions of the INEEL Copper Cable Recycling Technology Demonstration.

Table 1. Operational parameters and conditions of the INEEL Copper Cable Recycling Demonstration

Working Conditions	
Work area location	Bonneville County Technology Center, Idaho Falls, ID
Work area access	Public access with restrictions to equipment operational areas
Work area description	Work area restricted and controlled due to noise and safety requirements, requiring training, safety glasses, and ear protection for entry. Under certain conditions, respirators and anti-C clothing were required.
Work area hazards	Noise hazards Surrogate contamination (cesium and cobalt nitrate) Tripping hazards Lifting and cutting cable Forklift operation
Equipment configuration	Two portable Sea-Land Containers stacked one on top of the other
Labor, Support Personnel, Special Skills, Training	
Work crew	Minimum work crew: • 1 Forklift operator • 2 Nukem equipment operators • 2 Laborers
Additional support personnel	• 1 Data Collector • 1 Health and Safety Observer (periodic) • 1 Test Engineer
Special skills/training	Review and briefing of operation manual. Skill was required to maintain feed rate into conveyor. Operator training, skill, and experience are required for setup and operation of NUKEM equipment.
Waste Management	
Primary waste generated	No primary wastes were generated other than the insulation and dust material.
Secondary waste generated	Disposal of miscellaneous waste was through the Bonneville County landfill. Personal Protective Clothing
Waste containment and disposal	The copper was returned to the INEEL excess area at CFA. The insulation and dust material was taken to the INEEL landfill.
Equipment Specifications and Operational Parameters	
Technology design purpose	Equipment is designed to grind the wire and separate it into three output streams; copper, insulation and dust material.
Portability	Equipment can be packaged and transported to recycling site.

Materials Used	
Work area preparation	No facility preparation was necessary for the demonstration. HEPA filters were obtained and set up. Cobalt, cesium nitrate, and phosphorescent powder were used for surrogate contamination on the cable. 55-gal drums were used for the copper containers. 2 x 4 x 8-ft wooded boxes were used to contain the insulation and dust.
Personal protective equipment	Hearing protection Cotton glove liners (when applicable) Tyvek coveralls (when applicable)* Respirators (when applicable)* Pair of rubber gloves (when applicable)* Shoe covers (when applicable)* Steel toe shoes, safety glasses, leather gloves
Utilities/Energy Requirements	
Power, fuel, etc.	Diesel fuel for 150-kW generator Gasoline for forklift

* Used when processing cable containing simulated contaminants.

SECTION 3
PERFORMANCE

Results

The NUKEM Copper Cable Recycling Technology operated very well over the entire test period of approximately five days. Twenty-one 2 x 4 x 8-ft waste boxes containing 27,100 lb of copper cable were processed during the demonstration. The demonstration generated nine and one half 55-gallon drums of clean copper (17,250 lb), five 2 x 4 x 8-ft waste boxes of granular insulation, and four 2 x 4 x 8-ft waste boxes of dust. A photograph of the clean copper product of this process is shown in Figure 8.

Figure 8. Close-up of the clean copper granules.

During the demonstration, work was performed in 10-hour shifts. Assuming 8 hours of productive time, we had a maximum throughput of 1,500 lb/hr. An average throughput during the entire demonstration was 847 lb/hr, assuming 32 hr of operation time. This included the time required for setting up the equipment at the beginning of the day and shutting down and cleanup at the end of the day. This is the time used in the cost analysis (Section 5) for actual run-time and was used for calculating the average of 847 lb/hr for the entire demonstration. Each time the equipment is shut down and restarted, approximately 2 hr is required to balance the air movers and to allow the copper to clean out of the system. This may vary, but it needs to be considered each time the equipment is started and stopped.

The individual conductors in the cable included stranded and solid wire. The copper conductors ranged in size from 0.0348 to 0.3938 inches in diameter. Cables with a diameter of 1.2 inches or greater must be no longer than 30 inches in order not to overburden the grinder. An overall insulated cable may contain multiple insulated inner conductors or wires.

Simulation of Radioactive Contamination on the Cables

Contamination Simulant

Simulation of radioactively contaminated cable allowed the demonstration to be conducted in a nonradiation area and to eliminate the risk of contaminating the equipment to the extent it could not be returned to NUKEM.

The surrogate used to simulate *loose* contamination was a phosphorescent powder, which was dusted onto the surface of the cable prior to processing. During processing, samples of copper, insulation, and dust were collected and examined with a black light. The results show no phosphorescent powder in the processed copper wire or the insulation granules. As expected, a small amount of phosphorescent powder was detected in the dust samples. After processing, the entire system was examined using a black light. Phosphorescent powder was found on the conveyor, on the entrance to the pre-shedder, the first stage of dust absorbers, and in the dust filter bags, all of which was expected. The results obtained using the phosphorescent powder to simulate loose contamination indicate that the Copper Cable Recycling Technology is capable of separating the copper from the simulated contamination applied to the cables' insulation or outer covering.

Two other nonradioactive chemicals were used to simulate the *fixed* radioactive contamination on the copper cable. Cesium nitrate was chosen to simulate the radioactive cesium-134 and -137 isotopes that are frequently seen at the INEEL.

The fixed contamination simulant was applied to the cable using a commercially available hand-pressurized sprayer. The spray was restricted to the center of the cable length, leaving six inches of each end without simulant. The simulant was allowed to air dry on the cable and then was placed back in 2 X 4 X 8-ft wooden boxes for processing. The simulant was fixed to the cable by applying latex paint over the already-applied simulant on the cable. A similar hand pressurized sprayer was used to apply the paint. Of the 27,100 lb of cable processed, approximately 15,000 lb were treated with a surrogate contamination.

Each cable was separated by wire size [about 0.5 mm (small), 1 mm (medium), and 2 mm (large)] into wooden boxes (2 X 4 X 8 ft). The cable varied from single strands of wire to large 2-½-inch cables with 5 conductors of multiple small wires. Many of the cables had a very thin copper shield under the outer insulation with a center of multiple large strands of copper wire.

Sampling

We collected samples of insulation and copper granules directly into 125-ml and 30-ml plastic bottles from the processed streams of insulation (see Figure 4) and copper (see Figure 6) as they flowed into the 55-gallon drums. The dust was sampled by removing it from the dust collection bags and placing it into 125-ml bottles. All bottles were labeled as to the item sampled and date and time taken. Samples were recorded in log book LN-589. All samples were then transported to the Idaho Nuclear Technology and Engineering Center (INTEC) for analysis.

Analysis

We performed chemical analysis to quantify the concentrations of surrogate contaminant on the cable before it was processed and on the copper granules after processing. Since the surrogate contaminant is nonradioactive, the analysis must be a chemical process rather than radiation level detection. It was necessary that some amount of surrogate contaminant make it through the system in order to evaluate the effectiveness of the process. For this reason, we applied a much higher concentration of surrogate contamination than would normally be present when detecting low-level radiation. This insured that a measurable quantity of surrogate contaminant remained on the copper granules after processing.

The analysis was performed on the samples after leaching 50 ml of sample with 70 ml of high-purity water. The leachate was filtered, labeled, and sent to an analytical chemistry laboratory for analysis. The cesium was analyzed by atomic absorption.

Decontamination Factor

We determined the decontamination factor (DF) by calculating the relative reduction in the concentration of surrogate contaminant. The cable was analyzed to determine the initial concentration (IC) of surrogate contaminant on the cable before processing. Samples of the processed copper were then analyzed to determine the final concentration (FC) of surrogate contaminant in the copper granules. The initial concentration was then divided by the final concentration to give the decontamination factor (DF=IC/FC). Initial concentrations and the final concentrations are given in micrograms of surrogate contaminant per gram of copper (µg/g).

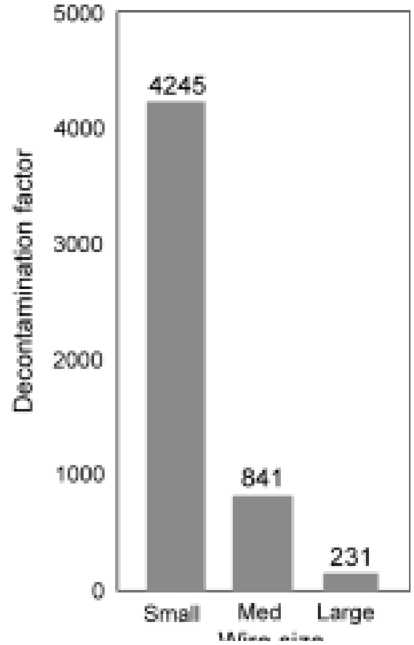

Figure 9. Decontamination factor.

Conclusion

Using the simulant allowed us to calculate decontamination factors for the copper cable recycling process. The data show that the Copper Cable Recycling Technology works well. Decontamination factors ranging from 143 to 6744 were achieved. These depend greatly on the type of cable used. The larger the copper wires in the cable, the longer it took to process. The decontamination factors followed this trend. The smallest copper wire in the cable gave the highest decontamination factor, apparently because it is mechanically easier to process the smaller wire (cut, size, separate, and move). The data represent cesium only. However, we assume that other radionuclides would have similar decontamination factors if they behave chemically and mechanically as cesium does.

The copper recycling equipment operated very well over the demonstration period of approximately five days. A total of 27,100 lb of copper wire in twenty-one 2 x 4 x 8-ft waste boxes were processed. This resulted in nine and a half 55-gallon drums (17,250 lb) of clean copper granules, five 2 x 4 x 8 ft-boxes of surrogate-contaminated granular insulation and four 2 x 4 x 8-ft boxes of surrogate-contaminated dust. All operations were performed safely and without incident. Hearing protection is recommended based on short, periodic exposure to noise levels exceeding acceptable limits. The copper cable recycling technology becomes cost effective on jobs larger than 25,000 lb of cable. Other considerations, such as waste storage cost, and preservation of natural resources may significantly influence the benefit of using this technology. The process can achieve up to 80% reduction in the final waste volume when using the granular insulation as void filler in waste storage boxes. Decontamination factors as high as 6000 can be achieved on small wire (up to 0.5-mm diameter) and as high as 400 on large wire (up to 2-mm diameter).

SECTION 4
APPLICABILITY AND ALTERNATIVES

Competing Technologies

Decon and Recovery Services of Oak Ridge, LLC
PO Box 5298
Oak Ridge, TN. 37831
(423) 241-0638 Contact: Lance Escue

Decon and Recovery Services of Oak Ridge, LLC, provides a similar service to recover copper from contaminated cable. Their system is permanently installed at the Oak Ridge facility and requires shipping the cable to their facility for processing, whereas our demonstration used a mobile unit. The demonstration was directed at the cost benefit of recycling contaminated copper cable and no attempt was made to compare the two technologies or services.

Applicability of the Technology

The ability to recycle copper cables from a nuclear facility decommissioning project would result in significant reductions in the volume of waste requiring disposal. Typically, large amounts of copper cable are encountered in these facilities and require disposal either at radioactive waste disposal sites or at sanitary landfills.

Typically, very little D&D waste is recycled or reused. Thus, not only do huge amounts of radioactive and noncontaminated material end up in disposal facilities, but the recycle potential for these materials is lost. The consequences are the continued high cost of disposing of D&D wastes and the wasting of our natural resources. Because the volumes of waste associated with the decommissioning of nuclear facilities are very high, these activities have a very negative impact on disposal facilities. This is particularly true of low-level waste disposal sites, where decommissioning of surplus facilities often adds significantly to their overall work volumes. The Copper Cable Recycling Technology has immediate application at DOE sites where facility D&D is planned or underway. These include all major DOE sites at which the decommissioning of several thousands facilities is planned over the next 20 years.

Although the INEEL has very little radiologically contaminated wire/cable in its facilities, reactors operated by commercial utilities may have a considerable amount. For this reason, there is a high level of interest in how effective this technology performs with radioactively contaminated wire/cable. It has the potential to recover costs and preserve natural resources on many D&D projects throughout the United Sates.

Patents/Commercialization/Sponsor

Nukem Nuclear Technologies is the exclusive United States licensee of the Copper Cable Recycling Technology. Nukem is based in Columbia, South Carolina. RADOS of Stuttgart, Germany is a specialty subcontractor to NUKEM and provided the technology/equipment for the demonstration.

SECTION 5
COST

Introduction

This section discusses the costs of disposition of copper cable for the innovative and the baseline technologies. The innovative technology and the baseline technology costs are approximately equal for a job where 25,000 pounds of copper cable are processed. Larger quantities of cable will increase the cost effectiveness of the Copper Cable Recycling Technology. The comparison includes the credit for recycling the copper material.

Methodology

This analysis is based on the innovative technology being a vendor–provided service to the Government, as opposed to Government purchase or rental of the equipment. Accordingly, the majority of labor involved in the innovative technology is assumed to be vendor-provided rather than INEEL-provided. The observed activities for the innovative technology include mobilization, set-up, demobilization, and disposal. In the demonstration, INEEL laborers segmented the cable in an activity separate from feeding the cables into the NUKEM equipment. In past jobs using the NUKEM technology, the cable was segmented as it was fed into the equipment. We assumed in this cost analysis that segmenting is not a separate activity and that the NUKEM operators and one INEEL laborer would segment the cable as part of the feed process. The INEEL laborer would have two duties, helping segment the cables and operating the forklift. Disposal of four boxes of dust is assumed in the cost analysis. However, it is possible the dust material be further compacted or used as void filler, further reducing the waste volume. The innovative technology generated five boxes of insulation material waste that we assume to be useful as a void filling material. Consequently, disposal costs for the five boxes of insulation are not included in our analysis. Mobilization of the innovative technology includes airfare, per-diem, car rental, shipping the equipment, and INEEL procurement costs. Demobilization includes decontaminating the equipment prior to leaving the INEEL. The D&D work costs include donning and doffing personal protective equipment, machine processing, sales of the recycled product, and laboratory analysis.

The demonstration crew included four process operators for the NUKEM equipment and one forklift operator/laborer. The INEEL provided the forklift operator. We believe this composite crew is typical of any crew used for the operating the copper cable recycling technology.

Because the demonstration of the innovative technology was performed in an uncontaminated area with uncontaminated cable, we adjusted the costs for contaminated work based on historical costs for donning and doffing PPE and by estimating the cost of decontaminating the equipment.

Costs for the baseline technology include transporting 21 boxes of waste cable to a disposal area and the associated disposal charges.

Labor rates for the INEEL-furnished crewmembers and equipment are based on standard rates for the INEEL site. There were some productivity losses associated with the use of the baseline and innovative technologies. Appendix B presents additional details relating to the cost analysis.

Cost Analysis

Costs to Procure the NUKEM Copper Cable Recycling Technology

At present, the NUKEM Copper Cable Recycling Technology is available only as a vendor-provided service, i.e., only as a service by NUKEM, with no purchase or rental options. The most recently quoted price is $14,500 per-day, which includes equipment and operators. This is the cost of the equipment used in the demonstration project.

Unit Costs and Fixed Costs

Table 3 summarizes the unit costs and fixed costs for the innovative and baseline technologies. The costs are based on a job size of 27,100 pounds of cable. The innovative technology costs are for a vendor-provided service and equipment and include the cost to process the cable and the costs for laboratory analysis of samples collected during the processing. Appendix B, Table B-2, presents the baseline technology costs. Appendix B, Table B-3, presents the innovative technology costs.

Table 3. Costs and production rates

COST ELEMENT	INNOVATIVE COST	PRODUCTION RATE	BASELINE COST
Mobilization	$47,200 each	N/A	N/A
D&D Work	$2.23/lb	847 lb/hr	N/A
Demobilization	$33,267 each	N/A	N/A
Waste Disposal	$150/cf of dust	N/A	$150/cf of cable

Break-Even Point

A large portion of the innovative technology's costs is for mobilization and demobilization, which remain relatively the same irrespective of the quantity of cable processed. Consequently, the innovative technology compares differently with the baseline technology for different amounts of cable processed. Figure 10 shows the relationship between cost and the amount of cable processed and indicates that for jobs processing more than 25,000 lb of cable, the innovative technology will be more cost effective than the baseline technology.

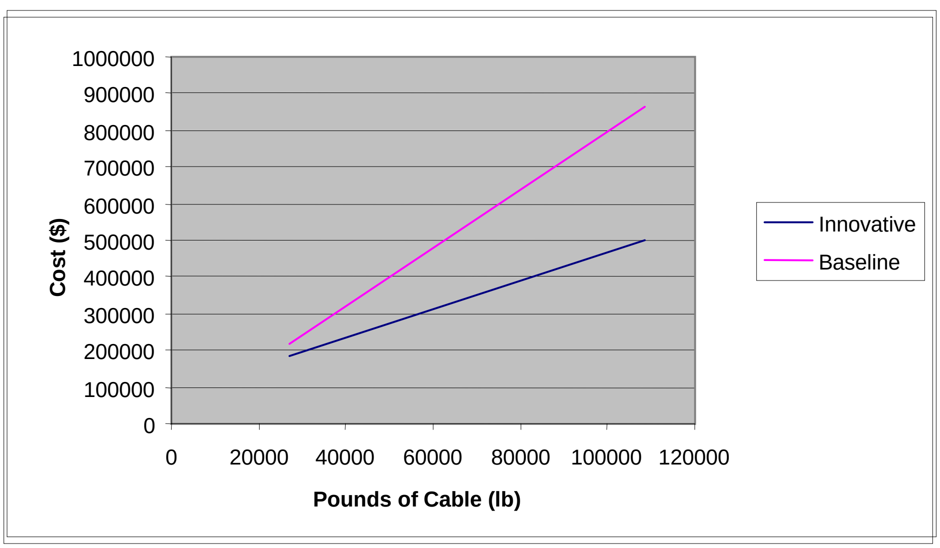

Figure 10. Job cost as a function of job size.

Pay-Back Analyses

Because the innovative technology is currently available only as a vendor-provided service, there are no capital costs to recover.

Observed Costs for Demonstration

Figure 11 summarizes the observed costs for the innovative and baseline technologies based on a job size of 27,100 pounds. Details relating to these costs are presented in Appendix B.

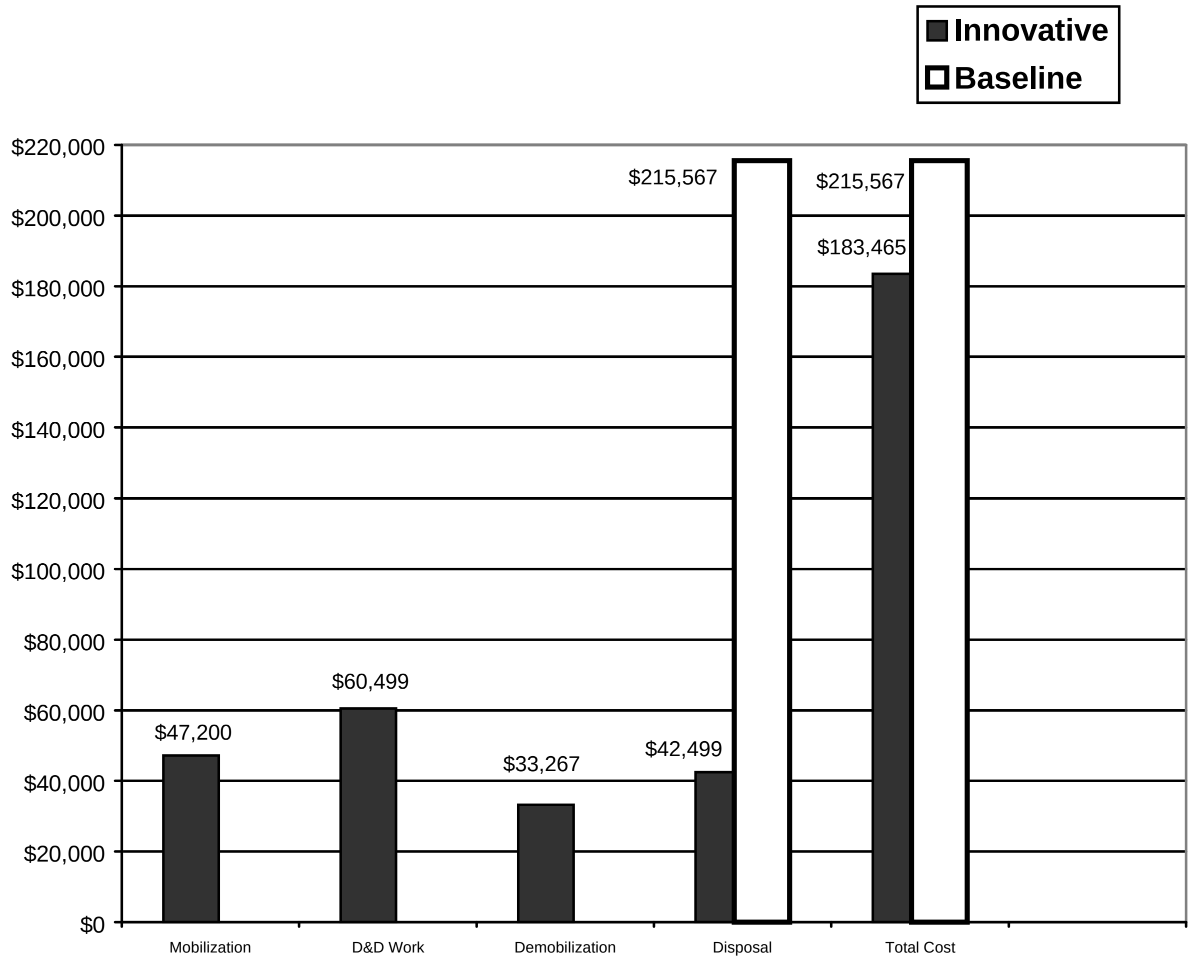

Figure 11. Summary of Technology Costs

Cost Conclusions

Mobilizing and demobilizing the innovative equipment are substantial costs and, in this demonstration, are approximately 40% of the total cost for this size job. For jobs smaller than this demonstration, the baseline method (disposal) is less expensive than the innovative technology. Jobs larger than the demonstration may have significantly more cost savings for the innovative technology (see Figure 9 for costs as a function of job size). Future jobs should require less time to set up the HEPA filtration system, which for this demonstration required several days, due to HEPA equipment sizing and availability problems. However, 4 hours are assumed in this cost analysis as being typical of future work. Coordination of the HEPA filter requirements for the NUKEM Copper Cable Recycling Technology is a critical factor in minimizing the setup time. Hookup to power is anticipated to be easier in future jobs. The model demonstrated is not able to run off of the site's electrical grid, so a generator and special electrical hookup were required. Future models are anticipated to run on congenital power. Future use on contaminated cable would require implementation of contamination controls and release surveys, including transportation authorizations in accordance with 49 CFR.

Production rates observed in this demonstration are for nonradioactive contaminated work areas. NUKEM's experience with decommissioning at commercial nuclear facilities is a mix of working conditions. Some conditions require wearing respirators. Other situations do not. If wearing respirators is required, the overall production would be reduced and costs would be higher than reported in this cost analysis.

For most of the demonstration, the workers wore neither respirators nor anti-contamination clothing. Our cost analysis includes daily costs for PPE but does not include respirators, cartridges, additional breaks for heat and fatigue, nor loss of dexterity and productivity from wearing respirators. If respiratory protection and the typical PPE were worn, it may have reduced the production rate by an additional 25 to 50% because of more frequent work breaks, heat stress, loss of dexterity, etc. The respiratory protection loss factors are from the *Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates,* Atomic Industrial Forum, Inc., May 1986. The additional costs of work associated with working in contaminated areas may make the baseline technology more cost effective than the innovative technology in some cases.

Disposal costs at the INEEL are assumed to be $\$150/ft^3$ for radioactive waste. This assumption is based on historical costs observed at the INEEL for operating the Radioactive Waste Management Complex. These do not include costs for transportation, packaging the waste, closure of the disposal facility, or long-term surveillance and maintenance. And the cost comparison is sensitive to the disposal cost. Sites that have lower disposal costs would favor the baseline technology, whereas sites with higher disposal costs would favor the innovative technology.

The potential to reduce costs comes from two areas. The first is from the reduced volume of waste going to disposal facilities. The savings are realized from decreased packaging and transportation costs and from extending the lives of the disposal facilities. The second is recycle of the copper. Copper is a natural resource and its recycle ultimately represents a cost saving to the country. Owing to the moderate size and nature of INEEL surplus facilities, we expect only moderate cost savings. However, DOE complex wide, the savings realized could be extremely large.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The NUKEM Copper Cable Recycling Technology meets the Department of Transportation requirements of 49 CFR. For this demonstration, however, no radioactive contamination was involved, and the equipment was therefore easily released from the INEEL. The INEEL did not require receipt inspection for radioactive contamination because the equipment was received off site and was surveyed to be below unallowable limits prior to its shipment from Germany. Because the equipment was not demonstrated within the INEEL boundaries, no survey was required to release the equipment prior to shipment back to Germany. The cable processed was surveyed and found to be 100% clean to ensure no contamination was released off site. For this project, a test plan, operational procedure, and job safety analysis were used to ensure all requirements and regulatory considerations were addressed.

Safety, Risks, Benefits, and Community Reaction

Safety issues associated with using the NUKEM Copper Cable Recycling Technology are primarily noise levels and radioactive contamination hazards. The noise risk is mitigated by using proper hearing protection and monitoring equipment. The radioactive contamination hazard is mitigated by properly using personal protective equipment, HEPA filtration systems, and continuous air monitoring equipment. Risks associated with using the technology are acceptable. However, allowable release limits of the recycled copper to the public is specific to each individual site and is under state and federal oversight.

Industrial Safety Noise Monitoring

Industrial Hygiene personnel monitored noise during the demonstration per INEEL MCP-153. Monitoring is required to (a) determine workplace noise levels, (b) ensure adequate controls have been implemented, and (c) ensure compliance with applicable standards.

A description of the noise monitoring task and specific details associated with the monitoring events follows:

Personal protective equipment (PPE) used by this employee:

- Blue coveralls
- Eye/face safety protection
- Leather gloves
- Hearing muffs

Personal monitoring results:

- **Sample 1**
  Sample date: 11/18/1999
  Peak level: 115.6 dBA
  Exposure limit: 84.5 dBA/9hr
  Time-weighted average (TWA) exposure level: 87.2 dBA
  Comments: laborer
  Monitoring time: 8:28
- **Sample 2**
  Sample date: 11/18/1999
  Peak level: 96.5 dBA
  Exposure limit: 84.5 dBA/9hr
  TWA exposure level: 76.7 dBA
  Comments: laborer
  Monitoring time: 8:35
- **Sample 3**
  Sample date: 11/18/1999
  Peak level: 111.2 dBA
  Exposure limit: 84.5 dBA/9hr
  TWA exposure level: 96.5 dBA
  Comments: operator
  Monitoring time: 8:29

Area monitoring was performed to document sound levels associated with the operation of the NUKEM Technology. The area results are as follows:

- **Sample 4**
  Sound level: 84.0 dBA
  Sample date: 11/16/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: near operator's ear, while loading the conveyer belt
- **Sample 5**
  Sound level: 82.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: near operator's ear, while loading the conveyer belt
- **Sample 6**
  Sound level: 79.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: approximately 10 ft from conveyer belt
- **Sample 7**
  Sound level: 92.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: outside near the grinder exhaust system
- **Sample 8**
  Sound level: 87.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: outside near separator exhaust system
- **Sample 9**
  Sound level: 106.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: inside between separator and grinder
- **Sample 10**
  Sound level: 103.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: inside near the control panel
- **Sample 11**
  Sound level: 96.0 dBA
  Sample date: 11/17/1999
  Exposure limit: 85.0 dBA/8hr
  Comments: inside upstairs

The exposure limit represents the noise level under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse health effects. In areas routinely occupied for long periods, the worker's average exposure was well below the exposure limit. Inside the containment structure, workers were exposed to noise levels exceeding acceptable exposure limits for short periods. Because of this potential for noise exposure above recommended limits, work controls were instituted to require hearing protection during all operations

SECTION 7
LESSONS LEARNED

Implementation Considerations

Two options may be considered for implementing the copper recycling technology. Option one is to set up the technology at NUKEM's facility and ship the copper cable to NUKEM for recycling. Option two is for NUKEM to develop a portable unit that could be easily deployed at the customer's location. There are advantages and disadvantages to both options, and each customer should consider which option would provide the most cost-effective results for their recycling needs. At present, the innovative technology is available only as a vendor-provided service, i.e., only as a leased service operated and staffed by NUKEM, with no purchase or rental option.

Each time the Copper Cable Recycling Technology is shut down and restarted, about 2 hours are required to balance the air movers at the beginning of the day and to allow the copper to clean out of the system at the end of the day. This may vary, but it needs to be considered each time the technology is started and stopped. The technology is more cost effective if it can run continuously for as long as possible to avoid the startup and shutdown procedures associated with balancing the air movers and removing the remaining copper from the system. Double shifts or around-the-clock operation should be considered for more cost-effective operation.

Also, automating the cable sizing process that prepares the cable for feeding into the system could significantly reduce costs.

Technology Limitations and Need for Future Development

We suggest the following be considered to decrease setup time and to provide each customer with a ready-to-operate recycle unit:

- Convert all motors on the recycle unit to U.S. standards, i.e.: change from 50 to 60 Hz. This would allow operating the recycle unit using U.S. commercial power
- Provide HEPA filter systems with the recycle unit
- Design the unit as one piece, thus reducing setup time and costs associated with using a crane for setup
- Provide a power hookup cable with the system
- Provide all exhaust and dust collection equipment.

Technology Selection Considerations

Based on the INEEL demonstration, the innovative technology is better suited for large recycle projects, greater than 25,000 lb. There are instances where the baseline technology would be preferable. This consideration is based on disposal costs and the level of effort required to prepare the cable for recycling.

APPENDIX A
REFERENCES

Copper Wire Recycle, Idaho National Engineering and Environmental Laboratory, Technology Opportunity Statement Summary ID-7.2.23.

APPENDIX B
COST COMPARISON DETAILS

Basis of Estimated Cost

The activity titles shown in this cost analysis come from observation of the work during demonstration. In the estimate, activities are grouped under higher level work titles per the work breakdown structure shown in the *Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary* (HTRW RA WBS) (USACE 1996). The HTRW RA WBS, developed by an interagency group, was used in this analysis to provide consistency with established national standards.

The costs shown in this analysis are computed from observed duration and hourly rates for the crew and equipment. The following assumptions were used in computing the hourly rates:

- The NUKEM Copper Cable Recycling Technology is currently offered only as a vendor-provided service. The rate used in this cost analysis is based on a quotation from the vendor of $14,500 per day and the observed workday length (average) of 8.5 hr ($1,705.88/hr).
- The INEEL provided support for the innovative technology: a forklift, generator, truck, and crane. The equipment rates and equipment operator rate is based on standard rates at the INEEL.
- The HEPA filter unit was rented. The rate used in the cost analysis of $13.01 is based on the unit's rental rate plus the cost of the filter amortized over the period of operation [rental rate is $5.29/hr for each HEPA filter plus $7.81/hr ($250 each filter for 32 hours of operation = $7.81/hr)].
- The standard labor rates established by the Idaho National Engineering and Environmental Laboratory (INEEL) are used in this estimate and include salary, fringe, departmental overhead, material handling markups, and facility service center markups.
- The equipment and labor rates do not include the Bechtel BWXT Idaho, LLC general and administrative (G&A) markups. G&A is omitted from this analysis to facilitate understanding and comparison with costs for an individual site. The G&A rates for each DOE site vary in magnitude and in the way they are applied. Decision-makers seeking site-specific costs can apply their site’s rates to this analysis without having to first back out the rates used at the INEEL.

The analysis does not include costs for oversight engineering, quality assurance, administrative costs for the demonstration, or work plan preparation costs.

Activity Descriptions

This section describes the scope, computation of production rates, and assumptions (if any) for each work activity.

Mobilization (WBS 331.01)

Air fare, round-trip: This item is the innovative technology cost for round trip air fare between South Carolina and Idaho for four process engineers.

Per-diem: Included in this line item is per-diem allowance for four NUKEM process operators for one week, for the innovative technology. Per-diem rates are per the U.S. General Services Administration.

Car rental: Included in the costs for the innovative technology is the rental of one car for the period of the demonstration, one contiguous week.

Shipping and handling, round-trip: This item concerns the innovative technology. NUKEM has indicated that the round-trip cost for shipping the NUKEM Copper Cable Recycling Technology from South Carolina to Idaho is $9,000, and that it allows four hours loading and unloading time (demurrage) per round-trip shipment (i.e., two hours at each end of the trip). This cost analysis includes costs for INEEL labor and equipment supporting the loading and unloading. The site support includes one crane, one crane operator, one forklift, and one forklift operator in the costs for this line item.

HEPA filter setup: The HEPA filter setup required several days effort. The duration was longer than normal because the HEPA filter requirements were miscommunicated and we had difficulty locating an acceptable unit. Based on the test engineer's judgment, a reasonable time to allow for the HEPA filter setup is 4 hr.

Electrical hookup: The hookup to power required several hours. Problems with locating an acceptable power cable caused delays not representative of future work. Based on the test engineer's judgment, a reasonable time to allow for the electrical hookup is 1 hr.

Unpack and setup: Uncrating the NUKEM equipment, connecting the components together, and general setup is approximately 12 to 15 hours.

Cable Processing Work (WBS 331.17)

Meetings and donning personal protective equipment (PPE): This includes the labor time spent in the prejob safety meeting each morning and includes standby time for the NUKEM Copper Cable Recycling Technology. It also includes the labor and material cost for donning the articles of clothing listed in table B-1. The duration of the donning and the number of donning events are based on observations of the demonstration.

Table B-1. Cost for personal protective equipment (per man/day)

Equipment	Cost Each	Number of Times Used Before Discarded	Cost Each Time Used ($)	No. Used Per Day	Cost Per Day ($)
Rubber overboots (pvc yellow 1/16-in. thick)	$12.15	30	$0.41	1	$0.41
Glove liners pr. (cotton inner)	$0.40	1	$0.40	2	$0.80
Rubber Gloves pr. (outer)	$1.20	1	$1.20	2	$2.40
Tyvek	$3.30	1	$3.30	1	$3.30
Respirator (full face)	$222	50	$4.44	1	$4.44
Cartridges	$7.51	1	$7.51	2	$15.02
TOTAL COST/DAY/PERSON					**$25.96**

Processing: This includes processing cable by the NUKEM machine. Cables are segmented and placed on a conveyor that feeds into the preshredder. The preshredder reduces the cable into lengths that can be most efficiently processed by the grinder. The activity includes periodic emptying of dust collection bags and the bins used to capture copper and insulation granules. The NUKEM operators are supported by a site forklift and laborer who operates the forklift and helps segment the cable. Production rate for the innovative technology is based on a total operation time of 32 hr processing 27,100 lb of copper cable (847 lb/hr).

Sales: This cost element assumes that INEEL sells the scrap copper when the NUKEM processing is completed. The income from the sale offsets some of the costs. The rate for salvage copper used in Table B-2 is based on the national average rate for salvage copper.

Sample Analysis: Two types of analysis were performed for the innovative technology: cobalt by inductively coupled plasma and cesium nitrate via atomic absorption. This would be typical for a field characterization scenario. Different types of analyses may be associated with other scenarios, such as field screening or confirmatory sampling. The sample analysis costs observed for this demonstration are used in the cost analysis.

Demobilization (WBS 331.21)

Decontaminate: Based on the test engineer's judgment, two days of effort are assumed in this cost analysis for decontaminating the NUKEM equipment prior to release from the INEEL.

Ship and Handle - Round Trip: See mobilization task.

Disposal (WBS 331.18)

Transport and Unload: This activity includes loading the waste onto a truck, transporting it to the disposal area, and unloading it. The quantity of waste for the innovative technology is four boxes of dust and five boxes of insulation. The baseline technology has 21 boxes of waste for disposal. The truck capacity is 12 disposal boxes per trip, which would require one trip for the innovative technology waste and two trips for the baseline technology waste. The time required for each trip is 1 hr to load, 0.5 hr to transport, and 1 hr to unload.

Disposal of Dust and Insulation Materials: The quantity of waste for the innovative technology is four boxes of dust and five boxes of insulation. The insulation material can be used as void filler for waste disposal on other projects and is not included in the costs for disposal for the innovative technology. Only the four boxes of dust are included in the cost analysis. The baseline technology has 21 boxes of waste for disposal. The cost for the box material and labor for constructing the boxes is included in the analysis; standard rates used at INEEL are \$600/box. The disposal fee is \$9,600/box (2 x 4 x 8-ft box at \$150/ ft^3) plus the cost of the box (\$600/box), a total cost of \$10,200 per box.

Disposal of PPE Waste: This cost analysis assumes 1 ft^3 of PPE waste for the workers loading the waste for the baseline technology. The three operators of the NUKEM equipment plus the forklift operator are assumed to generate 2 ft^3 of PPE waste each day of operation.

Cost Estimate Details

The cost analysis details are summarized in Tables B-2 and B-3. The tables break out each member of the crew, each labor rate, each piece of equipment used, each equipment rate, each activity duration, and all production rates, so that site-specific differences in these items can be identified and a site-specific cost estimate developed.

Table B-2. Baseline Technology Cost Summary

Work Breakdown Structure	Unit	Unit Cost $/Unit	Quantity	Total Cost	Computation of Unit Cost: Prod Rate	Duration (hr)	Labor Item	$/hr	Equipment Items	$/hr	Other $	Comments
Facility Deactivation, Decommissioning, & Dismantlement							**Total Cost =**					**$ 215,566.60**
Disposal (WBS 331.18)										Subtotal =		$ 215,566.60
Transport & Unload	ls	608.30	2	$ 1,216.60		5.00	TD, LB, FO	105.86	FT, FL	15.80		
Disposal of Cable	box	10,200.00	21	$ 214,200.00							10,200	Box $600 ea+fee of $150/cf
Disposal PPE	cf	150.00	1	$ 150.00							150	Disposal fee = $150/cf

Labor and Equipment Rates used to Compute Unit Cost

Crew Item	Rate $/hr	Abbrev-eation	Crew Item	Rate $/hr	Abbreveation	Equipment Item	Rate $/hr	Abbrev-eation	Equipment Item	Rate $/hr	Abbrev-eation
Heavy Equipment Op	38.65	HO	Laborer	32.86	LB	Forklift	3.30	FL	Flatbed Truck	12.50	FT
Forklift Operator	38.65	FO	Driver	34.35	TD						

Notes:

1. Unit cost = (labor + equipment rate) X duration + other costs, or = (labor + equipment rate)/production rate + other costs.
2. Abbreviations for units: ls = lump sum; ea = each; loc = location; ft^3 = cubic feet.
3. Other abbreviations: PPE = personal protective equipment.

Table B-2. Innovative Technology Cost Summary

Work Breakdown Structure	Unit	Unit Cost $/Unit	Quantity	Total Cost	Computation of Unit Cost: Prod Rate	Duration (hr)	Labor Item	$/hr	Equipment Items	$/hr	Other $	Comments
Facility Deactivation, Decommissioning, & Dismantlement							**Total Cost =**					**$ 183,464.58**
Mobilization (WBS 331.01)										Subtotal =		$ 47,199.95
Air Fare - Round Trip	ea	1,913.00	4	$ 7,652.00								4 process operators
Per Diem	wk	495.00	4	$ 1,980.00								4 process operators
Car Rental	ea	42.00	1	$ 42.00								
Ship & Handl - Round Trip	ea	4,666.30	1	$ 4,666.30		2.00	HO, FL	77.30	CN, FL	5.85	4,500	$4,500 for shipping
HEPA Filter Setup	ea	6,875.56	1	$ 6,875.56		4.00			NK, HF	1718.89		
Electrical Hookup	ea	1,743.53	1	$ 1,743.53		1.00	EL	37.65	NK	1705.88		
Unpack & Setup	ea	20,470.56	1	$ 20,470.56		12.00			NK	1705.88		
INEEL Procurement Cost	ls	3,770.00	1	$ 3,770.00								5.2% of total vendor cost
D&D Work (WBS 331.17)										Subtotal =		$ 60,498.73
Meetings & Don PPE	ea	543.23	5	$ 2,716.13		0.25	FO	38.65	NK,HF (stand by)	1718.89	104	PPE $25.96 ea for 4 persons
Processing	lb	2.09	27,100	$ 56,589.41	847 lbs/hr		FO	38.65	NK , FL, GN, HF	1730.03		Production rate 847 lb/hr
Sales	lb	-0.80	17,275	$ (13,820.00)								$0.80/lb assumed
Doff PPE	ea	436.13	5.0	$ 2,180.66		0.25	FO	38.65	NK (stand by)	1705.88		
Lab Analysis - Samples	ea	90.37	142	$ 12,832.54								
Demobilization (WBS 331.21)										Subtotal =		$ 33,266.62
Decontaminate	ea	28,600.32	1.0	$ 28,600.32		16.00	RCT, LB	68.63	NK, HF (stand by)	1718.89		
Ship & Handl - Round Trip	ea	4,666.30	1	$ 4,666.30		2.00	HO, FL	77.30	CN, FL	5.85	4,500	
Disposal (WBS 331.18)										Subtotal =		$ 42,499.28
Transport & Unload	ls	199.28	1	$ 199.28		2.50	TD, LB	67.21	FT	12.50		
Disposal Insulation & Dust	box	10,200.00	4	$ 40,800.00							10,200	Box $600 ea+fee of $150/cf
Disposal PPE	cf	150.00	10	$ 1,500.00							150	Disposal fee = $150/cf

Labor and Equipment Rates used to Compute Unit Cost

Crew Item	Rate $/hr	Abbrev-eation	Crew Item	Rate $/hr	Abbreveation	Equipment Item	Rate $/hr	Abbrev-eation	Equipment Item	Rate $/hr	Abbrev-eation
Heavy Equipment Op	38.65	HO	Laborer	32.86	LB	Forklift	3.30	FL	Flatbed Truck	12.50	FT
Forklift Operator/Laborer	38.65	FO	Driver	34.35	TD	Crane-Trackmobile	2.55	CN	HEPA Filter Rental	13.01	HF
Radiation Control Tech	35.77	RCT				Generator	7.84	GN			
Electrician	37.65	EL				NUKEM Copper Recycle	1705.88	NK			

Notes:
1. Unit cost = (labor + equipment rate) X duration + other costs, or = (labor + equipment rate)/production rate + other costs
2. Abbreviations for units: ls = lump sum; ea = each; and, loc = location; ft^3 = cubic feet.
3. Other abbreviations: PPE = personal protective equipment

APPENDIX C
ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
CFA	Central Facilities Area
D&D	decontamination and decommissioning
DDFA	Deactivation and Decommissioning Focus Area
DOE	United States Department of Energy
DB	decibel
G&A	General and Administrative
HEPA	High-efficiency particulate air
INEEL	Idaho National Engineering and Environmental Laboratory
LLW	low-level waste
LSDDP	Large-Scale Demonstration and Deployment Project
NETL	National Energy Technology Laboratory
OMB	Office of Management and Budget
OST	Office of Science and Technology
PPE	personal protective equipment
RCT	radiation control technician
TWA	time-weighted average
WBS	work breakdown structure