GammaCam™ Radiation Imaging System

Deactivation and
Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

GammaCam™ Radiation Imaging System

OST Reference # 1840

Deactivation and
Decommissioning Focus Area

Demonstrated at
Chicago Pile 5 (CP-5) Research Reactor
Large-Scale Demonstration Project
Argonne, Illinois

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 if 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 online at http://em-50.em.doe.gov.

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Technology Description

GammaCam™, a gamma-ray imaging system manufactured by AIL System, Inc., would benefit a site that needs to locate radiation sources. It is capable of producing a two-dimensional image of a radiation field superimposed on a black and white visual image. Because the system can be positioned outside the radiologically controlled area, the radiation exposure to personnel is significantly reduced and extensive shielding is not required.

How it Works

The GammaCam™ system is designed to provide two-dimensional information on the position and relative strengths of gamma-ray radiation fields located from a few feet to several hundred feet from the observer. The system consists of a portable sensor head that contains both gamma-ray and visual imaging systems and a portable computer for control. The sensor head is shown in Figure 1 mounted on a tripod. The data is collected and displayed by the computer that can be located several hundred feet from the sensor head. Figure 2 shows a sample output of the superimposed radiation and visual images for a cesium source located on a desk. Note: Actual output is in color, not black and white as shown.

Figure 1. GammaCam™ mounted on tripod.

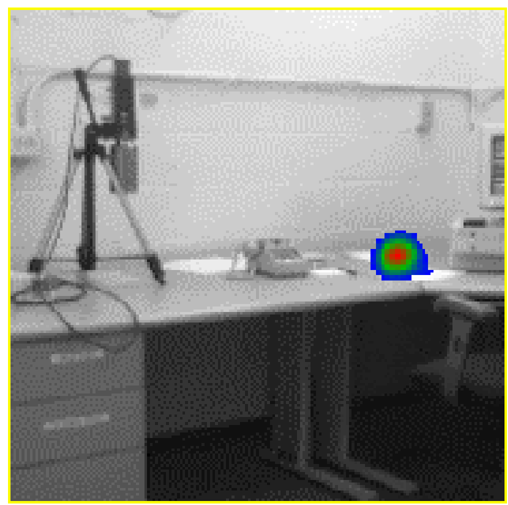

Figure 2. Image of a test source.

The gamma-ray imaging system uses a coded aperture for imaging of the radiation field. The gamma ray energy sensitivity of the system is approximately 0.1 to 2.0 Mega-electron Volts (MeV). The system is unable to distinguish between gamma rays of different energies and thus cannot be used to identify specific radioactive isotopes. The sensitivity of the system is approximately 1 micro-Rad (μR) dose at the sensor head for a 7:1 signal-to-noise ratio. The data acquisition time can be varied from 10 milliseconds to many hours. The field-of-view of the gamma-ray imaging system is either 25° (1.3° angular resolution) or 50° (2.6° angular resolution). Both the collection time and the field-of-view are controlled by a computer. The radiation and visual images are stored in a PCX format on disk.

Demonstration Summary

The demonstration of GammaCam™ in December 1996 was part of the Large-Scale Demonstration Project (LSDP) whose objective is to select and demonstrate potentially beneficial technologies at the Argonne National Laboratory-East (ANL) Chicago Pile-5 Research Reactor (CP-5). The purpose of the LSDP is to demonstrate that by using innovative and improved decontamination and decommissioning (D&D) technologies from various sources, significant benefits can be achieved when compared to baseline D&D technologies. This demonstration is sponsored by the U.S. Department of Energy (DOE), Office of Science and Technology, Deactivation and Decommissioning Focus Area (DDFA).

The purpose of these tests was to determine the capabilities, limitations, and suitable applications of the GammaCam™ system in the following three areas:

- surveying large floor or wall areas that may be contaminated due to spills,
- use of the system to identify the relative location and strength of different radioactive sources located in a large concrete vault through an opening in the shield wall, and
- demonstration of the usefulness of the composite two-dimensional radiation and visual images in determining shielding needs and in positioning subsequent shielding.

The baseline technology for comparison is a standard manual survey. Since the output from the GammaCam™ system is a composite video image showing relative radiation field strength, the technology is not directly comparable to the baseline because the baseline can only provide quantified results at specific locations.

CP-5 is a heavy-water moderated and cooled, highly enriched, uranium-fueled thermal reactor designed to supply neutrons for research. The reactor had a thermal-power rating of 5 megawatts and was operated for 25 years until its final shutdown in 1979. These 25 years of operation have produced activation and contamination characteristics representative of other nuclear facilities within the DOE Complex. CP-5 contains many of the essential features of other DOE nuclear facilities and can be safely used as a demonstration facility for the evaluation of innovative technologies for the future D&D of much larger, more highly contaminated facilities.

An AIL engineer operated the GammaCam™ system and provided digital images of the collected data. ANL personnel from CP-5 and the Environment, Safety, and Health (ESH) Division provided support in the area of health physics (HP). Argonne National Laboratory personnel wrote the test plan and generated a data report describing the information collected. Cost analysis was performed by the U.S. Army Corps of Engineers (USACE), and benchmark activities were performed by ICF Kaiser.

Key Results

The key results of the demonstration are as follows:

- The GammaCam™ system performed well during the CP-5 demonstration by successfully providing two-dimensional color images of gamma radiation fields superimposed on the corresponding visual black and white image. No significant problems with the system were identified in the 3-day test despite considerable movement and relocation of the device.
- The use of the GammaCam™ system in determining shielding requirements and in positioning shielding will result in a significant reduction in the radiation dose received by operating technicians. This benefit will be more pronounced in high radiation areas.
- The GammaCam™ system can provide useful information concerning the relative strengths of the various sources and their locations from outside the radiological area. This provides useful information for planning a decontamination process to be obtained with minimal radiation dose to the operator. It is also possible to use triangulation to determine the distance of the sources relative to the GammaCam™ sensor.

- The GammaCam™ system can provide information on floor and wall contamination from outside the contaminated area. This eliminates the need for extensive worker protection in obtaining these measurements. It will also reduce the radiation exposure to personnel if the floors and walls were highly radioactive.
- Training in the setup and use of the GammaCam™ is easy and can be done in a few hours. Because of some of the characteristics of the imaging system, a day of training in the use of the system is required to properly interpret the resulting images.

Contacts

Technical

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Demonstration

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Licensing Information

No licensing or permitting activities were required to support this demonstration.

Web Site

The CP-5 LSDP Internet address is http://www.strategic-alliance.org.

Other

All published Innovative Technology Summary Reports are available online at http://em-50.em.doe.gov. The Technology Management System, also available through the EM50 Web site, provides information about OST programs, technologies, and problems. The OST Reference # for GammaCam™ is 1840.

SECTION 2

System Configuration and Operation

The GammaCam™ system provides a two-dimensional pseudo-color image of a gamma-ray radiation field superimposed on a corresponding black-and-white visual image. The GammaCam™ consists of a sensor head that contains both gamma-ray and visual imaging systems and a portable computer. The sensor head is approximately 60 lb and 19 in x 10 in x 15 in. Control of the data collection and image parameters such as field-of-view is done by the portable computer, which can be located as much as 200 ft from the sensor head. The measured images are displayed on the liquid crystal display (LCD) screen of the computer. Figure 3 shows the personal computer (PC) for controlling the system and a typical image displayed on the LCD display. Figure 4 shows an actual image from the screen and the corresponding scan information from a saved data file.

Figure 3. Image of the personal computer used to control data collection and to process data.

The sensor head can be mounted on a tripod or suspended by a sling from an overhead crane hook. The GammaCam™ uses standard 120 VAC at 60 Hz. Power consumption is approximately 250 watts. The television camera and the GammaCam™ system are air cooled. High-efficiency particle air (HEPA) filters are used on the air intake of the sensor head enclosure to minimize dust and contamination.

The visual image is acquired by a standard video camera. A framegrabber digitizes this image into a 370 (horizontal) by 260 (vertical) pixel image for display. The field-of-view of the camera is 73 degrees in the horizontal direction and 55 degrees in the vertical direction.

The gamma-ray imaging system uses a coded-aperture mask, a scintillator screen, an image intensifier, and a charged coupled detector (CCD) array to acquire an image of the radiation field. The CCD array is cooled to a temperature of approximately -40 °F to reduce noise. During a scan, the CCD integrates the light signal over a period of time varying from 10 milliseconds to 1 h. Longer collection intervals can be achieved by summing the data from a series of one hour images.

Figure 4 shows the visual and radiation images. The television image is in black and white, while the radiation field image is color coded based on intensity with red corresponding to the highest radiation and blue the lowest. The maximum and minimum signal intensities are given above and below the color key. The yellow square in the center corresponds to the GammaCam™ radiation field-of-view. After the data is collected, the radiation field at the position of the camera mask is calculated in terms of dose rate and integrated dose and displayed below the color key. The entire image is saved to disk using a PCX format. A typical file size is 200 kilo-bytes (kB).

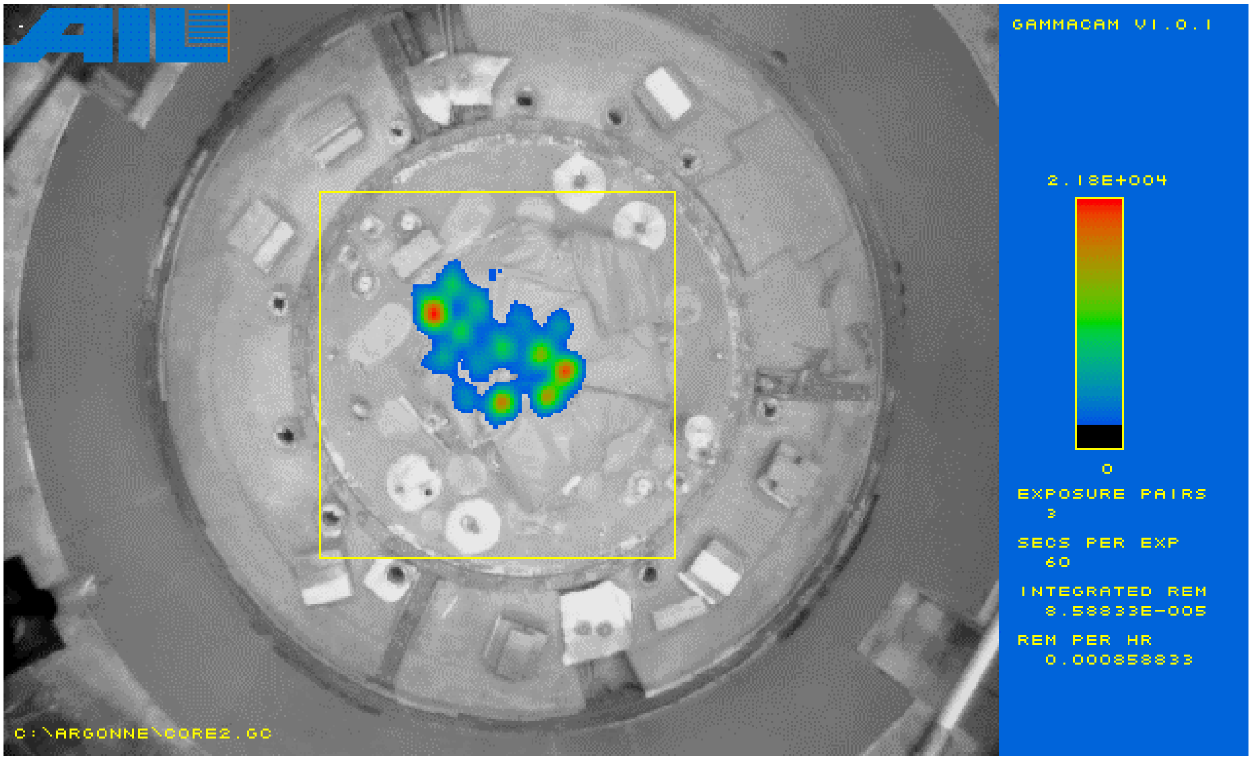

Figure 4. Display of CP-5 Reactor internals using GammaCam™ Imaging System.

The specification for the sensitivity of the system is 1 µR integrated dose from a Cs-137 point source with a signal-to-noise ratio of 7:1. The system reports dose rate and integrated dose at the sensor head when the integrated dose exceeds 10 µR. Visual images can be obtained at lower radiation exposures but with higher noise.

A coded aperture system distributes the radiation field over the surface of the detector system and then uses a mathematical transformation to obtain the actual spatial distribution. In this transformation, the presence of any uniform background is subtracted out of the image. Thus, large background fields that are uniformly distributed over the sensor head will have little effect on the measured gamma-ray distribution. This feature allows the GammaCam™ to image radiation fields even in the presence of large background fields. The effectiveness of the GammaCam™ in high radiation fields was not tested at CP-5, but has been demonstrated at other facilities.

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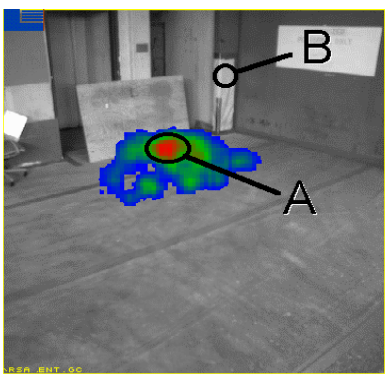
Demonstration Plan

The testing of the GammaCam™ system covered three areas of interest. The first was in the use of the system to monitor and characterize large floor and wall areas. The second was concerned with using the system to characterize the position and relative intensities of radiation sources positioned within a concrete vault while minimizing worker exposure. The third was to use the device to characterize radiation areas for subsequent positioning of shielding to reduce radiation levels to workers. Over 24 images were obtained during the 3-day test. A complete set of images is available in the technical data report. The measured radiation fields were relatively low in the CP-5 demonstration. Tests of the GammaCam™ system at other locations in fields as high as 50 rad/h can be found in the references.

Setup of the device took approximately 30 min. The sensor head was mounted on a tripod or mounted to an overhead crane hook with a simple sling. During the 3-day testing period the entire system was loaded and unloaded from the crane and the tripod many times and moved between various locations within CP-5. It was also operated in several areas in which there was high electronic noise. No failure of any portion of the system occurred during the test period.

The advantage of using the GammaCam™ system to characterize floors or walls is that it can cover a large surface area in a relatively short period of time while minimizing the possibility of contamination of the sampling device or workers. Figure 5 shows the use of the GammaCam™ to characterize a floor space at the entry to the rod storage area in CP-5. The GammaCam™ was tripod mounted and positioned approximately 17 ft from the radiation area, which consisted of a cesium spill. The image in Figure 5 illustrates the system's ability to characterize large areas. The image shown was produced with an overnight exposure. The hot spot (A) corresponded to a contact field strength of 2.8 milli-Rad (mR)/h. The GammaCam™ measured 7.7 μR/h from 16.7 ft away. All contact radiation measurements provided in this document were obtained from standard health physics instrumentation available at CP-5.



Exposure Time	16.5 h
Distance	16.7 ft
Measured Field at Source	2.8 mR/h (Contact)
Field Measured by GammaCam™	7.7 μR/h
Field-of-View	50 degrees
Maximum Signal (Arbitrary Units)	4,280
Minimum Signal (Arbitrary Units)	1,580
Noise Level (Arbitrary Units)	527
Signal-to-Threshold Ratio	2.6 to 1

Figure 5. Image of rod storage entry area and GammaCam™ parameters of the image.

A second hot spot (B) was not seen in the image. The fixed contamination at this location had a field of 800 μR/h (contact). Calculations indicate that this source was below detection threshold for the measured signal-to-threshold ratio. Note: Actual output is in color, not black and white as shown above.

The system's dynamic range depends upon several factors including source strength, distribution, distance, exposure time and background radiation conditions. The limited dynamic range in this image is largely a result of the length of integration time. Since the hot spot (A) identified in the image was visible on the system display after the first 10 min of exposure, an exposure of 2 to 3 h would have had a better dynamic range. Future generations of the system's software will not discard the image with the maximum signal-to-threshold ratio, but preserve it in memory in addition to the current image.

A series of images were taken of sources located in the Cave room. The Cave consists of a large room surrounded by thick concrete shielding. A shield plug in the ceiling of the Cave had been removed and the GammaCam™ was used to image the various radiation sources located within the room through the shield plug opening. The system was rigged to a crane and suspended above the shield plug opening, which is located below the rectangular steel plate shown in the image of Figure 6. This image is a good example of how the system is able to identify and locate separate sources in a situation in which a conventional radiation meter with no directional sensitivity is unable to resolve the individual sources.

Exposure Time	2 min
Distance	6 ft to cover
Measured Field at Source	200mR/h (Contact)
Field Measured by GammaCam™	10 mR/h
Field-of-View	50 degrees
Maximum Signal (Arbitrary Units)	187,000
Minimum Signal (Arbitrary Units)	11,100
Noise Level (Arbitrary Units)	3,700
Signal-to-Threshold Ratio	23.8 to 1

Figure 6. Image of two sources in Cave area.

It is possible to use the orientation of the objects in different images as the camera is moved to perform triangulation to determine how far each source is below the steel plate. In these tests this triangulation effort was complicated by the changes in the orientation of the camera relative to the floor. It was possible, however, to use a least squares technique to show that both objects were located approximately 14 ft below the steel plate. Note: Actual output is in color not black and white as shown.

Several images of the CP-5 Reactor were acquired with the sensor head suspended from the crane directly over the center of the reactor core (Figure 4). The top shielding plug of the reactor had just recently been removed and the shielding shown in Figure 4 has been placed to reduce radiation streaming from various holes in the remaining shield plug. Figure 7 shows a close-up image of the top of the core with seven well defined sources that had not been completely shielded. Figure 8 shows the result of placing a lead brick (indicated by arrow) on the most intense source in Figure 7. The discrepancy between the radiation and visual source position is due to parallax between the two imaging systems. Once the highest radiation source shown in Figure 7 had been eliminated, the remaining sources have a higher contrast. In addition, a new hot spot (indicated with a circle) is now detectable.

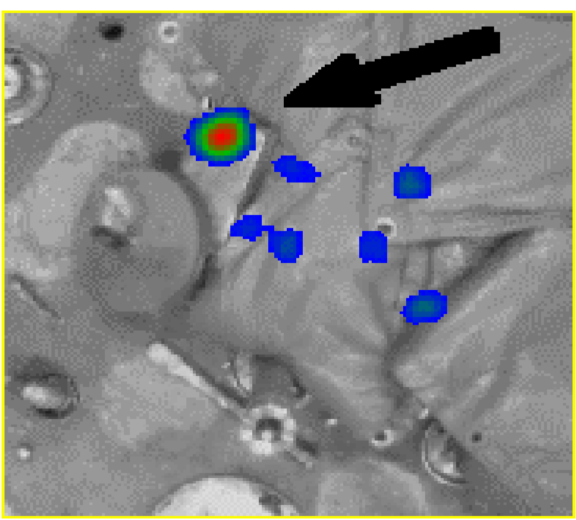


Figure 7. Radiation field before placing lead brick.

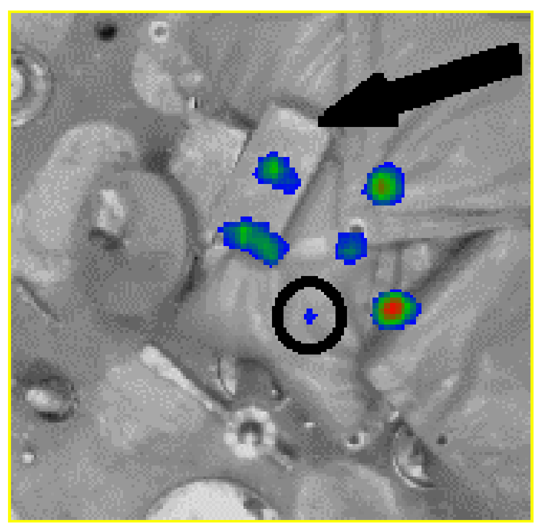


Figure 8. Radiation field after placing lead brick.

SECTION 4

Technology Applicability

Any site that needs to locate radiation sources would benefit from the use of the GammaCam™ system. In decommissioning a room containing glove boxes or an area containing extensive piping, a gamma camera can provide useful information on the number, location, and intensity of radiation sources. This information can be used to locate hot spots and position shielding to minimize worker exposure. Since much of this information is obtained with minimal radiation exposure to personnel, this is a useful tool in implementing As Low as Reasonably Achievable (ALARA) programs. The GammaCam™ system enables characterization of high radiation sources when manual surveys would be impossible because of personnel dose constraints.

Another useful application is in piping or processing systems to locate accumulation of radioactive materials. Similarly, the effectiveness of various techniques on removing buildup can also be monitored. A GammaCam™ is especially useful if the systems are in a high radiation area or in an area that contains contamination.

Similarly the GammaCam™ is ideal in determining the radiological conditions on floors or walls in contaminated areas. The ability to place the camera outside the contaminated area greatly reduces the technician time in donning protective clothing or in providing radiation shielding.

Competing Technologies

The baseline technology with which the GammaCam™ system competes is manual surveys by trained health physics technicians (HPTs). Manual surveys are time consuming, tedious, and directly expose the personnel to radiation. This leads to high labor costs, unreliable data, and potentially unnecessary worker exposures. The GammaCam™ system is not a directly comparable technology to manual surveys as its output is a composite video image showing relative radiation field strength rather than quantified results from specific locations.

Similar, but not identical competing technologies include:

- In Situ Gamma Spectroscopy with ISOCS (an In Situ Object Counting System) developed by Canberra Industries, Inc.;
- Integrated Characterization and Archiving System developed by Coleman Research Corporation;
- RadScan 600 developed by BNFL Instruments, Ltd.

Data comparing the performance of GammaCam™ to the competing technologies listed above is not available.

SECTION 5

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Introduction

This analysis provides an estimate of cost for the GammaCam™ technology. The GammaCam™ technology provides characterization data, which is different from the conventional method of manual radiological survey, and these data are used differently in planning future D&D work. GammaCam™ identifies where a source is located as well as the radiation field strength at the sensor. Manual surveys can only indicate the radiation field strength at a specified location and do not identify source location. Consequently, direct comparison of the cost for GammaCam™ with conventional radiological survey methods has limited value. An estimate of baseline cost for conventional survey methods is provided in this analysis to give the reader a sense of the relative costs of the GammaCam™ and baseline technology. Refer to Appendix B for more information on cost comparisons.

Methodology

The GammaCam™ technology was demonstrated at ANL under controlled conditions which facilitated observation of the work procedures and typical duration of those procedures. The cost analysis is based on those scans using the GammaCam™, which appear to be representative of typical work.

The manual survey was not demonstrated concurrently. The baseline is developed from recollections of previous manual surveys under similar conditions to those of the demonstration. Labor, equipment, production rates, and productivity loss factors (PLF) were provided by site personnel at ANL or from similar work being performed elsewhere.

Since the baseline costs are not based on observed data, additional efforts are applied in setting up the baseline cost analysis to ensure unbiased and appropriate production rates and crew costs. Specifically, a team consisting of members from the Strategic Alliance (ICF Kaiser, an ANL D&D technical specialist, and a test engineer for the demonstration) and the USACE review the assumptions to ensure a fair comparison.

The selected basic activities being analyzed come from 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, is used in this analysis to provide consistency with the established national standards.

Some costs are omitted from this analysis to facilitate understanding and comparison with costs for the individual site. The ANL indirect expense rates for common support and materials are omitted from this analysis. Overhead and general and administrative (G&A) rates for each DOE site vary in magnitude and the way they are applied. Decision makers seeking site specific costs can apply their site's rates to this analysis without having to first retract the rates used at ANL. The impact resulting from this omission is judged to be minor because overhead is applied to both the innovative and the baseline technology costs. Engineering, quality assurance, administrative costs, and taxes on services and materials are also omitted from this analysis for the same reasons indicated for the overhead rates.

The standard labor rates established by ANL for estimating D&D work are used in this analysis for the portions of the work performed by local crafts. Costs for site owned equipment, such as trucks for transport or HPT radiological survey equipment, are based upon an hourly rate for Government ownership that is computed using Office of Management and Budget (OMB) Circular No. A-94. Quoted rates for the vendor's costs are used in this analysis for performing training of the site's personnel and include the vendor's G&A, overhead, and fee mark up costs. Additionally, the analysis uses an 8-h work day with a 5-day week. The production rates and observed duration used in the cost analysis do not include "non-productive" items such as work breaks, donning and doffing clothing, loss of dexterity [(due to cumbersome personnel protective equipment (PPE)], and heat stress. These "non-productive" items are accounted for in the analysis by including a Productivity Loss Factor (PLF). The PLF is an historically based estimate of the fraction of the workday that the worker spends in non-productive activities.

Cost Data

The prices shown in Table 1 are based on recent quotes from the vendor. These prices will change as the vendor refines the cost for manufacturing and the market potential is better understood.

Table 1. Innovative technology acquisition costs

ACQUISITION OPTION	ITEM	COST
Equipment Purchase	GammaCam™	$163,000 - $ 200,000
Vendor Provided Service	Instruction	$ 5,817
Equipment Lease	1 Month 2 Month 3 Month	$ 30,000 $ 25,000 /month $ 20,000 / month

Observed unit costs and production rates for principal components of the demonstrations for both the innovative and baseline technologies are presented in Table 2.

The unit costs and production rates shown do not include mobilization, set-up, or other losses associated with non-productive portions of the work (such as suit-up, breaks, etc.). The preliminary survey, shown below, is intended to locate the "hot spots" while the detailed survey provided mapping of the source. The preliminary and detailed surveys, using GammaCam™, have different field of views and set-up distances. Consequently, the detailed survey covers a smaller area per unit of time relative to the preliminary survey.

Table 2. Summary of unit costs and production rates observed during the demonstration

INNOVATIVE TECHNOLOGY			BASELINE TECHNOLOGY		
Cost Element	**Unit Cost**	**Production Rate**	**Cost Element**	**Unit Cost**	**Production Rate**
Preliminary Survey	$9.00 each	2 min each	Preliminary Survey	Not Predictable	
Detailed Survey	$0.28/ft^2	15 ft^2/min	Detailed Survey	$0.34/ft^2	5.6 ft^2/min

Summary of Cost Variable Conditions

The DOE complex presents a wide range of D&D work conditions because of the variety of functions and facilities. The working conditions for an individual job directly affect the manner in which D&D work is performed and, as a result, the costs for an individual job are unique. The innovative and baseline technology estimates presented in this analysis are based upon a specific set of conditions or work practices found at CP-5, and are presented in Table 3. This table is intended to help the technology user identify work differences that can result in cost differences.

Table 3. Summary of cost variable conditions

Cost Variable	GammaCam™	Manual Survey
Scope of Work		
Quantity and Type	One preliminary scan to cover 205 ft^2 and two detailed scans to delineate hot spots to cover 62 ft^2	Manual survey using an Eberline RO-7 with preliminary survey of area and follow-up survey of hot spots covering 62 ft^2
Location	Vault located below the reactor floor (Cave Room) and reactor core	Assumed to be reactor core
Nature of Work	Preliminary survey performed at a distance identifies hot spots and follow-up survey provides detailed survey at close range of any identified hot spots	Preliminary survey from walkway across reactor moving extended probe around the reactor area to determine where sources are located, shielding and plans for follow-up survey are developed based on the preliminary survey, and the follow-up survey sweeps the probe over the hot spot surfaces
Work Environment		
Worker Protection	Anti-contamination coveralls with hood and respirator	Anti-contamination coveralls with hood and respirator
Level of Contamination	Classified as a contaminated area and a radiation area	Classified as a contaminated area and a radiation area
Work Performance		
Acquisition Means	Equipment leased and operation performed by site personnel (initial instruction in operation provided by vendor)	Site personnel with site owned equipment
Production Rates	Rates for preliminary surveys varied from 205 ft^2/min to 1,584 ft^2/min (cost analysis based on 205 ft^2/min) and detailed survey varied from 21 ft^2/min to 51 ft^2/min (cost analysis based on 31 ft^2/min)	Preliminary survey is not a structured procedure (no production rate) and the detailed survey uses a production rate of 5.5 ft^2/min (observed in manual surveys of the fuel storage basin, C-Reactor, Richland Operation Office)
Equipment and Crew	One HPT and one D&D worker for setup and operation	Two HPTs using one RO-7
Work Process Steps	1. Ship equipment to site 2. Transport from receiving to work location 3. Instruction for operators (one time) 4. Setup equipment and wrap with plastic 5. Preliminary survey 6. Detailed surveys 7. Data evaluation 8. Decontaminate and release 9. Transport to Shipping/Receiving 10. Shipping to New York	1. Prepare survey plans 2. Transport to work area 3. Setup 4. Conduct preliminary survey 5. Decontaminate and release 6. Return transport 7. Develop shielding and plans for follow-up survey 8. Transport to work area 9. Setup 10. Conduct detailed survey 11. Decontaminate and release 12. Return transport 13. Data Evaluation and Report
End Product	Characterization for planning work	Characterization for planning work

Potential Savings and Cost Conclusions

Innovative Technology

The costs elements for the GammaCam™ are shown in Figure 9. A significant portion of the cost is related to a one time expense for instructing the site personnel who will operate the equipment and for mobilization and demobilization of the equipment (where the equipment is leased). The costs for the GammaCam™ are sensitive to the rates charged for leasing the equipment which is related to the length of time for the lease (rates used in this analysis were based on a one month lease). The number of hot spots identified will control the number of setups and surveys and affects costs substantially. Additionally, the cost for shipment can vary, depending upon distance and location of site. The time required to ship, which can vary from 3 to 10 days, will also impact the length of time required for leasing. Another factor that can result in significant cost variation is the geometry of the area being scanned. Lower survey production rates may result from columns or objects that block the view of the scanner due to additional setups or less than optimal distances from the object. Production rates for scans at a distance of 11 ft and 50 degree field of view were 137 ft^2/min while scans at distances of 6 ft and 25 degree field of view were 6.2 ft^2/min. Finally, depending on the strength of the source, the production rate may vary due to time required to achieve the proper resolution.

The GammaCam™ technology may be more cost attractive for use in radiation fields higher than those measures in CP-5 demonstration. In situations where the radiation field severely limits work time and requires substantially more preparation for entry than was assumed in the baseline for this analysis, then the GammaCam™ could have substantial advantages. In some instances of extremely high radiation doses, the GammaCam™ is an enabling technology, allowing location and relative quantification of source term strength in areas where the baseline technology (manual surveys) is not an option.

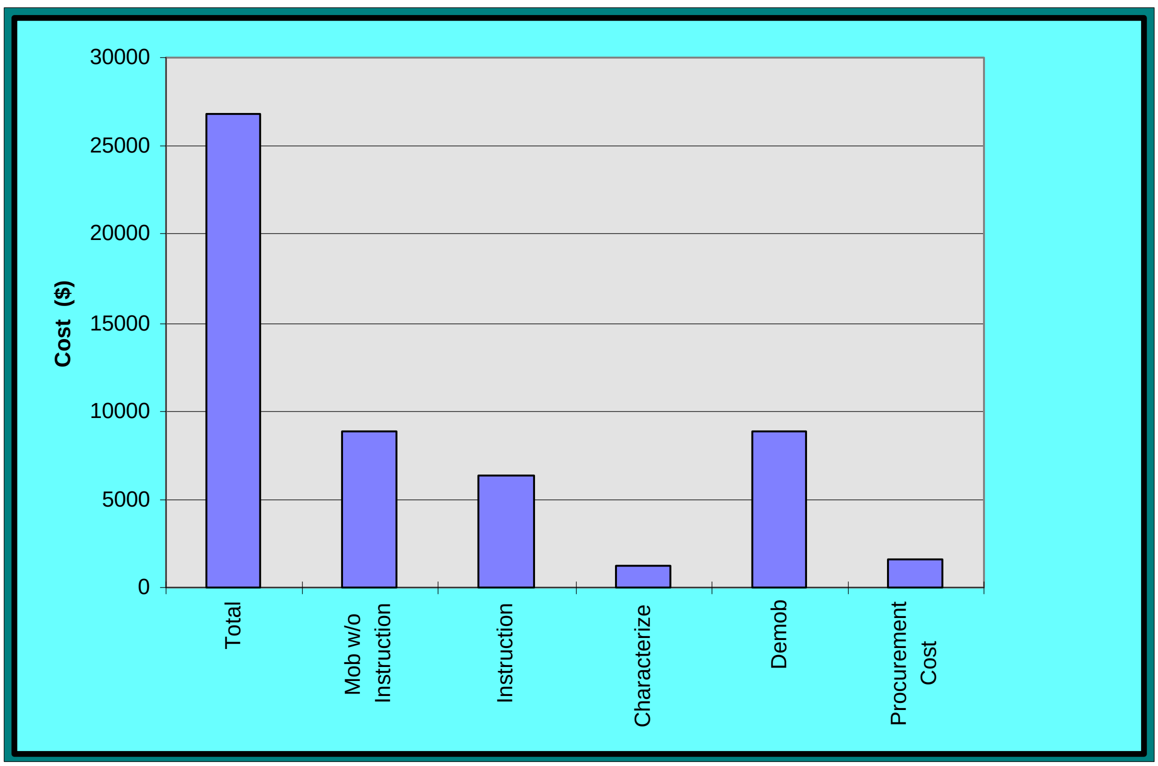

Figure 9. GammaCam™ cost.

Baseline

The costs for the baseline approach are shown in Figure 10. These costs are based on surveys being performed in areas of relatively low personnel exposure where few limitations of worker stay times need to be imposed. The costs for performing work in more severe radiation fields will be substantially greater than the cost shown in this analysis.

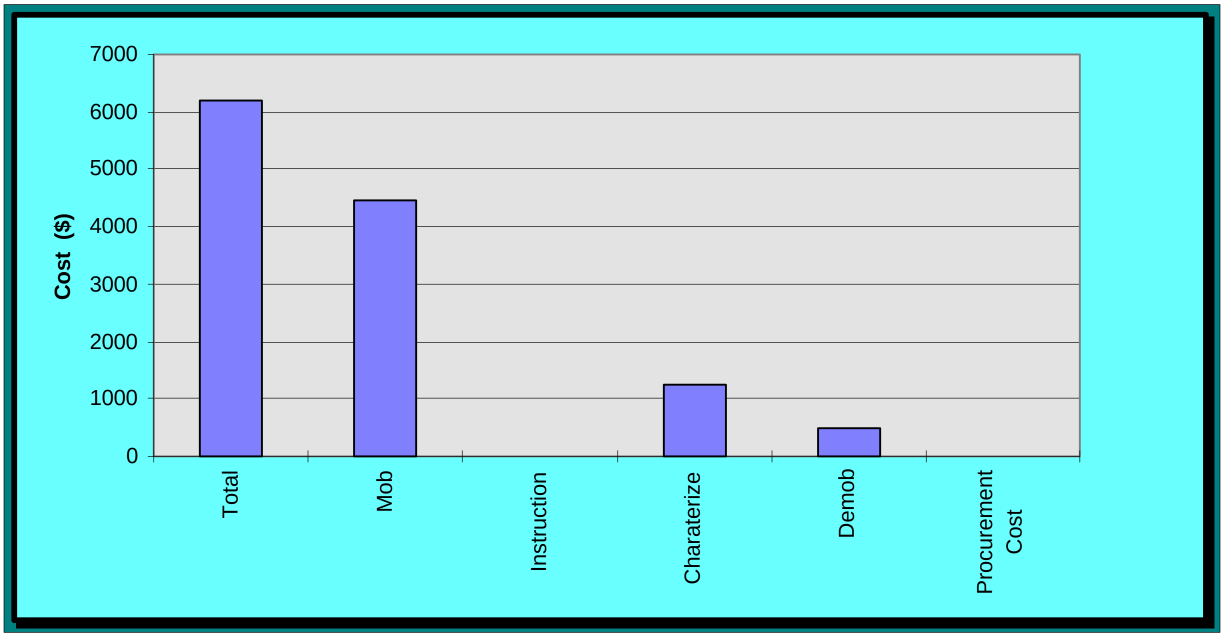

Figure 10. Baseline cost.

Comparison

The innovative cost is compared with the baseline cost as a function of the size of the job in Figure 11. Two situations are analyzed: 1) typical (set-ups for 200 ft^2 is 3 and 15 for 1,000 ft^2; and 2) obscured where columns and equipment require more set-ups (assume 10 at 200 ft^2 and 100 for 1,000 ft^2). The baseline method is not sensitive to this parameter and is shown as a single line.

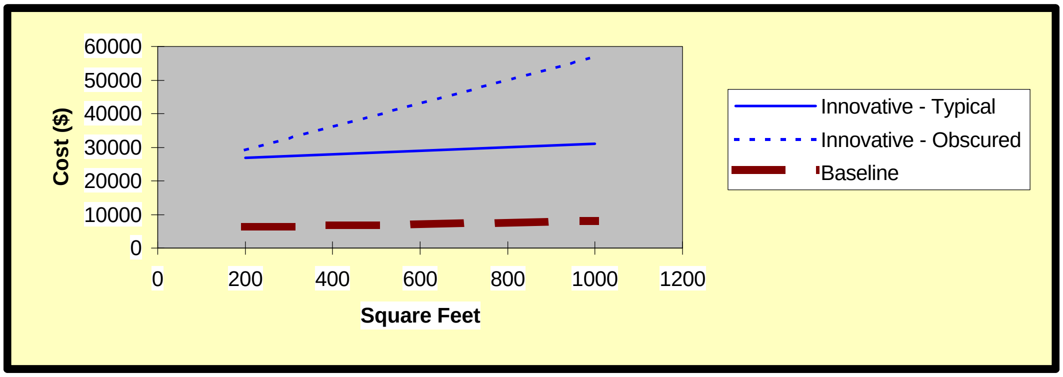

Figure 11. Comparison of innovative and baseline.

SECTION 6

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Regulatory Considerations

The regulatory/permitting issues related to use of the GammaCam™ technology at the ANL CP-5 Research Reactor consist of the following safety and health regulations:

- Occupational Safety and Health Administration (OSHA) 29 *Code of Federal Regulations* (CFR) 1926

—1926.300 to 1926.307	Tools - Hand and Power
—1926.400 to 1926.449	Electrical - Definitions
—1926.28	Personal Protective Equipment
—1926.52	Occupational Noise Exposure
—1926.102	Eye and Face Protection
—1926.103	Respiratory Protection

- OSHA 29 CFR 1910

—1910.101 to 1910.120 (App E)	Hazardous Materials
—1910.211 to 1910.219	Machinery and Machine Guarding
—1910.241 to 1910.244	Hand and Portable Powered Tools and Other Hand-Held Equipment
—1910.301 to 1910.399	Electrical - Definitions
—1910.95	Occupational Noise Exposure
—1910.132	General Requirements (Personal Protective Equipment)
—1910.133	Eye and Face Protection
—1910.134	Respiratory Protection
—1910.147	The Control of Hazardous Energy (Lockout/Tagout)

- 10 CFR 835 — Occupational Radiation Protection

Since GammaCam™ is designed for use when decontaminating structures, there is no regulatory requirement to apply CERCLA's nine evaluation criteria. However, some evaluation criteria required by CERCLA, such as protection of human health and community acceptance, are briefly discussed below. Other criteria, such as cost and effectiveness, were discussed earlier in this document.

Safety, Risks, Benefits, and Community Reaction

The safety issues with the GammaCam™ system are limited to those routinely encountered in an industrial environment.

Reduction in personnel radiation exposures should also be realized by reducing the amount of time personnel are required to collect data in a radiological area.

A benefit of GammaCam™ is that superimposed radiation and visual images can provide the public with an improved understanding and confidence in the measured data.

SECTION 7

[redacted]

Implementation Considerations

The GammaCam™ system demonstrated at CP-5 is a commercially available instrument. During the tests, the sensor head and data processing unit were moved many times within the facility and no problems were encountered. The distance between the sensor head and the control computer is limited to 200 ft. As configured, the system requires 120 VAC power, which may be a problem in remote areas or in facilities where the power has been disconnected. A key advantage of the system is that it provides images even if the sensor head is located in a high background radiation field. The primary weaknesses of the system are that GammaCam™ cannot directly measure a uniform radiation field and there is a need to watch for image artifacts under certain conditions.

As compared to the baseline of manual surveys, use of the GammaCam™ system may:

- increase the speed at which HPTs can survey radiation fields;
- result in lower exposures to personnel performing surveys, particularly in high radiation areas;
- provide better characterization information on the position and relative strength of gamma radiation sources; and
- aid public acceptance that remediation efforts were complete and successful.

Technology Limitations and Needs for Future Development

There are several limitations associated with the use of coded aperture system that need to be considered in planning a radiation survey. The first is that a radiation field with a uniform intensity will not be detected. This problem can be overcome by making sure that the field-of-view includes a non-uniform region. The second is that the system can introduce image artifacts for objects near the edge of the field-of-view. For example, a source located on the left side of the image can produce an image where there is an artifact image on the right side. The size and position of the artifacts are well known and the impact of the artifact can be minimized by operator training. The coded aperture system also has some limitations in terms of the maximum-to-minimum signal that can be detected across the field-of-view in the presence of noise. This is a result of each signal being distributed across the scintillator screen. The transforming of the measured detector spatial distribution into an actual radiation-field distribution requires separating these various components from each other and this can lead to limitations on the ratio of the maximum-to-minimum signal detected. Typical values for the maximum-to-minimum signal ratio varied from 2.6 to 30 in these tests with a mean value of 14.

The GammaCam™ system technology would benefit from the following design improvements:

- Indication on the final image of the parallax between the radiation and visual field-of-view.
- Implementation of a range meter to provide the distance between the sensor head and the radiation source to allow more reliable estimates of the actual source strength.

Technology Selection Considerations

Any large nuclear site can use this technology. The GammaCam™ system is used to provide visual information on the location and relative strengths of radioactive sources. It will reduce radiation exposures since this information can be obtained with minimum radiation dose to the technician. This information can also be obtained without construction of elaborate shielding and will therefore reduce costs in situations that would normally require substantial preparation before entry. The system is also well suited to monitor a radiation field over time. One application is to use the system to monitor the radiation changes within a piping system during the decontamination process. The system has some minor limitations in regards to imaging uniform fields and artifacts, but these can be minimized by operator training.

APPENDIX A

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APPENDIX B

TECHNOLOGY COST COMPARISON

This appendix contains definitions of cost elements, descriptions of assumptions, and computations of unit costs that are used in the cost analysis.

Innovative Technology - GammaCam™

Mobilization (mob) (WBS 331.01)

Ship Equipment

Definition: Transport GammaCam™ equipment from Deer Park, New York to Shipping/Receiving at Argonne National Laboratory. This cost element includes the added time required for lease of the equipment due to time spent in shipment.

Assumptions: Based on quoted rates from United Van Lines of $307.90 one way plus $411 for insurance (covers both ways) and 7 to 10 days for shipping ($307.90 + $411/2 = $513.40). Additional costs include equipment stand-by time for 7 days. For a one month lease ($30,000 per month/22 days per month/8 hours per day = $170.45/h). The lease rate for 3 months is $20,000 per month and for 2 months is $25,000 per month.

Unload and Transport

Definition: Transport GammaCam™ equipment from receiving area to CP-5. This cost element includes the added time required for lease of the equipment due to time spent in transport.

Assumptions: Assumed to include one heavy truck and driver for 2 h. Rate for truck driver based on rental rate from Means (1996 Means) of $19/h. Standby for GammaCam equipment is included.

Unpack, Survey, and Prepare

Definition: Equipment is unpacked, surveyed for radiological contamination, and prepared for use (includes wrapping cables and body with plastic to minimize potential contamination).

Assumptions: Assumed duration of 4 h and crew make up based on judgment of the test engineer. Crew consists of one HPT and one D&D worker ($56/h + $33.60/h = $89.60/h) for 4 h.

Instruction for Site Crew

Definition: Instruction to ensure proper use and interpretation of characterization results. This is an estimated activity and was not observed during the demonstration.

Assumptions: It assumes that the vendor provides one operator to perform on-the-job training during the first day of operation of the equipment. Cost is based on quote from vendor for $5,817. It is assumed that the instruction is conducted concurrent with performing work. Consequently, there are no allowances for the ANL crew in the instruction time.

Set Up and Move for Next Survey

Definition: Time required for setting up, allowing equipment to reach operating temperature, and moving from one survey location to the next.

Assumptions: The duration is assumed to be 1/2 h (15 min required for reaching operation temperature). Crew is assumed (based on judgment of the test engineer for what would be normal practice for work) to consist of one HPT and one D&D worker.

Preliminary Survey

Definition: A survey of a large area at low resolution for the purpose of identifying "hot spot" locations.

Assumptions: A preliminary type of survey was assumed to use a 50 degree field of view. The scan for Cave 4 was used to represent this type of preliminary survey. Wall area scanned was 205 ft^2. Crews were assumed (based on the judgment of the test engineer for what would be normal practice for D&D work) to consist of one D&D worker and one HPT.

Detailed Survey

Definition: After the preliminary survey has identified the hot spot locations, the GammaCam™ equipment is moved to a closer proximity to the hot spot for detailed survey.

Assumptions: The surveys for Cave 5 and Core 4 were used for detailed scans. Even though these surveys did not necessarily cover the same area as the preliminary scan, they were assumed to be representative of detailed type of scans because they had a 25 degree field of view and had adequate resolution. The analysis uses the total of the duration for each of these scans and the total of the area covered by each of these scans in the analysis. Consequently, the unit cost for the detailed scan is based on an average 4 min/62.6 ft^2. Crews were assumed (based on the judgment of the test engineer for what would be normal practice for work) to consist of one D&D worker and one HPT.

Evaluate Data and Produce Final Report

Definition: This activity includes review of the data and summarizing into a final report.

Assumptions: The duration and crew for this activity are assumed to be 1 h for one HPT.

PPE

Definition: This cost element provides for the personal protective clothing used during the work activity.

Equipment	Quantity in Box	Cost Per Box	Cost Each	No. of Reuses	Cost Each Time Used	No. Used Per Day	Cost Per Day
Respirator			1,933	200	10	1	10.00
Resp. Cartridges			9.25	1	9.25	2	18.50
Booties	200	50.00	0.25	1	0.25	4	1.00
Tyvek	25	85.00	3.4	1	3.4	4	13.60
Gloves (inner)	12	2.00	0.17	1	0.17	8	1.36
Gloves (outer)			7.45	10	0.75	1	0.75
Glove (cotton liner)	100	14.15	0.14	1	0.14	8	1.12
Total							46.33

The PPE costs are predominantly from the ANL activity cost estimate (ACE) sheets for 1996. (Costs for outer gloves, glove liners, and respirator cartridges are from commercial catalogs.)

Daily Meeting

Definition: This cost element provides for safety meeting and project planning meetings during the work.

Assumptions: The estimate assumes one 15 min safety meeting per day (based on typical practice at ANL).

Productivity Loss Factor

Definition: Losses from productive work occurring during the course of the work due to PPE changes, ALARA, height of reach inefficiencies, etc.

Assumption: The duration used for the preliminary survey and the detailed survey do not account for work breaks or PPE changes, and were not observed and recorded during the demonstration. Consequently, these types of costs are estimated and added to the cost for the innovative technology in this cost element. The duration of work performed in the controlled area (activities outside the controlled area, such as evaluation of the data, are not included in the computation) is adjusted by a factor of 1.27 to account for these losses (particularly work breaks and suiting up) based on the factors shown below (AIF, 1986):

Base	1.00	
+Height	0	
+Rad/ALARA	0	(not considered since most work is waiting)
+Protective Clothing	0.15	
= Subtotal	1.15	
X		
Resp Prot	1.00	(no factor used, losses included in observed times)
=Subtotal	1.15	
X		
Breaks	1.10	
=Total	1.27	

Demobilization (WBS 331.21)

Survey Equipment and Decontaminate

Definition: GammaCam™ equipment is surveyed for contamination and decontamination is performed as needed for free release.

Assumption: The assumed duration of 4 h was used for a crew of one HPT.

Load and Transport Equipment

Definition: Same as Mobilization - Unload and Transport

Shipping

Definition: Same as Mobilization - Shipping

Procurement Costs

Definition: This cost element accounts for the 9.3 percent costs charged to the project for award of the GammaCam™ equipment lease and administration of that procurement.

Costs for demonstration of the GammaCam™ innovative technology are based on assuming a preliminary survey (using Cave 4) followed by more detailed surveys of hot spots identified by the preliminary survey (Cave 5 and Core 4). This scenario is intended to represent the cost for normal D&D work using the GammaCam™ (normal being defined by the vendor experience and judgment of the test engineer) and does not follow the sequence of events of the demonstration. Other adjustments of the observed data from the demonstration are shown below:

- Work will be performed assuming the equipment is leased and operated by site workers (rather than purchase of equipment or vendor provided service) because of the relatively large capital expense, the limited number of opportunities to use the equipment, cost for mobilizing vendor personnel and the relative ease of learning to operate the equipment.

- GammaCam™ equipment hourly rates were based on vendor quotes (based on one month lease).

- During the demonstration, the vendor personnel as well as the HPT and D&D personnel were present throughout the demonstration and this is assumed to not represent normal work (assume one HPT and one D&D worker).

The activities, quantities, production rates and costs observed during the demonstration are shown in Table B-1, Cost Summary: Innovative Technology-GammaCam™.

TABLE B-1 Cost Summary: Innovative Technology-GammaCam™

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor HRS	Labor Rate	Equipment HRS	Equipment Rate	Other	Total UC	Total Quantity (TQ)	Unit of Measure	Total Cost (TC) note	Comments
MOBILIZATION 331.01								**Subtotal**	**$15,208**	
Ship Equipment	0.00	$ -	40.00	$170.45	$ 513	$7,331	1	Each	$ 7,331	Shipping from Deer Park, NY to Argonne National Laboratory (ANL) (equipment lease period extended by shipping time of one week) lease rate is $170.45/h
Unload & Transport	2.00	$49.67	2.00	$189.45		$ 478	1	Each	$ 478	Teamster and Truck to transport equipment from receiving to CP-5 plus standby for GammaCam equipment
Unpack, Survey & Prepare	4.00	$89.60	4.00	$170.45		$1,040	1	Each	$ 1,040	One Health Physics Technician (HPT) @ $56/h and one D&D worker at $33.60/hr (includes wrapping instrument with plastic sheeting, instrument check out and initialization)
Instruction for Site Crew					$6,358	$6,358	1	Each	$ 6,358	One time cost for vendor to travel to site, participate in site required training, provide on the job training to site crew, and return home (includes 9.3% additional cost for ANL procurement)
CHARACTERIZATION 331.17								**Subtotal**	**$ 1,223**	
Set-Up & Move	0.50	$89.60	0.50	$170.45		$ 130	3	Location	$ 390	Initial setup, move equipment to next survey location, and prepare for next survey (preliminary and 2 detailed survey) 1/2 h includes required time for equipment to reach operating temperature crew is 1 HPT and 1 D&D
Preliminary Survey	0.0002	$89.60	0.0002	$170.45		$ 0	205	Square Feet	$ 9	Identify location of hot spots from a distance of 6 ft with 50 degree field of view (205 ft^2 surveyed in 2 minutes), crew includes one HPT and one D&D worker

TABLE B-1 Cost Summary: Innovative Technology-GammaCam™ (cont.)

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor HRS	Labor Rate	Equipment HRS	Equipment Rate	Other	Total UC	Total Quantity (TQ)	Unit of Measure	Total Cost (TC) note	Comments
Detailed Survey	0.0011	$89.60	0.0011	$170.45		$ 0	62.6	Square Feet	$ 17	Detailed survey of two hot spots, distance of 6 ft with field of view of 25 degrees (2 scans of 31.3 ft^2 each and 2 minutes each survey), crew includes one HPT and one D&D worker
Evaluate Data & Final Report	1.00	$56.00				$ 56	1	Each	$ 56	One HPT
PPE					$ 46	$ 46	2	Man Day	$ 93	Assumed cost per person per day of $46.33
Daily Meeting	0.50	$89.60	0.50	$170.45		$ 130	1	Each	$ 130	One safety meeting each morning prior to beginning work
Productivity Loss Factor	2.03	$89.60	2.03	$170.45		$ 528	1	Each	$ 528	Duration in controlled area X 1.27%
DEMOBILIZATION 331.21								Subtotal	**$ 8,821**	
Survey Equip & Decon	4.00	$56.00	4.00	$170.45	$ 106	$1,011	1	Each	$ 1,011	Survey equipment for free release and remove protective plastic wrap, other costs include waste disposal of 2 ft^3 of low level waste @ 52.78/ ft^3
Load & Transport Equipment	2.00	$49.67	2.00	$189.45		$ 478	1	Each	$ 478	Teamster and Truck to transport equipment to shipping/receiving
Shipping	0.00	$ -	40.00	$170.45	$ 513	$7,331	1	Each	$ 7,331	Return to Deer Park, NY
PROCUREMENT COST									**$ 1,601**	
Procurement Cost					$1,601	$1,601	1	Each	$ 1,601	Cost for procurement of equipment of 9.3% of amount of procurement (standard rate for ANL contracting)

Note: TC = UC * TQ

TOTAL: $26,853

Mobilization (WBS 331.01)

Preliminary Survey Plans

Definition: This cost element is for planning the initial manual survey and developing the necessary documentation that is needed to allow that work to begin.

Assumption: The effort is assumed to be 4 h for 1 HPT @ $56.00/h.

Transport Personnel and Equipment

Definition: The on-site transport to the CP-5 is provided in this cost element.

Assumption: The effort is assumed to be 1 h for a crew of two HPT's. This work will be performed twice, once for the preliminary survey and once for the detailed survey.

Source Check Instrument

Definition: Response check for Eberline RO-7.

Assumptions: The effort is assumed to be 10 min. This work will be performed twice, once for the preliminary survey and once for the detailed survey.

Detailed Survey Plans

Definition: This cost element is for planning the follow-up survey, which will provide detailed surveys of the hot spots identified in the initial survey and provide the necessary documentation needed for that work to begin.

Assumption: The effort is assumed to be 8 h for one HPT.

Shielding Preparation

Definition: This cost element provides for collecting the shielding for the detailed surveys and getting it in place.

Assumptions: The effort is assumed to be 2 days for a crew of two HPTs. Costs for the shielding is assumed to be $ 1,739 for twenty 12 inch X 72 inch lead wool blankets (based on historic costs from previous D&D projects at ANL).

Characterization (WBS 331.17)

Set-Up and Move

Definition: Time required for setting up in one location, initializing the GammaCam equipment, waiting for the operating temperature to stabilize, and moving from one survey area to the next.

Assumptions: The duration is ½ h per location (one preliminary and two detailed) and the crew is assumed (based on the judgment of the test engineer) to be one D&D worker and one HPT.

Preliminary Survey

Definition: RO-7 probe is attached to a long rod (provides distance between HPT and the source) which is moved around within the volume of the area being surveyed. Areas having strong sources are identified for follow-up survey. Readings are noted as the probe is moved.

Assumptions: Total duration of survey is assumed to be 15 min. The crew is assumed to be two HPT's.

Detailed Survey

Definition: Detailed survey of previously identified hot spots using the RO-7 with extended probe. The probe is swept over the surface and readings are manually recorded.

Assumptions: The production rate used is 5.5 ft^2/min based on observed duration of similar work (with the RO-7) in the fuel storage basin at the C-Reactor, Richland Operations Office. Crew is assumed to be two HPT's.

Daily Meeting

Definition: This cost element provides for safety meeting and project planning meetings during the work.

Assumptions: The estimate assumes one 15 min safety meeting per day (based on typical practice at ANL). This work will be performed twice, once for the preliminary survey and once for the detailed survey.

PPE

Definition: This cost element provides for the personal protective clothing used during the work activity.

Equipment	Quantity in Box	Cost Per Box	Cost Each	No. of Reuses	Cost Each Time Used	No. Used Per Day	Cost Per Day
Respirator			1,933	200	10	1	10.00
Resp. Cartridges			9.25	1	9.25	2	18.50
Booties	200	50.00	0.25	1	0.25	4	1.00
Tyvek	25	85.00	3.4	1	3.4	4	13.60
Gloves (inner)	12	2.00	0.17	1	0.17	8	1.36
Gloves (outer pair)			7.45	10	0.75	1	0.75
Glove (cotton Liner)	100	14.15	0.14	1	0.14	8	1.12
Total							46.33

The PPE costs are predominantly from the ANL activity cost estimates for 1996 (costs for outer gloves, glove liners, and respirator cartridges are from commercial catalogs).

Productivity Loss Factor

Definition: Losses from productive work occurring during the course of the work due to PPE changes, ALARA, height of reach inefficiencies, etc.

Assumption: The duration used for the preliminary survey and the detailed survey do not account for work breaks or PPE changes, and were not observed and recorded during the demonstration. Consequently, these types of costs are estimated and added to the baseline cost in this cost element. The duration of work performed in the controlled area (activities outside the controlled area, such as evaluation of the data, are not included in the computation) is adjusted by a factor of 1.27 to account for these losses (particularly work breaks and suiting up) based on the factors shown below (AIF, 1986):

Base	1.00
+Height	0
+Rad/ALARA	0 (not considered, most work is waiting)
+Protective Clothing	0.15
= Subtotal	1.15
X	
Resp Prot	1.00 (no factor used, losses observed)
=Subtotal	1.15
X	
Breaks	1.10
=Total	1.27

Data Evaluation and Report

Definition: This cost element provides for review of the survey results and development of survey reports (including maps of the maximum readings).

Assumptions: The effort for this is assumed to require 10 hours.

Demobilization (WBS 331.21)

Decontaminate and Survey Out

Definition: Equipment and personnel are surveyed for contamination and decontamination is performed as needed for free release.

Assumption: The duration of 1 h is assumed for two HPT's. This work will be performed twice, once for the preliminary survey and once for the detailed survey.

Transport for Return

Definition: Same as Mobilization - Unload and Transport

Assumption: This work will be performed twice, once for the preliminary survey and once for the detailed survey.

- The manual survey of the reactor core area is assumed to consist of a preliminary survey from the walk way crossing the reactor top where the location of potential hot spots are identified. This is followed with planning for the follow up survey of the hot spots and development of shielding to protect the HPTs during the detailed survey. The survey work is performed using an RO-7 with extended probe.

- The hourly rates for government owned equipment are based on amortizing the initial purchase price, including its shipping costs, over the service life of the equipment using a discount rate prescribed in the OMB circular No. A-94 of 5.8%. Service life of 5 to 15 yrs (depending on the individual piece of equipment) is used with an assumed use of 500 hours per year.

- The radiological data collected will not be used for compliance with closure requirements, but will be used in planning D&D work.

The activities, quantities, production rates and costs utilized in the baseline are shown in Table B-2.

TABLE B-2 Cost Summary: Baseline Technology - Manual Survey

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor Hour	Labor Rate	Equipment Hour	Equipment Rate	Other	Total UC	Total Quantity (TQ)	Unit of Measure	Total Cost (TC) note	Comments
Mobilization (WBS 331.01)								**Subtotal**	**$ 4,467**	
Preliminary Survey Plans	4	$ 56.00	0	$ -	$ -	$ 224.00	1	Each	$ 224	Labor for one health physics technician (HPT) @ $56/h standard rate for Argonne National Laboratory (ANL)
Transport to Work Area	1	$112.00	1	$ 1.25		$ 113.25	2	Each	$ 227	Two trips (for preliminary survey and again for detailed survey) crew of two HPTs plus one Eberline RO-7
Source Check Instrument	0.1666	$112.00	0.1666	$ 1.25		$ 18.87	2	Each	$ 38	Two trips (preliminary and detailed surveys)
Detailed Survey Plans	8	$ 56.00	0			$ 448.00	1	Each	$ 448	One HPT
Shielding Preparation	16	$112.00			$1,739	$ 3,531.00	1	Each	$ 3,531	Two HPTs and 20 lead blankets at $87 each.
Characterization (WBS 331.17)								**Subtotal**	**$ 1,268**	
Setup and Move	0.5	$112.00	0.5	$ 1.25		$ 56.63	3	Each	$ 170	Crew of two HPTs and an Eberline RO-7 includes setup in survey area for preliminary survey and detailed surveys
Preliminary Survey	0.25	$112.00	0.25	$ 1.25		$ 28.31	1	Each	$ 28	Crew of two HPTs quickly determine which areas are hot and which are not
Detailed Survey	0.003	$112.00	0.003	$ 1.25		$ 0.34	62.6	Square Feet	$ 21	Crew of two HPTs survey identified hot areas, based on a production rate of 5.5 ft^2/min
Daily Meeting	0.25	$112.00	0.25	$ 1.25	0	$ 28.31	2	Each	$ 57	Typical daily meeting for D&D work at ANL is 15 min (for 2 events, preliminary and detailed surveys)
Personal Protection Equip	0	$ -	0	$ -	$ 46	$ 46.33	4	Man Day	$ 185	Assumed cost per person per day of $46.33 (for 2 events, preliminary and detailed surveys)
Productivity Loss Factor	2.4634	$ 98.90	2.4634	$ 1.25		$ 247	1	Each	$ 247	Productivity Loss Factor (adjusts for changes, breaks, respiratory protection, and ALARA and extends the work duration by 127%)
Data Evaluation and Report	10	$ 56.00				$ 560.00	1	Each	$ 560	

TABLE B-2 Cost Summary: Baseline Technology - Manual Survey (cont.)

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor Hour	Labor Rate	Equipment Hour	Equipment Rate	Other	Total UC	Total Quantity (TQ)	Unit of Measure	Total Cost (TC) note	Comments
Demobilization (WBS 331.21)								**Subtotal**	**$ 479**	
Decon and Survey Out.	1.00	$112.00	1	$ 1.25	$ 13	$ 126.45	2	Each	$ 253	HPT labor and ¼ ft^3 of Low Level waste disposal for swipes @ $52.78/ ft^3 (for 2 events, preliminary and detailed surveys)
Transport for Return	1	$112.00	1	$ 1.25	$ -	$ 113.25	2	Each	$ 227	Same as Mobilization cost element

Note: TC = UC * TQ **TOTAL $ 6,215**

APPENDIX C

[redacted]

ACE	Activity Cost Estimate
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
CCD	Charged Coupled Detector
CFR	Code of Federal Regulations
CP-5	Chicago Pile-5 Research Reactor
Cs^{137}	Cesium - 137
D&D	decontamination and decommissioning
DDFA	Deactivation and Decommissioning Focus Area
DOE	Department Of Energy
ESH	Environment, Safety and Health
FCCM	Facilities Capital Cost Of Money
FETC	Federal Energy Technology Center
ft	foot (feet)
ft^2	square feet
G&A	General and Administrative
HEPA	High Efficiency Particulate-Air
H&S	Health And Safety
HP	health physics
HPT	Health Physics Technician
h	hour (s)
HTRW	hazardous, toxic, radioactive waste
Hz	Hertz
kB	kilo-bytes
ICT	Integrating Contractors Team
LCD	Liquid Crystal Display
lin ft	linear feet (foot)
LLW	low-level waste
LS	lump sum
LSDP	Large-Scale Demonstration Project
MeV	Mega-electron Volts
min	minute (s)
μR	micro-Rad
mR	milliRad
NESP	National Environmental Studies Project
OMB	Office of Management and Budget
OSHA	Occupational Health and Safety Administration
PC	personal computer
PLF	productivity loss factor
PPE	personnel protective equipment
RA	Remedial Action
USACE	United States Army Corps of Engineers
VAC	Volts - Alternating Current
WBS	Work Breakdown Structure