INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0593

GammaModeler™ 3-D Gamma-Ray Imaging Technology

Deactivation and Decommissioning Focus Area
and Characterization, Monitoring, and Sensor
Technology Crosscutting Program

Prepared for
U.S. Department of Energy
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Summary Report

GammaModeler™ 3-D Gamma-Ray Imaging Technology

OST/TMS ID 2402

Deactivation and Decommissioning Focus Area
and Characterization, Monitoring, and Sensor
Technology Crosscutting Program

Demonstrated at
U. S. Department of Energy
Hanford Site, 221-U Facility
Richland, Washington

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 on the OST Web site at www.ost.em.doe.gov/ost under "Publications."

TABLE OF CONTENTS

SECTION 1

SUMMARY

Technology Summary

Project Background

The Canyon Disposition Initiative (CDI) project is evaluating the feasibility of using the DOE Hanford site processing facilities as assets for disposal of low-level wastes. As part of the study, an extensive characterization of the 221-U facility is underway as the “pilot” facility. In support of CDI characterization project objectives, the GammaModeler™ system was comprehensively demonstrated to facilitate deployment of 3-D Visual and Gamma-Ray Imaging technology, and to compare performance and cost of the GammaModeler™ to the GammaCam™ (2-D system). The GammaModeler™ system was used to survey a portion of the facility and provide 3-D visual and radiation representation of contaminated equipment located within the facility.

The 3-D GammaModeler™ system software was used to deconvolve extended sources into a series of point sources, locate the positions of these sources in space and calculate the 30 cm. dose rates for each of these sources. Localization of the sources in three dimensions provides information on source locations interior to the visual objects and provides a better estimate of the source intensities. The three dimensional representation of the objects can be made transparent in order to visualize sources located within the objects. Positional knowledge of all the sources can be used to calculate a map of the radiation in the canyon. The use of 3-D visual and gamma ray information supports improved planning decision-making, and aids in communications with regulators and stakeholders with only a minimal cost increase (<10%).

System Description

The 3-D GammaModeler™ visual and gamma ray imaging system was developed by AIL Systems Inc. to remotely survey large areas for gamma-ray emissions and display the results as combined 3-D representations of the radiation sources and the equipment. The GammaModeler™ system is an upgrade of the AIL GammaCam™ system that provides 2-D images of the radiation environment overlaid on the video picture of the scene. The 3-D GammaModeler™ system consists of four modules: a sensor head, a portable PC compatible computer, a pan and tilt controller, and a 3-D workstation. The sensor head, shown in figure 1, incorporates a coded aperture gamma ray imaging detector, a high-resolution video camera, a laser range finder (new), and a pan and tilt assembly (new). The sensor head is controlled remotely by the PC and the pan and tilt controller. The pan and tilt assembly allows the sensor head to be panned a full 360 degrees and tilted +/- 73 degrees. The sensor head was mounted the canyon crane hook with a special interface mount. Remote operation and control of the sensor head allows for safe image acquisition in high radiation environments, minimizing operator exposure. During image taking operation, a pseudo-color image of gamma ray emitting sources is overlaid on the video picture of the scene.

Figure 1 GammaModeler™ Sensor Head

At each camera location with observed gamma ray emissions, additional images are taken of key reference features in the scene along with the measured range, and pan and tilt directions to these features. Viewing the same features from another location allows the relative camera positions to be calculated. These calculated camera positions are adjusted to place the object at a desired position or an absolute position if known. Knowledge of the camera locations is essential to triangulating the observed gamma sources in the 2-D images in order to position the sources in three dimensions.

The baseline 2-D GammaCam™ has also been mounted from the crane hook. However its mounting fixture allows only downward looking images to be taken. This prevents measurements of objects obscured by any shielding above the object or obtaining measurements from other viewing angles.

Without the ability to pan and tilt, 3-D rendering is not possible without entering the canyon and changing the mounting fixture for the GammaCam™.

The GammaModeler™ system with its ability to pan and tilt the sensor head and measure range has extended the uses of gamma imaging systems in highly contaminated areas. First, the GammaModeler™ system with its remote pan and tilt capability allows the sensor head to completely scan of an area without requiring a radiation worker to change the sensor head direction. This reduces the potential exposure for the radiation worker. Second, the GammaModeler™ system with its range and direction measurement capability, allows analysis of the radiation environment in 3-D. The localization of sources and calculation of dose environment can substantially reduce exposure to the radiation worker and allow improved execution of any D&D operation.

Demonstration Summary

The objective of the demonstration of the 3-D GammaModeler™ visual and gamma-ray imaging system at the Department of Energy Hanford site is to identify potentially beneficial technologies for the Canyon Disposition Initiative (CDI). The Canyon Disposition Initiative (CDI) is a jointly funded project at the Department of Energy's Hanford site, which is located in the southeastern Washington State. Participating Environmental Management (EM) offices include the Office of Waste Management (EM-30), the Office of Environmental Restoration (EM-40), The Office of Science and Technology (EM-50), and the Office of Nuclear Material and Facility Stabilization (EM-60). This partnership is evaluating the feasibility of utilizing the five massive fuel reprocessing facilities (canyons) in the 200 Areas (B Plant, T Plant, U Plant, Plutonium Uranium Extraction Facility, and the Reduction Oxidation Plant) as waste repositories, among other disposition alternatives. The 221-U Facility is the "pilot" project for the CDI. As part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation/Feasibility Study, extensive characterization of the 221-U Facility is underway. The characterization data collected, measured, derived, etc. are required to support a Performance Assessment (PA), which will lead to a Record of Decision (ROD).

The demonstration was performed from August 18 – August 26, 1999. Measurements were taken during four of those days.

The key results of the demonstration are as follows:

- The AIL GammaModeler™ system could be mounted on the U-Facility's crane hook and positioned to any location within the canyon. The pan and tilt assembly allows fine pointing of the sensor head at the equipment of interest. The laser range finder provided distance measurements to the objects being surveyed.

- The pan and tilt capability allowed the system to view objects that may have been blocked if a fixed viewing direction system was used.

- The system performed well during the demonstration and obtained data on 21 objects of interest to the CDI study. Real time display of the gamma ray images to the operator showed that seven of these objects had detectable emissions. For these objects, additional views were obtained to allow 3-D rendering. The 3-D rendering showed the sources in relationship to the visual objects.

- During the demonstration, 3-D renderings were generated for several of these objects and were presented during the outbrief presentation. Post demonstration analyses refined the 3-D rendering results but did not substantially change any of the results.

- Operation of the GammaModeler™ system is relatively simple and some training is required to assure relevant data are obtained. Currently, the use of the 3-D rendering software requires experience in modeling the source distributions.

- Several of the U-Facility cells were imaged. Even with the limited viewing angles that could be obtained for these cases, the 3-D rendering software still allowed 3-D representations of the source locations and strengths to be determined.

- For one U-Facility cell, the system was able to determine the source distributions and intensities at distances greater than forty feet. These sources are of high intensities and would not be accessible to RCTs using hand-held instrumentation.

- The cost of using the GammaModeler™ is approximately ten percent greater than that for the baseline GammaCam™. The difference is due to the cost of equipment rental and 3-D rendering of an object. However only the GammaModeler™ system with its ability to measure sensor head pointing direction and range can produce a 3-D rendering of an object or region. From multiple views obtained using the GammaCam™ the location of sources can be inferred but not accurately determined.

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Licensing

No licensing activities were required to support the demonstration.

Permitting

No permitting activities were required to the support the demonstration.

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 GammaModeler™ is 2402.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The 3-D GammaModeler™ system consists of four modules; a sensor head, a portable PC compatible computer, a pan and tilt controller, and a 3-D workstation. The demonstration setup is schematically shown in figure 2. For the demonstration, the sensor head was attached to the 221-U facilities 10-ton crane hook using an AIL designed crane hook interface. The PC compatible computer and the pan and tilt controller were located in the crane cab. Two 100 foot cables (a system cable and a pan and tilt cable) were routed along the crane bridge from the sensor head to the equipment in the crane cab. The 3-D workstation was located in the office portion of the U facility.

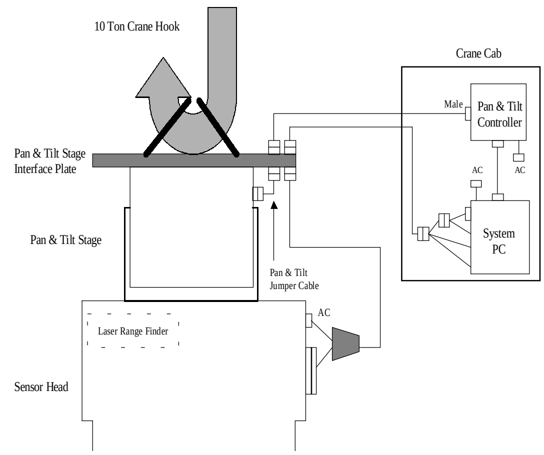

Figure 2 GammaModeler™ Setup

The sensor head has a gamma ray imaging detector, a high-resolution video camera, a laser range finder, and a pan and tilt assembly. The gamma ray imaging detector belongs to a class of cameras called spatially coded aperture cameras. The gamma ray photons passing through the coded aperture in the sensor head cast a complicated gamma shadow on a gamma detector (scintillator). This shadow created by the gamma ray flux is detected by the scintillator, which converts the gamma shadow into a visible shadow. The visible shadow is amplified through an optical system and is detected by a low-noise charged coupled device (CCD) imaging camera. The signals representing the gamma shadow are read out by the CCD camera and are then digitally processed by the computer. A gamma ray image of the objects is reconstructed by applying a decoding process on the gamma shadow of the coded aperture. The reconstructed image is displayed over a video image of the observed scene obtained with the video camera. The pan and tilt assembly provides the ability to point the sensor head in any direction.

The sensor head was wrapped in plastic prior to canyon entry to protect it from airborne contamination. The plastic wrap did not cover the video/laser range finder window but was taped to its edges to assure the seal. For the demonstration, the sensor head was inverted when attached to the crane hook. During installation of the sensor head to the crane hook, the slack in the cable was looped and rigidly secured to the crane hook. This prevented the sensor head from being lowered below the canyon deck and into the open cells. By mounting the sensor head on the crane hook, the sensor head could be remotely positioned anywhere in the canyon and could point in any direction using the pan and tilt assembly. However, the tilt angles were restricted to +/- 73 degrees so looking straight down on an object was not possible. The video field of view (FOV) was 73^o horizontal by 55^o vertical and the gamma FOV was 25^o by 25^o degrees with an angular resolution of 1.3 degrees. The sensor head has a spectral range from ~100 keV to > 1.3 MeV with a sensitivity for ^{137}Cs of one microR dose with the highest sensitivity in the center of the FOV. The system is able to operate in both low level (< 15 microR/hr) and high level (>100 R/hr) radiation environments with no shielding required.

The crane operator positioned the sensor head near the objects and AIL personnel operated the GammaModeler™ system during the survey measurement for gamma radiation sources. A pseudo-color image of gamma ray emitting sources is displayed as a composite picture with the video picture of the scene. A four sigma detection threshold of the statistical image noise is used to suppress displaying noise fluctuations. The gamma ray intensities above this detection threshold are automatically scaled to indicate the highest radiation level as red and the lowest level as blue. The video picture has a wider FOV than the gamma FOV so the boundaries of the gamma images are indicated in the composite picture by a rectangular box as seen in figure 3. Parallax corrections are applied in positioning the gamma ray image with respect to the video image so the gamma sources appear at the proper visual location. The exposure time required to obtain a gamma image is dependent upon several factors including gamma ray energy, the distance to the source, and the shape and distribution of the source. Additional images taken by the operator provide vector range to key references in the scene. These marker images are used to locate the position of the sensor head. The system software, *GammaSoft™*, produces a single file that contains all the images and the system measurement parameters. This file is copied to a disk for transfer to the 3-D workstation located outside the canyon area.

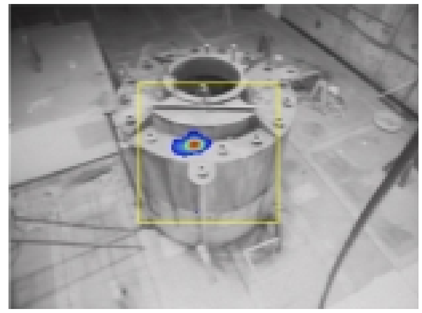

Figure 3 Gamma Image #4 obtained for the High Rad Tank on cell 35

The demonstration test plan defined the data to be acquired, the data analysis and reporting. BHI personnel provided a list of objects they desired to have imaged.

For the data to be acquired, two-dimensional (2-D) image data files will be obtained of selected objects from three or more angles using the 3-D GammaModeler™ system suspended from the crane. These 2-D images will provide visual information on the object as well as gamma source information on/within the objects. Other demonstration data will consist of information needed to evaluate costs the GammaModeler™ system relative to those for the GammaCam™ system.

For the data analysis, the captured 2-D images and supporting data of selected object are imported into the 3-D workstation. The visual/gamma images and data are then processed and used to create the 3-D renderings of the selected objects with the location(s) of the radiation source(s) indicated. The radiation source(s) will be display in color indicating the source(s) strength(s). The 3-D renderings are provided in AutoCAD 14 compatible format with gamma sources located.

System Operation

For the demonstration in support of the characterization project objectives of the CDI, a list of objects on the canyon deck that needed to be surveyed was provided by BHI. During the demonstration period, open canyon cells were added to the list (indicated by italic). The objects contained in the list were the following:

- REDOX Pulsar on cell 4.
- High Rad Equipment and PUREX Centrifuge on cell 6
- Fuel carriers on cell 15
- REDOX Dissolver on cell 15
- Transport Box on cell 19
- Fuel carriers on cells 19 and 20
- T-Plant Ventilators on cell 21 (there are 5 stacked)
- Column (thimble across from cells 23 and 24
- Vessel on pipe trench side across from cell 26
- Empty dissolver on cell 32
- High Rad Tank on cell 35
- Shipping casks located on cells 31 through 35
- *Deep cell 10*
- *Pump equipment in cell 7*
- *Equipment in cell 25*
- *Equipment in cell 39*

The high rad tank on Cell 35 was the first object imaged during the demonstration and took the longest to acquire the complete image set because this object served as a training experience for the operator. The positioning of the sensor head and the acquisition of all the images required a total of 1 1/2 hours. The greatest amount of time was required to precisely position the laser range finder at the reference point. This object was measured from four viewing directions. In addition to the four gamma images, a total of 27 marker images were obtained. Later, other objects will detectable radiation required about 30 minutes to acquired the completed set of data for the 3-D rendering. Objects with no detectable radiation required about 10 minutes of data acquisition.

For each object, the crane hook and sensor head are positioned so the object is in the gamma FOV and an initial gamma image is taken. The typical exposure time for the image is a few minutes. The captured image is displayed on the PC computer screen to the system operator in the crane cab. If no gamma radiation is detected, the crane hook and sensor head can be positioned to characterize the next object on the list. If a gamma radiation is detected above threshold, the operator needs to obtain two or more images of the object from several additional angles in order to generate a 3-D rendering of the object.

For those objects with detected radiation and before the crane hook can be translated to a new location, the operator must obtain some ”marker images” to allow the sensor head location to be determined. For each “marker image”, the sensor head is panned and tilted in order to point the laser range finder at a reference point in the scene. The reference points are selected to be points seen from more than one viewing angle or are unique locations on the object being surveyed. The composite gamma-ray image and the “marker images” are stored in a single file for later analysis on the 3-D workstation. For each viewing direction, gamma images and additional “marker images” are obtained. The new “marker images” must contain some common reference features so the relative sensor head positions can be determined. The coordinate system for the 3-D rendering can be relative to the sensor head positions or some position in or on the object surveyed. If the absolute canyon position of a reference can be determined then the 3-D rendering can be adjusted to be in the canyon coordinate system if desired.

All image files were imported to the 3-D workstation. The 3-D workstation houses the *GammaSoft™* software, the *3-D processing* software, the AUTOCAD software and the *GammaCad™* software. The *GammaSoft™* is same as that on the system PC. The *3-D processing* software is used to locate the sensor head positions, deconvolve extended 2-D radiation sources into a series of point sources, and calculate the 3-D positions of the radiation sources. The AUTOCAD software is used to generate 3-D representations of the visual objects. The *GammaCad™* software is used to merge the radiation source data with the 3-D AUTOCAD drawing of the visual objects.

For those objects that had no detectable radiation, *GammaSoft™* is used to complete the analysis and evaluated the upper limit for any potential gamma radiation. *GammaSoft™* can generate images in any standard graphic format for export to another program if desired.

For those objects with detectable radiation, *GammaSoft™* is used to export two text files, a marker file and a gamma ray image file, that are used by the *3-D processing* software. The marker text file contains an ordered list of the range and direction to each reference point for a given sensor head location. Using all the marker files, the relative positions of the sensor head locations can be determined. From the gamma radiation image data, location in the image corresponds to a direction from the gamma detector axis. For extended sources, line sources, etc., the 2-D image can be deconvolved into a series of point sources using our knowledge of the point-spread function for the detector. The locations in the image of the resulting point sources are the directions to the true locations for the sources. The deconvolution analysis also provides the intensity of the source at the sensor head. This intensity can be converted to a dose at the sensor head for the source. Similar to the reference points the sources seen in a 2-D view must be cross-referenced to the sources seen in another 2-D view. By knowing the sensor head positions, the pointing directions for the sensor head, the directions of the radiation sources for each view, and the cross-referencing of the sources, the 3-D location of the sources can be calculated along with their source strengths. The source strengths are calculated from each image in which the source is detected. If there is no differential attenuation between the views, then the calculated source strengths agree. If there is a difference, then the largest value for the source strength is reported. The results are stored to a file that can be used by *GammaCad™* to merge these results with the visual representations in AUTOCAD.

The 3-D source file can be used with a “dose” program that allows the dose to be calculated at any point in the coordinate system of the object. If the absolute coordinates of the objects are established, then the multiple 3-D source files can be combined to calculate the overall radiation field resulting from the objects being characterized. This capability can be used in the future as the remaining objects are surveyed to create a map of the radiation environment relative to the contaminated equipment. This capability will be very usefully in supporting the CDI objectives.

In the detailed analysis after the demonstration, it was noted that additional corrections were required in the 3-D analysis to correctly locate the position the sources. First the sensor head was not mounted truly level on the crane hook, resulting in the sensor head not rotating around the vertical axis while being panned. Secondly, the tilting of the 55 pound sensor head caused a compensating motion of the crane hook and this effect must by taken into account. With known dimensions such as cell sizes etc., the magnitude of the corrections were determined and incorporated into the *3-D processing* software.

In the future, additional changes could be made to the hardware design to eliminate these effects. First, leveling adjustments could be added to the mounting interface (the crane hook interface) to level the base of the pan and tilt assembly. Second, a different pan and tilt assembly could be designed that would pivot the sensor head through its center of gravity (this would not cause a compensating moment of the crane hook).

SECTION 3
PERFORMANCE

Demonstration Plan

The demonstration of the AIL 3-D GammaModeler^{TM} visual and gamma-ray imaging system was completed at the DOE Hanford site, 221-U facility as a part of the Canyon Disposition Initiative Project. The system was used to provide images and radiation measurements of equipment, tanks, etc., on the canyon deck and in the processing cells.

The canyon portion of the building is approximately 800 feet long, 36 feet wide and is divided into twenty sections. Each section is approximately 40 feet long and contains two process cells. The cells contain process equipment, such as vessels, centrifuges, piping etc. The cells measure approximately 13 by 18 feet and are 28 feet deep from the top of the concrete cell covers to the bottom of the cell. Cell 10 is designed to accumulate water in the canyon and is 47 feet deep. A diagram of the facility cross section is shown in figure 4.

The 221-U facility was not used for any “true” processing activities. However, the cells and the canyon deck are being used for storage of contaminated equipment. Figure 5 shows some of the equipment stored on the canyon deck.

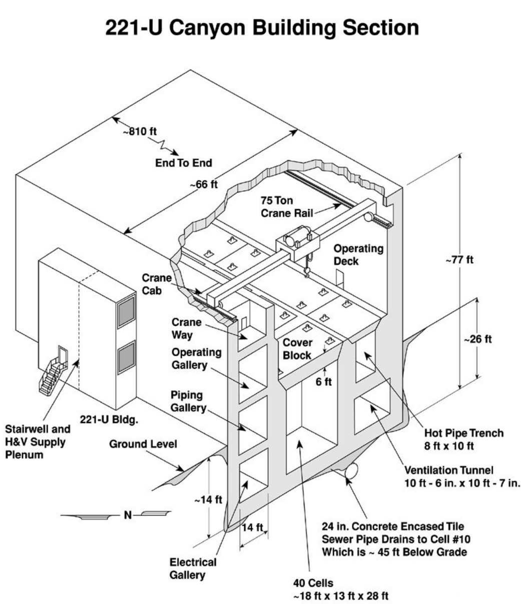

Figure 4 Cross Section of the 221-U facility.

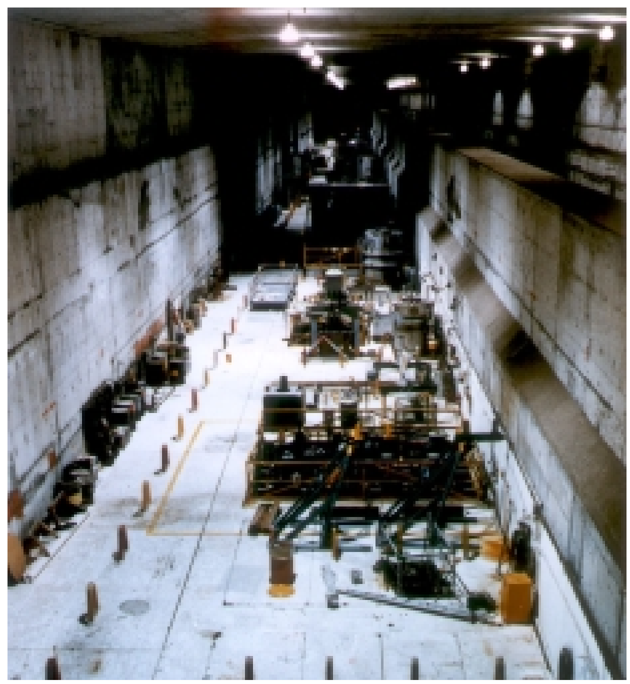

Figure 5 221-U facility (canyon) deck.

The CDI personnel provided a list of objects they desired to have surveyed and imaged. The list included equipment of most interest located on the deck. During the demonstration, several open cells were also surveyed.

The primary objectives of this demonstration were to evaluate the capability of the imaging system for surveying objects for radiological contamination to yield high-quality, usable characterization information to meet CDI project requirements, to support the Performance Assessment, and to compare the 3-D system to the 2-D baseline system.

Results

A total of 20 objects were imaged during the demonstration period at the 221-U Facility. With the narrow FOV, multiple images had to be taken to completely survey large objects. Seven of these objects had observable gamma radiation and measurements were taken at several viewing angles to support the 3-D rendering of the objects. The objects in italic were added to the original list provided by BHI.

The objects with detected radiation are the following:

- A high rad tank on Cell 35
- A High Rad equipment and PUREX Centrifuge on Cell 6
- *The interior of Cell 10*
- *Equipment in Cell 25*
- Centrifuge parts on the canyon deck
- *Pump equipment in Cell 7*
- Fuel Carrier on the canyon deck

Examples of objects with no detected radiation are the following:

- Shipping casks (multiple views)
- Another fuel carrier on the canyon deck
- The thimble (multiple views)
- Heat exchanger (multiple views)
- Dissolver tank
- Ventilator (multiple views)
- Cell 39 (multiple views)

The High Rad tank on cell 35 was the first to be imaged and analyzed. Four gamma images were obtained. One image was shown previously as figure 3. Figures 6,7and 8 are the other viewing angles. In the views from the front (fig 6) and the back (figs. 3, and 8), the source is observed to be an elongated source rather than a point source. The view from the side does not show the source strongly. This is probably due to some internal structure that attenuates the gamma radiation. The source seen in fig. 7 is treated as an ambiguous source that cannot be triangulated with other views. For sensor head position 1, the source appears to be near the bottom of the object. However, for sensor positions 3 and 4, the source is not near the bottom but appears to be in other locations. 3-D analysis shows that the source position seen by sensor position 1 is very close to the position seen in the gamma image.

Figure 6 Sensor Position 1

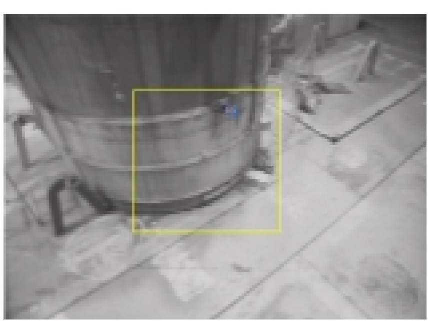

Figure 7 Sensor Position 2

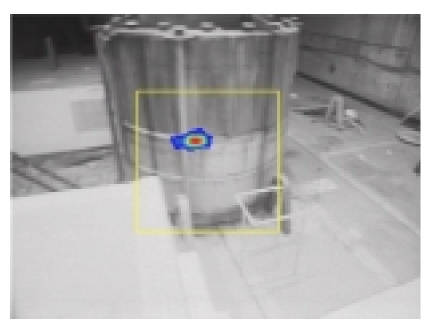

Figure 8 Sensor Position 3

The “marker” reference points were cell seams on the canyon deck, the bail hooks on the cell 35 cover blocks, and points on the object itself. These reference points were seen in two or more sensor head locations and allowed the relative positions of the sensor head to be calculated. The relative positions of the sensor head could be further adjusted to allow the bottom center of the tank to be defined as x=0, y=0, and z=0. Since this tank is located on the cell 35 cover of the canyon, the absolute canyon location for this location is approximately x = 18, y = 700, and z = 0. For this demonstration, the 3-D localization and rendering is done in the coordinate system of the object.

In the coordinate system of the object, the y direction is along the canyon length, and the x direction is across the canyon. In figure 6 (sensor head position 1), the sensor is located in the positive y direction and in the negative x direction relative to the tank. Sensor positions 3 and 4 are behind the tank in the negative y direction. Sensor position 4 was taken from a higher elevation than sensor position 3 with the sensor head tilted down more to keep the tank in the FOV.

For each 2-D image, the extended source was deconvolved into five point sources. The direction from the sensor head to the source locations was determined and the intensity at the sensor head. Knowing the sensor head locations and the directions to the sources, the source positions are determined by the positions of closest approach for the source ray traces. Figure 9 shows a 3-D plot locating the sensor head locations (small labeled boxes), the direction ray traces from the sensor locations, the locations of closest approach, and the source position for each pair of ray traces. In this figure, the sensor head locations have been adjusted so that the coordinate (0,0,0) corresponds to the bottom center of the tank. The same program that generates this plot generates the file, which contains the source locations and the 30-cm dose values.

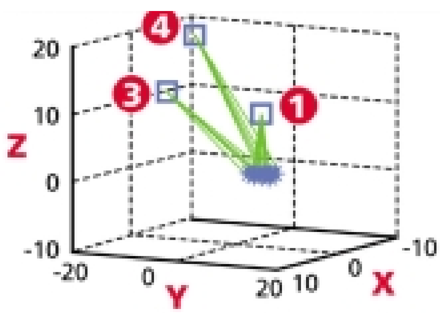

Figure 9 Calculated sensor Positions, Source Positions

A 3-D representation of the object was generated using AUTOCAD. From the marker image data, it was determined that the tank diameter was 10 feet. The tank’s center was positioned at x=0 and y=0. There the visual representation coordinate system is the same as that for the gamma radiation analysis. The tank was made transparent so that the sources located interior to the tank can be seen in the merged drawing. *GammaCad*™ is used to merge the gamma radiation data with the visual representation. *GammaCad*™ opens the AUTOCAD drawing of the visual object and the file containing the gamma radiation source information. The data for the sources are the following:

Source	X	Y	Z	30 cm dose
1	-0.6	4.6	0.8	678 mR/hr
2	-1.2	4.6	0.6	350 mR/hr
3	-1.8	4.6	0.7	253 mR/hr
4	0.1	4.6	0.9	440 mR/hr
5	0.5	4.2	0.6	343 mR/hr
Ambiguous Source				
1	3.6	1.8	4.5	25 mR/hr

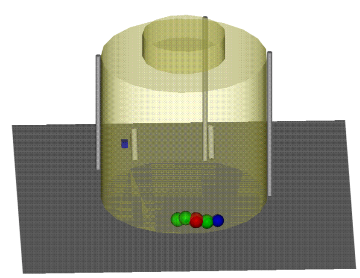

Figure 10 3-D Rendering of High Rad Tank

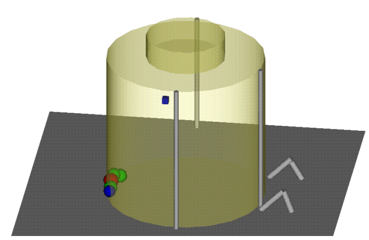

Figure 11 Rotated 3-D Rendering of High Rad Tank

The *GammaCad*™ creates color spheres for each of the point sources. The color of the spheres is related to the strength of the source. Red corresponds to those sources in the highest 1/3 intensity. Green corresponds to the middle third. Blue corresponds to the lowest third.
Figures 10 and 11 show the merged 3-D visual and gamma radiation results as an AUTOCAD representation. AUTOCAD allows the object to be viewed from any direction. The two figures represent different rotations of the same object. Five colored spheres represent the extended source; their color relates to the 30-cm dose

strength. The center sphere is red and corresponds to 678 mR/hr (the most intense source). In figure 10, the sphere on the right is blue representing 253mR/hr (within the lowest third strength). The other spheres are green and have values between 243 and 461 mR/hr.

The cube in the figures 10 and 11 is the ambiguous source seen in the 2-D image from sensor position 2. The source location is positioned near the surface of the tank at the location observed from the sensor head. Extrapolating the direction rays for this source would place the ambiguous source near the edge of the five located sources. The cube is blue because it is estimated to have a strength of less than 25 mR/hr at position indicated.

This object was rendered during the demonstration and was shown at the presentation on the last day of the demonstration. The initial 3-D analysis and rendering required a little over 3 hours of analysis time. During the detailed post demonstration analyses, additional corrections were identified and improvements to the analysis software were made. However, the results presented in this report are essentially the same results presented in near real time.

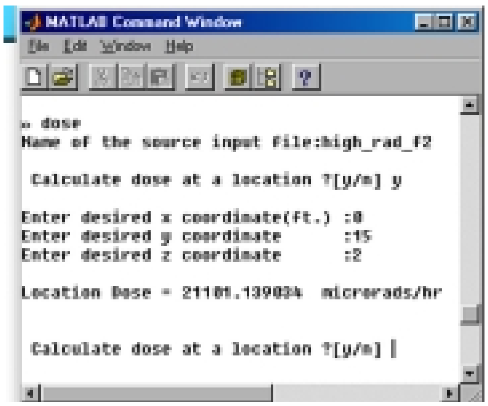

Figure 12 Typical dose calculation

The radiation source file can be accessed by a program called *dose* that calculates the dose at any position in the coordinate system. Figure 12 shows a screen capture of a dose calculation for the same high rad tank. The program requests the file name and then the coordinates for the point where the dose is desired. The coordinates correspond to a location near the edge of the radiation exclusion zone. The calculated dose is 21 mR/hr. The calculation can be repeated for another location.

The 3-D capability of the GammaModeler^{TM} system allows the sources locations to be easily seen, and the relative and absolute intensities to be known. For sources that are internal to objects, the locations are easily identified and characterized.

Additional 3-D rendering results are presented in Appendix C.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The baseline technology with which the GammaModeler™ system competes is the GammaCam™ system. The GammaModeler™ system represents an advancement of the GammaCam™ with additional features such as the laser range finder, pan and tilt assembly, and upgraded software that provides a capability for 3-D rendering of gamma radiation sources and visual objects.

Similar, but not identical competing technologies include:

- In Situ Gamma Spectroscopy with ISOCS (an In Situ Object Counting System) developed by Canberra Industries, Inc.
  The ISOCS is a Germanium based gamma-ray spectroscopy system that identifies radioactive isotopes and provides real time quantitatively assays the radioactive contents of containers, surfaces, and samples. The entire system is mounted on a portable cart, which allows rotation of the detector about a horizontal axis. The ISOCS does not produce an image but different collimators can be placed in front of the detector for defining a 30, 90, or 180 degree field of view.

- RadScan 600 developed by BNFL Instruments, Ltd.
  BNFL's RadScan imaging system is a shielded collimated detector. The collimators can have a 2, 4, or 9 degree field of view. An image is produced by raster scanning the sensor head and recreating the gamma image by overlapping the results of each measurement. Because of the shielding requirement associated with this detector, the inspection head weighs approximately 105 kg (230 lbs). This system does provide some spectroscopic information for isotope identification.

- Cartogram developed by Eurisys Mesures.
  The CARTOGAM gamma camera has been developed with the aim of providing a very compact and portable device. The detection head is contained in a stainless steel cylinder. Its external diameter is 8 cm for a length of 40 cm. The shield is tungsten ranging from 16 mm to several centimeters. The collimator has a double-cone opening, of either 30 or 50 degrees. The gamma image is formed directly on the scintillator. The minimum detectable dose with this system is higher than that for the GammaCam™. This system does provide some spectroscopic information for isotope identification.

Technology Applicability

The applicability and benefits of AIL's 3-D GammaModeler™ Gamma Ray Imaging technology at the 221-U facility includes:

- Characterization with minimum exposure to personnel
- Rapid characterization via imaging of large areas from a safe standoff distance
- Characterization in a high radiation environment
- Characterization of radiation environment internal to the equipment
- Characterization that provides a visual electronic records
- 3-D localization of sources provides better estimates of radiation intensities, which leads to cost effective D&D planning and operation.
- Pan and Tilt capability allows measurements from new directions previously not available.

Patents/Commercialization/Sponsor

- Patents have been granted to AIL Systems Inc for this coded aperture technology.
- The system is commercially available for gamma surveys at radiological contaminated sites. The technology can be applied to those sites where characterization, remediation, and D&D activities are planned.

SECTION 5
COST

Methodology

This cost analysis compares the innovative technology, the GammaModeler^{TM}, against the baseline GammaCam^{TM} technology. The selected basic activities being analyzed originate from the Hazardous, Toxic, and Radioactive Waste Remedial Action Work Breakdown Structure (HTRW RA WBS) and Data Dictionary, USACE, 1996.

Some costs are omitted from the analysis to facilitate understanding and comparison with costs for the individual site. The Hanford 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. The impact resulting from the omission is judged to be minor because overhead is applied to both the innovative and baseline technology costs. Engineering, quality assurance, administrative costs, and taxes on services and material are also omitted from the analysis for the same reasons indicated for the overhead rates.

An average labor rate ($60.00) is used in this analysis for the portion of the work performed by local crafts. Additionally, the analysis uses a 10-hour workday with a 4-day week. Operations in the canyon area is usually limited to 4 hours. During the demonstration period, two 3-hour operations were achieved in a single day. The production rates and the observed duration used in the cost analysis do not include “nonproductive” items such work breaks, loss of dexterity [due to cumbersome personnel protective equipment (PPE)], and heat stress. A Productivity Loss Factor (PLF) is a historically based estimate of the fraction of the workday that the worker spends in nonproductive activities and is not included in the analysis. The PLF is the same for the GammaModeler^{TM} and the GammaCam^{TM} since they are similar technologies.

Cost Analysis

The prices shown in Table 1 are based on recent quotes from AIL System Inc. The equipment costs used in the analysis are based on the one-month lease costs for each instrument. Equipment purchase and leases includes AIL Systems provided instruction.

Table 1. Technology acquisition costs

ACQUISITION OPTION	GammaModeler^{TM}	GammaCam^{TM}
Purchase	$260,000	$230,00
One month lease	$25,000	$20,000

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 the 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 the 221-U facility.

Cost Conclusions

The cost elements for the GammaModeler™ and GammaCam™ are shown in figure 13. The percentage of objects with radiation compared to those with no detectable radiation will substantially affect the costs because of the additional effort to acquire data from multiple views and the effort to complete a 3-D rendering. Based on the demonstration, the assumed ratio of objects with radiation to those with no detectable radiation is 1:3. The analysis performed shows that use of a GammaModeler™ system will result in less than a ten percent increase in cost. Another factor that can influence the costs is the time to take the image. The sources are assumed to have greater than tens of mR/hr source strength. It is possible to image much weaker sources with accumulation times being an hour or greater.

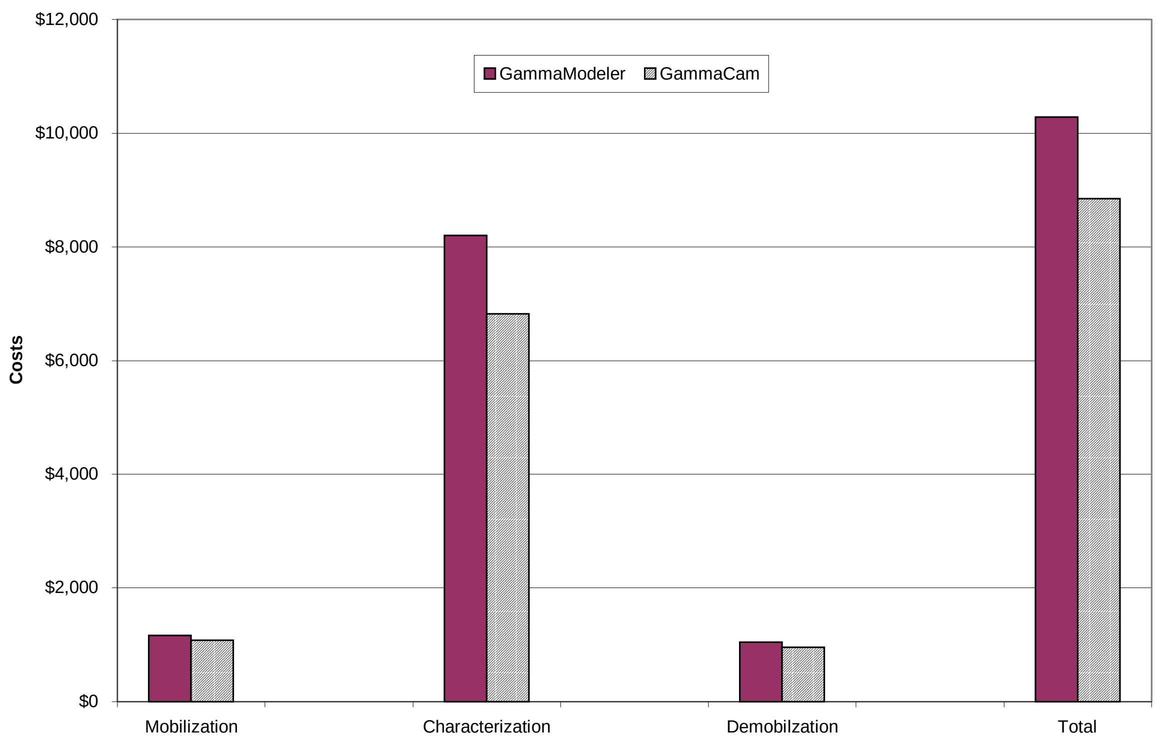

Figure 13 Technology Cost Comparison

It is important to note that the GammaModeler™ technology acquires and produces additional data that cannot be acquired by the baseline technology. The GammaModeler™ system collects sensor head angle information and range data that are required for 3-D processing. 3-D processing is not possible from multiple 2-D images acquired with the GammaCam™. These data allows better understanding of the source locations (even internal to the visual objects). With source locations known, estimates of the dose in the vicinity of an object can be determined. The pan and tilt capability allows the gamma camera to examine the objects from directions different than the single view provided by the baseline technology. This additional information can be very important in any characterization effort - in this case, in support of the CDI.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

- The GammaModeler™ system is designed as a survey tool for inspecting and measuring contaminated objects. There are no special regulatory permits required for use of this technology.

- Although the demonstration took place at a Comprehensive Environmental Response, Compensation, and Liability Act (CERLA) site, no CERLA requirements apply to the surveys conducted. However, some evaluation criteria required by CERLA, such as protection of human health and community acceptance, are briefly discussed below.

Safety, Risks, Benefits, and Community Reaction

The purpose of the GammaModeler™ technology is to provide data needed for cleanup, D&D characterization, radiation source localization and determination, and planning. The safety issues with the GammaModeler™ system are limited to those routinely encountered in an industrial environment.

This technology can be utilized in high radiation areas with the operator located in a low radiation area reducing radiation exposure.

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

Implementation of this technology has no adverse impacts on community safety.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The demonstration at the 221-U Facility has resulted in the following recommendations for future measurement operations.

- The GammaModeler™ system, as demonstrated, only had a narrow FOV (25^o) capability because of the placement of the laser range finder. Restoring the wide FOV (50^o) would allow greater portions of the objects to be imaged with a single image. This could lead to a reduction in images and time to complete an object inspection.
- Improve the cable management. After the attachment of the sensor head to the crane hook while at the canyon deck level, the extra lengths of the two system cables that went from the crane cab to the sensor head and pan and tilt assembly were looped and tied to the crane hook. This action prevented the sensor head from being lowered below the deck level and into the cells. Likewise, for some positions of the sensor head, the pull of taut cables can cause an unknown amount of rotation of the sensor head.
- The base of the pan and tilt assembly was not mounted level on the crane hook. This caused some initial difficulty in the post-demonstration 3-D analysis to identify the problem and its magnitude. Changes were made to the analysis software to incorporate correction terms for this effect. Future measurements should image an object with known dimensions in order to rapidly assess any tilting and allow correction to be made for this effect.
- Reverse mounting of the sensor head for inverted operation. The demonstration utilizes the sensor head in an inverted position. This position causes the video and gamma images to be inverted also. For ease in recognizing the objects in the images it would be beneficial to reverse the mounting of the sensor head in order to have the images right side up.
- Finer control for the pan and tilt would allow the operator to quickly position the laser range finder for the marker images.
- Availability of existing drawings of the objects to be 3-D rendered would allow quicker generation of the AUTOCAD visual representations of the objects and would reduced the time and effort to crate these rendering.

Technology Limitations and Needs for Future Development

- There are limitations associated with the use of a coded aperture system that can influence a radiation survey. The first is that a uniform radiation field cannot be detected. This can be overcome by making sure that the FOV includes a non-uniform region. The coded aperture also has some limitations in terms of the maximum-to-minimum signal that can be detected in the FOV. The image threshold is related to the total radiation in the FOV. If there are many sources in the FOV, the threshold increases leading to limitation on the ratio of the maximum-to-minimum signal detected.

- The deployment platform for the GammaModeler™ system must be robust and level. It can be moved but should not rotate or tilt during the measurement. Additional uncertainties caused by platform rotation or tilting could prevent 3-D rendering of the radioactive sources.

- The dose estimates are based on calibrations of the instrument using isotopic sources. For a given dose estimate, knowledge of the isotope is assumed. However spectral modification often occurs due to intervening material and the calibration values do not account for these changes in the source spectrum. Future developments to provide a measure of this spectral modification can lead to better dose estimates.

Technology Selection Considerations

- Any nuclear site can use this technology. In particular, the 3-D capability of the GammaModeler™ allows the radiation environment interior to an object to be determined. This information is obtained remotely without the need of exposing workers to the radiation source. The remote pan and tilt capability of the system allows the operator ease in locating radiation sources

- The visual and gamma radiation results are saved in digital format and can be easily archived for a permanent record of the measurement survey.

APPENDIX A
REFERENCES

GammaCam^{TM} Radiation Imaging System, 1998, Innovative Technology Summary Report, U.S. Department of Energy, Office of Environmental Management, DOE/EM-0345.

Hazardous, Toxic, and Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary. 1996, Head quarters United States Army Corps of Engineers, 20 Massachusetts Avenue, NW, Washington, D.C., 20314-1000.

Management/Test/Work Plan for Demonstration of 3-D Gamma-Ray Imaging Technology at the U-Facility Canyon Using AIL System's 3-D GammaModeler^{TM}, prepared for FETC contract DE-AC26-99FT40555.

Migliaccio, R. and Petito D. (AIL Systems Inc.) and Nutter, V. and Smith, D. (Consolidated Edison of New York), 1996 "Gamma Ray Imaging in Nuclear Power Plants," *Nuclear Plant Journal* March-April.

APPENDIX B
TECHNOLOGY COST COMPARISONS

This appendix contains definitions of cost elements, descriptions of assumptions, and computation of unit costs that are used in the cost analysis. An assumption in the technology cost comparison is that the GammaModeler™ and the GammaCam™ systems are available on-site. System unit costs are based on the one-month lease rates for each system.

Innovative Technology – 3-D GAMMAMODELER™

Mobilization (WBS 331.01)

Transport Equipment to Work Area
Definition: The GammaModeler™ is transported from the on-site storage location to the work area.

Duration is ¾ hour for D&D worker.

Functional Tests of Equipment
Definition: The GammaModeler™ equipment is turned on to assure that video and gamma images can be obtained.

Duration is ½ hour. This includes cooldown time for the sensor head.

Prepare Equipment for Use
Definition: The equipment is prepared for use in canyon area (includes wrapping cables and sensor head with plastic to minimize potential contamination).

Crew consists of one radiological control technician (RCT) for one hour (based on experience during the demonstration).

Install Equipment in Canyon on Crane
Definition: The equipment is moved into the canyon area for installation on the crane hook. The system computer and pan and tilt controller are installed in the crane cab. System cables are connected. The system is turned on and tested for functionality before personnel in canyon are released.

System cables are already installed in canyon. Two RCTs and one D&D worker are required for canyon entry for installation of equipment on crane hook. System operator and crane operator are in the crane cab. The RCTs and D&D workers require PPE for canyon entry. The system operator and the crane operator do not require personnel protective gear. This activity requires 1 hour.

Personnel Protection Equipment
Canyon entry requires the personnel to use personnel protection equipment. The donning and doffing of the equipment takes 1 hour per person. The equipment is single use only.

Characterization (WBS 331.17)

Set Up and Move Equipment
Definition: The time required for moving from one survey area to the next.

The duration is 1/6 hour and the crew is the crane operator.

Surveys
Definition: The time required to acquire a gamma image. If radiation is detected, additional marker images and other views with marker images are taken. Based on the 221-U Facility demonstration, one of three objects have radiation and required the additional data.

The time to acquire a survey for an object without any detectable radiation is ¼ hour. The acquisition of the complete data set for 3-D rendering is 0.75 hours.

Transfer 2-D Data to Workstation
Definition: The data files are transferred out of the canyon area for processing. The data disks are surveyed for contamination prior to release.

This task requires one RCT for one hour.

Process 2-D Data
Definition: This activity includes processing the 2-D data from the measurement using the GammaSoft software, generate report for images with upper limits and generating files required for 3-D processing.

This task requires one RCT for 0.5 hours per image.

3-D Rendering
Definition: This activity includes determining the locations of the sensor head for each view, locating sources and cross referencing them between views, calculating the locations and intensities of each source, generating 3-D representation of visual objects in AUTOCAD format, merge gamma radiation data with visual representation, and generate report.

Daily Meetings
Definition: This cost element provides for safety/ project-planning meetings during the work.

The estimate assumes one 15 min safety meeting per day. One RCT, one D&D and one crane operator are in attendance.

Demobilization (WBS 331.21)

Remove Equipment from Canyon
Definition: The equipment is de-mounted from crane hook, removed from canyon area, and the plastic wrap removed from sensor head.

Requires 3 workers-one hour.

Survey and Decontaminate Equipment
Definition: Equipment is surveyed for contamination. Decontamination is performed as needed for free release.

This task requires one RCT for two hours.

Transport Equipment to Storage
Definition: The equipment is transported to an on-site storage area.

The effort is assumed to be ¾ hour for one D&D worker.

Personnel Protection Equipment
Canyon entry requires the personnel to use personnel protection equipment. The donning and doffing of the equipment takes 1 hour per person. The equipment is single use only.

The activities, quantities, and costs utilized in the innovative technology are shown in Table B-1: Innovative Technology Cost Summary.

Table B-1. Innovative Technology Cost Summary – 3-D GAMMAMODELER™

Task	Unit Cost (UC) Labor Hour	Labor Cost	Equipment Hour	Equipment Cost	Other	Total UC	Total Quantity (TQ)	Unit Of Measure	Total Cost (TC)	Comments
Mobilization								**Subtotal**	$1272	
Transport Equipment to Work Area	0.75	$60.00	0.75	$156.00	$0	$162	1	Each	$162	1 D&D worker
Functional Test of Equip.	0.50	$60.00	0.50	$156.00	$0	$108	1	Each	$108	1 RCT & Equipment
Prepare Equipment for Use	1.00	$60.00	1.00	$156.00	$0	$216	1	Each	$216	1 D&D worker
Install Equipment in Canyon	5.0	$60.00	1.00	$156.00	$0	$456	1	Each	$456	2 D&D + 1 RCT + crane operator +1Elec.(1 hour)
Personal Protection Equipment	1.0	$60.00			$50	$110	3	Person	$330	3 workers(1.0 hour)
Characterization								**Subtotal**	$7927	
Set Up and Move Equipment	0.32	$60.00	0.16	$156.00	$0	$44	35	Object	$1540	1 D&D worker 1 crane operator (0.16 hour)
Surveys(no radiation detected)	0.50	$60.00	0.25	$156.00	$0	$69	14	Object	$ 966	Total of 21 objects being surveyed
(radiation detected)	1.50	$60.00	0.75	$156.00		$207	7	Object	$1449	
Transfer Data to Workstation	1.00	$60.00	1.00	$156.00	$0	$216	4	Each	$864	4days of imaging
Process 2-D Data/Report	0.5	$60.00	0.5	$156.00	$0	$108	14	Object	$1512	14 objects without detectable radiation
3-D Rendering/Report	3.0	$60.00			$0	$180	7	Object	$1260	3-D rendering performed @ AIL Systems

Daily Meetings	0.75	$60.00	0.25	$156.00	$0	$84	4	Day	$336	1 D&D + 1 RCT + crane operator (0.25 hour)
Demobilization								**Subtotal**	$1044	
Remove Equipment from Canyon	3.0	$60.00	1.0	$156.00	$0	$336	1	Each	$ 336	1 D&D + 2 RCT (1 hour)
Survey and Decontaminate Equipment	1.0	$60.00	1.0	$156.00	$0	$216	1	Each	$ 216	1 RCT
Transport to Storage	0.75	$60.00	0.75	$156.00	$0	$162	1	Each	$162	1 D&D worker
Personal Protection Equipment	1.0	$60.00			$50	$110	3	Person	$330	3 workers

BASELINE TECHNOLOGY -- 2-D GAMMACAM™

Mobilization (WBS 331.01)

Transport Equipment to Work Area
Definition: The GammaCam™ is transported from the on-site storage location to the work area.

The duration is ¾ hour for D&D worker.

Functional Tests of Equipment
Definition: The GammaCam™ equipment is turned on to assure that video and gamma images can be obtained.

The duration is ½ hour. This includes cooldown time for the sensor head.

Prepare Equipment for Use
Definition: The equipment is prepared for use in canyon area (includes wrapping cables and sensor head with plastic to minimize potential contamination).

Crew consists of one radiological control technician (RCT) for one hour (based on experience during the demonstration).

Install Equipment in Canyon on Crane
Definition: The equipment is moved into the canyon area for installation on the crane hook. The system computer and pan and tilt controller are installed in the crane cab. System cables are connected. The system is turned on and tested for functionality before personnel in canyon are released.

System cables are already installed in canyon. Two RCTs and one D&D are required for canyon entry for installation of equipment on crane hook. System operator and crane operator are in the crane cab. The RCTs and D&D workers require PPE for canyon entry. The system operator and the crane operator do not require PPE. This activity requires 1 hour.

Personnel Protection Equipment
Canyon entry requires the personnel to use personnel protection equipment. The donning and doffing of the equipment takes 1 hour per person. The equipment is single use only.

Characterization (WBS 331.17)

Set Up and Move Equipment
Definition: The time required for moving from one survey area to the next.

The duration is 1/6 hour and the crew is the crane operator and D&D worker.

Surveys
Definition: The time required to acquire a gamma image. If radiation is detected, additional marker images and other views with marker images are taken. Based on the 221-U Facility demonstration, one of three objects have radiation and required the additional data.

The time to acquire a survey for an object without any detectable radiation is ¼ hour. The acquisition of multiple 2-D images 0.75 hours. Crane operator and D&D worker required.

Transfer 2-D Data to Workstation
Definition: The data files are transferred out of the canyon area for processing. The data disks are surveyed for contamination prior to release.

This task requires one RCT for one hour.

Process 2-D Data
Definition: This activity includes processing the 2-D data. For images with no detected radiation upper limits are established. For multiple images with detected radiation dose values are estimated and locations are inferred.

This requires one RCT for 0.5 hour (no radiation) ,1.5 hour per object (radiation detected).

Daily Meetings
Definition: This cost element provides for safety/ project-planning meetings during the work.

The estimate assumes one 15 min. safety meeting per day. One RCT, one D&D and crane operator in attendance.

Demobilization (WBS 331.21)

Remove Equipment from Canyon
Definition: The equipment is de-mounted from crane hook, removed from canyon area, and the plastic wrap removed from sensor head.

Requires 3 workers one hour.

Survey and Decontaminate Equipment
Definition: Equipment is surveyed for contamination. Decontamination is performed as needed for free release.

This task requires one RCT for one hour.

Transport Equipment to Storage
Definition: The GammaCam™ equipment is transported to an on-site storage area.

The effort is assumed to be ¾ hour for one D&D worker.

Personnel Protection Equipment
Canyon entry requires the personnel to use personnel protection equipment. The donning and doffing of the equipment takes 1 hour per person. The equipment is single use only.

The activities, quantities, and costs utilized in the baseline technology are shown in Table B-2: Baseline Technology Cost Summary.

Table B-2. Baseline Technology Cost Summary – 2-D GAMMACAM™

Task	Unit Cost (UC) Labor Hour	Labor Cost	Equipment Hour	Equipment Cost	Other	Total UC	Total Quantity (TQ)	Unit Of Measure	Total Cost (TC)	Comments
Mobilization								**Subtotal**	$1172	
Transport Equipment to Work Area	0.75	$60.00	0.75	$125.00	$0	$139	1	Each	$139	1 D&D worker
Functional Test of Equip.	0.50	$60.00	0.50	$125.00	$0	$93	1	Each	$93	1 RCT & equipment
Prepare Equipment for Use	1.00	$60.00	1.0	$125.00	$0	$185	1	Each	$185	1 D&D worker
Install Equipment in Canyon	5.0	$60.00	1.0	$125.00	$0	$425	1	Each	$425	2 D&D + 1 RCT + crane operator + elec. (1 hour)
Personal Protection Equipment	1.0	$60.00			$50	$110	3	Person	$330	3 workers
Characterization								**Subtotal**	$7253	
Set Up and Move Equipment	0.32	$60.00	0.16	125.00	$0	$39	21	Each	$819	1 D&D + crane operator (0.16 hour)
Surveys no radiation radiation	0.50 1.50	$60.00 $60.00	0.25 0.75	$125.00 $125.0	$0	$61 $184	14 7	Object	$854 $1288	1 D&D + crane operator
Transfer Data to Workstation	1.00	$60.00	1.00	$125.00	$0	$185	4	Each	$740	1 RCT
Process 2-D Data/Report Radiation detected	0.5 1.5	$60.00 $60.00	0.5 1.5	$125.00 $125.00	$0	$93 $278	14 7	Object	$1302 $1946	1 RCT worker

Daily Meetings	0.75 $60.00	0.25 $125.00	$0	$76	4	Day	$304	1 RCT + 1D&D + crane operator (0.25 hour)
Demobilization						**Subtotal**	$959	
Remove Equipment from Canyon	3.0 $60.00	1.0 $125.00	$0	$305	1	Each	$305	1 D&D +2 RCT
Survey and Decontaminate Equipment	1.0 $60.00	1.0 $125.00	$0	$185	1	Each	$185	1 D&D worker
Transport to Storage	0.75 $60.00	0.75 $125.00	$0	$139	1	Each	$139	1 D&D worker
Personal Protection Equipment	1.0 $60.00		$50	$110	3	Person	$ 330	3 workers

APPENDIX C
ADDITIONAL 3-D RENDERING RESULTS

Additional objects were 3-D rendered during this demonstration. The cell results presented in this appendix represent cases where it is not possible to obtain optimum viewing angles because all images were taken looking sharply down into the cell.

<u>Cell 10</u>

Multiple images of sources in the deep cell, cell 10, were obtained. 3-D rendering was accomplished during the demonstration. This cell had only one cover removed but the GammaModeler™ pan and tilt capability allowed images to be obtained for regions under the remaining cover. The baseline technology system, the GammaCam™, mounted pointing straight down on the crane hook could <u>not</u> obtain measurements for sources under the cell cover. Figure 14, shows a gamma image of cell 10 looking under the cell cover at a region of strong sources. Figure 15 imaged an area of the cell that was not under the cover but adjacent to the source seen in Figure 14. These images and others provide information on the entire cell so the source distribution and intensity can be displayed in a 3-D rendering This deep cell is designed to accumulate water and had water a level covering the actual sources. Triangulation of regions where the images overlap showed the radiation to be coming from near the surface of the water. In the analysis for this case, not all the source positions are triangulated but are mapped to the constant level in the cell. The source distribution is represented by 15 point sources ranging from 1.2 R/hr to 9.2 R/hr. While the sources are in the range of several R/hr, the dose at the canyon deck level is at the mR/hr level when calculated using the *dose* program.

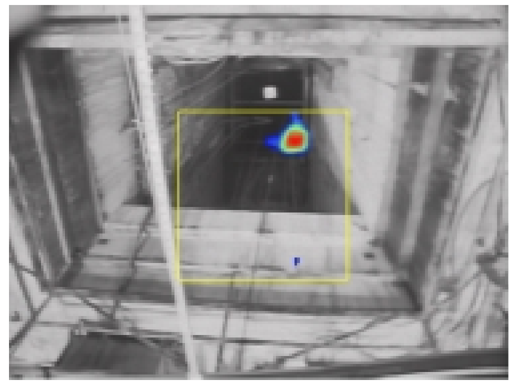

Figure 14 Image of Sources under Shield Cover

Figure 15 Images of Sources in Open Part of Cell

For all cell renderings, the up-canyon corner of the cell at the deck level is the origin of the coordinate system. For cell 10, the absolute canyon coordinates for this corner are x = 19, y = 53, and z = 0. The rendering for cell 10 is shown in Figure 16 (presented on next page). The remaining shield cover is rendered opaque whereas the cell is made transparent in order to observe the source locations. If the rendering is rotated to correspond to viewing with the downward looking baseline GammaCam™ , all the sources located under the shield would not be observed. The sources under the shield account for greater than 70 percent of the radioactive inventory for this cell.

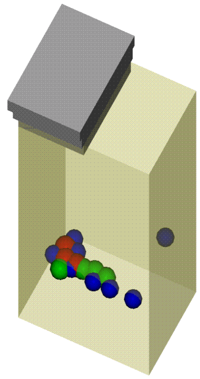

Figure 16 3-D rendering of Cell 10

<u>Cell 25</u>

Another cell that was surveyed during the demonstration was cell 25. Cell 25 has processing equipment stored deep in the cell and pumps stored on racks at the top of the cell Four images of this cell were taken. Again looking down into the cell restricts the viewing angles for the 3-D rendering. Even with restrictive viewing the source locations could be calculated and a visual representation of the cell contents could be created. The coordinate origin for this representation was the up-canyon corner at the deck level. Figures 17 and 18 show two of the 2-D images taken for cell 25.

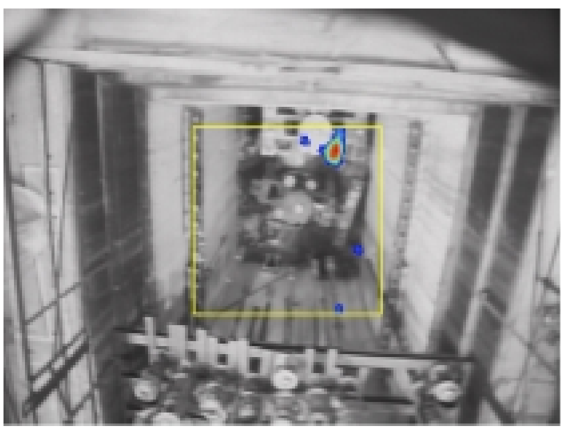

Figure 17 Cell 25 Image

Figure 18 Cell 25 Image (Another View)

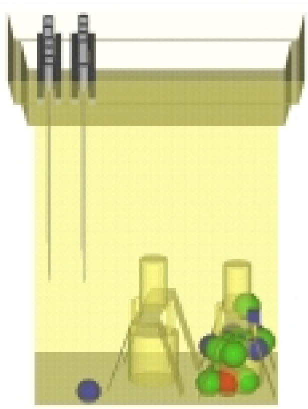

Figure 19 3-D Rendering of Cell 25

Figure 19 uses source data from four images to create the radiation source location for the rendering. The sources are primarily located in the tank portion of only one object located in the cell. Another isolated source is located on the floor under the pumps near the back edge of the cell. The pumps were not gamma imaged so it is not known if they contain any radioactive contamination. The 3-D rendering view is from the side of the cell, allowing the location of the sources to be easily seen. For this rendering the cell, both the cell walls and the objects are transparent so the source location can be seen.

APPENDIX D
ACRONYMS AND ABBREVIATIONS

2-D	Two Dimension
3-D	Three Dimension
AIL	AIL Systems Inc.
ALARA	As Low As Reasonably Achievable
AUTOCAD	Computer Aided Drafting Software Package
BHI	Bechtel Hanford, Inc.
CCD	Charge Coupled Device
CDI	Canyon Disposition Initiative
CELCLA	Comprehensive Environmental Response, Compensation, and Liability Act
D&D	Decontamination and Decommissioning
DOE	U. S. Department of Energy
dose	Software to Calculate Dose Using Gamma Source File
FETC	Federal Energy Technology Center
FOV	Field of View
GAMMACAD	Software to Merge Gamma Source File Data with AUTOCAD drawing
GAMMASOFT	Operating software of GammaModeler™ system
G&A	General and Administrative
κeV	Thousand electron Volts (Unit of Energy)
MeV	Million electron Volts (Unit of Energy)
mR/HR	milliRad/ Hour (Unit of Dose Rate)
NETL	National Energy Technology Laboratory
PA	Performance Assessment
PC	Personal Computer
PLF	Productivity Loss Factor
PPE	Personnel Protective Equipment
R	Rad (Unit of Dose)
R/HR	Rad/Hour (Unit of Dose Rate)
RCT	Radiological Control Technician
RL	U. S. Department of Energy, Richland Operation Office
ROD	Record of Decision
USACE	U. S. Army Corps of Engineers
WBS	Work Breakdown Structure