GAMMA RAY IMAGING IN DECONTAMINATION AND DECOMMISSIONING

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ABSTRACT

A portable, remotely operated gamma ray imaging system called GammaCam™ has been developed to produce accurate two-dimensional photographs of gamma ray emitting objects. The GammaCam™ has been tested at Department Of Energy (DOE), commercial and foreign nuclear facilities. GammaCam™ development began with the 1993 Technology Reinvestment Project (TRP) award from the Defense Advanced Research Project Agency. The GammaCam™ was made commercially available in late 1996 and is currently in use at DOE and commercial nuclear sites.

Technology evaluations have validated gamma ray imaging applications in the areas of enhancing shielding placement, remote surveys of large areas, monitoring of dynamic radiological conditions, waste management, and decontamination and decommissioning (D&D) job planning.

This paper presents the results of gamma ray images captured at various nuclear facilities. The images captured by the GammaCam™ that are applicable to the D&D process are shown and discussed. The theory of operation will also be presented. The benefits of using gamma ray imaging detectors to optimize shielding, reduce exposure, and to reduce survey and task time will be discussed.

NOMENCLATURE

ALARA	As Low As Reasonably Achievable
CCD	Charged Coupled Device
D&D	Decontamination & Decommissioning
FOV	Field Of View
HP	Health Physicist
INEEL	Idaho National Engineering & Environmental Laboratory
PC	Personal Computer
SNR	Signal To Noise Ratio
UBM	Uranium Bearing Material

INTRODUCTION

The current method of identifying radiation sources by manually passing a radiation survey meter over an area and recording the meter reading has disadvantages. Radiation exposure to the technician, the labor intensive search of large areas, and the inability to locate smaller sources in the presence of larger ones, are some of the disadvantages of the current method of identifying radiation sources. A more direct way to locate radiation sources would be to take a gamma picture of a suspected area from a safe standoff distance. This picture would specify the radiation location and intensity in the scene. Taking a picture from a distance would significantly reduce radiation exposure of Health Physicist (HP) technicians, reduce the time to locate radiation sources, specify the location of both large and small radiation sources, and therefore be a significant benefit to nuclear facilities. Such a camera exists and is called the GammaCam™. This paper discusses the GammaCam™ and its use in D&D applications.

DESCRIPTION OF GAMMA RAY IMAGING SYSTEM (GammaCam™)

The GammaCam™ (see Fig. 1) is a radiometric gamma imaging camera that produces a two dimensional image of a gamma scene. The GammaCam™ is comprised of a sensor head and portable 80X86 PC compatible computer. The sensor head weighs 55 pounds. The sensor head dimensions are 19 inches in length, 10 inches in width, and 15 inches in height. System set-up consists of mounting the sensor head on a tripod (if required), connecting the system cable from the sensor head to the portable PC, and connecting the 120 Vac power cords to the PC and the sensor head. System set-up time is less than five minutes. After set-up and a short warm-up period (less than ten minutes), image acquisition can begin. Image acquisition begins with aiming the sensor head at the area of interest and activating the image capture process via the remotely located PC (up to 100 feet from sensor head).

Figure 1. GammaCam™ system.

All sensor head functions (image capture, data analysis, data storage) are controlled remotely from the PC. Images captured by the sensor head are presented on the PC display with radiation intensity shown in pseudocolor over a black and white visual image provided by the spatially aligned video camera.

Theory of Operation/Specifications

The GammaCam™ is a two dimensional camera that images X-ray or gamma-ray emitting objects located within the camera field of view (FOV). This camera 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 gamma photon 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 detector (camera). The digital signals representing the gamma shadow that are read out by the CCD imaging detector are then digitally processed by the computer. A gamma image of objects is reconstructed by applying a decoding process on the gamma shadow of the coded aperture. The reconstructed image is displayed in pseudocolor on the portable computer screen over a black and white visual image of the observed scene (which is obtained by a small video camera contained in the sensor head). Image processing time is less than 30 seconds. Overlay of gamma images in color on a visual black and white picture of the scene allows the operator to visually identify the location and see the shape of gamma emitting objects.

The range of gamma ray intensity with a particular image is automatically scaled to indicate the highest radiation levels as red and the lowest levels as blue. The system is able to operate in both low level (<15 µR/hr) and high level (>50 R/hr) radiation environments without requiring the use of heavy and bulky shielding.

The exposure time required to obtain a gamma image is dependent upon several factors including gamma ray energy, source strength, the distance to source, and the spatial distribution of the source. The pseudocolor gamma image overlayed on the black and white image of the scene captured by the GammaCam™ can be saved as digital data and as a PCX file.

Table 1 defines the specifications associated with the GammaCam™.

IMAGES CAPTURED BY THE GAMMACAM™

Argonne National Laboratory D&D Technology Demonstration at CP-5 Plant

During the week of December 4, 1996, a demonstration of the GammaCam™ was performed at Argonne National Laboratory Chicago Pipe Five (CP-5) Reactor facility. This demonstration was part of a Large Scale Technology Demonstration Program that evaluated new technologies applicable to D&D.

The CP-5 facility is a research nuclear reactor operated from the late fifties into the seventies. The facility was in the second phase of D&D operations during this demonstration. This facility possessed several readily accessible areas with radiation levels of up to hundreds of mR/hr. The GammaCam™ was demonstrated in several areas of the CP-5 Reactor facility.

Floor Contamination Image. The GammaCam™ was mounted on the tripod in the Rod Storage Area (RSA) entry area and pointed towards some known areas of fixed contamination on the floor. The image illustrated in Fig. 2 demonstrates the system's ability to characterize large areas. This image was produced with an overnight exposure (16.5 hrs). The hot spot (red area) had a field of 2.8 mR/hr on contact and 35 µR/hr at the sensor head. The source was at a distance of 16.7 feet from the sensor head.

Cave Area Cover Image. An image was taken of a covered access hole in the Cave Room. The sensor head was rigged to an overhead crane and positioned over the access hole. The image shown in Fig. 3 shows two separate sources. This image is a good example of how the system is able to identify and locate separate sources where a conventional sensor, such as an Ion Counter, characterizes the combined field at the position of the counter. The ability to identify close adjacent sources is also beneficial for D&D operations.

Exposure Time:	2 min
Distance:	6 feet
Field at Source:	200 mR/hr contact
Field at Sensor:	10 mR/hr

Table 1. Performance specifications of GammaCam™.

Spectral Range	<80 keV to >1.3 MeV	Energy response is not flat and spectral response reduces gradually beyond cutoff
Sensitivity	1 μR integrated dose for ^{137}Cs point source and 7:1 SNR	Highest sensitivity in center of FOV
Exposure Time	User Selectable, 10 msec to 1 hr. Software Summing for >1 hr	Short exposure time used for strong sources and long exposure time for weak sources
FOV	25° Narrow Mode 50° Wide Mode	Spatial Resolution = 1.3° Spatial Resolution = 2.6°

Top of Reactor Core Images. Several images of the reactor core were acquired with the sensor head suspended from the crane directly over the center of the core. The reactor plug had been recently removed. Shielding had been placed over the core structure and can be seen in Fig. 4. This image identifies two strong sources and one weaker source underneath the blankets.

Exposure Time: 6 min
Distance: 10 feet
Field at Source: 9 mR/hr contact

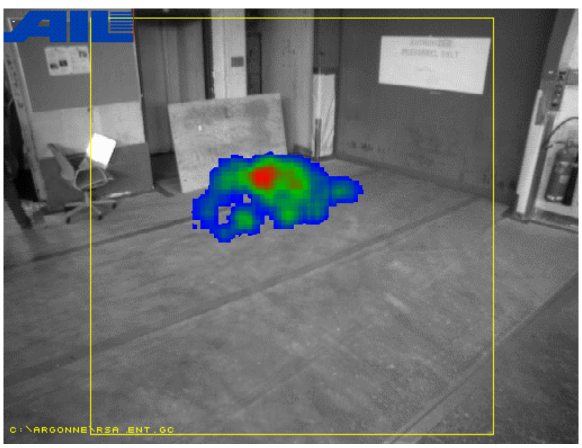

Figure 2. RSA entry area.

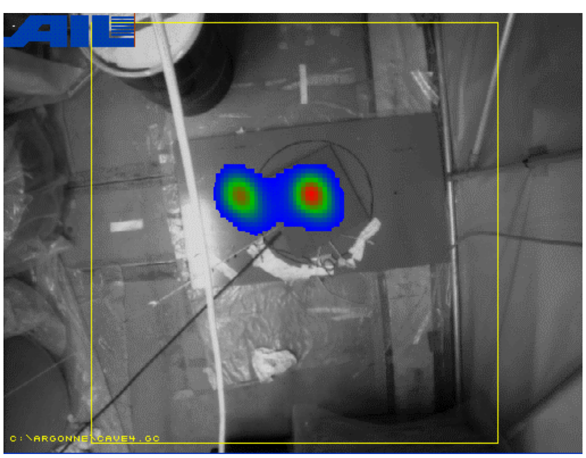

Figure 3. Cave area cover.

Shielding the Core Images. The next series of images of the core demonstrates how gamma ray imaging was used to efficiently implement and evaluate shielding.

The sensor head was lowered to a distance of six feet from the core and a short exposure was taken (see Fig. 5). The hot spot (red) captured in the image was then precisely located. A hand sketch of the area was then provided to the HP. The HP then placed a lead brick approximately five inches to the right and four inches below the hot spot (This displacement is a result of the parallax between the optical axes of gamma ray optics and the black and white video camera.)

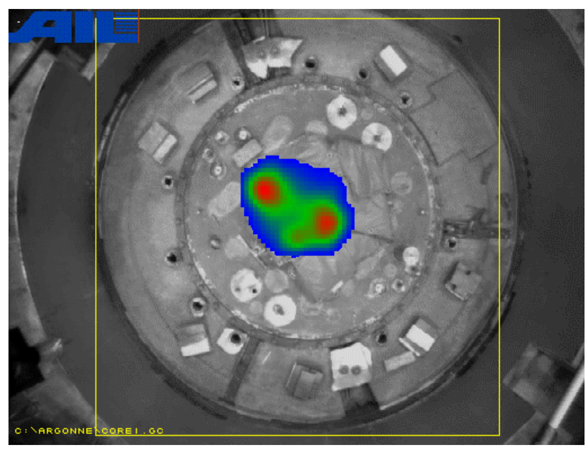

Figure 4. CP-5 reactor.

Exposure Time: 2 min
Distance: 6 feet
Field at Source: 9 mR/hr contact

After placement of the lead brick, another image was taken. Figure 6 shows the placement of the lead brick to the right of the brick where the hot spot previously existed. Note that the original hot (red) spot no longer exists because it is below the threshold of the system. Notice that a new hottest spot (previously green, now red) appears to the lower right.

Exposure Time: 2 min
Distance: 6 feet
Field at Source: 9 mR/hr contact

These images provide an example of how the GammaCam™ can be used to efficiently evaluate/implement shielding from safe standoff distances. The system's ability to visually identify where shielding is required is a significant benefit to D&D operations. Additionally, the system's ability to validate shielding integrity is a major benefit to D&D operations.

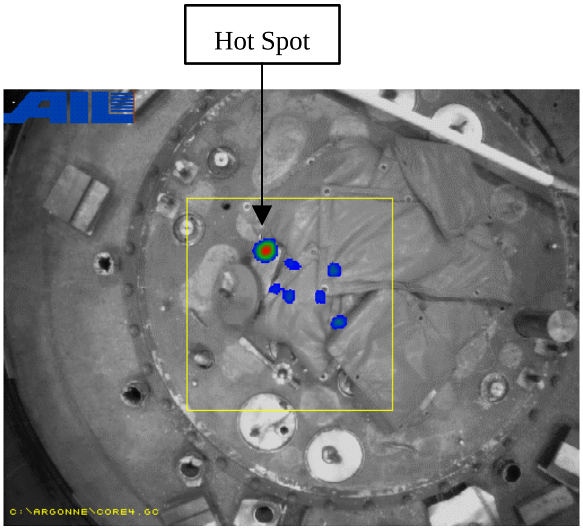

Figure 5. Hot spot identified.

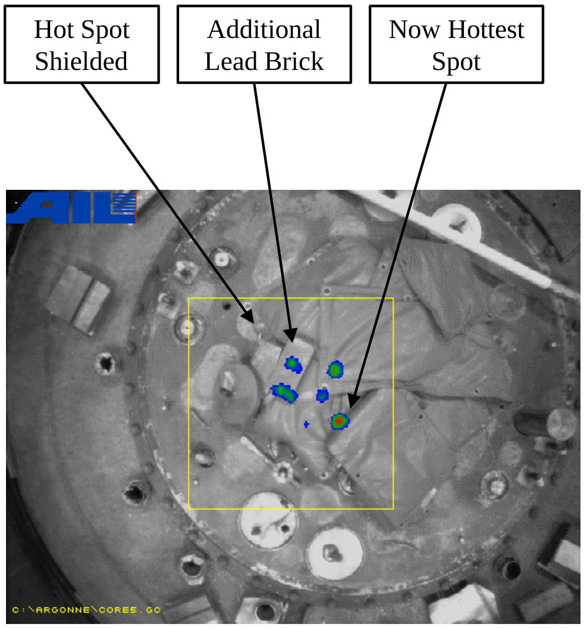

Figure 6. Hot spot shielded.

Another benefit to D&D shielding operations is that radiation worker exposure is reduced during shielding evaluations/operations because imaging is performed from safe standoff distances.

INEEL Dismantlement of ROVER Facility

The GammaCam™ has been used at the INEEL Idaho Chemical Processing Plant during dismantlement of the facility for processing of ROVER nuclear fuel. The ROVER Facility contained equipment for thermal and chemical processing of graphite-matrix fuel. The facility was constructed between 1978 and 1983, and continued to process ROVER fuel until 1984. Following completion of the processing campaign, the facility sat idle until 1995, when dismantlement of the facility was initiated. The objectives of the dismantlement included recovery of the remaining uranium bearing material (UBM) and stabilization of the remaining radioactive contamination in the facility. The extended period of shutdown resulted in uncertainties about the location and concentration of UBM in the facility. The GammaCam™ was used to verify the location of radioactive materials in the facility and to verify that the material had not spread through the facility during the shutdown period.

The thermal-processing portion of the ROVER Facility consists of two primary areas: a Material Handling Cave for handling of fuel assemblies and product, and the Cell 3-4 area containing the thermal burners. The Cell 3-4 area is 20 feet x 20 feet x 30 feet and contains the Primary and Secondary Burners (Vessels 100 and 104), ventilation equipment heaters, and miscellaneous process piping. Most UBM was expected to be located inside the two burners. Vessel 100, the Primary Burner, is 16 feet long. Vessel 104, the Secondary Burner, is approximately five-feet long. Both burners are suspended from the cell ceiling. The GammaCam™ was suspended from a crane and lowered into the cell to image the two vessels.

Vessel 104 Images. As depicted in Fig. 7a and 7b, Secondary Burner Vessel 104 is about 3 feet to the left of Vessel 100. These images were taken at the 27-foot elevation. The top image was taken in the wide FOV mode while the bottom image is the same photograph in the narrow FOV mode. These images demonstrate the improved spatial resolution of the narrow FOV mode. The second image provides a much more accurate representation of the actual vessel size and location.

Exposure Time:	6 min
Distance:	10 feet
Field at Source:	400 mR/hr contact

Vessel 100 Images. The four images in Fig. 8a through 8d depict the Primary Burner; Vessel 100 in four to six-foot sections. Figure 8a was taken at the 27-foot elevation and shows the ceiling and 24-foot elevation grating. The radiation source detected at the left edge of the FOV (yellow box) is the Secondary Burner, Vessel 104, as shown in Fig. 7. The radiation level from Vessel 104 is significantly higher than Vessel 100. Due to the dynamic range of the system, Vessel 100 does not register as a radiation source although the vessel is in the middle of the FOV and is reading 200 mR/hr at contact (or one foot). The dynamic range of the scene is dependent upon exposure time.

Figure 8b was taken at the 21-foot elevation. This image clearly identifies the mid-section of Vessel 100 in the FOV. The 24-foot grating is again visible and is located near the top of the FOV. Vessel 104 stops at the 24-foot elevation and therefore does not interfere with the imaging of Vessel 100 at this elevation.

Figure 8c was taken at the 16-foot elevation. The large color pattern represents the lower portion of Vessel 100. An extraneous blue pattern appears in the lower left corner of this image. Additional images determined that this is a “ghost” image of Vessel 104. Ghosting potentially occurs because the camera uses spatially coded aperture technology. Radiation arriving from outside of the sensor head FOV is partially coded and is interpreted by the system as a source. A trained operator can isolate true sources from ghost (partially coded) sources by several techniques. These techniques include using the GammaCam™ partially coded FOV function to compare wide FOV narrow FOV images which normally eliminates ghosts, or by taking multiple images with slightly different viewing angles, which causes ghost images to shift relative to the black and white video.

The image depicted in Fig. 8d was taken at the 12-foot elevation. The bottom of the vessel is readily visible represented by the large color pattern. Again, ghosting is present and caused by the high radiation levels of Vessel 104. Figure 8 images were captured from a distance of 14 feet with an exposure time of four minutes. The field at the source was 200 mR/hr contact.

Figure 7a. Vessel 104 wide FOV.

Figure 7b. Vessel 104 narrow FOV.

Figure 8a. Vessel 100.

Figure 8b. Vessel 100.

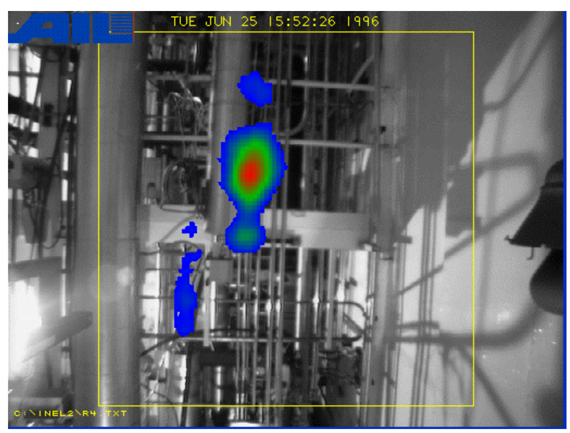

Figure 8c. Vessel 100.

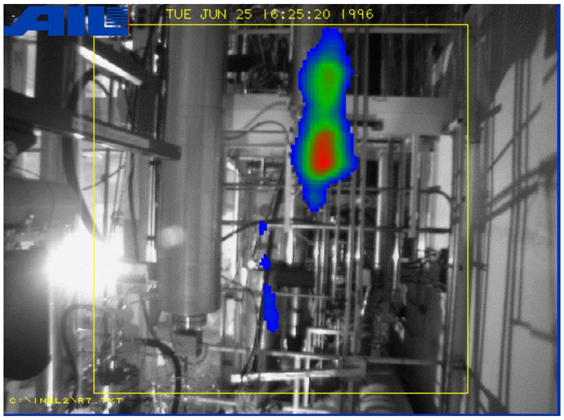

Figure 8d. Vessel 100.

The sequence of images for both Vessel 104 and Vessel 100 confirmed to ROVER project personnel that the majority of UBM material was located in the two process vessels as expected. These images assisted in the planning of recovery activities and delayed intended visual inspections, which saved personnel exposure.

D&D APPLICATIONS

The GammaCam™ images presented in this paper demonstrate that gamma ray imaging technology has been applied to several D&D areas.

Source Location Determination

GammaCam™ images identify gamma ray sources by providing a visible picture of source location. Conventional radiation survey tools do not provide a visible picture of source location. The system's ability to identify close adjacent sources is applicable to D&D operations because conventional source location techniques often miss sources adjacent to each other. Including a GammaCam™ image of the area's radiological conditions with the Radiation Work Permit (RWP) and area survey map can improve job planning and communications.

Relative Source Strength Determination

The GammaCam™ system captures pictures of the highest gamma source in its FOV. The highest captured source strength is shown relative to lower strength sources captured in its FOV.

Shielding Operations

The GammaCam™'s ability to image a work area, determine where shielding is required and evaluate the effectiveness of shielding placement are applicable to many areas in D&D. GammaCam™ images of D&D shielding operations result in improved shielding planning, avoidance of unnecessary shielding, and the avoidance of worker exposure during pre- and post shielding operations. Additionally, the ability of the sensor head to operate in both low-level (<15 μR/hr) and high-level (>50 R/hr) radiation environments without the use of shielding is especially useful during D&D operations.

Waste Management

The GammaCam™ provides an image of the highest gamma sources in the FOV. Having knowledge of the largest sources provides D&D personnel with the ability to prioritize sources and then plan for source disposition. This knowledge results in the ability to classify radioactive waste for separation which leads to cost effective sorting of radioactive waste during D&D operations.

Monitoring of Dynamic Radiological Conditions

The GammaCam™ can be used to monitor the changing radiological conditions that occur during decontamination. During a series of evaluations at Indian Point Unit 2 Nuclear Power Generating Station in New York, the system was used to remotely identify the distribution of radiation within a letdown line undergoing chemical decontamination. After chemical decontamination was completed, the area was re-imaged and a substantial decrease in radiation was confirmed. The before and after images of the decontamination process provided a measurable tool in which to monitor dynamic radiological conditions. (Migliaccio, R., et al, 1996, "Gamma Ray Imaging in Nuclear Power Plants," Nuclear Plant Journal, March-April 1996).

OTHER APPLICATIONS FOR GAMMA RAY IMAGING

Other applications for GammaCam™ imaging include Nuclear Treaty Verification. The imaging of nuclear warheads can validate warhead quantity without dismantling the nuclear missile and without revealing design details.

Another application for gamma ray imaging is waste storage. The imaging of radioactive waste containers provides a picture of the container shielding effectiveness. Imaging of the area surrounding the container can help identify spills. Capturing images of waste containers before and after shipment to waste storage sites improves waste control and handling efficiency.

Nuclear disaster characterization is another area where, in the event of a nuclear spill/accident, GammaCam™ images can be used to remotely survey the area from a safe standoff distance. This remote survey can be used to formulate the action plan.

The monitoring of radiation therapy for patients and nuclear medicine control are some of the medical applications for gamma ray imaging.

There are other applications of gamma ray imaging technology that have yet to be discovered. New applications are being discovered as the GammaCam™ is deployed at Nuclear Research facilities, Commercial Nuclear Power Plants, Nuclear Waste Storage sites and Nuclear Medicine facilities.

BENEFITS OF USING GAMMA RAY IMAGING IN D&D OPERATIONS

Gamma ray imaging benefits in D&D operations include reduction of radiation exposure to personnel. Consistent with ALARA principles, a user's exposure to radiation fields is minimized because of the sensor head's ability to operate at large standoff distances, typically 15 to 30 feet (or more) from the area being imaged. In addition, the PC can be positioned up to 100 feet from the sensor head. Unplanned exposure is also avoided because sources missed with conventional survey methods are typically captured with imaging.

Another benefit of gamma ray imaging is the ability to provide a visual image of source location and relative strength. Gamma ray imaging provided by the GammaCam™ visually specifies source location, which can supplement conventional radiological survey methods. Captured dominant source strength information, relative to other sources in the FOV, provides prioritization of source elimination.

The reduction in radiation survey time is another benefit of gamma ray imaging. Survey time utilizing gamma ray imaging is significantly less than conventional methods because characterization via imaging of a large area is made possible. In addition, sources located close together are less likely to be missed with imaging.

Gamma ray imaging can improve job planning/execution, which is an important benefit to D&D operations. The ability to capture a gamma image of an area enables job planning and execution to be performed with more factual information than is available through conventional radiation survey methods.

Gamma ray imaging is a benefit to shielding operations because imaging can help determine where shielding is required, and the effectiveness of the shielding installation. Pre- and post images of a shielding site will reduce the task time associated with shielding operations.

CONCLUSION

Gamma ray imaging is a new tool in the evaluation and assessment of gamma ray radiation. Many applications exist which promise to make the current D&D processes safer and more efficient. Remote gamma ray imaging radiation surveys can provide Health Physicists with the locations of the dominant sources, thus streamlining conventional survey methods. Radiation worker exposure is reduced during gamma ray imaging surveys. Gamma ray imaging improves D&D job planning because having a picture of the sources can result in reduced unplanned exposure and efficient job execution.

ACKNOWLEDGMENT

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