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GAMMA RAY IMAGING SYSTEM

(GRIS)

GammaCam™

Cooperative Agreement No. DE-FC07-94ID13281

Final Report

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Prepared For:

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By
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This report describes the activities undertaken during the development of the Gamma Ray Imaging System (GRIS) program now referred to as the GammaCamTM. This report is being submitted in accordance with the requirements of the Cooperative Agreement No. DE-FC07-94ID13281 with the DoE. The purpose of this program is to develop a 2-dimensional imaging system for gamma-ray energy scenes that may be present in nuclear power plants. The report summarizes the overall accomplishments of the program and the most recent GammaCam measurements made at LANL and Estonia. The GammaCam is currently available for sale from AIL Systems as an off the shelf instrument.

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1.0 Program Objective

The objective of the GRIS program was the development of a two dimensional imaging system for gamma-ray energy scenes. The program, as part of the ARPA TRP, focused on merging existing military technologies into a product with dual use applications. The GRIS primary commercial market is the nuclear power industry. On the military side ARPA has indicated a need for a GRIS type system to aid in the monitoring of nuclear facilities around the globe. The purpose of this monitoring is to prevent the proliferation of unauthorized nuclear materials.

2.0 Program Schedule

The GRIS program has been scheduled in accordance with the programs key objectives. Those objectives:

1. System Requirements Analyses
2. System Definition
3. Technology Evaluation
4. System Design
5. System Fabrication
6. Laboratory Testing
7. Alpha Testing
8. Productization Planning
9. Business Planning/Program Management

are the same as originally reported and have all been completed.

3.0 Program Status

3.1 Progress

The GammaCam has recently undergone successful demonstration and evaluation as part of the Paldiski Naval Nuclear Training Center Solid Waste Characterization Expedition. The results of this expedition are incorporated into a DOE report entitled "Paldiski Waste Characterization Expedition - Expedition Technical Report", additional information on the operation and utilization of the GammaCam are described in the reports and articles of Appendix 1.

3.2 Product Status

The GammaCam Model M31 is now available as an off the shelf product. The current list price for the standard system is \$179,900 with 12 week delivery ARO. This includes the sensor head, computer host, tripod, transit cases and associated cables.

The marketing of the GammaCam is being performed in accordance with the Environmental Monitoring Business Plan of the Diversified Products at AIL Systems. Portions of this Business Plan are included in Appendix 2.

4.0 Summary

The Estonia expedition concluded the contractual phase of the TRP Program. The GammaCam success as a TRP is illustrated by the over 80 inquiries received by both government and commercial nuclear operators in response to the March-April article in Nuclear Plant Journal.

The GammaCam has taken military technologies and signal processing expertise and focused it on an industrial problem. The end result is an American made instrument that is available for use globally in nuclear monitoring applications.

Appendix 1

1-1 Gamma Ray Imaging In Nuclear Power Plants

1-2 The Role of GammaCam in Health Physics

1-3 Using GammaCam in Decontamination and Decommissioning

1-4 GammaCam Model: M31

1-5 GammaCamTM Radiation Measurements - Los Alamos National Laboratory Los Alamos, New Mexico 12, 13 December 1995.

1-6 GammaCam Demonstration at Idaho National Engineering Laboratory

*Reprint - Removed
for separate processing*

The Role of GammaCam™ in Health Physics

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Benefits to Health Physics Activities:

- Remote radiation imaging to identify locations of strongest sources
- System generated radiation images optimize job control survey approach
- Gamma images supplement data of conventional surveys and improve job planning
- Evaluate shielding requirements and implementation

Abstract

The GammaCam™ is a portable instrument that produces accurate two-dimensional images of gamma ray emitting objects. The system provides real-time pseudo-color gamma ray imagery superimposed on a conventional black and white video picture. Remote operation of the sensor head allows safe acquisition of gamma ray images in high radiation environments. Health Physicists can use the gamma ray images as a fundamental part of an overall dose reduction strategy. This application note illustrates how the system recorded gamma ray images can be used in a multitude of applications including survey management, job planning and shielding evaluation.

Introduction

Time, distance and shielding are the principals of the ALARA (As Low As Reasonably Achievable) philosophy. The GammaCam gamma ray imaging system reduces the collective exposure of personnel in a cost effective manner by using the ideals of ALARA. The primary benefit of the GammaCam system is its ability to remotely image gamma radiation at typical distances of 10 to 30 feet (or more). Using the system as a general ALARA tool, a health physicist (HP) can rapidly perform a preliminary characterization of an area and identify the precise location of the strongest sources while minimizing exposure. Job control surveys are optimized when the HP uses the system generated radiation images to design the survey approach. The detailed spatial map would indicate specific areas to concentrate the survey effort thereby increasing the survey utility. Job planning for work crews can be more effective if the Radiation Work Permit (RWP) included an image of the radiological conditions together with the survey of the area. Consistency and quality of radiological surveys would improve.

Advantages of Remote Imaging

Imaging radiological environments simplifies the task of characterizing large areas, reducing both time and exposure. Unlike point sensors like Geiger counters and ion chambers which quantify radiation intensity at the single location of the sensor, an imaging device measures the radiation intensity of a two dimensional scene. Large areas can be imaged efficiently with the GammaCam. For instance, using the systems 50° wide field of view (FOV) mode at a distance of 30 feet, the system images a square area 28 feet on a side, or approximately 780 square feet.

The imaging approach increases the distance between the user and the radiation source significantly reducing dose. Additional dose savings are achieved with the remote control features of the PC compatible processor which provides complete sensor control at distances of 100 feet (200 feet available) from the sensor head.

Playing it Safe

Remote imaging allows investigations into hazardous areas such as glove boxes, storage drums or storage compartments, where unknown radiological conditions coupled with significant airborne and surface contamination may be present. In these applications, the GammaCam can accurately localize an inaccessible source quickly without having to put personnel or the sensor in a hazardous area. In fact, while characterizing a site in Estonia, this aspect of remote imaging was necessary to avoid very high levels of Radon contamination.

The Tammiku site was being used to store radwaste from industry, hospitals and universities. It consisted of three underground cells each measuring roughly 6 feet wide and 40 feet long. Figure 1 shows the system in a tripod mounted configuration positioned in front one of three closed access covers. The sensor head was pointed with a 30° depression angle. An eight minute integration

Figure 1: Tripod mounted GammaCam imaging underground compartment in Tammiku, Estonia

GammaCam™

Application Note

Figure 2: Stereo pair of images used to triangulate location of the source.
2a) Eight minute integration, 2b) Image with the GammaCam moved 40 inches to the right

Shielding Evaluation

yielded the image shown in Figure 2a which shows a strong point source approximately 10° to the right of the GammaCam axis. The closed access cover prevented the acquisition of a video data used to correlate the source to an object inside the cell. To overcome the absence of a visual cue, the sensor was moved to the right 40 inches to form a stereo pair of images. The image acquired with a lateral offset is shown in Figure 2b. Note that the source is now approximately 1° to the right. Triangulation of the two images allowed the dominant source to be localized to 13 feet behind the hatch, 4.5 feet below ground level.

GammaCam was used in several areas of the Idaho National Engineering Laboratories (INEL) during an August 1995 evaluation of the system. Images of an empty Navy fuel cask used for transporting spent nuclear fuel was acquired and served as an example of using the GammaCam to evaluate shielding. A gamma ray image of the empty, though contaminated fuel cask is shown in Figure 3a. The image was acquired at a distance of 33 feet using a 10 minute exposure time. Both this image and a close-up image shown in Figure 3b, which was acquired at distance of 9.5 feet using a one minute exposure, clearly shows the gamma ray photons emanating from the base of the cask

platform. According to a facility radiological control technician, the source was Co-60 contamination towards the center of the cask base and which had been previously measured as 1200 mR/hr (contact measurement with cask elevated). The intensity at the side of the cask where the source was imaged was 100 mR/hr (contact).

The GammaCam provides valuable insight in identifying source locations which maximize shielding benefits and also maximize the efficiency of shielding utilization. Safely quantifying the effectiveness of shielding such as lead blankets, pigs and cement casks from comfortable ranges is another substantial benefit of the system.

Figure 3: Navy Fuel Cask at INEL imaged at a distance of a) 33 feet and b) 9.5 feet

Locating Dominant Sources Remotely

Images were also taken at INEL inside test cells of the Advanced Test Reactor (ATR). The cells contain piping, valves and filters to support various loop experiment at the ATR. The components often become contaminated with radioactive sediment. Since the rooms themselves were contaminated areas it was decided to perform the imaging with the GammaCam sensor mounted on a tripod and positioned safely outside the cubicle doorway.

Figure 4: Hot valve at the ATR imaged outside doorway in 4 minutes

The image shown in Figure 4 was taken using a 4 minute exposure. The valve identified in the gamma ray image has a source strength of 37 mR/hr (contact) and was at a distance of 17 feet from the GammaCam sensor. The background field at the GammaCam sensor position was 20 mR/hr. A conventional survey of the cubicle and any subsequent job planning could now be performed more efficiently. Knowledge of the precise locations of the dominant sources would obviously reduce the time spent in areas and consequently reduce exposure.

Supplemental Data to Conventional Surveys

It is said that a picture is worth a thousand words. Hard copies of the system recorded gamma ray images have a striking impact on a surveys understanding and effectiveness when included as supplemental data to conventional radiological surveys. An example of such a survey is shown in Figure 5. The images provide memorable illustrations of radiological hazards giving sight to something that is normally invisible. When used in conjunction with an RWP, the images increase workers awareness of the gamma ray hazards.

Figure 5: Increased awareness of gamma ray hazards by adding GammaCam images to radiological surveys

The GammaCam is a joint development of AIL Systems Inc., Consolidated Edison Co. of New York, Inc. and Industrial Quality Inc.

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For further information, Contact the AIL Business Development Office at 1-800-944-1180 or 1-516-595-5150

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GammaCam™

Application Note

Using GammaCam™ in Decontamination and Decommissioning

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Applications:

- Expedite Site Characterization Using Remote Surveys
- Identification and Classification of Radiological Waste for Separation
- Source Localization to Prioritize Waste Removal Activities
- Monitor Progress of Decontamination Processes

Abstract

The GammaCam is a portable instrument that produces accurate two-dimensional images of gamma ray emitting objects. The system provides real-time pseudo-color gamma ray imagery superimposed on a conventional black and white video picture to quickly locate and measure radiation sources from a safe distance. The ability to operate remotely and at large stand-off distances is essential in a wide range of applications where significant dose savings are achieved.

Introduction

The major challenge being faced by the D&D and environmental restoration industry is cost. Cost efficient technologies must be leveraged to streamline activities and minimize waste volume. Gamma ray imaging provides a valuable addition to conventional technologies by quickly providing the precise locations of radiological hazards. The system recorded radiological images can improve the accuracy of disassembly and removal plans. The high cost of waste disposal provides strong incentives to minimize waste volume. In this application, the GammaCam can be used to accurately identify and classify radioactive waste during separation activities. During processes such as chemical decontamination, the system could provide real time acquisition of gamma ray images in high radiation environments. In addition to being a valuable ALARA tool, the GammaCam can improve processes specific to the D&D and remediation arenas. This

application note addresses several examples where the system has previously demonstrated its ability to refine D&D operations.

Site Characterization

GammaCam was used to take wide area images of outdoor waste storage containers during an August 1995 evaluation of the instrument at the Idaho National Engineering Laboratories (INEL). The INEL 16/17 storage area is an outdoor facility used to hold storage boxes containing radioactive material that is to be buried, compacted or incinerated. The images gathered in this area clearly show the utility of the GammaCam to quickly characterize large areas from safe standoff distances as well as its ability to image through shielding.

An image of two stacked storage containers taken from a standoff distance of 22 feet is shown in Figure 1.

The containers held valves with high levels of activity. The valves are shielded by concrete inside the container. The sensor was operating in its narrow (25°) field of view (FOV) mode and covered a square area of approximately 100 ft². This image was acquired with an exposure time of only 10 minutes. The source strength measured on contact with the container was 800 mR/hr while the background field at the position of the GammaCam sensor head was 8 mR/hr. It should be noted that the field strength reading at the sensor position is a combination of fields due to sources in the FOV and background fields originating outside the FOV. The dominant sources were imaged in the top container and the spatial distribution of the radiation coincide with existing INEL facility records.

Source Localization

During April, 1996, GammaCam was used to image objects with very

Figure 1: Containers at the INEL 1617 Storage Area

high radiation levels at the former Soviet Union Nuclear Submarine Training Facility in Paldiski, Estonia. The facility was recently abandoned by the Soviets and turned over to the Estonian Government. Building 307 is an above ground solid waste storage facility that consisted of seven storage cells. Records from the former managers of the facility were incomplete and there was significant uncertainty as to what was contained in the storage cells of Bldg. 307. A cross-section view of Cell 5 whose interior dimensions were roughly 12 ft by 12 ft by 20 ft is given in Figure 2. The cement walls surrounding Cell 5 were 3 ft thick. There are three cell openings, the middle of which is shown with its cement plug still in place. The objects shown under opening 1 were suspected to be control rods.

Strong radiation fields with strengths between 3 to 15 R/hr were present in the vicinity of the openings when the plugs were removed. The remote operational capabilities of GammaCam enabled the acquisition of gamma ray images with a minimal exposure to the field technicians. A GammaCam manipulator specifically designed for this expedition allowed the sensor head to be lowered through the openings. The tilt and azimuth angles of the sensor head were also adjustable using the manipulator. In addition, an ion chamber was attached to the side of the sensor head to allow the recording of the field strength at the sensor head position.

The system was first lowered through opening 3 as depicted in Figure 2. At the sensor position, the field strength was approximately 17 R/hr. The image acquired in the systems narrow FOV mode and an exposure time of 1.2 seconds is given in Figure 3. The image shows that the dominant source of radiation is at the base of the cell over the suspected control rods. This image identifies the location of the dominant source of radiation in cell 5 and the orientation of the control rods. Additional

Figure 2: GammaCam Images Control Rods in a Hostile Environment

imaging was performed with GammaCam lowered down through opening 1. Figure 4a shows the black and white video image alone and Figure 4b shows the radiation image with the pseudo-

color overlay. This image was also acquired in the narrow FOV mode with an exposure time of 0.25 seconds. The field strength at the sensor head position was 60 R/hr. The images shown in

Figure 3: Control Rods Imaged in Cell 5 through Opening 3

Figure 4a: Image Acquired In Cell 5 Through Opening 1. Black and White Video Only

Figure 4 provides valuable information that precisely identifies the control rods with the strongest gamma ray activity. This information will be used in the future to plan and prioritize waste removal activities. It also illustrates the systems ability to operate in high radiation environments while minimizing exposure to personnel.

Classifying Radioactive Waste for Separation

An application currently being addressed is using the GammaCam as an integral component in a waste separation facility. In one configuration, the sensor head would be situated 9 feet above an 8 ft by 8 ft sorting table in a look down mode. Operation of the system in its Wide (50°) FOV mode would result in a spatial resolution of roughly 5 inches. Mixed waste would be spread out over the table and images acquired

Figure 4b: Image With Pseudo-Color Overlay Showing Distribution of Radiation

by the GammaCam would be used by the system operator to locate and classify the waste. The operator would then use a robotic arm to remove the objects of interest. The process would be repeated until only low level waste remained.

Monitoring Decontamination Processes

In a series of evaluation trails at the Indian Point Unit 2 Nuclear Power Generating Station of Consolidated Edison Co. of New York, Inc., the system was used to remotely identify the distribution of radiation within a letdown line undergoing chemical decontamination. Instrument setup typically took between 5 and 10 minutes. Setup and operation of the system did not interrupt or displace other ongoing activities. The distance between the sensor and the letdown line was approximately 25 ft. Contact readings on the letdown line indicated a strength of 800 to 1200 mR/hr while the field strength at the sensor head was 50 mR/hr.

The gamma ray image shown in Figure 5 was acquired using a 2 minute exposure. The radiation distribution within the letdown line can be easily seen and exhibits precise alignment with the true location of the letdown line. The highest concentration of radiation is seen within the right elbow, a result of fluid flow dynamics which often cause debris to collect at the places of increased turbulence. A survey instrument was used to confirm the radiation distribution measured by the

Figure 5: Letdown Line Before Chemical Decontamination

system. At the conclusion of the full system decontamination, the area was reimaged and confirmed a substantial decrease of radiation.

It was necessary to remove the GammaCam during the actual decontamination process because of dynamic radiological conditions and the fact that the evaluation instrument required some operator control at the sensor head. The system has since been upgraded and is currently capable of complete autonomous operation in adverse and dynamic radiological environments to provide real-time feedback of decontamination effectiveness. The value of having such a system visualize the changing conditions during the decontamination process is clearly advantageous when coupled to conventional methods. The simple setup, remote operation and wide field

of view coverage of the GammaCam results in the elimination of many sensors, saving time and reducing worker exposure.

Conclusions

The GammaCam is a new dimension in the evaluation and assessment of gamma ray radiation. Many applications exist in D&D which promise to make current processes safer and more efficient. Remote surveys can provide health physicists with the locations of the dominant radiological sources thus streamlining conventional survey activities. Decreasing exposure to radiation hazards is inherent to the systems ability to operate remotely and at large standoff distances. GammaCam provides users with the precise locations of radiological sources in an easy to use format.

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GAMMACAM™ PORTABLE GAMMA RAY IMAGING SYSTEM

The **GammaCam™** is a portable gamma ray imaging system that revolutionizes the assessment of radiological environments by providing accurate two dimensional spatial mappings of gamma ray emitting nuclides in real time. Remote operation and control allows safe image acquisition in high radiation environments, minimizing operator exposure.

FEATURES

- Portability
- Easy Setup
- High Spatial Resolution
- High Sensitivity
- User Friendly

APPLICATIONS

The system can be tailored to countless applications which include:

■ Critical Path Survey Management	■ Monitoring of Dynamic Radiological Conditions
■ Safe, Remote Surveys of Large Areas	■ Cost Effective Sorting of Radioactive Waste
■ Evaluation of Shielding Requirements and Implementation	

GAMMACAM™ SAMPLE IMAGERY

3-D Relief of
Gamma Ray
Intensity

Control Rods

Exposure Time: 0.25 sec

PWR Reactor Cavity

Exposure Time: 5 min

Filter in Drum

Exposure Time: 4 min

SPECTRAL RESPONSE RELATIVE TO 0.66 MeV

GammaCam™
Radiation Measurements
Los Alamos National Laboratory
Los Alamos, New Mexico
12, 13 December 1995

The GammaCam™ INEL Model, shown in Figure 1, was brought to TA-18 of the Los Alamos National Laboratory (LANL) to take images of radiation sources. The objective of the measurements was to determine the GammaCam™ effectiveness in imaging special nuclear material (SNM) in various configurations. The sources and their configuration were determined by the test leader Dr. Ken Butterfield.

Figure 1...The INEL Model of the GammaCam™ Weighing in at < 60 Pounds

The GammaCam™ was brought to the High Bay of TA-18 and setup to make the measurements as determined by Dr. Butterfield. The initial measurement was made of 3 separate sources. The resultant image is shown in Figure 2.

Figure 2. GammaCam™ resolves three separate sources

The source in the drum is ^{235}U while those in the file safe were ^{239}Pu . The dose rate of the sources measured on contact with the drum and the file safe were on the order of $100\mu\text{R/hr}$. The image shown was taken in a long exposure made up of 12 five minute exposures of the primary and complimentary coded aperture masks. This resulted in a total exposure time of 2 hours. No effort was made to image the sources in less time. It should be noted that an initial, single, five minute exposure successfully imaged the source in the drum, unfortunately this data was accidentally erased before it could be saved.

The GammaCamTM was then moved closer to the sources. The position was established to put the sources at the edge of the systems gamma ray FOV. The sources as shown in Figure 3 were at the lower left edge, in the case of the drum and in the upper right corner, in the case of the top drawer of the file safe, of the GammaCamTM field of view. The second drawer of the file safe was on the upper left edge. The results are shown in Figure 3. The results show attenuation due to the placement of the sources at the edge of the FOV.

Figure 3 Gamma Sources at Edge of FOV

Some attenuation is normal based on the cosine loss in aperture as a function of angle. This loss is accentuated in the corner since both angles are maximized. In addition at the time of the test the GammaCamTM was configured with a prototype mask. This mask is oversized (0.6 inches thick instead of 0.45) due to delivery constraints on the mask material and restricted the transmission of the low energy gamma's ($<1.33\text{MeV}$ of ^{60}Co that the mask was designed for) 80% more than the normal mask size would. This oversized mask effectively limited the FOV to 19 degrees from the 25 degrees it is designed for.

The results support the reduced FOV. In that the source in the top drawer of the file safe is stronger but due to the masks FOV was attenuated.

In order to determine in scene dynamic range of the GammaCamTM the ^{239}Pu source was brought out of the safe and placed on the drum containing the HEU source. The sources were at a distance of 7.9 feet from the front of the camera. The images in Figure 4 show four different exposure time settings for the GammaCamTM from 2 minutes down to 5 seconds. The GammaCamTM images show that the signal from the Pu source is strong enough to over shadow the smaller HEU source in the drum. This "in scene" dynamic range limit is currently on the order of 20:1.

Figure 4a. GammaCam™ System Display Allows User To Configure Data As Desired

Figure 4b. In As Little As 5 Seconds The GammaCam™ Could Image The Unshielded Source.

The GammaCam™ was then setup to look at both the file-safe and the drum again. The resultant image in figure 5 illustrates the systems ability to again view multiple sources. What should be noted is that in the images of Figure 4 the Pu source on the drum was successfully imaged with the source in the file-safe acting as background. This gives a strong example of the GammaCam™s ability to operate in significant levels of background and still produce an effective image of the scene within the field of view.

Figure 5 The GammaCam™ Image Shows The Background Source Suppression From The Image In Figure 4.

The Pu source was then put behind 3 inches of high density, plastic like shielding to determine the systems ability to image through this material. Exposures of 5 minutes and one hour were taken at a range of 15 feet. The results are presented in Figure 6.

Figure 6a 5 Minute Integration Of Shielded Source, Magnified In GammaCam™s View Mode.

Figure 6b Even For Highly Shielded Sources The GammaCam™ Still Produces A Valid Image.

A more complex set of sources was then configured to determine the systems ability to detect and process very low level data rates while exposing for long periods of time. The sources previously described were placed at a distance of 50 feet. The HEU in the drum, a Pu source in the file safe and the other Pu source behind the shielding material. The GammaCam™ was set up to run four consecutive total exposures of 8 hours, 4 hours, 2 hours and 1 hour. Half the time exposing each mask in 5 minute alternating cycles, i.e. 5 min. primary, 5 min. complimentary mask exposure repeated 48 times to generate four hours primary mask and four hours secondary mask data for a total exposure time of eight hours.

The results are shown in Figure 7. At this time since the two unshielded sources can be made out in the 2 hour and are quite clear in the 4 hour it is unclear as to why the eight hour image is not even better. It may be an error in code that is corrupting this data. This problem will be addressed and corrected at AIL immediately.

Figure 7a 8 Hour Exposure Indicates Processing Error

The GammaCam™ would be an effective tool for the safeguards group to incorporate into their cadre of wares. During the tests at LANL the GammaCam™ performed as expected for the majority of the tests run. The only exceptions being the 8 hour long exposure and the FOV test. The problem with the 8 hour exposure is thought to be a coding error and not of major concern. The reduction in sensitivity to objects

Conclusion:

Additional images were taken of sealed sources and were not made available to ALL.

Figure 7c 2 Hour Exposure Shows beginning of source in drum

Figure 7b 4 Hour Exposure clearly shows drum source and file-safe source.

on the edges of the field of view is attributed to the thick mask. With the proper mask in place (currently on order from the manufacturer) the system full field performance can be shown.

As part of the discussions that took place during the testing, Lawrence Livermore and Los Alamos scientist had suggestions on data display, storage and system operation. Many of these suggestions parallel our own desires and will be implemented in the near future. The group expressed the desire for image build up processing, segmented image storage and multitasking. The image build up processing, which would update the display based on the shorter exposure intervals of a multiple interval exposure is something that is on AIL's list of functions to incorporate. The storage of those individual exposures in an unprocessed raw form can also be implemented allowing for more detailed post processing. The intent of AIL was and still is to provide the operator with real time "turn key" images as is desired by the staff of the commercial nuclear power plants where we have demonstrated and tested the system. This can be expanded to include more file storing options for the use of the scientific community of the lab. Multitasking or giving the operator the ability to view and process the previous image while a current image is being taken is somewhat complex and is being addressed under a longer range goal to incorporate multiprocessing for this activity.

If more information regarding the test configurations and data are required contact Dr. Ken Butterfield of LANL TA-18. If specific information regarding the GammaCamTM operation, performance or data processing are required contact Doug Petito at AIL Systems Inc.

Images at 1617 Storage Area

The 1617 area is an outdoor storage facility for storage boxes containing radioactive material that is to be buried, compacted or incinerated. The radiation field in the vicinity of the instrument was about 8 mR/hr. The image in Figure 1 shows that the source of radiation is in the lower center portion of the storage box. This image was taken with one-minute exposure at a distance of 22 feet in front of the storage container. The record kept by the facility indicates that the source field at the surface of the box was approximately 200mR/hr. The box contains high radiation valves that are shielded by concrete inside of the container. The location of these valves shown in the gamma image coincides with the facility record.

Figure 1 A storage box in ICPP 1617 Storage Area (22 feet, 1-minute exposure)

An image of the same container from a different viewing angle is presented in Figure 2. Data from images taken at several view angles, such as two figures shown above, can be used to obtain a three-dimensional (tomographic) map. Figure 3 shows an image of several containers placed side by side. This image was taken at a distance of 57 feet with an exposure time of 10 minutes. Radiation field at the containers was not measured. The image indicates two areas of radioactive material concentration, one in each container. The count received by the GammaCam indicates that radiation emanating from the container on the left is about twice that of the one on the right.

Figure 2 A slant angle view of container shown in Figure 1 (30 feet, 1-minute exposure)

Figure 3 Long distance image of other containers in ICPP 1617 storage area, (57 feet, 10-minute exposure)

Images of ROVER Cave

The system was also used to image the ROVER Cave. The ROVER Facility was used for reprocessing of recovered fuel for an experimental spacecraft nuclear rocket engine. The ROVER Cave is a highly radioactive and contaminated area in the ROVER Facility. The placement of GammaCam at the ROVER Cave opening restricted the accessible views. Images were taken through a thick wrinkled acetate sheet with a vent port serving as a containment barrier for contaminating particles. Visual images are not of good quality because of the acetate sheet. The radiation field at the instrument was about 3 mR/hr. Two images are shown in Figure 4 and 5. The distance to sources indicated in these figures was a rough estimate. The image in Figure 4 shows the base of a small cylindrical fixture which is covered by a lead blanket. The pipe fixture is completely shielded with lead blankets except the base. The field at the base, according to the last available survey, was about 3 to 4 R/hr. The GammaCam was placed to the left of the cave opening and panned to the right to take an image of a filter structure covered heavily with powder-like particles. This image is shown in Figure 5. The GammaCam was placed so that the wall next to the opening provided shielding against the source seen in Figure 4. Filters looked like simple air-conditioning type filters. The thick dust visible on the filters is, as described by facility operators, ^{137}Cs dust attached to filter fibers that remained in the cave after fuel reprocessing. A 30-second exposure was used to acquire this image and the field strengths at the filter were estimated to be 3-4R/hr based on the old survey record.

Figure 4 A lead blanket shielded cylindrical vessel in ROVER Cave, (20 feet, 120-second exposure)

Images of Naval Cask at FAST Area

The GammaCam was used to image an empty Navy fuel cask at the fuel storage pool building (FAST). Navy fuel casks are used for transporting spent fuel. The imaged cask did not contain spent fuel. Gamma photons were radiating from a

small crack in the base of the cask. A facility RCT indicated that this was an older cask that had some porosity to the base. Most likely the radiation is due to ^{60}Co that had been trapped in the pores. The radiation field at the bottom of this cask had been measured previously by the facility RCT by raising the cask off the ground. The measured radiation field was approximately 1200mR/hr. The manual survey with a G-M counter by a facility RCT had reported that the hottest spot on the cask was at the base on one side of the cask. The on-contact radiation field was approximately 100mR/hr according to that survey. The image, shown in Figure 6, was taken with a one-minute exposure from a distance of about 9.5 feet. Radiation field at the instrument location was about 0.5 mR/hr. The position of the radiation agreed with the marking on the cask. A longer distance view (Figure 7) and a side view (Figure 8) were also taken in addition to the above image. The side view, as mentioned before, can be used to reconstruct a three-dimensional gamma image. The image shown in Figure 7 taken at 33 feet from the cask was obtained with a 10-minute exposure. This was done to demonstrate the capability of taking images at long distance.

Figure 5 Contaminated filter in ROVER Cave, (30-second exposure)

The location of the hot spot in the cask appeared in Figure 7, which is somewhat overexposed, agrees with that of Figure 6. A facility RCT informed us that they had spent nearly one hour to locate the hot spot of this cask with a G-M counter at short distance from the cask. The test demonstrated that the GammaCam placed at 30 feet did the same task completely in 10 minutes. The GammaCam could probably obtain a discernable image within a much shorter exposure time. Figure 8, a side view image, shows a small hot spot that gives some indication to the depth within the base of the cask where the radioactive material is located. The count and the size of the hot spot were smaller than that of Figure 6 because of shielding effect by the cask wall.

Figure 6 An empty Navy Fuel Cask, (9.5 feet, 1-minute exposure)

Figure 7 Navy Cask at 32 feet with 10-minute exposure (A false signal in lower right part due to display anomaly)

Figure 8 A side view of Navy Cask, false signals in front of cask base

Images of Calcining Bin Sets

The GammaCam was used to take gamma images of the Calcining Bin Sets. Figure 9 is an image of a calcined waste transfer duct where it leaves the gravel cover prior to entering the shed. This image was taken at a distance of 25 feet from the duct in two minutes. Figure 10 is an image of another transfer duct at about 50 feet away from the GammaCam. The distance was guessed rather than measured because of sun back lighting. In this case the Bin Set shed is at the top of the gravel pile. The duct is most contaminated where it flares out into a wider cross section near at the bend. This image was taken in one minute. A long, a ten-minute exposure, an image shown in Figure 11 indicates the same hot spot with larger radiation field coming from weaker sources in the surrounding area. The instrument was placed in a 100 $\mu\text{R/hr}$ field area. Radiation field at these sources was not measured, but their location coincides with general information provided by the facility manager.

Images of Advanced Test Reactor Cubicles

A GammaCam was used to take images of Cubicle 1D and 1A of the Advanced Test Reactor (ATR) at INEL. The test reactor cubicles contain piping, valves, and filters to support in-pile testing at the ATR. These components often become contaminated with radioactive sediment. The instrument was placed at the door of these cubicles and looked into the cubicle. Some of the gamma images of those cubicles are shown in Figures 12 and 13. Because of insufficient lighting and placement of the instrument, it was difficult to take a good visual image and to point the instrument to desired areas of the cubicle.

Figure 9 Image of Bin Set 2 base with a 60-second exposure at 25 feet, a false signal on right side

Figure 10 Image of top side of Bin Set 2, a 60-second exposure at 50 feet. Vertical streak of visual image is due to direct sun light illumination.

Figure 11 Image of Bin Set 2 top side, a 10-minute exposure

Figure 12 Image of ATR Cubicle 1D through the door

Figure 12 shows that radiation was emanating from the base of a pressurizer. This is most likely due to ^{60}Co sediment accumulated inside the vessel. Radiation from other sources in the cubicle was partially coded by the mask and appears as false signals (see Figure 12). The radiation field, where the instrument was located, was about 4 mR/hr. Figure 13, an image of Cubicle 1A, shows a single hot spot that is dominating the other sources in the scene. The cubicle wall near the door provided some shielding to minimize influence of other partially coded sources and reduced false signal. The video indicates that the source of the radiation is at the pipe joint. This image was taken in two minutes at approximate range of 17 feet from the indicated spot. The radiation field at the instrument is about 20 mR/hr. The location of sources shown in above two figures agrees very well with radiological survey maps provided by the ATR. Radiological maps do not indicate the precise location of sources, but they provide a clue to general locations where a source could be found. In contrast images taken by a GammaCam indicate precise location of these sources in a very short time.

Figure 13 Image of ATR Cubicle 1A through the door, (17 feet and 120-sec. Exposure) A false signal on right of contaminated valve.

The measurements at ATR were limited to those that could be viewed from the doorways and behind barriers demarcating high radiation or contaminated areas from safe area. This limitation was imposed by a regulation for assuring the radiation safety of operators, but not by limitations of the instrument. No further attempts were made to map Cubicle 1D more thoroughly. Radiation field at sources was not measured during the test because entry to those high radiation cubicles was undesirable.

Images of ^{239}Pu Slugs

Thirteen (13) one-gram plutonium slugs were placed in a stack to simulate a near point source². The pseudo color gamma image³ displayed on the computer screen is shown in Figure 14. Figure 15 is a three-dimensional plot of the above image generated with MATLAB Program from the recorded data file. The distance between the sensor module and the source was about 9.3 feet and the exposure time was four minutes. The peak signal to the noise ratio is about 60. A visual discernable image of the source can be obtained with a much shorter exposure time. The exposure time required to obtain a discernable visual image is subject to the operators' perception, however as a rule of the thumb, exposure time that produces an S/N ratio of about seven is considered to be adequate.

Figure 14 An image of stacked 13 ^{239}Pu slugs, (9.3 feet, 4-minute exposure)

A typical isotope mass fraction of constituent isotopes of Pu slugs used in the experiment, reported by a January 1995 assay, is 0.946354 for $^{239}\text{Pu}/\text{Pu}$, 0.05274 for $^{240}\text{Pu}/\text{Pu}$, 0.000695 for $^{241}\text{Pu}/\text{Pu}$, and 0.003236 for $^{241}\text{Am}/\text{Pu}$. ^{239}Pu decays to ^{235}U and to ^{231}Th by alpha-decay and then to ^{231}Pa by beta-decay and not all radioactive decays yield gamma photons. ^{241}Am is a daughter of ^{241}Pu by beta-decay. The branching ratio of the most intense gamma radiation from ^{239}Pu is less than 10^{-5} . Thus, very few radioactive decays from ^{239}Pu result in gamma photons. Because of the shorter life time of ^{241}Am compared to that of ^{239}Pu , most of the gamma photons radiating from the slug are from a ^{241}Am isotope. Calculated radioactivity from one slug is approximately 85 mCi, of which ^{241}Am contribution is about 11 mCi.

² Slugs were stacked roughly on top of each other, but they spread over a 2 inch diameter area.

³ All pseudo color images shown in this note are real time displays on the monitor screen of the personal computer (processing and display module).

The computed total gamma photons radiating from a one-gram ^{239}Pu slug are about 1.5×10^8 photons per second in the energy region between 0.04 and 1 Mev. Three intense gamma radiations from ^{241}Am are 59.54 keV (1.47×10^8 gamma/sec-slug), 98.95 keV (8.32×10^4 gamma/sec-slug), and 102.97 keV (7.99 gamma/sec-slug). Two dominant gamma radiations from ^{239}Pu are 51.63 keV (5.82×10^5 gamma/sec-slug) and 129.29 keV (1.36×10^5 gamma/sec-slug). The most intense gamma radiation from ^{241}Pu is at 208 keV. The total gamma radiation from ^{241}Pu is 2.39×10^4 gamma/sec-slug, which is relatively small compared to gammas from ^{241}Am . The calculated radiation field on the aperture (9.3 feet) from thirteen ^{239}Pu slugs, assuming a near point source, is then about 127 $\mu\text{R/hr}$.

Figure 15 A three-dimensional plot of gamma image shown in Figure 14

The radiation field at one foot in front of the stacked 13 slugs of Pu was approximately 4 mR/hr, which is measured with a G-M counter, is about a factor of 2.5 lower than the calculated value. The radiation field measured at the sensor module located 9.3 feet from the source was about 55 $\mu\text{R/hr}$. The general background radiation field measured in the vicinity where the instrument was placed was about 12 $\mu\text{R/hr}$ without ^{239}Pu slugs present. This implies that gamma radiation field at the sensor module contributed by 13 ^{239}Pu slugs was approximately 40 $\mu\text{R/hr}$. This value is 37 % of calculated value. Difference between calculated and measured field is probably due to: 1) point source assumption used for calculation, 2) variation in an isotope mass fraction of slugs used in the experiment, and 3) self shielding through stacked slugs.

Fourteen (14) ^{239}Pu slugs were then arranged in a cross pattern so that the imaging properties of the GammaCam could be evaluated. Figure 16 shows a typical image obtained by the GammaCam. There are more of the slugs in the top leg of the cross as indicated in the image by the difference in intensity. The image in Figure 16 was taken with an exposure time of four minutes at a distance 9.3 feet from sources. A slight parallax is noticeable due to an offset between a line of sight of the gamma camera and that of the video camera. The parallax will become less noticeable as the distance between the sensor and sources increases. The count received by a gamma camera pixel depends on the distance to

sources, source intensity, source geometry, radiation energy level, and intervening gamma attenuating materials. Estimation of source intensity can be made if the above conditions are known. Images of 14 Pu slugs arranged in a cross pattern taken with exposure time of two minutes, one minute, and 20 seconds are shown in Figures 17, 18, and 19 respectively.

Figure 16 Image of ^{239}Pu slugs in a cross pattern, (9.3 feet, 4-minute exposure)

The 2-minute exposure image in Figure 17 shows one of the slugs in the lower leg is less intense than the rest. The one-minute exposure image in Figure 18 does not agree with the 2-minute exposure image. Careful examination of recorded data revealed that several pixels in the 2-minute exposure are saturated due to instrument noise spikes. These noise spikes affected automatic threshold process and resulted in imperfect image recovery. The 20-second exposure image in Figure 19, however, shows that the particular slug in question is indeed less intense than the rest.

Pseudo color image displays shown in this note are normalized to the maximum counts within each image frame. This display mode maximizes the visual contrast for any given radiation scene and facilitates clear visual presentation. For each image taken, the absolute counts of all pixels as well as the count distribution of a shadow domain image are stored in a data file and available for further data analysis. A three-dimensional plot, a contour plot, or a projection plot of gamma images can be generated from image data files. Figure 15 is an example of three-dimensional plots. It does not identify the location of the source visually, but it provides more detailed numerical information for data analysts to perform numerical and image analysis. The system is also capable of displaying images in the absolute count mode. This mode gives absolute radiation field at the instrument aperture from sources. Many factors affect the accuracy of an absolute estimation of source radiation. Although accurate estimation of source radiation requires careful modeling and iterative computation, rough source radiation estimation could be obtained by simplifying assumption. The GammaCam can be customized to provide various display and data presentation.

Figure 17 Image of cross pattern Pu slugs (9.3 feet, 2-minute exposure)

Figure 18 Image of cross pattern Pu slugs, 1-minute exposure

Figure 19 Image of cross pattern ^{239}Pu slugs, 20-second exposure

Figure 20 Image of cross pattern ^{239}Pu slugs shielded by a 1/2-inch thick aluminum plate

Figure 21 Image of seven vertically arranged ^{239}Pu slugs with a $1\frac{1}{2}$ inch thick Melamine-Glucose Mix

Figure 22 Image of vertically arranged seven ^{239}Pu slugs shielded by $1/4$ inch thick depleted uranium plates, photons radiating through a gap between plates were detected

Several different shielding materials were placed in front of the ^{239}Pu slugs to attenuate gamma photons. Images obtained by the GammaCam with a shield; such as an aluminum plate, melamine-glucose mix (a TNT surrogate), a depleted uranium plate, or a Borated Poly plate, placed in front of Pu slugs are shown in Figures 20, 21, 22, and 23 respectively. These shielding materials were chosen because they roughly simulate materials used in nuclear weapons. Shielding affects images obtained by the GammaCam due to attenuation and scattering of gamma photons through the shielding material. The system was able to obtain an image of Pu sources in all cases except when slugs were shielded with a 1/4 inch depleted uranium plate. Depleted uranium (DU), as a very high z (atomic number) material, has the greatest attenuation coefficient of all the materials used in the test. Gamma photons leaking through a gap between two DU plates were imaged as seen in Figure 22. The aluminum plate used in this experiment is 1/2-inch thick. Analysis of the photon count data shows that the aluminum shield attenuated about 20% of gamma photons. The measured result was in a good agreement with a theoretical estimate. The thickness of Melamine-Glucose mix shield, in Figure 21, is about one and one-half inches. Several 1/4 inch thick depleted uranium plates were laid next to one another to form a shield in Figure 22. A one-inch thick Borated Poly plate was used as a shield in Figure 23.

Figure 23 Image of vertically arranged seven ^{239}Pu slugs shielded by a 1 inch thick Borated Poly plate

Conclusions

The GammaCam was effectively utilized over a ten-day period at the INEL to take images of a variety of gamma scenes under various conditions. The data set shown in this note is a subset of more than 100 images taken and stored during this demonstration. The test clearly demonstrated that a GammaCam is effective in taking images of a gamma scene in real time. Following the reported test at INEL, additional measurements for improving calibration and utilization procedures will be carried out by AIL. Among many contemplated improvements to the GammaCam, the processing

and display of measured photon count in a particular pixel normalized to a reference absolute "Counts per unit time" will be the most significant enhancement. This count information will be used to provide rough estimation of source radiation field assuming source gamma energy of ^{137}Cs at 30 feet. In other words, the initial guess of source radiation field is for a point ^{137}Cs source at a distance of 30 feet. For point sources this estimate will give an order of magnitude accuracy in the energy range between 80 and 1,500 keV and for a range of distance between 15 and 45 feet. Accurate source radiation field estimation requires detailed data on source energy, source geometry, distance to sources, intervening objects, and other environmental conditions. Modeling, algorithm, and software for accurate estimation of source radiation are currently under development at AIL.

The GammaCam as currently configured is an effective tool for locating hot spots quickly from a safe distance. This operational feature satisfies two of the basic principles of ALARA, time and distance. In fact the GammaCam can be used to develop a shielding placement plan, a plan for locating and removing the major radioactive materials from a work area. It is a state-of-the-art instrument for achieving ALARA goals.

Acknowledgment

We acknowledge valuable help rendered by numerous LITCO personnel to make the test possible at INEL. Particularly, contribution by Rob Howard in conducting the test at ATR is appreciated. Assistance from Mark Hendricks and Karl Griffin in facilitating timely access to test sites is also significant for successfully completing the test on schedule. Technical discussion with Jack Hartwell is very valuable and is acknowledged. Support by Don Shadely of Idaho Operations Office, U. S. Department of Energy in facilitating the test at ICPP is greatly appreciated.

Additional information

Contact D. Petito, AIL Systems inc. (800-264-7477) for information on the GammaCam and J. Nadler (208-526-0796) for information on INEL.

APPENDIX 2

1 Selected portions of AIL Systems Environmental Monitoring Business Plan - Diversification Products Group, June 1996.

**** Note:** The following has been extracted from AIL Systems Diversification Products Group 1996 Environmental Monitoring Business Plan

3.1 PRESENT SITUATION - GammaCam™

This section reviews briefly the present product status, potential product applications, market drivers, targeted market segments, and near term marketing strategy for developing sustainable business using the GammaCam as a unique market entrance product. More detailed discussions on market segments, market analysis, and marketing strategy are presented in the following sections.

3.1.1 GammaCam Instrument

AIL has developed a unique product, 'GammaCam™'. This Camera is capable of taking pictures in gamma (x-) ray spectra and has not been previously available to the nuclear industry. It is a portable staring imaging camera for viewing a wide field scene and recording, in near real time, an image of gamma ray emitting objects in the x-ray and gamma ray spectral range. It consists of a sensor module, an electronic module, and a signal processing and display computer. A sensor module and an electronic module of the GammaCam™ brassboard are usually mounted in a mounting frame as shown in Figure 3.1. The assembly weighs 55 pounds and is 10 x 16 x 18 inches in size.

Figure 3.1 GammaCam Instrument

Unshielded radioactive nuclides emit harmful radiation into the surrounding environment. Locating and identifying such radioactive materials is of utmost importance in ensuring health of workers. The traditional measurement method using G-M counters or non-imaging detectors is inefficient in locating and identifying radioactive nuclides. The GammaCam is a tool with an ability to quickly find radioactive sources and measure the source intensity from a safe distance. Its use can provide cost and operational advantages over traditional methods for radiological survey.

AIL developed technologies suitable for constructing a GammaCam and fabricated a brassboard in 1994. The brassboard was tested during 1995 at a commercial nuclear power plant and various facilities of U.S. Department of Energy. These alpha tests have convincingly demonstrated its performance and utility. During the first half of 1996, AIL has been carrying out development of Beta Model (Model I) and participating in a DoE sponsored radiological survey expedition to a former Soviet Submarine Reactor Training Center at Palidiski Estonia..

3.1.2 Product Heritage and Patent Position

Gamma (x-) ray cameras used in astrophysics observations, nuclear medical imaging, and quality inspection applications are bulky, heavy, costly, difficult to operate, and not suitable for industrial application. They are installed mostly at fixed installations or high valued platforms. The GammaCam is man portable, sensitive, operationally flexible, and relatively inexpensive. Therefore it can be easily deployed and used in commercial nuclear power plants. It can also be used for environmental restoration projects and nuclear nonproliferation applications. The GammaCam achieves the features noted above by utilizing unique, non traditional architecture and modern electro-optic technologies. The basic spatial modulation techniques to obtain high quality images in the gamma energy region, have been discussed in the scientific community since the early 1970's. AIL improved these earlier instrumentation by infusing modern techniques and electro-optic components into the product.

Unique technology, in both hardware and software, utilized in the GammaCam was invented and developed to maturity at AIL. A patent for a new spatial modulation scheme and an improved hardware architecture was filed in 1995. Currently the application of a PCT to protect the invention in several foreign countries is in progress. A PCT allows AIL to delay filing of patents in foreign countries for 18 months without incurring a large patent filing expense.

AIL has expended over \$2 million and 15 man-years of engineering effort, over a period of 18 months, to bring this unique technology to successful development of a brassboard (a functional GammaCam) and field test demonstration. No details of the unique hardware and software design feature have been disclosed or disseminated to the technical and engineering communities. AIL, therefore, believes that we have a technical and time advantage over potential competitors that are planning to produce a similar product.

A patent only provides superficial security and time limited protection, since intelligent scientists and engineers can improve upon an existing patent by adopting or developing advanced

technologies. The only way to protect AIL's technological competitive advantage is through retention of key technical staff and upgrading relevant technologies.

3.1.3 Market Environments

This section briefly discusses product applications, market drivers, and competition. Near term market entry opportunities, a current view on five year market size as well as a brief discussion of market entry strategy are also presented.

3.1.3.1 Product Applications

AIL has identified three potential applications of GammaCam in the nuclear industry; 1) radiological survey in operational nuclear power plants, 2) environmental restoration projects, and 3) nuclear nonproliferation and arms control operations.

The GammaCam is particularly useful in quickly locating, identifying, and measuring source flux of radiologically harmful materials and objects from a safe distance. It provides a means for meeting As Low As Reasonably Achievable (ALARA) objective in the nuclear industry. It serves as an instrumentation for quick characterization (survey) of medium-to-high radiologically hazardous installations. It can be used for sorting out radioactive materials to optimize waste management. It is also useful in long range surveillance of nuclear material storage sites to aid effective implementation of nuclear nonproliferation monitoring and arms control inspections.

3.1.3.2 Market Drivers

There are three market drivers associated with the GammCam: compliance to ALARA objectives for all nuclear facilities, environmental restoration, and nuclear nonproliferation. The present status of the nuclear industry can be summarized as follows:

- Meeting the ALARA objective is driven by regulatory mandate for ensuring the health of workers and safety of the general public.
- The ending of cold war between the world super-powers has precipitated closing of many of the nuclear material processing plants, weapon manufacturing facilities, and atomic research facilities. It has also generated a need for a tight control of nuclear fuel stockpiles. Several nuclear accidents and near miss incidences as well as the change in the attitude of world populous mandate the nuclear industry must assure the safe operation of operating nuclear facilities.
- Public demand to restore closed down nuclear sites to green field status.

Due to down sizing, declining funding availability, and demand for higher profitability, the nuclear industry is in need of cost effective radiological measurement instruments. The GammaCam has been developed to fill this instrumentation need for cost-effective operation of active nuclear power plants and environmental restoration projects (ERP). An evident match of the GammaCam

capability with this need and the market drivers discussed above has lead AIL to conclude that there are significant entry opportunities for the GammaCam in the nuclear industry.

3.1.3.3 Competition

There are several competing functionally similar products that were recently introduced or are in development. These products can produce 2-D gamma ray images. They differ in details of design but all use the traditional hardware architecture. In addition to the size and weight advantage, the GammaCam offers a larger throughput, improved spatial resolution, and ease of operation over competing gamma ray imaging cameras. Another important feature of the GammaCam is ability to operate in high background field as demonstrated during the Paldiski Expedition.

Some competing products provide energy resolution capability and some, like the GammaCam, do not. One competing spectroscopic product, (RMD's "Imaging Survey Meter"), although less sensitive and susceptible to high background flux, offers a price advantage (\$35,000) over the GammaCam. The Aladin Gamma Camera offered by Eurisys Measures is radiometric, as is the GammaCam, but less sensitive and not real-time. AIL believes that the GammaCam is presently the best gamma ray imaging product available in the market. Detailed description and comparison of competing products and a strategy to maintain the competitive edge are presented in Section 3.3.

Aside from the competition from other similar products, there are inherent factors to hinder an acceptance of the GammaCam by the nuclear industry. The most difficult obstacle is the reluctance of users to embrace and purchase a novel, high price product for their tool inventory without proven evidence of its operational and cost advantages. As discussed elsewhere, the GammaCam is not a panacea to solve all radiological measurement problems, but it provides a superior performance as an imaging camera within the intended operational and application conditions. An ability to develop a systematical approach to solve user needs with a complimentary instrument suite is one of the important keys to developing a successful business.

3.1.3.4 Market Entry Opportunities

Several Alpha and Beta tests of GammaCam have been conducted at various locations these demonstrations and tests have generated serious interest by potential customers. The marketability of the GammaCam is apparent from on-going negotiations of GammaCams', either Model I or customized models. A radiological survey expedition to Paldiski Estonia, conducted under a contract from the U.S. Department of Energy, was successfully concluded and additional funding for data reduction is expected. The event is noteworthy because of the exposure of GammaCam to technical as well as managerial experts involved in environmental restoration efforts of several European countries at Paldiski. AIL has received over 80 inquiries about the GammaCam from nuclear power plants and DOE site maintenance and operations (M&O) contractors resulting from a recently published technical article. We estimate, through brief telephone conversations, that about 25% of inquiries are seriously interested in purchasing either the GammaCam or engineering services within two years. The 1996 and 1997 sales projection reflects recent market interest and responses. Success of field tests and development of customer awareness of the

GammaCam utility is factored into a five year growth projection of the product sales and engineering services.