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GrayQb™ Single-Faced Version 2 (SF2) Open Environment Test Report

J.R.Plummer, D.M.Immel, J.T.Bobbitt, M.J.Negron

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EXECUTIVE SUMMARY

The GrayQb^{TM} Single Faced Version 2 (SF2) is a non-destructive examination device developed to generate radiation contour maps showing source locations and relative radiological levels present in an area under examination. This device allows for characterization of radioactively contaminated areas such as hot cells, gloveboxes, small and large rooms, hallways, and waste tanks. The goal of GrayQb^{TM} (pronounced "Gray Cube") is to provide a low cost easily deployable device to aid in the process of decontamination and decommissioning. The GrayQb^{TM} SF2 device is approximately a six inch cube weighing seven (7) pounds composed of a tungsten shield with integrated pin-hole, radiation imaging medium (Phosphor Storage Plate), and digital camera.

The GrayQb^{TM} SF2 device is a next generation device resulting from physical and software enhancements of the GrayQb^{TM} Single-Faced (SF) device developed by SRNL and tested in FY13 [1],[2]. Development of this device was funded as part of Technical Task Plan SR-09-17-01, In Situ Decommissioning and Technology Development, and sponsored by DOE-EM Office of Deactivation and Decommissioning (D&D) and Facility Engineering (EM-13). A patent detailing the imaging device developed under this task has been applied for [5].

This report details the design upgrades incorporated into the new version of the GrayQb^{TM} SF2 device and the characterization testing of this upgraded device. Results from controlled characterization testing in the Savannah River National Laboratory (SRNL) R&D Engineering Imaging and Radiation Lab (IRL) and the Savannah River Site (SRS) Health Physics Instrument Calibration Laboratory (HPICL) is presented, as well as results from the open environment field testing performed in the E-Area Low Level Waste Storage Area. Resultant images presented in this report were generated using the SRNL developed Radiation Analyzer (RAzer^{TM}) software program which overlays the radiation contour images onto the visual image of the location being surveyed.

Devices and technologies are presently available which provide radiation detection; a subset of these systems also provide mapping of detected sources onto photos. Advantages of the GrayQb^{TM} SF2 device over these other devices include its relative low cost, small size and no required wired connections when deployed. The small size and low weight of the GrayQb^{TM} SF2 device allow for deployments in areas not accessible by many other radiation detectors. Additionally, the GrayQb^{TM} SF2 can be easily carried and deployed on a tabletop or tripod with internal shielding in place.

The E-Area Low Level Waste Storage Area was selected for open environment field testing of the GrayQb™ SF2 device. The GrayQb™ SF FY13 testing was conducted indoors in areas of no measureable background radiation with low energy sources (<150 KeV) [1]. The E-Area environment differs from FY13 testing in that it possesses isotopes with higher energy and a constant field of low intensity background radiation which includes higher energy sources (>500 KeV). Additionally, E-Area locations examined possessed large fields of relatively uniform source intensity versus FY13 testing which focused on an area with a localized source. E-Area is a 195 acre centrally located site for storing hazardous and mixed solid waste generated at the SRS as well as occasional special shipments from offsite. This storage site consists of separate sections for accommodating various levels and types of radioactivity in waste materials: transuranic (TRU) alpha waste, low level beta-gamma waste, high level beta-gamma waste, and RCRA permitted waste streams. The RCRA Permitted TRU Pads consist of 11 concrete pads that are used to store, process, and repackage hazardous, mixed, and radioactive TRU waste. Field testing was conducted at TRU Pad 17.

In summary, FY14 testing of the GrayQb™ SF2 device demonstrated its ability to detect low energy isotopes, e.g. Am-241 and Pu-238, not only indoors in controlled environments with well-defined source locations, but also in open environment field areas with significant high energy background signals. Additionally, it was demonstrated that the device could detect higher energy isotopes (Cs-137 and Co-60) in a controlled setting and with additional testing and/or modifications to device and software, may be able to detect these isotopes in the open environment field testing. Based on FY14 device and software enhancements, test results, and patent application, the GrayQb™ SF2 is ready for Technology Transfer and Commercialization consideration.

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ABBREVIATIONS AND UNITS

2D	Two Dimensional
3D	Three Dimensional
AM	Additive Manufacturing
DOE	U.S. Department of Energy
EM-13	DOE Office of Environmental Management - Office of Deactivation and Decommissioning and Facility Engineering
FOV	Field of View
GQ1	GrayQb^{TM} SF2 Unit One - one of four devices manufactered for FY14 testing
GQ2	GrayQb^{TM} SF2 Unit Two - one of four devices manufactered for FY14 testing
GQ3	GrayQb^{TM} SF2 Unit Three- one of four devices manufactered for FY14 testing
GQ4	GrayQb^{TM} SF2 Unit Four - one of four devices manufactered for FY14 testing
GrayQb^{TM}	Pronounced “Gray Cube”
GrayQb^{TM} SF	GrayQb^{TM} Single-faced
GrayQb^{TM} SF2	GrayQb^{TM} Single-faced Version 2
HPICL	Health Physics Instrument Calibration Laboratory
IRL	R&D Engineering Imaging and Radiation Lab
PSP	Phosphor Storage Plate
GUI	Graphical User Interface
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TRU	Transuranic waste

UNITS

cm	centimeter (1 m = 100 cm)
in	inch
hr	hour
m	meter
mR	millirem, roentgen equivalent man
mrad	millirad, unit of absorbed dose, for beta and gamma radiation, 1 rad of exposure = 1 rem of dose
s	Second
KeV	kiloelectron Volt (1KeV = 10^3 electron Volts)

1. INTRODUCTION

The GrayQb^{TM} Single Faced Version 2 (SF2) is a non-destructive examination device developed by SRNL to generate radiation contour maps showing source locations and relative radiological levels present in the area under examination, Fig. 1. This device allows for characterization of radioactively contaminated areas such as hot cells, gloveboxes, small and large rooms, hallways, and waste tanks. Development of this mapping device began from a need to identify radiation locations in support of decontamination and decommissioning efforts; the GrayQb^{TM} SF2 device uniquely addresses this need by providing a relatively low cost, small size and easily deployable device.

Figure 1. GrayQb^{TM} Single Faced Version 2 (SF2)

The GrayQb^{TM} SF2 device is a next generation device resulting from physical and software enhancements incorporated into the GrayQb^{TM} Single-Faced (SF) device developed by SRNL and tested in FY13 [1],[2]. Development of this device was funded as part of Technical Task Plan SR-09-17-01, In Situ Decommissioning and Technology Development and sponsored by the DOE-EM Office of Deactivation and Decommissioning (D&D) and Facility Engineering (EM-13).

The focus of the FY14 GrayQb^{TM} task was to field test this technology in an open environment setting. This document will discuss the re-designed GrayQb^{TM} SF2 device and testing conducted using the refined device. The process of deploying the device will be presented to include software capabilities provided to automate results. Pre-field testing characterization of the device conducted in the R&D Engineering Imaging and Radiation Lab (IRL) and the Savannah River Site (SRS) Health Physics Instrument Calibration Lab (HPICL) will be discussed. Lastly, results obtained during the open environment field test conducted at the E-Area Low Level Waste Storage area will be reviewed and conclusions presented.

2. BACKGROUND

2.1. Summary

The GrayQb™ SF2 is a two dimensional (2D) radiation mapping device used to identify source locations and relative radiation levels present, Fig.2. This device provides resultant images in 2D, Fig. 2, i.e. images with height and width information, versus three dimensional (3D) results which would also provide depth information, e.g. a hologram or 3D computer aided design (CAD) file. GrayQb™ SF2 FY14 testing was performed using Phosphor Storage Plates (PSP) as the radiation intensity imaging medium. PSPs are widely used in medical applications and non-destructive examination (NDE); they are sensitive to short-wavelength (e.g. X-ray, gamma) electromagnetic radiation and once exposed can be read using commercially available PSP scanners.

Figure 2. GrayQb™ SF2 generated radiation map

Devices and technologies are presently available which provide radiation detection; a subset of these systems also provide mapping of detected sources onto photos. Advantages of the GrayQb™ SF2 device over these other devices include its relative low cost, small size and ability to operate with no wired connections when deployed. Other detection systems typically cost $100-$200k due to their use of costly detection crystals; the GrayQb™ SF2 is projected to cost less than $7k to manufacture making it economical to deploy multiple devices at one time. The low cost of GrayQb™ SF2 also makes it feasible to dispose of the device without significant financial loss if it becomes contaminated, unlike the costly crystal-based detectors. The small size of the device combined with no wired field connections allow for deployments of the GrayQb™ SF2 in areas not accessible by most other radiation detectors. Additionally, the GrayQb™ SF2 can be easily carried and deployed on a tabletop or tripod with its internal shielding in place.

The GrayQb™ SF2 device resulted from significant hardware, software and deployment improvements incorporated into the GrayQb™ Single-Faced (SF) device, Fig. 3, developed by SRNL and tested in FY13. Testing of the original GrayQb™ SF device demonstrated the ability of the device to locate low energy radiation sources (< 150 KeV) in controlled environments in areas having no measureable background signal. Detection sensitivity of the GrayQb™ SF was determined by testing to be 0.2 mrad. Based on refinements to the GrayQb™ SF device, a separate patent application is in process for GrayQb™ SF2.

Figure 3. Front and side view of first version GrayQb™ SF

Refinement opportunities to the GrayQb™ SF device were identified and developed when open environment field testing of the GrayQb™ technology was funded in FY14 by the EM-13 program. The final GrayQb™ SF2 device, like its predecessor, is a passive mapping device consisting of a tungsten shield with integrated pin-hole, digital camera, and radiation imaging medium. The device provides qualitative data identifying areas with source locations and relative radiation levels. The device is designed to be used in conjunction with other radiation monitoring devices to confirm and determine radiological conditions of the environment to ensure personnel safety.

2.1 GrayQb™ SF2 Upgrade

2.1.1 Refinement Areas Identified

The first version GrayQb™ SF test results identified refinement opportunities related to improving and automating alignment of the PSP image onto the digital image. Overlay images developed using the FY13 device required manual manipulation and the use of rudimentary trending tables to adjust the source maps onto the photo. Additionally, improvements to the deployment process to provide ease of use and more consistent results were considered important goals. The photosensitivity of the PSP plate was an issue present in the GrayQb™ SF which possessed seams allowing light to penetrate to the PSP. GrayQb™ SF2 refinement goals included the following:

- Improve alignment accuracy in overlaying radiographic spectra onto the visible image to eliminate the need for manual adjustment through both device and software upgrades.
- Upgrade software to a more user friendly Graphic User Interface (GUI) program.
- Design and fabricate new pinhole to improve alignment and accuracy of radiographic image onto PSP.
- Address photosensitivity of the PSP.
- Simplify deployment and processing for operator use.

2.1.2 Implementation of Refinements

The GrayQb™ SF2 upgrades included refinements to the device, the software, and the deployment process. The device re-designs included modification of the pinhole and a major redesign of the device housing. A user friendly software program, implementing a graphical user interface (GUI) to process images into final overlay results, was developed. The deployment process improvements include the development of the PSP pre-illumination device and the PSP cartridge holder. Upgrades were made with the original goals of device portability (small and light weight), low cost and ease of deployment (no wires) kept in mind.

The final GrayQb™ SF2 device addressed the refinement opportunities by developing and implementing the following upgrades:

- Use of optics to align camera and pinhole centers to facilitate image alignment and device calibration.
- Development of new housing to stabilize tungsten shield, imaging medium (PSP), and camera to eliminate small movements of parts to facilitate image alignment and consistency of results.
- Development of new housing with no seams in dark material to eliminate light penetration to photosensitive PSP.

- Development and fabrication of new simple pinhole to collimate results and improve alignment and accuracy of radiographic image onto PSP.

- Development of PSP holder for stabilization, ease of insertion and removal from the PSP pre-Illuminator to the GrayQb™ SF2 device.

- Development of software program providing a user graphical interface for automating the importing of the PSP images, digital images, and the processing of results. The software generates radiation contour maps superimposed onto the photo of the area under examination.

- Provide the ability to calibrate each GrayQb™ SF2 device in the software for better alignment results.

In addition to addressing the original refinement opportunities, during the redesign the following additional upgrades were incorporated into the final design and deployment process:

- Added cavity within the new GrayQb™ SF2 housing to provide for side and back shielding of imaging the medium.

- Developed the PSP pre-illuminator device to erase and apply a uniform background to the PSP plates prior to deployment.

- Movement of the PSP further from tungsten shield with integrated pin-hole to provide maximized-width higher resolution PSP images.

2.1.3 GrayQb™ SF2 Device

The redesigned GrayQb™ SF2 device is roughly a six inch cube weighing seven (7) pounds, Fig. 4. Immediately noticeable is the addition of the mirror to the front of the device. This mirror allows for the coaxial alignment of the PSP acquired radiation image to the camera (visual) image. The device does not contain a radiological source and does not require a power source. An expanded view of the GrayQb™ SF2 device is shown in Fig. 5. Device refinements are discussed in the following sections.

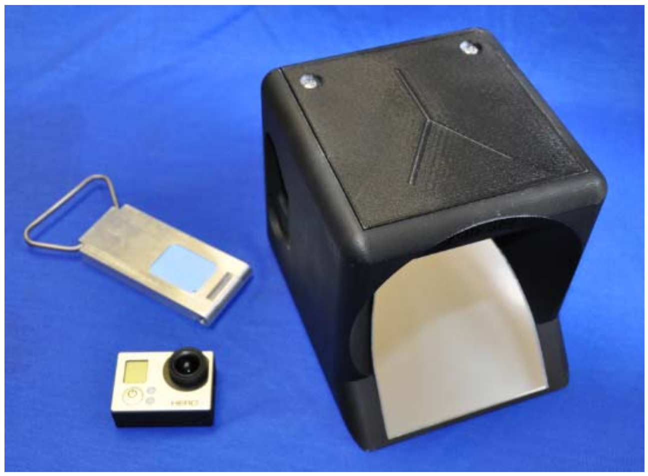


Figure 4. GrayQbTM SF2 device with PSP cartridge holder and camera.

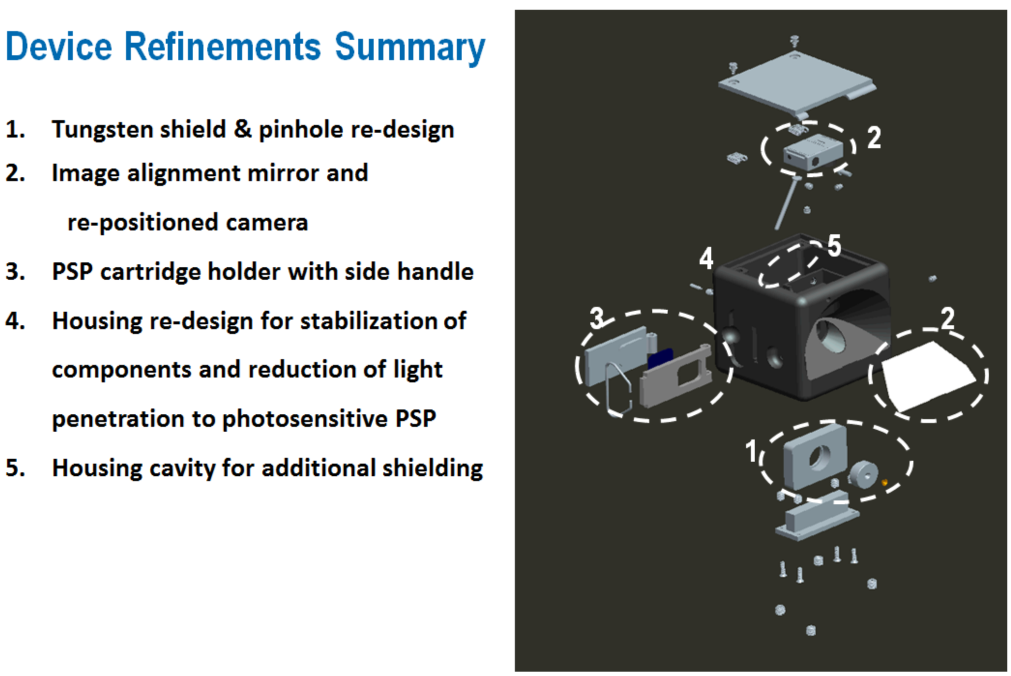


Figure 5. Illustration of GrayQb™ SF2 device expanded view

2.1.3.1 Enhancements - Tungsten shield and pinhole re-design

The pinhole was redesigned to provide a more accurate mapping of the radiation intensity on the PSP at the edge of the field of view (FOV). This was accomplished by reverting to a traditional pinhole design with a removable pinhole section. Copper was used for the removable section, and proved acceptable for the energy levels (i.e., Am-241 and Pu-238) being imaged, Fig. 6. For higher energy sources, the removable section could be made of tungsten.

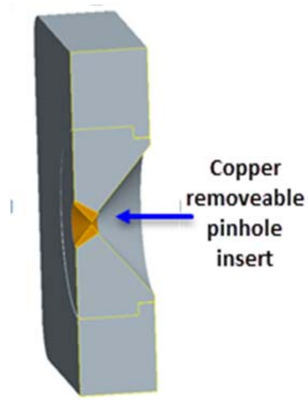


Figure 6. Tungsten shield and copper pinhole

Making the pinhole removable allows for a trade-off on focus and energy level. A smaller pinhole provides a better focus, while a larger pinhole allows a lower energy level to be imaged faster if less resolution of the radiation image is acceptable.

2.1.3.2 Enhancements - Alignment Mirror

The focal points of the camera and pinhole in the GrayQb™ SF housing were offset by two (2) inches, Fig. 7. This led to complications in aligning the images. A major change for GrayQb™ SF2 was to have both the camera and pinhole coaxially aligned, Fig. 8. To achieve this alignment, a polymer mirror was placed at a 45 degree angle in front of the pinhole. The mirror allows the camera to be mounted above the pinhole facing downward and to acquire a reflected image that is coaxially aligned with the pinhole. With non-coaxially aligned images, the distance to the object is required to be known to accurately overlay the two images. Distance data had to be collected in the field during testing and factored into the overlay calculations. By having the radiation and visual images coaxially aligned on the GrayQb™ SF2, the software processing of the images is greatly simplified as is the data collection during deployment.

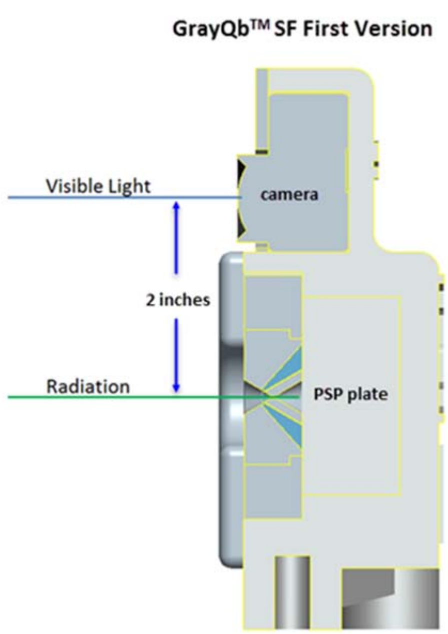


Figure 7. GrayQbTM SF camera and pinhole offset

For most imaging applications, the mirror material chosen must be essentially transparent to the radiation. In certain high energy fields however, a mirror that provides some shielding can be an advantage. Thin Mylar was originally tested as a mirroring material, but was found to be difficult to properly tension to acquire a clear photo. A plastic mirror was tested and selected as it provided a much clearer visual image and was anticipated to be robust when deployed in a D&D environment. Should a GrayQb™ SF2 unit be dropped or mishandled, the Mylar mirror could tear and provide little or no image to the camera, whereas a plastic mirror might scratch or crack, but would still allow a visual picture to be obtained.

Resultant overlay images developed using the FY13 device required a manual overlay manipulation by the user to acquire a final acceptable result. Scan and digital images were imported onto the laptop, and then rudimentary trending tables applied to adjust the source maps onto the photo. This adjustment was necessary due to the center of the pinhole and the camera being offset by approximately two inches in the original SF design.

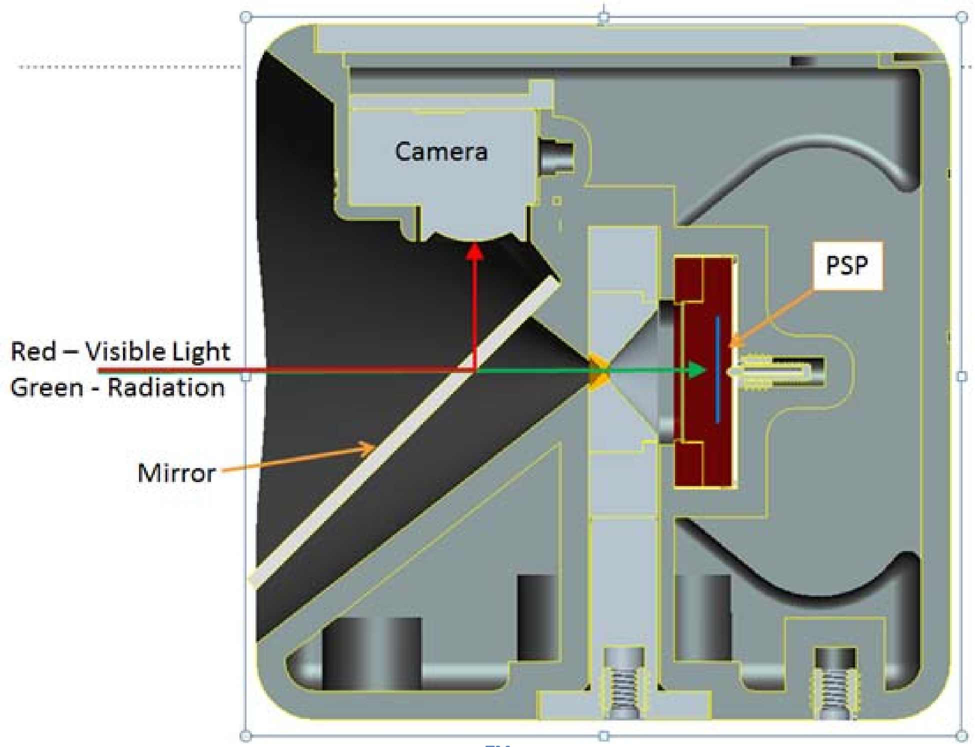


Figure 8. GrayQb™ SF2 side view cutaway

2.1.3.3 Enhancements - PSP Cartridge Holder

In the original GrayQb™ SF, the PSP plate was integrated with the tungsten shield and pinhole; this required that for each deployment, the tungsten shield with PSP apparatus be removed from the housing in order to remove the PSP for processing. This process presented two problems, first, in order to provide consistent overlay results, the pinhole location needed to be static in the device; removal of the tungsten shield and pinhole with each deployment caused an undesirable tolerance in the pinhole location for alignment. Second, removal of the PSP by an operator who was wearing gloves was very difficult.

To alleviate the alignment issues, the tungsten plate and pinhole were integrated into the housing and a new PSP holder was designed, Fig. 9. The holder securely locates the PSP within the holder itself, and in conjunction with features of the housing, the holder is securely located relative to the pinhole camera. To facilitate removal of the holder from the housing, even with a gloved hand, a large handle was added, Fig. 10.

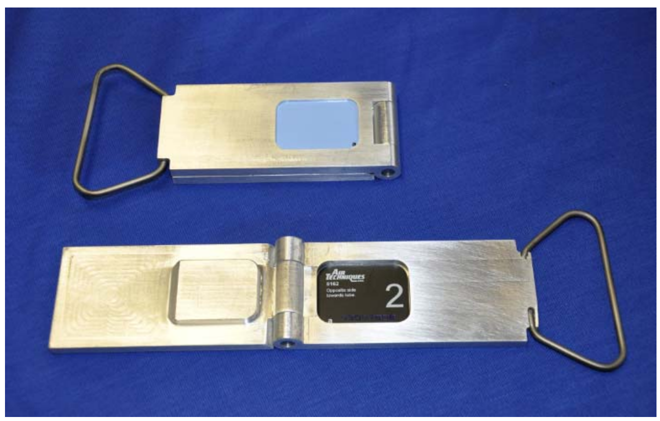


Figure 9. PSP cartridge holder

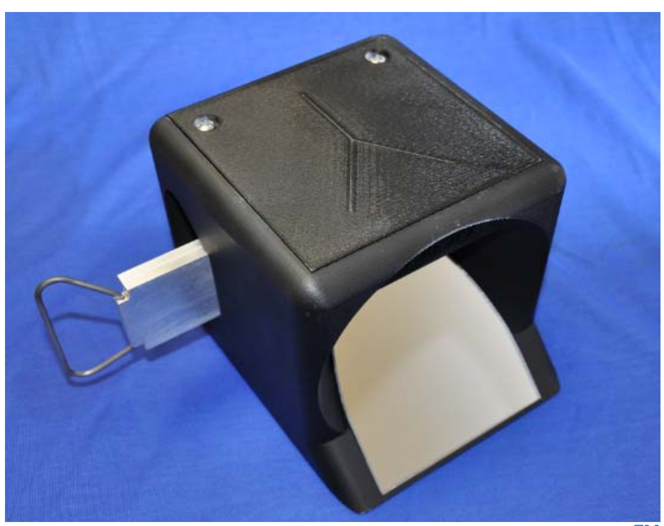


Figure 10. PSP cartridge holder being inserted into GrayQb™ SF2

2.1.3.4 Enhancements - Housing Re-design

The GrayQb™ SF2 housing was extensively redesigned over the original GrayQb™ SF configuration, Fig. 11. This was primarily driven by the need to accommodate the design to coaxially align the camera and pinhole images. Additional considerations included accommodating the new PSP cartridge holder and stabilization of components within the housing for enhanced repeatability of results between deployments. Stabilization was achieved by securing and allowing the tungsten shield and pinhole to remain inside of the housing between deployments and by using spring plungers to always bias the camera, PSP cartridge holder and pinhole to one position in the housing, Figure 12. These modifications provided an economical solution to achieve lower tolerances of component relative position within the device yet maintained the ability to manufacture a low cost device using additive manufacturing. Another benefit of additively manufacturing (AM) the housing as one piece is that it eliminated the need to seal seams to prevent light leaks onto the photosensitive PSP. AM allowed a complex housing design to be manufactured in a cost effective and timely manner. The use of polymer housing allowed the weight to be kept to a minimum for ease of deployment and to maintain a weight manageable for a glovebox environment.

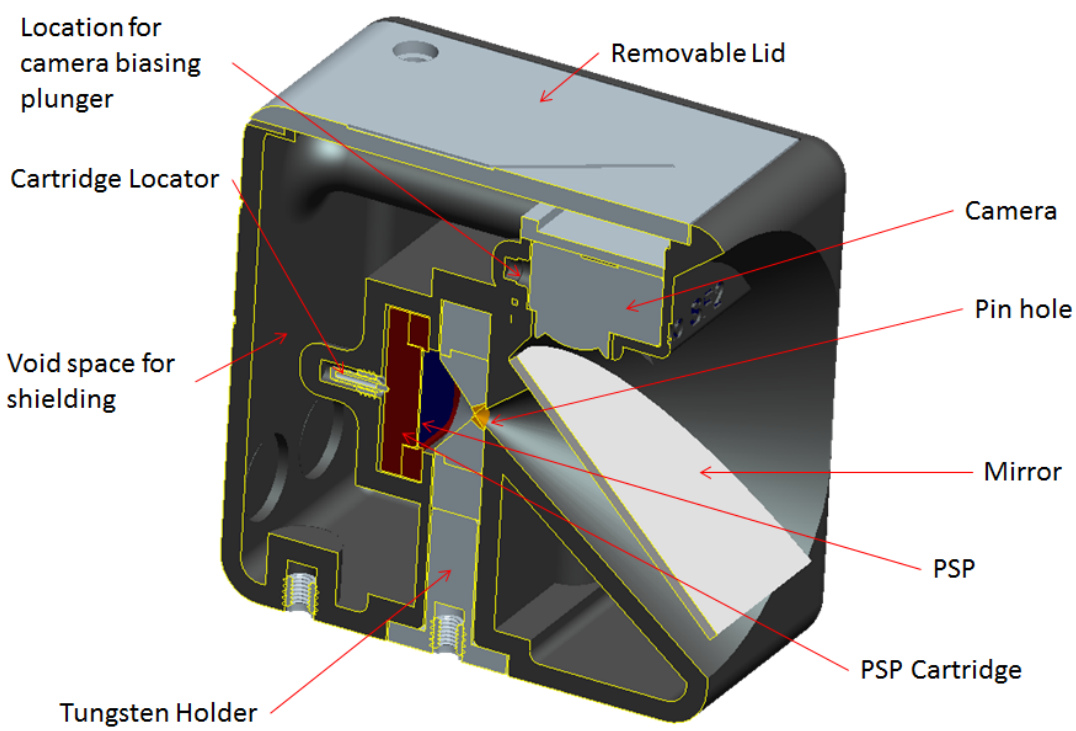


Figure 11. Housing Features

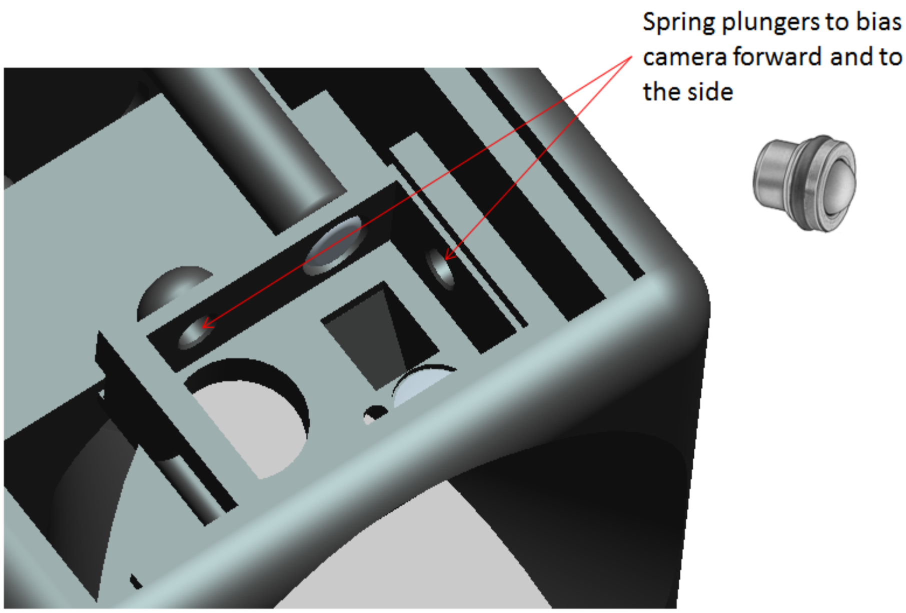


Figure 12. Housing spring plungers

An additional feature is a guide for aiming the camera. Due to the location of the camera in the housing, it is not possible to see the viewfinder, therefore lines were added to the top of the camera to help define the direction the camera is aimed and the field of view of the camera, Figure 13.

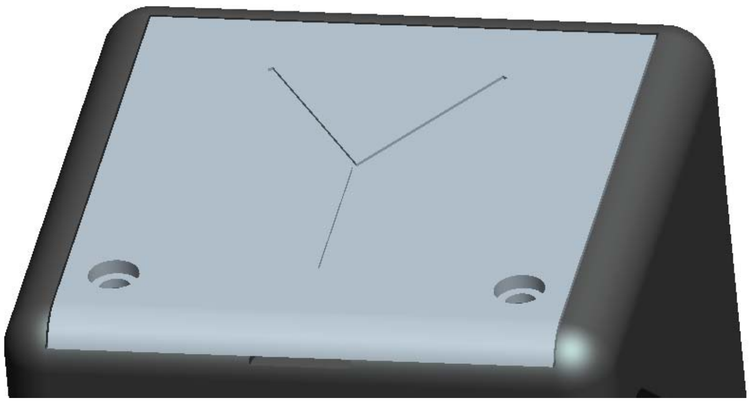


Figure 13. Housing sighting lines showing device field of view

2.1.3.5 Enhancements - Housing Cavity for Internal Shielding

The housing was also modified to allow the addition of shielding for use in environments that have high levels of contamination to the back or sides of the housing. The previous design did not have space for shielding, so in environments that required it, the use of an external shield was required. The void space in the housing allows lead, steel, or tungsten shot to be poured into the housing, Fig. 14. By allowing the shielding to be added when needed, it is also possible to place the unshielded camera in an area where the operator has reduced dexterity, such as a glovebox, and then add shielding. This reduces the weight the operator needs to manipulate at any one time. Once the shielding is in place, the PSP can be introduced, an image taken, and PSP then removed. The shielding can then be removed, followed by the housing.

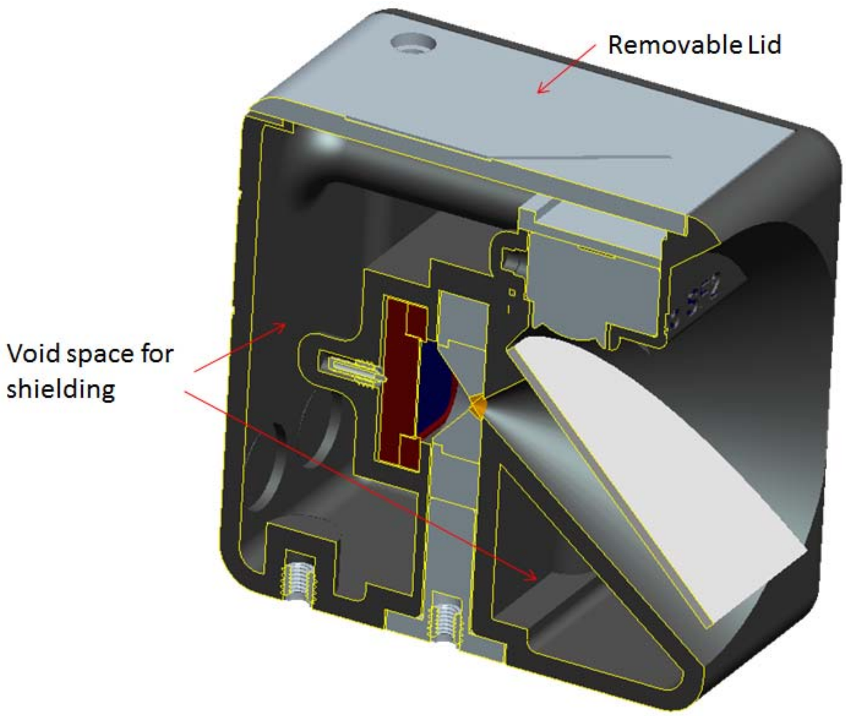


Figure 14. Housing cavity for internal shielding

2.1.4 PSP Pre-Illuminator

Upgrades incorporated to ease deployment and improve results include the PSP pre-illuminator device, and as discussed previously, the PSP cartridge holder. The PSP pre-illuminator, Fig. 15, effectively prepares the PSP for deployment by erasing any current image and applying a uniform background. Many commercial PSP scanners will not provide an image if a preset intensity threshold is not reached on the plate, applying a background ensures that this threshold is reached and that there is always a resultant image even when no radiation has been detected. The pre-illuminator was developed using UV light as the source of erasure and for background intensity application.

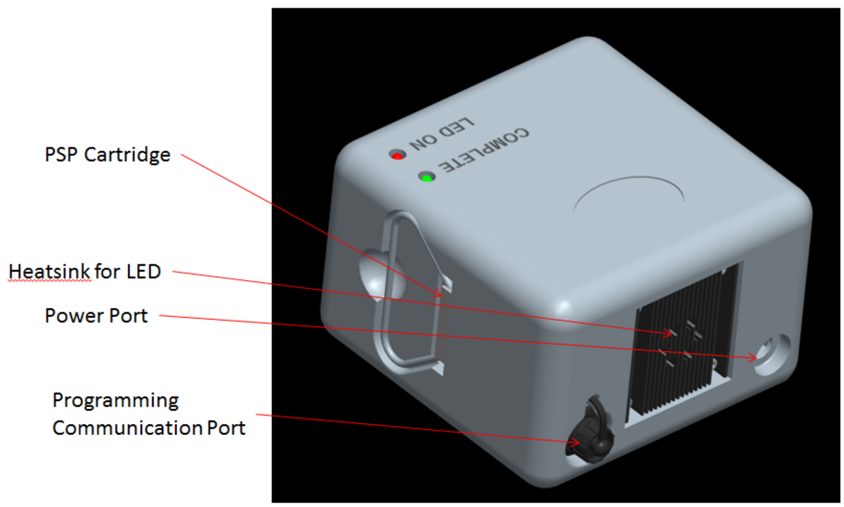


Figure 15. PSP Pre-Illuminator

The PSP cartridge holder was designed to easily insert the PSP into the pre-illuminator and then remove and insert the PSP into the GrayQb™ SF2 housing for deployment. This entire process simplifies the deployment process for the user and improves results.

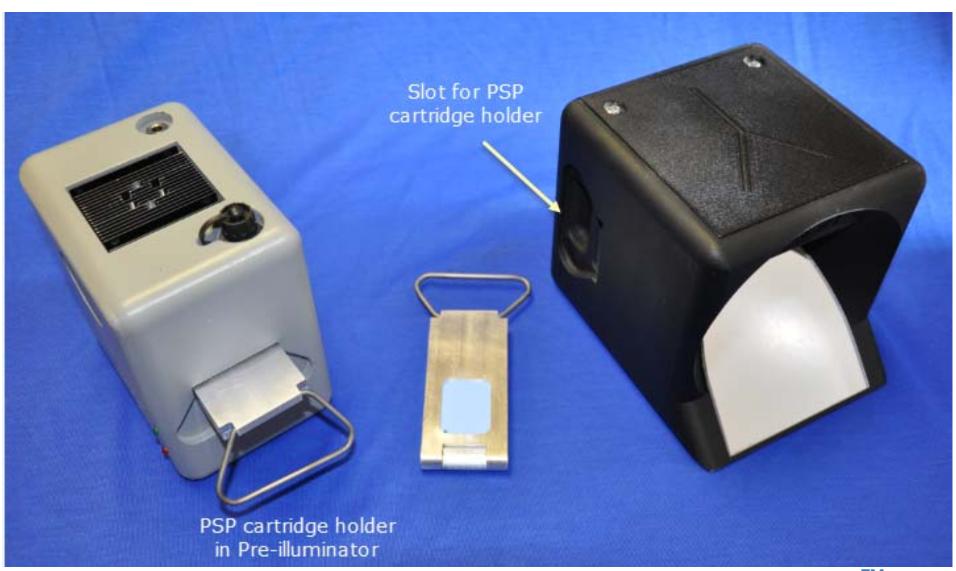


Figure 16. PSP cartridge holder shown with PSP pre-illuminator and GrayQb™ SF2

2.1.5 Software Program

The Radiation Analyzer™ (RAzer™) software program was created to generate GrayQb™ SF2 results. RAzer™ imports the raw data (PSP image and digital image), generates the radiation contour maps from the PSP image and superimposes the results onto the digital image of the area under examination, Fig 17. The goals of the new software were to provide a user friendly program, automated alignment of radiation maps onto digital images, and the ability to customize each GrayQb™ SF2 device in the software for better alignment results. RAzer™ result images can be saved to disk in .jpg format for later use and can be printed from the RAzer™ program. When an image is saved, the directory and filename are stamped onto the saved image, Fig 18.

Figure 17. RAzer™ software Graphical User Interface (GUI)

Figure 18. Result saved as .jpg file on disk with directory and filename stamp shown at top

A laptop is used to collect and process GrayQb™ SF2 results. Software on the laptop includes the ScanX Scanner software and the RAzer™ software. The ScanX software is provided by the scanner vendor; it initiates the PSP scan on the USB connected scanner and imports the resultant PSP image onto the laptop. The ScanX scanner software can be started from the RAzor™ software GUI or from the laptop desktop, Fig 19.

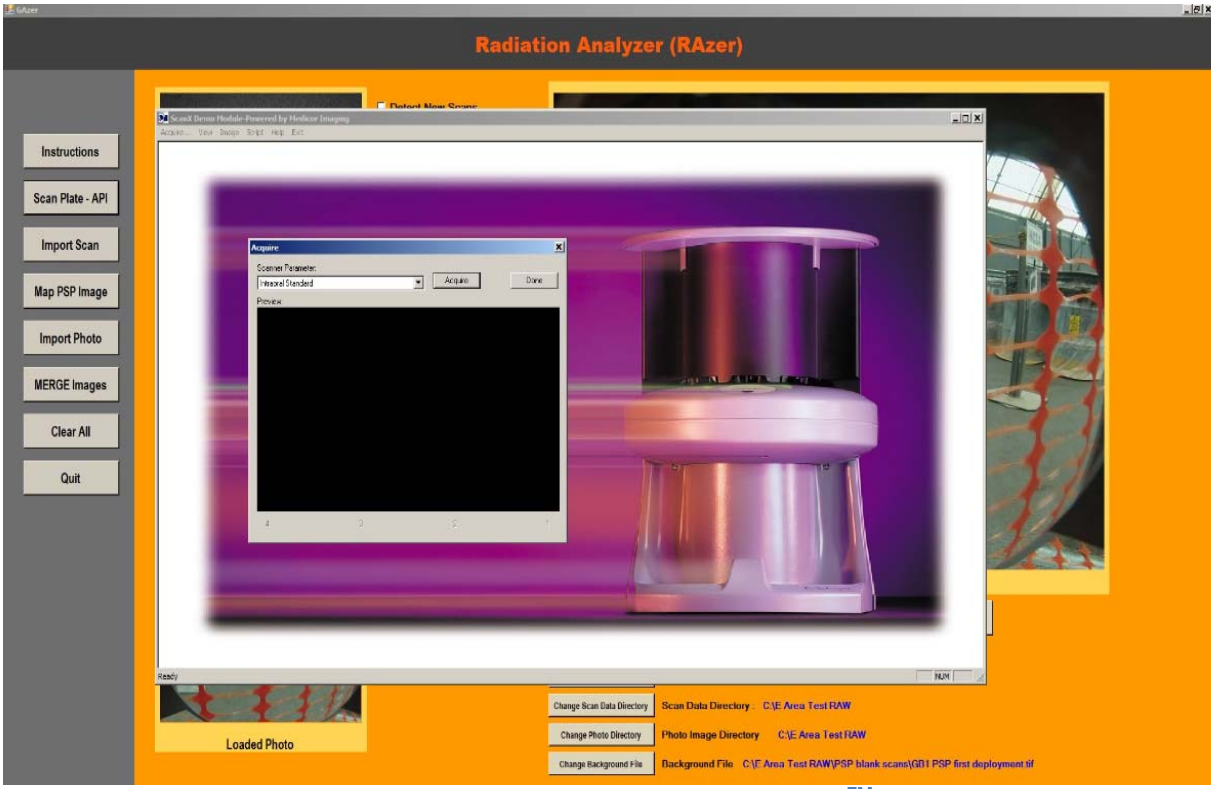


Figure 19. ScanX Scanner software called from RAzer™ program

RAzer™ provides both automated and manual data collection and result generation. When the *Detect New Scan* box is checked on the main display, RAzer™ will detect new scanner images on the laptop and prompt the user to import the corresponding digital image, Fig 20. The user will be asked which GrayQb™ SF2 device was used and can optionally enter a description for the result. Once the user completes these steps, the image and photo will be automatically processed into a final resultant image and displayed on the main screen. Command buttons located at the left of the main display allow the user to manually select and load desired scans and photos for processing.

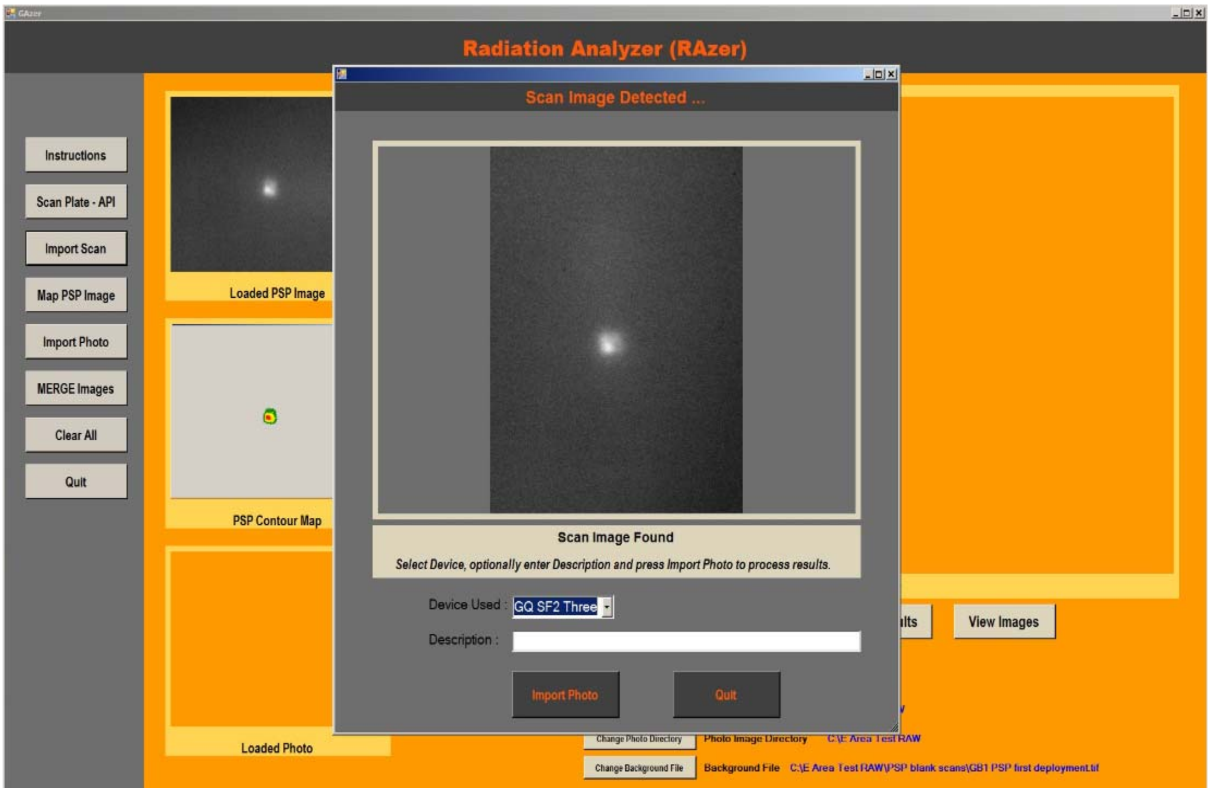


Figure 20. Pop up window when new scan image detected on laptop for automated results processing

IRL testing of the GrayQb™ SF2 devices demonstrated that each device possessed a slightly different coaxial alignment of the scanner image and visual image. Each GrayQb™ SF2 was alignment tested in the IRL and HPICL labs to determine its unique coaxial offset. The RAzer™ software provides alignment customization for each device. By selecting which GrayQb™ SF2 was used to collect the current results being processed, the overlay is adjusted appropriately to obtain correct alignment of the scan image and visual image centers. If the device used to collect a result is unknown, the GrayQb™ *Device used* selection box can be set to *Unspecified* in the RAzer™ software where an average, but not as accurate, offset is used.

Several features were added to RAzer™ after testing with high energy sources in the HPICL. Because the higher energy isotopes tested (Cs-137 and Co60) caused a more disperse signal on the PSP image, the ability to add or remove overlay colors from the final results was incorporated, as was the ability to set new intensity ranges for the image color map. The RAzer™ software is being prepared for copyright.

3 TESTING

3.1 Methodology

Preparation of the GrayQb™ SF2 for deployment requires that the device be initially configured with a pre-illuminated PSP plate, a charged camera, and optional internal shielding. Once prepared, the device is simply placed facing the area to be evaluated and left for an appropriate time period based on dose and energy level of expected isotopes. After retrieving the device, the PSP plate is removed and scanned. The scanned PSP image and camera visual image are imported onto the RAzer™ laptop where the software produces the final overlay result. Once the GrayQb™ SF2 is retrieved from the area under examination, processing the images and obtaining a result takes only a few minutes. Detailed deployment steps are provided in Appendix A.

GrayQb™ SF2 testing was performed using Air Techniques Phosphor Storage Plates (PSP), Fig 21, as the radiation detection imaging medium. PSPs are light-weight, safe to handle without protective gloves, and do not become radioactive when exposed to radiation. The ScanX PSP Scanner device, Fig. 22, was used to read the PSP plate during testing. All PSPs were scanned using PSP feeder slot 2 (right side) of the scanner. It was noted during initial test results that scans varied slightly depending on which slot was used to read the PSP. To be consistent the right side was selected for use during testing.

Figure 21. Phospor Storage Plates (PSPs)

Figure 22. ScanX PSP Scanner

The RAzer™ laptop is used to collect and process GrayQb™ SF2 results. The ScanX software on the laptop is used to import the PSP images from the scanner. The RAzer™ software is used to import the camera visual images onto the laptop. The RAzer™ software then generates the radiation contour maps from the PSP image, Fig. 23, and superimposes the results onto the digital image of the area under examination, Fig 24.

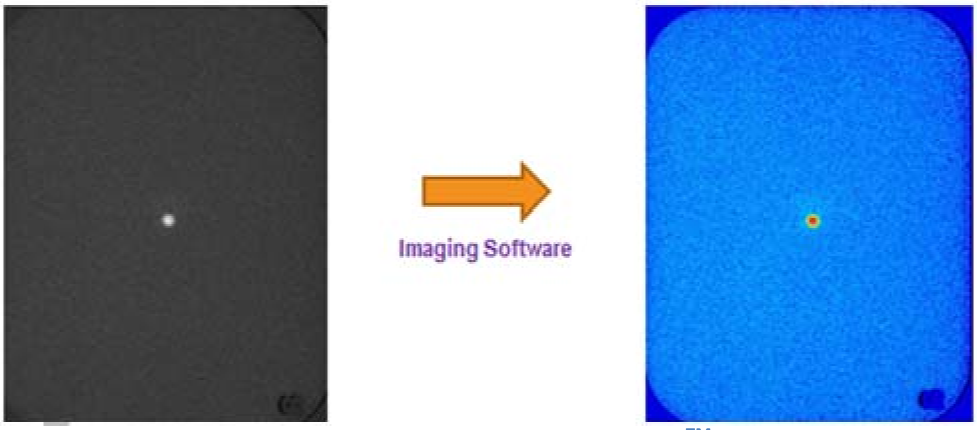


Figure 23. PSP image from scanner and PSP image with RAzer™ intensity map applied

Figure 24. Resultant Image using RAzer™ software

To process results in the field, the RAZER™ laptop and ScanX PSP Scanner are required to be collocated at the test site. Optionally, the PSPs can be removed from the device and placed in dark carrying case for processing later offsite. Preparation of the PSP plates at the test site can be performed conveniently, if desired, with the small portable PSP Pre-illuminator device. A typical on-site deployment is shown in the HPICL GrayQb™ SF2 testing photo in figure 25. GrayQb™ SF2 HPICL and E-Area test results were generated and evaluated immediately in the field to determine the most useful configurations for additional testing.

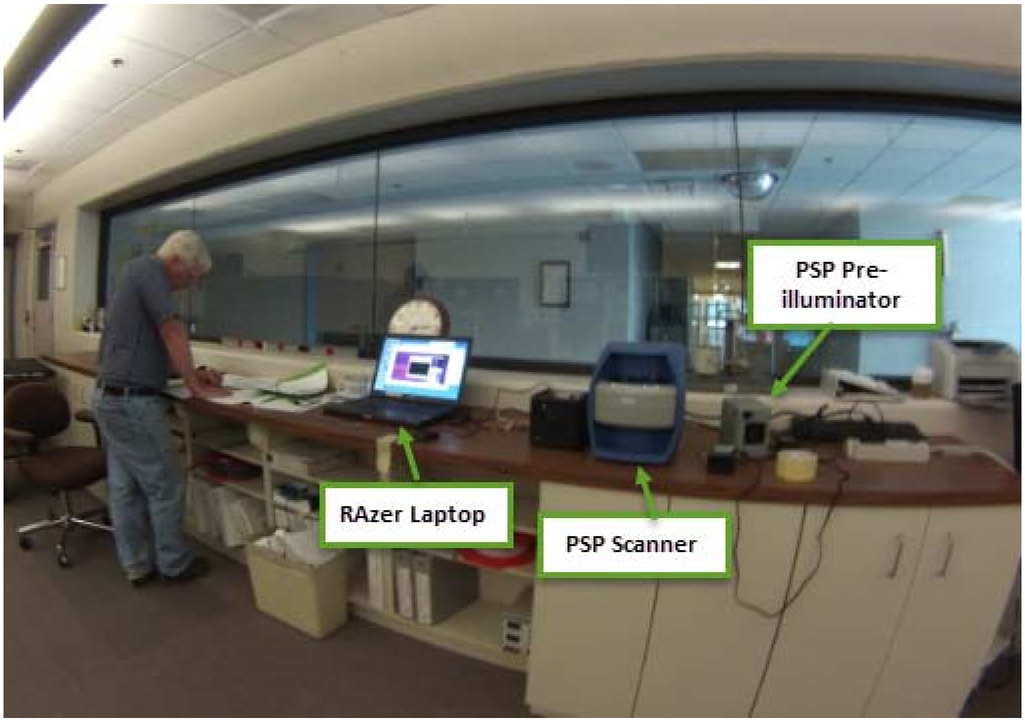


Figure 25. Typical deployment for processing results at test site

3.2 FY14 Testing Overview

Testing of the re-designed GrayQb™ SF2 device consisted of initial characterization in controlled indoor environments with final field testing conducted in an open environment area. Four GrayQb™ SF2 devices, 1 through 4, were manufactured in the R&D Rapid Prototyping Lab for the purposes for testing. In this document, these devices are abbreviated as GQ1 for GrayQb™ SF2 device one, GQ2 for GrayQb™ SF2 device two, and so forth. Initial device characterization was performed at the R&D Engineering Imaging and Radiation Lab (IRL) and at the Savannah River Site (SRS) Health Physics Instrument Calibration Lab (HPICL) to determine device performance and validate software results. Lastly, device performance was tested in the field at the E-Area Low Level Waste Storage Area, an open environmental site.

3.3 R&D Engineering Imaging and Radiation Lab (IRL) Testing

Basic characterization of the GrayQb™ SF2 device was conducted in the R&D Engineering IRL. The purpose of this testing was to validate device performance after extensive redesign, to characterize basic device parameters such as field of view (FOV), and to determine the degree of coaxial alignment of the scanner image and visual image. IRL testing was conducted using an x-ray generator in lieu of an isotopic source to characterize each device.

IRL testing of the GrayQb™ SF2 devices demonstrated that each device possessed a slightly different coaxial alignment of the scanner image and visual image. This variation was expected as the devices were not manufactured as precision instruments. Alignment offset for each device was determined by imaging an x-ray spot with the device centered in front of the x-ray source. RAzer™ results of this 0 degree deployment were obtained using an unadjusted overlay algorithm. These results were compared to where the x-ray source was expected to appear on the image. The difference required to correctly align the source in the visual image was determined for each device then these alignment corrections, Table 1, were entered into the RAzer™ program to validate with testing performed at the HPICL with actual isotopic sources.

Table 1. Summary of alignment offsets for each GrayQb™ SF2 device as determined at IRL.

GrayQb Test Device #	Device Abbreviation	x-axis offset (% of FOV)	y-axis offset (% of FOV)
Device alignments as determined from testing at IRL			
GrayQb SF2 - One	GQ1	11	1
GrayQb SF2 - Two	GQ2	11	5
GrayQb SF2 - Three	GQ3	10	3
GrayQb SF2 - Four	GQ4	15	3

3.4 Health Physics Instrument Calibration Lab (HPICL) Testing

The primary goal of HPICL testing was to validate overlay alignment and to characterize response to higher energy isotopes prior to field testing. Additionally, it was desired to characterize the dose sensitivity and field of view for comparison to FY13 results. A test plan was developed which outlined the test setup and objectives [3], a list of tests conducted at HPICL can be found in Appendix B, HPICL Test Listing. Tests were conducted to meet the following objectives:

1. Dose detection level. This test collected results from varying source doses to determine the PSP dose detection level. This test was designed to confirm a predicted dose detection level of about .2 mrad for the lower energy source. It was estimated higher dose would be required for higher energy levels to be detected.
2. Field of view response. A sampling of points at different angles was performed to better characterize pinhole and PSP response at wider angles.
3. Validate the RAzer™ programs ability to correctly overlay the PSP image and digital image. A sampling of points at different distances and angles to validate alignment results were performed.
4. Characterization of PSP plates in response to higher energy isotopes. FY13 testing consisted of low energy source isotopes, testing in the HPICL included deployments using higher energy isotopes of Cs-137 and Co-60 as sources.

GrayQb™ SF2 HPICL testing was performed with low and high energy isotopes. Low energy testing was conducted using an apparatus with seven Am-241 sources, Fig. 26. This apparatus was especially useful for validating alignment as it provided seven source areas of reference in the results. High energy testing was performed using Cs-137 and Co-60.

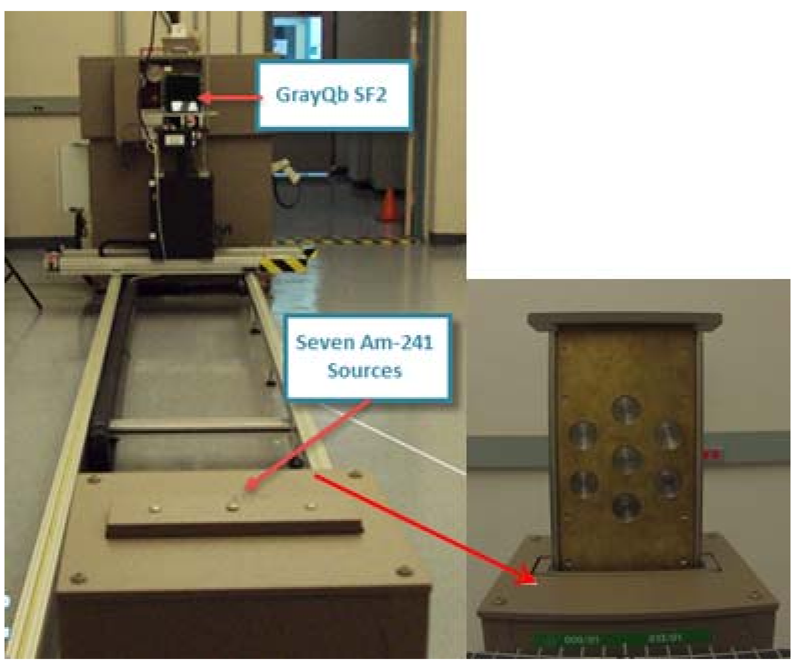


Figure 26. Testing room with the seven Am-241 sources at HPICF

3.4.1 Dose Detection Level

Testing to determine the dose required for a detectable intensity to be present on the PSP image was performed using the seven Am-241 source. While keeping the distance to the source constant, the exposure time was adjusted to vary the dose to determine the level at which a recognizable image could be seen on the PSP. Results obtained, Fig. 27, confirmed that a detectable intensity could be seen on the PSP at a .2 mrad dose. FY13 testing showed a response near .1 mrad, it is thought that the FY14 increase to .2 mrad is due to minor shielding from the new alignment mirror which covers the pin-hole.

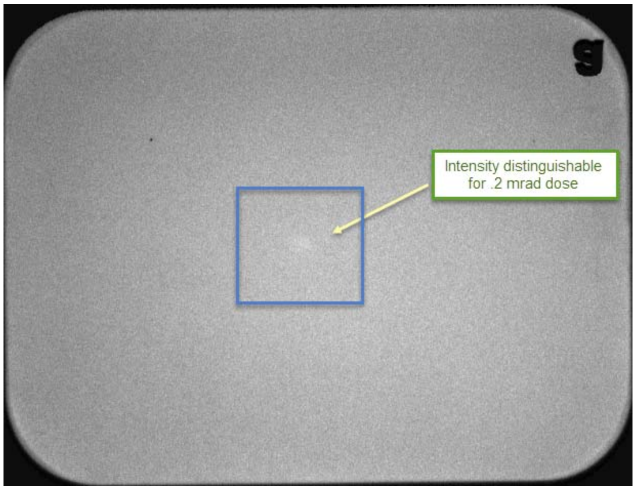


Figure 27. Am-241 dose detected at .2 mrad

3.4.2 Field of View Response

Testing to determine the pinhole response at wider angles was performed using the Am-241 source. A typical angle test setup is shown in figure 28. PSP results at the 40 degree angle from centerline, figure 29, shows improvement of the PSP response over the first version GrayQB™ SF to provide a clearer and more accurately shaped image at greater angles.

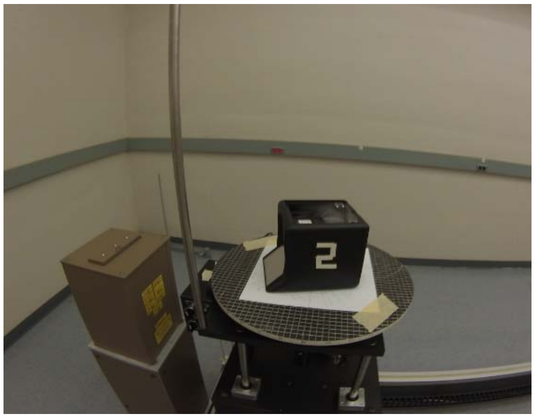


Figure 28. Position of device for angled Am-241 tests

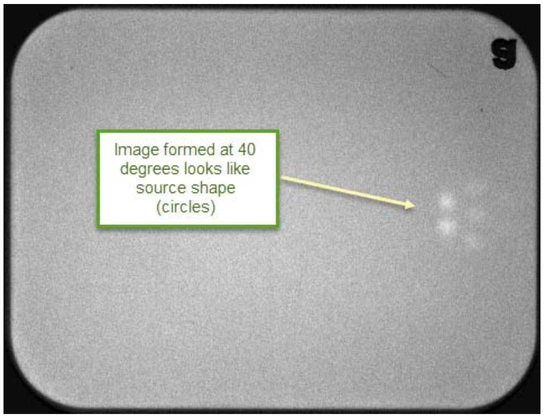


Figure 29. Image formed on PSP when device placed at 40 degrees from centerline

3.4.3 Overlay Alignment Validation

HPICL results obtained using the RAzer^{TM} software validated the programs ability to correctly overlay the images. Several resultant images obtained from HPICL testing using the RAzer^{TM} software with default settings selected are shown in figure 30 below.

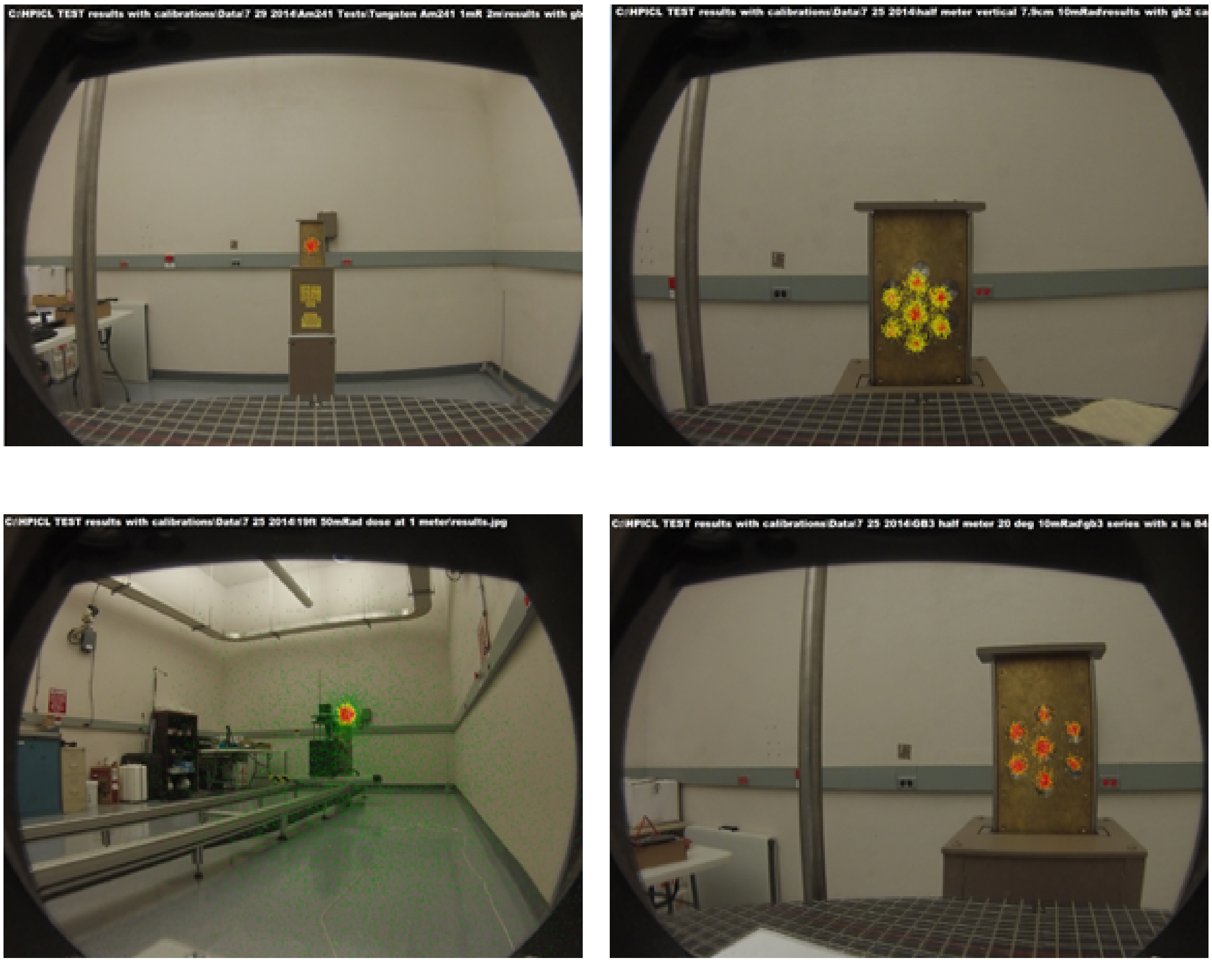


Figure 30. Examples of HPICL results obtained using RAzer^{TM} program

3.4.4 Response to Higher Energy Isotopes

Testing was performed using Cs-137 and Co-60 sources to determine the device response to higher energy isotopes. This was the first GrayQb^{TM} testing performed using sources with energy levels greater than 150 KeV. HPICL testing with higher energy isotopes demonstrated that the GrayQb^{TM} SF2 could be used to map these isotopes. A higher total dose as compared to lower energy isotopes, however, was required to isolate the source location for mapping. Additionally, the PSP image does not result in a crisp localization but rather a blur of intensity in the area of the source.

The RAzer™ result from the Co-60 source demonstrates the ability of GrayQb™ SF2 to localize higher energy intensities, figure 31. The higher energy results displayed large fields of intensity over the entire visual image making it difficult for a user to visually localize the source in the photo. This led to an upgrade of the RAzer™ software enabling the user to remove intensity colors from results. Figure 32 shows the Co-60 results from Figure 31 with the green and yellow colors removed from the mapping. Removal of the lower intensity colors clarifies the position of the source on the image.

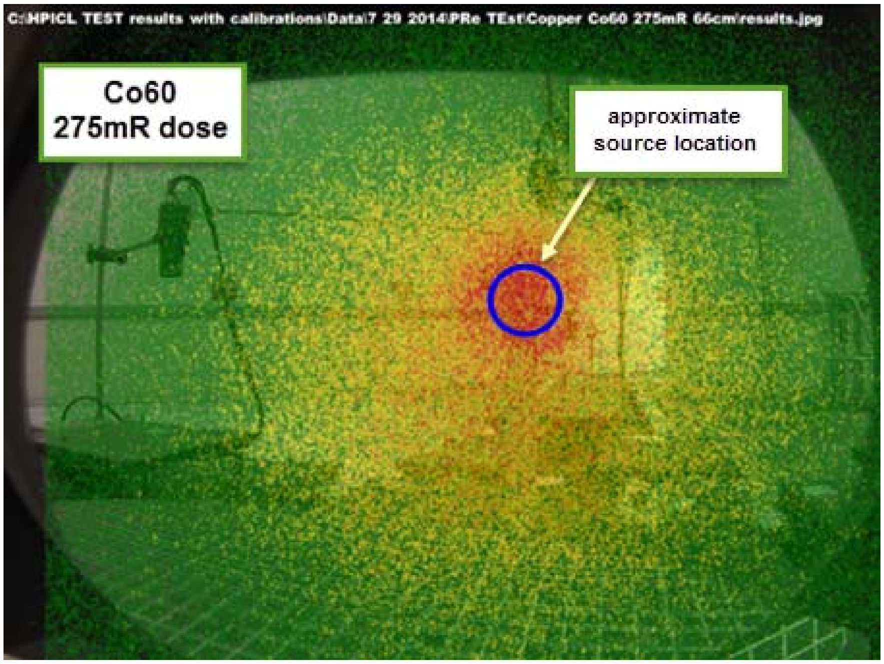


Figure 31. Co-60 results with a total dose of 275mR during HPICL testing

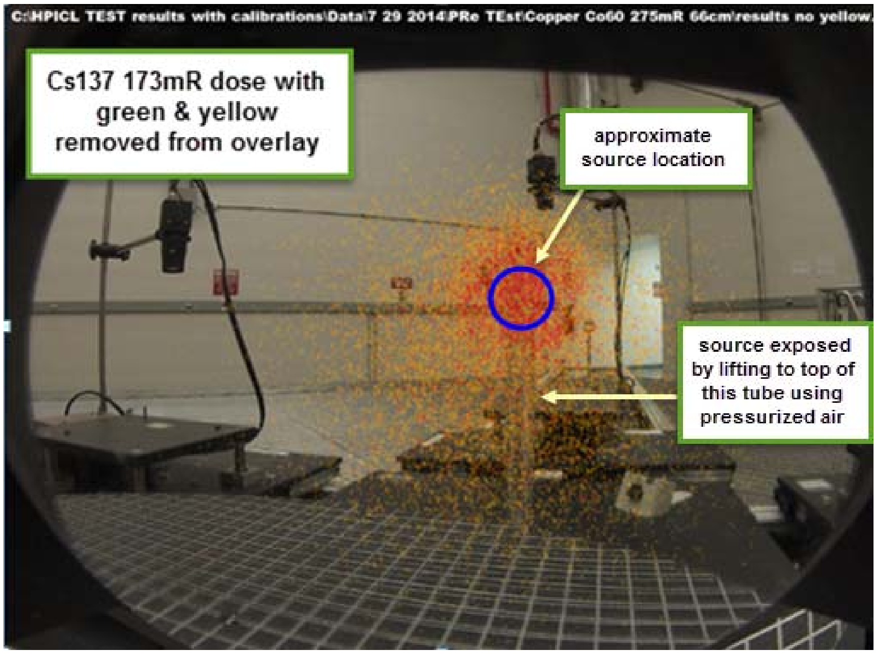


Figure 32. Co-60 results with lower intensity colors removed from mapping

HPICL test results with the Cs-137 source are shown in figure 33. The evolution of the PSP image resolving the source location as the dose is increased can be seen. As the dose increases, the intensity mapping begins to concentrate over the source location.

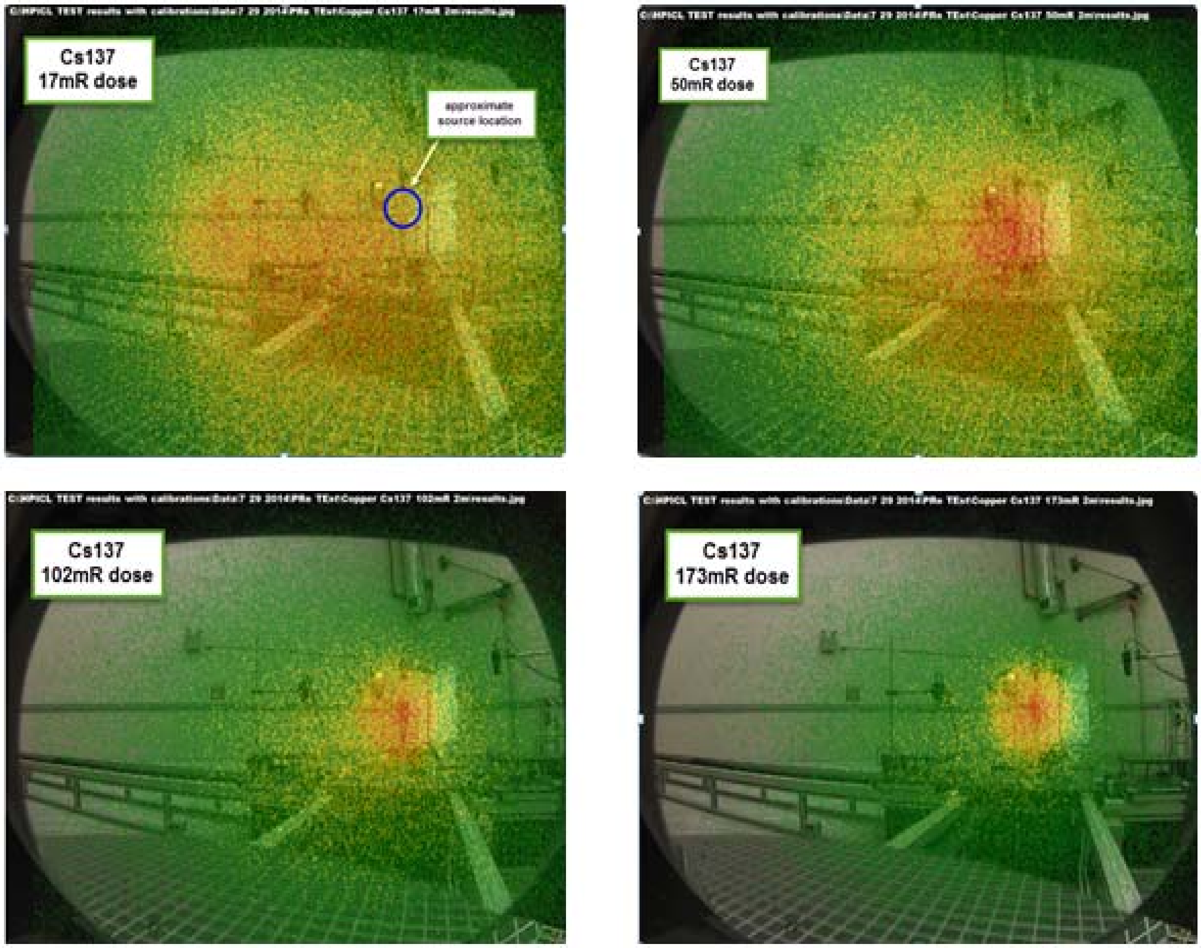


Figure 33. Evolution of PSP resolution of Cs137 source as dose is increased during HPICL testing

3.5 Open Environment Testing

Testing conducted in E-Area was completed to characterize the performance of the GrayQb^{TM} SF2 device in a low level waste open environment [4]. GrayQb^{TM} SF testing last year (FY13) was conducted in areas of no measureable background radiation with low energy sources (<150 KeV). The E-Area environment differs from FY13 testing in that it possesses isotopes with higher energy and a constant field of low intensity background radiation which includes higher energy sources (>500 KeV). Additionally, E-Area locations generally possess large fields of relatively uniform source intensity versus FY13 testing which focused on an area with a localized source.

3.5.1 E-area Low Level Waste Storage Area

The E-Area Low Level Waste Storage Area is a 195 acre centrally located site for storing hazardous and mixed solid waste generated at the Savannah River Site as well as occasional special shipments from offsite, Fig 34. This storage site (or burial ground) is known as E-Area and consists of separate sections for accommodating various levels and types of radioactivity in waste materials: transuranic (TRU) alpha waste, low level beta-gamma waste, high level beta-gamma waste, and RCRA permitted waste streams. The RCRA Permitted TRU Pads consist of 11 concrete pads that are used to store, process, and repackage hazardous, mixed, and radioactive TRU waste. GrayQb^{TM} SF2 Testing was conducted at TRU Pad 17.

Figure 34. E-Area Low Level Waste Storage Area and test location TRU Pad 17

3.5.2 TRU Pad 17 Test Location

E-Area GrayQb^{TM} SF2 open environment testing was conducted at TRU Pad 17. This location was chosen due to the higher potential of drums staged there to have variable intensities versus most other E-Area locations which store uniform intensity material. TRU Pad 17 includes two High Radiation Areas (HRAs) comprised of roughly 20 drums in a single layer, Figs. 35 & 36. Tests 1 thru 10 were performed with the GrayQb^{TM} SF2 located between the two HRAs to determine the effect of high radiation background on the PSP imaging medium and the effectiveness of the GrayQb^{TM} SF2 internal shielding. Test 11 was performed with the device outside of this area.

SRNL and E-Area Health Physics personnel deployed and recovered the devices in accordance with E-Area policies and procedures. SRNL personnel processed the device PSPs and digital images at the test site using the ScanX PSP scanner and RAzer^{TM} software. PSP vendor literature suggested degraded PSP performance in temperatures exceeding 86^{o} F; therefore testing was not performed when temperatures exceeded this threshold.

Figure 35. TRU Pad 17 E-Area test location with High Radiation Areas (HRAs)

Figure 36. HRA used for TRU Pad 17 testing

Initial E-Area operations surveys were completed of TRU Pad 17 to determine dose rates and isotopes present. The general area dose rate between the two HRAs was 35 mR/hr. A Falcon 5000 Portable HPGe-based detector with radionuclide identification capability was used to collect a spectrum of the area, Fig 37. The spectrum indicated isotopes of Am-241, Pb X-rays, Pa-233, and Cs-137 present, Fig. 38.

Figure 37. Falcon 5000 detector for radionuclide identification

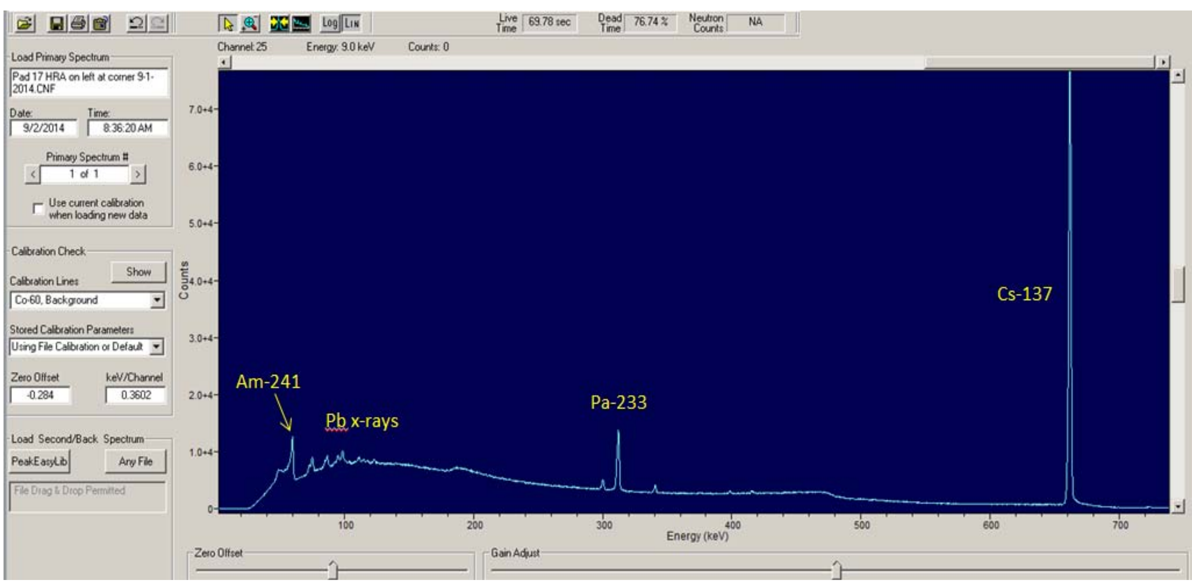


Figure 38. Radionuclides identified by Falcon 5000 in test area

3.5.3 Test Configurations

The four GrayQb™ SF2 devices and their tripods were deployed at various distances, heights, time periods and shielding configurations. Testing configuration variables are described in Table 2. Initial test configurations were developed based on device performance previously determined at the IRL and HPICL; however, these areas possessed no measurable background radiation, so it was unclear how the TRU Pad 17 background radiation would affect results. The test plan was written to conduct initial testing at various times, height and shielding that seemed reasonable with final deployments to be determined once initial results were evaluated. Results were generated and reviewed immediately in the field to determine the most useful configurations for final deployments.

Table 2. Testing Configuration Variables

Testing Variable	Purpose
Time	Evaluate deployment time results given higher energy sources and low intensity background
Location - Distance	Evaluate results looking directly at first row of drums arranged several rows deep to determine if higher intensities can be detected in back rows
Location - Height	Evaluate results looking down at drums arranged several rows deep to determine if higher intensities can be better localized looking down at drums
Shielding	Evaluate usefulness and adequacy of current device shielding 1) Deployment with no additional internal side and back shielding (to determine usefulness of GrayQb shielding) 2) Deployments with GrayQb side and back shielding in place

The first four tests were conducted for 30, 60 and 120 minute time intervals to evaluate the results of deployment time. Two of these devices were deployed at the 60 minute time period, one with and one without internal shielding to determine the usefulness and effectiveness in this environment. Test 5 was performed closer to the HRA for a longer period of time for additional time and distance data. Tests 6 and 7 were made with the devices deployed at an elevated level looking down at the drums in the HRA. Test 7 was conducted with an unshielded device. Test 8 was configured with the GrayQb™ SF2 directly facing an area of higher intensity noted in Test 2 and 6 results. Tests 9 thru 11 were added to determine the effect of a longer deployment time and greater distance on results. Test 11 was performed without the HRA located behind it and at the greatest distance from the HRA to determine if the distance could be increased yet acceptable results produced.

Tests 3 and 7 were performed without internal shielding added to the device, all other tests were performed with internal shielding. The GrayQb™ SF2 housing cavity for all other tests was filled with steel shot to provide internal shielding to the sides and back of the PSP imaging medium in the device, Fig 39.

Figure 39. GrayQb SF2 with internal steel shot shielding (left) and w/o shielding (right)

A summary of all tests conducted during E-Area open environment testing is shown in Table 3. Deployment locations are shown in Figures 40 thru 42.

Table 3. List of E-Area test configurations

Test	GrayQb Device #	Area Dose Rate (mR/hr)	Time (hr)	Total Area Dose (mR)	Shielding (steel	Height (in)	Distance from HRA fence* (in)	Test Location
September 4, 2014 Short Term Morning Deployments								
1	GQ1	32	0.5	16	Yes	33	62	figure 40
2	GQ2	32	1	32	Yes	24	62	figure 40
3	GQ4	32	1	32	No	42	62	figure 40
4	GQ3	32	2	64	Yes	26	62	figure 40
5	GQ1	40	3.1	124	Yes	3	18	figure 41
6	GQ2	25	2.25	56	Yes	100	44	figure 41
7	GQ4	32	2.25	72	No	94	38	figure 41
8	GQ3	39	1.5	59	Yes	27	7	figure 41
September 10-11, 2014 Long Term Overnight Deployments								
9	GQ1	28	21.75	609	Yes	84	88	figure 42
10	GQ3	27	21.3	575	Yes	29	94	figure 42
11	GQ4	9	21.3	192	Yes	69	148	figure 42

** this is the distance from the device to the vertical plane defined by the HRA boundary fencing*

Figure 40. E-Area deployment locations 1 thru 4

Figure 41. E-Area deployment locations 5 thru 8

Figure 42. E-Area deployment locations 9 thru 11

3.5.4 Open Environment Test Results

Results from each test are shown in Appendix C.

3.5.4.1 Test 1

The Test 1 deployment was for 30 minutes and did not produce any distinguishable results; it was thought that the time period was not long enough and that the device may need to be closer to any potential source. After the data was imported from the GQ1 device, it was prepared for a second deployment, Test 5, at a location closer to the HRA and for a longer period of time.

Although test 1 provided no source results, it did immediately demonstrate that the software overlay color scheme denoting intensities was not well suited for the area being evaluated. The HRA was surrounded by red material fencing and held drums with yellow and magenta markings making the software color scheme of magenta, red, orange, and yellow for displaying the highest intensities difficult to distinguish in the resultant photos. To help in evaluating results, some photos in later tests were converted to black and white and their results regenerated.

3.5.4.2 Test 2 and 3

Test 2 and 3 GrayQb™ SF2 devices were deployed together for a 60 minute time period; the Test 2 device was deployed with internal shielding and the Test 3 device was deployed without shielding. Results for Test 2 showed a faint potential area of higher intensity radiation, Fig.43. The result for Test 3 was flooded with indistinguishable intensity. These two devices were deployed together again in Test 6 and 7, to have a second set of results to evaluate shielding effectiveness. Shielding results are discussed at the end of the Test Results section.

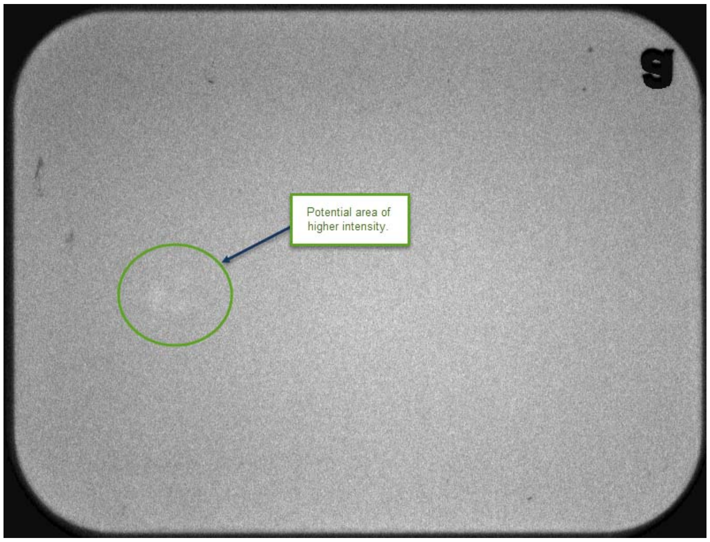


Figure 43. Test 2, a 60 minute deployment the area of interest beginning to develop

3.5.4.3 Test 4

Deployment 4 was directly facing the center drums of the HRA for 120 minutes; its results were generally inconclusive. However, we do see the HPICL high energy phenomena where the radiation intensity mapping is beginning to resolve more precisely over the drums with greater dose exposure (time). This is discussed further in the results analysis section.

3.5.4.4 Test 5

Deployment 5 was also directly facing the center drums but was 44 inches closer than Test 4 and in place for 189 minutes. Results seem to indicate that there is a higher intensity radiation field coming from the two drums directly in front of the device, the single color of intensity indicates the field is uniform, Fig. 44.

Figure 44. Test 5 results with intensity concentrating over drums with uniform intensity

3.5.4.5 Test 6 and 7

Tests 6 and 7 were performed at a greater height looking down at the area of interest to determine if higher intensities could be better localized looking down at the drums. The Test 6 device was deployed with internal shielding and the Test 7 device was deployed without shielding. Results of deployment 6 showed a faint potential area of higher intensity radiation, Fig.45, in the same location as noted in Test 2. It was decided to make our last test of the day with a GrayQb^{TM} SF2 directly facing this area of interest. The unshielded device used for Test 7 again produced results flooded with indistinguishable signal. Shielding results are discussed at the end of the results section.

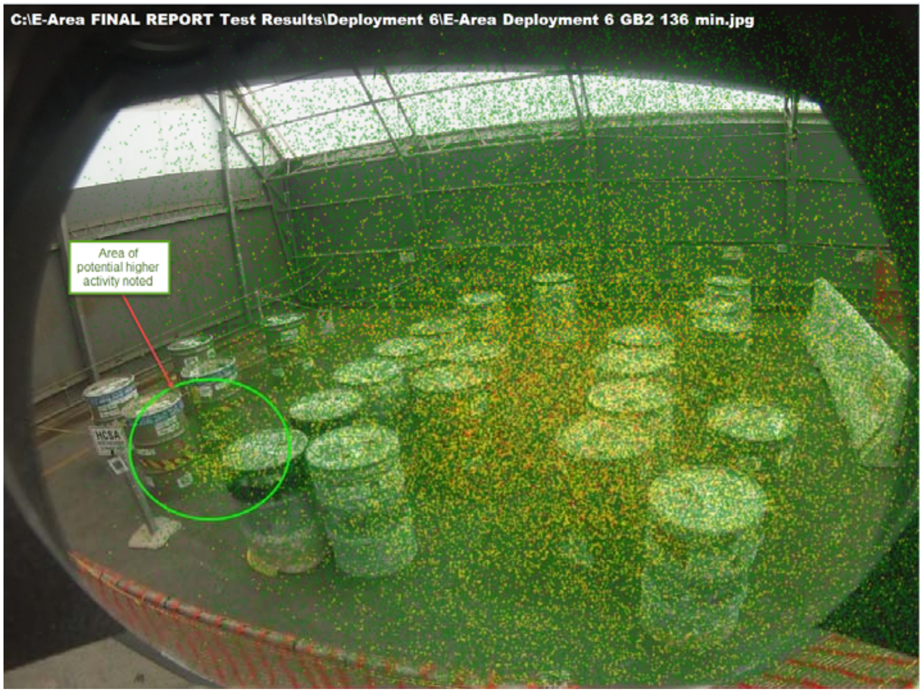


Figure 45. Test 6 with potential higher intensity location

3.5.4.6 Test 8

Test 8 was performed with the GrayQb™ SF2 device directly facing the area of interest noted in Tests 2 and 6 for 88 minutes. The results obtained from this deployment clearly indicate a source of higher intensity, Fig 46. To better distinguish the field intensity mapping on the visual image, the result is also shown using a black and white photo. These results demonstrate the GrayQb™ SF2's ability to detect higher intensities in open environment areas of background radiation.

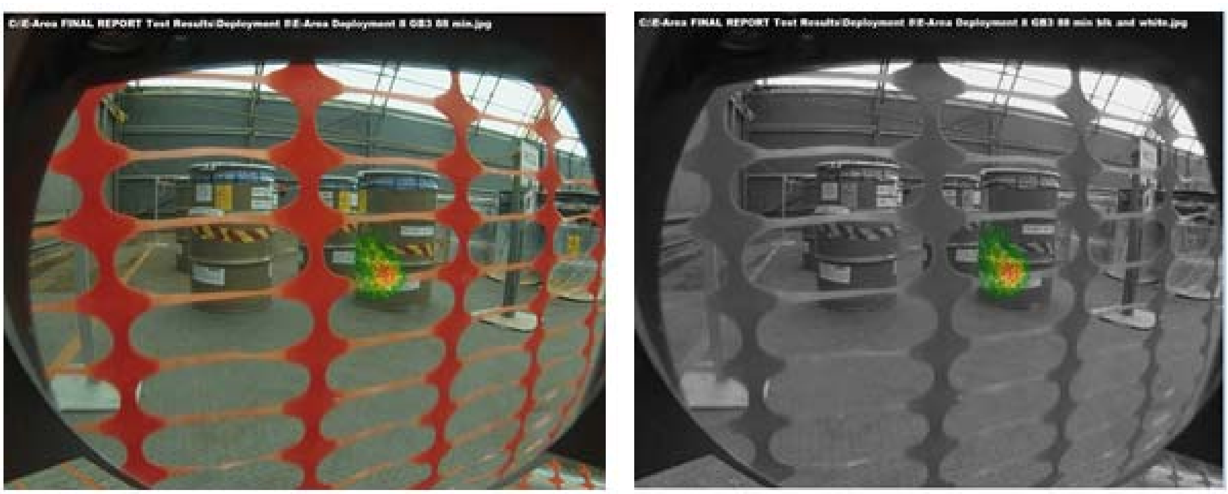


Figure 46. Test 8 results with default settings (left) and with black and white photo (right)

3.5.4.7 Test 9, 10, and 11

Tests 9 thru 11 were added to determine the effect of longer deployment times on results. It was hoped that the increased time would allow for a more defined result to develop in particularly for any potential high energy source location. Additionally, the distance from the HRA was increased with these final tests to determine if a greater area could be evaluated with a longer deployment time. Devices were deployed overnight for approximately 21 hours.

Test 9 and 10 results, Fig. 47 & 48, clearly show the location of high intensity identified in Test 8. Additionally, Test 9 and 10 results demonstrate the usefulness of using multiple GrayQb SF2 devices in a 3D area, versus a 2D surface such as a wall, to triangulate a source location.

Figure 47. Test 9 results

Figure 48. Test 10 results

Test 11 was performed without the HRA located behind the device and was the greatest distance from the area under evaluation. The higher intensity drum from Test 8 appears to be starting to form an image on the Test 11 result, Fig 49, as does the concentration of source intensity to the drum area, Fig 50. A longer deployment time may have clarified these areas more in the resultant image.

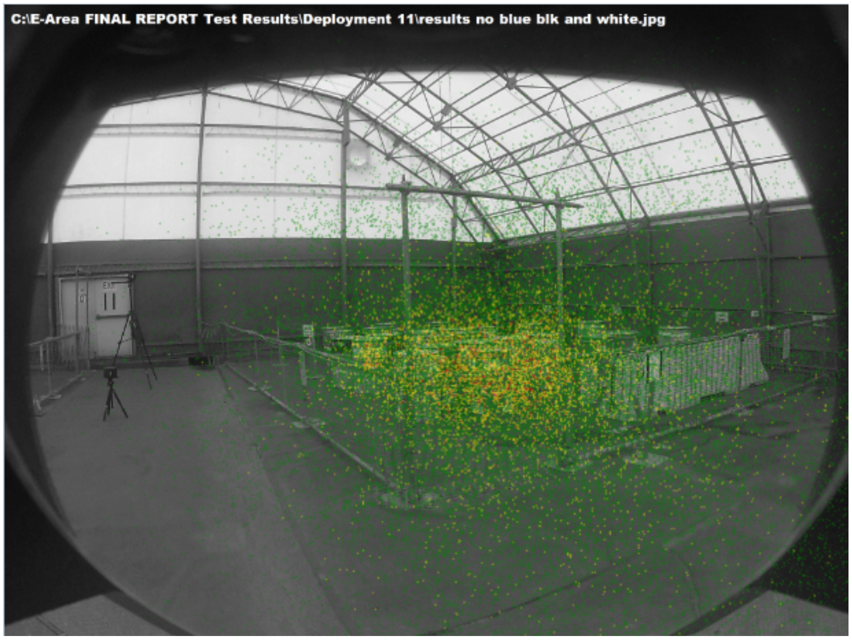


Figure 49. Test 11 results

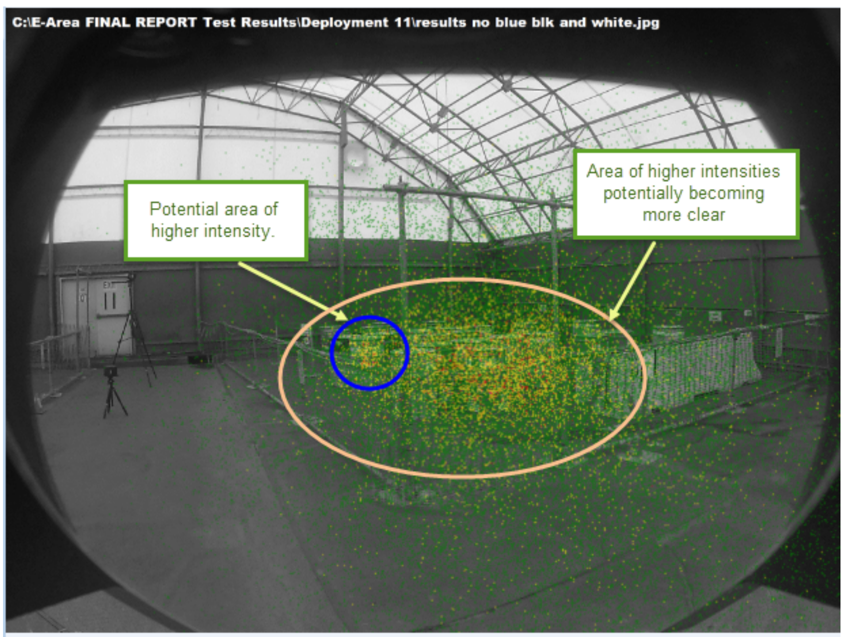


Figure 50. Test 11 results with annotations

3.5.4.8 Shielding Results

The internal shielding provided by filling the GrayQb ™ SF2 housing cavity with steel shot proved to work very well. Test 2 and 3 devices were deployed together; the Test 2 device was deployed with internal shielding and the Test 3 device was deployed without shielding. Test 6 and 7 devices were also deployed together with the Test 6 device having internal shielding and the Test 7 device with no shielding. Side by side results of these tests are shown in figures 51 & 52. The images obtained from the GrayQb SF2 without shielding displayed widespread energy and no discernible areas of concentration as compared to the GrayQb SF2 with internal shielding deployed in the same location for the same period of time.

Another benefit found from including the shielding as part of the device was faster deployment and more options for device location. The GrayQb ™ SF2 was able to be mounted with internal shielding (steel shot) onto a tripod and placed where desired for testing. Typically providing shielding for a detector in the field involves building external shielding for the device. Placing the external shielding around other detectors increases deployment time, additionally it requires the detector to be situated on a surface so that the bulky shielding can be put into place around it which limits the deployment location opportunities.

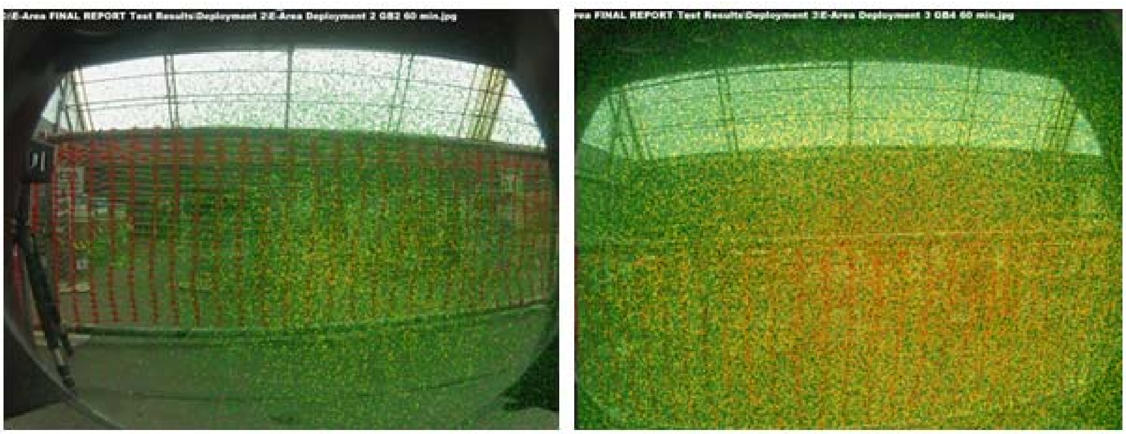


Figure 51. Test 2 (left) with internal shielding & Test 3 (right) without shielding for same deployment

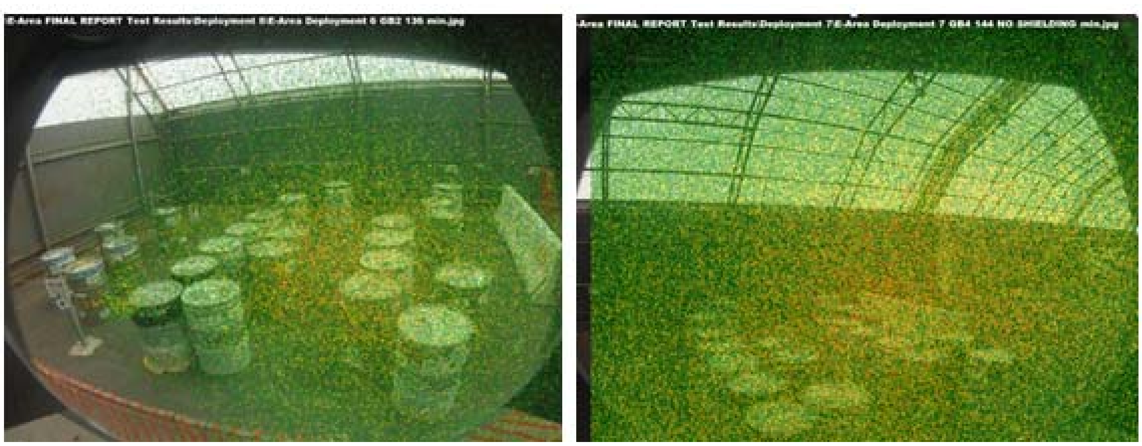


Figure 52. Test 6 (left) with internal shielding & Test 7 (right) without shielding for same deployment

3.5.5 Analysis of Open Environment Results

The GrayQb™ SF2 has potential for providing useful results in a short period of time. In Test 2, after a 60 minute deployment, results showed a potential area of higher intensity that was later confirmed in Test 6 after 120 minutes. Based on these results, a GrayQb™ SF2 was placed looking directly at this area of interest (Test 8). Test 8 results, fig. 53, demonstrated the ability of the GrayQb™ SF2 to map an area of higher radiation intensity in an open environment with measureable low and high energy background radiation. Additionally, Test 8 results were obtained in the short deployment time of 88 minutes. Based on HPICL results, the higher intensity source found in Test 8 was thought to be from a lower energy isotope. HPICL testing showed that low energy isotopes resolved on the final image as well defined mapped locations, similar to Test 8, and higher energy isotopes possessed less definition around the source on the resultant image. Data obtained on the drum identified as having the higher intensity corroborated that the source was from a low energy isotope.

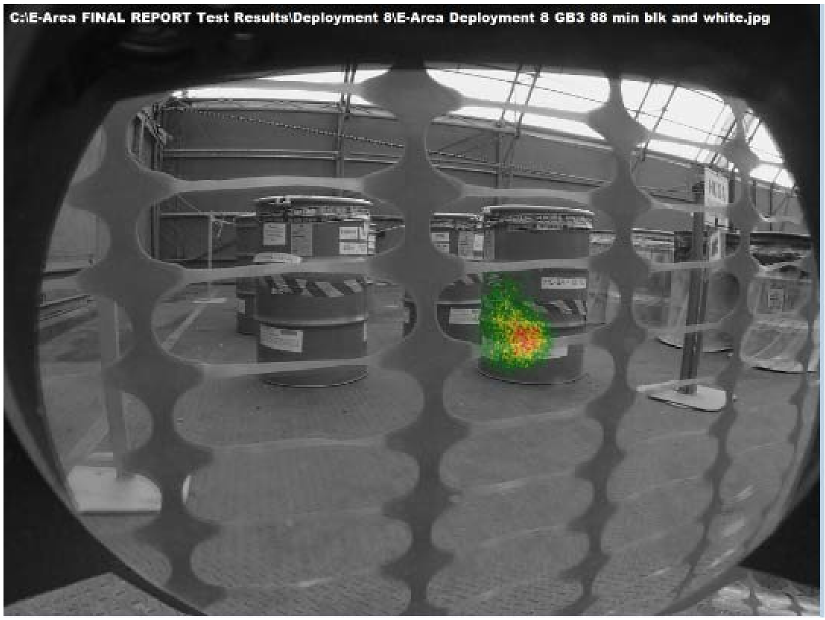


Figure 53. Test 8 results

Results demonstrated that internal shielding in the form of steel shot located in the GrayQb™ SF2 housing cavity dramatically improved resultant images. Another benefit found from including the shielding as part of the device, was faster deployment into the area under examination and greater flexibility in deployment location. The GrayQb™ SF2 device with internal shielding was able to be mounted onto a tripod and easily placed where desired for testing.

Results from Tests 1, 2, 4 and 11 demonstrated the phenomena noted with high energy isotope (Cs-137 and Co-60) testing at HPICL. These E-Area results exhibit how the mapping begins to concentrate over the area of higher intensity as the overall dose is increased, Fig. 54. Test 1, 2, 4 and 11 total area doses were 16, 32, 64 and 192 mR respectively.

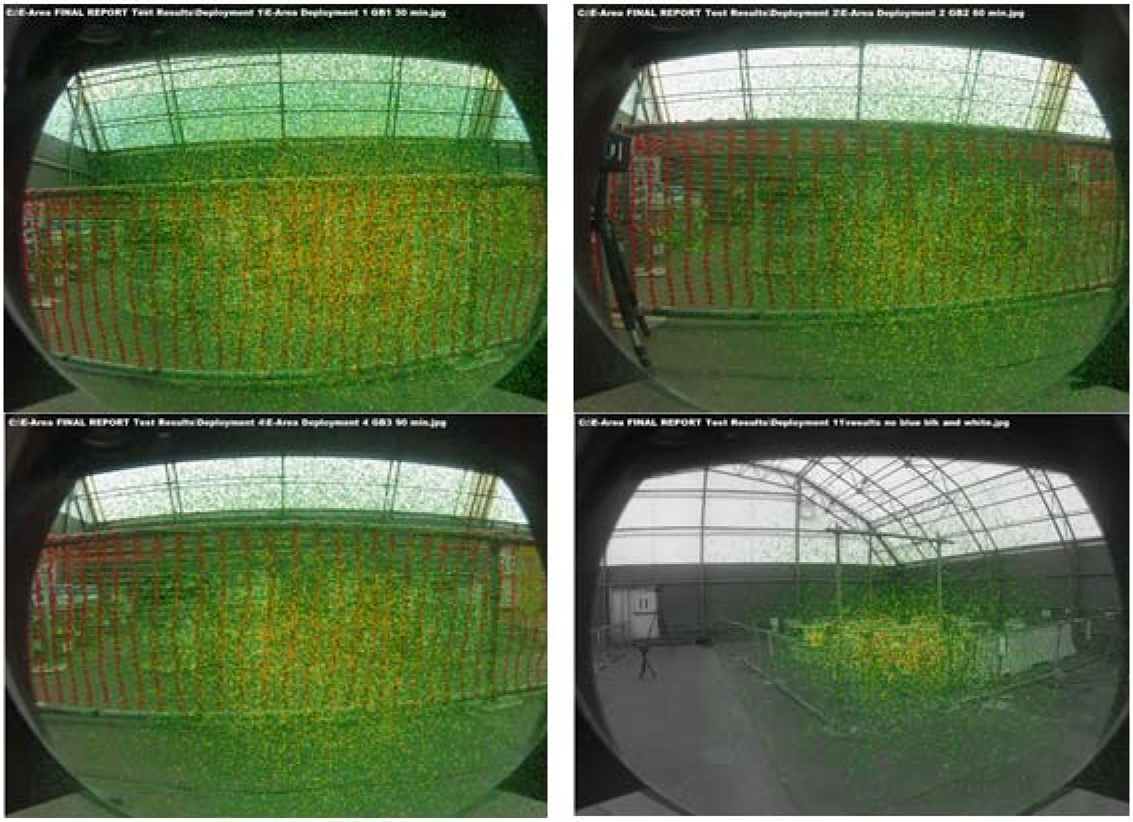


Figure 54. Tests 1, 2, 4 and 11 showing intensity mapping resolving over drums as dose increases

Tests 9 and 10 demonstrate that two resultant views of the same area provide information to assist in triangulating the location of the source when examining a 3D space, Fig. 55. The recommendation is that when examining an area that possesses depth, versus 2D locations such as a wall, that multiple GrayQb™ SF2 devices be deployed. Given the low cost of the device, this is an economical solution for determining location.

Figure 55. Test 9 and 10 results demonstrating usefulness of multiple views to triangulate source position in 3D area

4.0 CONCLUSIONS

In summary, FY14 testing of the GrayQb™ SF2 device demonstrated its ability to detect low energy isotopes, e.g. Am-241 and Pu-238, not only indoors in controlled environments with well-defined source locations, but also in open environment field areas with measureable high energy background radiation. Additionally, it was demonstrated that the device could detect higher energy isotopes (Cs-137 and Co-60) in HPICL and with additional testing and/or modifications to device and software, may be able to detect these isotopes in the open environment field testing. The GrayQb™ SF2 can economically triangulate source position in a 3D space with the simultaneous deployment of multiple devices and can be easily carried and deployed on a tabletop or tripod with internal shielding in place. GrayQb™ SF2 device operating characteristics are shown in Table 4.

Based on FY14 device and software enhancements and test results, the GrayQb™ SF2 is ready for Technology Transfer and Commercialization consideration.

Table 4. GrayQbTM SF2 device characteristics

Parameter	Target Values	GrayQb™ SF	GrayQb™ SF2
Ambient Light Sensitivity		PSP are light sensitive	
PSP Heat Sensitivity		extreme thermal variation	
Spatial Resolution	1°	1°	1°
Field of View	80°	Spherical: 72°	Hortizontal: 87, Vertical: 66
Detection sensitivity determined using an x-ray generator		0.2 mrad	0.2 mrad
Detection sensitivity determined in HPICF (using ^{241}Am sources)		0.1 mrad	0.2 mrad*
Detection sensitivity determined in HPICF (using Cs137 sources)		not tested	25 mrad**
Detection sensitivity determined in HPICF (using Co60 sources)		not tested	100 mrad**
Suggested Detection Sensitivity	0.2 mrad	0.2 mrad	0.2 mrad

**reduction of .1 mrad resulting from minimal shielding of radiation to PSP from addition of mirror ** estimate based on limited testing with source strengths*

5.0 REFERENCES

[1] "Single-Faced GrayQb™ A Radiation Mapping Device," SRNL-STI-2013-00654, Dec. 2013.
[2] "Task Technical and Quality Assurance Plan for GrayQb™ Single Face Version 2 (SF2) Open Environmental Space Testing," SRNL-RP-2014-00401, April 2014.
[3] "GrayQb™ SF2 Calibration Facility Test Plan," SRNL-L4500-2014-00048, July 2014.
[4] "GrayQb™ Single-Faced Version 2 (SF2) Open Environment Test Plan," SRNL-TR-2014-00196, August 2014.
[5] Immel, D., Bobbitt, J., Plummer J.; Savannah River Nuclear Solutions, LLC, assignee. A Radiation Imaging System. United States Patent Application No. 14/559,419. 2014 Dec 3,

APPENDIX A - DEPLOYMENT STEPS

Deployment Steps

A GrayQb™ SF 2 deployment involves the following steps:

1. Identify deployment location and time based on dose rate measurements. The deployment time increases as the dose rate decreases and the distance from the area of interest increases.

2. Optionally prepare device shielding by adding a metal shot to the GrayQb housing cavity. See Note 1.

3. Configure the device camera to take a photo every 60 seconds and turn the camera on for deployment. See Note 2.

4. Prepare the PSP plate as follows:

   - Place the PSP plate to be used into the PSP Cartridge holder.

   - Insert the PSP Cartridge holder into the SRNL developed PSP illuminator device to erase the PSP plate and apply a background signal.

   - Remove the PSP Cartridge holder from the PSP Pre-illuminator and insert it into the GrayQb SF2 device.

5. Place the GrayQb SF2 device at the test location facing the area of interest. Use the FOV figure located on top of the GrayQb SF2 device to help lineup the device correctly to include the area of interest. Threaded inserts are located on the bottom of the GrayQb™ SF2 so that it can be easily attached to a tripod if desired for deployment.

6. Retrieve device when deployment time has elapsed.

7. Remove the PSP Cartridge holder from the GrayQb SF2 device. Scan the PSP plate using the ScanX Duo scanner to obtain the radiological image from the PSP. The PSP is highly sensitive to UV light and should be shielded from daylight as much as possible while being transferred from the GrayQb device to the scanner.

8. Connect the device camera to the laptop via the USB port and use the RAzer™ software to import the digital image from the camera onto the laptop.

9. Using the RAzer™ software, produce resultant images. The RAzer™ software can automatically detect new scans imported on the laptop by the scanner software and will prompt the user to import the associated area of interest photo. Once the photo has been imported, the RAzer™ software will automatically super-impose the PSP image and the visual data from the camera to produce a resultant image (Fig. 6).

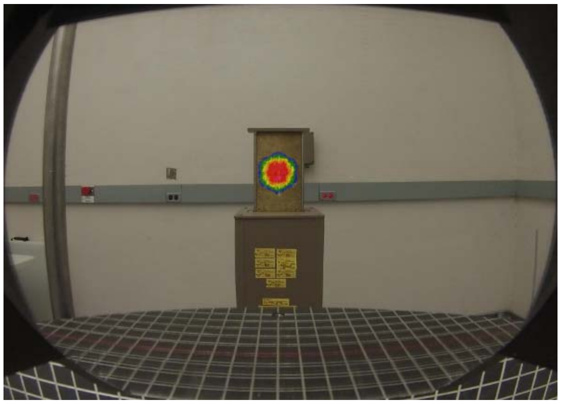


Fig. 6. Illustration of a GrayQb™ SF 2 deployment outcome from July 2014 Calibration Facility

Note 1. Shielding should be added if the GrayQb™ SF2 is to be deployed in an area possessing a background radiation.

Note 2. For areas allowing Wi-Fi, the GoPro camera can optionally be operated using the GoPro App on an apple device. This app enables the user to view the visual image as seen by the camera and to activate the camera shutter remotely.

APPENDIX B - HPICL TEST LISTING

Tests Conducted with Am-241

Test	GrayQb Device #	Total Dose (mrad)	Calculated Time for dose (sec)	Distance (m)	Angle (degrees)
July 25th, 2014 **Testing with seven Am241 source**					
1	GQ2	0.1	7.3	1	0
2	GQ2	0.2	14.6	1	0
3	GQ2	0.3	21.9	1	0
4	GQ2	0.5	36.5	1	0
5	GQ2	1	73	1	0
6	GQ2	5	365	1	0
7	GQ2	50	3651	1	0
8	GQ2	10	180.6	0.5	15
9	GQ3	10	180.6	0.5	20
10	GQ2	10	180.6	0.5	30
11	GQ3	10	180.6	0.5	40
12	GQ2	10	180.6	0.5	-40
July 29th, 2014 **Testing with seven Am241 source**					
1	GQ2	0.1	29.7	2	0
2	GQ3	0.2	59.5	2	0
3	GQ2	0.3	89.2	2	0
4	GQ3	0.5	149	2	0
5	GQ2	1	298	2	0
6	GQ3	0.05	14.8	2	0
Test	GrayQb Device #	Total Dose (mrad)	Calculated Time for dose (sec)	Distance (m)	Angle (degrees)

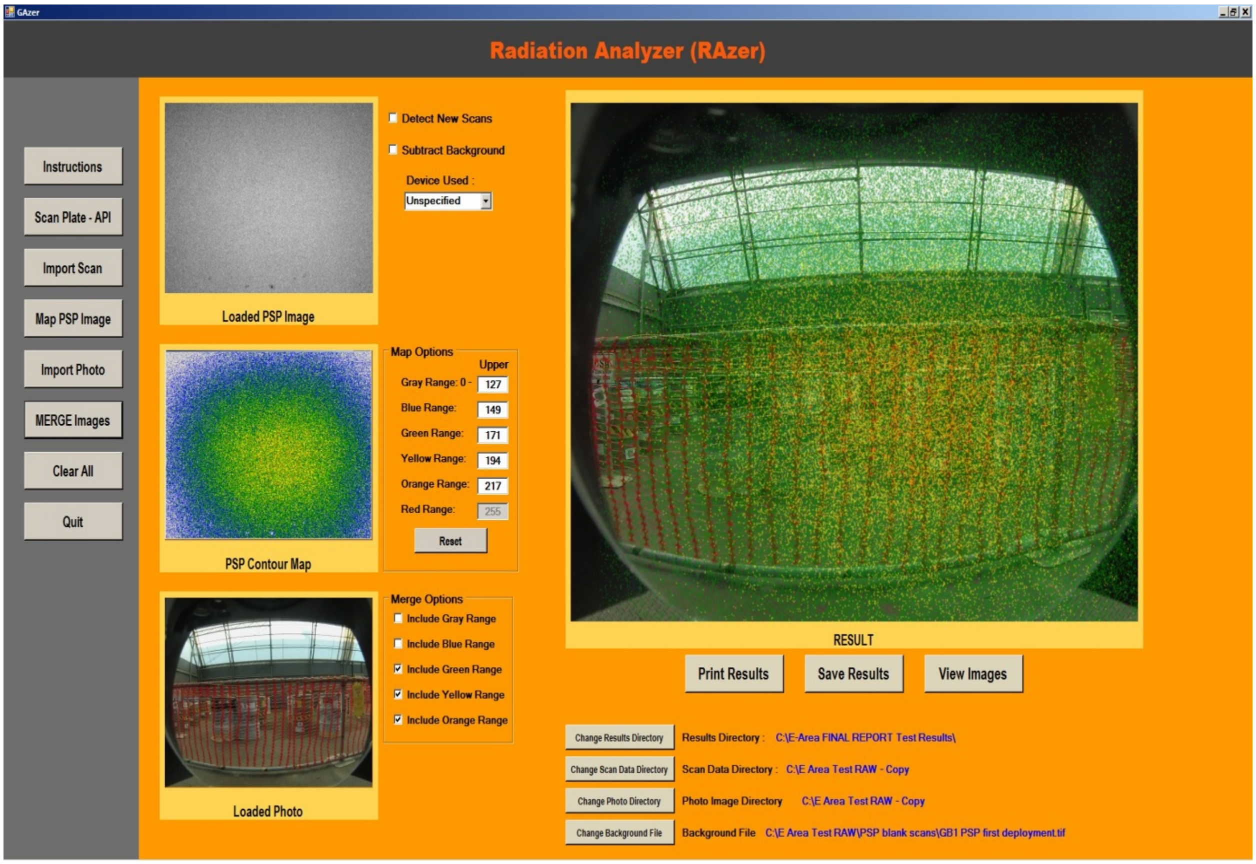
APPENDIX B - HPICL TEST LISTING, Continued

Tests Conducted With Cs-137 and Co-60

Test	GrayQb Device #	Total Dose (mrad)	Calculated Time for dose (sec)	Distance (m)	Angle (degrees)
July 29th, 2014 **Testing with Cs137**					
1	GQ2	17	LSI Cmptr Controlled	2	0
2	GQ3	17	LSI Cmptr Controlled	2	0
3	GQ2	50	LSI Cmptr Controlled	2	0
4	GQ3	50	LSI Cmptr Controlled	2	0
5	GQ2	102	LSI Cmptr Controlled	2	0
6	GQ3	102	LSI Cmptr Controlled	2	0
1	GQ2	173	LSI Cmptr Controlled	2	0
2	GQ3	173	LSI Cmptr Controlled	2	0
3	GQ2	102	LSI Cmptr Controlled * w/Internal Shielding	2	0
July 29th, 2014 **Testing with Co60**					
1	GQ2	13	LSI Cmptr Controlled	2	0
2	GQ3	13	LSI Cmptr Controlled	2	0
3	GQ2	275	LSI Cmptr Controlled	2	0
2	GQ3	275	LSI Cmptr Controlled	2	0

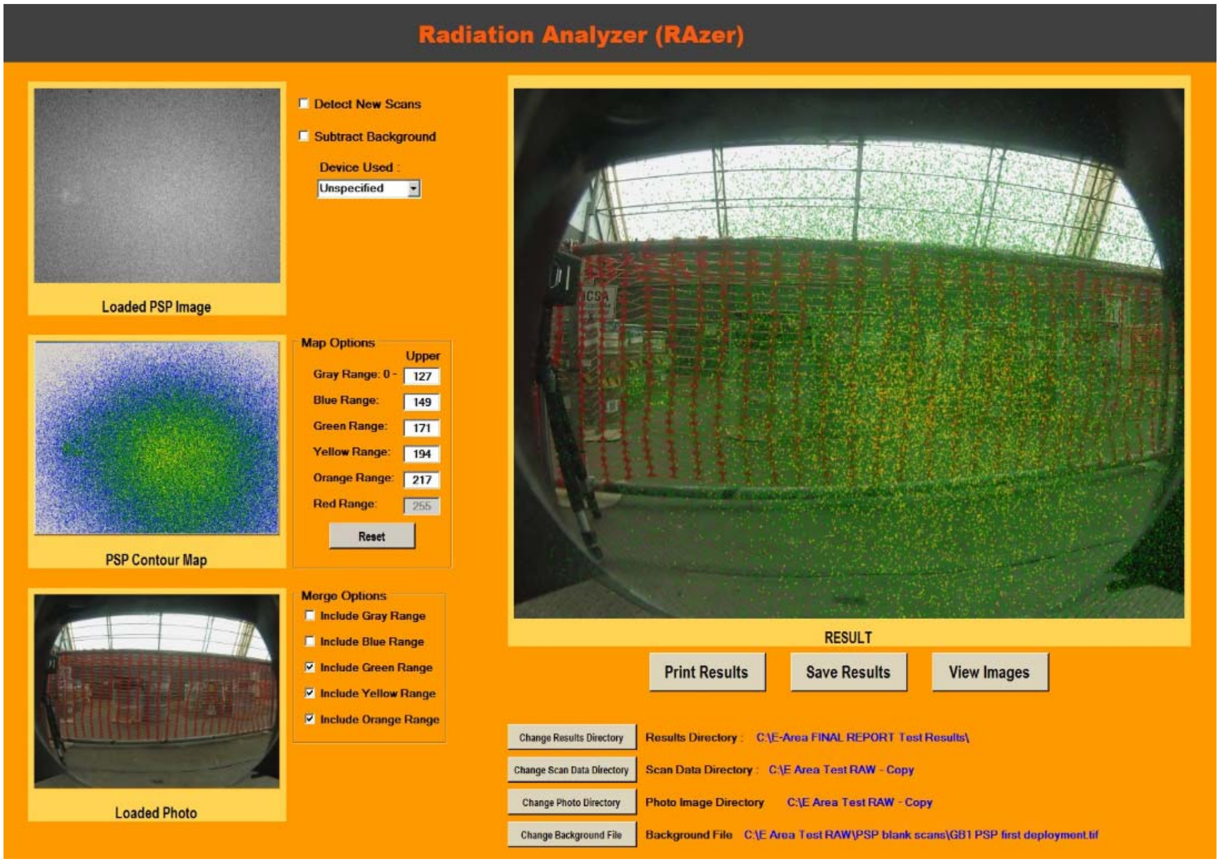
APPENDIX C - E-AREA RESULTS

DEPLOYMENT 1



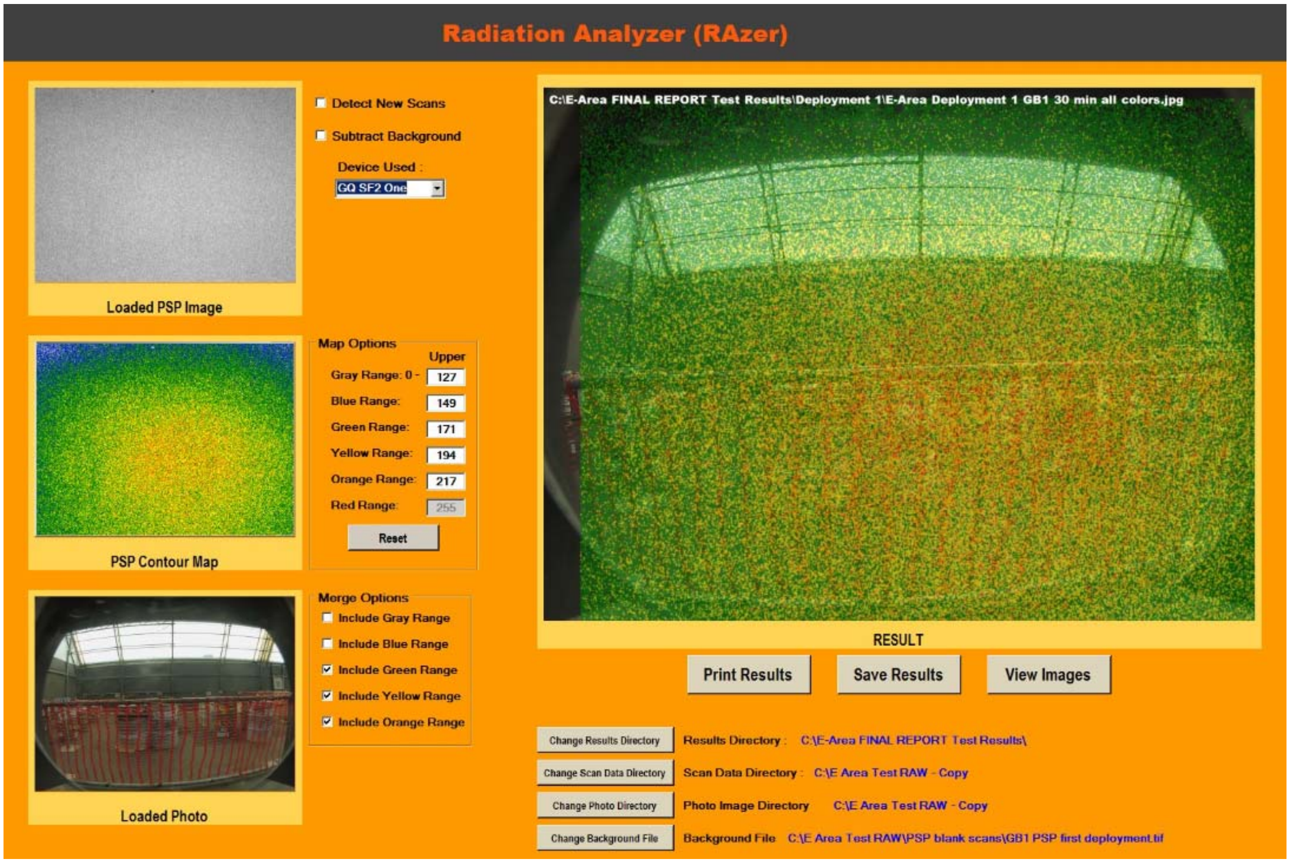
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 2



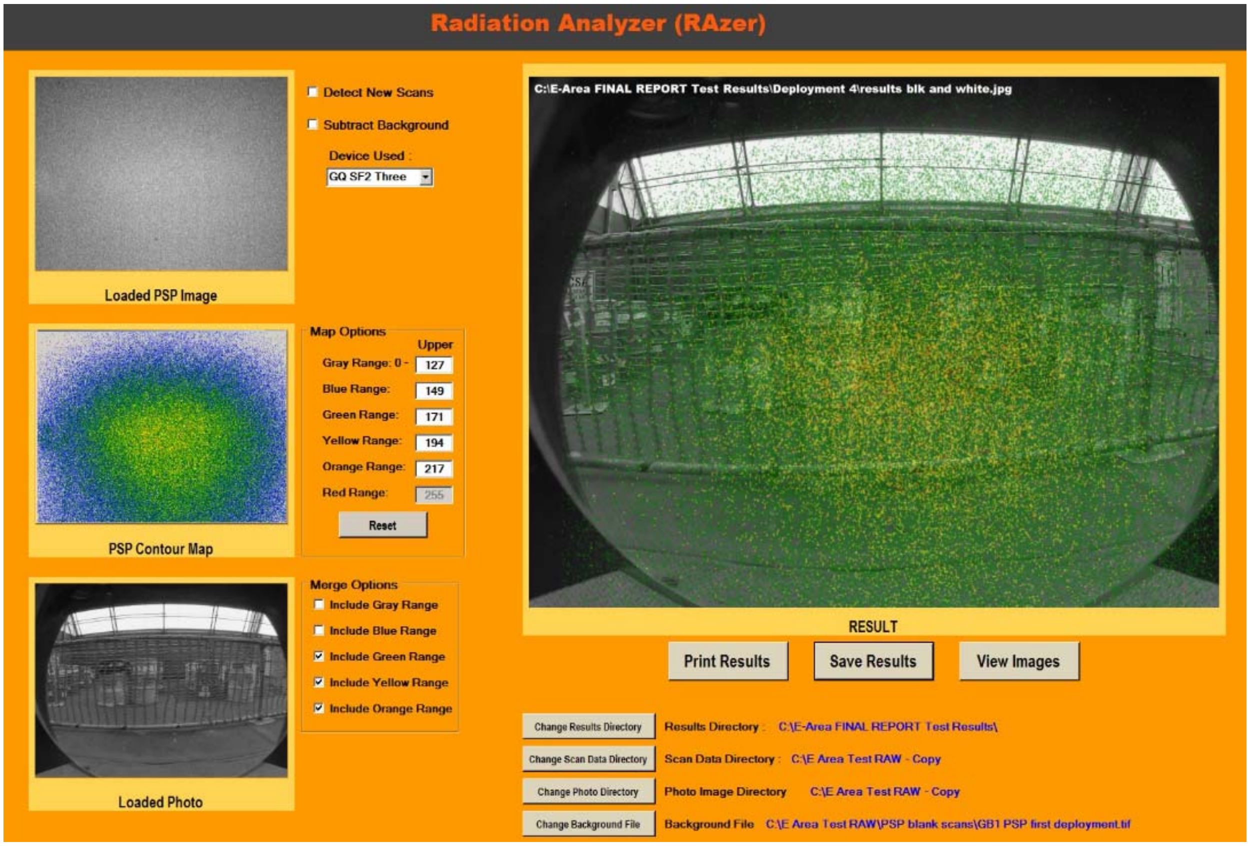
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 3



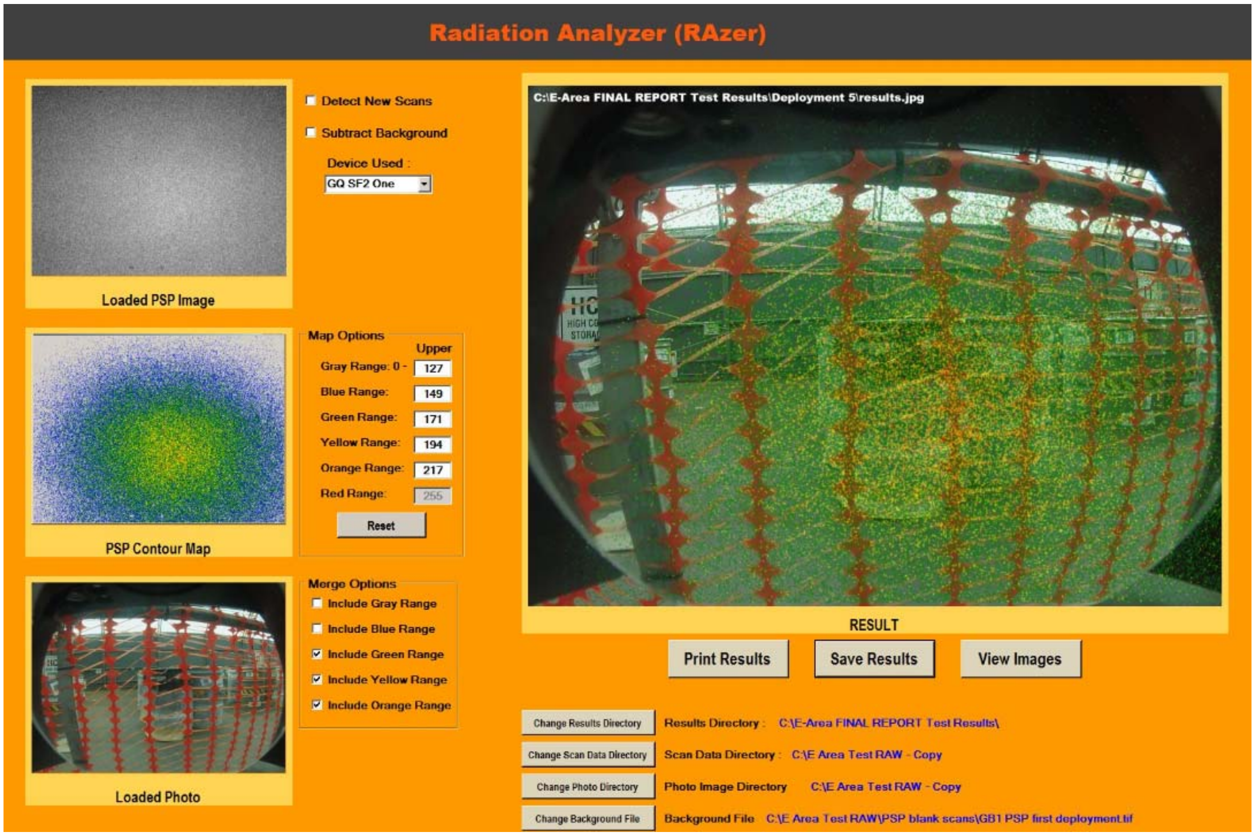
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 4



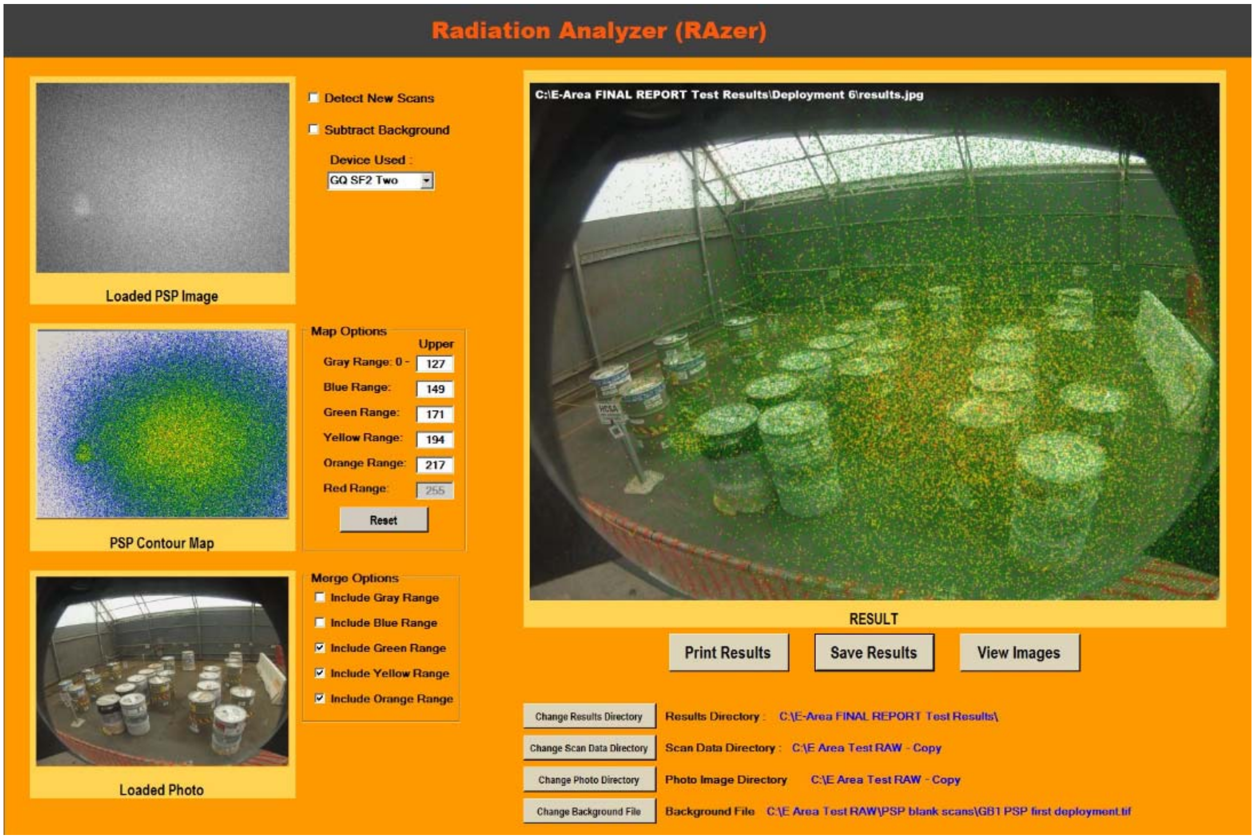
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 5



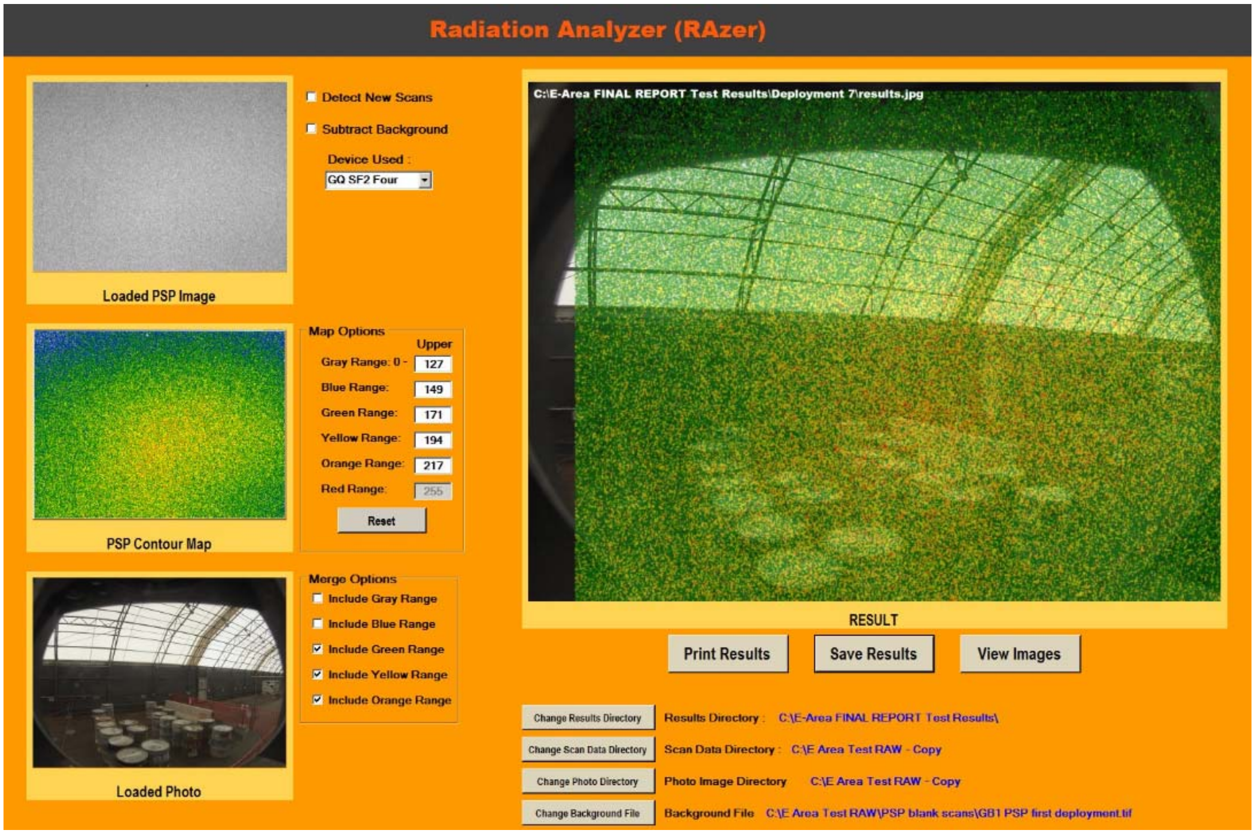
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 6



APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 7

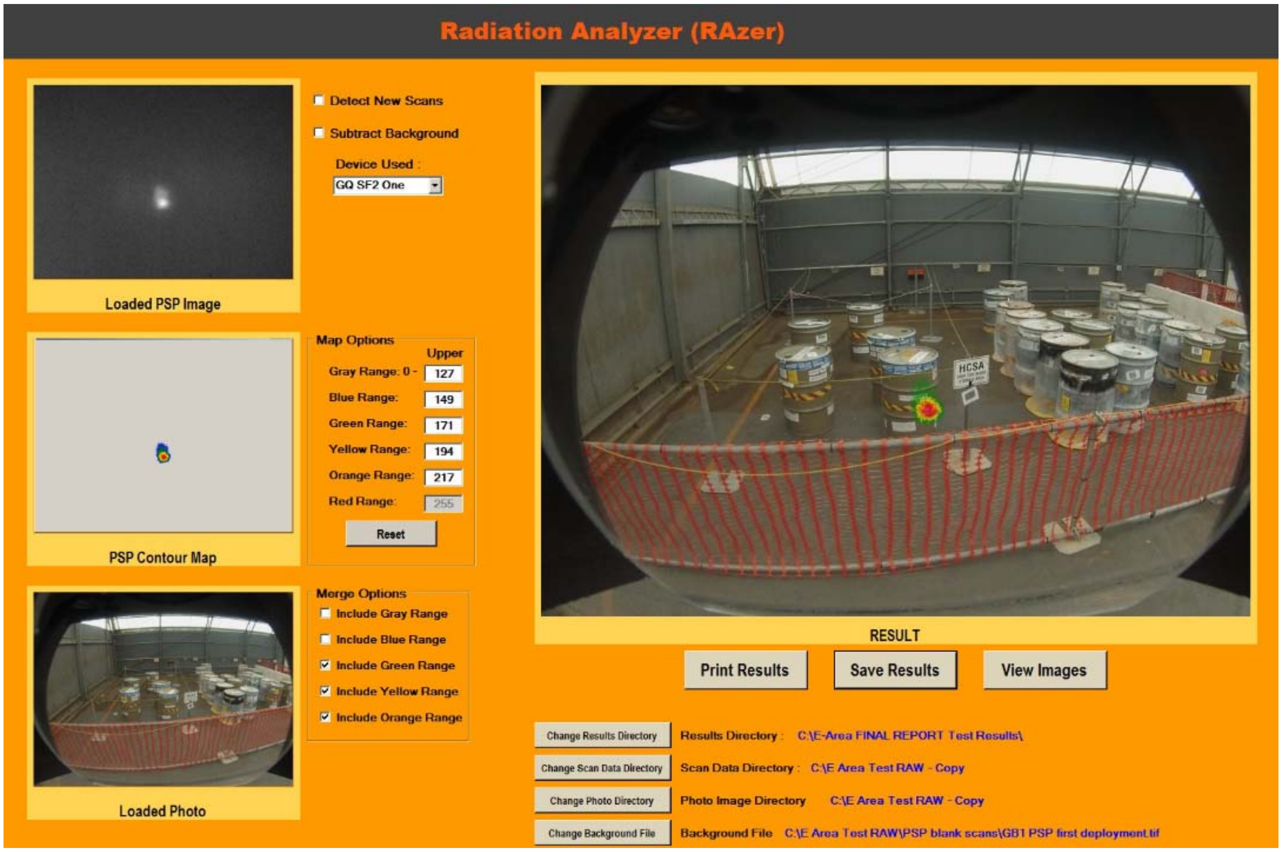


APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 8

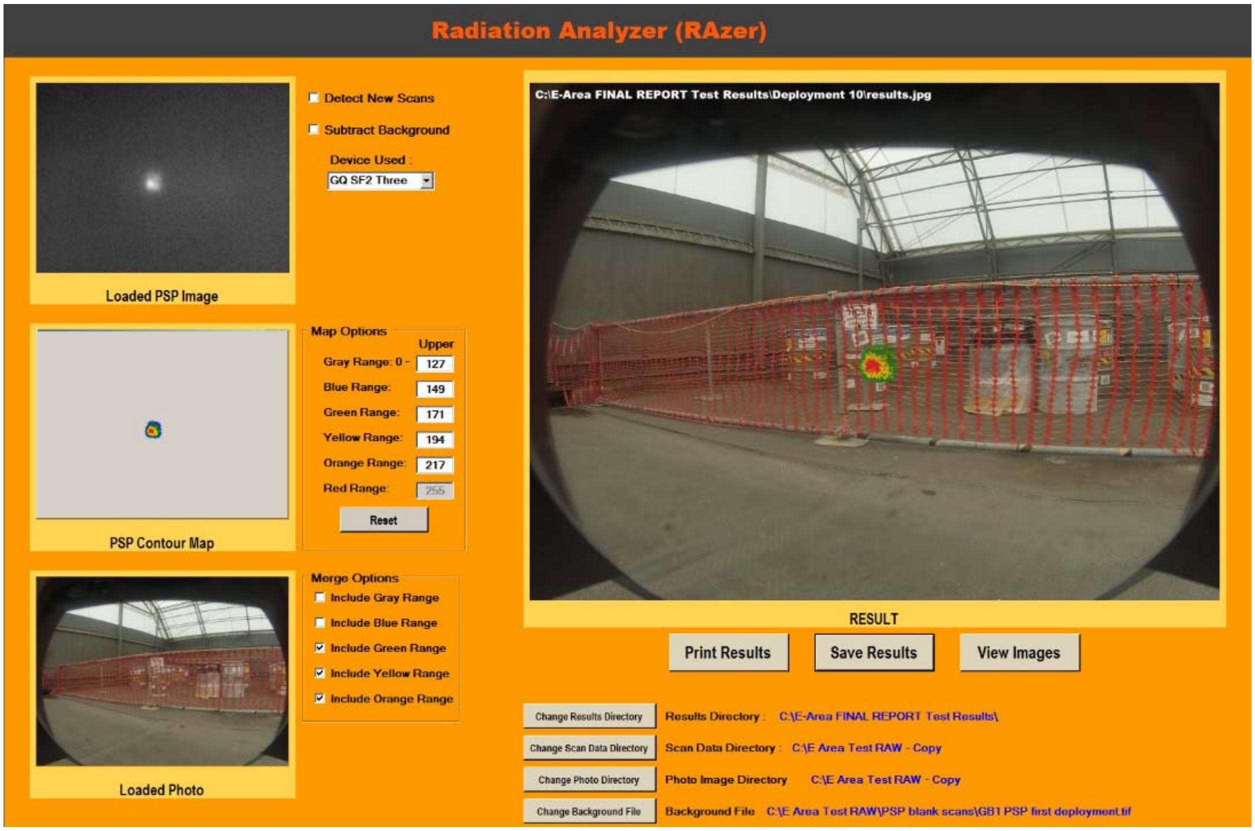
APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 9



APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 10



APPENDIX C - E-AREA RESULTS, Continued

DEPLOYMENT 11