

GrayQb Single-Faced Version 2 Open Environment Test – 16344

Jean Plummer *, David Immel *, John Bobbitt *, Mike Negron **

* Savannah River National Laboratory

** Savannah River Nuclear Solutions

ABSTRACT

The GrayQb™ 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™ (pronounced “Gray Cube”) is to provide a low cost easily deployable device to aid in the process of decontamination and decommissioning (D&D). The GrayQb™ SF2 device is approximately a six inch cube weighing seven (7) pounds composed of a tungsten shield with integrated collimator, radiation imaging medium (Phosphor Storage Plate), and digital camera.

This paper details the design upgrades incorporated into the new version of the GrayQb™ SF2 device and the characterization testing of this upgraded device. Device results from controlled testing performed at the Savannah River Site (SRS) Health Physics Instrument Calibration Laboratory (HPICL) are presented, as well as results from the open environment field testing performed in the E-Area Low Level Waste Storage Area. Follow on work performed deploying the GrayQb SF2 device at the Hanford Plutonium Reclamation Facility (PRF) to assist in the radiological characterization of the canyon will also be presented.

Testing of the redesigned 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 a significant high energy background. 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, would likely be able to detect these isotopes in the open environment field testing.

Follow on 2015 work performed at Hanford proved GrayQb to be a useful tool in the radiological characterization of the PRF canyon. Distribution tendencies of the radiological hot spots were identified that provided insights which will assist in more efficient planning of the continued D&D effort. Hot spots were identified which can be targeted during the future D&D effort and used as markers during the NDA assessment to quantify the radiological environment.

INTRODUCTION

Development of the GrayQb™ Single Faced Version 2 (SF2) radiation mapping device began from a need to identify radiation locations in support of decontamination and decommissioning efforts. The goal of the GrayQb™ (pronounced “Gray Cube”) device is to provide a low cost easily deployable device to aid in the process of D&D. Devices and technologies are presently available which provide radiation detection; subsets of these systems also provide mapping of detected source locations onto a photo. Advantages of the GrayQb™ SF2 device over these other devices include its relative low cost (<\$7k to manufacture), small size and no required wired connections when deployed. The low cost of GrayQb™ SF2 makes it feasible to deploy multiple devices at one time and to dispose of the device without significant financial loss should it become contaminated. The small size and low weight of the GrayQb™ SF2 device allow for deployments in areas not accessible by many other radiation detectors. Additionally, the GrayQb™ SF2 can be easily carried and deployed on a tabletop or tripod with optional internal shielding in place.

DESCRIPTION

The GrayQb™ Single Faced Version 2 (SF2) device is a six inch cube weighing seven (7) pounds composed of a tungsten shield with integrated collimator, radiation imaging medium (Phosphor Storage Plate), and digital camera, Figure 1. Presently, the device employs 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 1 - GrayQb™ Single Faced Version 2 (SF2)

Deployment of the GrayQb™ SF2 consists of placing the device facing the area to be examined for a prescribed length of time dependent on the expected dose (typically 3 to 24 hours) as shown in Figure 2. The device is then retrieved to remove the radiation sensitive PSP plate for scanning by an external digital scanner. The camera housed in the device is also retrieved to download the digital images from the area examined. PSP results and area photos are imported to a laptop where resultant overlay images are generated using the SRNL developed RAZer™ (Radiation Analyzer) software program, Figure 3. GrayQb™ images provide qualitative results in the form of relative radiological energy intensities observed, it does not provide quantitative measurements of radiation detection nor does it provide isotope identification.

Once the GrayQb™ SF2 is retrieved from the area under examination, processing of the images and obtaining a result takes only a few minutes.



Figure 2 - Deployment of four GrayQb™ devices facing area of interest



Figure 3 - GrayQb™ SF2 generated radiation map

GRAYQB™ SF2 UPGRADE

GrayQb™ SF2 is a next generation device resulting from physical and software enhancements incorporated into the GrayQb™ Single-Faced (SF) device developed by SRNL and tested in 2013, Figure 4 [1],[2]. The GrayQb™ SF2 upgrades included improvements to the device resulting in patent application [3], the deployment process, and the development of a user friendly software program to automate processing of results.

GrayQb™ Single Face (SF) Prototype



GrayQb™ SF Version 2 (SF2)



Figure 4 - Evolution from prototype to Single Face to SF2

Device Redesign

The GrayQb™ SF2 housing was extensively redesigned over the original GrayQb™ SF configuration. This was primarily driven by the desire to use optics to align camera and pinhole centers to coaxially align the camera and pinhole images to simplify the image overlay process, Figure 5. Additional considerations included accommodating a 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. This design provided an economical solution to secure components within the device yet maintained the ability to manufacture a low cost device using additive manufacturing (AM). The use of AM also enabled the housing to

be created as one piece eliminating device seams and preventing light penetration to the photosensitive PSP. The use of the polymer housing allowed the weight to be kept to a minimum for ease of deployment and enabled a complex housing design to be manufactured in a cost effective and timely manner.

Other device improvements included a simplified pinhole to collimate results, an added cavity within the housing which provides space for optional shielding of the imaging medium and movement of the PSP further from the tungsten shield to provide maximized-width higher resolution PSP images.

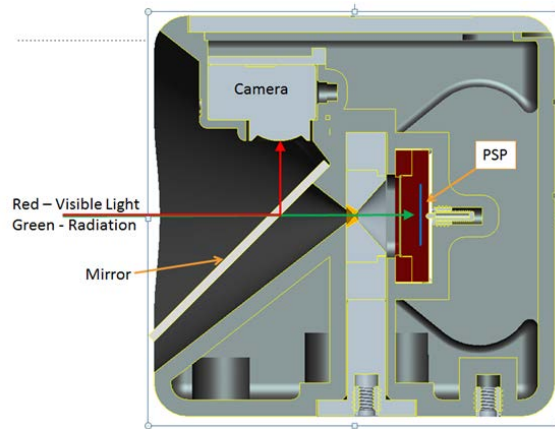


Figure 5 - GrayQb™ SF2 side view cutaway showing use of optics to align centers of PSP and digital images

Deployment Process Improvements

Deployment process upgrades included the development of the PSP pre-illumination device and the PSP cartridge holder. The PSP pre-illuminator erases and applies a uniform background to the PSP plates prior to deployment, Figure 6. The PSP holder provides ease of insertion and removal of the PSP into the pre-illuminator and the GrayQb SF2 device, Figure 7.

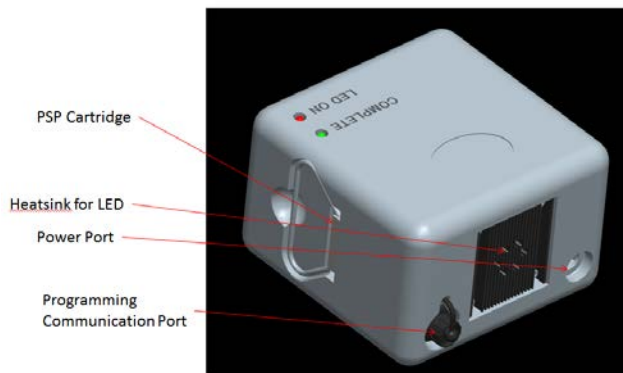


Figure 6 - PSP Pre-Illuminator



Figure 7 - PSP cartridge holder being inserted into GrayQb™ SF2

Analysis Software Program

The Radiation Analyzer™ (RAzer™) software program was created to import the raw data (PSP image and digital image), generate the radiation contour map from the PSP image and superimpose the result onto the digital image of the area examined.

TESTING 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 process for attaining images is as follows:

- Deploy GrayQb device for predetermined amount of time based on expected dose and energy level of expected isotopes.
- Retrieve GrayQb device
- Remove PSP from holder, scan and import scanned image to laptop via USB, Figure 8,
- Import camera images to laptop via USB
- Imported images are processed and overlaid using the RAzer™ program

Once the GrayQb™ SF2 is retrieved from the area under examination, processing of the images and obtaining a result takes only a few minutes.

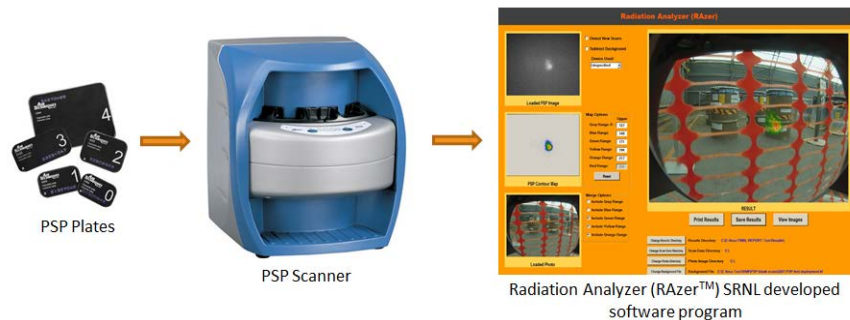


Figure 8 - PSP plate is scanned after deployment and imported to RAzer™ program on laptop for processing

The GrayQb suite of equipment includes the device, scanner, pre-illuminator and laptop. The suite is highly portable and can easily be set up at a test location to process results on-site, Figure 9.

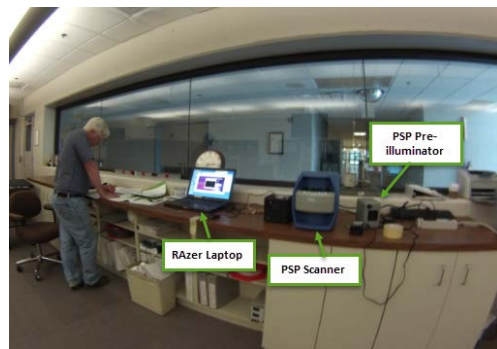


Figure 9 - GrayQb suite deployed at a test location

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 were manufactured in the R&D Rapid Prototyping Lab for the purposes of testing; these devices are abbreviated as GQ1 for GrayQb™ SF2 device one, GQ2 for GrayQb™ SF2 device two, and so forth. A summary of the device characterization is provided in Table I.

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°	Horizontal: 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

Table I - GrayQb Device Characterization

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.

Health Physics Instrument Calibration Lab (HPICL) Testing

Controlled isotopic testing of the device was conducted at the HPICL facility which offers a variety of isotopes and test apparatus for calibration and testing of radiological devices. Low energy isotope testing was conducted using an apparatus with seven Am-241 sources, Figure 10. 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.

Tests were conducted to determine minimum dose detection level, to validate the Razer™ software and to characterize the PSP response to higher energy sources. Exposure of the device to various dose levels, determined that the PSP could readily detect a level of about 0.2 mrad for a lower energy source (Am-241). Tests were performed at different distances and angles to validate alignment results; several images obtained from HPICL testing using the Razer™ software with default settings selected are shown in Figure 11.

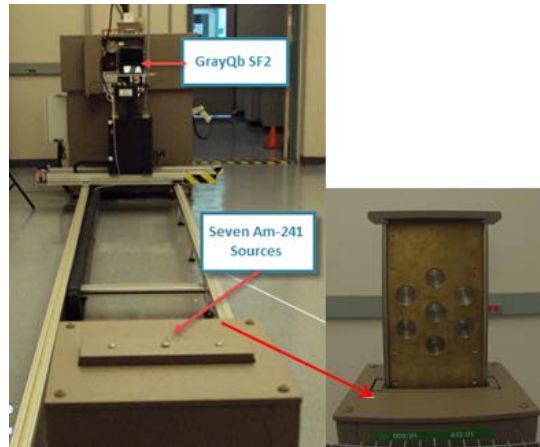


Figure 10 - Testing room with the seven Am-241 sources at HPICF

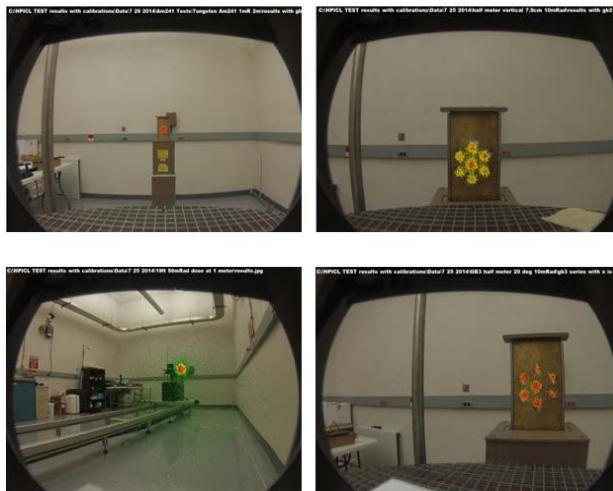


Figure 11 - Examples of HPICL results obtained using Razer™ program

Testing was performed using Cs-137 and Co-60 sources to determine the device response to higher energy isotopes. This was the first GrayQb™ testing performed using sources with energy levels greater than 150 KeV. HPICL testing with higher energy isotopes demonstrated that the GrayQb™ 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. HPICL test results with the Cs-137 source are shown in figure 12. 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.

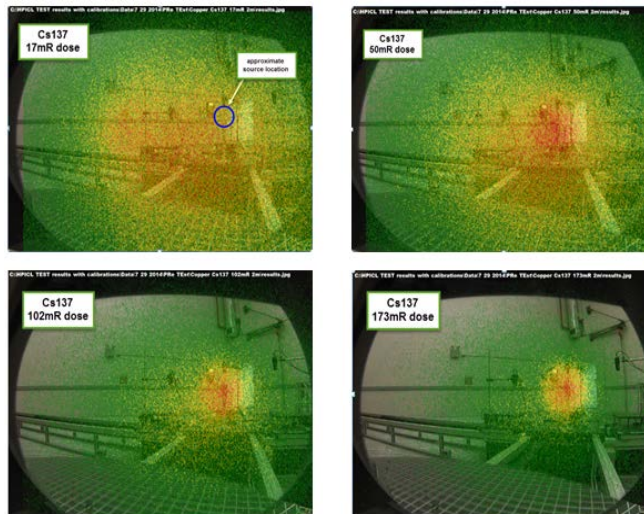


Figure 12 - Evolution of PSP resolution of Cs137 source as dose is increased during HPICL testing

Open Environment Field Testing

The Savannah River Site (SRS) Low Level Waste Storage Area was selected for open environment field testing of the GrayQb™ SF2 device. 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™ SF2 Testing was conducted at TRU Pad 17, Figure 14. TRU Pad 17 was chosen due to the higher potential of drums staged there to possess non uniform 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.



Figure 13 - E-Area Low Level Waste Storage Area and test location TRU Pad 17



Figure 14 - TRU Pad 17 E-Area test location with High Radiation Areas (HRAs)

Initial surveys were completed at the test location 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, Figure 15. The spectrum indicated isotopes of Am-241, Pb X-rays, Pa-233, and Cs-137 present, Figure 16.



Figure 15 - Falcon 5000 detector for radionuclide identification

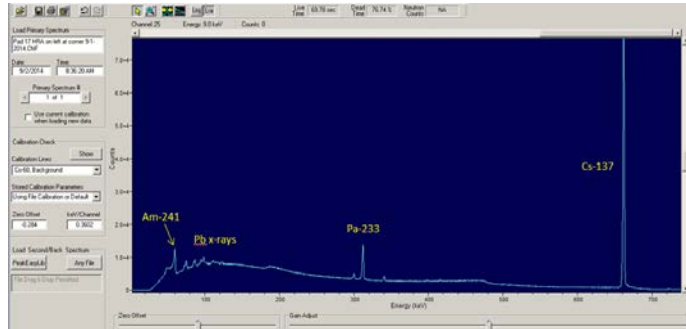


Figure 16 - Radionuclides identified by Falcon 5000 in test area

Test Configurations

The four GrayQb™ SF2 devices mounted on tripods were deployed at various distances, heights, time periods and shielding configurations. Tests 1 thru 10 were performed with the GrayQb™ 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™ SF2 internal shielding. Test 11 was performed with the device outside of this area. Test deployments 5 thru 8 are shown in Figure 17. Tests 3 and 7 were performed without internal shielding added to the device. The GrayQb™ SF2 housing cavity for all other tests were filled with steel shot to provide internal shielding to the sides and back of the PSP imaging medium in the device, Figure 19.



Figure 17 - E-Area deployment locations 5 - 8



Figure 18 - GrayQb SF2 with internal steel shot shielding (left) and w/o shielding (right)

A summary of the tests conducted during E-Area open environment testing is shown in Table II.

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*

Table II- E-Area test configurations

Analysis of Open Environment Results

The GrayQb™ SF2 for provided useful results in a short period of time. In Test 2, after a 60 minute deployment, results showed a potential area of higher intensity, Figure 19, which was later confirmed in Test 8, Figure 20, after an 88 minute deployment. Test 8 results 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.

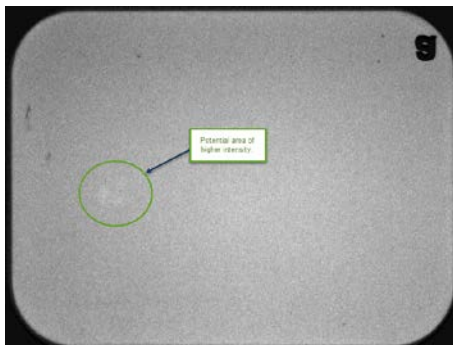


Figure 19 - 60 minute deployment the area of interest beginning to develop

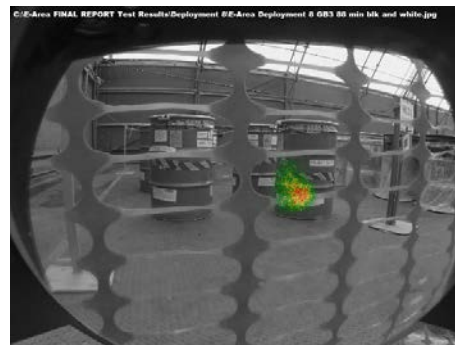


Figure 20 - Test 8 results

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.

Tests 9 and 10 demonstrated 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 21 - Test 9 and 10 results demonstrating usefulness of multiple views to triangulate source position in 3D area.

FOLLOW UP ACTIVITIES PERFORMED AT HANFORD

The Savannah River National Laboratory (SRNL) in partnership with CH2M Plateau Remediation Company (CHPRC) deployed the GrayQb™ SF2 radiation imaging device at the Hanford Plutonium Reclamation Facility (PRF) to assist in the radiological characterization of the canyon [4]. The deployment goal was to locate radiological contamination hot spots in the PRF canyon, where pencil tanks were removed and decontamination/debris removal operations are on-going, to support the CHPRC facility D&D effort.

The PRF canyon GrayQb™ deployment was performed using the overhead crane to position and hold the devices for the surface examinations. For the purposes of this deployment, a crane fixture was designed and fabricated at SRNL that held four devices enabling four examinations to be performed during each deployment, Figure 22. The fixture was deployed using the overhead crane, Figure 23.

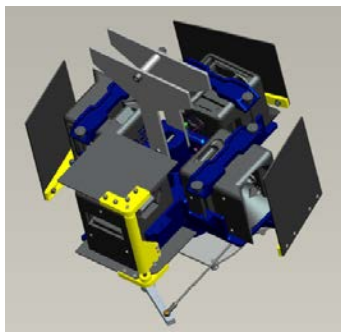


Figure 22 - GrayQb™ Crane Deployment Fixture



Figure 23 - Deployment fixture with four mounted GrayQb devices in PRF

The SRNL 3D Visualization System was employed to assist in determining the minimum number of deployments required to examine all surfaces of the canyon (walls, floor and ceiling) given the field of view (FOV) of the GrayQb™ device, Figure 24. By importing the PRF canyon drawings and the GrayQb™ device design files into the 3D system, the device FOV could be projected onto the canyon surfaces and moved about in the canyon to determine required placement for complete coverage. It was determined that all surfaces could be examined with ten deployments which provided 40 GrayQb™ examinations.

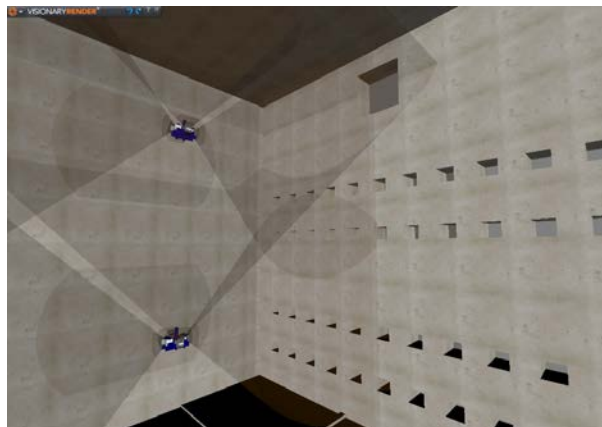


Figure 24 - 3D Visualization GrayQb™ cluster in PRF canyon with FOV shadowed on wall.

The PRF canyon GrayQb™ deployment was performed September 7 - 12, 2015. Ten deployments were completed as planned with each deployment consisting of a cluster of four GrayQb™ devices mounted on a crane platform fixture. The ten deployments resulted in forty evaluations completed; preliminary resultant images were provided to CHPRC at the test site.

Data collected examined over 80% of the canyon surfaces. Deployment 3 (D3) and deployment 4 (D4) were performed at essentially the same location which provided very useful information. First, the duplicate examination of the same location using two different GrayQb™ devices produced results that were almost identical, thus demonstrating the repeatability of the results, Figure 25. Secondly, the two data sets provided a validation for the application of the post processing methodologies used to adjust for deployment time and for the drop off in intensity sensitivity as the angle of exposure increases. D3 lasted 6.5 hours and D4 lasted 15 hours, after completing post processing adjustments for time the results demonstrated similar intensities demonstrating a successful time algorithm. After applying the hot spot algorithm to the post processed data, D3 and D4 identified the same hot spots.

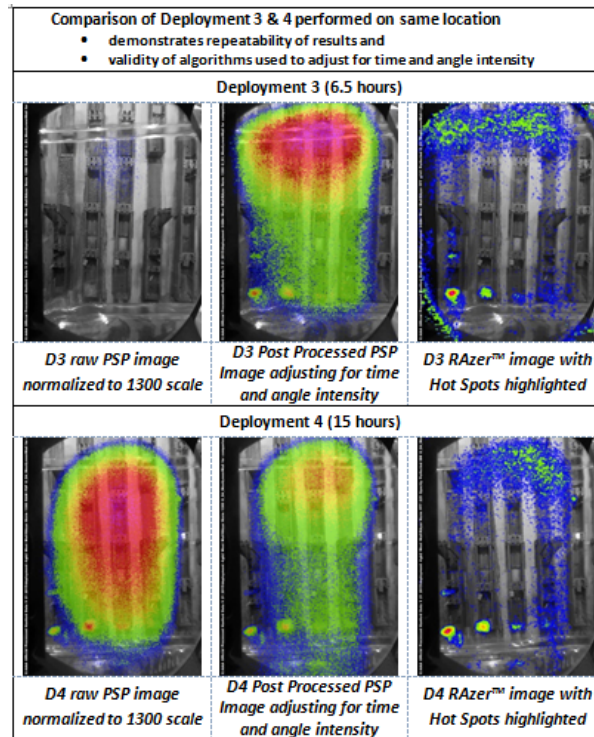


Figure 25 - Comparison of Deployments 3 and 4 analyzing the same location

Montage views were created for CHPRC of the floor, east and west walls. The canyon floor montage created by stitching together results from deployments 6 through 10 is shown in figure 26. The radiological intensity on the floor in the circled area was much higher than the floor to the right of it that hot spots appearing in deployment 8 (D8) did not appear in deployment 9 (D9). Although we can see hot spots all along the floor of the canyon, the "hot" areas to the right of the red square are much lower in intensity than the spot to the left of the square

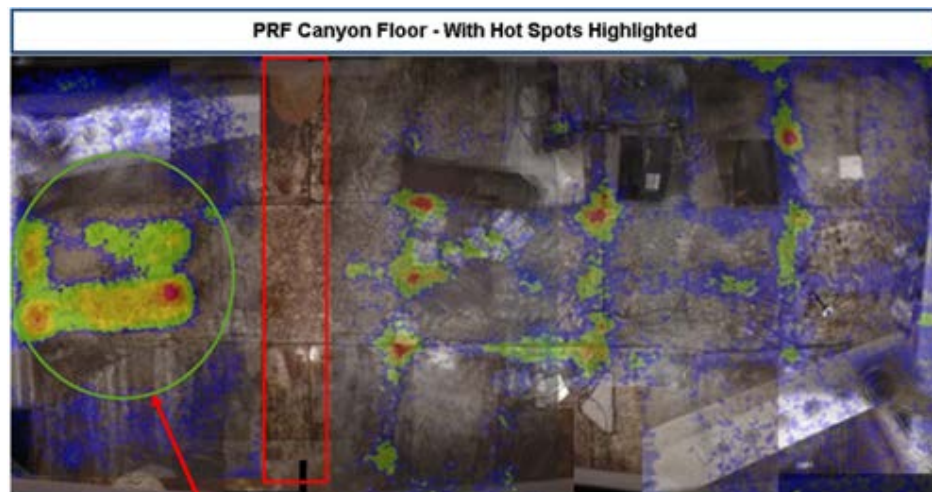


Figure 26 - Montage view of PRF canyon floor

CONCLUSION

In summary, 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

The GrayQb™ SF2 proved to be a useful tool in the radiological characterization of the PRF canyon. Distribution tendencies of the radiological conditions were identified that provided insights which will assist in more efficient planning of the continued D&D effort. Hot spots were identified which can be targeted during the future D&D effort and used as markers during the NDA assessment to quantify the radiological environment. Consideration should be made for a follow-up deployment to evaluate in-process decontamination efforts. Additionally, as hot areas originally identified by GrayQb™ are cleaned, new hot spots that were less intense than the original hot spots may present themselves; this allows for a drill down methodology, if needed, to reach the desired cleanup criteria.

REFERENCES

- [1] "Single-Faced GrayQb™ A Radiation Mapping Device," SRNL-STI-2013-00654, Dec. 2013.
- [2] "GrayQb™ Single-Faced Version 2 (SF2) Open Environment Test Plan, Rev 1" SRNL-TR-2014-00216, February 2015.
- [3] 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
- [4] "GrayQb™ Single-Faced Version 2 (SF2) Hanford Plutonium Reclamation Facility (PRF) Deployment Report" SRNL-STI-2015-00673, November 2015