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# Single-Faced GrayQb™

# A Radiation Mapping Device

*Testing at SRNL*

**E. B. Farfán, D. M. Immel, M. H. Phillips, J. T. Bobbitt and J. R. Plummer**

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# EXECUTIVE SUMMARY

GrayQb™ is a novel technology that has the potential to characterize radioactively contaminated areas such as hot cells, gloveboxes, small and large rooms, hallways, and waste tanks. The goal of GrayQb™ is to speed the process of decontaminating these areas, which reduces worker exposures and promotes ALARA considerations. The device employs Phosphorous Storage Plate (PSP) technology as its primary detector material. PSPs, commonly used for medical applications and non-destructive testing, can be read using a commercially available scanner. The goal of GrayQb™ technology is to locate, quantify, and identify the sources of contamination. The purpose of the work documented in this report was to better characterize the performance of GrayQb™in its ability to present overlay images of the PSP image and the associated visual image of the location being surveyed. The results presented in this report are overlay images identifying the location of hot spots in both controlled and field environments.

The GrayQb™ technology has been mainly tested in a controlled environment with known distances and source characteristics such as specific known radionuclides, dose rates, and strength. The original concept for the GrayQb™ device involved utilizing the six faces of a cube configuration and was designed to be positioned in the center of a contaminated area for 3D mapping. A smaller single-faced GrayQb™, dubbed GrayQb SF, was designed for the purpose of conducting the characterization testing documented in this report. This lighter 2D version is ideal for applications where entry ports are too small for a deployment of the original GrayQb™ version or where only a single surface is of interest. The shape, size, and weight of these two designs have been carefully modeled to account for most limitations encountered in hot cells, gloveboxes, and contaminated areas. GrayQb™ and GrayQb™ SF share the same fundamental detection system design (e.g., pinhole and PSPs). Therefore, performance tests completed on the single face GrayQB in this report is also applicable to the six- faced GrayQB (e.g., ambient light sensitivity and PSP response). This report details the characterization of the GrayQb™ SF in both an uncontrolled environment; specifically, the Savannah River Site (SRS) Plutonium Fuel Form Facility in Building 235-F (Metallurgical Building) and controlled testing at SRS's Health Physics Instrument Calibration Facility and SRS's R&D Engineering Imaging and Radiation Systems Building.

In this report, the resulting images from the Calibration Facility were obtained by overlaying the PSP and visual images manually using ImageJ. The resulting images from the Building 235-F tests presented in this report were produced using ImageJ and applying response trends developed from controlled testing results.

The GrayQb™ technology has been developed in two main stages at Savannah River National Laboratory (SRNL): 1) the GrayQb™ development was supported by SRNL's Laboratory Directed Research and Development Program and 2) the GrayQb™ SF development and its testing in Building 235-F were supported by the Office of Deactivation and Decommissioning and Facility Engineering (EM-13), U.S. Department of Energy – Office of Environmental Management.

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| | |
|---|---|
| DOE | U.S. Department of Energy |
| EM-13 | DOE Office of Environmental Management - Office of Deactivation and Decommissioning and Facility Engineering |
| GrayQb™ | Six-faced GrayQb™ |
| GrayQb™ SF | Single-faced GrayQb™ with a camera |
| HPICF | Health Physics Instrument Calibration Facility |
| ImageJ | Image Processing and Analysis in Java |
| PMT | Photomultiplier tube |
| PSP | Phosphor Storage Plate |
| PuFF | Plutonium Fuel Form Facility |
| SRNL | Savannah River National Laboratory |
| SRS | Savannah River Site |

**UNITS**

| | |
|---|---|
| A | Ampere |
| Ci | Curie (1 Ci = 3.7 x $10^{10}$ nuclear decays per second) |
| cm | centimeter (1 m = 100 cm) |
| Gray | Unit of absorbed dose (Gy = 1 J/kg) |
| h | Hour |
| m | meter |
| mrad | millirad (1 mrad = $10^{-3}$ rad) |
| rad | Unit of absorbed dose (1 Gy = 100 rad) |
| R | Roentgen , unit of exposure (R) |
| s | Second |
| V | Volts |
| µA | microA (1 µA = $10^{-6}$ A) |
| µCi | microCi (1 µCi = $10^{-6}$ Ci) |

## 1.0 Introduction

Nuclear facilities that perform cleanup operations need to determine the location and extent of radioactive contamination. Typically, portable hand-held rate-count instruments are used to determine radiation dose rate levels in the contaminated areas. These survey operations are time-consuming and expose personnel to unnecessary risk. Some areas may be too small, confined, or have limited entry for personnel to access. Existing portable instruments may be difficult to deploy in these areas.

SRNL has designed a device, GrayQb™, to generate a map of radioactive contamination within an enclosed area. GrayQb™ is a device with six radiation detection faces [1-4]. The GrayQb™ concept is to use multiple layers of Phosphor Storage Plates (PSP) to identify the relative intensities of radiation and to assist with radionuclide identification within a contaminated area. The PSPs are highly radiosensitive and ideal for mapping in low dose-rate environments. The PSPs used in GrayQb™ are commonly used for imaging purposes where the radiation source and dose rate are known [5-16]. PSP common uses are medical imaging and nondestructive testing. The PSP technology was developed with the goal of "minimal dose" in mind, particularly with respect to reducing patient doses from medical imaging, and hence, have the requisite sensitivity for detecting low-dose contamination areas.

A new smaller version of GrayQb™ was developed for the purposes of conducting characterization of GrayQb™ performance. This new version includes only a single face instead of six faces as is the case for the original GrayQb™ device. This single-faced GrayQb™, known as GrayQb™ SF (Figure 1), is ideal for applications where entry ports are too small for a deployment of the original GrayQb™ version or where only a single surface is to be scanned. GrayQb™ SF weighs about 3.6 kg (8 lbs) including a camera. The addition of a camera offers the capability to provide a superimposed radiographic mapping image and the visible image of the field-of-view. Four fully-functional GrayQb™ SF devices were developed and tested (Units 2 through 5). Unit 1, the first GrayQb™ SF prototype, was not used for testing the GrayQb™ technology since Units 2 through 5 were improved versions of Unit 1.


**Figure 1. GrayQb™ SF.**

One of the main goals of this effort was to test the GrayQb™ technology in an uncontrolled environment such as the Plutonium Fuel Form Facility in Building 235-F (Metallurgical Building) at the Savannah River Site (SRS) [2, 17], where a number of parameters remained unknown (e.g., exact locations of radiological contamination). The Building 235-F was constructed in the 1950s as part of the original SRS and has been used for a variety of nuclear materials process missions since that time. The building's most recent mission provided for the receipt, storage (within the vaults), and disbursement of plutonium bearing materials in support of the SRS and the Department of Energy (DOE) missions. In 2006, the vaults were de-inventoried and the facility was transitioned to a reduced surveillance and maintenance state. Currently, the reduced surveillance and maintenance state is primarily focused on the operation and maintenance of systems for monitoring and containing the residual radiological materials deposited within the process areas.

## 2.0 GrayQb™ SF Testing Protocol

The GrayQb™ SF testing protocol [18-20] involved four main tasks as follows:

1) Testing at the SRS R&D Engineering Imaging and Radiation Systems Building 781-A,
2) Pre-testing at the SRS Health Physics Instrument Calibration Facility (HPICF),
3) Deployment in the Building 235-F, and
4) Post-testing at HPICF.

The work planned to be completed at 781-A involved the development and preliminary testing of GrayQb™ SF using an x-ray generator [17]. The pre-testing at HPICF involved controlled radiation exposures of the GrayQb™ SF devices using known sources to ensure the proper functionality of the GrayQb™ SF devices prior to conducting tests at 235-F. The testing at HPICF was to involve seven americium-241 sources. The radionuclide of most interest at 235-F is plutonium-238. Americium-241 and plutonium-238 are both alpha emitters, which also emit relatively low-energy photons. Previous tests of GrayQb™ involved cesium-137 and cobalt-60 sources at HPICF, which provided confidence that the proposed technology would work for mapping of contaminated areas. These previous tests also included americium-241 sources and provided assurance that the GrayQb™ technology would be useful for mapping areas contaminated with low-energy photon emitters such as plutonium and uranium isotopes. Since the expected dose rates where the deployments were to take place in Building 235-F have been reported to be relatively low (e.g., 0.02 mrad/h at 120 cm from the hot spot in the Control Area and 22 mrad/hr at 30 cm from the hot spot in the East Maintenance Bay Area), post-testing was also scheduled at HPICF to confirm the proper functionality of the GrayQb™ SF devices should no results be obtained due to the low expected dose from the testing at 235-F. In addition, the pre- and post-testing at HPICF were to be completed to also verify select GrayQb™ SF performance characteristics determined at 781-A (e.g., linear response and minimum detection limit).

## 3.0 Materials and Methods

### 3.1 <u>Testing and Development at SRS R&D Engineering Imaging and Radiation Systems Building 781-A</u>

Initial testing and development of the GrayQb™ SF device was performed at SRS Building 781-A. Several modifications were made during characterization arising from the requirements of the 235-F deployment and initial test results. Since plutonium-238 emits low-energy photons and the dose rates in the deployed areas in Building 235-F were relatively low, a simple pinhole adapter was used and a shutter system was not included in the GrayQb™ SF design. A foam insert versus tungsten shielding was used to better hold the PSP in place; this was feasible because no source was expected from behind the unit. Additionally, a 3.0 mm piece of foam was inserted between the PSP plate and the pinhole, which moved the PSP away from a metal seam on the device which allowed light in and to ascertain if more sensitivity and resolution could be obtained with the PSP plate further away from the pinhole. The last modification was the inclusion of a camera to obtain overlay images of the contamination and contaminated area. Several tests were performed at SRS Building 781-A using an x-ray generator. Some of these tests verified the results from previous PSP tests and others involved the testing of the new GrayQb™ SF version.

3.1.1 *Ambient Light Sensitivity*

A test to determine the ambient light effect on PSPs was conducted. Four PSPs were exposed to an x-ray generator for 15 seconds at 120 kV and 360 μA. The distance between the x-ray source and the PSPs was 93.1 cm. The two light images shown in Figure 2 were exposed to low-level ambient light after the x-ray exposure (the numbers are the PSP serial numbers). The two dark images in Figure 2 were not exposed to ambient light. This test indicated that PSPs are light sensitive and must be kept in the dark after a radiation exposure; otherwise, the image on the PSPs will rapidly degrade as shown by the two light images in Figure 2.

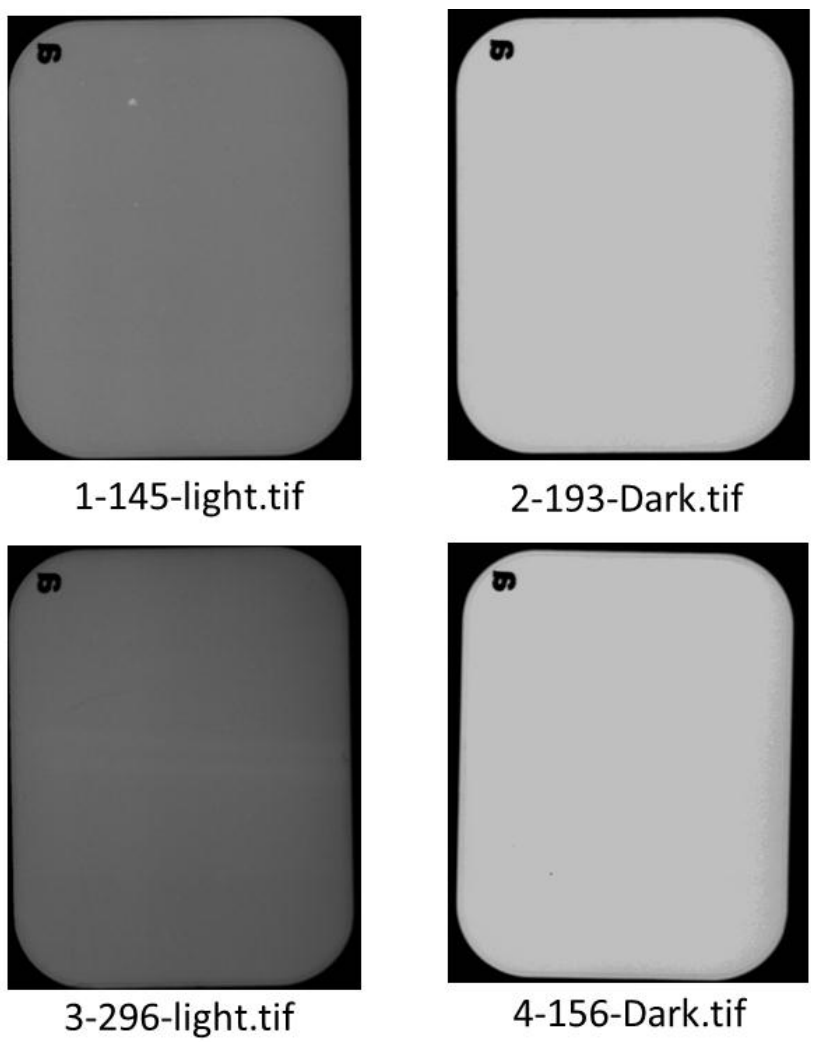


**Figure 2. PSP light sensitivity test.**

3.1.2 *ScanX Discover Settings*

The ScanX Discover manufacturer has suggested the following settings: PMT value of 1,200 V and a threshold of 600 V based on the equation: Threshold = 0.5 * PMT. However, the use of that PMT value seems to be too high (i.e., because the resulting images were too dark); consequently, the ScanX Discover "Intraoral Standard" settings were used for GrayQb™ tests (Figure 3).

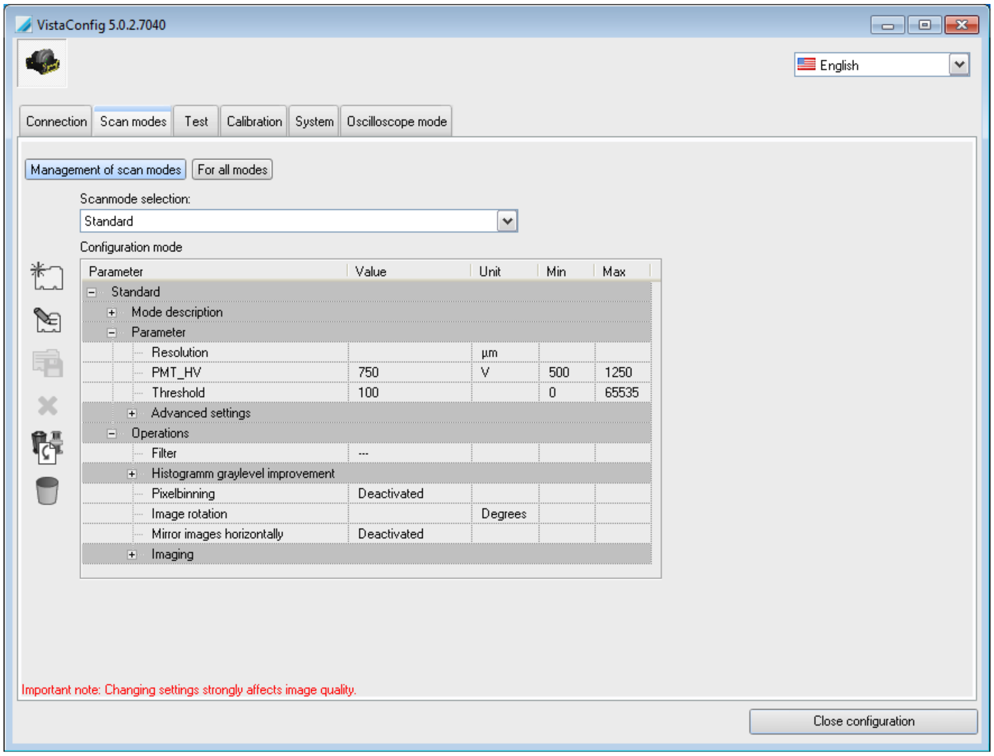


**Figure 3. ScanX Discover settings.**

3.1.3 *Phosphor Storage Plate Response*

Tests were conducted to determine the response of the PSPs to radiation. Four PSPs were exposed to an x-ray generator for each of the time periods indicated in Table 1. Through this testing, it was determined that a linear relationship between the gray levels of the exposed images and x-ray generator current exists; this relationship is further consistent with the PSP response to radiation that has been reported in the literature [5-16]. Consequently, it was concluded that PSPs have a linear response to radiation exposure for the range of radiation exposure tested.

**Table 1. Parameters for PSP response determination.**

| Exposure Time (s) | X-ray generator current (µA) |
|---|---|
| 3.75 | 75 |
| 7.50 | 75 |
| 7.00 | 10 |
| 11.3 | 25 |
| 15.0 | 75 |
| 30.0 | 75 |

### 3.1.4 *Spatial Resolution*

The spatial resolution is the angle necessary to distinguish two sources as separate sources. The spatial resolution tests included x-ray exposures of PSP through a 1-mm pinhole at 0 °, 0.50 °, 1.0 °, 2.0 °, 4.0 °,

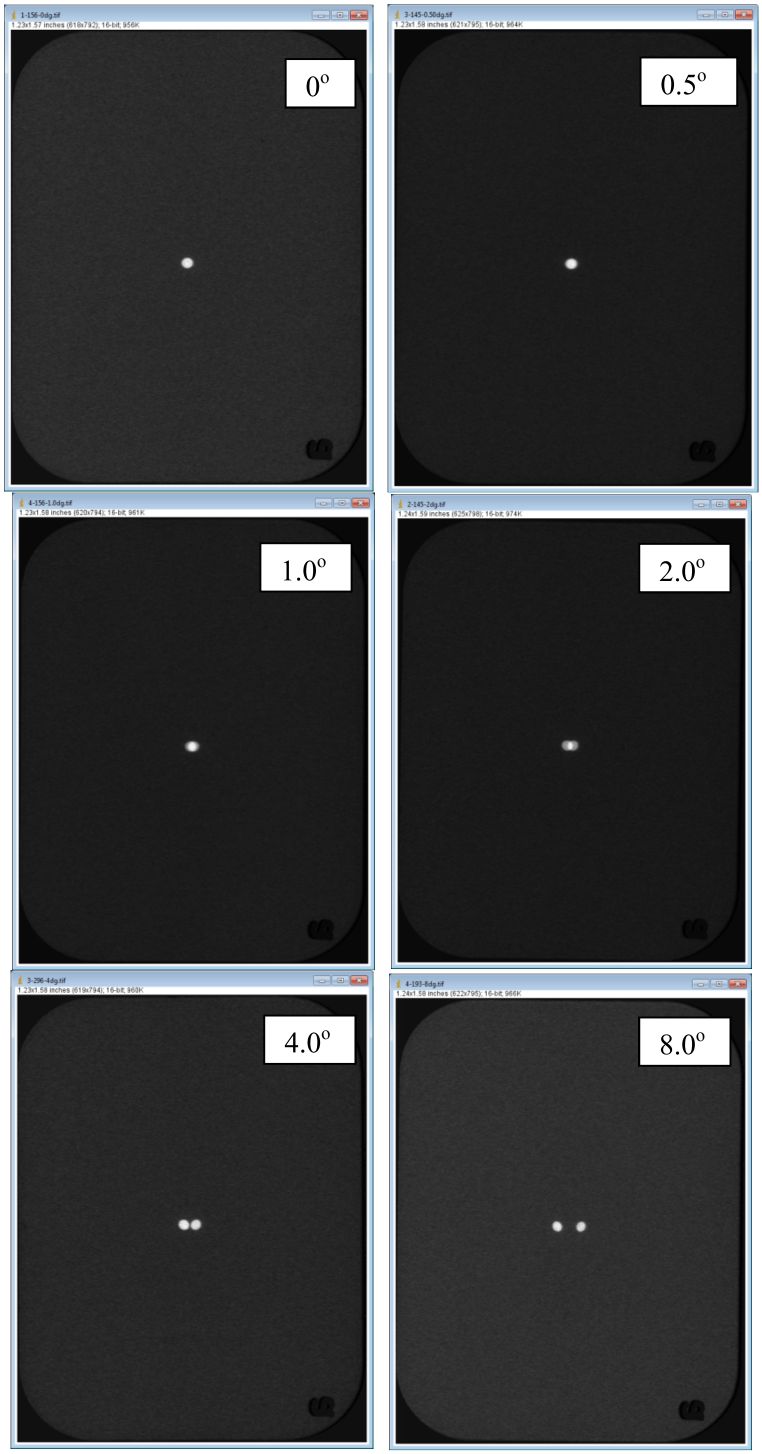


**Figure 4. Spatial resolution determination.**

and 8.0 °, using the following constant exposure parameters: 21 s, 10 µA, and 78.2 cm away from the PSPs. The results are shown in Figure 4 and indicate that the resolution is 1°. An enlarged image of the PSP exposure at 1° is shown in Figure 5. Some overlap of the two sources does exist in the image at 1° (i.e., the brighter area seen in Figure 5); however, the image still shows the existence of two sources.

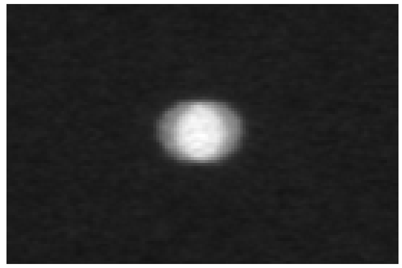

**Figure 5. Spatial resolution of 1°.**

3.1.5 *Spot Check*

Tests were conducted to determine the effects of the x-ray generator spot size on the PSP image. It was determined the x-ray beam diameter (~µm) was smaller than the pinhole size (~ mm), which meant that the x-ray generator could be run without affecting the dose rate. If the x-ray beam diameter were larger than the pinhole size, then only a fraction of the overall dose would be adsorbed by the PSP. The x-ray exposure scenarios are listed in Table 2. The SuA values are essentially the same for different x-ray tube currents (µA). The spot locations and areas of the spots and PSPs (Table 3) are consistent for the same exposures (SuA values in Table 2), but with different tube currents (µA).

**Table 2. X-ray exposure for spot check.**

| Spot | KV | µA | Dial | Seconds | SuA | File |
|---|---|---|---|---|---|---|
| 1 | 120 | 130 | 1 | 2.00 | 260.0 | 1-156-260SuA-Spot1 |
| 2 | 120 | 80 | 2 | 3.25 | 260.0 | 2-145-260SuA-Spot2 |
| 3 | 120 | 73 | 9 | 3.60 | 262.8 | 3-296-263SuA-Spot3 |
| 4 | 120 | 37 | 9 | 7.00 | 259.0 | 4-193-263SuA-Spot4 |

**Table 3. PSP and spot areas, mean, and location.**

| | Area (in) | Mean | X | Y | XM | YM | Perimeter |
|---|---|---|---|---|---|---|---|
| 1-PSP | 1.83720 | 533.3211 | 0.61241 | 0.78774 | 0.60346 | 0.79034 | 5.46657 |
| 1-spot | 0.00119 | 2798.848 | 0.61395 | 0.81008 | 0.61398 | 0.81007 | 0.12760 |
| 2- PSP | 1.83797 | 519.9232 | 0.60879 | 0.78921 | 0.60096 | 0.78932 | 5.57032 |
| 2-spot | 0.00119 | 2895.890 | 0.61091 | 0.81133 | 0.61098 | 0.81141 | 0.12760 |
| 3- PSP | 1.83572 | 500.9473 | 0.61246 | 0.79060 | 0.60494 | 0.78821 | 5.65336 |
| 3-spot | 0.00118 | 2882.007 | 0.61587 | 0.81441 | 0.61595 | 0.81435 | 0.12760 |
| 4- PSP | 1.83595 | 482.0718 | 0.60703 | 0.78770 | 0.60071 | 0.79037 | 5.50561 |
| 4-spot | 0.00117 | 2717.336 | 0.60963 | 0.80973 | 0.60971 | 0.80986 | 0.12479 |

3.1.6 *Determination of dose rate and x-ray tube current relationship*

Tests were conducted to determine the relationship between dose rate (mrad/s) and x-ray tube current (μA). A radiation meter (Eberline Model RO-20) located 1 m from the x-ray generators was exposed to the x-ray beam at 120 kV with a 0.163 cm brass filter to discard low-energy photons. Using a mirror and camera connected to a laptop, the readings from the radiation meter were recorded using the laptop located outside the x-ray generator booth (Figures 6 and 7).

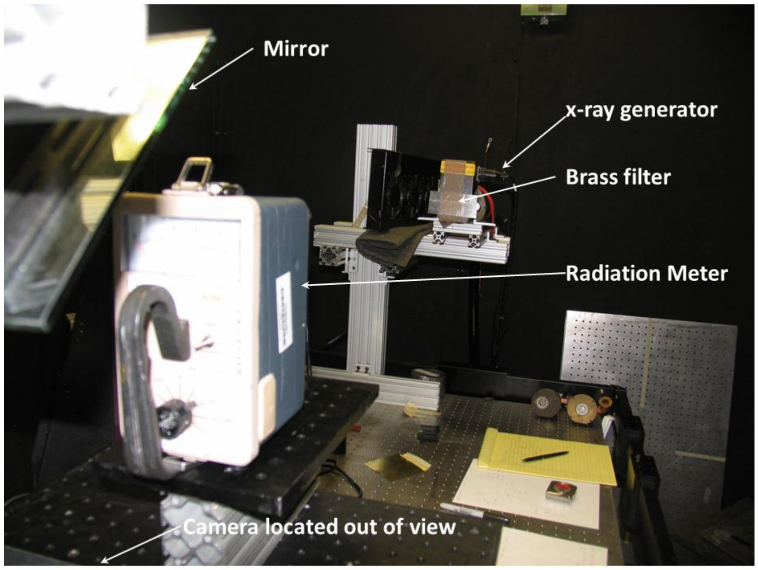


**Figure 6. Test setting for the determination of dose rate (mrad/h) and x-ray tube current (μA).**

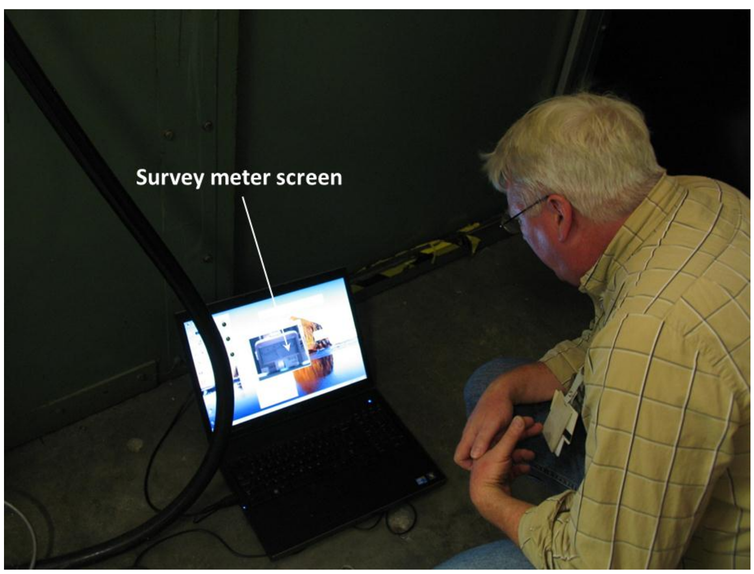


**Figure 7. Recording dose rates (mrad/h) outside of the x-ray booth (Dr. David Immel).**

To verify the results from the Eberline Model RO-20, a Bicron Model MicroRem LE (for low energy) radiation meter was setup the same way as the Eberline Model RO-20 meter. Only the first seven data points obtained by the Eberline Model RO-20 meter were verified because of the restriction to the highest scale on the Bicron Model MicroRem LE (x1000) meter. The Bicron Model MicroRem LE meter units are µrem/h (a rad is about an R for gamma rays and x-rays). Therefore, the highest scale on the Bicron Model MicroRem LE meter is 200 mrad/h. The first scale used on the Eberline Model RO-20 meter was the 500 mrad/h scale. The slope of the Eberline Model RO-20 meter is 97% of the Bicron Model MicroRem LE meter, which is well within the variability of the setup; thus, these instruments read equivalently. The modeled dose rates as calculated using the Monte Carlo N Particle Transport Code [21] resulted in a positive linear response similar to the measured values, although with a different slope (Figure 8).

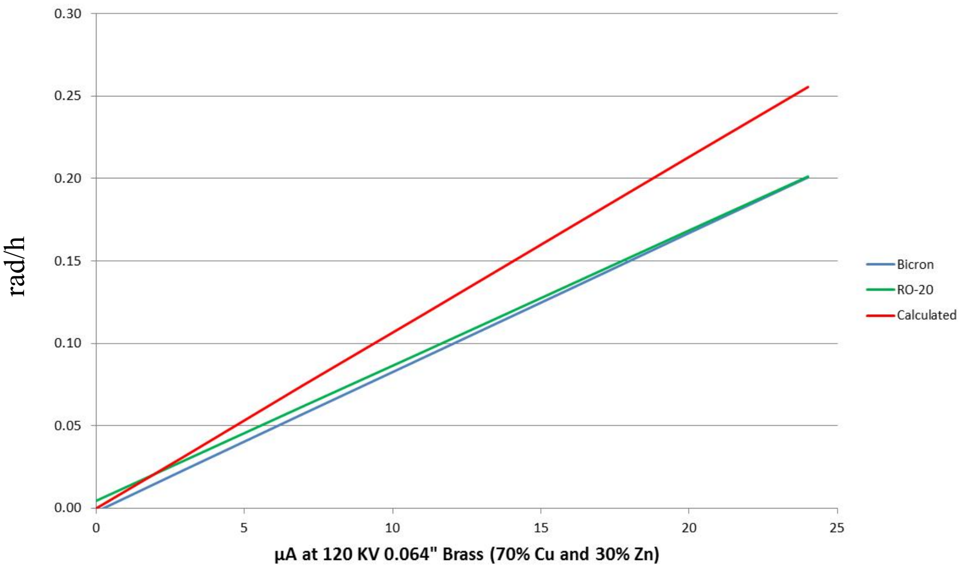


**Figure 8. Relationship between dose rate (rad/h) and x-ray tube current (µA).**

### 3.1.7 *Pixel Size*

Since both the resolution and quality of digital images are related to pixel size, tests were conducted to determine the GrayQb™ SF pixel size. It was concluded that the pixel size is determined by the pinhole size of the device, which is 0.64 mm for the GrayQb™ SF.

### 3.1.8 *Field of View*

The GrayQb™ SF field of view is 72°. The pinhole size for GrayQb™ SF was determined by the tool used to make the hole shown in Figure 9.

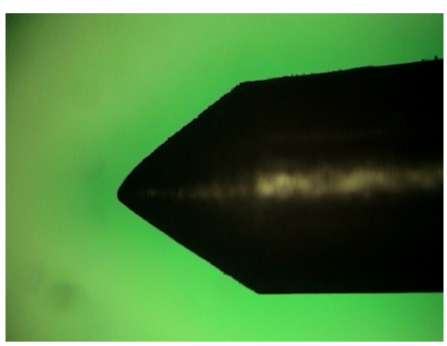

**Figure 9. Profile of the tool used to make the GrayQb™ SF pinhole (the measure cone angle is 72°).**

The GrayQb™ SF pinhole was tested using an x-ray generator (200 µA-s exposures) by horizontally rotating the PSP from -30° to +30° with 4° steps and vertically from 0° to 8° with 2° steps (Figure 10). The four corners received double exposures.

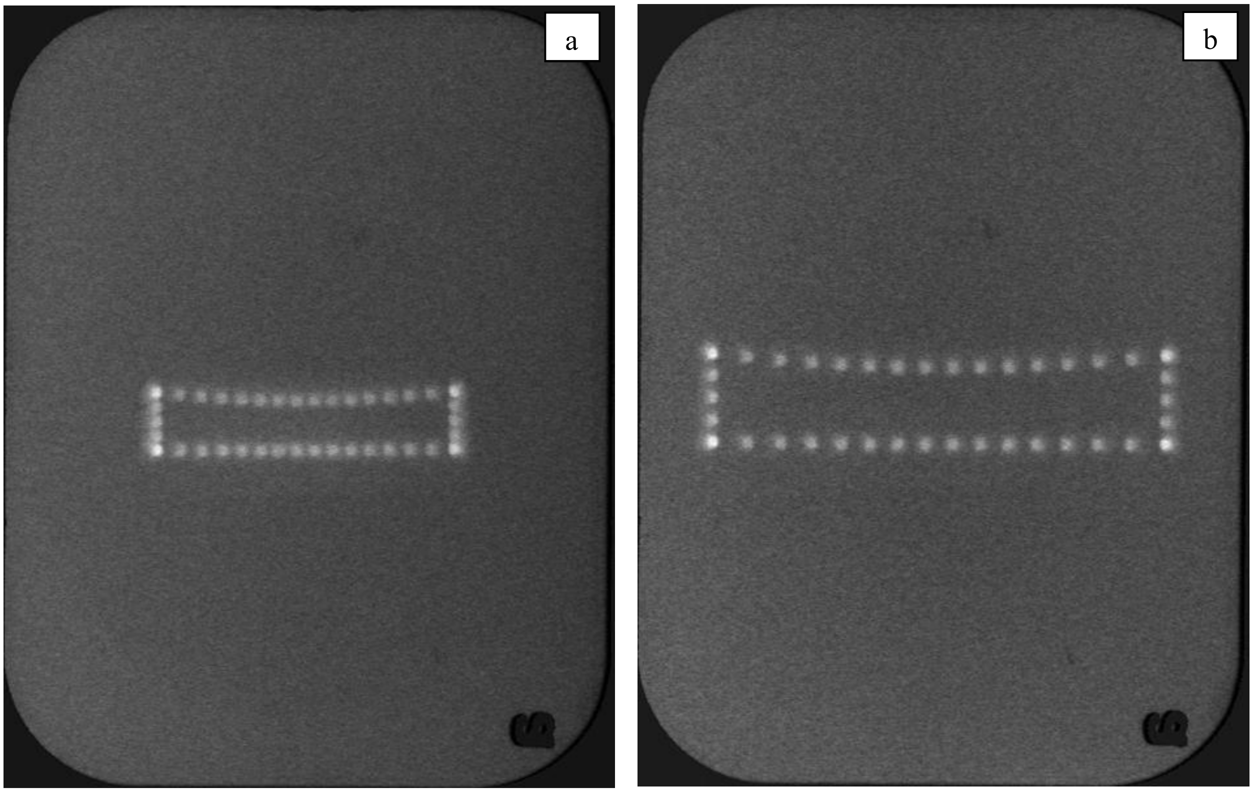


**Figure 10. GrayQb™ SF pinhole test. a) Pinhole located 3.3 mm from PSP.**

**b) Pinhole located 6.3 mm from PSP**

3.1.9 *GrayQb™ Detection Sensitivity Determination*

The sensitivity tests involved background exposures of 200 SuA (20 µA at 10 s). Each of four PSPs in a GrayQb™ face was individually exposed for 2, 4, 8, and 16 s. This step was repeated twice using different PSPs for each exposure. Next, the same step exposures (2, 4, 8, and 16 s) were completed for 2000SuA (20 µA at 100 s). From Figure 8, 20 µA is equivalent to 0.043 mrad/s; therefore, the equivalent absorbed doses (mrad) are listed in Table 4. The detection sensitivity is 0.17 mrad as shown in Figure 11. This remarkable sensitivity makes the GrayQb™ technology feasible for mapping of contaminated areas with low dose rates. This sensitivity and the values of other parameters were verified at HPICF.

**Table 4. Time vs. exposure based on Figure 27.**

| Time (s) | Absorbed Dose (mrad) |
|---|---|
| 2 | 0.086 |
| 4 | 0.172 |
| 8 | 0.344 |
| 16 | 0.688 |

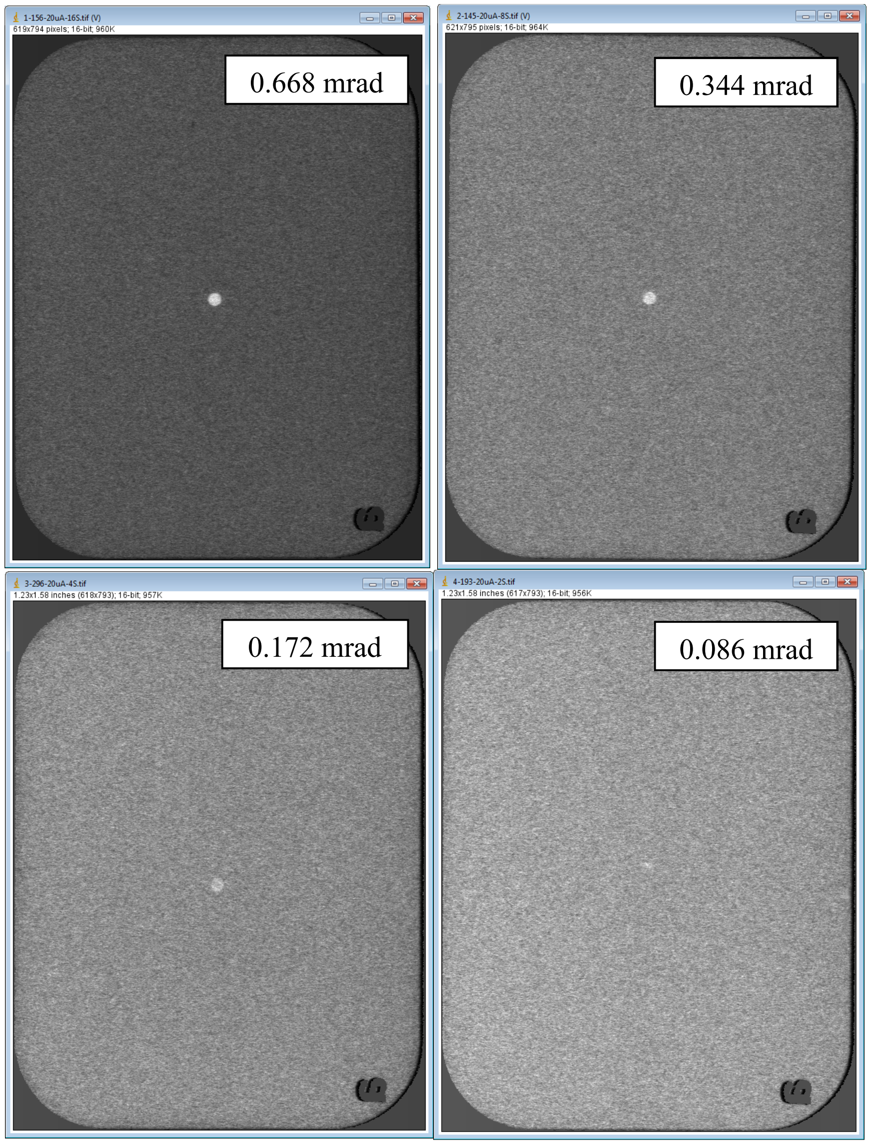


**Figure 11. GrayQb$^{TM}$ sensitivity analysis.**

### 3.1.10 *GrayQb$^{TM}$ SF Camera Testing*

GrayQb$^{TM}$ SF uses a GoPro HERO3 camera with built-in Wi-Fi and remote capabilities (Figures 12-14). Up to 50 GoPro HERO3 cameras can be controlled with a smart phone or tablet from distances up to 180 m using the Wi-Fi remote and GoPro App. The GoPro HERO3 camera can be charged using a USB cable and a computer. Four tests were completed to verify the performance of this camera. Test 1 involved taking 225 pictures (a picture every 60 s). The camera battery lasted for 3.75 h and the amount of SD card space required was 0.51 GB. Test 2 involved the same parameters as those of Test 1 with the same results. Test 3 included taking 11,626 pictures (a picture every 0.5 s). This test lasted for 1.38 h and stopped because the battery was dead. Test 4 involved taking a continuous video for 1.15 h. The video was saved in four folders and stopped because the 8 GB SD card was full. A few more tests were completed to determine the camera battery charging time, which was consistently about two hours.

During a GrayQb$^{TM}$ SF deployment into a contaminated area, the device is bagged to protect it from becoming contaminated. A transparent cover was designed to protect the camera lens from contamination as shown in Figure 12 b.


**Figure 12. a) GoPro HERO3 camera (http://gopro.com/). b) Lens cover.**

**Figure 13. Side view of GrayQb$^{TM}$ SF with a GoPro HERO3 camera.**

**Figure 14. Front view of GrayQb$^{TM}$ SF with a GoPro HERO3 camera and tungsten collimator.**

3.2 Pre-Testing at HPICF

In preparation for the testing at Building 235-F, six tests were completed at HPICF (Table 5). These tests also helped to validate the initial results obtained in SRS Building 781-A using an x-ray generator and to further characterize the performance of the GrayQb$^{TM}$ technology. GrayQb$^{TM}$ SF Units 2, 3, and 5 were used to complete the testing, which involved GrayQb$^{TM}$ SF exposures to seven 1-Ci americium-241 sources illustrated in Figures 15-16. Only Units 2 and 3 had GoPro HERO3 cameras. When facing the americium-241 sources, Units 3 and 5 was on the right and left sides of Unit 2, respectively (Figure 17).

**Table 5. Pre-test at HPICF.**

| Test | Dose Rate (mrad/h) | Time (s) | Distance (cm) | Total Dose (mrad) | GrayQb SF positions |
|---|---|---|---|---|---|
| 1 | 267.3 | 673.3 | 43.3 | 50.00 | Left: Unit 5, Center: Unit 2, Right: Unit 3 |
| 2 | 49.77 | 673.3 | 99.6 | 9.232 | Left: Unit 5, Center: Unit 2, Right: Unit 3 |
| 3 | 12.12 | 673.3 | 200.0 | 2.268 | Left: Unit 5 at 30° on its side, Center: Unit 2 at 0°, Right: Unit 3 at 30° |
| 4 | 1.448 | 3600 | 599.6 | 1.448 | Left: Unit 5 at 30° on its side, Center: Unit 2 at 0°, Right: Unit 3 at 30° |
| 5 | 5.399 | 333.4 | 300.0 | 0.500 | Left: Unit 5 at 30° on its side, Center: Unit 2 at 0°, Right: Unit 3 at 30° |
| 6 | 5.399 | 166.7 | 300.0 | 0.250 | Left: Unit 5 at 30° on its side, Center: Unit 2 at 0°, Right: Unit 3 at 30° |

The six tests summarized in Table 5 involved distances from 43.3 to 599.6 cm between the GrayQb™ SF units and the seven americium-241 sources. The total doses varied from 0.25 to 50.0 mrad. The three GrayQb™ SF units were placed side by side. Tests 1 and 2 involved Units 2, 3, 5 exposed side by side (Figure 17). Test 3 through 6 involved exposures of Units 2 and 5 while Unit 3 was at about 30° on its side (Figure 18). Unit 2 was facing the exact center of the seven sources as shown by the red laser light in Figure 18. For taking the photograph used for this figure, the camera was not set in place in Unit 2; however, it was set in its place in Unit 2 before the actual testing occurred.

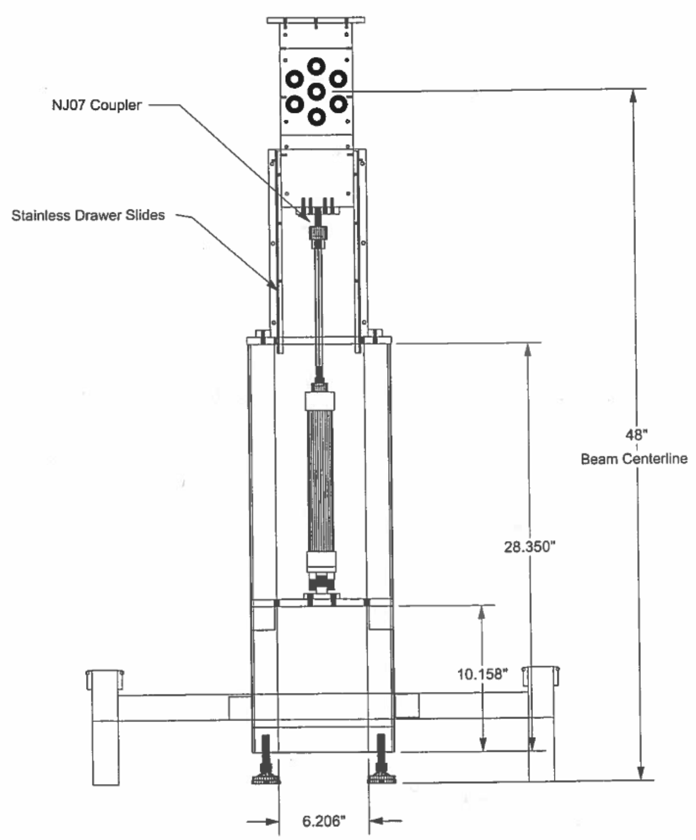


**Figure 15. Diagram of the seven $^{241}$Am sources at HPICF.**

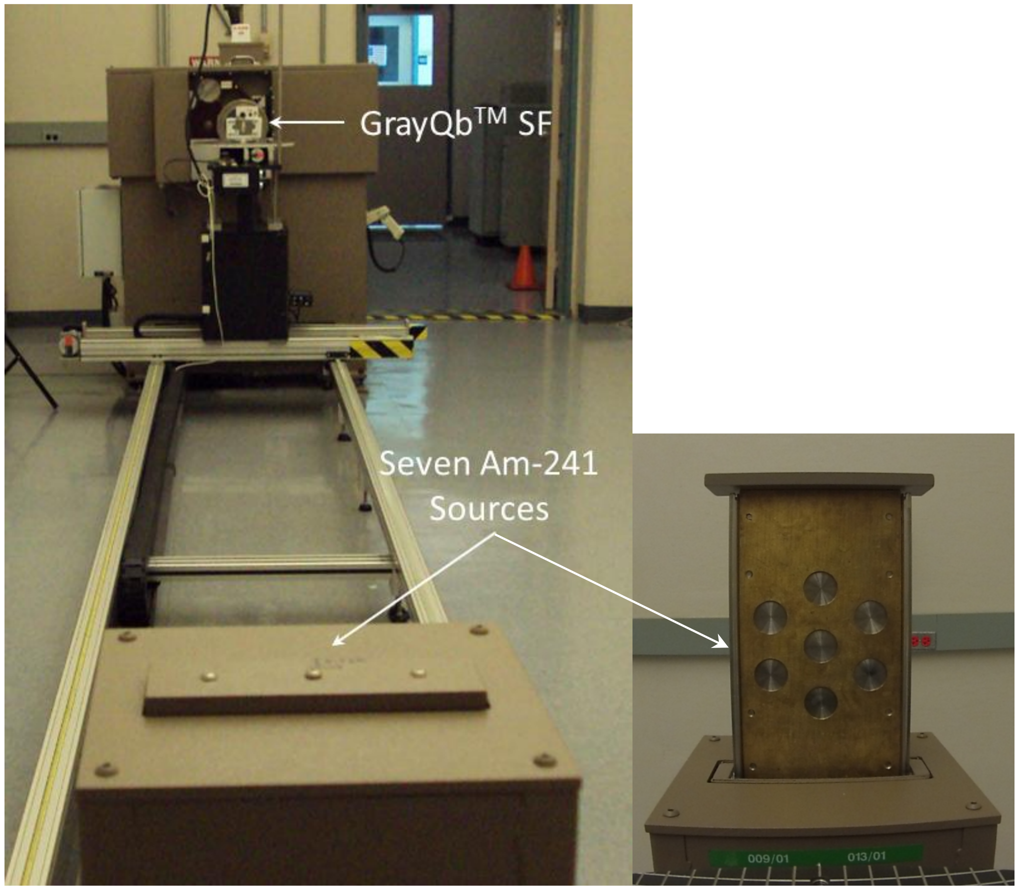


**Figure 16. Test locations of GrayQb™ SF and the seven $^{241}$Am sources at HPICF.**

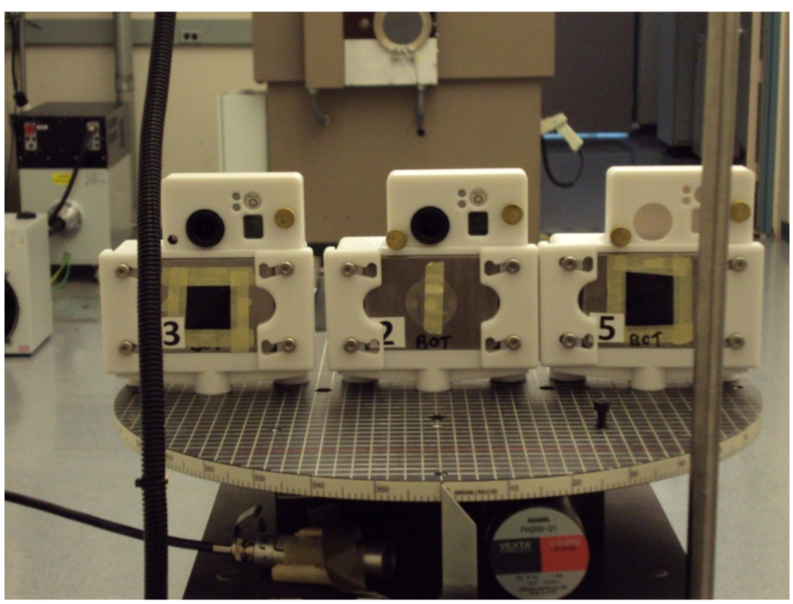


**Figure 17. Position of Units 2, 3, and 5 for Tests 1 and 2 at HPICF.**

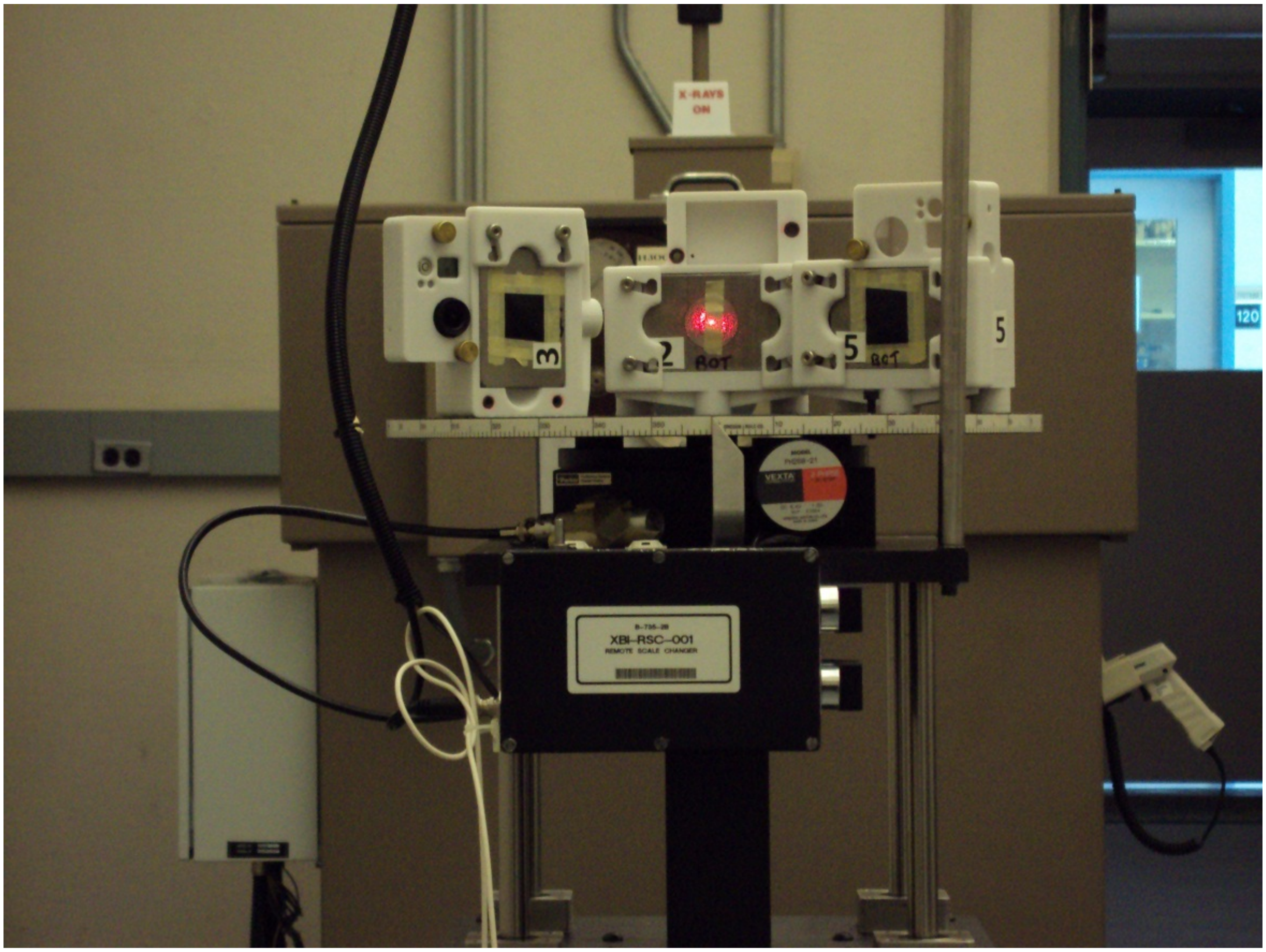


**Figure 18. Position of Units 2, 3, and 5 for Tests 3 through 6 at HPICF. Unit 2 was placed on the center of the seven $^{241}$Am sources as indicated by the red laser light.**

### 3.3 Testing at Building 235-F

Building 235-F and its support facilities have been shut down for a number of years. All of these facilities are candidates for deactivation and decommissioning. Currently, the various facilities are being surveilled and maintained to monitor and contain the residual radiological material in the process areas. Due to its process history and need for deactivation and decommissioning, Building 235-F is an ideal test bed for radiation mapping technologies. Preparation, deployment, and retrieval of radiation mapping devices was a straightforward process with the support of the Building 235-F Risk Reduction Project staff.

The testing in Building 235-F included three tests using GrayQb™ SF Units 2, 3, and 5 (Table 6) in the East Maintenance Area. Tests 7 and 9 involved placing Units 2 and 3 in the East Maintenance Area near Cell 1 (Figure 19). During Tests 7 and 8, the door that provides access to Cell 1 was open. During Test 9, this door was closed. Test 8 involved Unit 5 (without a camera) located near Units 2 and 3 (Test 7). In addition, Test 9 involved mapping a bagged manipulator of Cell 1 in the Building 235-F Shift Operations Base (Figure 19). The dose rate of 22 mrad/h for Tests 7 and 9 involving the East Maintenance Area was read from a survey meter at 30 cm from a known hot spot (Figure 20). The dose rate in the Shift Operations Base was 0.02 mrad/h at 152 cm from the Cell 1 Manipulator (Figure 21). An illustration of the position of Units 2 and 3 for Test 7 and Unit 5 for Test 8 in the 235-F Shift Operations Base is presented in Figure 22.

**Table 6. Testing at 235-F.**

| Test | Test Location in SRS Building 235-F | Dose Rate (mrad/h) | Time (h) | Distance (cm) | GrayQb SF Units | Cell 1 Access Door |
|---|---|---|---|---|---|---|
| 7 | East Maintenance | 22 (at 30 cm) | 90.5 | 122 | 2, 3 | Open |
| 8 | East Maintenance | 22(at 30 cm) | 90.5 | 152.4 | 5 | Open |
| 9 | East Maintenance | 22(at 30 cm) | 92 | 92 | 2, 3 | Closed |
| | Shift Operations Base | 0.02 (at 122 cm) | 98 | 152 | 5 | N/A |

The GrayQb™ SF testing in Building 235-F involved the following steps: 1) bag the GrayQb™ SF units in Building 235-11F (Figure 23); 2) deploy the units into Building 235-F (Figure 24); 3) leave the units unattended for specific periods of time; 4) retrieve, survey and unbag the units; 5) extract and process the data from the units; and 6) provide results. Steps 5 and 6 take only a few minutes (15 to 20 minutes). These steps are specific to a Building 235-F deployment (Steps 1 through 4). The three test configurations are summarized in Table 6.

In this report, the resulting images from the Calibration Facility were obtained by overlaying the PSP and visual images manually using ImageJ (see Section 4.1 for details). The resulting images from the Building 235-F tests presented in this report were produced using ImageJ and applying response trends developed from controlled testing results (Appendix A).

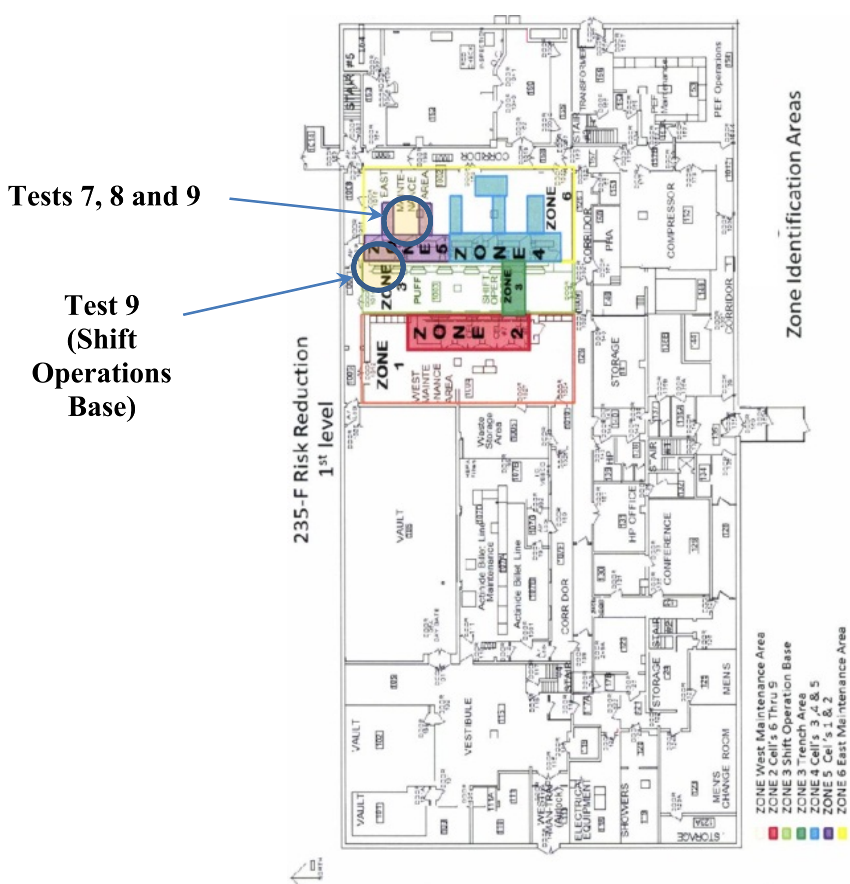


**Figure 19. GrayQb™ SF Deployment locations in 235-F.**

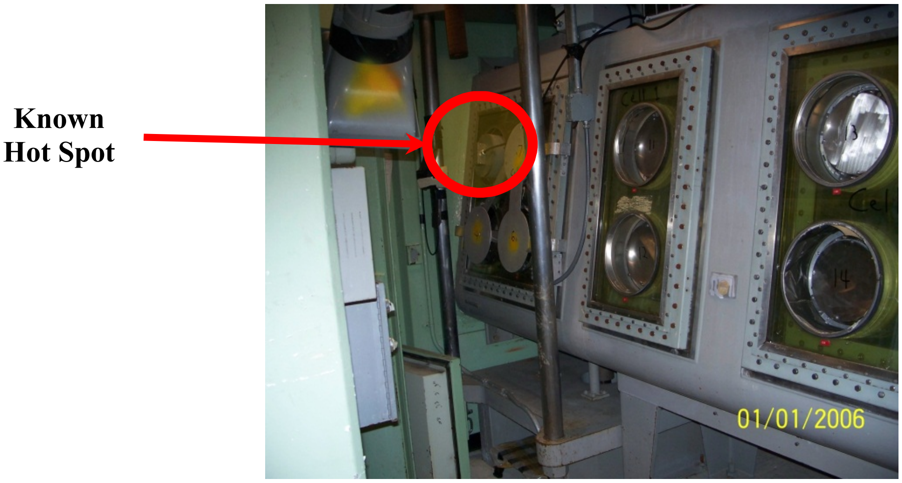


**Figure 20. Known hot spot in the 235-F East Maintenance Area (22 mrad/h at 30 cm from hot spot).**

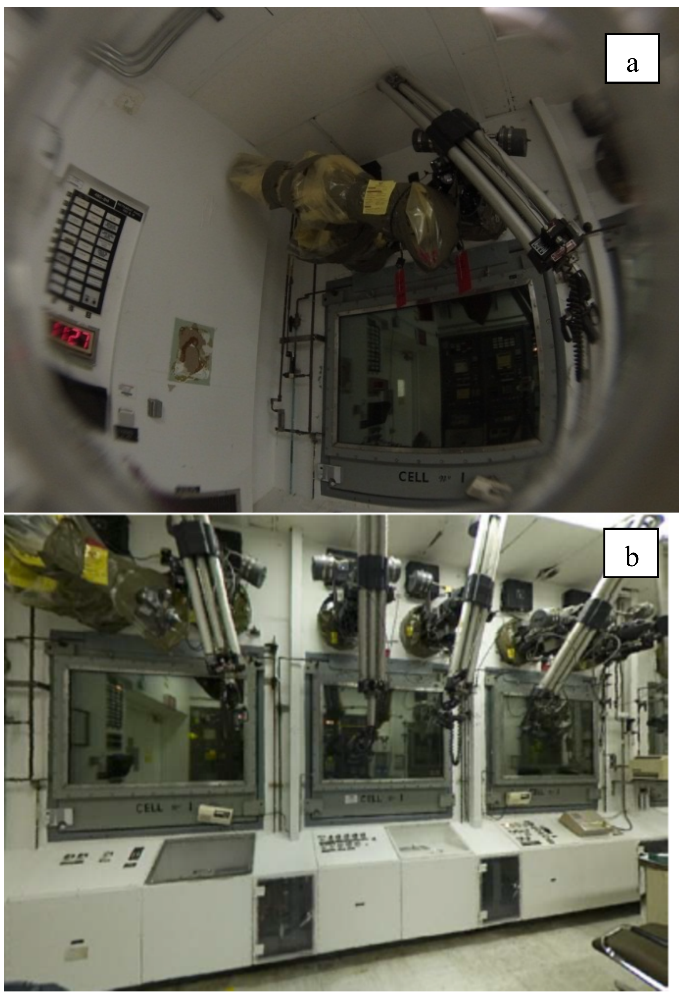


**Figure 21. Bagged Cell 1 Manipulator in 235-F Control Area (0.02 mrad/h at 152 cm from manipulator). a) Photograph obtained by GrayQb™ SF Unit 5. b) 235-F Cell 1.**

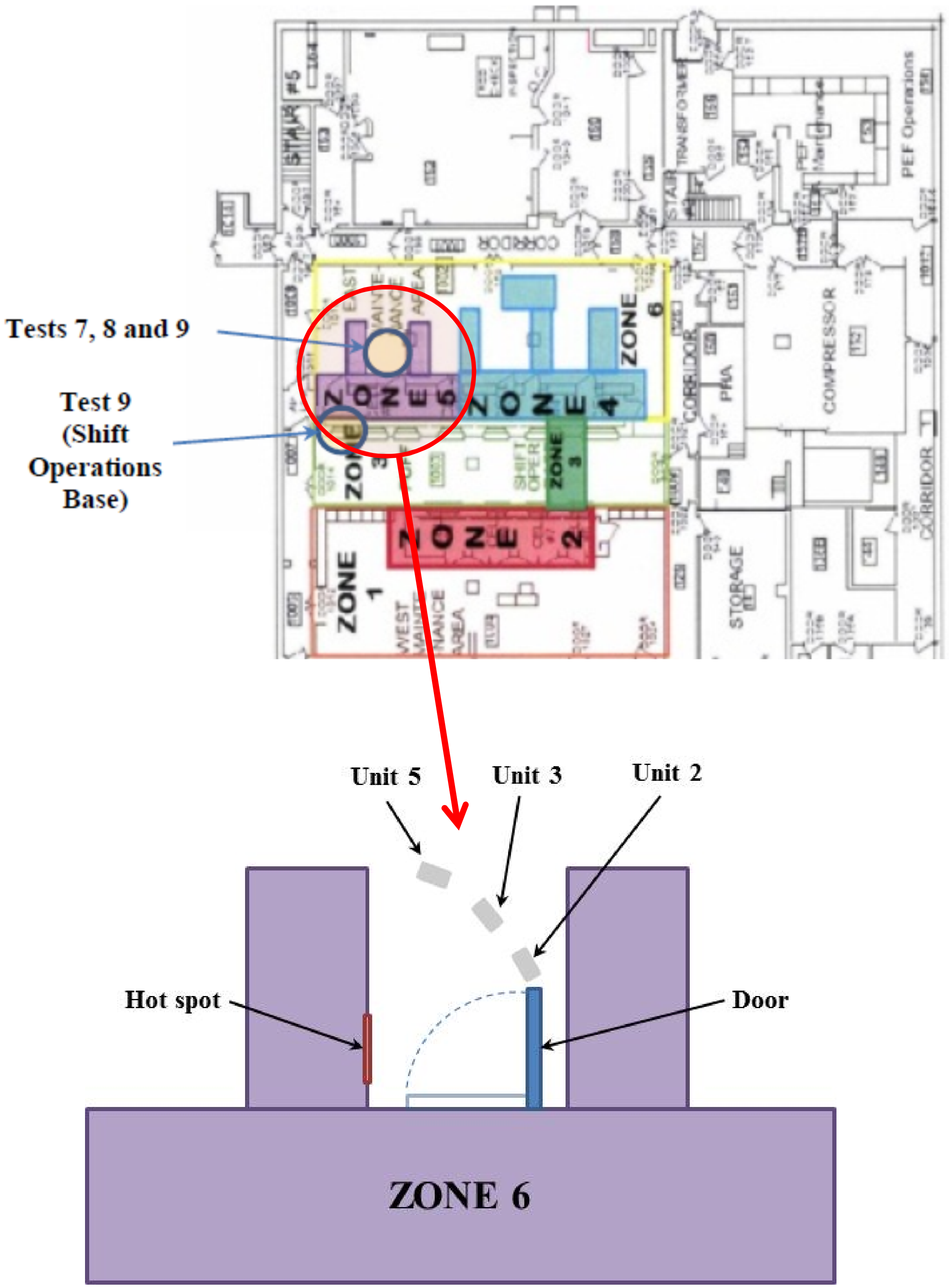


**Figure 22. Illustration of the locations of Unit 2 (Test 7), Unit 3 (Test 7), and Unit 5 (Test 8) in the 235-F East Maintenance Area. The access door was open for Tests 7 and 8.**


**Figure 23. In preparation for a GrayQb™ SF deployment, the devices were bagged in 235-11F.**

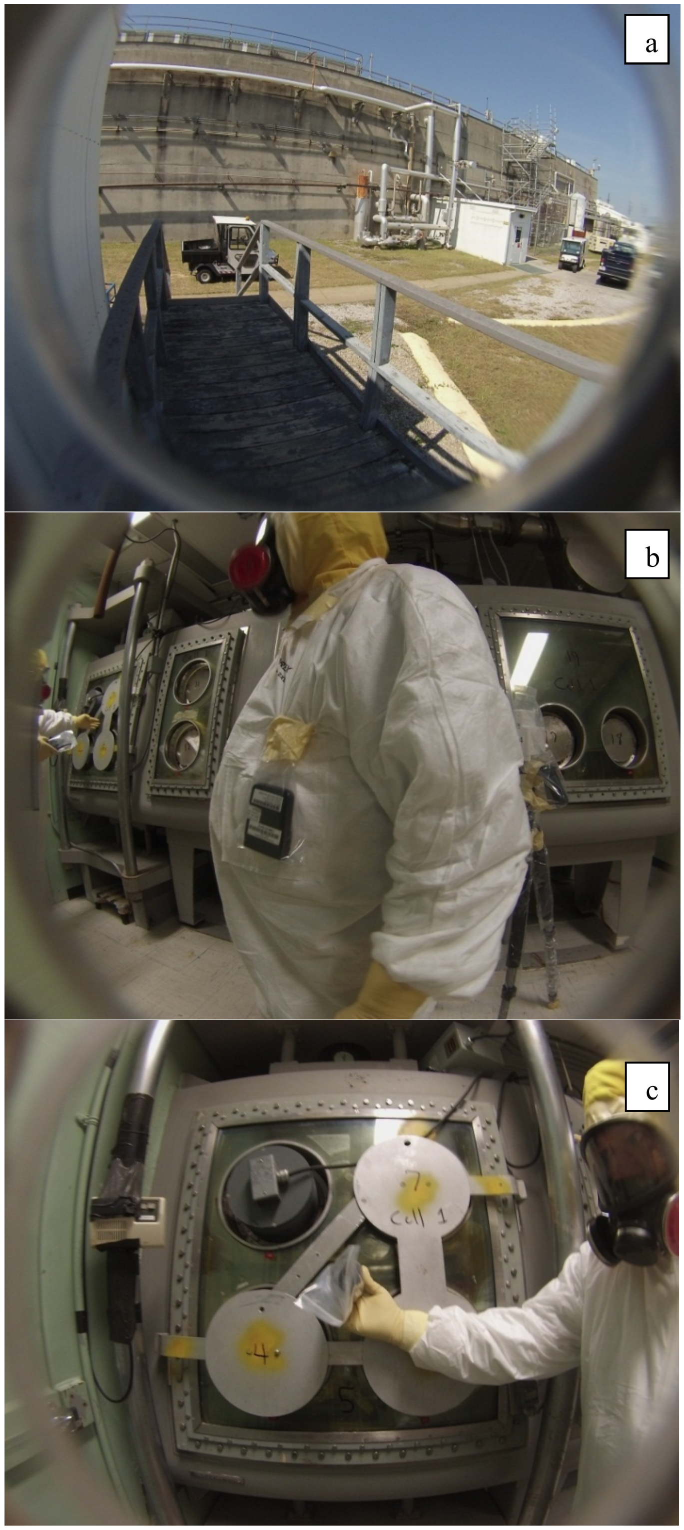


**Figure 24. Deploying GrayQb™ SF units into 235-F. Pictures taken from the GrayQb™ SF units. a) Transporting the units from 235-11F to 235-F. b) Selecting the position of the units in front of the known hot spot. c) Centering a unit in front of a hot cell.**

3.4 Post-Testing at HPICF

The original purpose of the post-testing at HPICF was to verify the functionality of the GrayQb™ SF units after their deployments in a relatively low dose rate environment such as the Building 235-F Shift Operations Base (0.02 mrad/h) where no data were expected to be obtained, however, the deployments in the Building 235-F East Maintenance Area (22 mrad/h) did provide results. Therefore, some of the post-testing was completed to duplicate tests included in the pre-testing (Tests 1 through 6) and to conduct further testing of the technology (e.g., determine the minimum total dose required for acceptable results from a future GrayQb™ deployment). A summary of the post-testing at HPICF is presented in Table 7. When facing the americium-241 sources, Unit 3 was on the left side of Unit 2 and Unit 5 is on the right side of Unit 2 (Table 7 and Figure 25). All the test results, presented in this report, involving ambient light sensitivity, PSP response, spatial resolution, pixel size, and detection sensitivity can be applied to both GrayQb™ and GrayQb™ SF. Test 10, similar to Test 1, was completed to verify the reproducibility of results from GrayQb™ SF.

**Table 7. Post-testing at HPICF.**

| Test | Dose Rate (mrad/h) | Time (s) | Distance (cm) | Total Dose (mrad) | GrayQb SF Units | GrayQb SF positions | Compared to Test |
|---|---|---|---|---|---|---|---|
| 10 | 264.9 | 673.3 | 43.3 | 49.550 | 2, 3 | Side by Side. Center: Unit 2, Left: Unit 3 | 1 |
| 11 | 49.36 | 673.3 | 100.0 | 9.2310 | 2 | Center | 2 |
| | 24.48 | 673.3 | 142.0 | 4.5783 | 3 | Left | |
| | 15.76 | 673.3 | 177.0 | 2.9467 | 5 | Right | |
| 12 | 1.448 | 3600 | 599.6 | 1.4480 | 2 | Center | 4 |
| | 1.261 | 3600 | 642.6 | 1.2608 | 3 | Left | |
| | 1.388 | 3600 | 612.5 | 1.3877 | 5 | Right | |
| 13 | 164.9 | 673.3 | 43.3 | 49.550 | 2 | Center | 1 and 10, with foam switched |
| | 26.04 | 673.3 | 109.0 | 4.8694 | 3 | Left | |
| | 10.27 | 673.3 | 173.5 | 1.9211 | 5 | Right | |
| 14 | 12.12 | 75.0 | 200.0 | 0.2526 | 2 | Center | 3 |
| | 7.535 | 75.0 | 253.6 | 0.1570 | 3 | Left | |
| | 6.933 | 75.0 | 264.4 | 0.1444 | 5 | Right | |
| 15 | 5.399 | 166.7 | 300.0 | 0.2500 | 2 | Center | 6 |
| | 3.738 | 166.7 | 360.6 | 0.1731 | 3 | Left | |
| | 4.052 | 166.7 | 346.3 | 0.1876 | 5 | Right | |
| 16 | 5.399 | 133.4 | 300.0 | 0.2000 | 2 | Center | 6, 15, 17, and 18 |
| | 3.738 | 133.4 | 360.6 | 0.1385 | 3 | Left | |
| | 4.052 | 133.4 | 346.3 | 0.1501 | 5 | Right | |
| 17 | 5.399 | 100.1 | 300.0 | 0.1500 | 2 | Center | 6, 15, 16, and 18 |
| | 3.738 | 100.1 | 360.6 | 0.1039 | 3 | Left | |
| | 4.052 | 100.1 | 346.3 | 0.1127 | 5 | Right | |
| 18 | 5.399 | 66.7 | 300.0 | 0.1000 | 2 | Center | 6, 15, 16, and 17 |
| | 3.738 | 66.7 | 360.6 | 0.0693 | 3 | Left | |
| | 4.052 | 66.7 | 346.3 | 0.0751 | 5 | Right | |

Test 11 involved three GrayQb™ SF units positioned as shown in Figures 25 and 26. Unit 2 was placed in front of the americium-241 source at a distance of 100.0 cm. Units 3 and 5 were each positioned at a constant angle at distances of 142.0 and 177.0 cm, respectively. The americium-241 source was within the field of view of all the units. This similar geometry was applied to Test 12 through 18 with different distances.

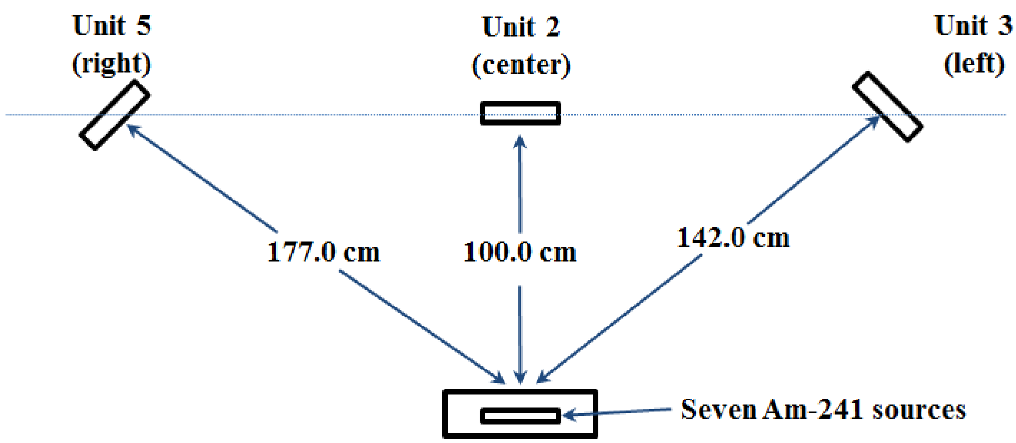


**Figure 25. Illustration of the GrayQb™ SF position for Test 11. Tests 12 through 18 had a similar geometry, but with different distances (thus, different angles for Units 3 and 5).**

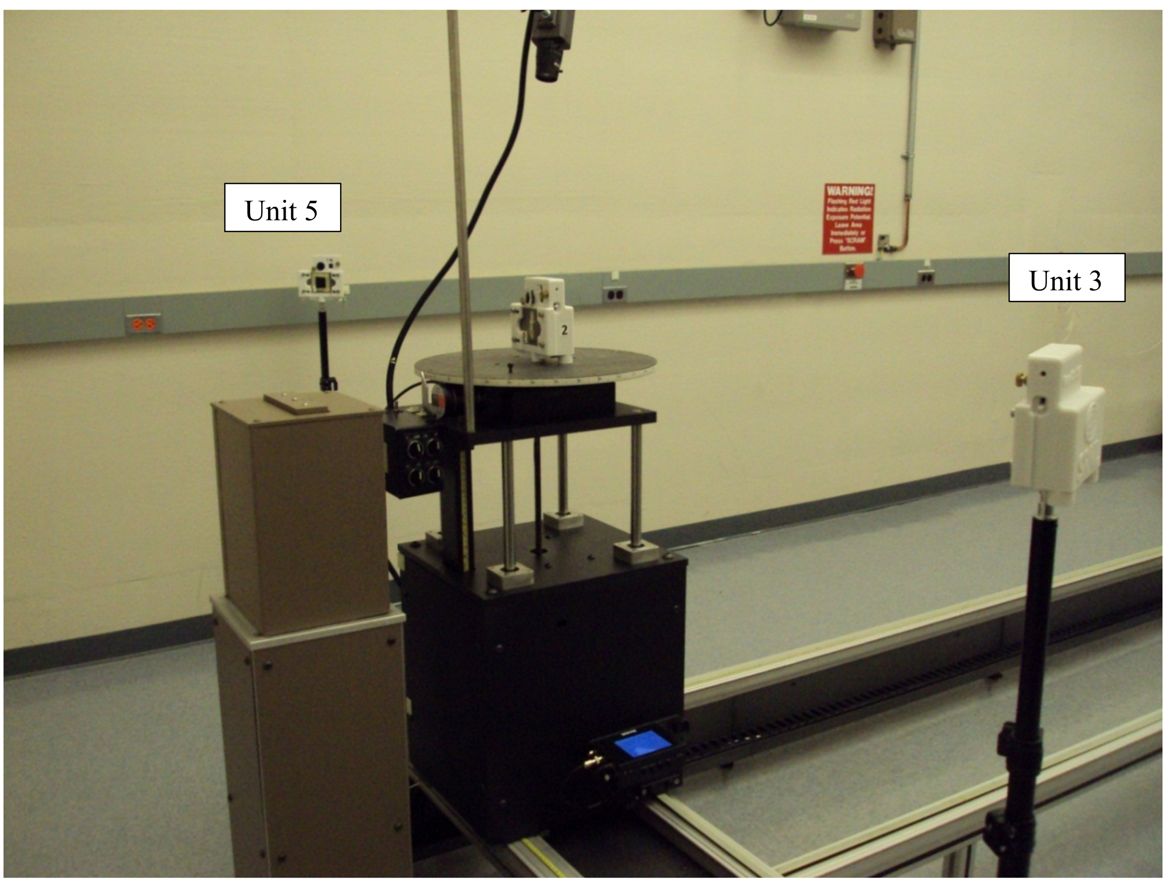


**Figure 26. Exemplification of the GrayQb™ SF position for Tests 11 through 18.**

All of the tests at HPICF and Building 235-F (Test 1 through 18 except Test 13 GrayQb™ SF Unit 2) included two pieces of foam used to hold the PSP and to maintain a distance of 6.6 mm between the PSP and pinhole as shown in Figures 27 and 28. In Test 13 (Unit 2), the positions of the pieces of foam were inverted increasing the distance between the PSP and pinhole to 10.3 mm. This caused a “zoom-in” effect as discussed in the next section.

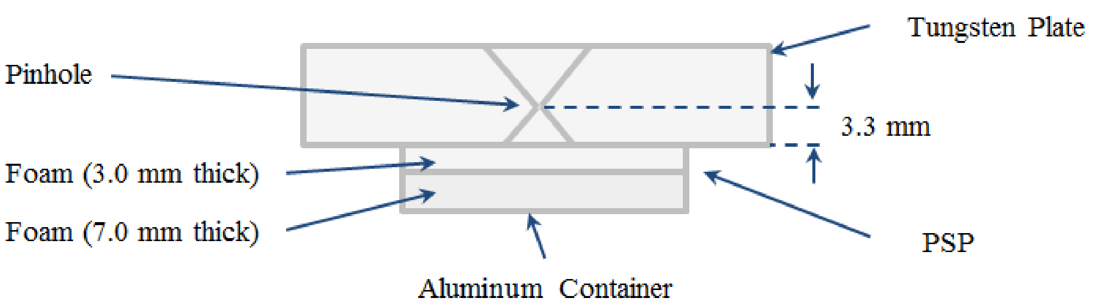


**Figure 27. Illustration of the PSP and pinhole positions for Tests 1 through 18 (except for GrayQb™ SF Unit 2 in Test 13).**

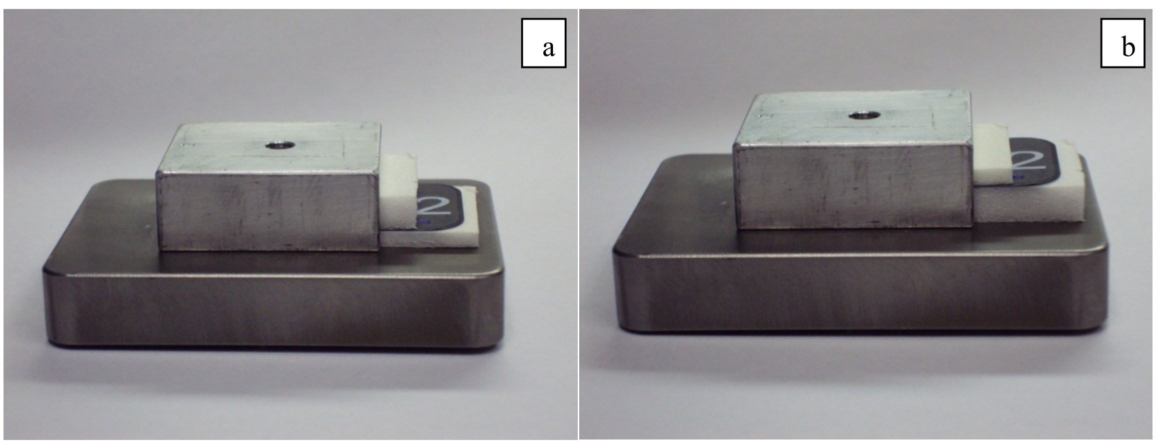


**Figure 28. a) PSP position for Tests 1 through 18 (6.3 mm between PSP and pinhole). b) PSP position for GrayQb™ SF Unit 2 in Test 13 (10.3 mm between PSP and pinhole).**

## 4.0 Results and Discussion

4.1 Process of overlaying images

Once GrayQb™ SF was retrieved from a contaminated area, the data acquisition process was completed in just a few minutes. The PSPs were removed from the device and scanned using one of the commercially-available PSP scanners (e.g., ScanX Discover or ScanX Duo) [22, 23]. The photographs were extracted from the GrayQb™ camera (GoPro HERO3) using a USB connection. The radiographic image and photograph are super-imposed using ImageJ software which is a public domain Java-based image processing program [24]. ImageJ can display, edit, analyze, process, and print images of various bits (e.g., 8-bit, 16-bit and 32-bit images). It can read many image formats and can calculate area and pixel value statistics of user-defined selections. ImageJ can measure distances and angles and can create density histograms and line profile plots. It supports standard image processing functions such as contrast manipulation, sharpening, smoothing, edge detection, and median filtering. ImageJ can also do geometric transformations such as scaling, rotation, and flips [24].

In this report, the resulting images from HPICF were obtained by overlaying the PSP and visual images manually using ImageJ. The resulting images from the Building 235-F tests presented in this report were produced using ImageJ and applying response trends developed from controlled testing results (Appendix A). The process of super-imposing the radiographic image from the PSP and the visual image of the camera is exemplified in Figure 29. The radiographic image is opened in ImageJ where a LUT (look up table) is applied that assigns colors based on intensity. The picture is also opened by ImageJ and a manual overlay of the scan onto the image was done. The resulting image presents the overlay of these two images with the source in various colors representing relative intensity similar to a heat map (e.g., white and blue denote the areas with the highest and lowest intensities, respectively).

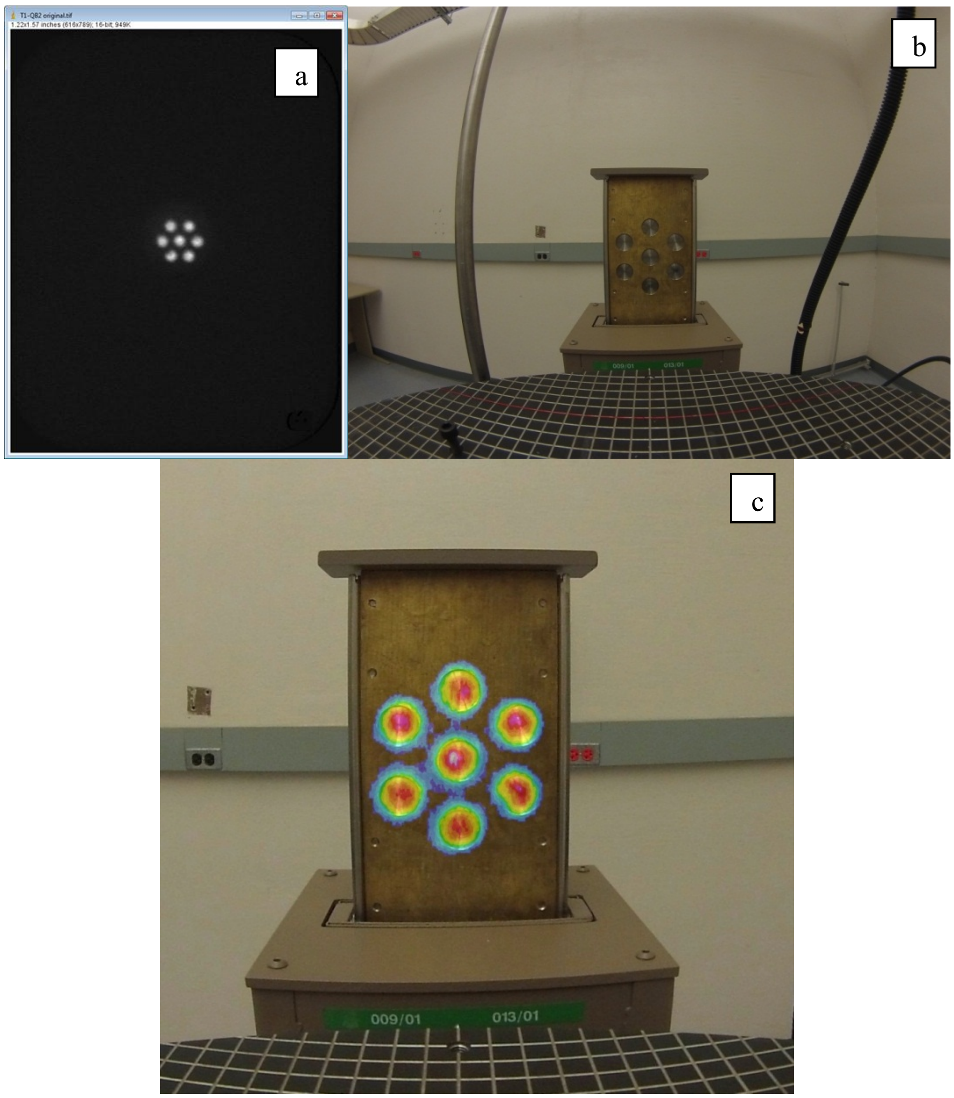


**Figure 29. Process of superimposing the images for Test 1 GrayQb$^{TM}$ SF Unit 2. a) Radiographic image from the PSP. b) Photograph from the GrayQb$^{TM}$ SF camera (GoPro HERO3). c) Super-imposed images.**

4.2 Test 1 Results

Tests 1 through 6 were completed at HPICF (Table 5). The total dose for Test 1 was the highest among all the tests (50.00 mrad) and the distance between the GrayQb™ SF Units 2, 3, and 5 was the shortest among all the tests except for Test 10 and Unit 2 in Test 13. With the high dose and short distance, the super-imposed images obtained from Test 1 are well-defined and accurately represent the shape of the source as shown in Figure 29 for Unit 2. One of the seven americium-241 sources has a slight non-circular shape as shown in Figure 30. This observation was repeated in both the pre- and the post-tests. The position of Units 2, 3, and 5 are illustrated in Figure 26 (Unit 3 was positioned at an angle from the source). Unit 5 did not include a camera; therefore, the image from the PSP was used as verification of the results obtained from Unit 3. Unit 2 in Tests 1 through 6 and Tests 10 through 18 was in front of the seven americium-241 sources and was aligned using a laser beam as illustrated in Figure 18.


**Figure 30. Test 1 Unit 3 resulting image (The position of Unit 3 is illustrated in Figure 25).**

4.3 Test 2 Results

The distance was increased from 43.3 to 99.6 cm and total dose was decreased from 50.00 to 9.232 mrad. The exposure time remained the same for Tests 1 and 2 (673.3 s). The resulting images of Units 2 and 3 are still well-defined and resemble the shape of the source (Figures 31 and 32, respectively).

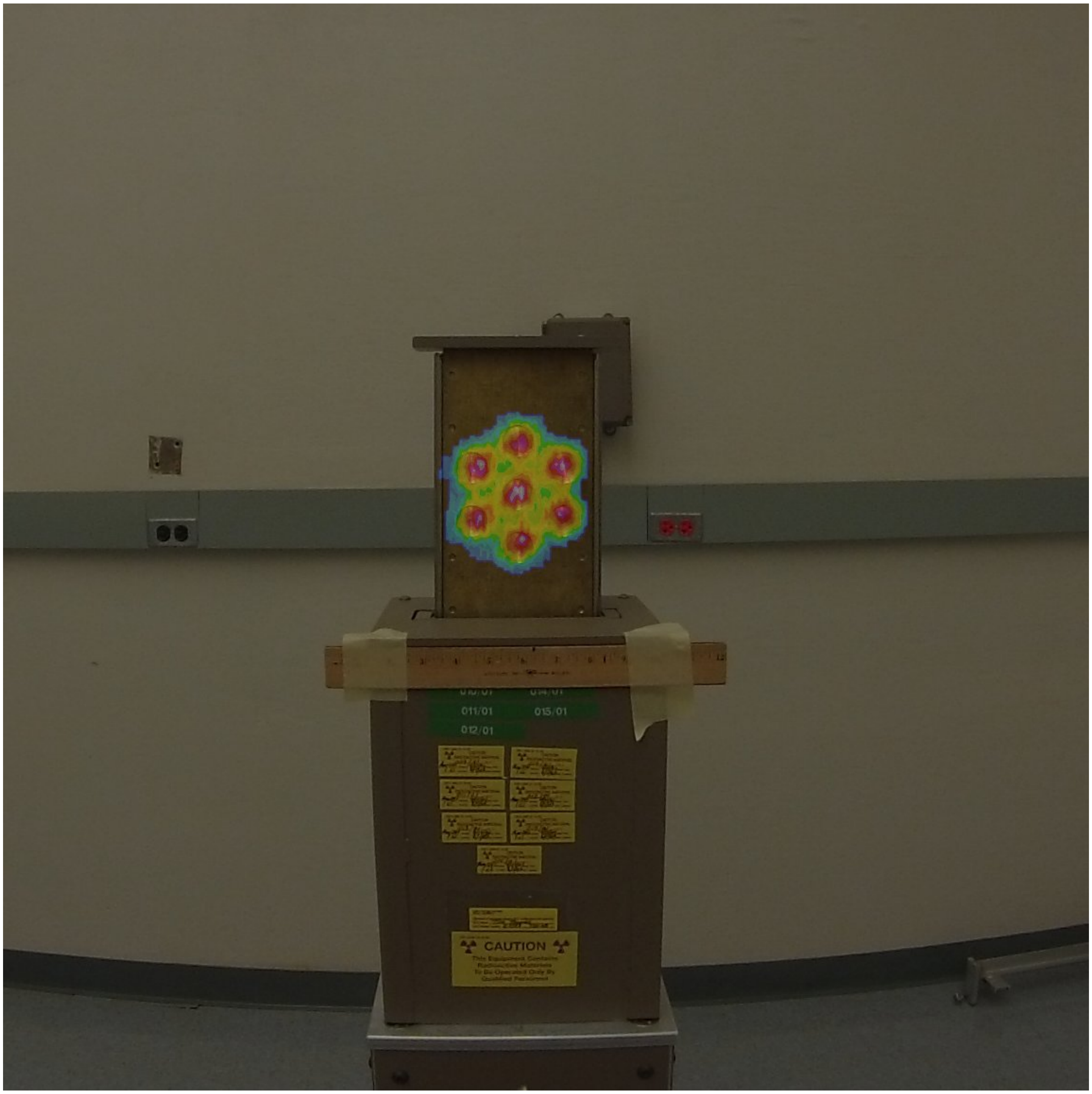


**Figure 31. Test 2 Unit 2 resulting image.**

**Figure 32. Test 2 Unit 3 resulting image.**

4.4 Test 3 Results

The distance between the source and the GrayQb™ SF units was increased to 200 cm and the total dose was decreased to 2.268 mrad. As the distance increases and dose decreases, the images of the seven americium-241 sources take a simpler shape as if there was only one source as shown in Figures 33 and 34. Unit 3 was positioned on its side; and the resulting image in Figure 34 reflects this position. Since the GrayQb™ SF pinhole and tungsten plate are symmetrical with respect to the center of the pinhole, any GrayQb™ SF position (e.g., upside down) does not affect the resulting image, but it should be rotated to account for deployment position of GrayQb™ SF.

**Figure 33. Test 3 Unit 2 resulting image.**

**Figure 34. Test 3 Unit 3 resulting image.**

4.5

4.6 Test 4 Results

The distance between the source and GrayQb™ SF units was 599.6 cm (maximum distance between the americium-241 sources and the target allowed at the HPICF). The total dose was 1.448 mrad. As observed from Test 3, the seven americium-241 sources are shown as one source by Unit 2 (Figure 35). The resulting image from Unit 3 is shown in Figure 36. The sources are close to the detection boundary of the Unit 3 field of view.

**Figure 35. Test 4 Unit 2 resulting image.**

**Figure 36. Test 4 Unit 3 resulting image.**

4.7 <u>Test 5 Results</u>

The preliminary tests of the GrayQb™ technology using the seven americium-241 sources indicated a minimum total dose of 10.0 mrad. The purpose of Test 5 was to expose the GrayQb™ SF Units to a total dose of 0.500 mrad at 300.0 cm. Test 5 was successful and the resulting images are shown in Figures 37 and 38.

**Figure 37. Test 5 Unit 2 resulting image.**

**Figure 38. Test 5 Unit 3 resulting image.**

4.8 Test 6 Results

The preliminary tests of the GrayQb™ technology using three americium-241 sources indicated minimum total dose of 0.019 mrad. The purpose of Test 6 was to expose the GrayQb™ SF Units to a total dose of 0.250 mrad at 300.0 cm. It was possible to obtain super-imposed image using Unit 2 (Center) as shown in Figure 39. An image of the source was also obtained from Unit 3, but image from the PSP showed some sporadic spots, which are non-existent (Figure 40). This effect shown in Figure 40 was caused because the dose value of 0.250 mrad is close to the PSP detectable limit of 0.172 mrad determined using an x-ray generator (Figure 11) and Unit 3 was at an angle of 30°.

**Figure 39. Test 6 Unit 2 resulting image.**

**Figure 40. Test 6 Unit 3 resulting image.**

4.9 Test 7 Results

Tests 7 through 9 were completed in SRS Building 235-F (Table 6). Test 7 involved a deployment time of 90.5 h at an approximate distance of 122 cm between the hot spot and Units 2 and 3. Figure 41 shows the resulting image of Unit 2. The dose rate at 30 cm from this hot spot was 22 mrad/h [235-F RadCon, personal communication]. Test 9 (Figure 45 – Unit 3) was conducted to verify the location of this hot spot as shown in Figure 41. Unit 2 (Test 7) was deployed below the hot spot at an angle; whereas, Unit 3 (Test 9) was positioned right in from of the hot spot. Units 2 (Test 7) and 3 (Test 9) show different locations of this spot. Thus, this hot spot is not surface contamination. Instead this hot spot is from contamination inside the structure; therefore, depending on the angle of view, the position of the hot spot will slightly vary. In addition, this spot shown in Figures 41 and 45 has a specific shape, which was observed in Test 7 and confirmed in Test 9

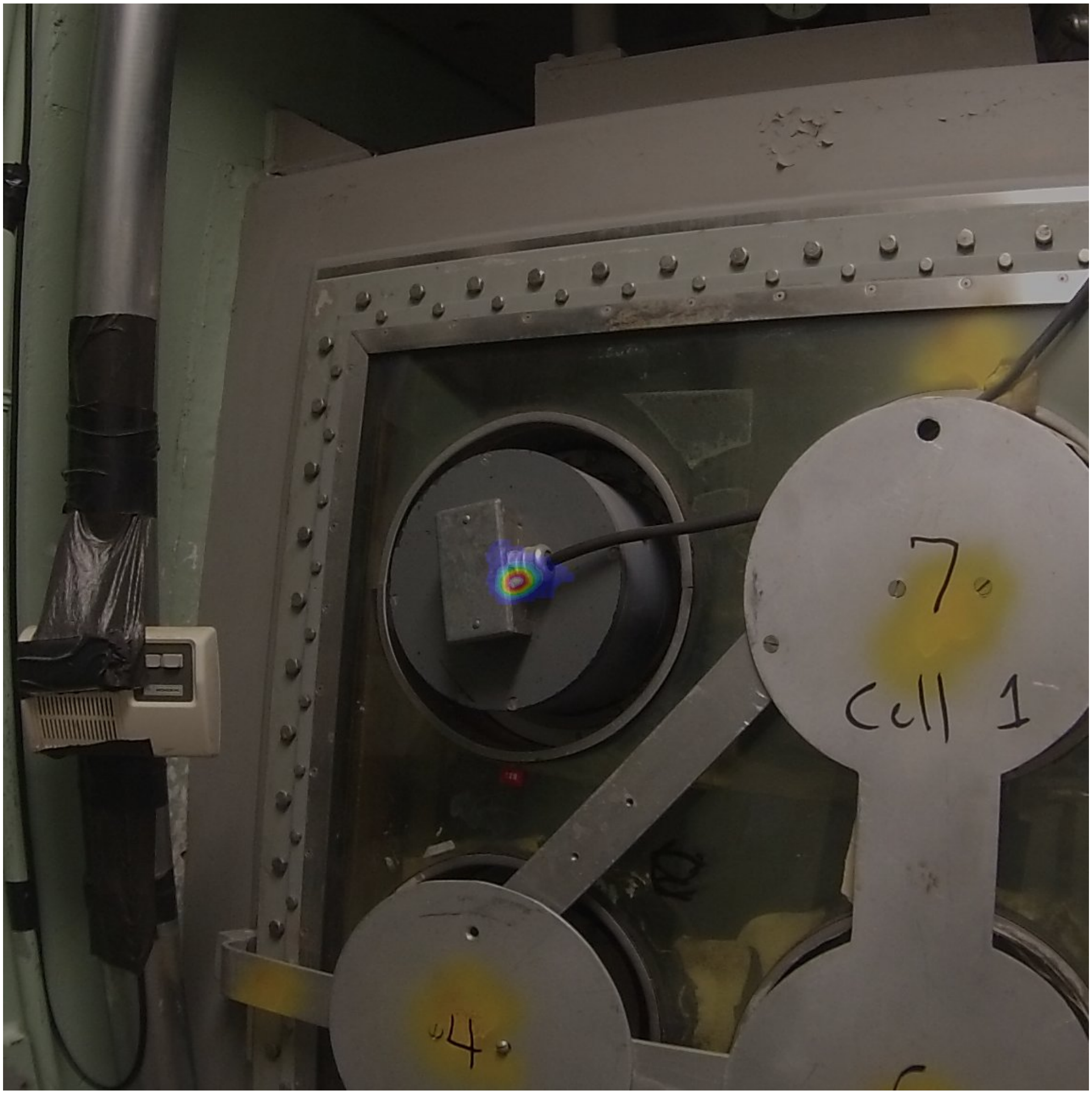


**Figure 41. Test 7 Unit 2 resulting image (at 122 cm from source).**

Unit 3 in Test 7 helped identify another hot spot shown in Figure 42 (below the number 6). Unit 3 was located lower than Unit 2 (Test 7). The hot spot observed in Figure 41 is barely visible in Figure 42 since this spot is inside the cylindrical structure. Some of metal components of the cylinder are shielding the hot spot; thus, it is not really visible from Unit 3.

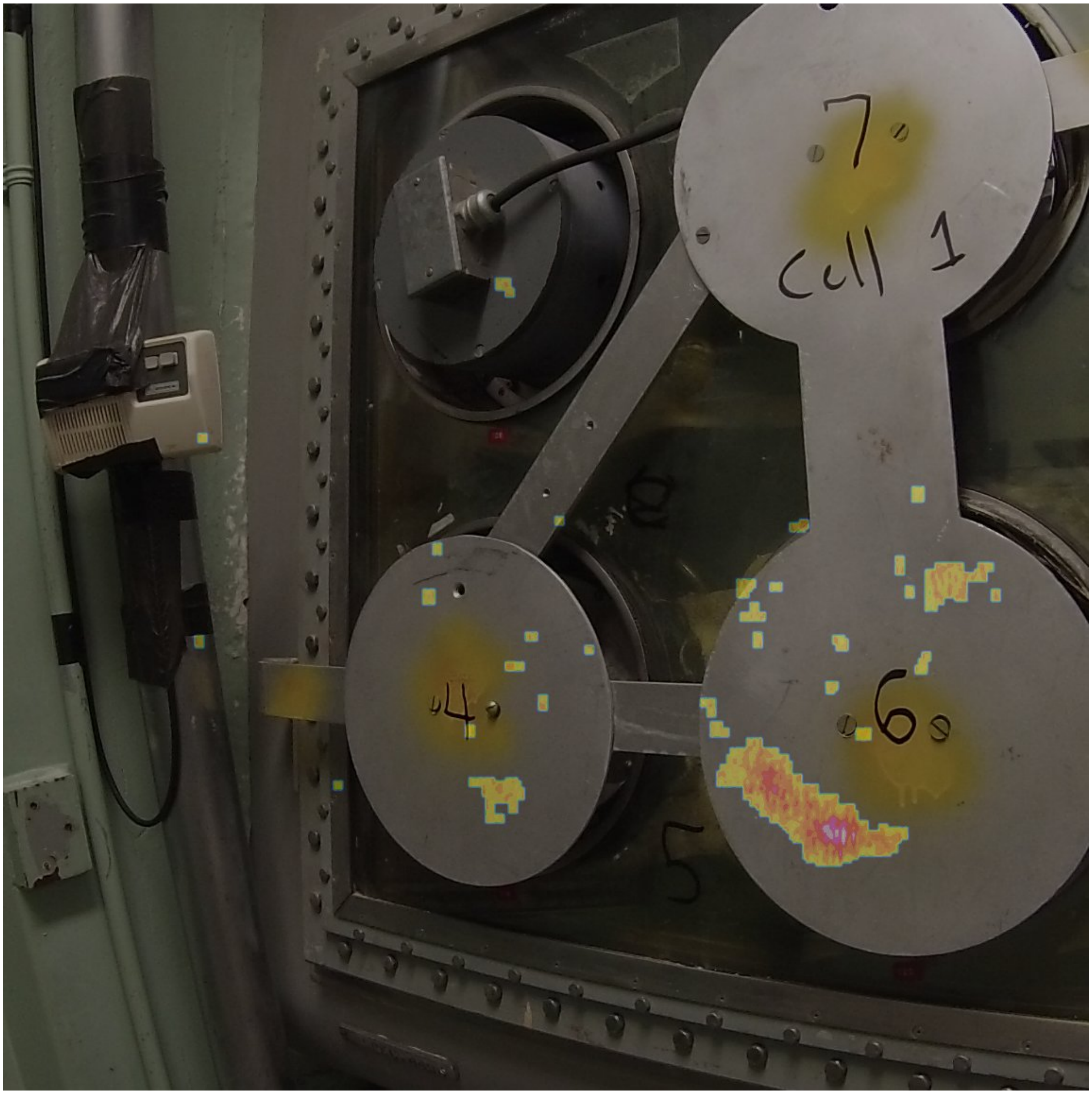


**Figure 42. Test 7 Unit 3 resulting image.**

4.10 Test 8 Results

This test involved placing Unit 5 in the 235-F East Maintenance Area at a distance of 152 cm from the hot spot shown in Figure 20. During Tests 7 and 8, the access door was open, but it was closed in Test 9. Unit 5 did not have a camera when Test 8 was conducted; consequently, only the PSP image was processed as shown in Figure 43. There is a hot spot shown near the center of the PSP image; however, the source and its location cannot be identified without the visual image.

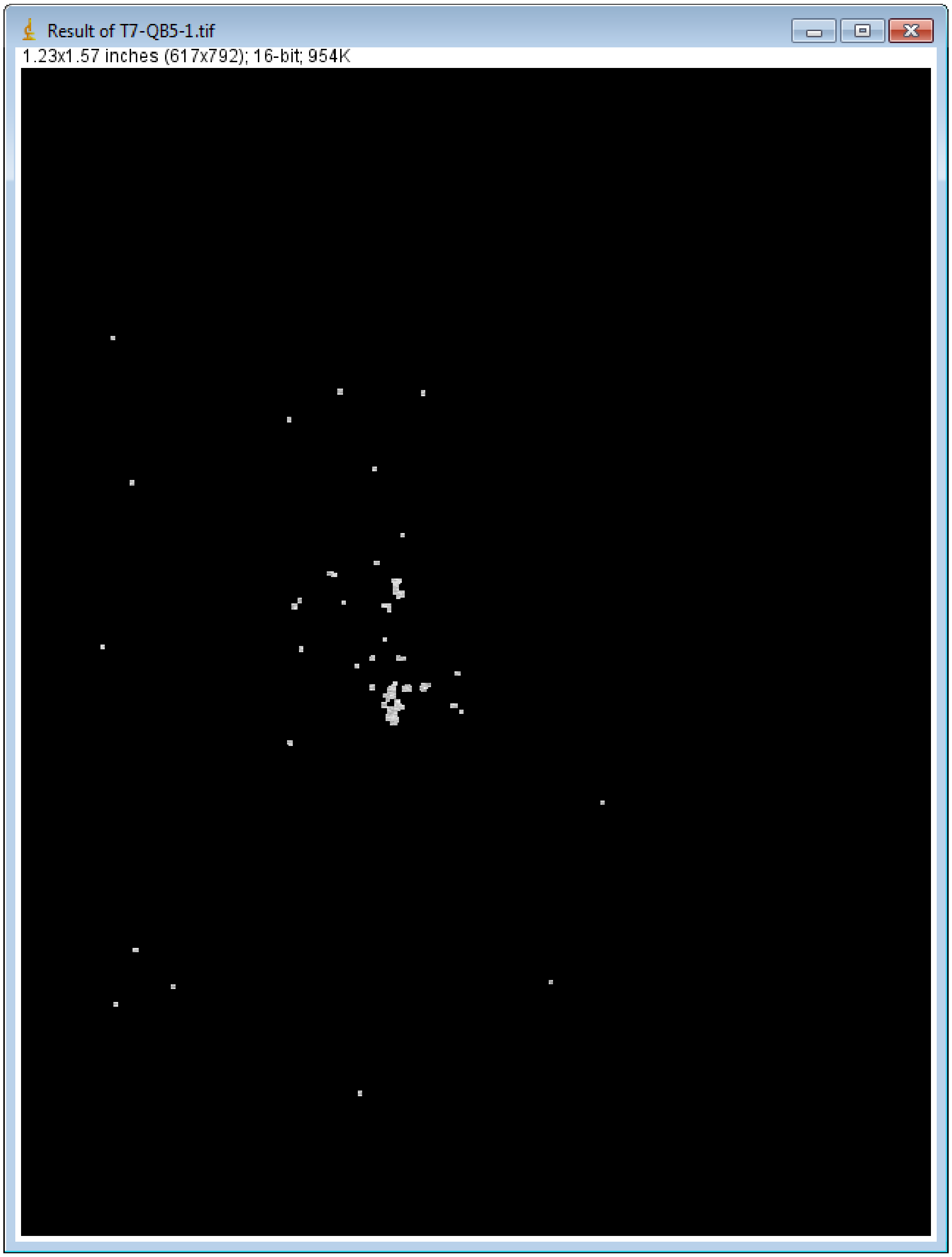


**Figure 43. Test 8 Unit 5 resulting image.**

4.11 Test 9 Results

The image from Unit 2 is shown in Figure 44. So far, the GrayQb™ SF results for this area of Building 235-F (Figures 41 - 43) have indicated clear locations of contamination; however, Figure 44 shows the same spots with lower intensity. This effect is attributed to the lower position of Unit 2 and the limited GrayQb™ SF field of view, which was blocked by the structure inside the cylinders.

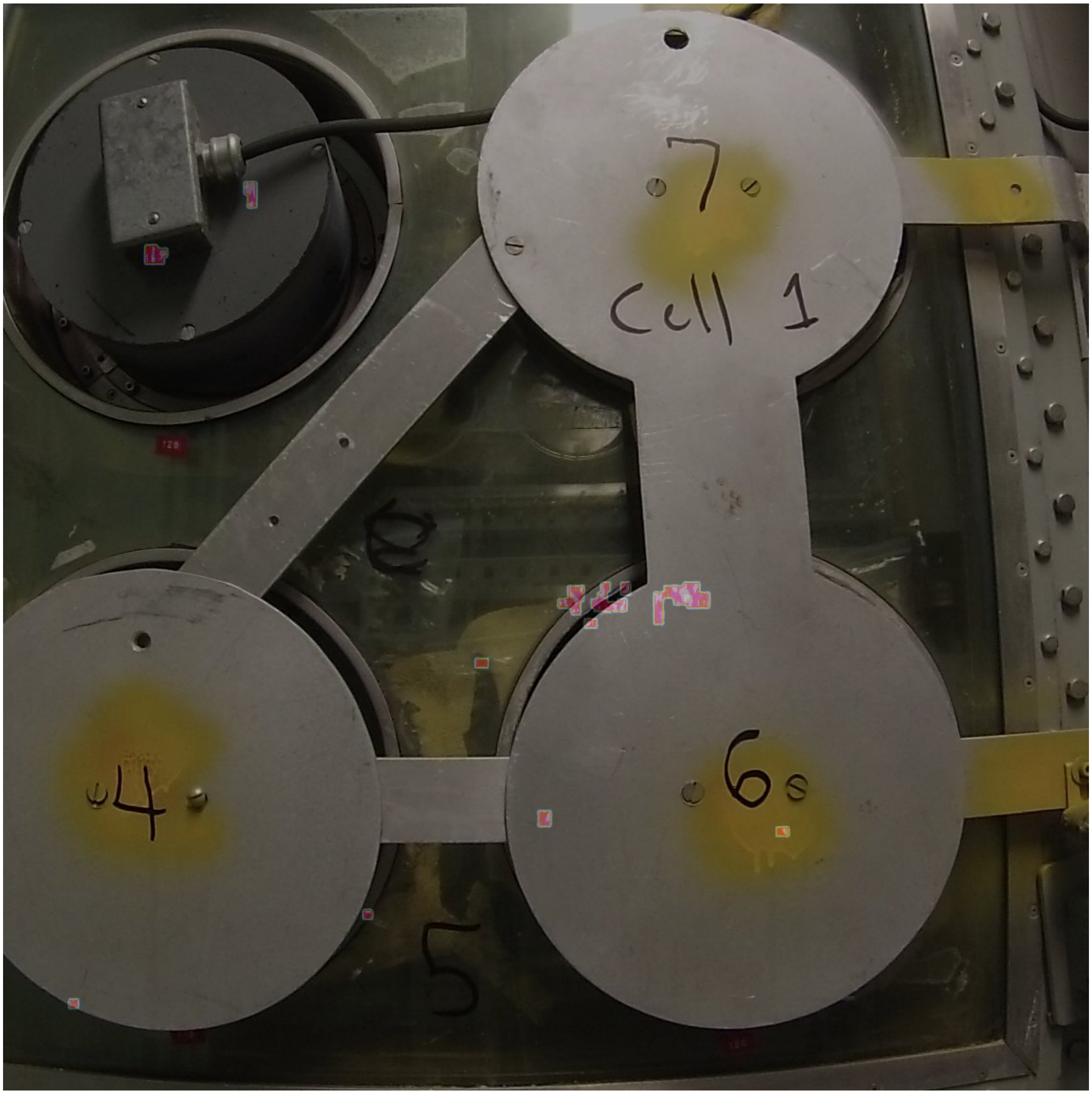


**Figure 44. Test 9 Unit 2 resulting image.**

The hot spot is clearly discernible on the image of Unit 3 (Test 9), which involved a deployment time of 92 h at a distance of 92 cm from the hot spot (Figure 45). This test was completed to verify the result from Unit 2 (Test 7) shown in Figure 41. The different locations of the hot spot identified by Unit 2 (Test 7) and Unit 3 (Test 9) demonstrate that the hot spot is not surface contamination but is located inside the structure. Thus, depending on the angle of view, the position of the hot spot will vary slightly. The top of bagged Unit 2 (Test 9) can be observed in the bottom right corner of Figure 45.

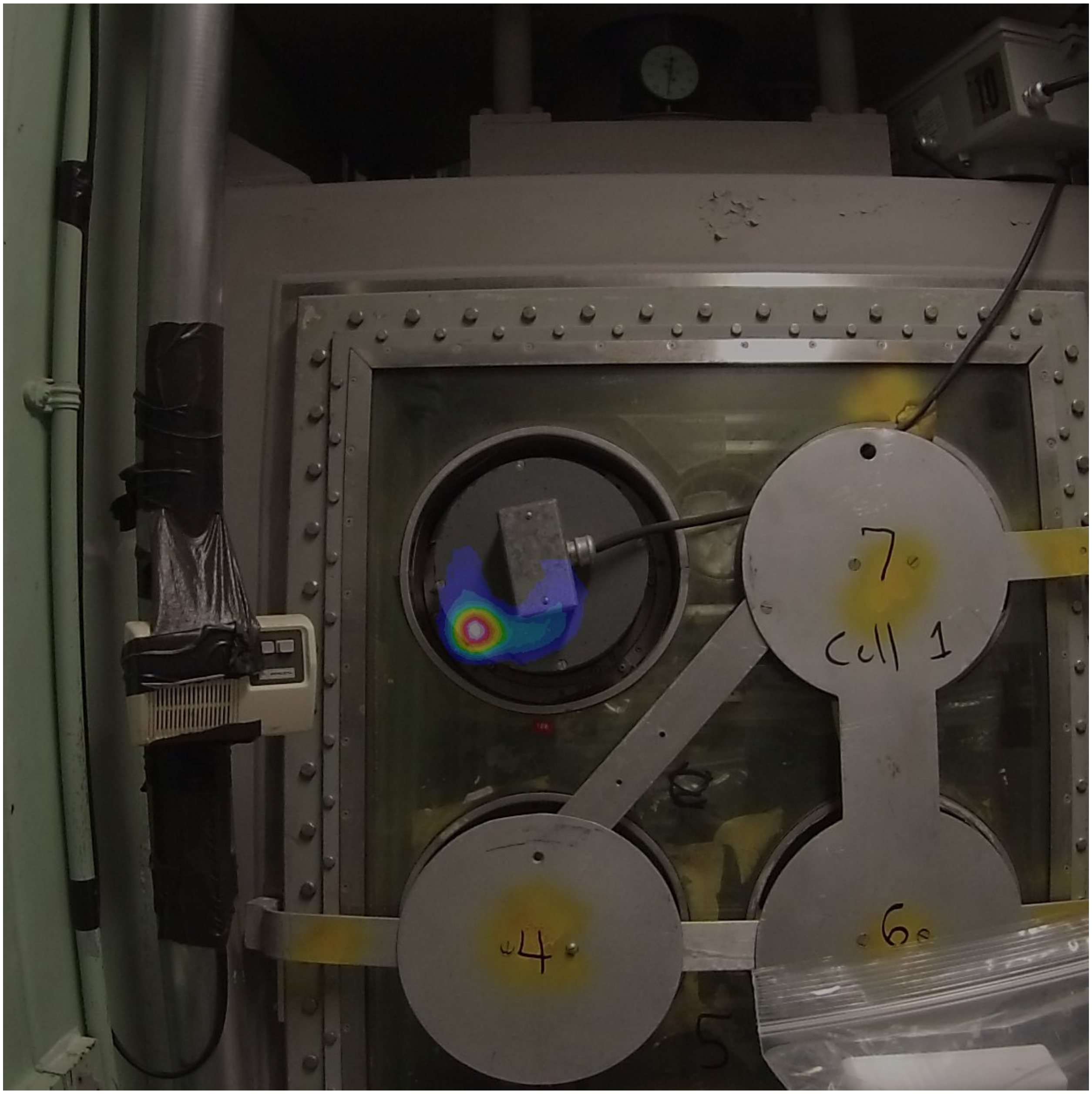


**Figure 45. Test 9 Unit 3 resulting image.**

4.12 Test 10 Results

Tests 10 through 18 were completed at HPICF. Test 10 was conducted to ensure the GrayQb™ SF results can be duplicated. Test 10, similar to Test 1, involved Units 2 and 3 positioned side by side (Unit 2 was centered) (Tables 5 and 7). The distance between the seven americium-241 sources and Unit 2 and 3 was 49.55 cm. The Unit 2 resulting image is presented in Figure 46 and resembles the image from Test 1 (Figure 29). Unit 3 was located on the left side of Unit 2 and its resulting image is shown in Figure 47.


**Figure 46. Test 10 Unit 2 resulting image.**


**Figure 47. Test 10 Unit 3 resulting image.**

4.13 Test 11 Results

Tests 11 through 18 involved Units 2, 3, and 5 with their own cameras (Table 7). Unit 2 was positioned in front of the center of the sources and was aligned using a laser beam. Unit 3 and Unit 5 were on the left and right sides, respectively, as illustrated in Figure 25. Units 2, 3, and 5 were located at 100.0, 142.0, and 177.0 cm from the seven americium-241 sources, respectively. The resulting images of Unit 2, 3, and 5 are shown in Figures 48, 49, and 50, respectively.

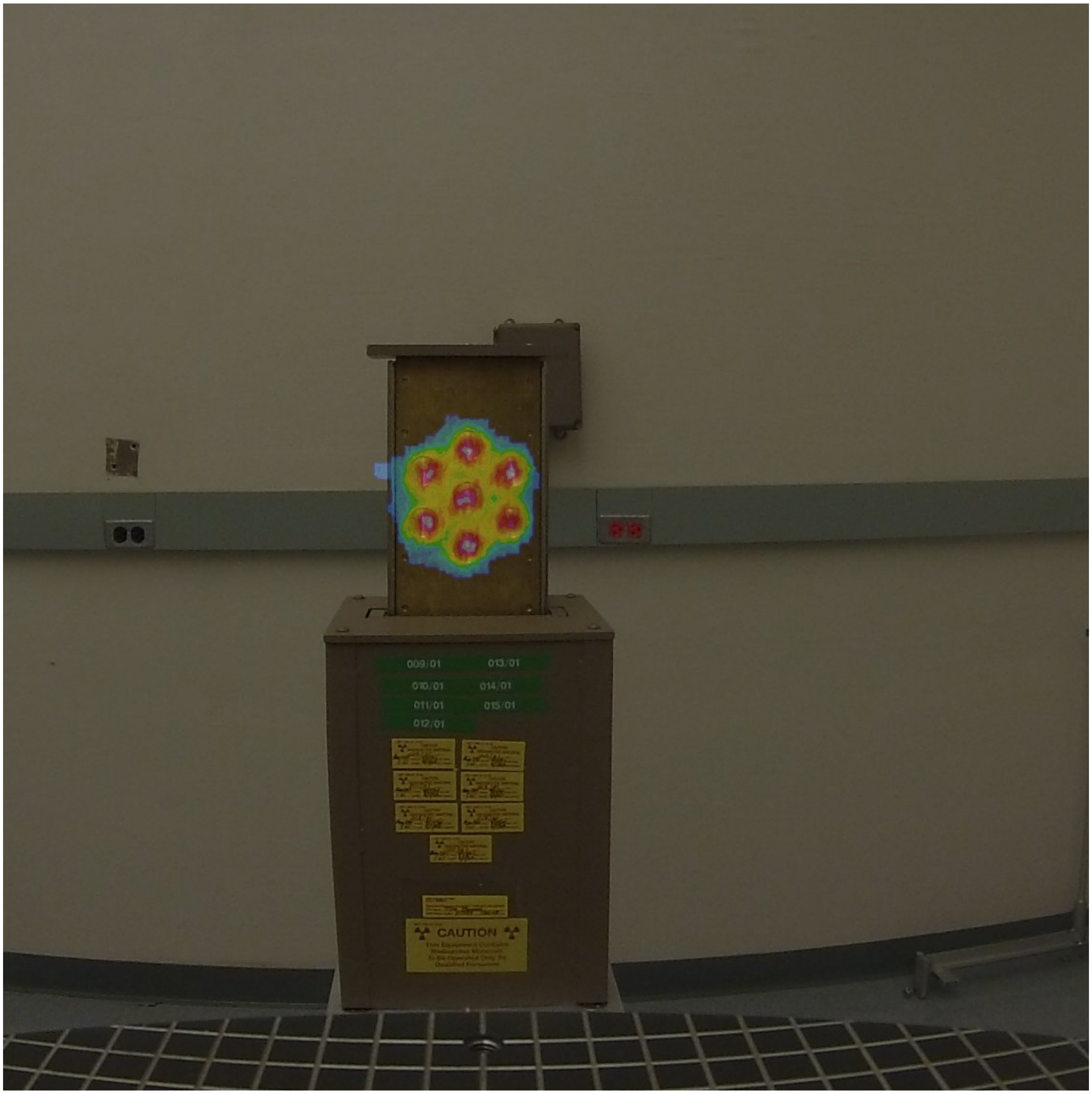


**Figure 48. Test 11 Unit 2 resulting image.**

**Figure 49. Test 11 Unit 3 resulting image.**

**Figure 50. Test 11 Unit 5 resulting image.**

4.14 Test 12 Results

This test involved a distance of 599.6 cm between Unit 2 and the seven americium-241 sources. Units 3 and 5 were positioned at 642.6 and 612.5 cm from these sources (Table 7). The total dose determined by the source operating equipment for Unit 2 was 1.4480 mrad. The doses for Units 3 and 5 were calculated to be 1.2608 and 1.3877 mrad, respectively (Figures 51 - 53). The cameras for Units 2, 3, and 5 for this test were set to take pictures every minute. The pictures, selected to be used to create the resulting images, were inadvertently the initial pictures taken during Test 12. These pictures did not show the source. However, it was still possible to generate resulting images as shown in Figures 51 - 53.

**Figure 51. Test 12 Unit 2 resulting image.**

**Figure 52. Test 12 Unit 3 resulting image.**

**Figure 53. Test 12 Unit 5 resulting image.**

4.15 <u>Test 13 Results</u>

Test 13 for Unit 2, similar to Tests 1 and 10, was conducted to verify the "zoom-in" effect caused by switching the positions of pieces of foam holding the PSP (Figure 54). The distance between the PSP and the pinhole was 10.3 mm for Unit 2 in Test 13. For all the other tests, this distance was 6.3 mm. The PSP image for Unit 2 (Test 13) was indeed larger than Unit 2 (Test 1 and 10) as shown in Figure 55. The results from Unit 3 and 5 are presented in Figures 56 and 57, which also show the other two units being exposed to the seven americium-241 sources.


**Figure 54. Test 13 Unit 2 resulting image.**

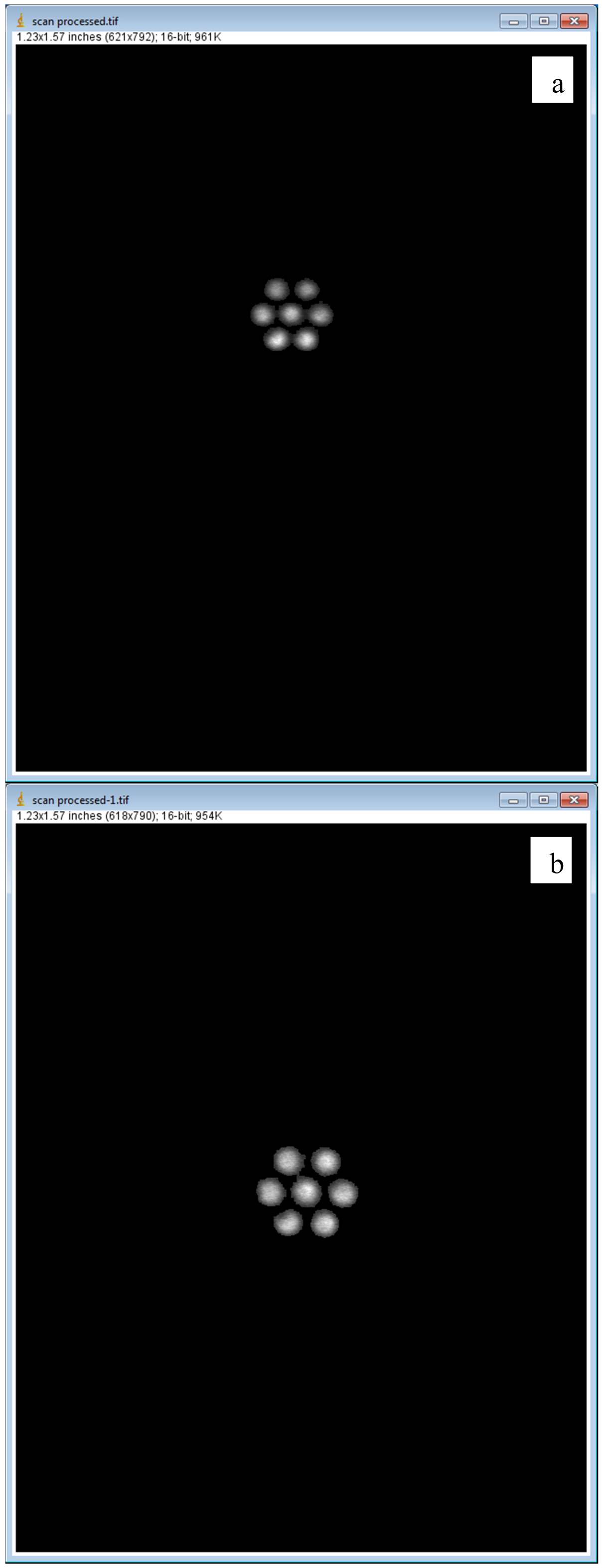


**Figure 55. GrayQb$^{TM}$ SF zoom-in effect. PSP image of a) Unit 2 (Test 1) and b) Unit 2 (Test 13).**

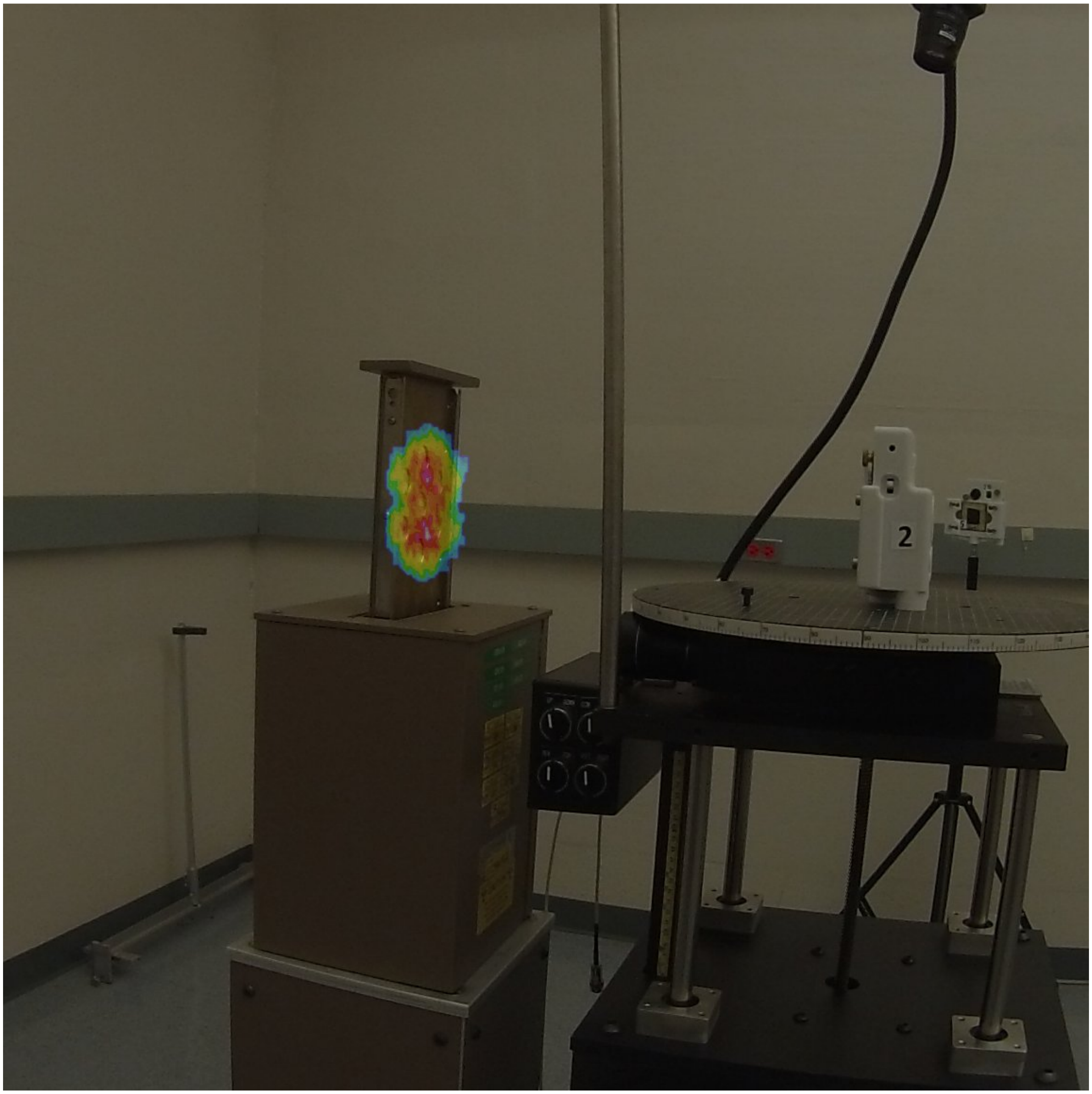


**Figure 56. Test 13 Unit 3 resulting image.**

**Figure 57. Test 13 Unit 5 resulting image.**

4.16 Test 14 Results

The result from Unit 2 of this test is comparable to that of Unit 2 of Test 3. The distance was 200.0 cm and the dose was 0.2526 mrad. At this low total dose, the seven americium-241 sources become one, but still recognizable, source as shown in Figure 58. The estimated total doses for Units 3 and 5 were 0.1570 and 0.1444 mrad, respectively. These total doses are below the minimal total dose necessary for a PSP to acquire an image, which was estimated to be 0.175 mrad; however, as observed in Figures 59 and 60, it is still possible to obtain overlay images.

**Figure 58. Test 14 Unit 2 resulting image.**

The exposure time for Test 14 was only 75.0 s. The resulting image of Unit 2 in Test 14 shows the seven americium-241 sources mid-way up. This was the result of an unfortunate camera setting selection for the Unit 2 camera, which was inadvertently set to take pictures every minute instead of every second.

**Figure 59. Test 14 Unit 3 resulting image.**

**Figure 60. Test 14 Unit 5 resulting image.**

4.17 Test 15 Results

Test 15, similar to Test 6, involved a distance of 300.0 cm between Unit 2 and the americium-241 sources. The Unit 2 total dose of 0.2500 mrad was close to that of Unit 2 for Test 14 (0.2526 mrad). The resulting image showing the americium-241 sources is still discernible (Figure 61). The results from Unit 3 (0.1731 mrad) and 5 (0.1876 mrad) are shown in Figures 62 and 63, respectively. At these low doses, the sources are still observable, but a few other random spots are also noticeable (Figures 61 – 63).

**Figure 61. Test 15 Unit 2 resulting image.**

**Figure 62. Test 15 Unit 3 resulting image.**

**Figure 63. Test 15 Unit 5 resulting image.**

4.18 Test 16 Results

Tests 16 through 18 were completed to validate the minimum dose necessary for GrayQb™ to acquire an image. The total doses for Unit 2, 3, and 5 for this test were 0.2000, 0.1385, and 0.1501 mrad, respectively (Figures 64, 65 and 66).

**Figure 64. Test 16 Unit 2 resulting image.**

**Figure 65. Test 16 Unit 3 resulting image.**

**Figure 66. Test 16 Unit 5 resulting image.**

4.19 <u>Test 17 Results</u>

The total doses for Units 2, 3, and 5 were 0.1500, 0.1039, and 0.1127 mrad. Even though these doses are below the estimated minimum total dose for GrayQb™ to produce images, overlay images were still produced; however, the shape and dimensions of the seven americium-241 sources were distorted (Figures 67 - 69).

**Figure 67. Test 17 Unit 2 resulting image.**

**Figure 68. Test 17 Unit 3 resulting image.**

**Figure 69. Test 17 Unit 5 resulting image.**

4.20 Test 18 Results

This test involved dose rates below the minimum dose suggested for image acquisition (0.1000, 0.0693, and 0.0751 mrad for Units 2, 3, and 5, respectively). Unit 2 still was able to produce an overlay image with some random spots (Figure 70). No overlay images were produced by Units 3 and 5 (Figures 71 and 72). Tests 16 through 18 verify that the minimum dose necessary for GrayQb™ SF to produce an acceptable overlay image is about 0.2000 mrad. This lower limit of the GrayQb™ SF dynamic range is a significant advantage over other radiation mapping technologies.

**Figure 70. Test 18 Unit 2 resulting image.**

**Figure 71. Test 18 Unit 3 resulting image.**

**Figure 72. Test 18 Unit 5 resulting image.**

4.21 GrayQb$^{TM}$ SF Characterization Summary

A summary of the GrayQb$^{TM}$ SF operating parameters characterized during the testing outlined in this document is presented in Table 8. These results can be extrapolated to the six-sided GrayQb$^{TM}$ instrument as the single face design tested in Building 235-F is as the same technology that would be used for GrayQb$^{TM}$.

The target values identified in Table 8 are key indicators that the GrayQb$^{TM}$ technology is feasible for mapping radioactively contaminated areas (field of view, spatial resolution, and minimum detectable total dose). The detection sensitivity was determined to be approximately 0.100 mrad as suggested by the literature [6-15]; however, better images can be obtained from PSPs at higher dose values. Based on the tests completed using an x-ray generator and americium-241 sources, the suggested detection sensitivity should be 0.200 mrad. The upper limit of the GrayQb$^{TM}$ technology dynamic range was estimated to be a few thousand rad; however, it is likely this upper limit is even higher. For most decommissioning and decontamination activities, the lower limit is more important than the upper limit of the dynamic range.

**Table 8. GrayQb$^{TM}$/GrayQb$^{TM}$ SF Characterization Summary.**

| Parameter | Target Values (before testing) [23] | GrayQb$^{TM}$ | GrayQb$^{TM}$ SF |
|---|---|---|---|
| Ambient Light Sensitivity | | PSP are light sensitive | |
| PSP response | | Linear | |
| Spatial Resolution | 1° | 1° | |
| X-ray spot influence on dose rate | | None | |
| Pixel size | | 1.00 mm | 0.64 mm |
| Field of View | 80° | 96 ° | 72 ° |
| Detection sensitivity determined using an x-ray generator | | 0.172 mrad | |
| Detection sensitivity determined in HPICF (using americium-241 sources) | | 0.104 mrad | |
| Suggested Detection Sensitivity | 0.200 mrad | 0.200 mrad | |

## 5.0 Conclusions

GrayQb$^{TM}$ technology allows for characterization of radioactively contaminated areas and can be used to speed the process and lower the cost of decontaminating these areas; reducing worker exposures and promoting ALARA considerations. Testing documented in this report, determined the GrayQb$^{TM}$ SF detection sensitivity to be 0.2 mrad. This remarkable sensitivity combined with low cost and ease of deployment makes the GrayQb$^{TM}$ technology ideal for mapping of contaminated areas with low dose rates. Testing performed at the 235-F PuFF facility exemplifies the usefulness of the device. It was thought that, due to very low dose rates in the selected area where the device was deployed, the GrayQB$^{TM}$ SF would likely not detect the contamination; however, not only did it detect the known area of contamination, it identified a second even lower dose area of contamination. Device characterization also demonstrated an impressive spatial resolution of 1°, which will allow contamination areas to be more accurately identified. Test results demonstrate that this technology can localize sources of radioactive contamination even at very low doses and then present the results as easy-to-understand images identifying hot spots as presented in this report.

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# Appendix A

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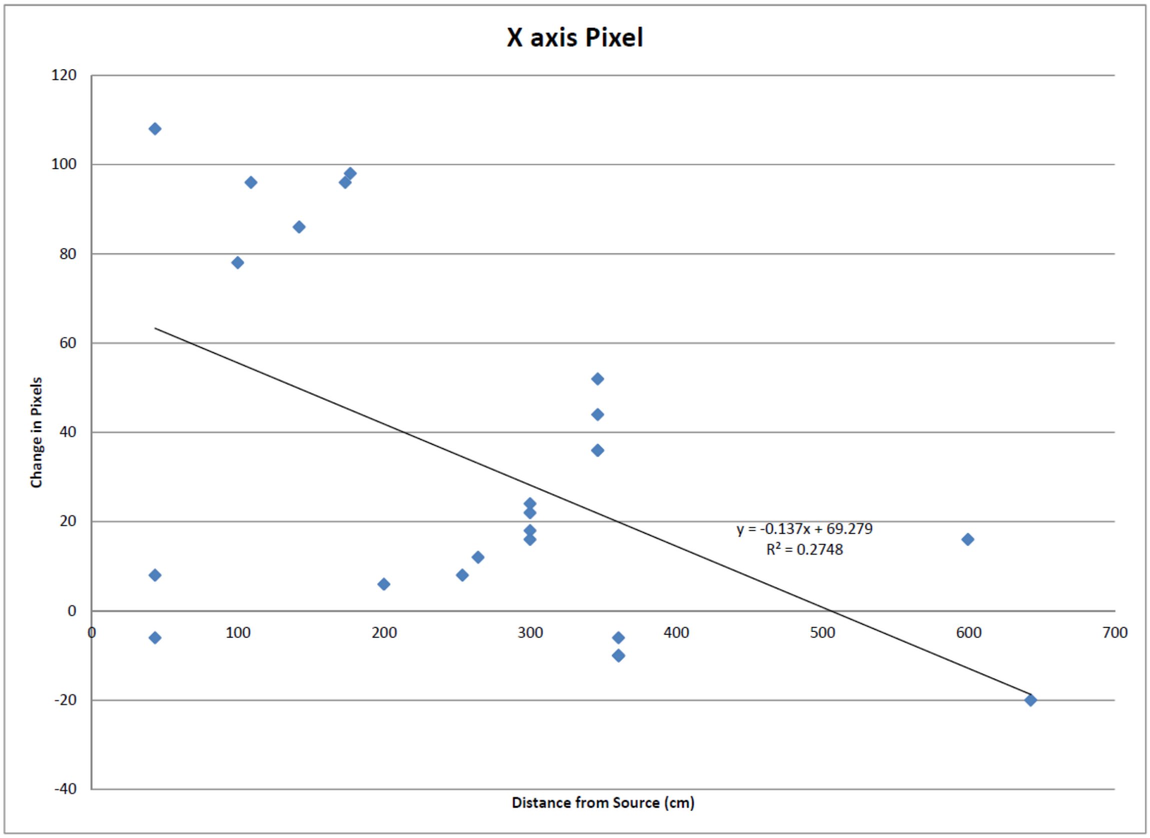
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80
60
40
20
0
-20
-40
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200
300
400
500
600
700
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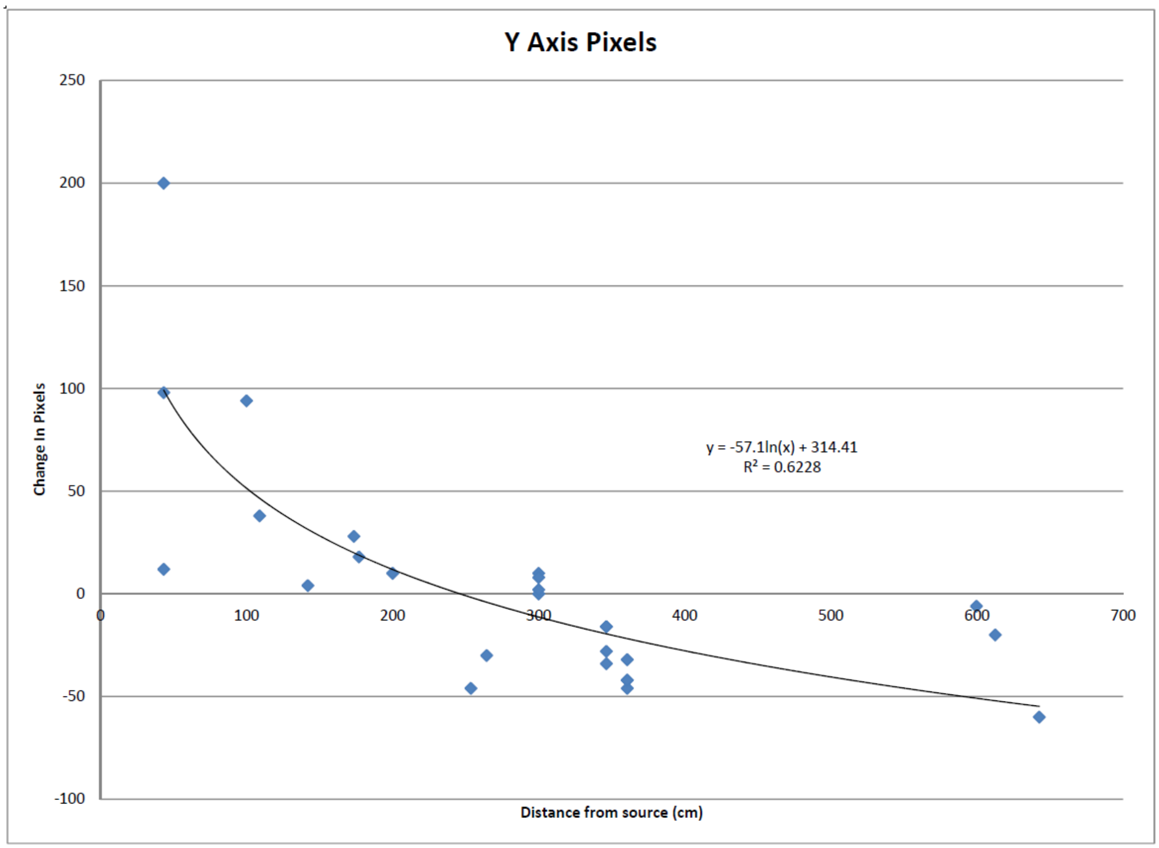
R² = 0.2748
Distance from Source (cm)


Y Axis Pixels
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200
150
100
50
0
-50
-100
Change In Pixels
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100
200
300
400
500
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y = -57.1ln(x) + 314.41
R² = 0.6228
Distance from source (cm)

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