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GrayQb™ Single-Faced Version 2 (SF2) Hanford Plutonium Reclamation Facility (PRF) Deployment Report

J.R.Plummer, D.M.Immel, M.G.Serrato, M.J.Dalmaso, D.J.Shull

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EXECUTIVE SUMMARY

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. 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 decontamination and decommissioning (D&D) effort. The PRF canyon D&D effort supports completion of the CHPRC Plutonium Finishing Plant Decommissioning Project. The GrayQb™ SF2 (Single Faced Version 2) 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. The Hanford PRF GrayQb™ Deployment was sponsored by CH2M Plateau Remediation Company (CHPRC) through the DOE Richland Operations Office, Inter-Entity Work Order (IEWO), DOE-RL IEWO-M0SR900210 [1].

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. 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). The device is then retrieved to remove the radiation sensitive phosphorus storage plate (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. 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. 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 [2].

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. 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. This was input into the jointly developed Hanford PRF GrayQb™ Deployment Plan [3].

The PRF canyon GrayQb^{TM} deployment was performed September 7 - 12, 2015. Ten deployments were completed as planned with each deployment consisting of a cluster of four GrayQb^{TM} devices mounted on a crane platform fixture. The ten deployments resulted in forty evaluations completed with summary results presented in the text of this document and individual results provided in Appendix B. Preliminary resultant images were provided to CHPRC at the test site. All GrayQb^{TM} devices were recovered and released from radiological controls by CHPRC; a contributing factor was the custom GrayQb^{TM} radiological bags provided by CHPRC. The crane platform fixture was not decontaminated and remained in the PRF canyon for future survey activities.

Data collected examined over 80% of the canyon surfaces. The initial deployment (D1) did not fully develop because the deployment time wasn't long enough; remaining deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time). Deployment 3 (D3) and deployment 4 (D4) were performed at essentially the same location; although this resulted in a small area of the east and west wall not being examined, this unintended deviation from the plan provided very useful information. First, the duplicate examination of the same location using two different GrayQb^{TM} devices produced results that were almost identical, thus demonstrating the repeatability of the results. Secondly, the two data sets provided a validation for the application of the post processing methodologies. D3 lasted 6.5 hours and D4 lasted 15 hours, after making 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.

The GrayQb^{TM} 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^{TM} 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.

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ABBREVIATIONS AND UNITS

2D	Two Dimensional
3D	Three Dimensional
AM	Additive Manufacturing
CHPRC	CH2M Plateau Remediation Company
D&D	Decontamination and Decommissioning
DOE	U.S. Department of Energy
EM-13	DOE Office of Environmental Management - Office of Deactivation and Decommissioning and Facility Engineering
FFT	Fast Forier
FOV	Field of View
GrayQb™	Pronounced "Gray Cube" (shortened version of GrayQb™ SF2 in this document)
GrayQb™ SF2	GrayQb™ Single-faced Version 2 radiation imaging device
HPICL	SRS Health Physics Instrument Calibration Laboratory
IEWO	Inter-Agency Work Order
IRL	R&D Engineering Imaging and Radiation Lab
NDE	Non-destructive Examination
PSP	Phosphor Storage Plate
PRF	Plutonium Reclamation Facility
RadCon	Radiological Control - Health Physics Operations
RAzer™	Radiation Analyzer Software
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
UV	Ultraviolet

1. INTRODUCTION

The Savannah River National Lab (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. 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 Plutonium Finishing Plant Decommissioning Project. The GrayQb™ SF2 (Single Faced Version 2) 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. The Hanford PRF GrayQb™ Deployment was sponsored by CH2M Plateau Remediation Company (CHPRC) through the DOE Richland Operations Office, Inter-Entity Work Order (IEWO), DOE-RL IEWO-M0SR900210.

2. BACKGROUND

2.1. GrayQb™ SF2 Device

The GrayQb™ SF2 (Single Faced Version 2) is a non-destructive examination (NDE) device developed by SRNL to generate radiation contour maps showing source locations and relative radiological levels present in the area under examination (Figure 1). This device allows for characterization of radioactively contaminated areas such as hot cells, small and large rooms, hallways, and waste tanks to support deactivation and decommissioning (D&D) activities. The GrayQb™ SF2 is a passive radiation mapping device composed of a custom tungsten shield, digital camera and a radiosensitive Phosphor Storage Plate (PSP). The device does not contain a radiological source and does not require an external power source. The device is approximately a 6 inch cube with a small lip where the mirror extends.

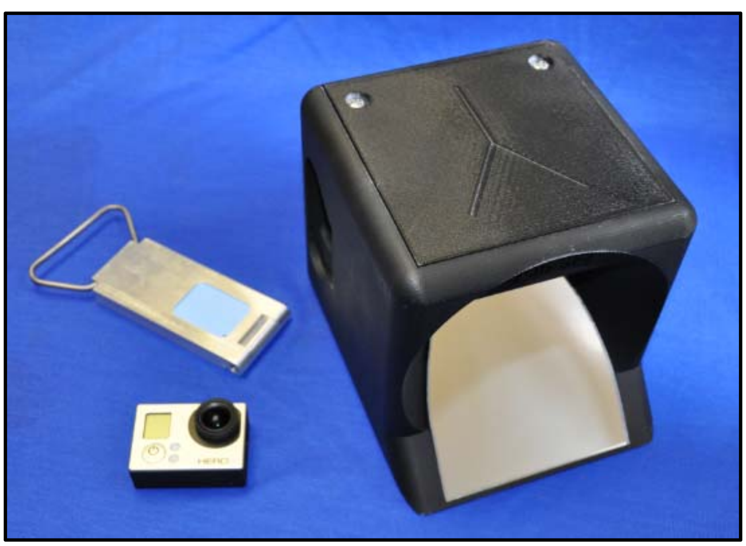


Figure 1 - GrayQb™ SF2 device with imaging plate holder and camera

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). The device is then retrieved to remove the camera and the radiation sensitive PSP plate for scanning by an external scanner. The PSP scanned result and the digital photos from the camera are downloaded to a laptop where resultant overlay images are generated using the SRNL developed RAzer™ (Radiation Analyzer) software. GrayQb™ images provide qualitative results in the form of relative radiological intensities observed; it does not provide quantitative measurements of radiation detection nor does it provide isotope identification. The device will not detect areas of radiological intensity if shielded from the device, e.g. if located behind equipment abandoned in place relative to the GrayQb™. See Appendix A for additional information on the GrayQb™ SF2 device and image processing.

3. DEPLOYMENT OVERVIEW

SRNL partnered with CHPRC to develop the Hanford PRF Deployment Plan [3] to capture the preparation activities, roles and responsibilities, and deployment scheme.

3.1. CONDUCT OF WORK

The PRF Canyon deployment was a joint effort performed by SRNL and CHPRC. The Hanford PRF canyon "hands on work" was performed and managed by CHPRC. SRNL personnel provided onsite device technical expertise and processing of preliminary results.

3.2.1 PRF Task Summary

SRNL support included:

- partnering with CHPRC to develop deployment and operational plans,
- design and fabrication of a crane deployment fixture to deploy the GrayQb™ devices into the canyon,
- shipping and use of GrayQb™ devices and processing equipment needed to support deployment,
- onsite GrayQb™ device technical expertise during the deployment,
- onsite crane deployment fixture technical expertise,
- onsite processing of preliminary results, and
- delivery of a technical report with final resultant images and a summary analysis.

CHPRC support included:

- partnering with SNRL to develop deployment and operational plans,
- performing onsite operations (hands on) work during the deployment of the devices,
- providing onsite work control and safety documentation,
- providing onsite cyber and wireless documentation, if required,
- providing a clean area for processing GrayQb™ results with the scanner and laptop,
- providing tailored radiological containment bags for the GrayQb™ devices, and
- providing radiation control support personnel to survey the GrayQb™ devices during the deployment activities.

3.2 GRAYQB™ SF2 CRANE DEPLOYMENT FIXTURE

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 GrayQb™ devices enabling four examinations to be performed during each deployment (Figure 2).

Three of the GrayQb™ devices were positioned in the crane deployment fixture to examine the three closest walls; the fourth GrayQb™ device was placed in the holder to face either upward to examine the ceiling or downward to examine the floor. The crane deployment fixture was affixed to the PRF crane hook for deployment as shown in Figures 3 & 4. The fixture included wirelessly activated shielding to minimize exposure of the PSP plate while being placed into position. The crane deployment fixture will not be decontaminated and will remain in the PRF canyon for future GrayQb™ deployment.

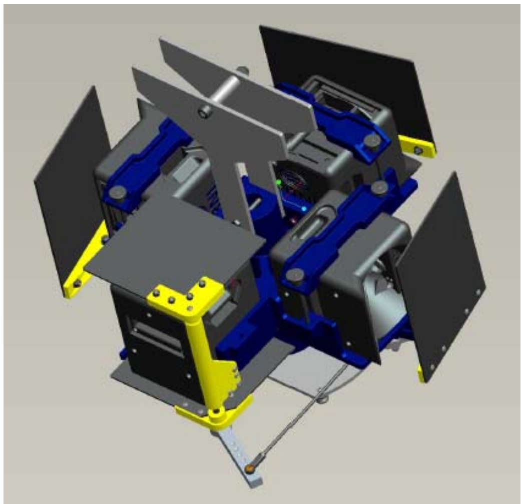


Figure 2 - GrayQb™ Crane Deployment Fixture

Figure 3 - Deployment fixture affixed to overhead crane hook for deployment

Figure 4 - Deployment fixture with four mounted GrayQb devices in PRF

3.3 PRF DEPLOYMENT SCHEME

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. 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. Figure 5 shows the GrayQb™ FOV projected on the walls and ceiling. Each deployment included four GrayQb™ devices with three of the devices examining the nearest facing wall and the fourth device facing either the ceiling or floor.

Figure 5 - 3D Visualization of Deployment 5 (lower GrayQb™ cluster) and Deployment 10 (upper GrayQb™ cluster) showing GrayQb™ FOV shadowed on wall.

The minimum number of deployments for complete coverage was determined to be ten (10) locations. The deployment scheme included five (5) locations along the upper third of the canyon and five (5) deployments along the lower third of the canyon. The deployment locations were planned to be positioned along the center line of the canyon, i.e. 13 feet from each side wall. To capture the entire floor surface in the device FOV, it was determined to be necessary to view it from the upper third of the canyon and conversely to view the entire ceiling it was necessary to view it from the bottom third of the canyon.

The deployment scheme included the contingency to modify the plan based on initial PRF GrayQb^{TM} results and CHPRC priorities. GrayQb^{TM} results are dependent on source strength, uniformity of the source over a large area, distance and time. Weak source strengths and uniform contamination over a large area require more deployment time and/or less distance to the area of interest to acquire positive results.

4. DEPLOYMENT

4.1. FIRST DAY ACTIVITIES

The deployment goal for the first day at PRF was to complete the required pre-deployment preparations and to place the first deployment of GrayQb^{TM} devices into the canyon for an overnight data collection. It was understood that the deployment locations and times developed for the deployment plan may be modified during the onsite deployment based on results obtained from the first deployment and CHPRC priorities and needs. It was desired by CHPRC to attempt to perform the first deployment for a relatively short period of time during Monday afternoon, then to finish the day with the overnight deployment in place.

First day preparations included a significant number of activities to be completed in order to initiate a first day deployment. The large number of activities that needed to be successfully completed on the first day was identified as a risk in the deployment plan; however, all activities were readily completed.

Required first day preparation activities included the following (the details of each of these activities are covered in subsequent subsections):

- SRNL equipment and fixture received and available at PRF site,
- processing of SRNL visitors onsite,
- assembly of the crane deployment fixture and wireless controls,
- wireless controls checkout,
- setup of the GrayQb^{TM} processing area, and
- SRNL instruction on GrayQb^{TM} device and fixture use.

4.1.1 SHIPPING, RECEIVING AND DELIVERY OF EQUIPMENT

The GrayQb^{TM} suite of equipment and crane deployment fixture were shipped to Pasco, WA, prior to arrival of SRNL personnel. The equipment was retrieved by SRNL personnel upon arrival in Pasco and brought to the PRF facility on the first day of deployment. SRNL equipment provided for the deployment included the following:

- The GrayQb^{TM} equipment suite which included five GrayQb^{TM} devices (one spare), analysis laptop, PSP scanner, 4 cameras and accessories, PSP illuminator, power strip and supplies.

- The crane deployment fixture and associated accessories to include the electronics developed to wirelessly activate fixture shielding, batteries and laser pointers.

4.1.2 PROCESS SRNL VISITORS ON SITE

SRNL acquired the required badging and dosimetry and completed visitor orientation and facility specific training provided by CHPRC prior to travelling to the work site. SRNL was escorted by CHPRC when required at the PRF.

4.1.3 CRANE DEPLOYMENT RIG

4.1.3.1 Crane Rig Assembly

The crane deployment fixture required assembly upon arrival at the Hanford site. The crane platform was assembled and the GrayQb™ devices prepared for mounting onto the crane platform with assistance from CHPRC. Upon assembly, checkout of electronics developed to wirelessly activate the crane fixture shielding was successfully performed.

4.1.3.2 Mounting of the Crane Deployment Fixture onto the Overhead Crane Hook

The crane deployment fixture was designed to be placed onto the PRF overhead canyon hook during the first deployment. CHPRC decided to use the north door for deployments into the canyon versus the PRF airlock, which greatly simplified the process. The crane deployment device remained on the canyon hook for the duration of the GrayQb™ deployments. The GrayQb™ devices were installed onto and removed from the holder at the north entrance for each deployment as shown in Figure 6.

Figure 6 - Loading the GrayQb™ devices on the fixture at the PRF canyon north door

4.1.4 WIRELESS CONTROLS CHECKOUT

The fixture’s wireless controls were required to be tested by CHPRC and certified to not interfere with safety systems in the PRF prior to use. A spare set of wireless controls was brought to Hanford and provided for testing. Given that the wireless testing could not be completed until the second day of deployment, CHPRC/SRNL decided to continue with the initial deployments without using the fixure’s deployment shields, i.e. the shields would remain in the open position while the fixture was positioned into place. The initial deployment plan called for the first deployments to be performed at the south end of the canyon; because the shields could not be used, CHPRC/SRNL decided to perform the first deployments closest to the device entry point (north end) to minimize the time the PSP was exposed during the deployment positioning process.

4.1.5 SETUP OF GRAYQB™ PROCESSING AREA

A clean area to setup as the GrayQb™ processing area was provided by CHPRC in a maintenance room in the PRF facility. Surface space (i.e. tabletop approximately 3’ x 6’) to accommodate the GrayQb™ scanner, laptop and working area for device processing and prepping for two persons was needed and provided (Figure 7). Additionally, a 20A or greater 120V power outlet was provided to power equipment as requested.

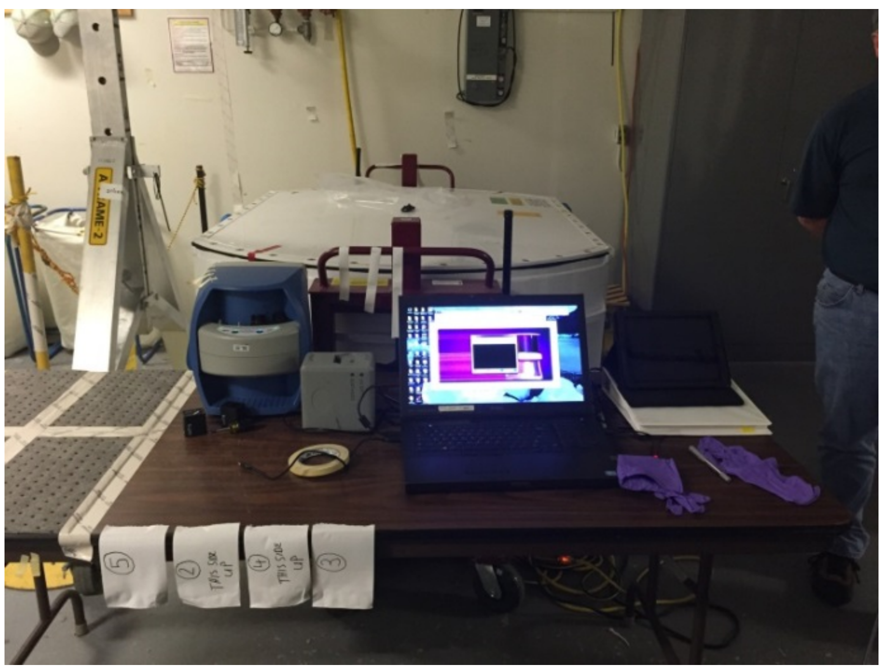


Figure 7 - SRNL GrayQb™ processing area in the PRF maintenance room

4.1.6 INSTRUCTION ON GRAYQB™ DEVICE AND CRANE FIXTURE USE

SRNL provided an introduction and instruction on the GrayQb™ devices, loading of the devices onto the crane deployment fixture and operation of the shielding electronics. CHPRC operators practiced using the wireless shielding controls and performed a dry run of loading the GrayQb™ devices onto the crane deployment device (Figure 8). During the dry run process, CHPRC operators suggested a method of labeling the GrayQb™ devices during the SRNL preparation process that greatly enhanced the success that the devices would be properly loaded and correctly oriented onto the crane deployment fixture (Figure 9).

Figure 8 - Dry run mounting of GrayQb™ devices onto crane fixture

Figure 9 - GrayQb™ devices labeled with CHPRC operator suggested scheme to ensure proper placement and orientation onto fixture

4.2 DEPLOYMENT STEPS

Each deployment of the GrayQb™ devices into the canyon included the following (the details of each of these activities are covered in the subsequent subsections):

1) Preparing four GrayQb™ devices for deployment, to include device bagging, then loading them onto the crane deployment fixture.
2) Positioning of the GrayQb™ devices in the canyon by the crane operator to the desired location for the current examination.
3) Maintaining the GrayQb™ devices in the desired position for the pre-determined deployment time (gross movement of devices during the deployment can negate results).
4) Returning of the GrayQb™ devices to north door, debagging & providing the devices to SRNL for image retrieval and processing of preliminary results
5) Generating preliminary results by scanning the PSP plates and importing scan and camera data onto the laptop for overlay by the RAzer™ software.

4.2.1 DEPLOYMENT DETAIL

This section provides details for each of the steps identified in the above overview. Additionally, the steps are annotated with the organization that was primarily responsible for the completion of the task described.

4.2.1.1 Preparation for Deployment

1. SRNL and CHPRC discussed and determined the daily and overnight deployment locations based on results to date, current conditions, dose rate measurements and CHPRC priorities, Figure 10.

Figure 10 - CHPRC and SRNL pre work planning

2. CHPRC provided the pre-job briefing prior to the daily deployment(s).

3. SRNL prepared four GrayQb™ devices for each deployment by performing the following steps:
   a) *PSP Plate.* Erased the PSP plate to be used then applied an even background intensity to the plate using the SRNL PSP Pre-illuminator. Loaded the PSP plate into the GrayQb™ SF2 device and secured into place.
   b) *Camera.* Changed the camera battery with a freshly charged battery between each deployment. Turned the camera on for deployment and installed in the GrayQb™ housing. Ensured camera settings were correct, typically set to take a photo every 5 minutes.
   c) *Labeling.* The GrayQb™ devices were labeled with tape using a scheme developed by the CHPRC operators to help ensure correct placement and orientation of devices into crane deployment fixture.

4. CHPRC accepted prepared GrayQb™ devices from SRNL and bagged the devices in the clean area of the maintenance room. CHPRC developed custom 6”x6”x6” clear 20 mil plastic radiological

bags from a housing provided by SRNL for use in bagging the GrayQb™ devices. Each device was individually bagged as shown in Figure 11.

5. CHPRC dressed out operators picked up the bagged GrayQb™ devices from the staging area and moved them to the north entrance to mount onto the crane deployment fixture (Figure 12). CHPRC prepared the jig for the deployment. This included swapping a fresh battery onto the fixture for actuating the shielding when needed and replacement of the fixture laser sight when needed.

Figure 11 - RadCon bagging GrayQb™ device with custom 6”x6”x6” clear 20 mil radiological bags

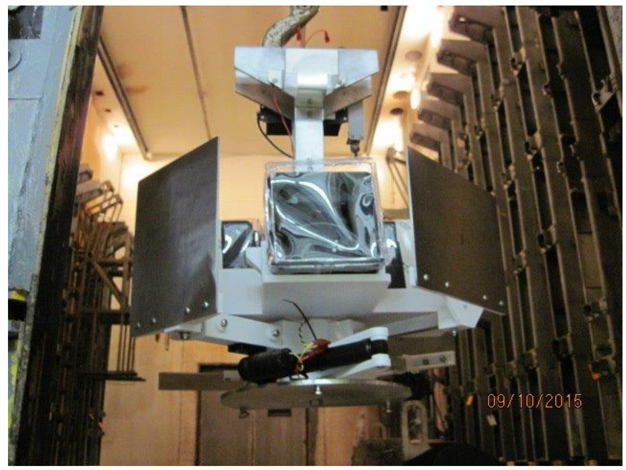


Figure 12 - Deployment fixture with four bagged and mounted GrayQb™ devices at north entrance of PRF canyon

4.2.1.2 Positioning of Devices in the Canyon

The CHPRC crane operator positioned the deployment fixture with GrayQb™ devices into the desired location. Placement was performed visually since no automated positioning system or location data was available to the crane operator as shown in Figure 13. Once the crane was in position and stable, the GrayQb™ shielding was opened by the CHPRC operators at the north entrance using a wirelessly operated switch for those deployments where the shields were used. Visual placement was assisted by the following:

- the crane hook position could be viewed from the crane station window located on the upper level of the canyon,
- a video camera at the north end of the canyon with pan tilt zoom (PTZ) capabilities could be viewed from the crane station,
- a laser pointer was affixed to the deployment device in parallel to the device field of view to assist in perpendicular correct deployment orientation with respect to the wall, and lastly,

- during the dry run loading of the devices onto the crane deployment fixture, the crane operator suggested marking the fixture with a large arrow that could be seen from the crane station to assist with correct orientation of the deployment device.

Figure 13 - Crane Operator Station

4.2.1.3 Maintaining the Crane Position at Deployment Location

GrayQb™ deployments at PRF lasted from approximately 3.5 to 15 hours. During this time, the gamma image of the area being examined is forming on the radiologically sensitive PSP plate. If the position of the GrayQb™ device moves significantly during the deployment, identifying the location of any detected gamma radiation can be compromised. It was noted that once the crane hook was in position, the fixture stabilized quickly and remained practically stable. The stability of the fixture was examined by viewing the GrayQb™ photos taken every 5 minutes at the deployment location.

4.2.1.4 Retrieval of GrayQb™ Devices

At the conclusion of the deployment period in the canyon, the following steps were performed:

1) CHPRC operators closed the GrayQb™ FOV shielding using the wirelessly operated switch, when shielding was used.
2) The CHPRC crane operator returned the crane deployment fixture to the north door unloading location.
3) CHPRC operators retrieved the GrayQb™ devices from the fixture and returned them to the radiologically controlled area of the maintenance room used to process results (Figure 14).

Figure 14 - Landing area for moving GrayQb devices between clean area and radiological area

4) The GrayQb™ devices were debagged and checked for transferable and fixed contamination. Radcon removed the PSP plate and camera from the GrayQb™ device and also checked them for contamination. SRNL devised a recovery scheme where after the completed rad survey of the devices, the PSP holder and camera were removed from the GrayQb™ housing and placed into a separate numbered container that matched the device number as shown in Figure 15. This recovery scheme proved to be essential in maintaining clarity in data acquisition and processing. The numbered container and emptied GrayQb™ device were delivered to SRNL for image retrieval and processing of results. SRNL was able to dry run PSP and camera removal with Radcon using the spare GrayQb™ device; dry run included the discussion to protect the PSP from ultraviolet (UV) light as much as possible while processing as UV light can erase the gamma signal on the plate.

Figure 15 - GrayQb undergoing radiological survey

4.2.1.5 Processing of Results

SRNL received the unbagged and uncontaminated GrayQb™ devices and the containers holding the PSP holder and cameras, as shown in Figure 16, and processed results as follows (see Appendix A for additional results processing information):

(1) Placed the PSP plate into the ScanX Duo scanner to obtain the gamma image on the laptop.
(2) Downloaded the photos from the GrayQb™ cameras onto the laptop.
(3) Produced preliminary resultant images using the SRNL developed RAzer™ software to process and superimpose the PSP image onto the visual data from the camera. Preliminary results were provided to CHPRC via USB flash drive.

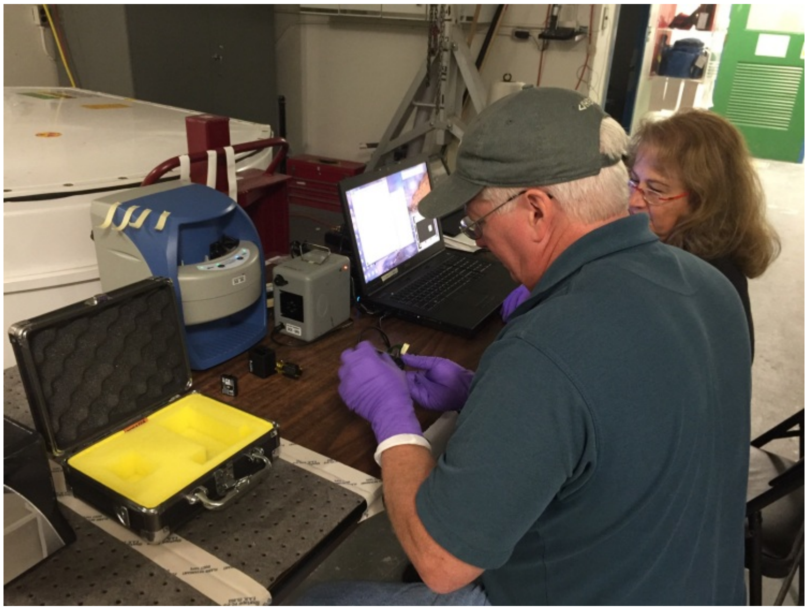


Figure 16 - SRNL Processing Station

4.3 DEPLOYMENT ACTIVITIES PERFORMANCE

The estimated time to prepare, deploy and process results between the deployments was three hours. This estimate was based on the activities shown in Table 1. It was expected that as experience was gained while performing these activities, the time to complete them would decrease.

Estimated time to perform deployment activities	
Activity	Est Time (min)
SRNL Deployment Prep (Section 5.1.1)	20
CHPRC Deployment Prep (Section 5.1.1)	30
CHPRC Crane Deployment (Section 5.1.2)	20
CHPRC Retrieval of Devices (Section 5.1.4)	60
SRNL Processing of GrayQb data (Section 5.1.5)	30
Total Time to prep, deploy and process	160

Table 1 - Estimated time required between deployments

Actual field experience showed deployment activities took a little over an hour for the first retrieval and prep cycle then improved with experience to an hour or less as shown in Table 2. This is the time from when the fixture began movement from the deployment location to when the next deployment was prepped and in place. This time does not include the prep time for operators to dress out and undress before and after deployment.

ACTUAL time to perform deployment activities	
Activity	Time (min)
Time between Deployment 1 & 2	73
Time between Deployment 2 & 3	60
Time between Deployment 3 & 4	50
Time between Deployment 4 & 5	63
Time between Deployment 5 & 6	55
Time between Deployment 6 & 7	55
Time between Deployment 7 & 8	53
Time between Deployment 8 & 9	59
Time between Deployment 9 & 10	57

Table 2 - ACTUAL time required between deployments

5.0 RESULTS

The PRF canyon deployment was performed September 7 - 12, 2015. Ten deployments were completed as planned. Each deployment consisted of four GrayQb™ devices; therefore forty sets of data were acquired. Each deployment data set included both a gamma image captured on the PSP plate and a digital photo of the area examined. The SRNL Developed RAzer™ (Radiation Analyzer) software produced preliminary resultant images from the PSP gamma image and the digital photo which were provided to CHPRC at the test site. CHPRC reported that the PRF canyon ambient dose rate ranged from 50 - 100 mR/hr at 30 cm from wall surfaces [4]. Most floor surface had undergone initial decontamination and debris removal with subsequent surface contamination measured from 60 to 1250 mR/hr at the time of the GrayQb™ deployment.

The goal was to maximize the deployment times of the GrayQb™ device in the canyon while working within the hours of the CHPRC work day. The plan was to conduct ten deployments in the canyon over six days at heights ranging from 9 to 20 feet above the floor surface. Two deployments would be performed during each 24 hour period, one deployment during the day shift and one deployment to be put in place at the end of the day shift to be left overnight in the canyon. Each morning consisted of retrieving the overnight deployment, processing the results then preparing and placing the day deployment.

5.1 DEPLOYMENTS PERFORMED

The initially planned first deployment was to be an overnight deployment to be positioned at the end of the first day activities, at the request of CHPRC with time permitting an initial test run was performed the afternoon of the first day. This deployment lasted roughly 3.6 hours just inside the north door at 9 feet above the floor surface (23' from the ceiling). The second test was an overnight deployment to maximize the device exposure in the canyon; this deployment lasted 15. 8 hours. Based on preliminary results from the first two deployments, the fixture minimum exposure was estimated to be roughly 6.5 hours. The test plan was adjusted to conduct a 6.5 hour test run during the day followed by an overnight test run for roughly 15 hours. Deployment times are shown in Table 3. Test runs 1 to 5 were completed at a height of 9 feet above the floor surface and test runs 6 to 10 were completed at a height of approximately 21.5 feet from the floor (Table 4). Originally, test runs 6 to 10 were to be completed at approximately 23 feet from the floor surface to capture the entire floor in the FOV; however, to obtain the 23 foot height required a different hook to be installed on the overhead crane between deployments 5 and 6. CHPRC/SRNL decided that the risk of changing out hooks to the presently successful deployment setup outweighed the desire to capture the edges of the floor. Deployments are abbreviated as "D#" in this document where # is the deployment number (1 to 10).

Deployment Times				
D#	Day/Shift	Start Time (from photo)	End Time (log)	Deployment Time (hrs)
D1	Monday/Day	11:58 AM	3:32 PM	3.6
D2	Monday/Overnight	4:47 PM	9:00 AM	15.8
D3	Tuesday/Day	9:57 AM	4:35 PM	6.5
D4	Tuesday/Overnight	5:28 PM	8:22 AM	15
D5	Wednesday/Day	9:21 AM	4:35 PM	7
D6	Wednesday/Overnight	5:36 PM	8:15 AM	14.8
D7	Thursday/Day	9:11 AM	5:00 PM	7.8
D8	Thursday/Overnight	5:53 PM	7:30 AM	13.6
D9	Friday/Day	8:29 AM	1:30 PM	5
D10	Friday/Afternoon	2:27 PM	7:40 PM	5.2

Table 3 - Deployment Times

Deployment Locations : estimated visually **PRF Canyon area of interest = 52’8”L x 26’W x 32’H** *For each deployment, one device faced the west wall and one device faced the east wall. The third device faced the closer of the north wall or the south wall and the fourth device faced either up (to examine the ceiling) or down (to examine the floor).*							
D#	West Wall	East Wall	South Wall	North Wall	Ceiling	Floor	Deployment Time (hrs)
D1	12.5'	12.5'		8'	23'		3.6
D2	12.5'	12.5'		17’	23'		15.8
D3	12.5'	12.5'		26’	23'		6.5
D4	12.5'	12.5'	26'		23'		15
D5	12.5'	12.5'	8'		23'		7
D6	12.5'	12.5'		8'		21.5'	14.8
D7	12.5'	12.5'		17’		21.5'	7.8
D8	12.5'	12.5'		26’		21.5'	13.6
D9	12.5'	12.5'	17'			21.5'	5
D10	12.5'	12.5'	8'			21.5’	5.2

Table 4- Deployment Locations, visually estimated

5.2 PSP POST PROCESSING

Post processing of the data was performed to validate preliminary information provided to CHPRC and to analyze the data for distribution tendencies, conclusions and to enhance the overall usefulness by normalizing data for time and distance and providing summary views. Post processing began with the adjustment of each PSP gamma image to correct for image alignment, remove outlier pixels, and to adjust for intensity, time and distance as described below.

- PSP image alignment corrected. When the PSP plate is fed into the scanner to be read, it rarely goes in at exactly a 90 degree angle; each raw PSP image was viewed and rotated, if required, to correct the PSP alignment. The greatest correction angle of the PSP files was less than 3 degrees.
- Outlier pixels, if present, were removed. On some of the PSP resultant images there were one or two “hot” pixels that would skew the results, these pixels were removed from the raw PSP images. A typical PSP image has a resolution of approximately 780 x 600 pixels.
- An intensity correction algorithm was developed and applied to each PSP image. A gamma source directly in front of the GrayQb device pinhole will produce a higher intensity on the PSP plate than the same gamma source located at an angle to the center line of the pinhole. Testing and data collection of this effect was performed at SRNL. Using this test data an algorithm to correct for this effect was developed and applied to the PSP images.
- Time and Distance normalization. The deployments at the Hanford PRF were completed for different periods of time and at various distances. The intensity of each PSP image was adjusted to normalize for the deployment length of time. Additionally, the floor PSP image intensities were distance normalized to match that of the walls.

5.3 PSP MONTAGE

The PSP montage shown in Figure 17 on the next page was created using the post processed PSP images. The montage consists of the PSP gamma images only, no overlays onto photos. It is useful for seeing areas of higher intensities and trends in the data. A 16 color intensity map was applied to the post processed PSPs. The colors are divided into sixteenths; the PSP values in the top sixteenth are colored white, the intensity legend is included in Figure 17. The PSP data has been roughly normalized for time and distance, thus the intensities from one PSP is “calibrated” to the intensities of the other PSPs. The PSP results have been arranged to depict the surface of the canyon they represent. A small area on the lower west and east wall was not examined (discussed later) and is shown with an “X” on the montage. This view helps to envision where the highest intensities are present. For instance, we can note that the south wall, most likely due to the floor, is much “hotter” than the rest of the canyon. Also, we can see a pattern of “hot spots” in the bottom wells of the strong backs along the bottom of the east and west walls.

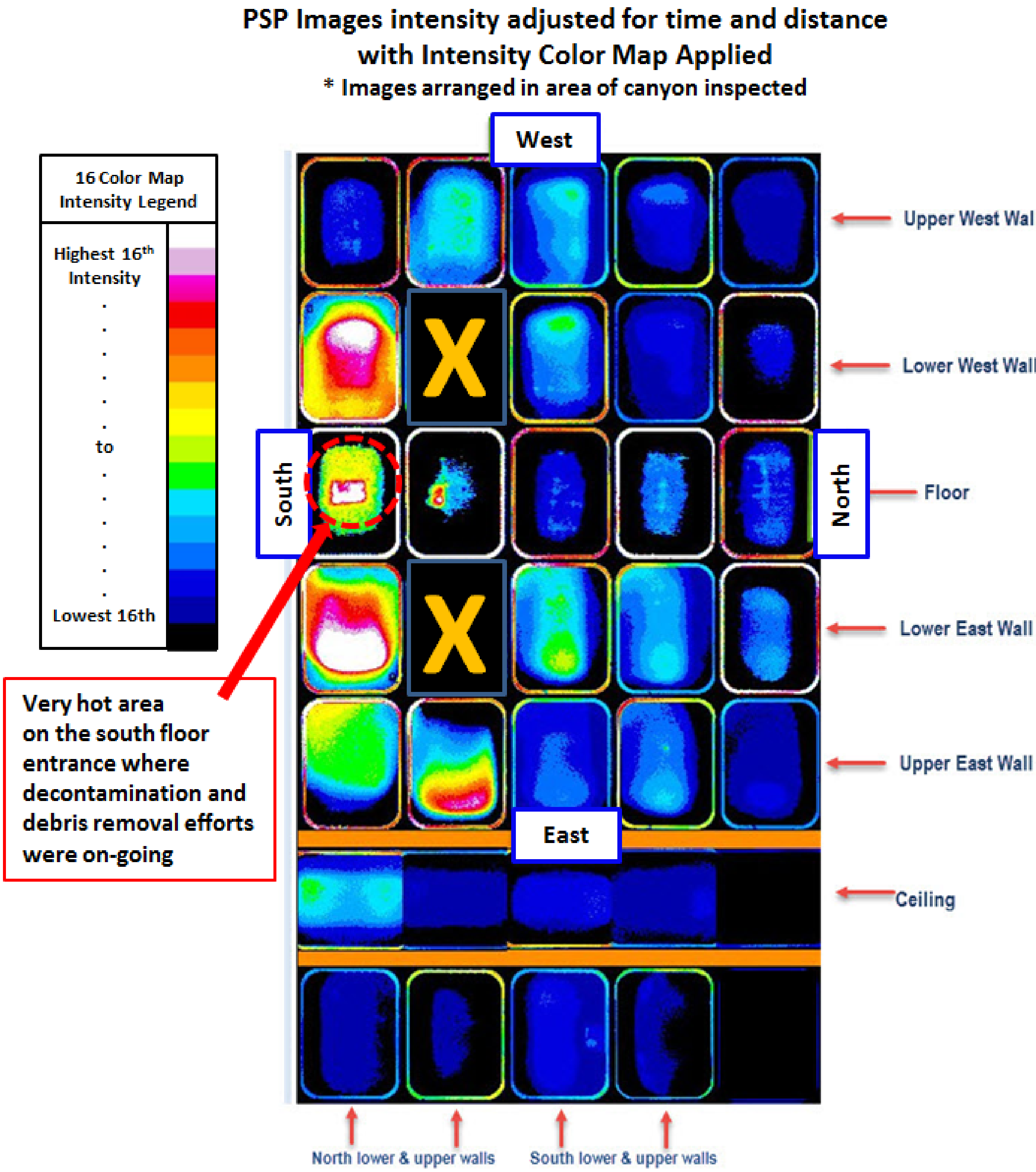


Figure 17 - Post processed PSP images with color map applied

5.4 PHOTO POST PROCESSING

Digital images were post processed to remove fisheye effect caused by the GoPro camera (Figure 18). Post processed digital images were used for final results Preliminary results provided to CHPRC were created using the raw image. Use of the photo with the fish eye removed required adjustment to the overlay algorithm; however by using raw calibration data it proved to be more accurate at overlaying the gamma image onto the photo and was therefore incorporated.

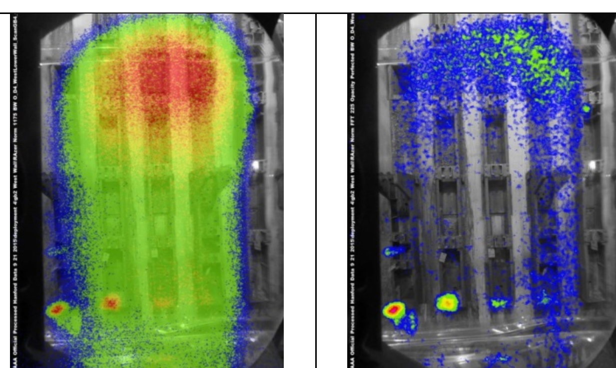
IMAGE WITH FISHEYE | IMAGE FISHEYE REMOVED

Figure 18- Removal of fisheye effect from digital images

5.5 PSP POST PROCESSING TO HIGHLIGHT HOT SPOTS

A Fast Fourier Transform (FFT) filter was applied to each post processed PSP image using the ImageJ freeware program. Applying the FFT filter highlights areas in the image where intensities are changing and thus helps to emphasize the hot spots in the image as can be seen in Figure 19. This FFT processed PSP is included in the results.

Application of FFT filter to highlight hot spots



D3 Post processed PSP result BEFORE FFT | ***D3 Post Processed PSP result AFTER FFT***

Figure 19 - Use of FFT filter to highlight hot spots

5.6 RAZER™ RESULTS

The SRNL developed Radiation Analyzer™ (RAzer™) software program was used to generate the deployment results. RAzer™ imports the 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 as shown in Figure 20. The radiological information from the PSP is presented as assigned colors similar to a heat map. Overlay colors represent different source intensities (e.g. magenta is the highest intensity, blue is the lowest intensity, etc.).

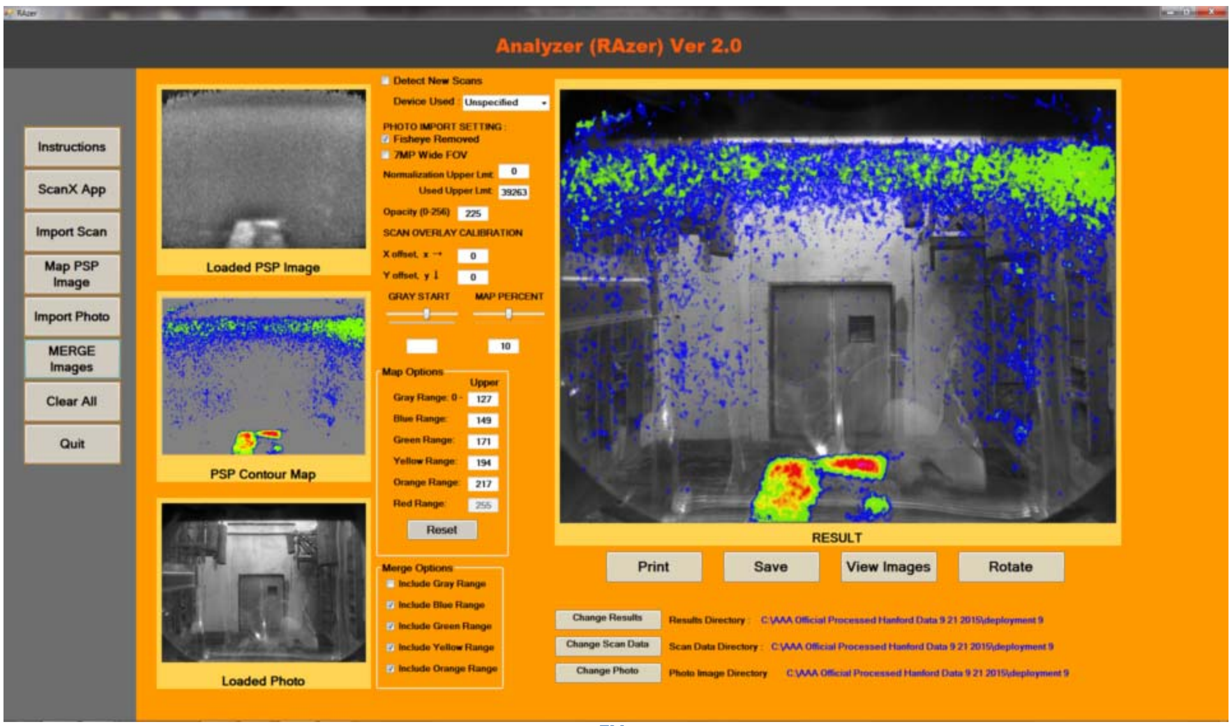


Figure 20 - RAzer™ Software Program

The results from each deployment are provided in Appendix B and are presented as a set of the three images shown in Figure 21. The data set includes the digital image of the area being evaluated for reference. The second image is the RAzer™ result of the deployment using the post processed PSP and digital image, but prior to the application of the FFT algorithm. The third image is the RAzer™ result using the PSP image post processed with the FFT algorithm to highlight hotspots.

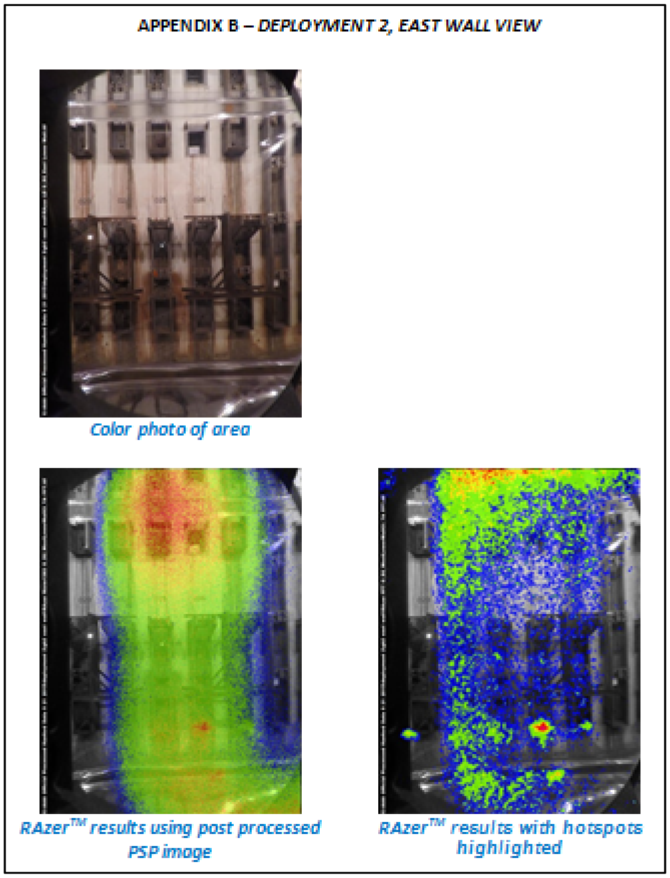


Figure 21- Example of the data set provided for each deployment in Appendix B

5.7 BACKGROUND RADIATION EFFECTS

During the deployment process it was noted on the preliminary image results, an additional background radiation shape was appearing on the processed PSP image as shown in Figure 22. It was initially thought to be "radiation shine" (radiation fluoresce emitted from the floor surface) scattering off the adjacent wall surfaces. This effect was most noted on the lower east and west wall sections and the south end of the canyon, where the floor emitted higher energy intensity than the north end canyon floor.

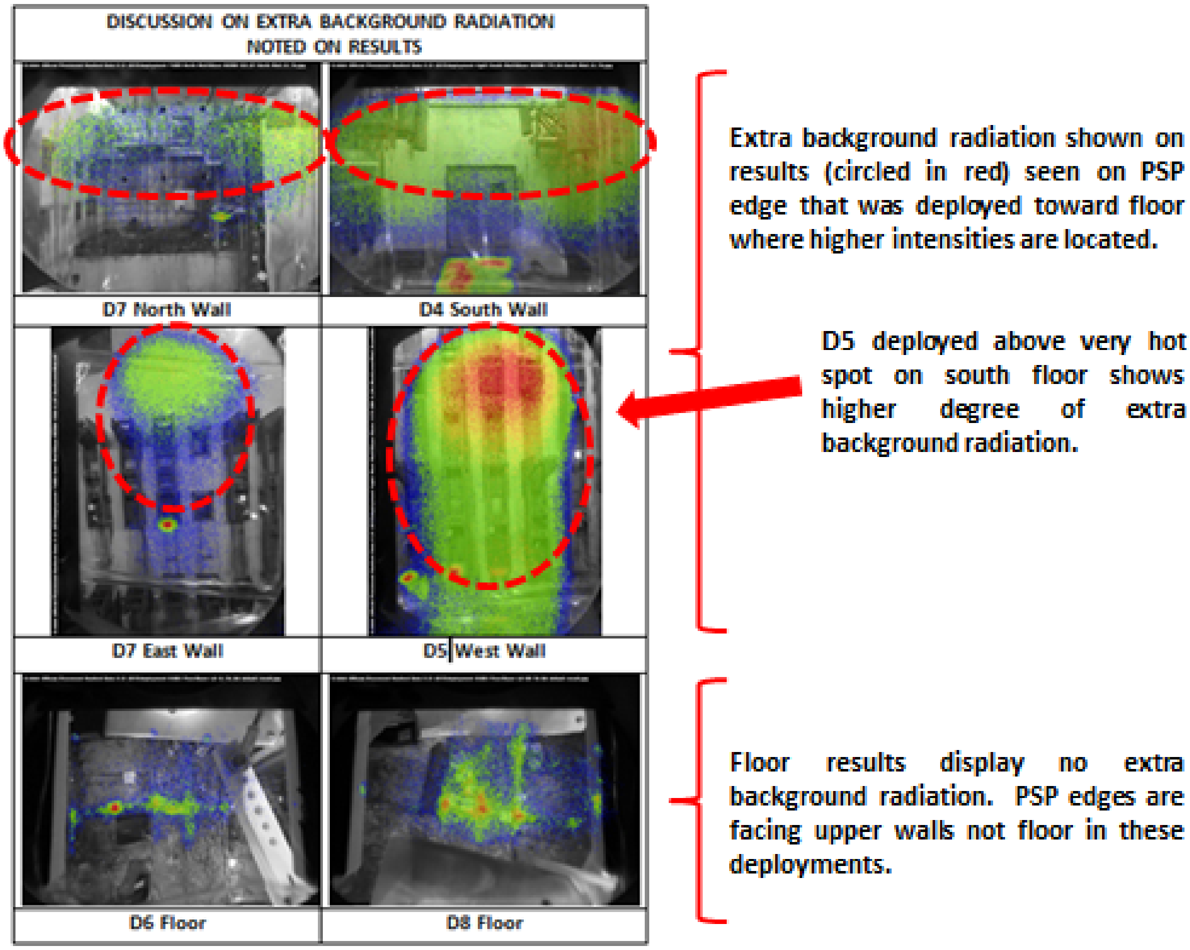


Figure 22 - Discussion of background radiation feature

During the initial deployments it was noted that the extra shine was primarily on the PSP edge closest to the floor. For Deployment 10 (D10) West Wall SRNL decided to add side shielding around the PSP holder inside the GrayQb^{TM} device to determine if the shine was from the walls or if radiation was entering from the side and accessing the PSP in the small area between the Tungsten plate and the PSP holder. The result obtained with the side shielding is shown in Figure 23. The additional shielding appeared to prevent the background shadow previously attributed to shine. Although the shadow is an extra feature on the PSP which makes the unprocessed PSP images more difficult to interpret during preliminary analysis, the shadows do not seem to ultimately hinder the acquisition of the hot spots. Deployment 10 overlapped with D9 on a significant hot spot that was still visible in D9 after the application of the FFT algorithm as can be seen in Figure 23. Another feature to note is that the uniform contamination on the wall is more clearly visible on the D10 result.

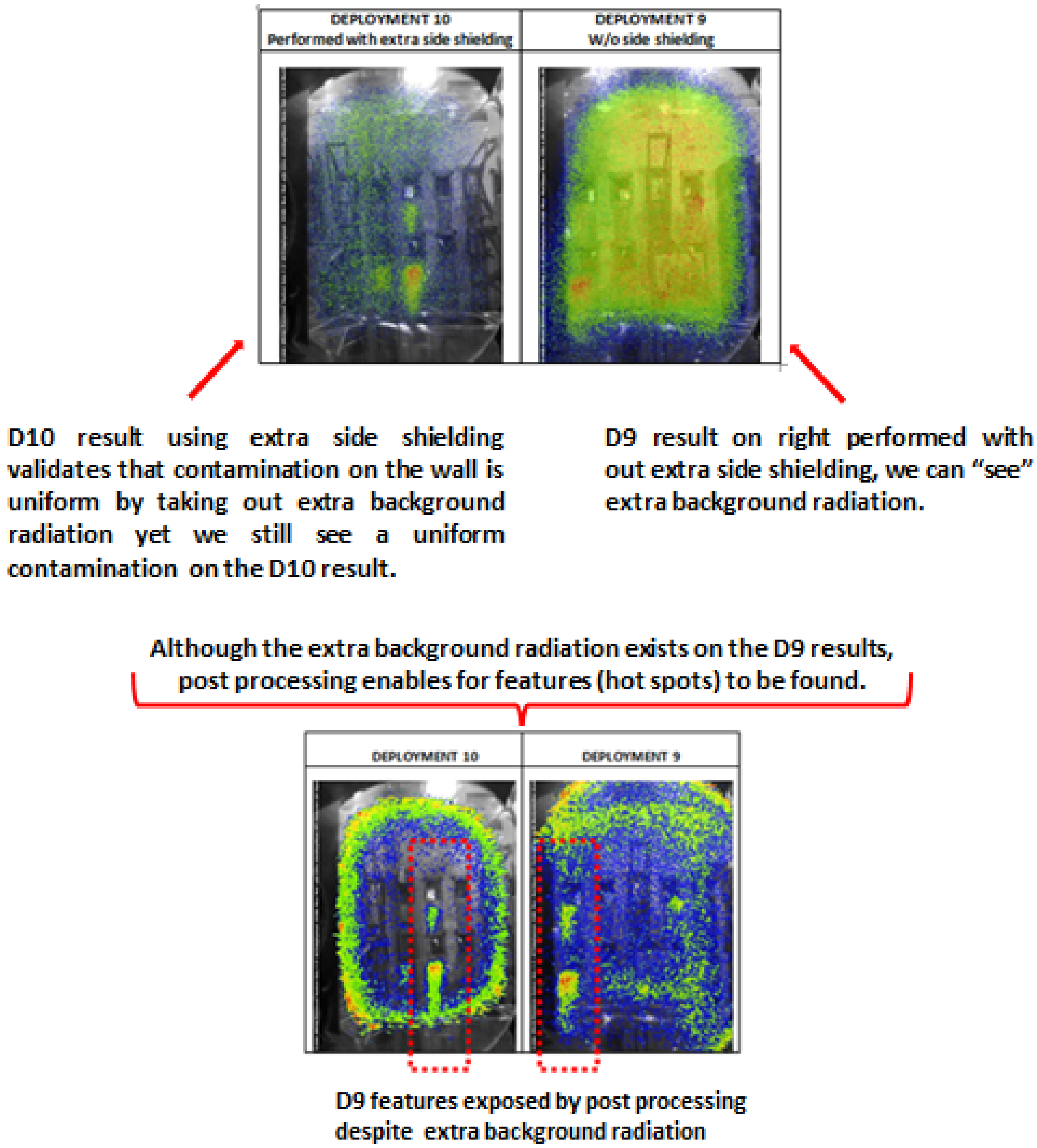


Figure 23 - Side shielding discussion

5.8 DEPLOYMENT ITEMS OF NOTE

5.8.1 Missing Coverage and Useful Information

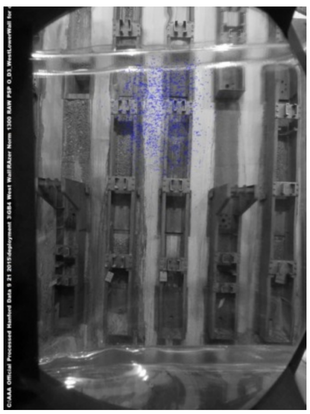
Deployment 1 (D1) did not produce complete PSP images due to the short deployment time, see Appendix B. D3 and D4 were performed at essentially the same location with the crane fixture rotated 180 degrees. The plan was for D4 to be rotated 180 degrees and moved closer to the south wall; while the fixture was rotated it was not moved closer to the wall so there is a small area along the lower east and west wall that did not get examined. This unintended plan deviation provided very useful information. First, the results obtained from D3 and D4 examining the same area of the east wall and west wall are almost identical, thus demonstrating the repeatability of the GrayQb™

results (Figure 24). Additionally, the crane fixture was rotated between the two views, so the same results were obtained using two different GrayQb™ devices. Lastly, the post processed intensities on the D3 and D4 were more similar than preprocessed results which was a good check for the time adjustment. D3 lasted 6.5 hrs and D4 lasted 15 hrs, when the preprocessed PSP for these deployments was held to the same normalization scale on RAzer™ (normalized to 1300), D3 barely showed any result compared to D4 (Figure 24, column 1). After adjusting the intensity for time, the Razer™ results for D3 and D4 were very similar (Figure 24, column 2). Hot spots located for D3 and D4 were almost identical (Figure 24, column 3).

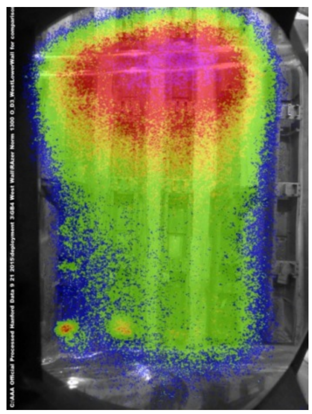
Comparison of Deployment 3 & 4 performed on same location

- **demonstrates repeatability of results and**
- **validity of algorithms used to adjust for time and angle intensity**

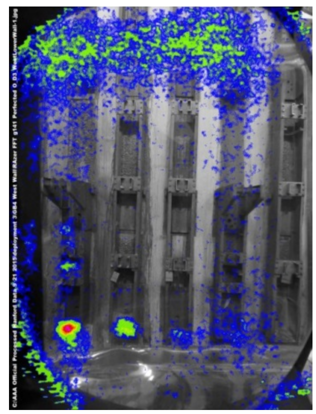
Deployment 3 (6.5 hours)



D3 raw PSP image normalized to 1300 scale

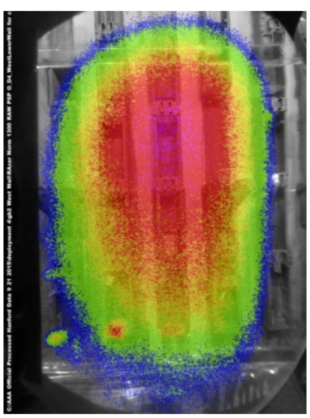


D3 Post Processed PSP Image adjusting for time and angle intensity

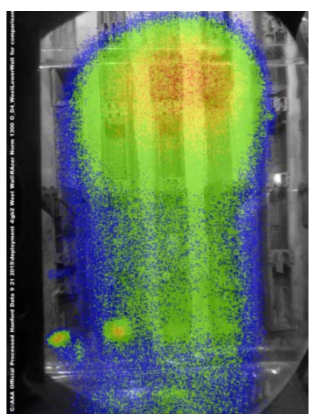


D3 RAzer™ image with Hot Spots highlighted

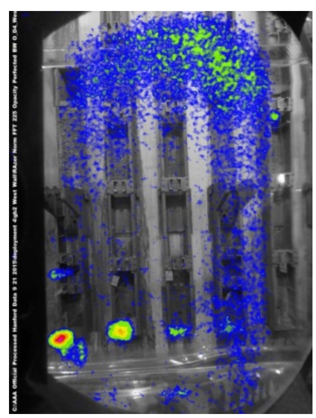
Deployment 4 (15 hours)



D4 raw PSP image normalized to 1300 scale



D4 Post Processed PSP Image adjusting for time and angle intensity



D4 RAzer™ image with Hot Spots highlighted

Figure 24 - Comparison of D3 and D4

5.8.2 North Wall

Images of the north wall demonstrated a uniform low level of radiation (Figure 25). Of interest in the results of the north wall (deployments 6, 7, & 8) is the hot spot visible on the table located in the North Mezzanine. CHPRC identified this object as a pan used to clean debris from the floor. This hot spot was still visible during D8 which was performed in the center of the canyon over 26 feet from the pan location.

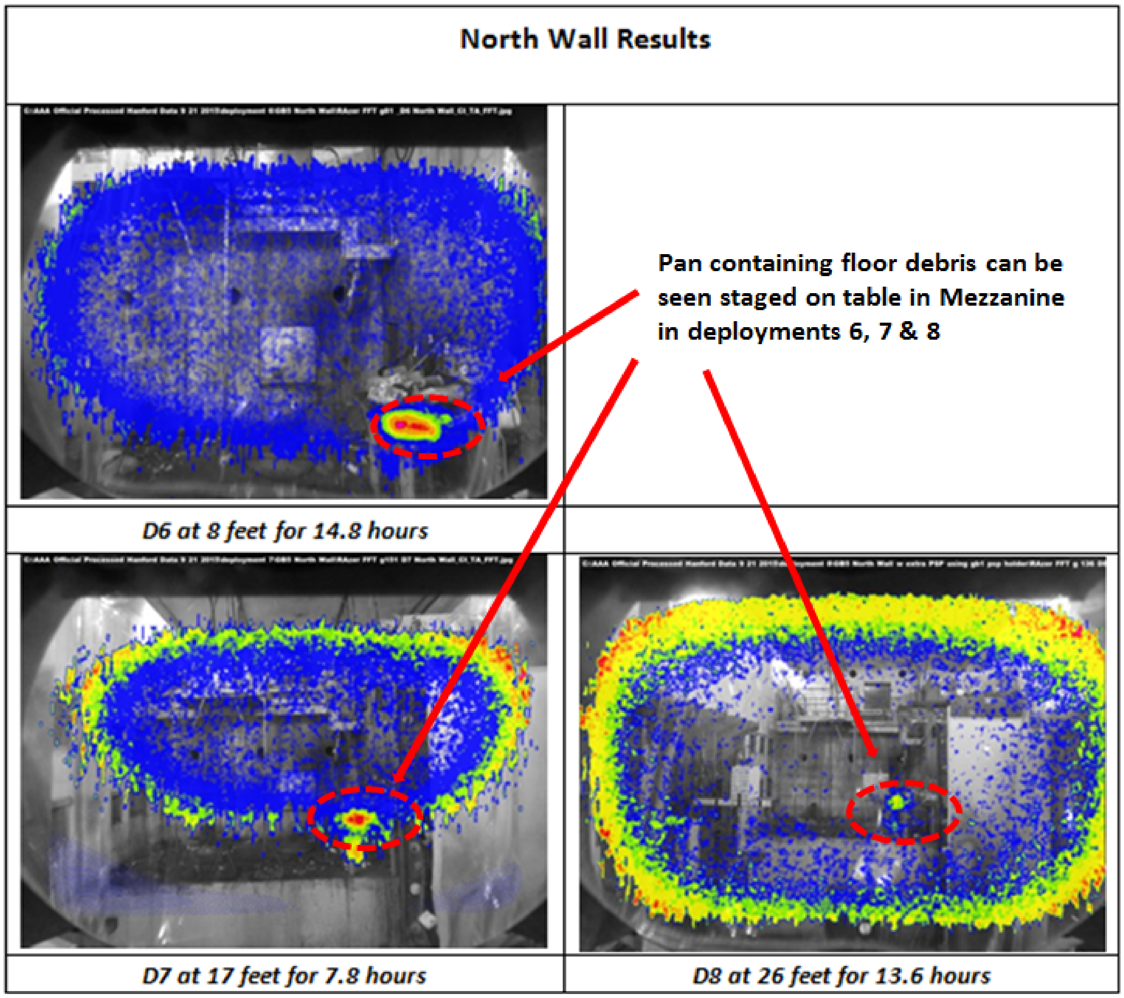


Figure 25 - North Wall results

5.9 SURFACE MONTAGES

Montages were created for the east and west walls and the floor by stitching together GrayQb™ photos. During deployment 5 where the fixture traversed from the north end of the canyon to the south end, the GrayQb™ cameras were configured to take a picture every 30 seconds. This allowed for photos to be taken across the entire canyon and provided the photos used in the stitched montages of the east and west walls (Figures 26 & 27). The floor was additionally stitched as it had interesting features and was identified later in the week as of interest to CHPRC because of the features noted (Figure 29).

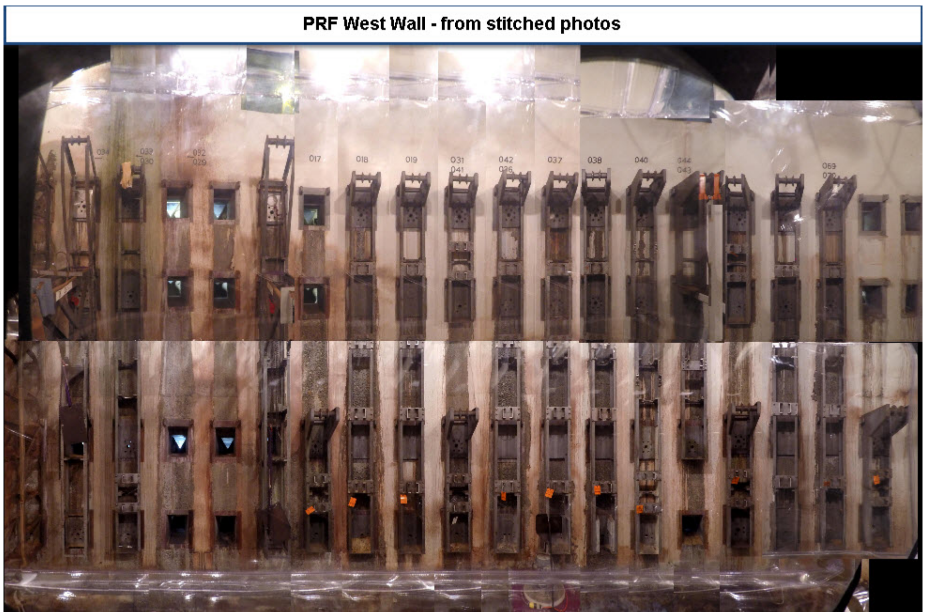


Figure 26- PRF West Wall from stitched photos

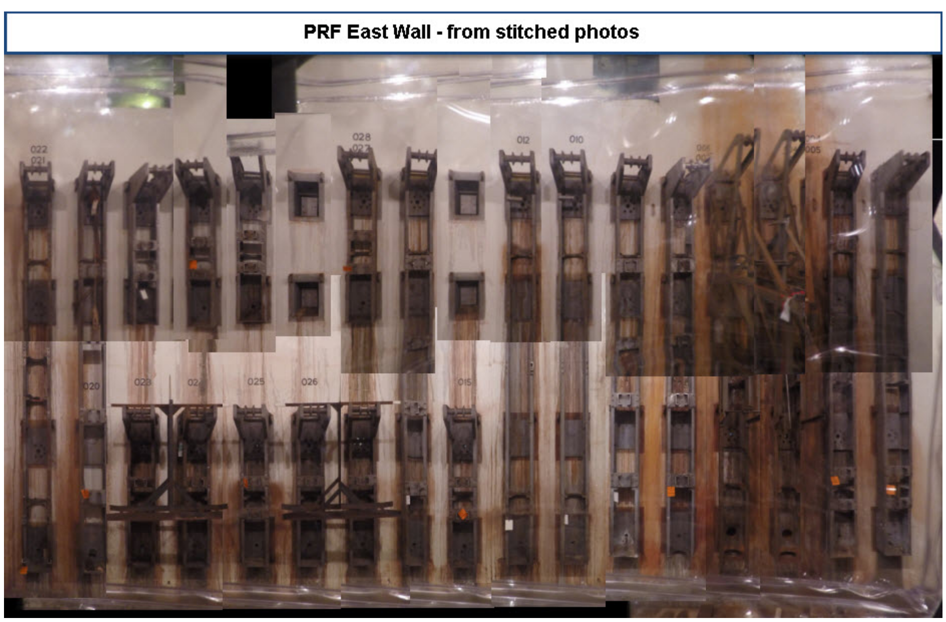


Figure 27 - PRF East Wall from stitched photos

Figure 28 - PRF floor from stitched photos

5.10 DEPLOYMENT LOCATIONS ON THE SURFACE MONTAGES

The area examined in the GrayQb^{TM} FOV for each deployment is shown in Figures 29, 31, and 32. These Figures are useful in conjunction with the individual deployment results provided in Appendix B to cross reference the results to the area examined as shown in Figure 30.

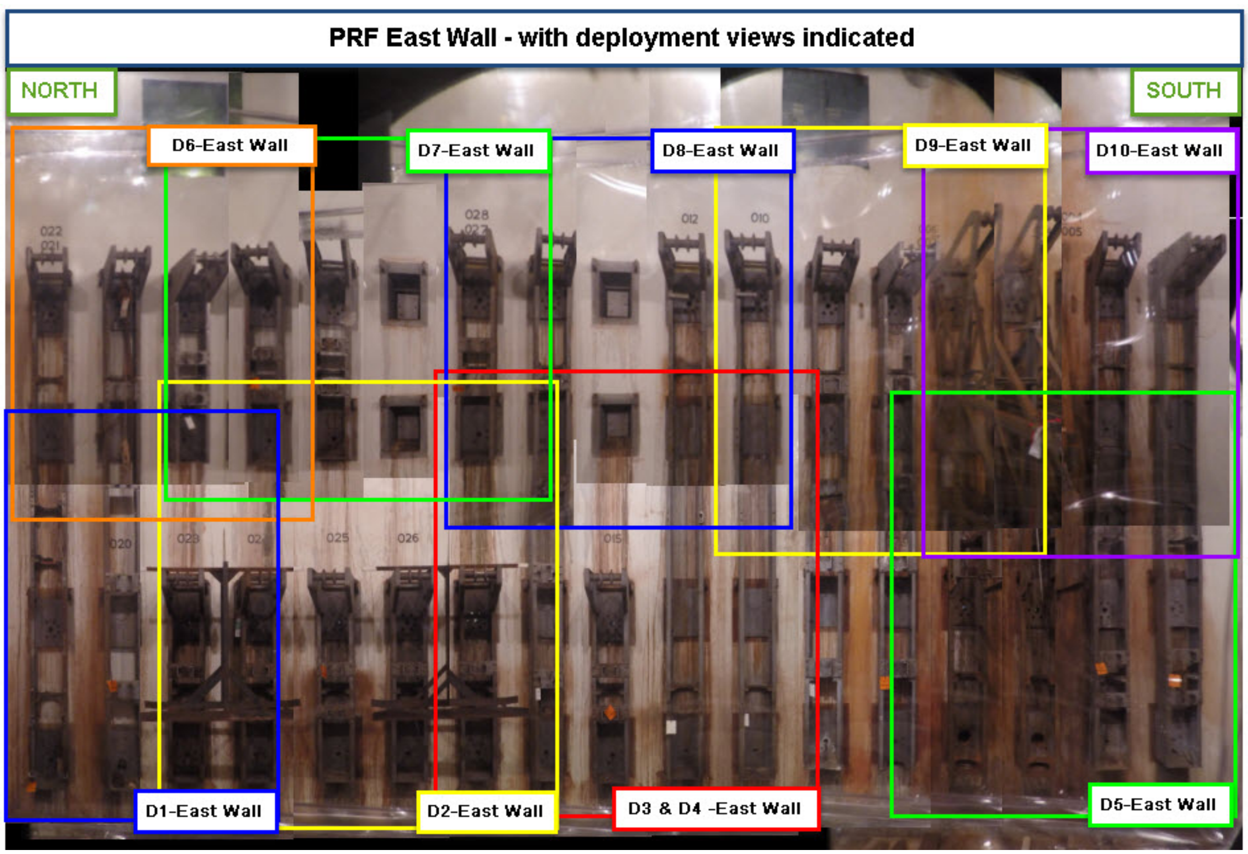


Figure 29 - PRF East Wall deployment locations

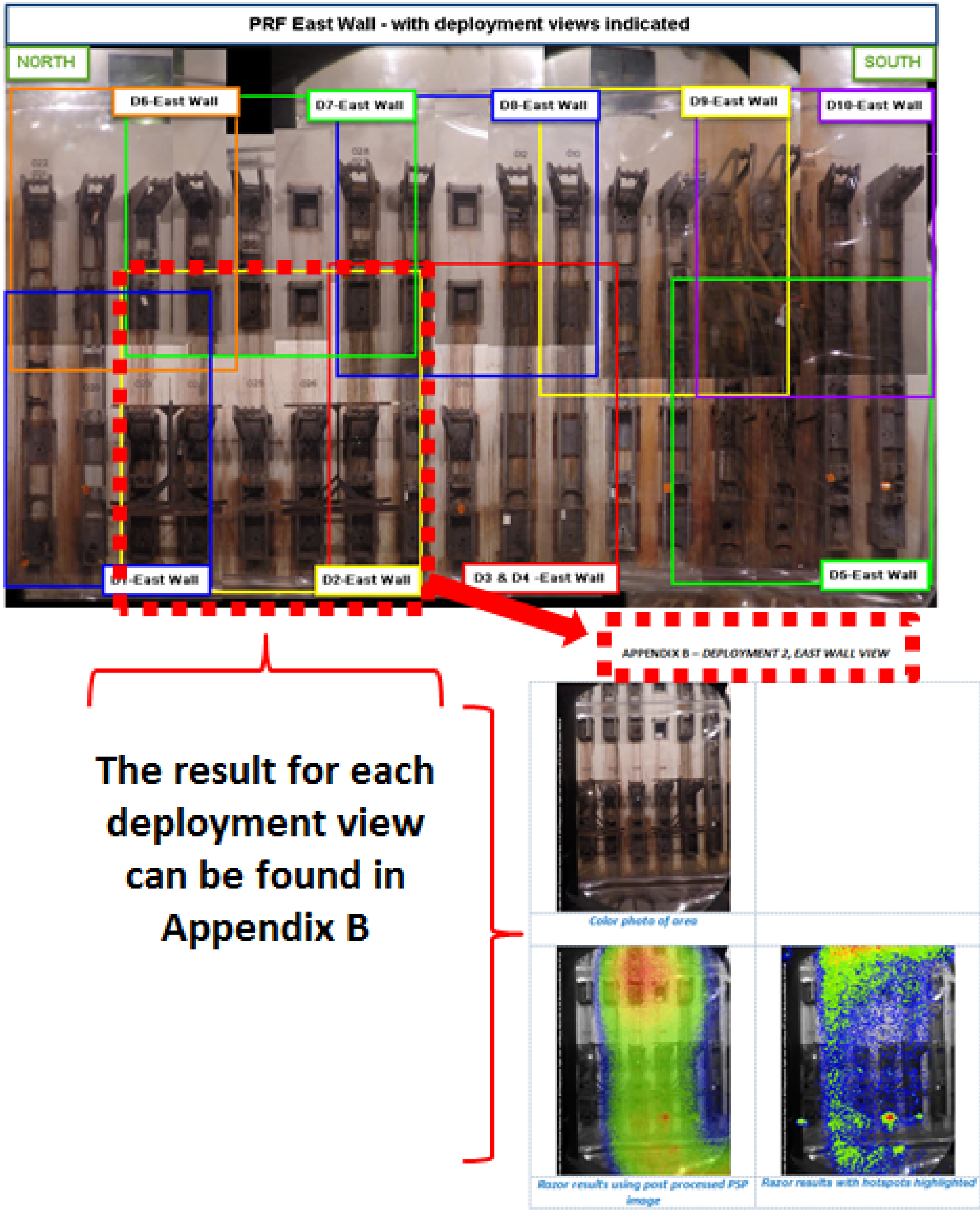


Figure 30 - Diagram showing relationship between deployment montage and Appendix B results

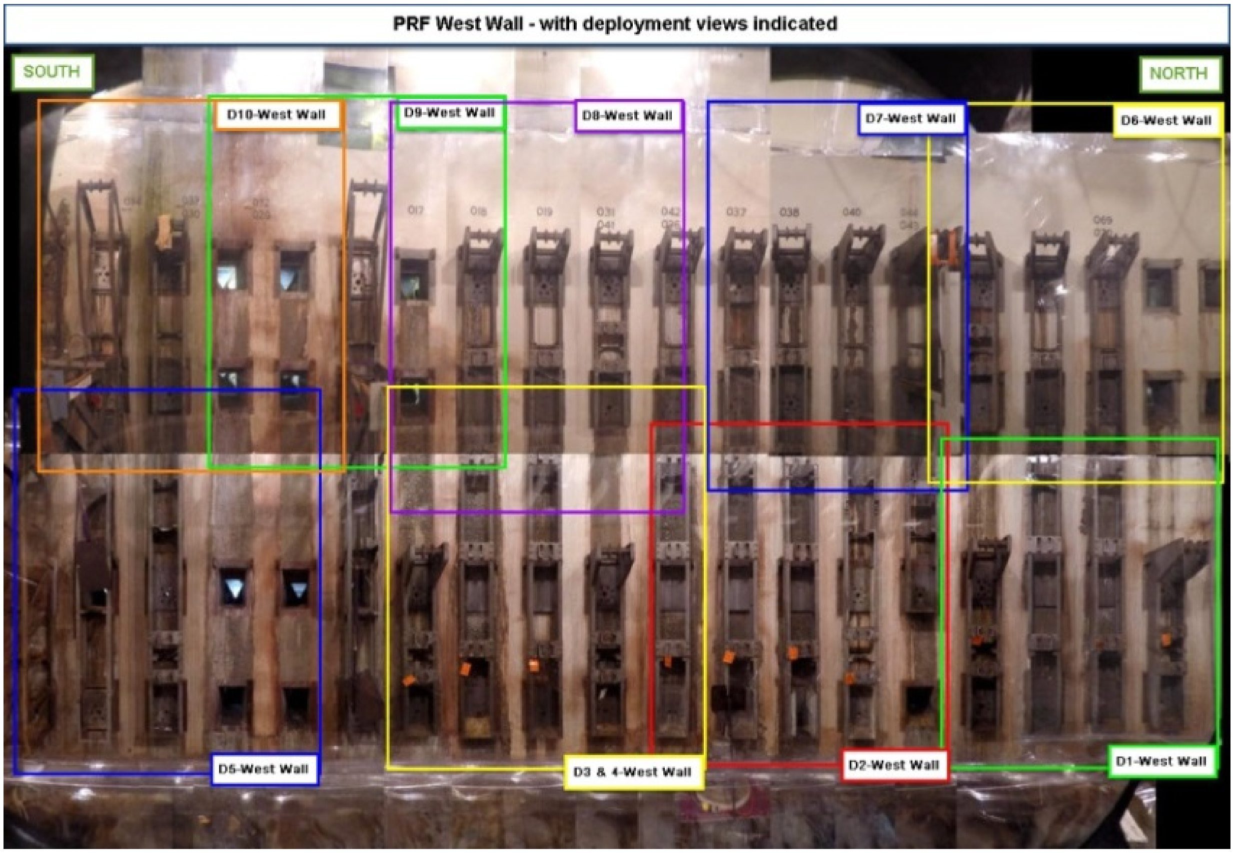


Figure 31 - PRF West Wall with deployment views indicated

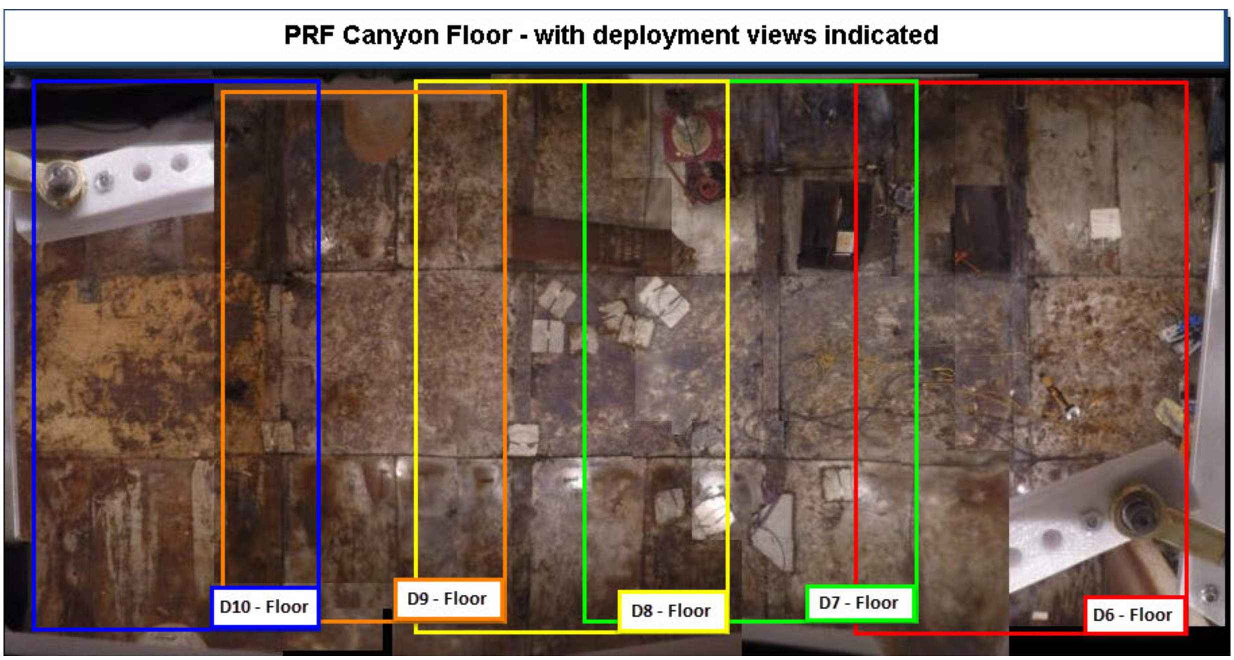


Figure 32 - PRF floor with deployment views indicated

5.11 HOT SPOT MONTAGES

Montages were created for the east and west walls and the floor showing locations of hot spots imaged by GrayQb^{TM} (Figures 33, 34 and 35). RAzer^{TM} hot spot results were hand overlaid onto the stitched images to provide one cohesive view of hot spots along the walls. Features in the RAzer^{TM} results were matched to features in the stitched image to overlay results. The colors representing the hot spots do not necessarily indicate equal intensities. In those cases where deployments overlapped and the same hot spot could be seen in two different views, the colors were made to be of equal color. Many, but not all, of the deployments had overlapping hot spots (Figure 36).

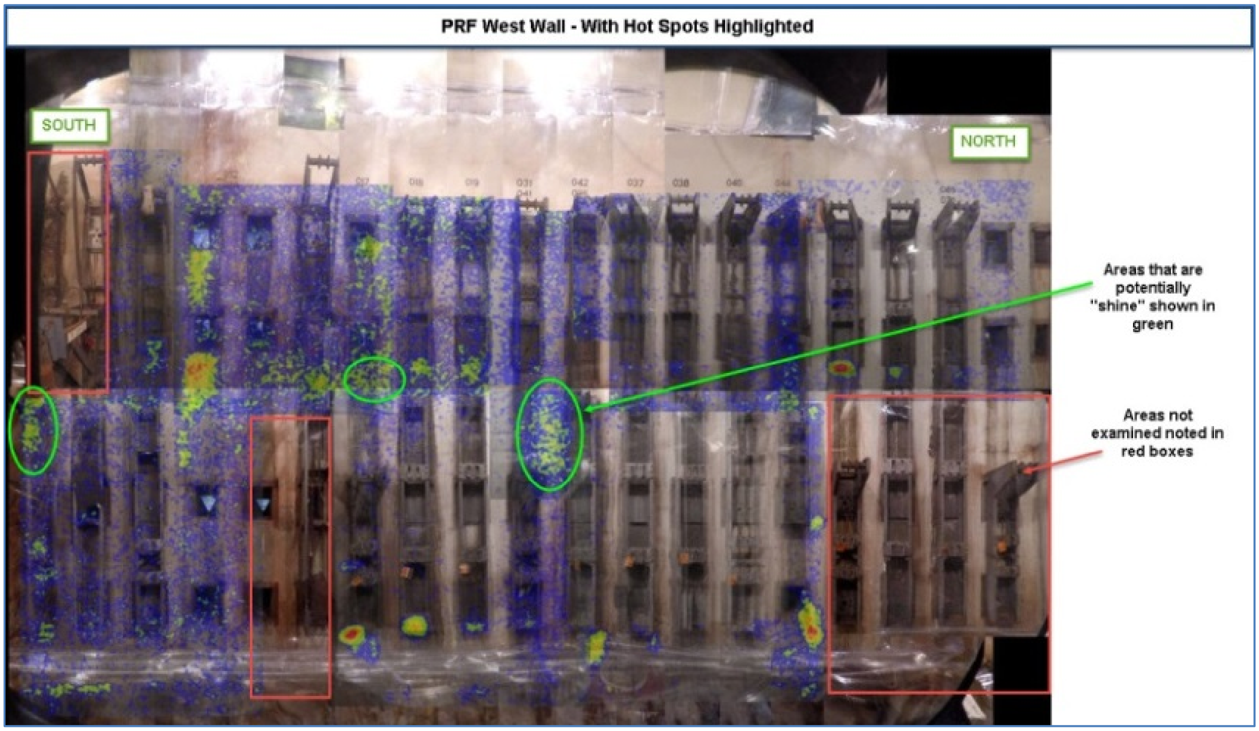


Figure 33 - PRF West Wall with hot spots highlighted

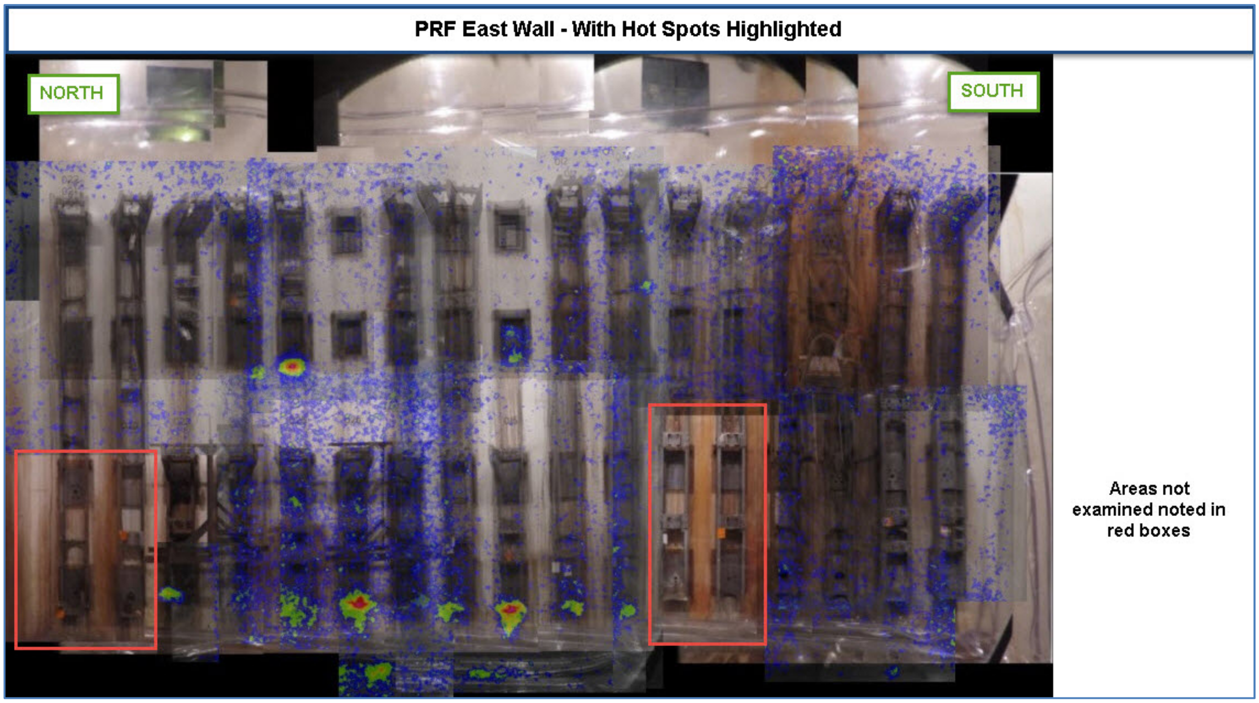


Figure 34 - PRF East Wall with hot spots highlighted

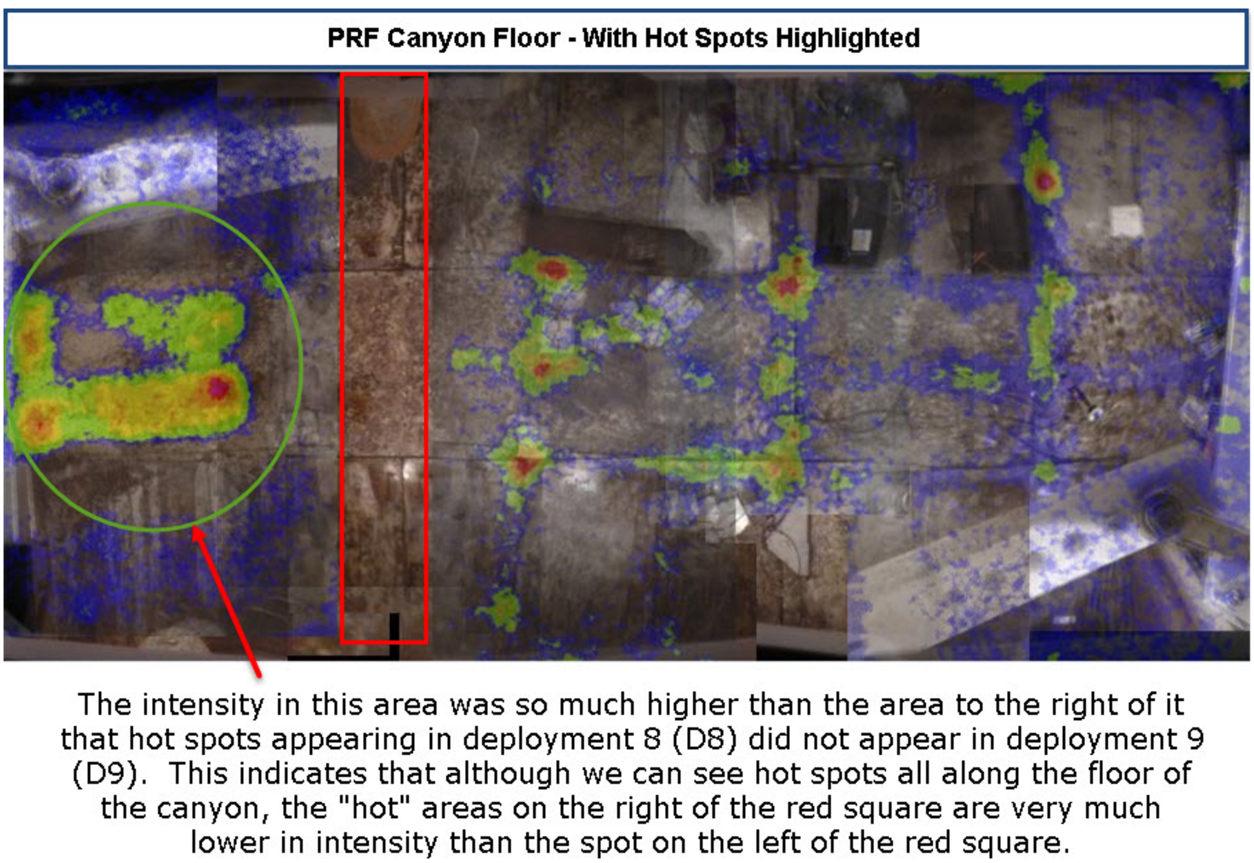


Figure 35 - PRF Canyon floor with hot spots highlighted

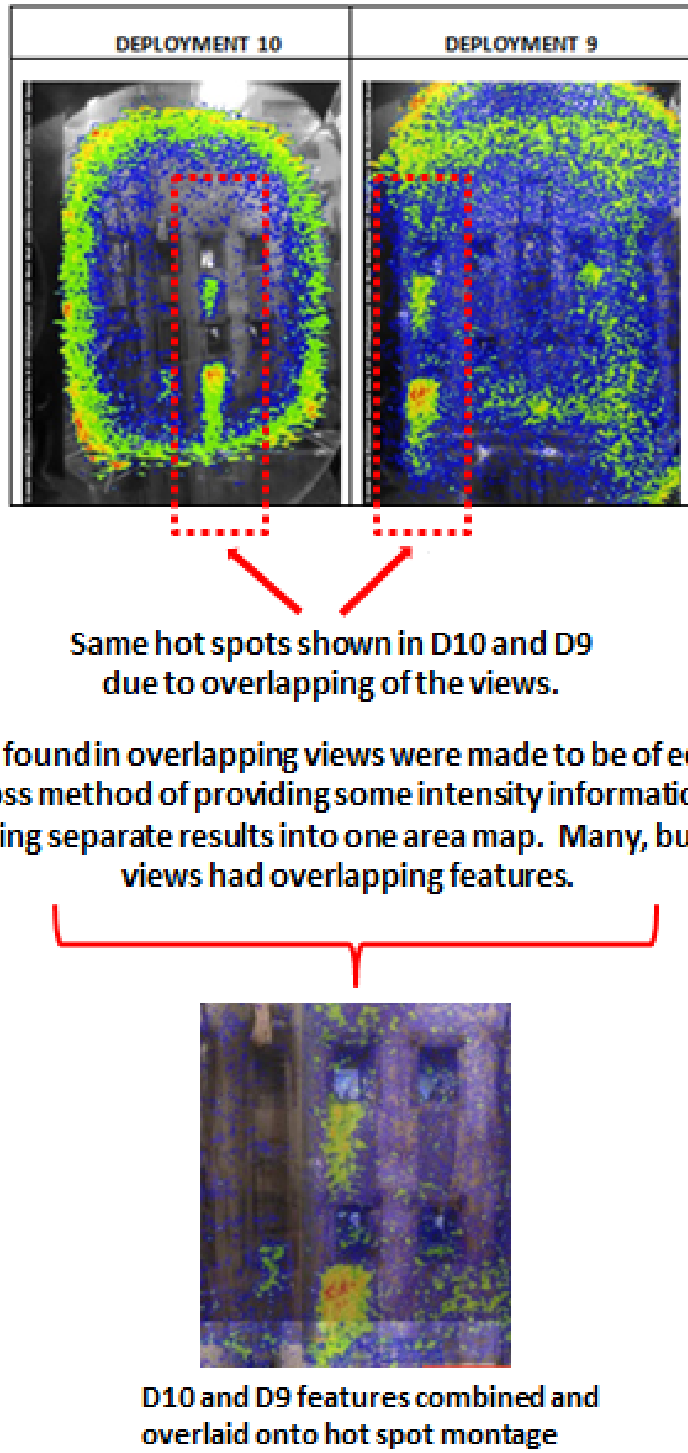


Figure 36 - Discussion of Hot Spot montage colors

6. CONCLUSIONS

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 Plutonium Finishing Plant Decommissioning Project. Data acquired included hot spots and enabled several conclusions to be made to focus the on-going PRF canyon D&D effort. CHPRC reported PRF canyon ambient dose rate ranged from 50 - 100 mR/hr at 30 cm from wall surfaces [4]. 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 with individual results provided in Appendix B and summary results presented in this document. All GrayQb devices were recovered and released from radiological controls by CHPRC; a contributing factor was the custom GrayQb radiological bags provided by CHPRC. The crane platform fixture was not decontaminated and remained in the PRF canyon for future survey activities.

Data collected examined over 80% of the canyon surfaces and identified trends and hot spots throughout the canyon that enabled several conclusions to be made that will facilitate the D&D effort and path forward planning. The initial deployment (D1) did not fully develop because the deployment time was too short (3.6 hours), subsequent deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time). Deployment 3 (D3) and deployment 4 (D4) were performed at essentially the same location; although this resulted in a small area of the east and west wall not being examined, this unintended deviation from the plan 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. Secondly, the two data sets provided a validation for the application of the post processing methodologies. D3 lasted 6.5 hours and D4 lasted 15 hours; after making post processing adjustments for time, the results demonstrated similar intensities indicating a successful time algorithm. After applying the FFT filter to the post processed data to highlight hot spots, D3 and D4 identified the same hot spots.

GrayQb™ results showed a relatively uniform contamination on the east and west walls with hot spots located on many of the lower strong back wells/ports, where the pencil tanks where once connected. Additionally, there were a few hot spots noted on the upper strong backs and several locations on the upper west wall showing a trail of contamination appearing to be external to the strong back well. Indications were that the stains on the wall were not any more contaminated than unstained wall areas.

The highest radiological energy intensity was at the south entrance canyon floor where decontamination and debris removal efforts were on-going. In general the east wall had slightly higher intensities than the west wall. Floor results indicated areas of higher intensity contamination along the crevices of the floor pans and wells. Also higher intensity contamination was identified in the area where the walls meet the floor; however these hot spots were much lower in intensity than the south entrance floor undergoing decontamination and debris removal efforts. The floor hot spots indicate that contamination has settled into crevice areas and are difficult to resolve through the decontamination process, as would be expected. No hot spots were detected on the ceiling; results indicate a general uniform relative contamination on the ceiling surface.

In summary, the GrayQb™ proved to be a useful tool in the radiological characterization of the PRF canyon. Distribution tendencies of the radiological conditions were identified that provide insights that will assist in more efficient planning of the continued decontamination and debris 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.

7. REFERENCES

[1] US DOE Inter-entity Work Order No. M0SR900210, dated 3/4/2015

[2] 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, 2014

[3] “GrayQb Single-Faced Version 2 (SF2) Hanford Plutonium Reclamation Facility (PRF) Deployment Plan”, SRNL-RP-2015-00352, August 2015, Revision 3

[4] SRNL - CHPRC, GrayQb™ Hanford PRF Deployment Telephone Conference, Sep 1, 2015.

[5] “Single-Faced GrayQb™ A Radiation Mapping Device,” SRNL-STI-2013-00654, Dec. 2013.

[6] “GrayQb™ Single-Faced Version 2 (SF2) Open Environment Test Report,”SRNL-TR-2014-00216, Sept. 2014.

APPENDIX A – ADDITIONAL GRAYQB PROCESSING INFORMATION

Hanford PRF characterization will employ Apixia Phosphor Storage Plates (PSP) as the radiation detection imaging medium. PSPs are widely used in medical applications and non-destructive examination (NDE) (Figure A-1). PSPs are sensitive to short-wavelength (e.g. X-ray, gamma) electromagnetic radiation and once exposed can be read using a PSP scanner device. A ScanX Duo PSP Scanner device (Figure A-2) will be used for PRF characterization. All scans will be processed using PSP feeder slot 2 (right side) of the scanner. PSPs are light-weight and safe to handle without protective gloves and do not become radioactive when exposed to radiation.

Figure A-1 - Phosphor Storage Plates (PSPs)

Figure A-2 - ScanX Duo PSP Scanner

Scanner results are downloaded to an attached laptop where an intensity map is applied (Figure A-3). The digital image (photo) of the examined area is also downloaded from the GrayQb™ digital camera to the laptop. The SRNL developed RAzer™ (Radiation Analyzer) software then super-imposes the PSP derived intensity map onto the digital image to produce resultant images (Figure A-4). Processing of results will be performed by personnel knowledgeable of the GrayQb™ SF2 and its operation.

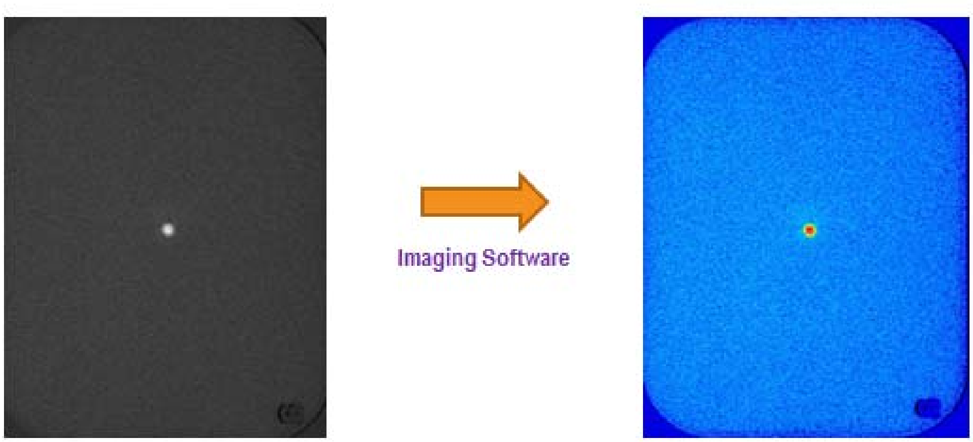


Figure A-3 - Scanned PSP Phosphor Storage Plates (PSPs) and PSP with intensity map applied.

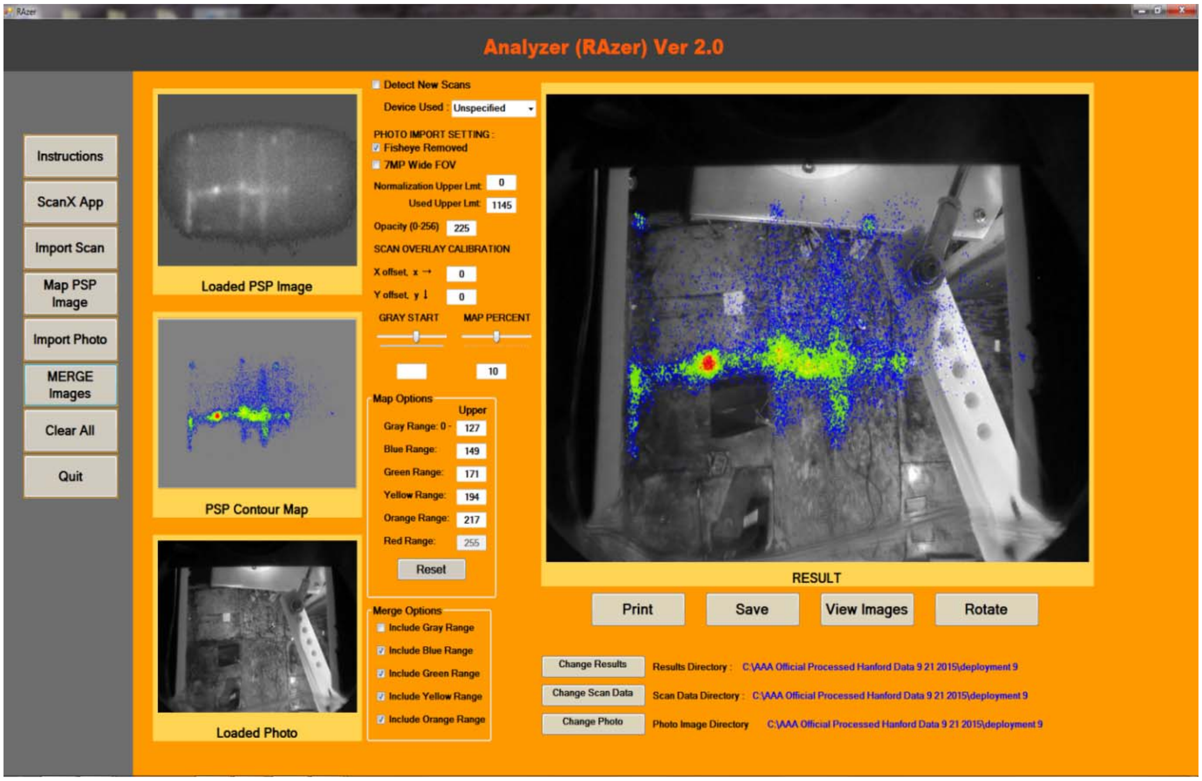
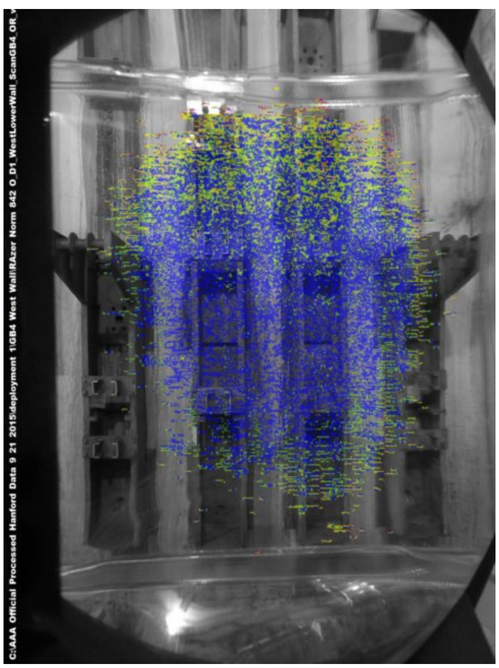


Figure A-4 - GrayQb^{TM} RAzer^{TM} Processing Software Version 2.0

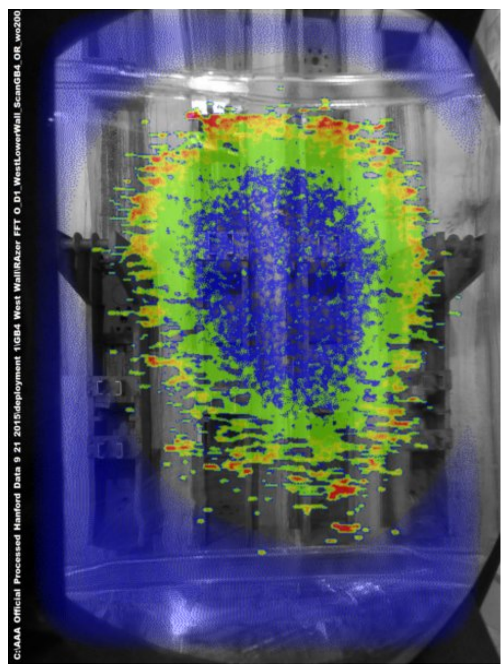
APPENDIX B – *DEPLOYMENT 1, WEST WALL VIEW*

Color photo of area

The first Deployment (D1) did not fully develop because the deployment time wasn't long enough; remaining deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time).



RAzer™ results using post processed PSP image

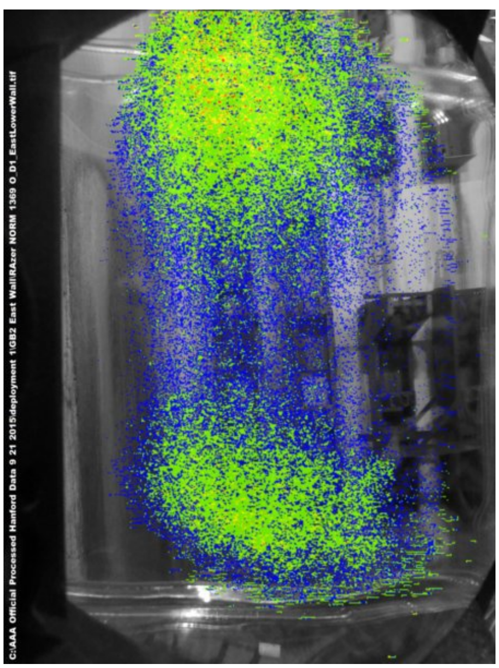


RAzer™ results with hotspots highlighted

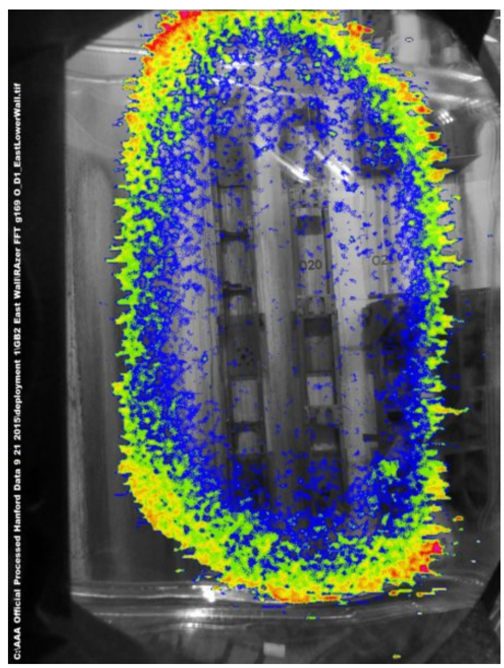
APPENDIX B – *DEPLOYMENT 1, EAST WALL VIEW*

Color photo of area

The first Deployment (D1) did not fully develop because the deployment time wasn't long enough; remaining deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time).

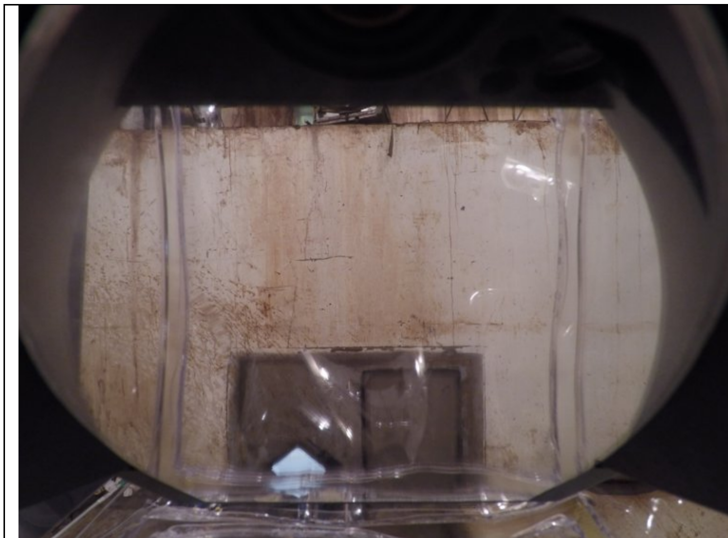


RAzer™ results using post processed PSP image



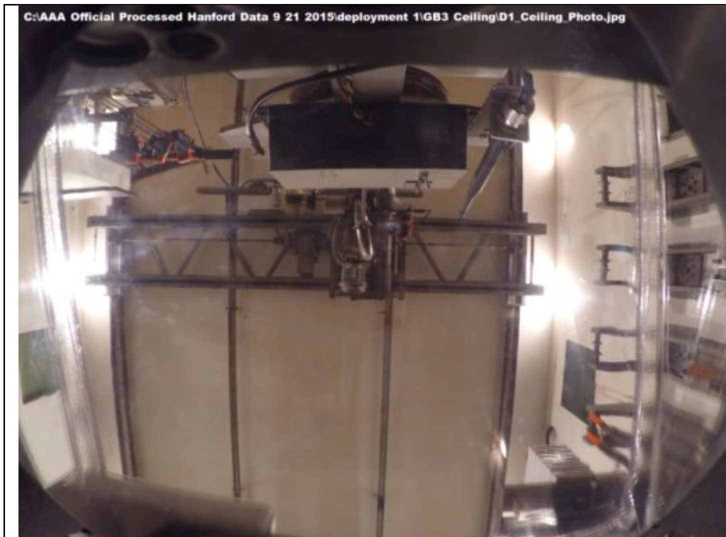
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 1, NORTH WALL VIEW*

<table>
<tr><td></td><td>Color photo of area

The first Deployment (D1) did not fully develop because the deployment time wasn’t long enough; remaining deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time).</td></tr>
<tr><td>
</td><td>RAzer™ results using post processed PSP image</td></tr>
<tr><td>N/A</td><td>RAzer™ results with hotspots highlighted</td></tr>
</table>

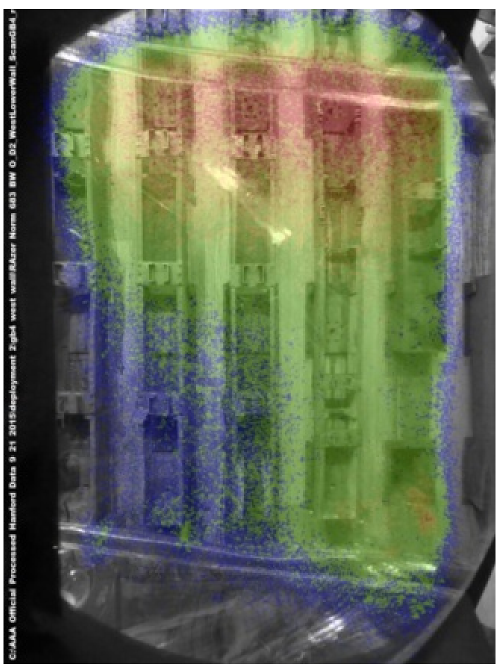
APPENDIX B – *DEPLOYMENT 1, CEILING VIEW*

<table>
<tr><td>
</td><td>Color photo of area

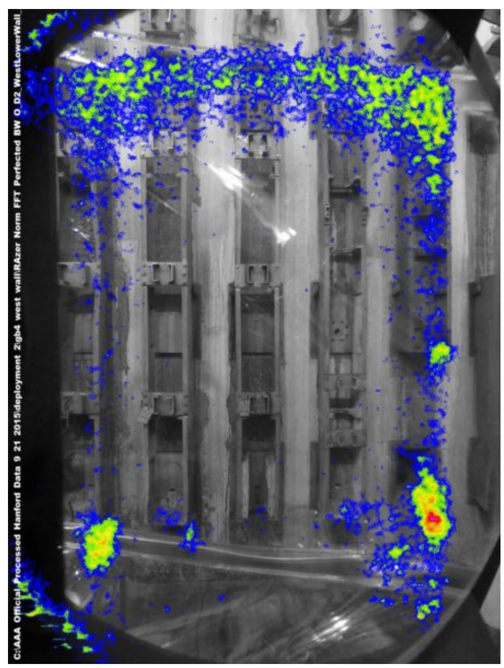
The first Deployment (D1) did not fully develop because the deployment time wasn't long enough; remaining deployment durations were performed for a longer period (6.5 hours was the determined optimal deployment time).</td></tr>
<tr><td>
</td><td>RAzer™ results using post processed PSP image</td></tr>
<tr><td>N/A</td><td>RAzer™ results with hotspots highlighted</td></tr>
</table>

APPENDIX B – *DEPLOYMENT 2, WEST WALL VIEW*

Color photo of area



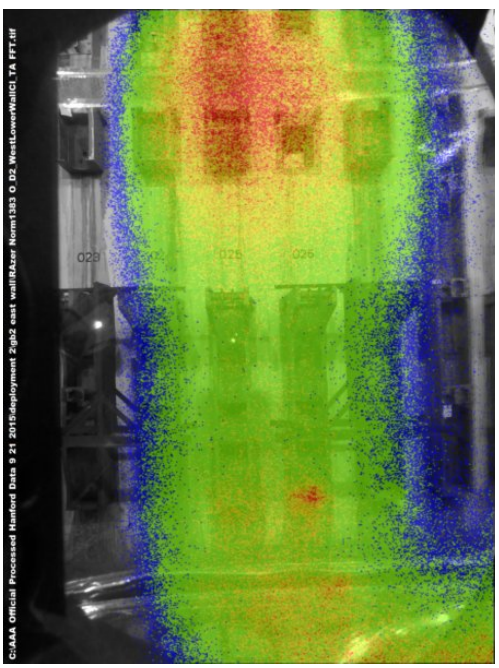
RAzer™ results using post processed PSP image



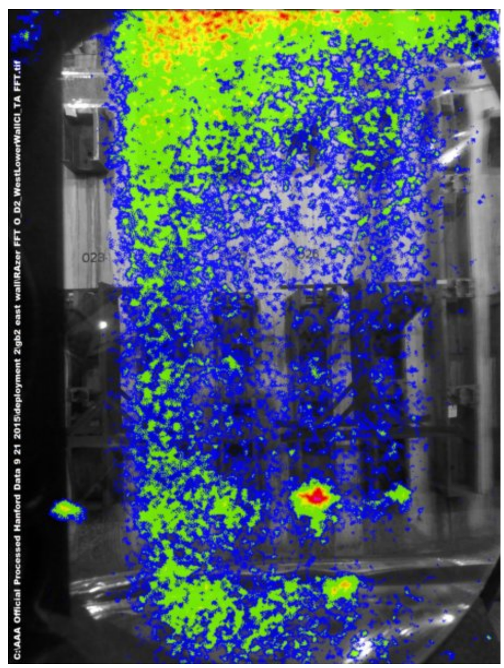
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 2, EAST WALL VIEW*

Color photo of area

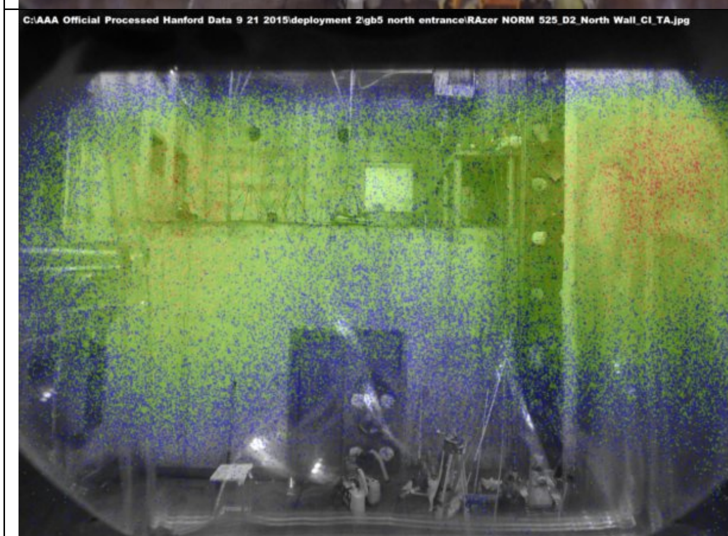
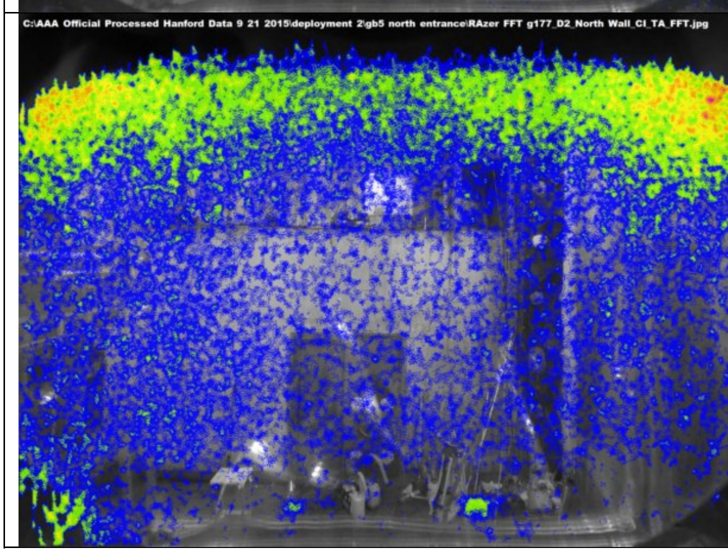


RAzer^{TM} results using post processed PSP image

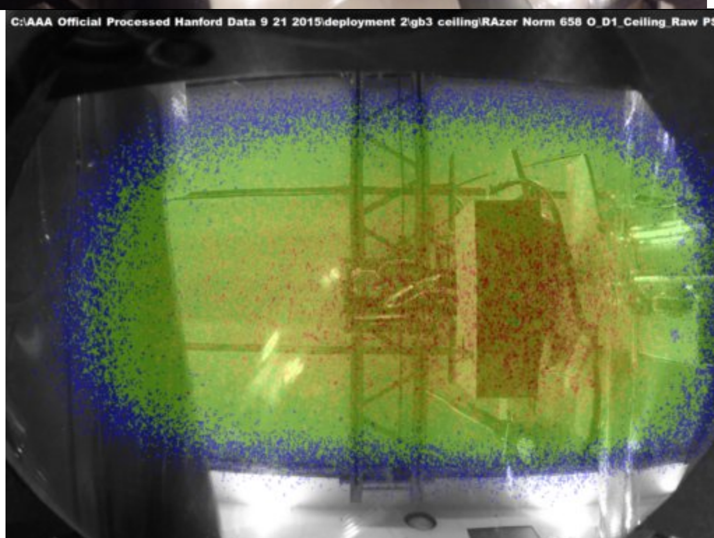
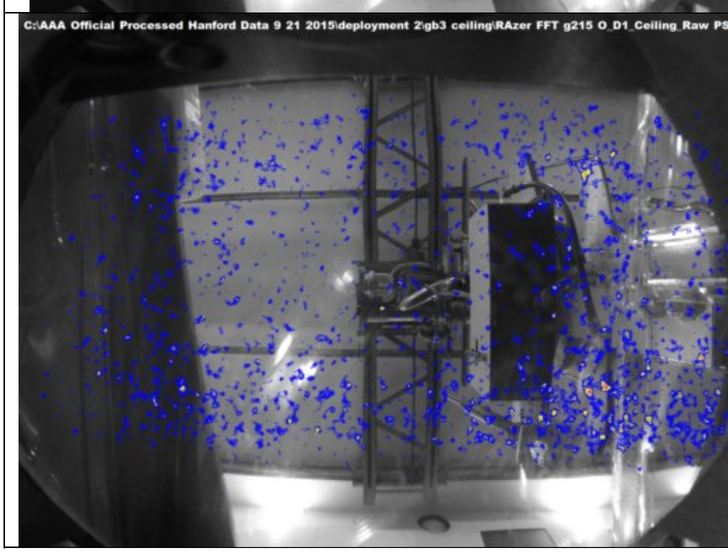


RAzer^{TM} results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 2, NORTH WALL VIEW*

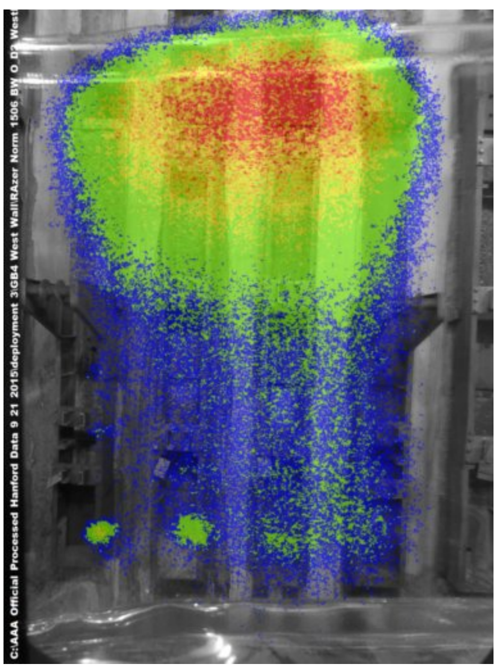
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 2, CEILING VIEW*

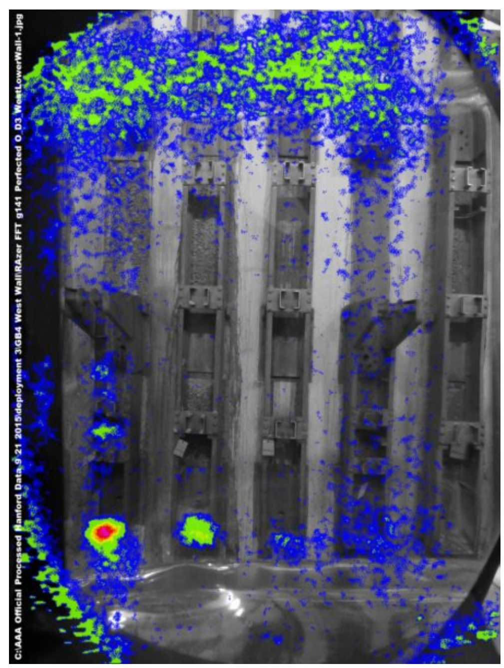
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 3, WEST WALL VIEW*

Color photo of area



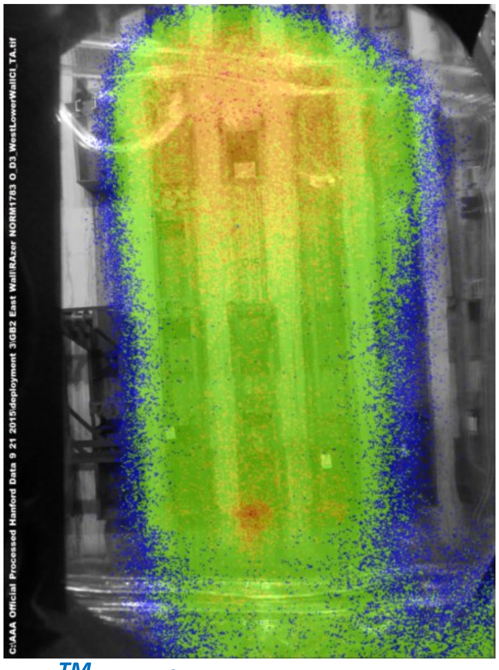
RAzer™ results using post processed PSP image



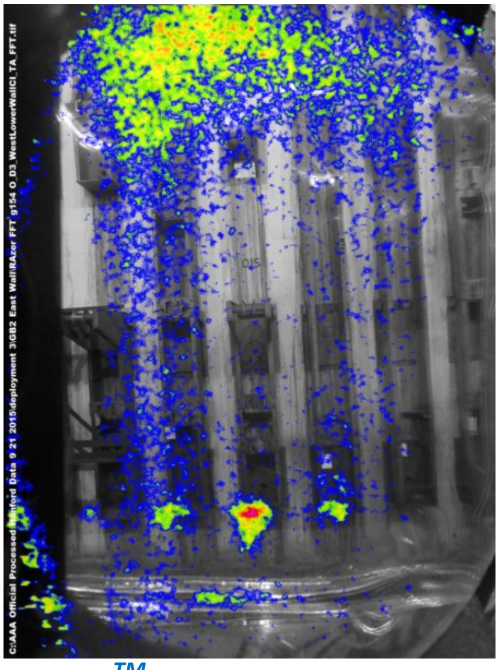
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 3, EAST WALL VIEW*

Color photo of area

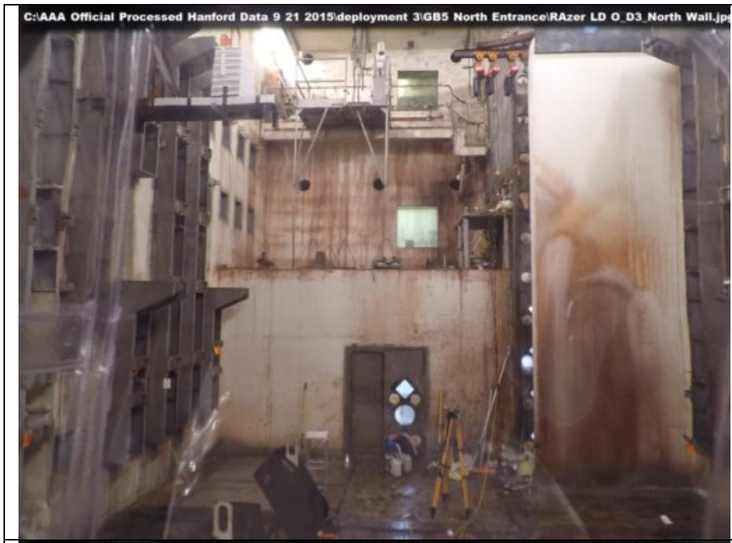
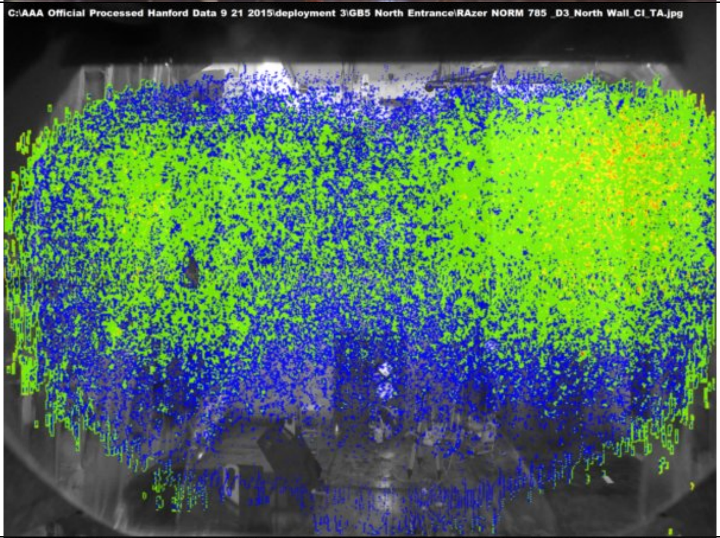
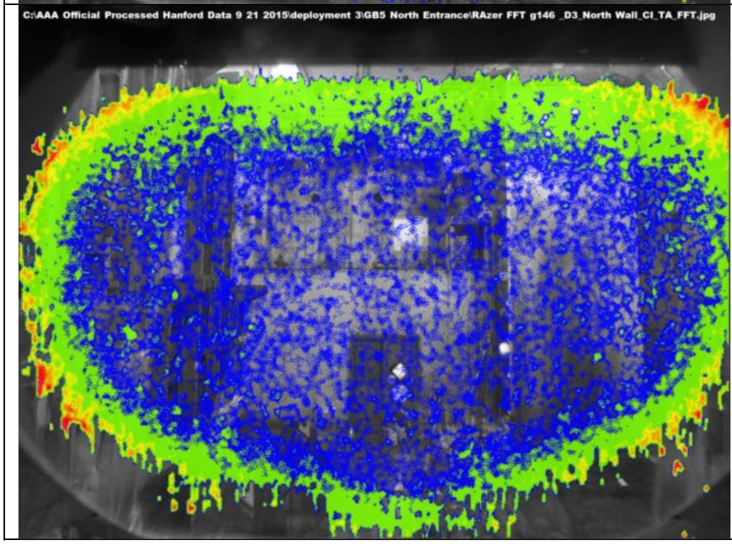


RAzer™ results using post processed PSP image

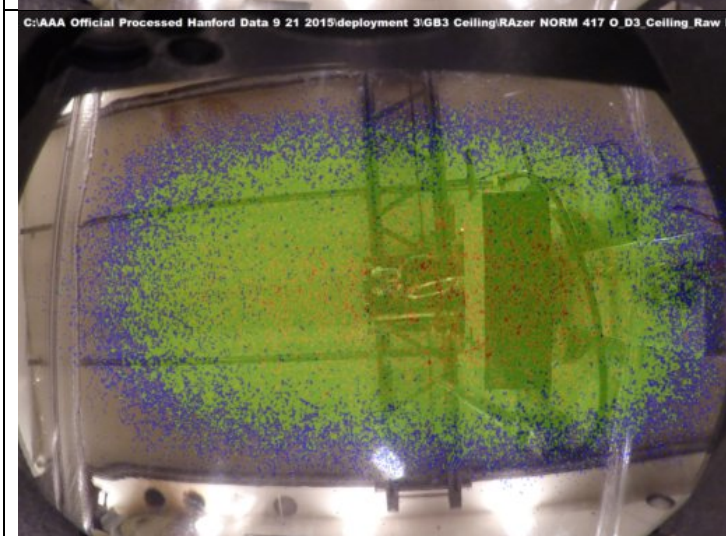
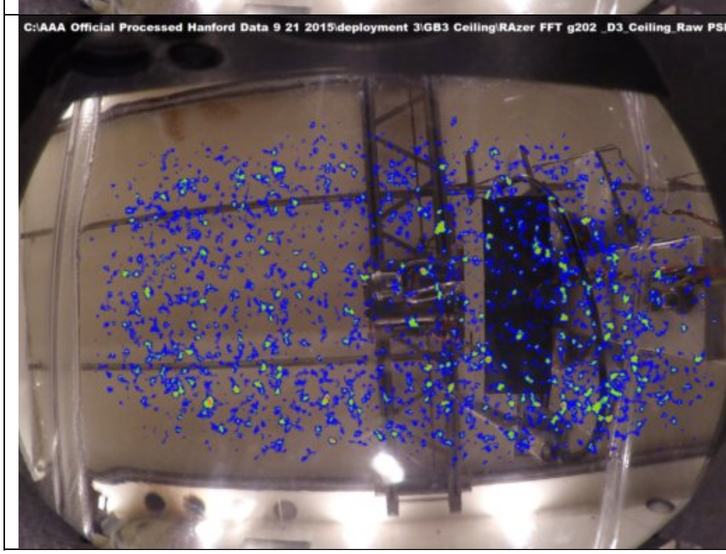


RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 3, NORTH WALL VIEW*

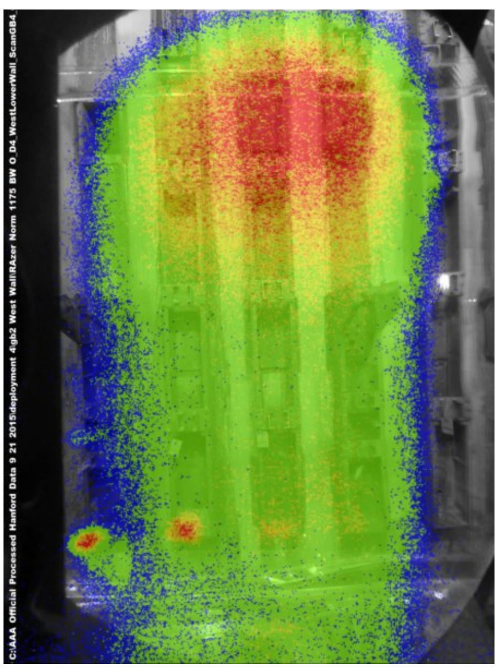
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 3, CEILING VIEW*

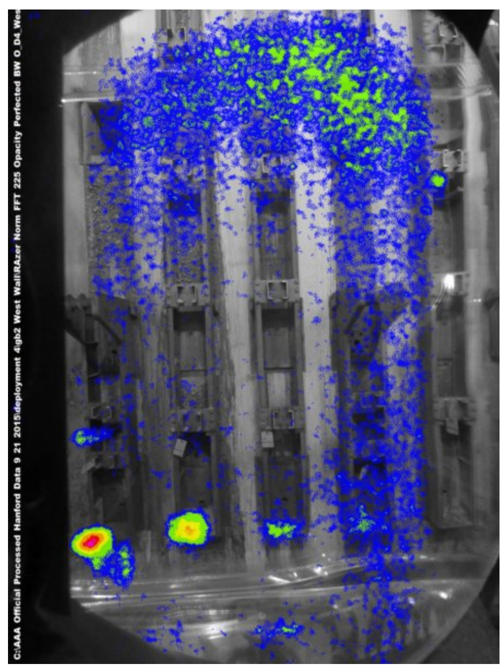
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 4, WEST WALL VIEW*

Color photo of area

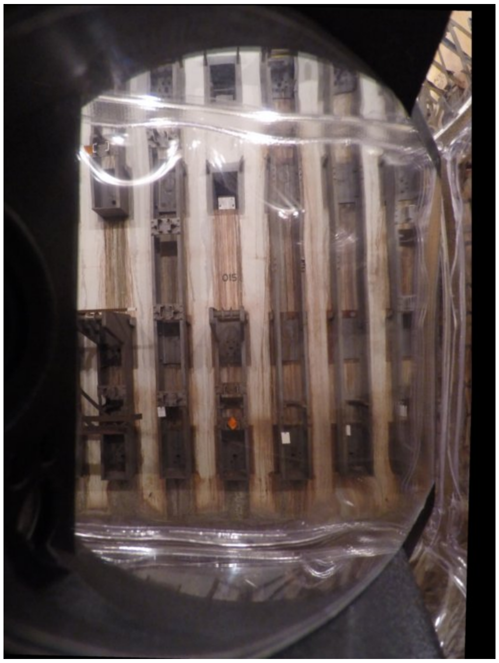


RAzer^{TM} results using post processed PSP image

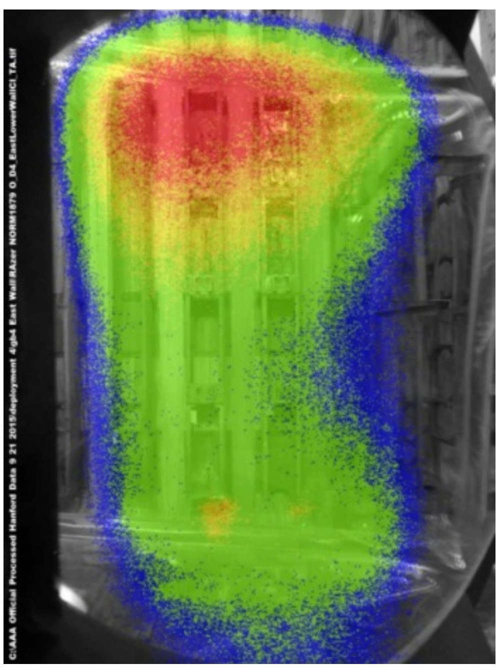


RAzer^{TM} results with hotspots highlighted

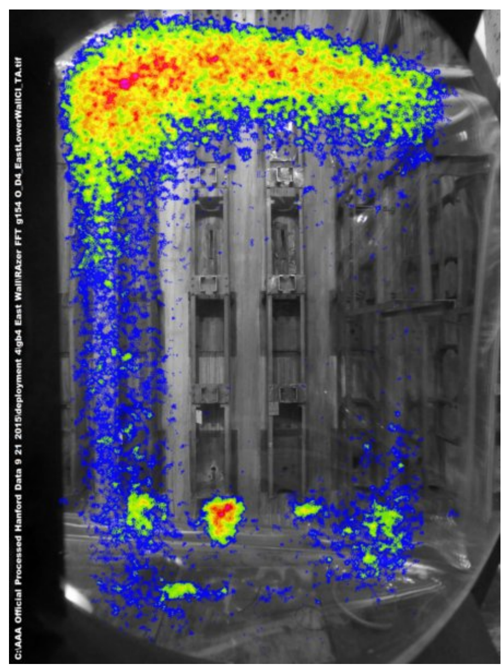
APPENDIX B – *DEPLOYMENT 4, EAST WALL VIEW*



Color photo of area

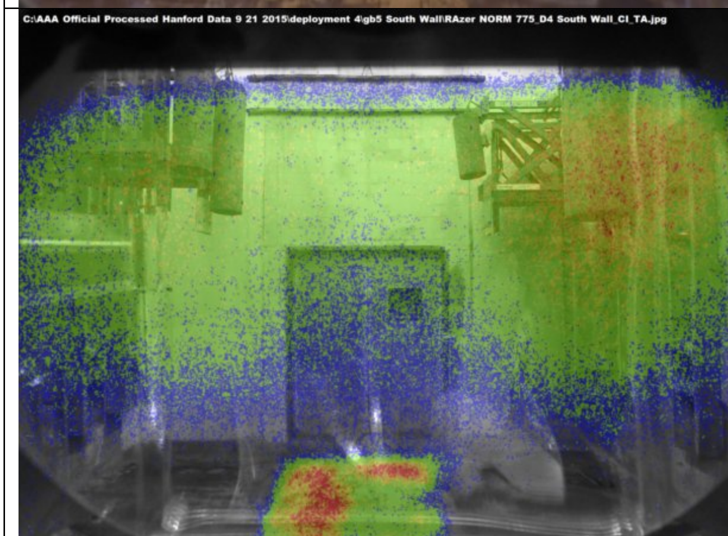
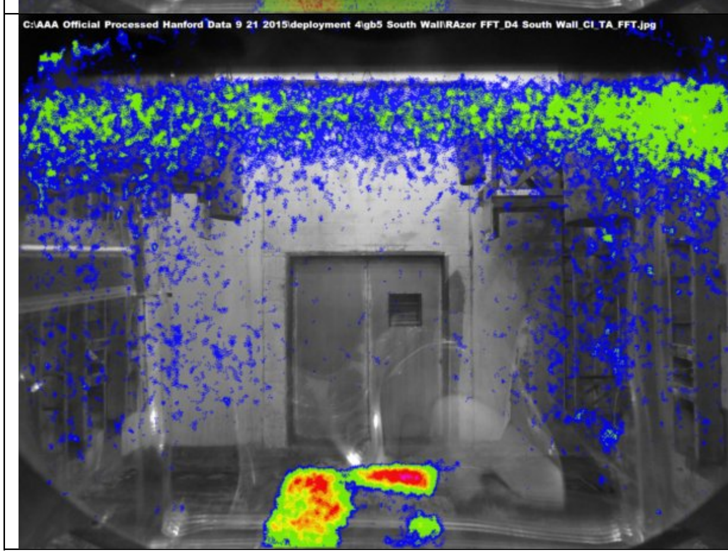


RAzer™ results using post processed PSP image

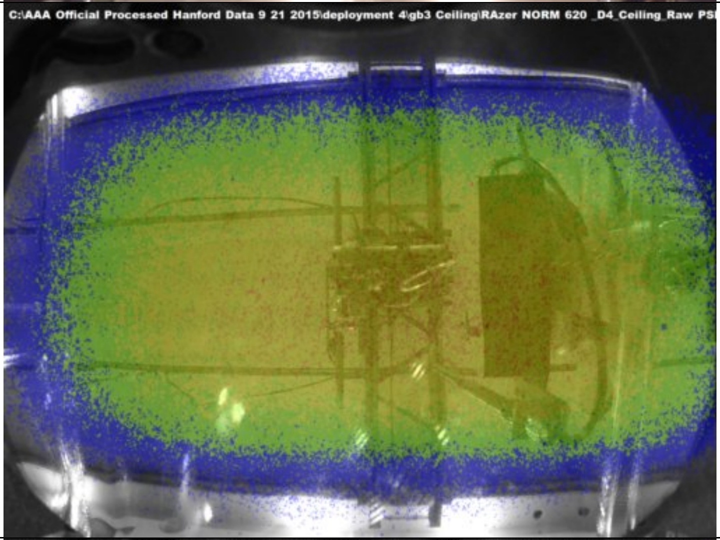
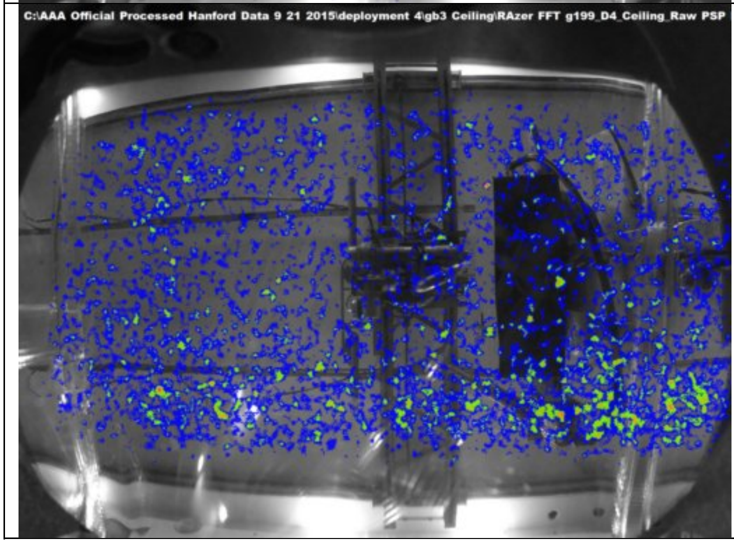


RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 4, SOUTH WALL VIEW*

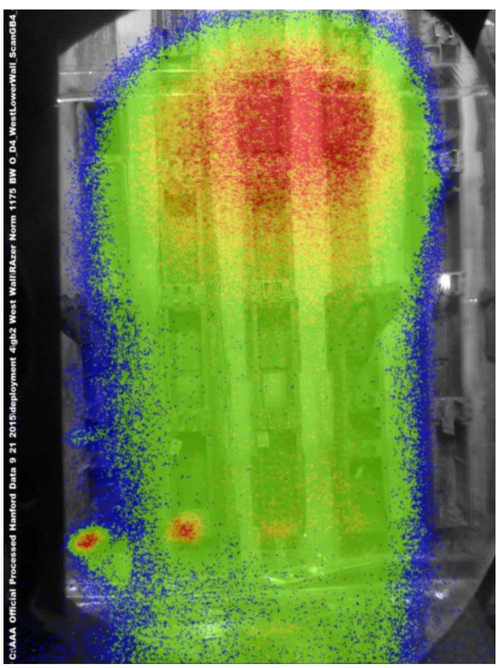
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 4, CEILING VIEW*

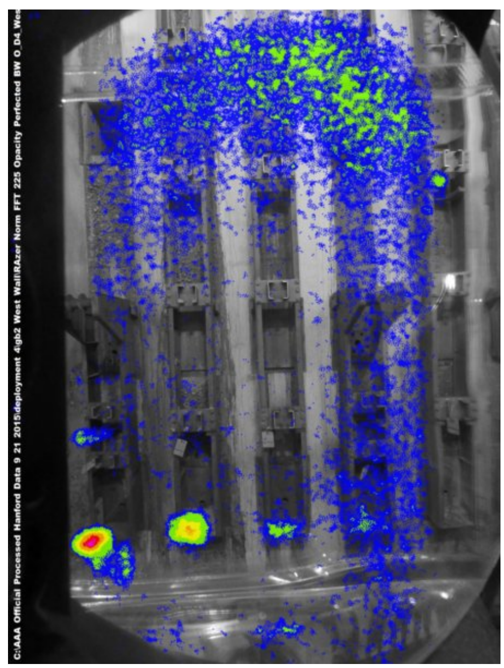
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 5, WEST WALL VIEW*

Color photo of area



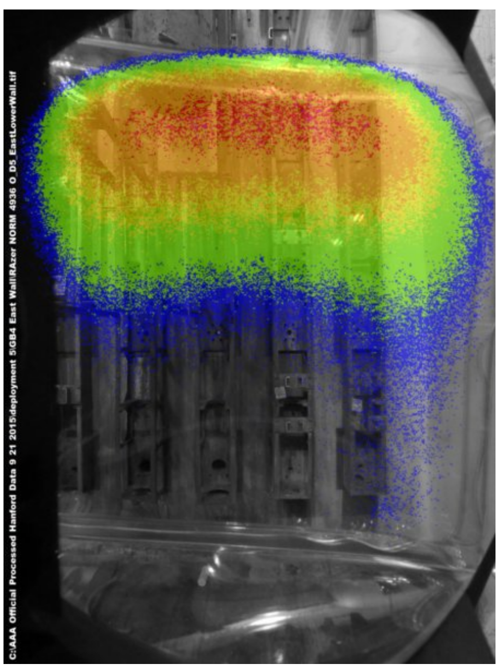
RAzer^{TM} results using post processed PSP image



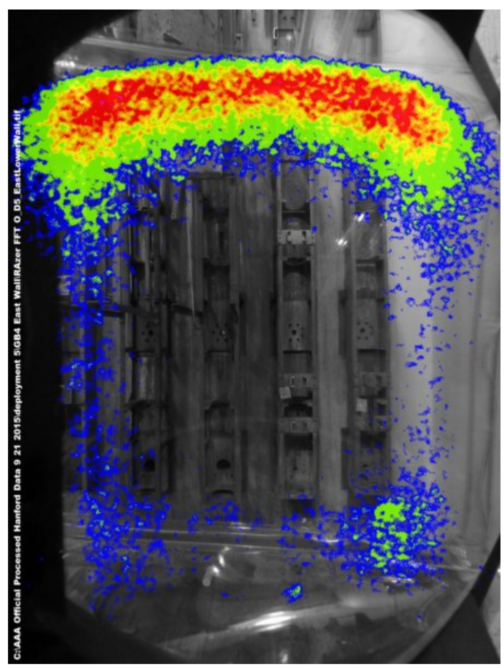
RAzer^{TM} results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 5, EAST WALL VIEW*

Color photo of area



RAzer^{TM} results using post processed PSP image



RAzer^{TM} results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 5, SOUTH WALL VIEW*

<table>
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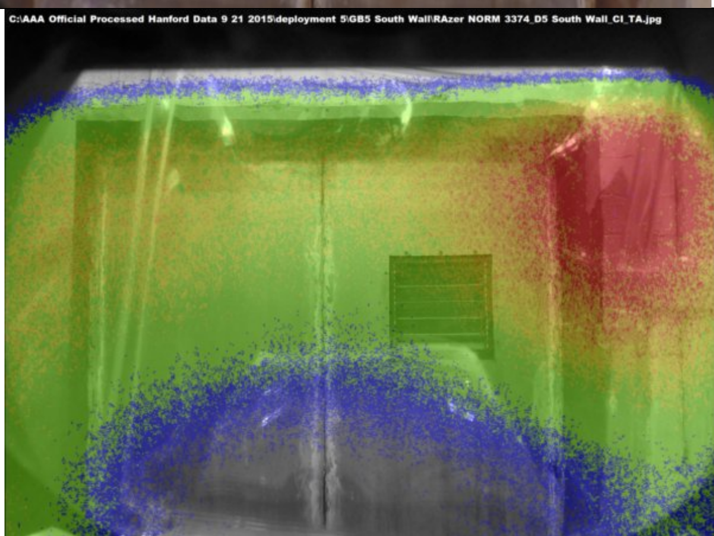
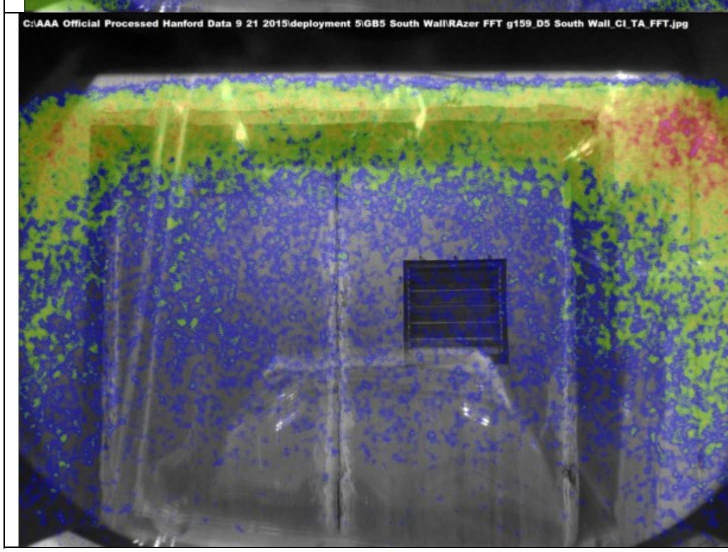
<tr><td>
</td><td>RAzer^{TM} results using post processed PSP image</td></tr>
<tr><td>
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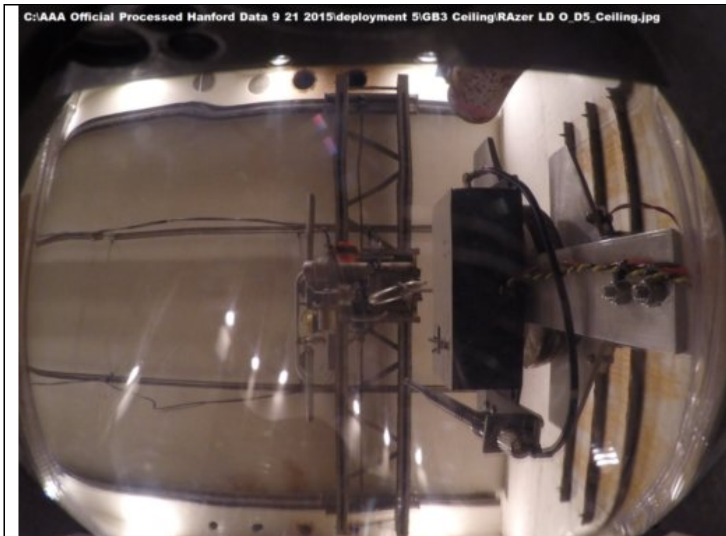
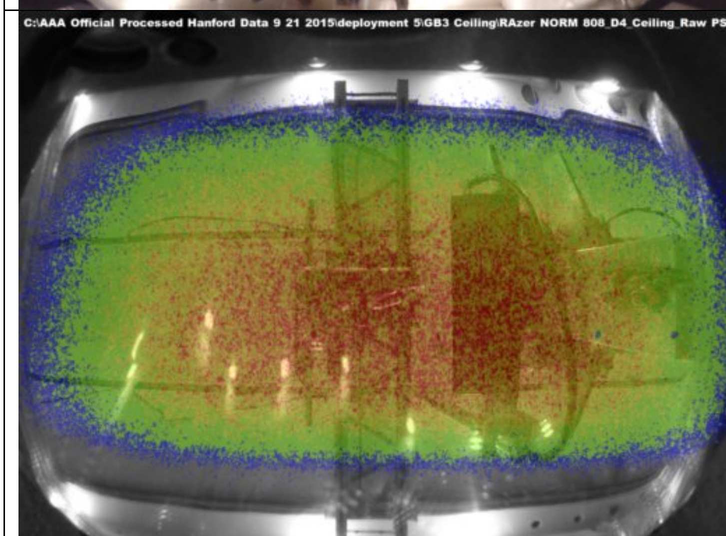
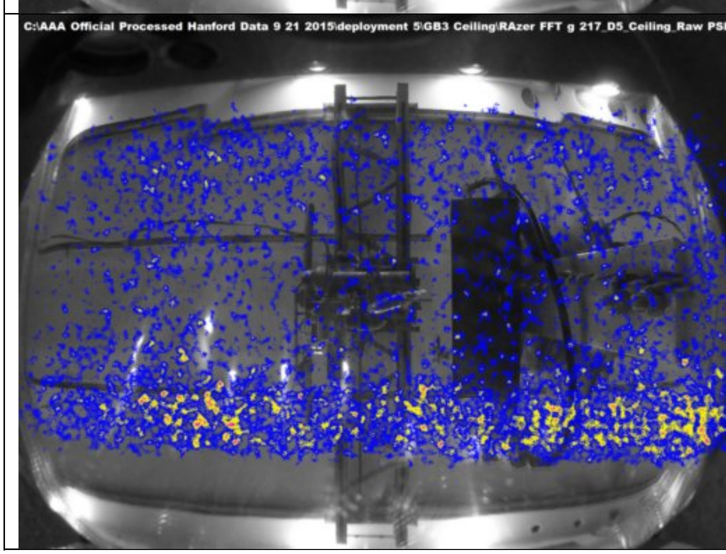
APPENDIX B – *DEPLOYMENT 5, CEILING VIEW*



Color photo of area



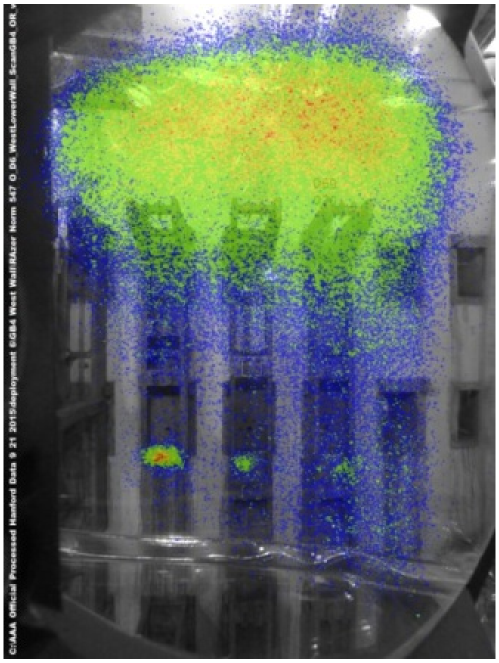
RAzer™ results using post processed PSP image



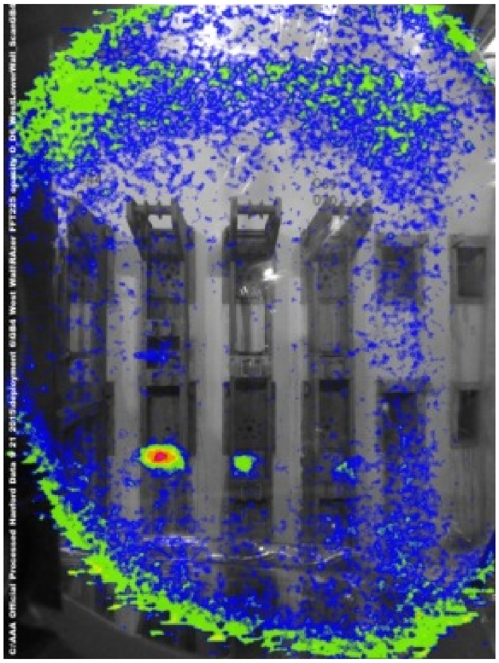
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 6, WEST WALL VIEW*

Color photo of area



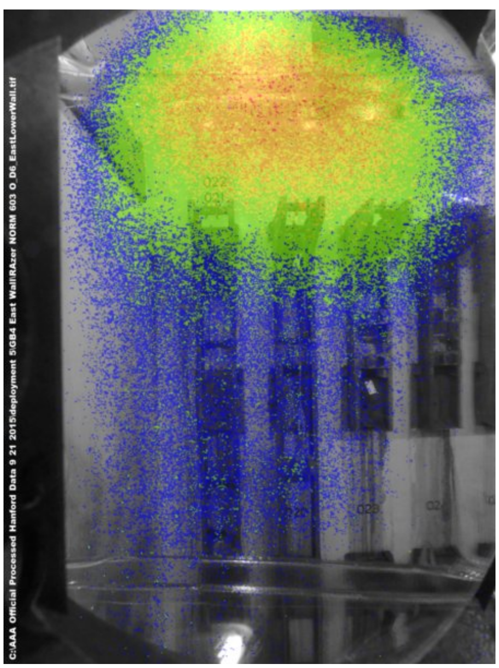
RAzer™ results using post processed PSP image



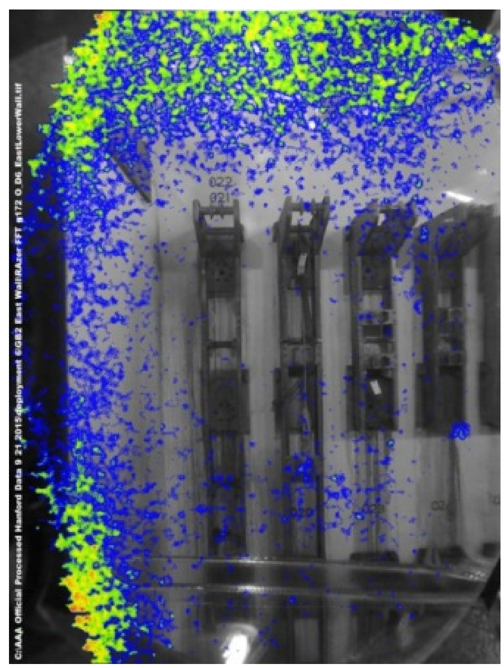
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 6, EAST WALL VIEW*

Color photo of area



RAzer^{TM} results using post processed PSP image

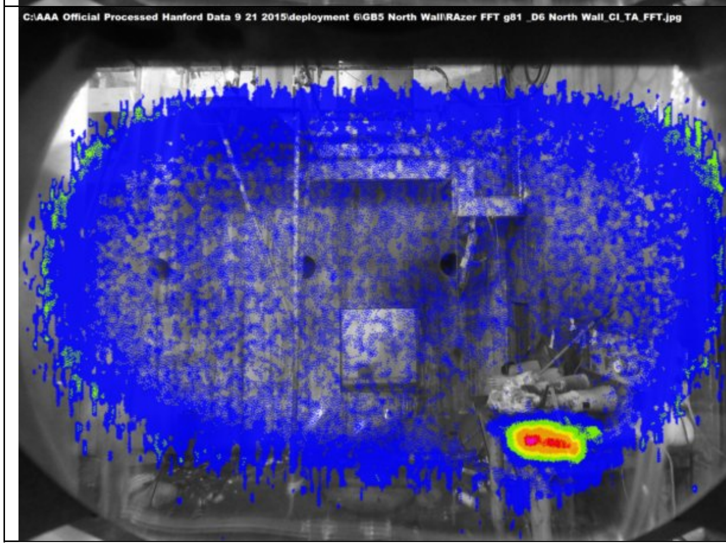


RAzer^{TM} results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 6, NORTH WALL VIEW*

Color photo of area

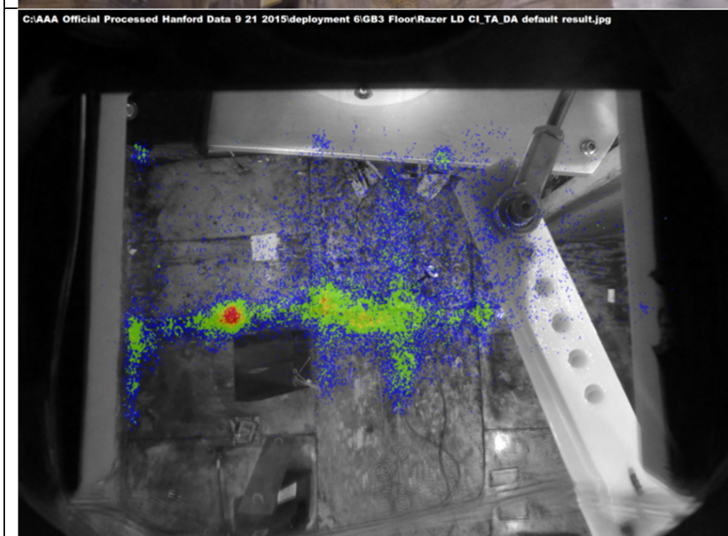
RAzer™ results using post processed PSP image



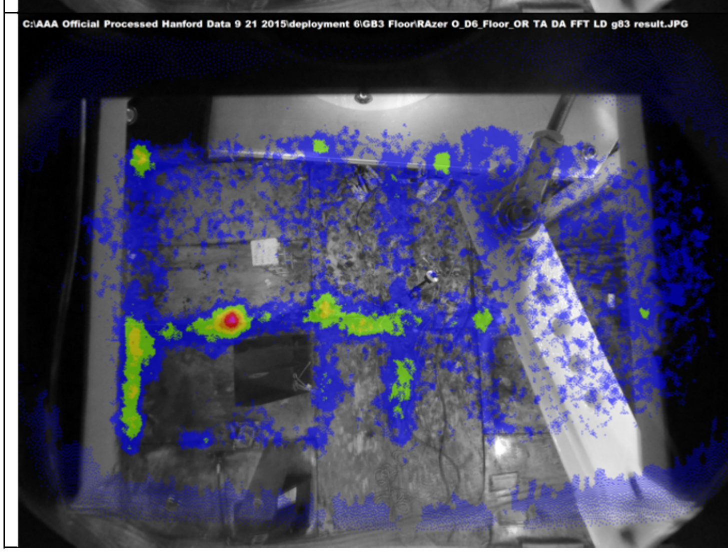
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 6, FLOOR VIEW*

Color photo of area



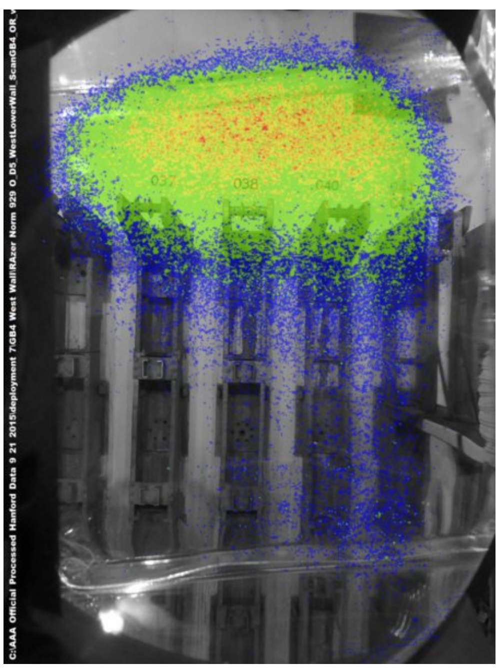
RAzer™ results using post processed PSP image



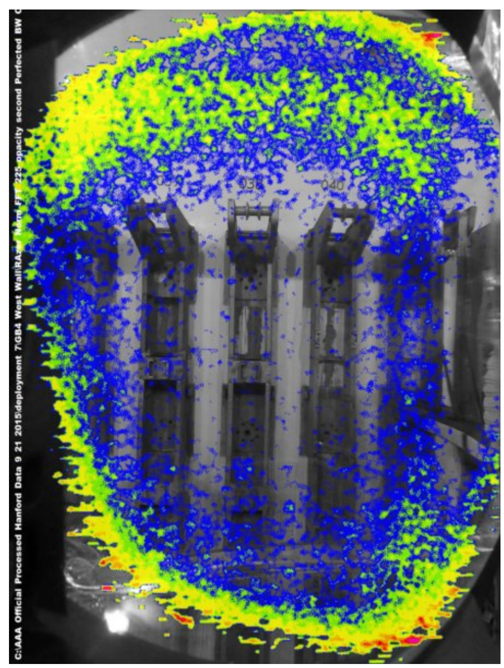
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 7, WEST WALL VIEW*

Color photo of area



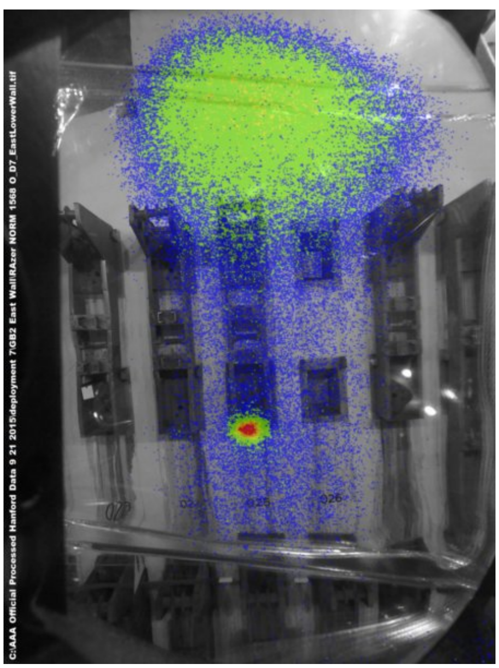
RAzer™ results using post processed PSP image



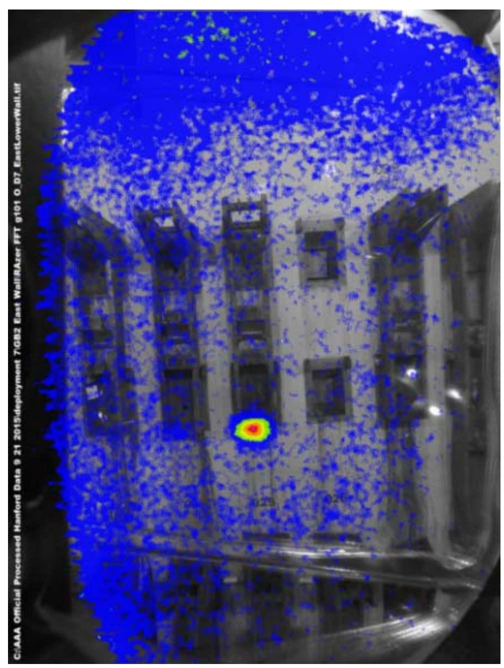
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 7, EAST WALL VIEW*

Color photo of area

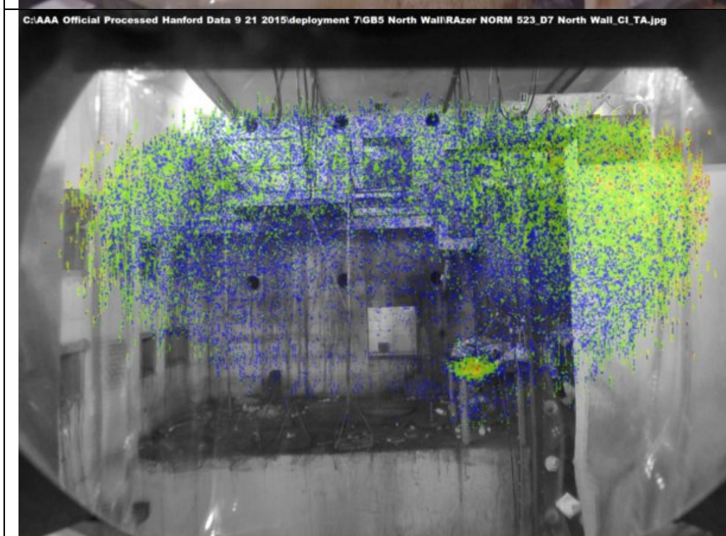
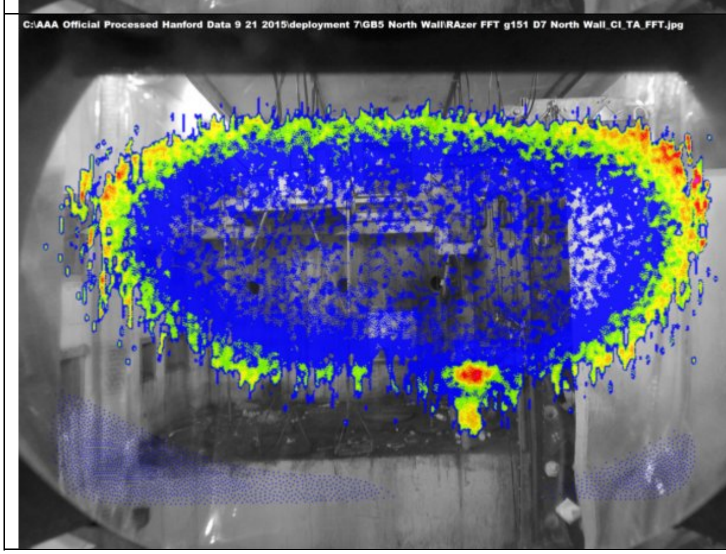


RAzer™ results using post processed PSP image

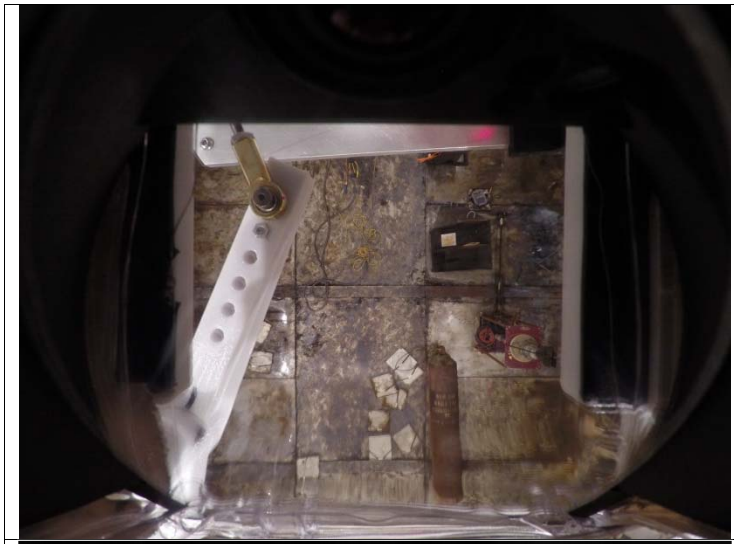
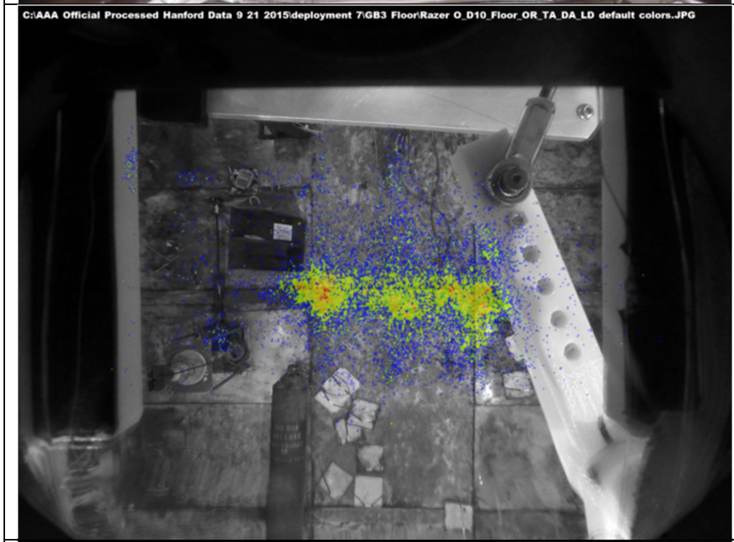
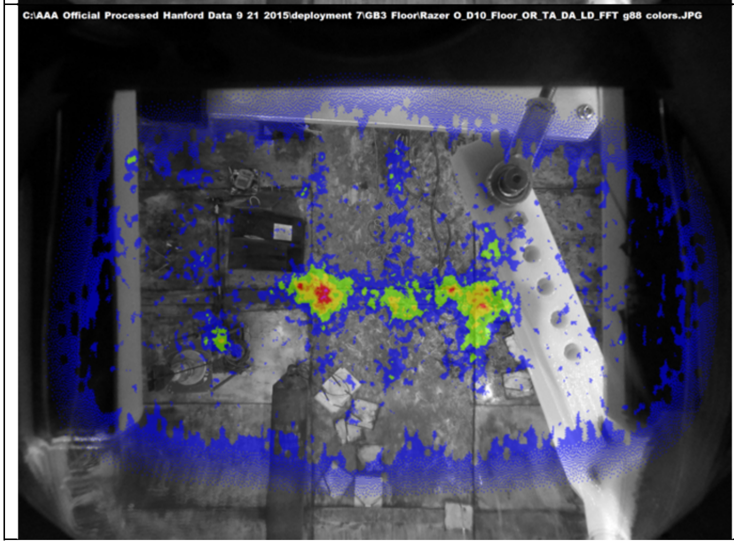


RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 7, NORTH WALL VIEW*

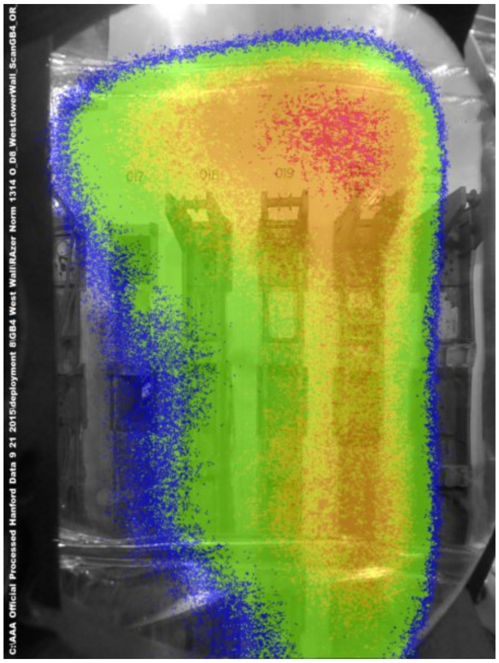
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 7, FLOOR VIEW*

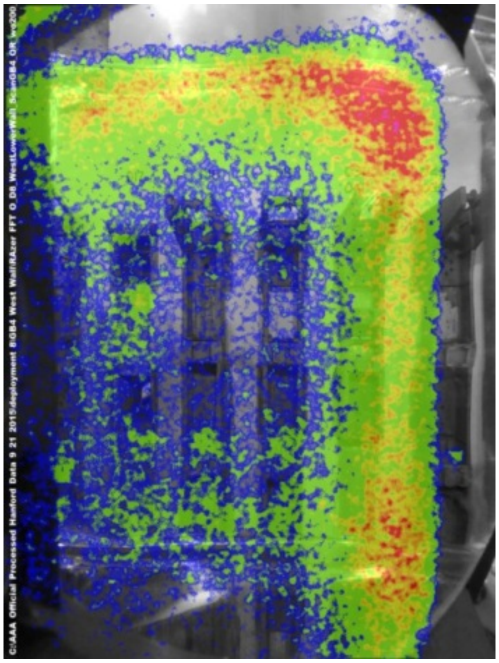
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 8, WEST WALL VIEW*

Color photo of area



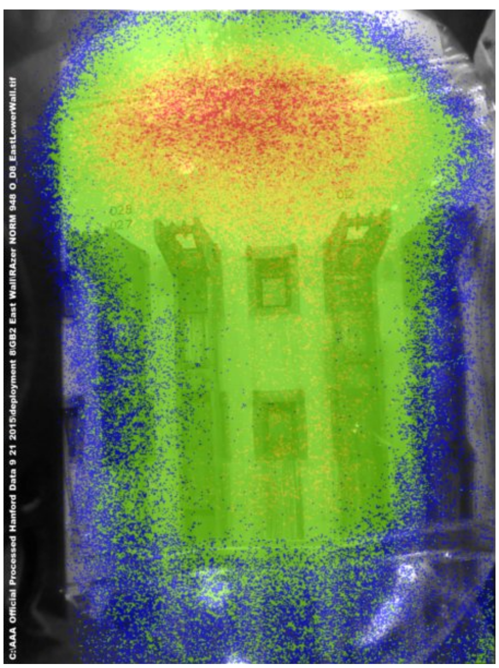
RAzer™ results using post processed PSP image



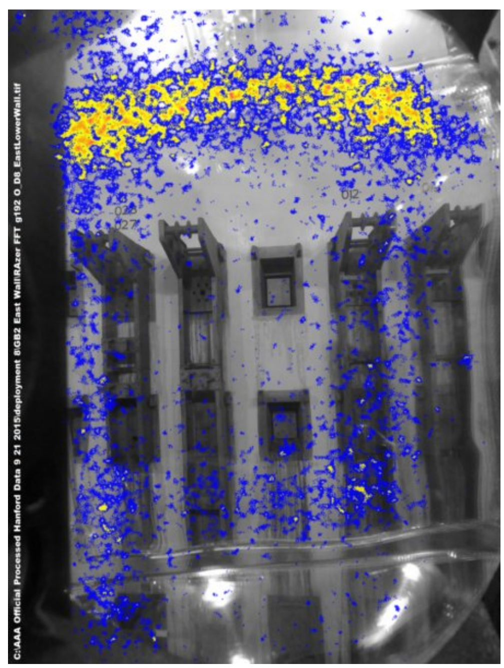
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 8, EAST WALL VIEW*

Color photo of area

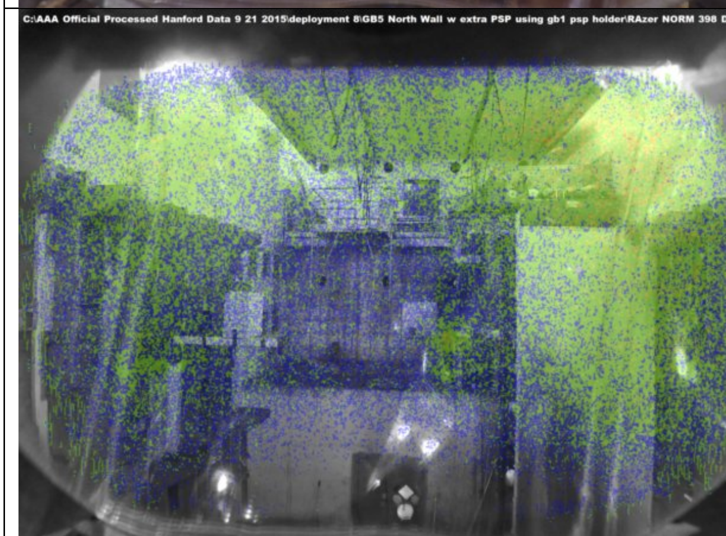
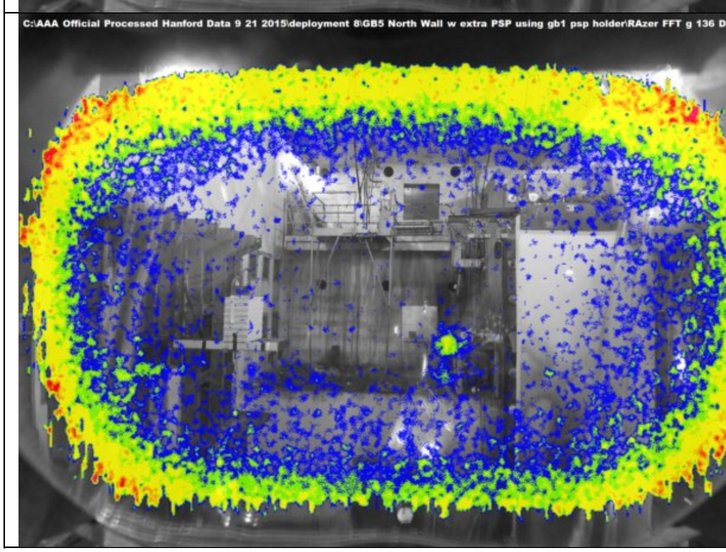


RAzer™ results using post processed PSP image

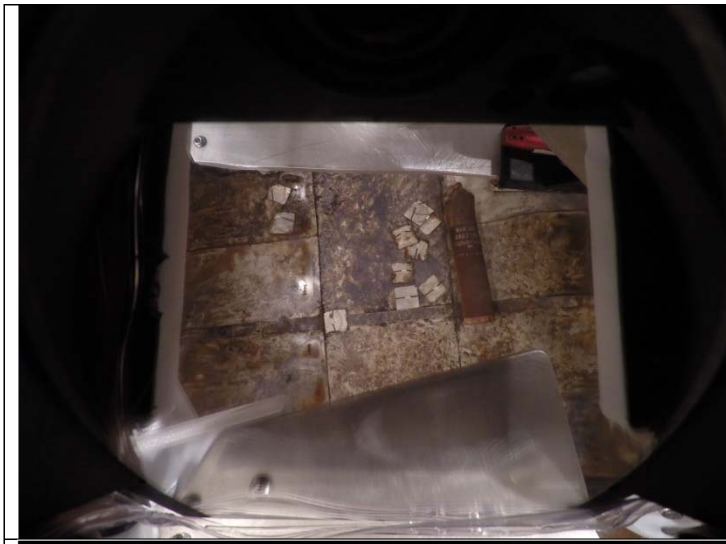
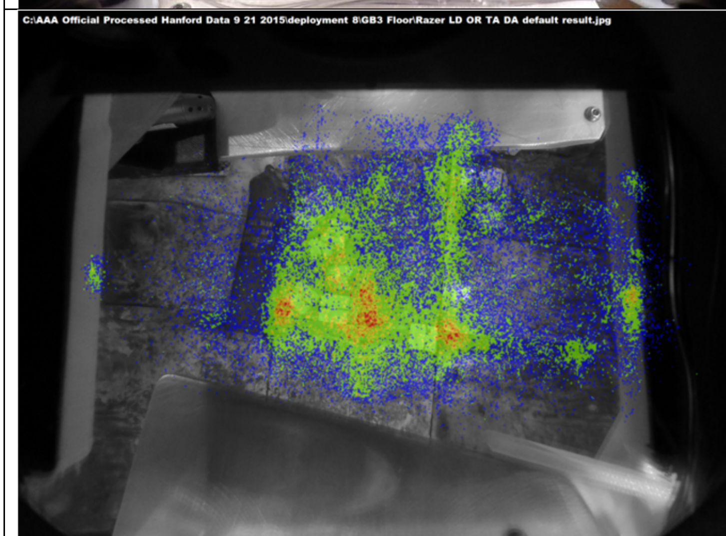
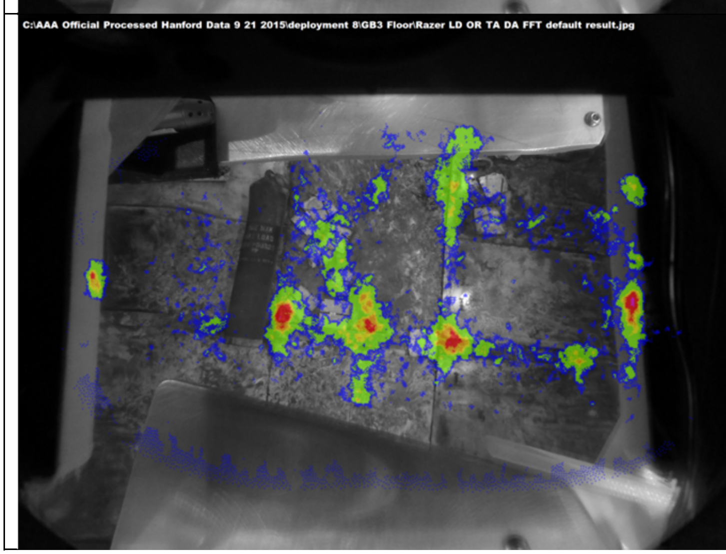


RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 8, NORTH WALL VIEW*

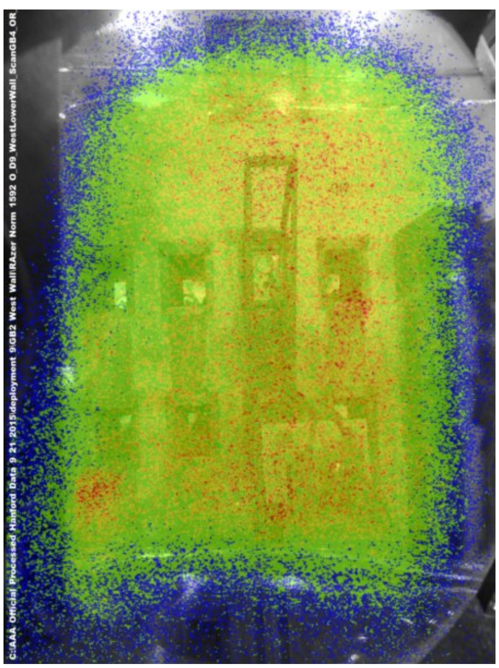
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 8, FLOOR VIEW*

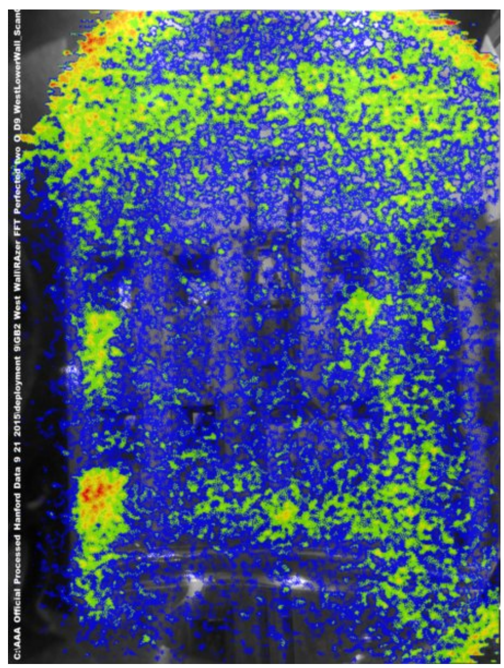
	***Color photo of area***
	***RAzer^{TM} results using post processed PSP image***
	***RAzer^{TM} results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 9, WEST WALL VIEW*

Color photo of area



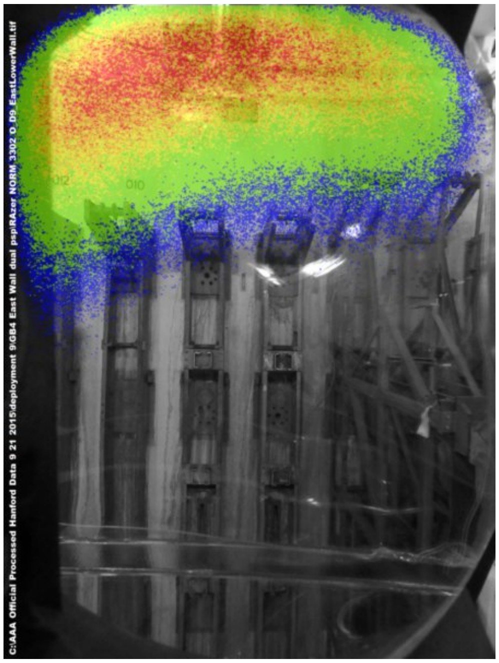
RAzer^{TM} results using post processed PSP image



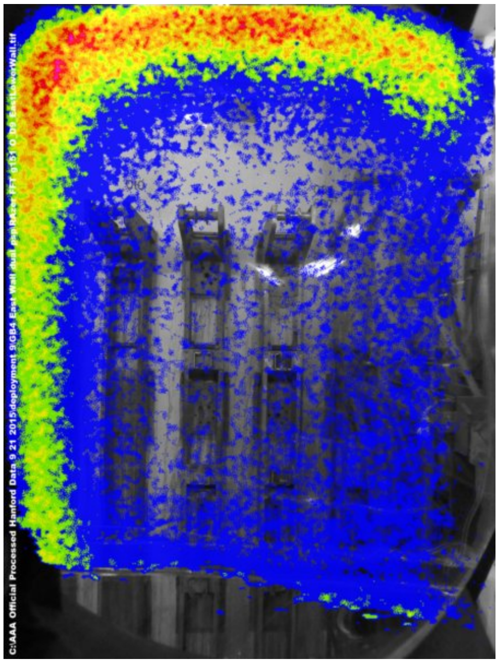
RAzer^{TM} results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 9, EAST WALL VIEW*

Color photo of area

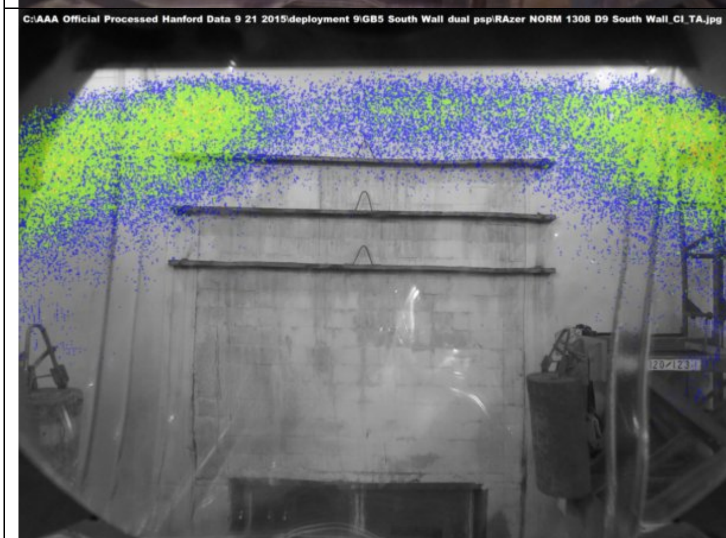
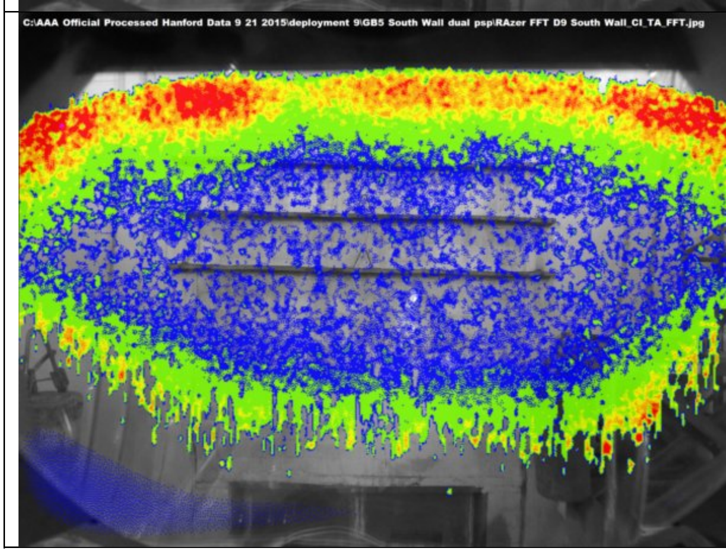


RAzer™ results using post processed PSP image

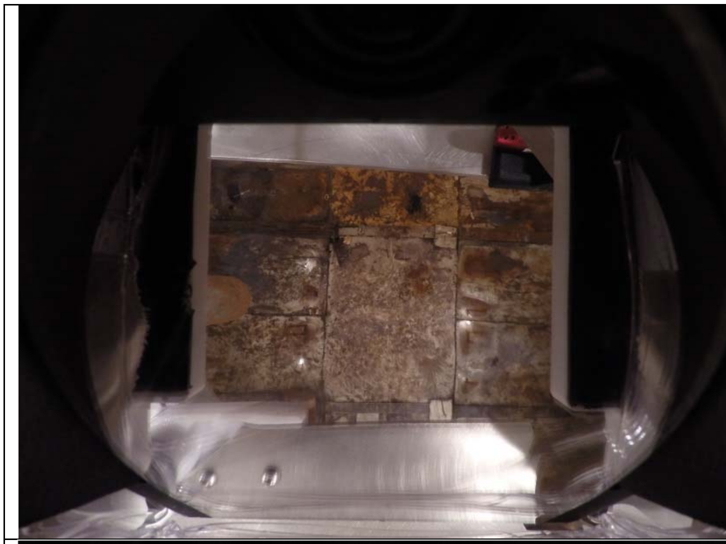


RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 9, SOUTH WALL VIEW*

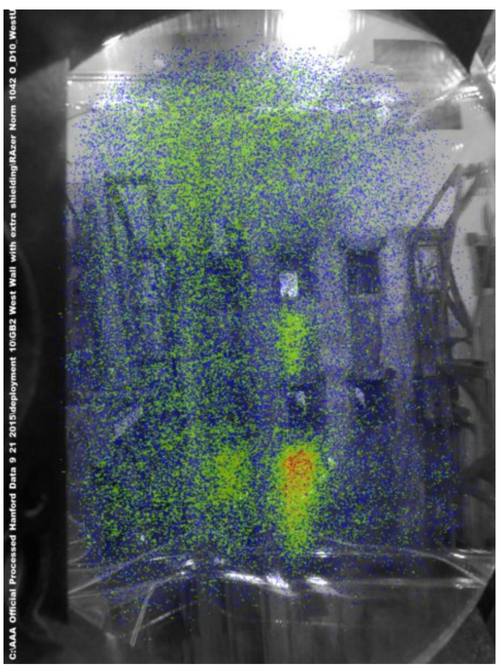
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 9, FLOOR VIEW*

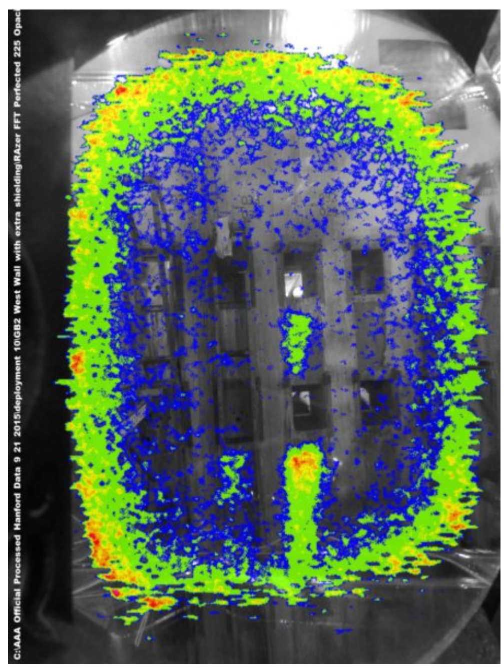
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 10, WEST WALL VIEW*

Color photo of area



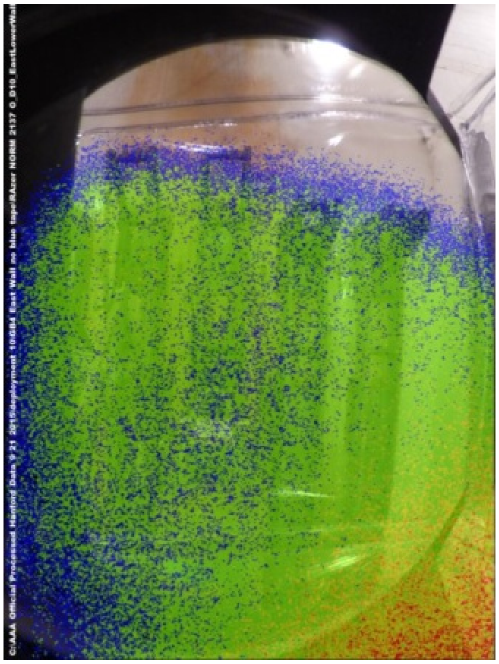
RAzer™ results using post processed PSP image



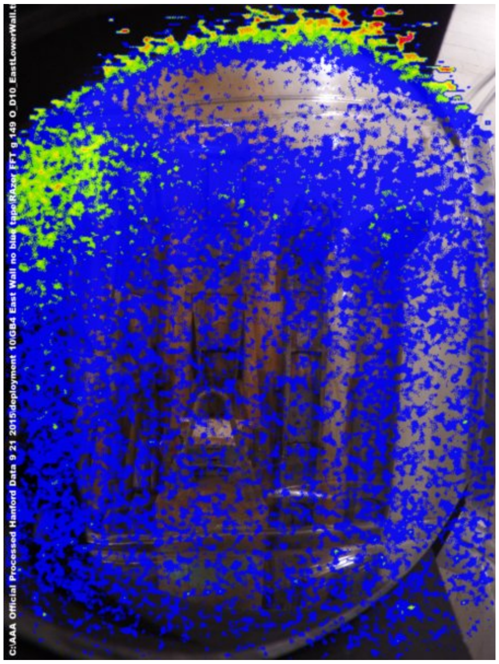
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 10, EAST WALL VIEW*

Color photo of area

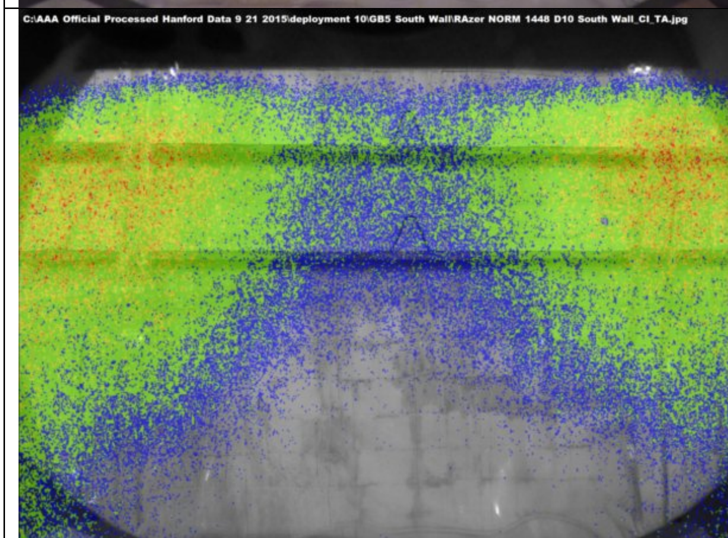
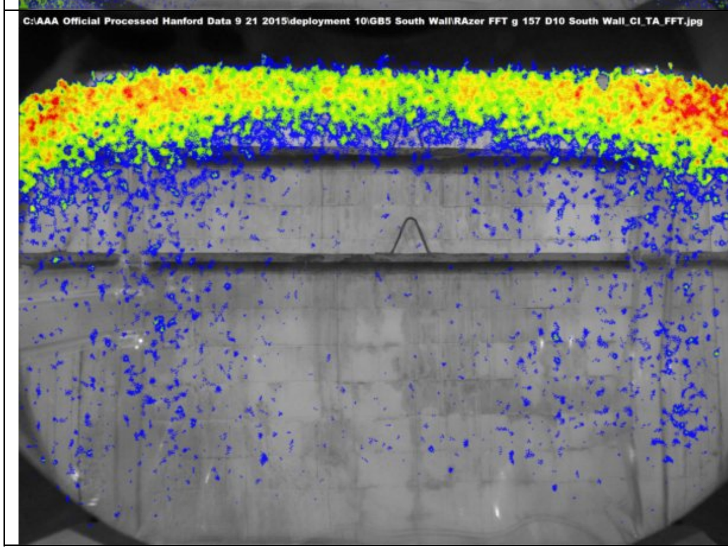


RAzer™ results using post processed PSP image



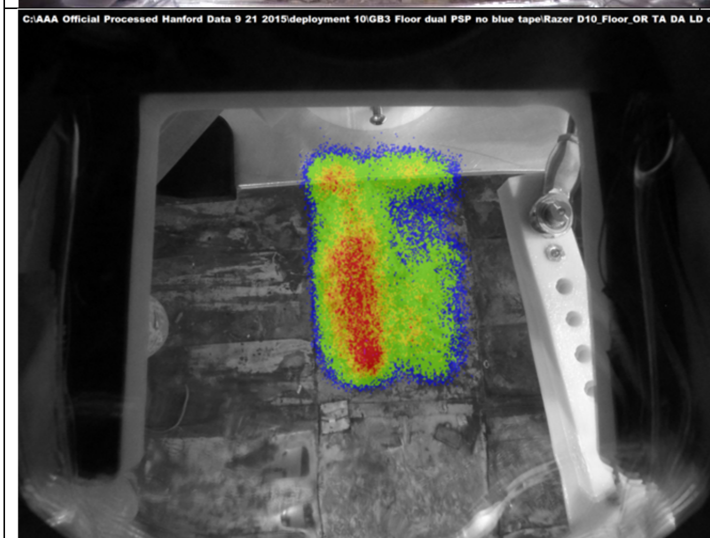
RAzer™ results with hotspots highlighted

APPENDIX B – *DEPLOYMENT 10, SOUTH WALL VIEW*

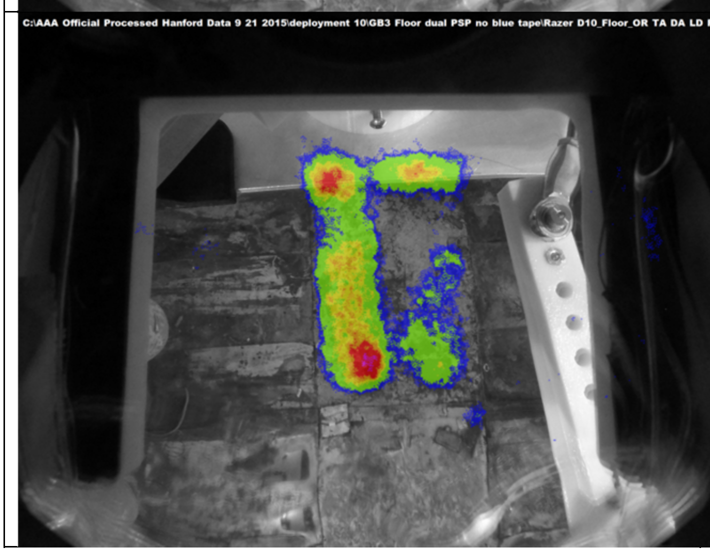
	***Color photo of area***
	***RAzer™ results using post processed PSP image***
	***RAzer™ results with hotspots highlighted***

APPENDIX B – *DEPLOYMENT 10, FLOOR VIEW*

Color photo of area



RAzer™ results using post processed PSP image



RAzer™ results with hotspots highlighted