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# RadBall™ Technology Testing in the Savannah River Site's Health Physics Instrument Calibration Laboratory

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**Abstract.** The United Kingdom's National Nuclear Laboratory (NNL) has developed a radiation-mapping device that can locate and quantify radioactive hazards within contaminated areas of the nuclear industry. The device, known as RadBall™, consists of a colander-like outer collimator that houses a radiation-sensitive polymer sphere. The collimator has over two hundred small holes; thus, specific areas of the polymer sphere are exposed to radiation becoming increasingly more opaque in proportion to the absorbed dose. The polymer sphere is imaged in an optical-CT scanner that produces a high resolution 3D map of optical attenuation coefficients. Subsequent analysis of the optical attenuation data provides information on the spatial distribution of sources in a given area forming a 3D characterization of the area of interest. The RadBall™ technology has been deployed in a number of technology trials in nuclear waste reprocessing plants at Sellafield in the United Kingdom and facilities of the Savannah River National Laboratory (SRNL). This paper summarizes the tests completed at SRNL Health Physics Instrument Calibration Laboratory (HPICL).

## 1. Introduction

The consequences of radiological operations at various U.S. Department of Energy (DOE) sites have resulted in substantially contaminated facilities (e.g., reactors, fuel and isotope processing facilities, laboratories, hot cells, gloveboxes, etc.). These facilities are usually associated with extremely high dose rates and it is therefore imperative to use remote technologies for characterization and decommissioning to keep worker exposures as low as reasonably achievable (ALARA) in these highly contaminated environments. Although technologies might already exist that could be tested, modified, and deployed for characterization and decommissioning efforts throughout the DOE complex, development of new and innovative technologies is also beneficial. In addition, though it might be possible to complete these tasks without remote/robotic systems, the benefits of remote systems regarding ALARA and cost concerns are expected to be substantial.

The United Kingdom's National Nuclear Laboratory (NNL) has developed RadBall™, a radiation-mapping device that can locate and quantify radioactive hazards within contaminated areas of the nuclear industry. This study completed at the Savannah River National Laboratory (SRNL) addresses key aspects of the testing of the innovative RadBall™ technology. RadBall™ presents a significant opportunity to expedite initial characterization of radiologically contaminated facilities with respect to ALARA concerns, initial decontamination strategies, and costs associated with the decontamination

efforts. RadBall™ will make radiation mapping safer and potentially more accurate and convenient than conventional detection devices, which are often much bigger and more cumbersome due to their electrical components and accessories. A single RadBall™ can be positioned in a highly contaminated area, glove box, or hot cell and left alone to collect data. Personnel would no longer spend valuable time carrying out manual scanning and surveying.

The device consists of a colander-like outer tungsten shell that houses a radiation-sensitive polymer sphere shown in Figure 1. The outer shell works to collimate radiation sources and those areas of the polymer sphere that are exposed react, becoming increasingly less transparent, in proportion to the absorbed dose. The polymer sphere is imaged in an optical-CT scanner developed at Duke University, which produces a high resolution 3D map of optical attenuation coefficients that are proportional to the absorbed dose.



**Figure 1.** Two components of a RadBall™ device: the outer collimation shell and inner polymer core.

The orientation of the opacity track provides the positional information regarding the source (achieved by using a reverse ray-tracing technique). The activity of the detected source is assessed by quantifying the magnitude of the opacity change (which follows a linear relationship with respect to the absorbed dose). NNL and SRNL have published information regarding RadBall™ development [1-3]. Information on the characterization and optical-CT scanning of the radiation sensitive polymer, PRESAGE™, has also been published [4-7].

A set of tests was performed at the Savannah River Site (SRS) Health Physics Instrument Calibration Laboratory (HPICL) using various gamma-ray sources and an x-ray machine with known radiological characteristics. The objective of these preliminary tests was to identify the optimal dose and collimator thickness of the RadBall™.

## **2. Experiments at SRS Health Physics Instrument Calibration Laboratory (HPICL)**

The HPICL at SRS contains nine Automated Irradiator Systems (Figure 2). The primary purpose of the equipment is to calibrate radiation detection instruments and test and verify personnel dosimeters. The sources and the exposures are therefore known with a high degree of certainty. The higher activity sources were ideal for the RadBall™ experiments since these sources provided shortened periods of exposure time. The highest  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  sources were used for the majority of the experiments at around 45.9 and 178 TBq (1,240 and 4,756 Ci), respectively. Three experimental phases were completed at the HPICL which included the exposure of 45 RadBall™ polymers. Selected experiments completed at the HPICL are presented in Table 1.

**Table 1.** RadBall™ Tests at HPICL.

	Test	Total Dose (Gy)	Radiation Source(s)	RadBall™	Collimator Thickness (mm)
Phase 1	5	3.0	$^{137}\text{Cs}$	N-1-6	5.0
	6	5.0	$^{137}\text{Cs}$	N-2-4	5.0
	13	3.0	1.5 Gy $^{137}\text{Cs}$ + 1.5 Gy $^{60}\text{Co}$ (collinear)	N-3-2	5.0
	14	6.0	3 Gy $^{60}\text{Co}$ (no collimator) + 3 Gy $^{60}\text{Co}$	N-3-3	5.0
	15	6.0	3 Gy 120 keV + 3 Gy 38keV x-ray (rotated 180°)	N-3-1	7.5
Phase 2	16	2.0	1 Gy $^{60}\text{Co}$ (no collimator) + 1 Gy $^{60}\text{Co}$	N-3-4	5.0
	19	3.0	166 keV x-ray	N-5-5	5.0
	20	3.0	2 Gy $^{137}\text{Cs}$ + 1 Gy $^{60}\text{Co}$ (collinear)	N-4-3	5.0
	28	0.5	$^{241}\text{Am}$	N-4-4	5.0
	29	3.0	1.5 Gy 120 keV x-ray, rotated 90° & 1.5 Gy 38 keV	N-4-5	5.0
Phase 3	30	3.0	1.5 Gy $^{137}\text{Cs}$ (no collimator) + 1.5 Gy $^{137}\text{Cs}$ (with collimator)	N-7-2	7.5
	31	3.0	2.0 Gy $^{137}\text{Cs}$ (no collimator) + 1.0 Gy $^{137}\text{Cs}$ (with collimator)	N-8-2	7.5
	43	3.0	$^{60}\text{Co}$ : Repeat experiment 42 using an angle of rotation of 10°.	N-8-4	7.5
	44	6.0	$^{60}\text{Co}$ : Irradiate RadBall™ with an initial dose of 1 Gy, then rotate the RadBall™ by 60° and give another 1 Gy dose. Repeat sequence until 6 irradiations have been completed and the RadBall™ has received a total dose of 6.0 Gy.	N-10-2	10.0
	45	6.0	$^{60}\text{Co}$ : Repeat exp. 44 with the RadBall™ tilted at a 45 degree angle.	N-10-1	10.0

**Figure 2.** RadBall™ positioned in front of an automated irradiator system at the HPICL.

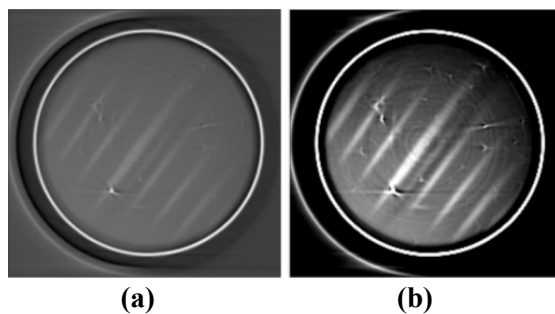
The tests at the HPICL consisted of three phases (Table 1):

- Phase 1 experiments were primarily used to obtain information on the target dose for RadBall™. Experiments were completed with a  $^{137}\text{Cs}$  source and a  $^{60}\text{Co}$  source over the range of 0.5 to 5 Gy.
- Phase 2 experiments investigated the RadBall™ performance with different radiation sources and different collimator thicknesses.
- Phase 3 experiments investigated the ability of the RadBall™ technology to perform with partially exposed RadBall™ polymers. RadBall™ polymers were given a radiation dose without the shielding collimator and then a second irradiation was performed with the collimator fitted.

The  $^{241}\text{Am}$  source was used for one exposure; however, due to its low activity and therefore long exposure times, it was not used in any other test. With the exception of experiment 28 ( $^{241}\text{Am}$  exposed at a distance of 30 cm) all experiments were completed with the RadBall™ positioned 100 cm away from the radiation source. At 30 cm, the  $^{241}\text{Am}$  source could not be considered a point source because it is large (consisting of seven separate sources and resembling an area source at 30 cm). An x-ray source was used, which generated various photon energies with peaks at 166 keV, 120 keV, and 38 keV. The x-ray source was not ideal since it generated a distribution of photon energies; however, the peaks available were near the 60 keV gamma ray energy emitted from  $^{241}\text{Am}$ . The x-ray machine offered a much higher rate of exposure than the  $^{241}\text{Am}$  source and was therefore much more convenient in terms of exposure time.

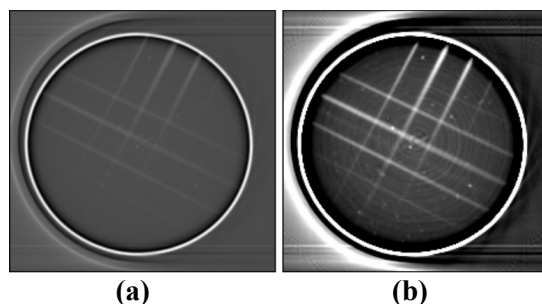
After irradiation at the HPICL, the RadBall™ polymers were sent to Duke University Medical Center for optical-CT scanning. The results from the optical-CT scan were subsequently analysed at NNL, using the Image Processing and Analysis in Java (ImageJ) software (ImageJ website: <http://rsbweb.nih.gov/ij/>).

Phase 1 experiments produced results similar to that displayed in Figure 3, which shows a horizontal slice of a RadBall™ (N-2-4) with (a) pre- and (b) post- contrast enhancement applied (a feature within the ImageJ software, which allows the contrast between the radiation tracks and the background to be enhanced). Seven tracks are visible in the slice with the widest diameter radiation track in the middle. This is to be as expected as the collimation hole facing the source was slightly larger than the other holes on the collimation device. The diminishing intensity of the peaks to the left and right of the middle peak are due to the orientation of the hole following the curvature of the collimator geometry. The direction that each hole was drilled was always perpendicular to the surface of the sphere.



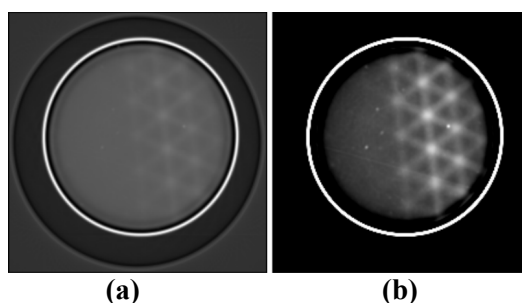
**Figure 3.** Images of (a) Pre and (b) Post contrast enhanced slices of RadBall™ N-2-4

Figure 4 shows the scan images of RadBall™ N-4-5 (Table 1) irradiated with two sources (1.5 Gy 120 keV x-ray and 1.5 Gy 38 keV at 90° to the first irradiation). The scans show four radiation tracks entering from the top left and three radiation tracks entering from the top right, which crossover in the middle of the RadBall™.



**Figure 4.** Images of (a) Pre- and (b) Post- contrast enhanced slices of RadBall™ N-4-5.

Figure 5 shows optical scan images for RadBall™ N-10-2 (Table 1). In this experiment the RadBall™ was given an initial dose of 1 Gy and then rotated by 60 degrees and exposed again. This exercise was repeated until six irradiations had been completed. The pattern appearing in the polymer is similar to isometric graph paper. Higher intensity bright spots appear where one or more radiation tracks intersect, increasing the radiation dose delivered to that area.



**Figure 5.** Images of (a) Pre- and (b) Post- contrast enhanced slices of RadBall™ N-10-2.

### 3. Discussions and Results

The RadBall™ technology has responded well during the HPICL calibration facility experiments. Radiation tracks were visible in all of the 45 experiments and demonstrated that the RadBall™ technology is sensitive to  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{241}\text{Am}$  sources over the radiation range of 0.5 to 8 Gy. Based on visual interpretation of the two-dimensional slice representations the target dose for the RadBall™ is 1.5 to 3.0 Gy and the optimum collimation thickness is 10 mm. Further work is ongoing to investigate whether the RadBall™ technology is able to characterize more complex radiation sources.

### 4. References

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