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Initial Results of the Nuclear Accident Dosimetry Intercomparison at the Armed Forces Radiobiology Research Institute's TRIGA Reactor

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Lawrence Livermore National Laboratory

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IER-602 CED-3b Report

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9 Institut de Radioprotection et de Sûreté Nucléaire
10 Belgian Nuclear Research Centre
11 Y-12 National Security Site
12 Sandia National Laboratories
13 Idaho National Laboratory

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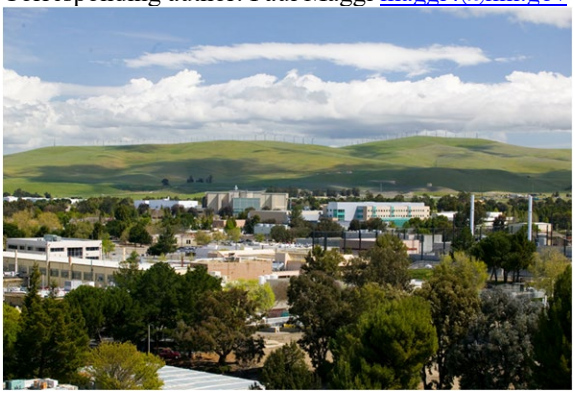

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Executive Summary

This report presents the initial results for IER-602, the international nuclear accident dosimetry intercomparison performed at the Armed Forces Radiobiology Research Institute (AFRRI). Ten groups participated (six DOE laboratories, three international groups, and one DOD group) in a week-long exercise in late June 2024. Two additional groups observed the exercise (one DOE laboratory, one university). Three days of irradiations were performed, and participants reported results within 24 hours of the irradiations. Results were compared to the reference values and performance criteria established by IER-484 AFRRI ER1 Dosimetry Characterization and ANSI/HPS N13.3-2013, respectively. Passing performance varied from 17% to 100%, with an average of 67%.

Introduction

From June 24 to June 28, 2024, the Armed Forces Radiobiology Research Institute (AFRRI) in Bethesda, MD hosted an international nuclear accident dosimetry intercomparison. AFRRI, a US Department of Defense facility operated by the Uniformed Services University, houses a TRIGA reactor suitable for high-dose neutron exposures. Previous intercomparisons have taken place at the Godiva and Flattop critical assemblies at the National Nuclear Security Site in Nevada.

This exercise was designed to test the participant's nuclear accident dosimetry systems under two irradiation conditions. The first (Tuesday) was a known irradiation where dosimeter placement and phantom locations with respect to the irradiation source were provided to the participants. The second (Wednesday) irradiation was blinded, where participants were only informed about dosimeter placement but not phantom locations. The phantoms for these irradiations were either saline-filled humanoid phantoms or aluminum plates, which is a surrogate in-air measurement. The phantoms were placed in a configuration previously characterized in August 2023 as part of IER-484; the characterized positions are depicted in Figure 1. Participants reported preliminary dose estimates 24 hours after the exposure and compared to the requirements of established by the ANSI/HPS-N13.3 Dosimetry for Criticality Accidents standard. Neutron doses ranged from 70 rad to 370 rad.

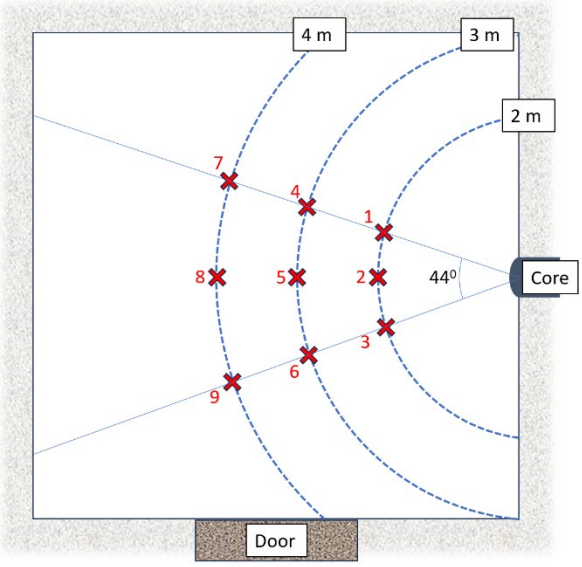

Figure 1: Characterized Irradiation Positions in AFRRI Exposure Room

A third irradiation was performed to test two new scenarios not previously encountered by the criticality accident community: the activation of "personal items" such as jewelry, glasses, coins (ref: ANSI/HPS-N13.3 A.4) and shielding of phantoms located further from the irradiation source by phantoms closer to the source. Three phantoms were arranged along the centerline of the exposure room at three different distances (positions 2, 5, and 6 in Figure 1). This was not a previously characterized setup, so reference values are not available. The phantom closest to the reactor was dressed in a lab coat, with personal items placed in the pockets in addition to deployed accident dosimetry. Participation in this irradiation was optional. Preliminary impressions from the labs were positive for this new setup, with additional analysis pending.

Compared to the Godiva critical assembly, AFRRI can return irradiated dosimeters within an hour of exposure. This results in the activated materials, primarily indium with a 54-minute half-life, being too activated to count without high detector dead time. While this was originally seen as a confounding factor for the participants, multiple groups indicated this will inform their dosimeter throughput estimates because faster receipt times better simulates the turnaround time were a criticality accident to occur.

Six Department of Energy (DOE) Labs, three international groups, and two DoD groups participated in the intercomparison, with two additional groups observing. The DOE labs were Lawrence Livermore National Laboratory (LLNL), Savanah River National Laboratory (SRNL), Hanford Site, Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), and the Y-12 National Security Complex (Y-12). The international participants were the Atomic Weapons Establishment (AWE) from the UK, Institut de Radioprotection et de Sûreté Nucléaire (IRSN) from France, and the Belgian Nuclear Research Center (SCK CEN). The DOD participant was the Norfolk Naval Shipyard (NNSY). Members of the AFRRI staff deployed dosimeters for testing purposes on behalf of AFRRI and the Naval Dosimetry Center (NDC), but were not active participants in the interncomparison. The two observer groups were from Idaho National Lab (INL), which may participate in future intercomparisons, and the members of the University of Wisconsin Accredited Dosimetry Calibration Laboratory (UWADCL).

Results

For each experimental set, a setup run without phantoms was performed to calibrate AFRRI's ceiling-mounted paired ion chamber system to the desired dose target and rate at a reference location. Setup runs are used to determine the required reactor power and duration to achieve the desired dose reference. The dose targets are given in Table 1.

Table 1: Irradiation targets provided to AFRRI

	Total Dose Target (Gy)	Distance	Position	Dose Rate
Tuesday	3.5	3 m	5	60 cGy/min
Wednesday	2.2	3 m	5	60 cGy/min
Thursday	3.5	3 m	5	60 cGy/min

The small size of the exposure room necessitated split runs for the first two experimental days. Each run was performed using the same irradiation parameters, but different phantoms/stands configuration. The run parameters, type, and positions are listed in Table 2. Run A denotes a BOMAB run; run B denotes a free-in-air (FIA) stand run. The calculated irradiation target values for each position were based on the IER-484 CED3b Report: AFRRI ER1 Dosimetry Characterization, Tables 5, 6, 7, and 8. The results from the tables were averaged for each position, and the standard deviation was used for the uncertainty.

Table 2: Run information

	Start Time	Stop Time	Duration (s)	Phantoms	Positions
Tuesday A	09:05:07	09:10:42	335	BOMAB	1, 5, 9
Tuesday B	10:51:09	10:56:46	337	FIA Stands	1, 5, 9
Wednesday A	08:20:50	08:24:15	205	BOMAB	4, 8, 3
Wednesday B	09:47:22	09:50:51	209	FIA Stands	2, 4, 6
Thursday	10:34:04	10:39:36	332	BOMAB	2, 5, 8

Table 3: Calculated Irradiation Target Values

		Neutron Dp(10) [Gy]			Gamma Dose [Gy]			Total Dose [Gy]		
Tuesday	BOMAB 1	3.68	±	0.36	5.53	±	0.42	9.21	±	0.55
	BOMAB 2	1.93	±	0.20	3.15	±	0.24	5.07	±	0.31
	BOMAB 3	1.21	±	0.18	2.17	±	0.20	3.38	±	0.27
	FIA 1	3.37	±	0.26	5.37	±	0.25	8.74	±	0.36
	FIA 2	1.60	±	0.05	2.88	±	0.04	4.48	±	0.06
	FIA 3	1.31	±	0.13	2.07	±	0.06	3.37	±	0.14
Wednesday	BOMAB 1	1.29	±	0.20	2.10	±	0.18	3.39	±	0.27
	BOMAB 2	0.67	±	0.20	1.36	±	0.16	2.03	±	0.25
	BOMAB 3	2.70	±	0.77	3.71	±	0.49	6.41	±	0.91
	FIA 1	2.16	±	0.25	3.48	±	0.27	5.64	±	0.37
	FIA 2	1.02	±	0.09	1.75	±	0.17	2.77	±	0.19
	FIA 3	0.89	±	0.18	1.85	±	0.06	2.74	±	0.19

For the Tuesday BOMAB run (Figure 2), BOMAB 1 (position 1, 2 m from core) was rotated 40^0 away from the core; this was to allow participants to test their angular correction factors. BOMABs 2 (position 5, 3 m from core) and 2 (position 9, 4 m from core) were aligned facing the core center. The FIA stands (Figure 3) were placed in the same locations, but the stand at Position 1 was aligned with the core.

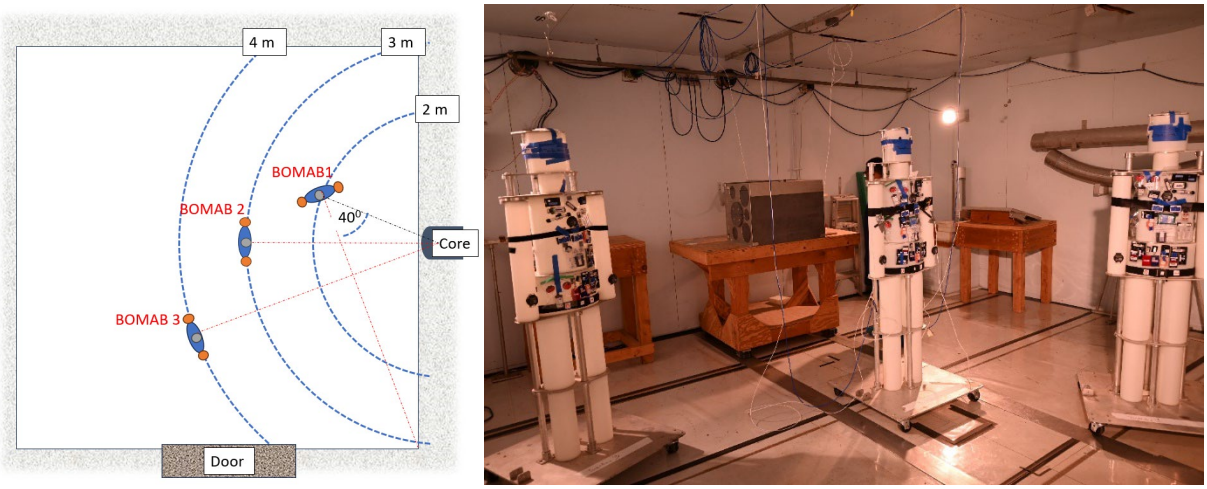

Figure 2: Schematic (left) of BOMAB setup (right) for Tuesday A run.

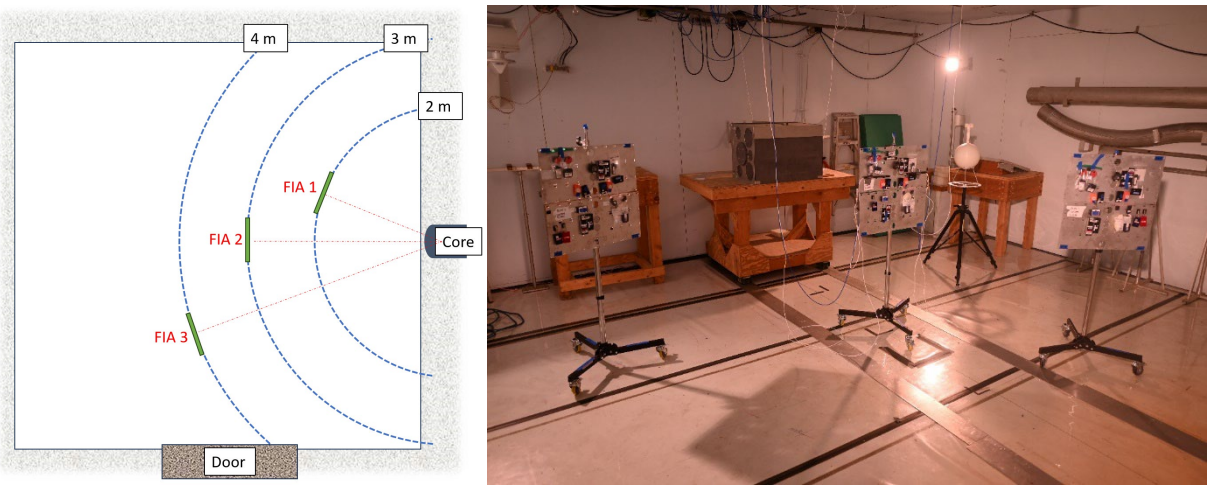

Figure 3: Schematic (left) of free-in-air (FIA) stand setup (right) for Tuesday B run.

For the Wednesday BOMAB run (Figure 4), BOMABs 1 (position 4, 3 m from core) and 3 (position 3, 2 m from core) were aligned facing the core center. BOMAB 2 (position 8, 4 m from core) was reversed, that is the phantom facing away from the reactor, to test the participants' ability to determine orientation with respect to the irradiation source. The FIA stands (Figure 5) were placed at positions 4 and 6 (3 m from core), and position 2 (2 m from core).

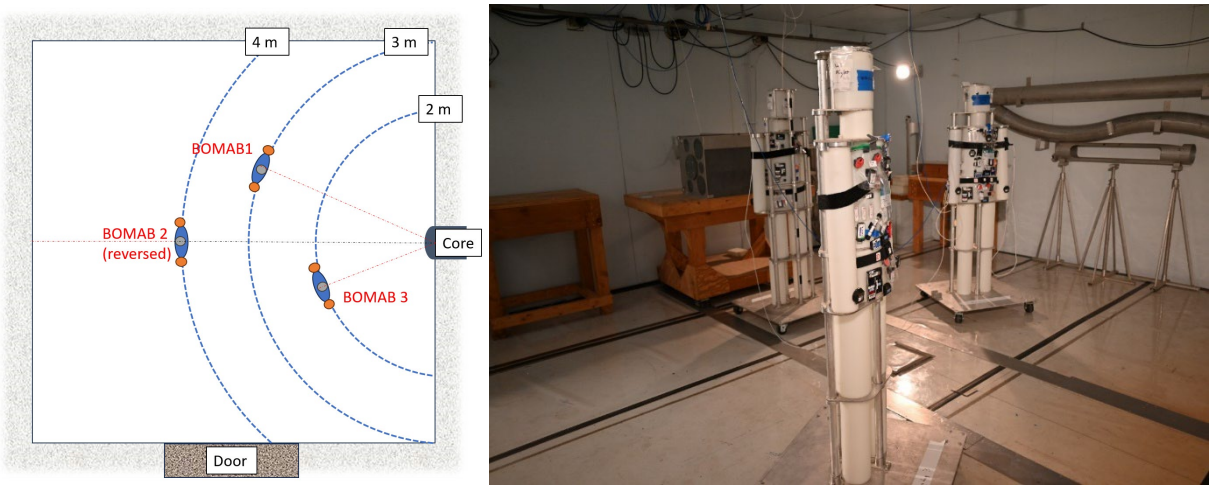

Figure 4: Schematic (left) of BOMAB setup (right) for Wednesday A run.

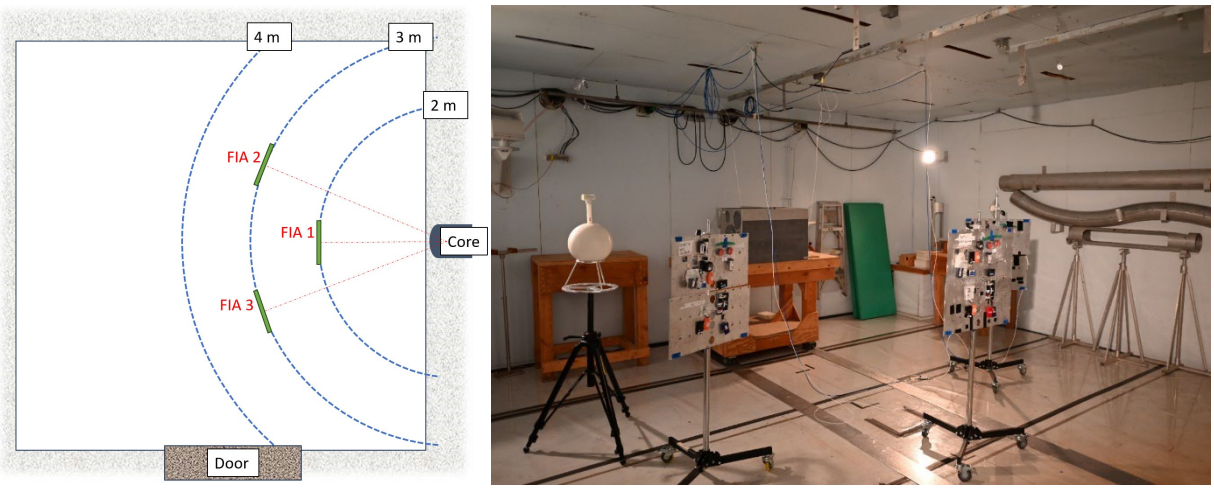

Figure 5: Schematic (left) of Free In Air (FIA) stand setup (right) for Wednesday B run.

The average dose value for each participant's dosimeters was compared with the target values established using the data from IER-484. In Appendix A, the results for the BOMABs are reported in Table 4 and Table 5; the results for the FIA stands are reported in Table 6 and Table 7.

With regards to general trends for the BOMAB runs, more participants met the ANSI/ANS criteria on the Wednesday run (80% average pass rate) compared to the Tuesday run (57% average pass rate) for the reported neutron doses. For photon doses, the pass rates were 60% on Tuesday and 88% on Wednesday.

Participants were not required to deploy dosimeters for the FIA stands. Passing rates were similar, though slightly higher (average 78% across all results), than the BOMAB runs.

When looking at the data as a cohort and rejecting outliers, the average value of all participants was consistent with the target value (difference range of -17% to +5%), indicating that there were not significant biases in the characterization.

The irradiation configuration along with setup pictures is presented in Appendix B. Appendix C contains dosimeter placement for each phantom or stand.

Data analysis for the Thursday run (setup in Figure 6, initial results Table 8 in Appendix A), notably the effects of shielding and activation of non-nuclear accident dosimeter personal items, will be reported in the CED 4a report. Further performance analysis and comparisons to previous nuclear accident dosimetry exercises will also be performed in the CED 4a report.

Appendix A: Participant Results

For the tables in Appendix A, red text and a light blue cell shading means the result was less than the lower test criteria; red text and light red cell shading means the result was more than the lower test criteria.

Table 4: Tuesday BOMAB run participant results

	Neutron [Gy]			Gamma [Gy]		
Lab Number	BOMAB 1	BOMAB 2	BOMAB 3	BOMAB 1	BOMAB 2	BOMAB 3
1	3.50	2.14	1.50	5.60	3.40	2.40
2	2.37	1.62	1.25	3.79	2.58	2.00
3		2.39				
4	4.41	2.25	1.75			
5	3.41	2.10	1.91	3.81	2.03	1.53
6	2.30	1.05	0.68	4.50	2.31	1.53
7	1.84	1.09	0.74			
8	2.27	1.23	0.68	4.21	2.54	1.88
9	2.43	1.56	0.95			
10	6.30	3.32	1.71			
Average	3.20	1.87	1.24	4.38	2.57	1.87
Standard Deviation	1.41	0.71	0.49	0.74	0.51	0.36
Target	3.68	1.93	1.21	5.53	3.15	2.17
Uncertainty	0.36	0.20	0.18	0.42	0.24	0.20
Upper Test Criteria	4.67	2.45	1.56	6.98	3.97	2.74
Lower Test Criteria	2.69	1.40	0.86	4.09	2.32	1.59
% Meeting Criteria	33%	60%	33%	60%	60%	60%

Table 5: Wednesday BOMAB run participant results

	Neutron [Gy]			Gamma [Gy]		
Lab Number	BOMAB 1	BOMAB 2	BOMAB 3	BOMAB 1	BOMAB 2	BOMAB 3
1	1.20	1.00	2.24	1.96	1.79	3.36
2	1.28	0.74	2.65	2.13	1.24	4.42
3	1.01	0.44	2.28			
4	1.10	0.78	2.19			
5	1.38	0.87	2.42	1.94	1.54	3.08
6	1.52	0.99	2.64	1.97	1.34	3.67
7	0.33	0.43	1.18			
8	0.93	0.67	1.90	1.40	1.13	2.83
9	1.09	0.83	2.01			
10	2.44	0.32	2.98			
Average	1.23	0.71	2.25	1.88	1.41	3.47
Standard Deviation	0.53	0.24	0.49	0.28	0.26	0.62
Target	1.29	0.67	2.70	2.10	1.36	3.71
Uncertainty	0.20	0.20	0.77	0.18	0.16	0.49
Upper Test Criteria	1.68	0.93	3.72	2.65	1.73	4.76
Lower Test Criteria	0.91	0.41	1.68	1.54	0.98	2.66
% Meeting Criteria	80%	70%	90%	80%	80%	100%

Table 6: Tuesday FIA run participant results

	Neutron [Gy]			Gamma [Gy]		
Lab Number	FIA 1	FIA 2	FIA 3	FIA 1	FIA 2	FIA 3
1						
2						
3						
4						
5	3.29	2.02	1.26	3.29	2.02	1.26
6	2.56	1.27	0.91	4.50	2.34	1.66
7	2.95	1.36	0.91			
8	3.01	1.36	0.84			
9	2.60	1.41	0.91			
10	7.98	8.12	3.71			
Average	3.73	2.59	1.42	3.90	2.18	1.46
Standard Deviation	2.10	2.72	1.13	0.86	0.23	0.28
Target	3.37	1.60	1.31	5.37	2.88	2.07
Uncertainty	0.26	0.05	0.13	0.25	0.04	0.06
Upper Test Criteria	4.26	2.00	1.66	6.74	3.60	2.59
Lower Test Criteria	2.49	1.20	0.96	4.00	2.16	1.55
% Meeting Criteria	83%	67%	17%	50%	50%	50%

Table 7: Wednesday F IA run participant Results

	Neutron [Gy]			Gamma [Gy]		
Lab Number	FIA 1	FIA 2	FIA 3	FIA 1	FIA 2	FIA 3
1	1.95	1.37	1.37			
2						
3						
4						
5	2.22	1.18	1.17	2.22	1.18	1.17
6	2.48	1.10	1.28	3.44	1.89	1.89
7						
8	1.72	0.93	0.92	2.43	1.43	1.49
9	2.11	1.12	1.15			
10	2.61	1.53	1.20			
Average	2.18	1.21	1.18	2.70	1.50	1.52
Standard Deviation	0.33	0.21	0.15	0.65	0.36	0.36
Target	2.16	1.02	0.89	3.48	1.75	1.85
Uncertainty	0.25	0.09	0.18	0.27	0.17	0.06
Upper Test Criteria	2.75	1.29	1.18	4.40	2.22	2.32
Lower Test Criteria	1.56	0.75	0.60	2.57	1.28	1.38
% Meeting Criteria	100%	67%	50%	33%	67%	67%

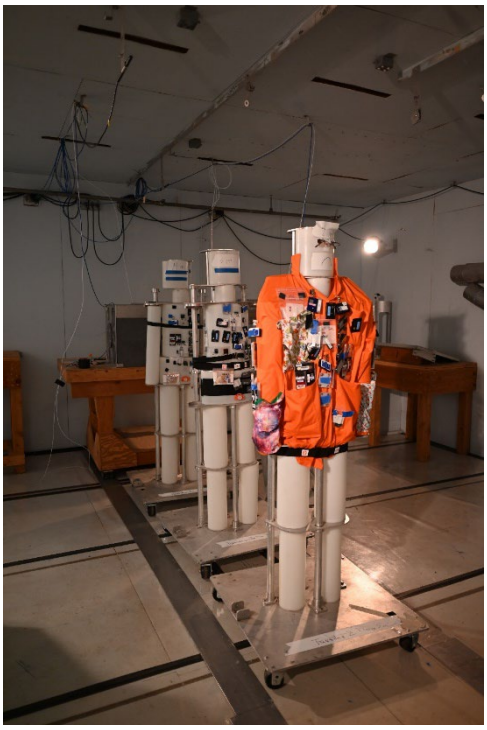

Figure 6: Setup of Thursday BOMAB run.

Table 8: Thursday BOMAB run average results

	Neutron [Gy]			Gamma [Gy]		
	BOMAB 1	BOMAB 2	BOMAB 3	BOMAB 1	BOMAB 2	BOMAB 3
Average	2.68	0.815	0.475	4.35	1.88	1.2
Standard Deviation	0.07	0.21	0.01	1.33	0.42	0.28

Appendix B: Dosimeter Placements

Table 9: Tuesday BOMAB 1 Dosimeters

BOMAB 1 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	1A - B0038635	Left (BOMAB R)
	1B - B0040829	Chest
	1C - B0040830	Right (BOMAB L)
AWE		
	753867 Orange	Front
	0007932 Black	Front
	753952 Orange	Front
	0014599 Black	Front
	753950	Back
	753922	Back
Belgium		
	SCK A	Front
	SCK B	Back
	SCK C	Left Side
Hanford		
	3	Front
	1	Back
	16	Front
IRSN		
	1	Front
	6	Back
LANL		
	5	Front
	6	Back
LLNL		
	1414646	Front
	1414647	Front
	1414650	Back
Norfolk Naval Shipyard		
	12	Front
	10	Front
	13	Back
	15	Back
Sandia		
	0397	Front
	0477	Back
	0421	Side
SRNL		
	6	Front
	4	Front
	3	Back
Y-12		
	0010395 Blue	Front
	902774 Red	Front

Table 10: Tuesday BOMAB 2 Dosimeters

BOMAB 2 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	2A B0041410	Left (BOMAB R)
	2B B0041505	Chest
	2C B0041525	Right (BOMAB L)
AWE		
	753978 Orange	Front
	0012366 Black	Front
	753838 Orange	Front
	0145264 Black	Front
	749298	Back
	753856	Back
Belgium		
	SCK D	Front
	SCK E	Front
	SCK G	Front Clip on right
	SCK K	Side
Hanford		
	7	Front
	13	Front
	15	Front
IRSN		
	3	Front
	4	Back
LANL		
	3	Front
	4	Back
LLNL		
	1414651	Front
	1414652	Front
	1414653	Back
Norfolk Naval Shipyard		
	2	Front
	3	Front
	5	Back
	6	Back
Sandia		
	0418	Front
	0477	Back
	0421	Side
SRNL		
	2	Front
	5	Front
	9	Back
Y-12		
	0048884 Blue	Front
	0045251 Blue	Back

Table 11: Tuesday BOMAB 3 Dosimeters

BOMAB 3 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	3A B0041682	Left (BOMAB R)
	3B B0041683	Chest
	3C B0041870	Right (BOMAB L)
AWE		
	749280 Orange	Front
	0141789 Black	Front
	0140883 Orange	Front
	Missing	Front
	7538353 Orange	Back
	753836 Orange	Back
Belgium		
	SCK L	Left Lower Torso
Hanford		
	4	Right Lower Torso
	14	Back
	23	Front
IRSN		
	5	Front
	8	Back
LANL		
	1	Front
	2	Back
LLNL		
	1414655	Front
	1414654	Front
	1414658	Back
Norfolk Naval Shipyard		
	8	Front
	11	Front
	14	Back
	7	Back
Sandia		
	0483	Front
	0681	Back
	0518	Side
SRNL		
	10	Front
	8	Front
	11	Back
Y-12		
	0039676 Blue	Front
	900042 Red	Front

Table 12: Tuesday FIA Stand 1 Dosimeters

FIA 1 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	1D B0040832	Front
AWE		
	753959 Orange	Front
	0006706 Black	Front
	753878 Orange	Front
	014632 Black	Front
Belgium		
	SCK H	Front
	SCK C	Front
Hanford		
	17	Front
	10	Front
IRSN		
	7	Front
LLNL		
	1414659	Front
Norfolk Naval Shipyard		
	4	Front
Sandia		
	0682	Front
Y-12		
	0051994	Front
	902246	Front

Table 13: Tuesday FIA Stand 2 Dosimeters

FIA 2 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	2D B0041527	Front
AWE		
	753966	Front
	0142534	Front
	753834	Front
	0137834	Front
Belgium		
	SCK F	Front
Hanford		
	12	Front
	11	Front
IRSN		
	9	Front
LLNL		
	1414660	Front
Norfolk Naval Shipyard		
	9	Front
Sandia		
	0683	Front
SRNL		
	7	Front
	1	Front
Y-12		
	0041946	Back
	0050123	Front

Table 14: Tuesday FIA Stand 3 Dosimeters

FIA 3 Placement		
25-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	3D B0041872	Front
AWE		
	753953	Front
	0146139	Front
	753972	Front
	0142185	Front
Belgium		
	SCK I	Front
Hanford		
	9	Front
	2	Front
IRSN		
	8	Front
LLNL		
	1414661	Front
Norfolk Naval Shipyard		
	1	Front
Sandia		
	0684	Front
Y-12		
	0050776	Front
	902682	Front

Table 15: Wednesday BOMAB 1 Dosimeters

BOMAB 1 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	Packet	Front Left Pocket
	2x Unlabeled	Front
AWE		
	6	Front
	8	Front
	9	Front
	12	Front
	ID Holder	Top Right Pocket
	Locket	Front
	753848	Front
Hanford		
	38	Front
	48	Front
	46	Right Arm
	47	Right Arm
	36	Left Arm
	44	Left Arm
	49	Back
	34	Back
IRSN		
	Cigarette	Front
	Sugar Packet	Front
	Belt	Belt
	NAD Pack	Bottom Right Pocket
	X020	Front
LLNL		
	10x rivets	Front
	4x rivets	Back
	1x rivet	Left Side
	1x rivet	Right Side
	Coins	Bottom Left Pocket
	2x Alanine	Front
	1x Alanine	Back
	NAD	Front
	NAD	Back
	NAD	Right Arm
	NAD	Left Arm
Norfolk Naval Shipyard		
	37	Front
	38	Front
	31	Front
	36	Back
	32	Back
	Battery	Top Left Pocket
	Smart Card	Top Left Pocket
	Coins	Top Left Pocket
Sandia		
	702	Back
	700	Front
Y-12		
	0042298	Front
	Glasses	Head
	Bracelet	Right Arm

Table 16: Wednesday BOMAB 2 Dosimeters

BOMAB 2 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	Unlabled	Front
AWE		
	2x ID Holder	Front
	6	Front
	5	Front
	7	Front
	11	Front
	12	Front
	753960	Front
	753863	Back
Hanford		
	45	Front
	43	Back
IRSN		
	Belt	Belt
	Sugar packet	Front
	X019	Front
LLNL		
	NAD x2	Front
	NAD x1	Back
	Alanine	Front, Back
Norfolk Naval Shipyard		
	34	Front
	45	Front
	39	Front
	44	Back
	40	Back
Sandia		
	703	Front
	704	Side
	705	Back
Y-12		
	0011179	Front, belt

Table 17: Wednesday BOMAB 3 Dosimeters

BOMAB 3 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	Unlabeled	Front
AWE		
	2x coins	Front
	TLD 10	Front
	TLD 12	Front
	TLD 5	Front
	TLD 11	Front
	TLD 8	Front
	753946	Front
	753877	Back
	2x ID Holder	Front
Hanford		
	39	Front
	47	Back
IRSN		
	Sugar Packet	Front
LLNL		
	NAD A	Front
	NAD B	Front
	Alanine Pellet	Back
Norfolk Naval Shipyard		
	43	Front
	33	Front
	35	Front
	42	Back
	41	Back
Sandia		
	707	Left Arm
	706	Front
	708	Back
Y-12		
	Watch	Front
	Soda Can	Front
	0044371	Left Arm

Table 18: Wednesday FIA Stand 1 Dosimeters

FIA 1 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	4D	Front
AWE		
	7538833 Orange	Front
	004139 Black	Front
	707376 Orange	Front
	005509 Black	Front
Belgium		
	Q	Front
Hanford		
	26	Front
IRSN		
	16	Front
LLNL		
	1414668	Front
Norfolk Naval Shipyard		
	20	Front
Sandia		
	694	Front
Y-12		
	0047621	Front
	903985	Front

Table 19: Wednesday FIA Stand 2 Dosimeters

FIA 2 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	5D	Front
AWE		
	753845 Orange	Front
	0009388 Black	Front
	753858 Orange	Front
	014f6391 Black	Front
Belgium		
	P	Front
Hanford		
	22	Front
IRSN		
	17	Front
LLNL		
	1414671	Front
Norfolk Naval Shipyard		
	16	Front
Sandia		
	699	Front
Y-12		
	0047819	Front
	900297	Front

Table 20: Wednesday FIA Stand 3 Dosimeters

FIA 3 Placement		
26-Jun-24		
Lab Name	Identification	Placement
AFFRI		
	6D	Front
AWE		
	753940 Orange	Front
	0002450 Black	Front
	753846 Orange	Front
	143892 Black	Front
Belgium		
	R	Front
Hanford		
	28	Front
IRSN		
	18	Front
LLNL		
	1414676	Front
Norfolk Naval Shipyard		
	24	Front
Sandia		
	698	Front
Y-12		
	0029968	Front
	0047174	Back