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LLNL-TR-715817

International Intercomparison Exercise for Nuclear Accident Dosimetry at the DAF Using GODIVA-IV

D. Hickman, B. Hudson

December 20, 2016

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

International Intercomparison Exercise for Nuclear Accident Dosimetry at the DAF Using GODIVA-IV

IER-148 CED-4a Report

Completion of Exercise and Preliminary Results

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December 15, 2016

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Auspices

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INTRODUCTION

The Nuclear Criticality Safety Program operated under the direction of Dr. Jerry McKamy completed the first NNSA Nuclear Accident Dosimetry exercise on May 27, 2016. Participants in the exercise were from Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), Savanah River Site (SRS), Pacific Northwest National Laboratory (PNNL), US Navy, the Atomic Weapons Establishment (United Kingdom) under the auspices of JOWOG 30, and the Institute for Radiological Protection and Nuclear Safety (France) by special invitation and NCSP memorandum of understanding. This exercise was the culmination of a series of Integral Experiment Requests (IER) that included the establishment of the Nuclear Criticality Experimental Research Center, (NCERC) the startup of the Godiva Reactor (IER-194), the establishment of a the Nuclear Accident Dosimetry Laboratory (NAD LAB) in Mercury, NV, and the determination of reference dosimetry values for the mixed neutron and photon radiation field of Godiva within NCERC.

METHODS

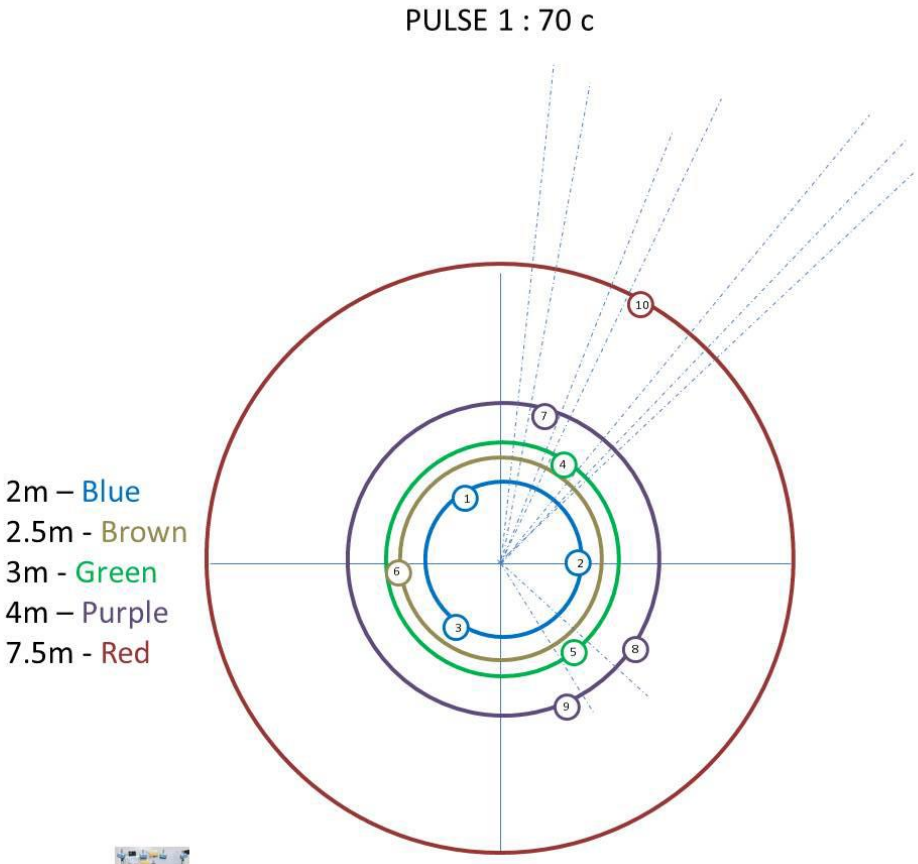
Laboratories were invited to test nuclear accident dosimetry materials that would be used at their respective facilities for determining the dose to individuals exposed in a nuclear criticality accident. Each laboratory was allowed to set up equipment at the NADLAB the week prior to irradiations if needed. Some laboratories had multiple dosimetry materials (and associated equipment) that needed testing.

Dosimtery materials were mounted onto one of three structures: a Ringers Lactate filled BOttle Man-akin ABsorption phantom (BOMAB); Acrylic (PMMA) slab phantom; or an aluminum plate suspended on a movable floor stand for free-in-air measurements. All dosimetry materials were mounted the week prior to the Godiva bursts. Each laboratory had opportunity to attach dosimetry to each type of mounting structure (BOMAB, PMMA, and Aluminum Plate).

Three daily Godiva bursts were performed starting on May 24, 2016. The first two bursts were designed to allow participants to self-evaluate and if necessary calibrate their dosimetry materials to known dose values. The third burst was an unknown dose level, at which time participants were expected to comply with limits established from the ANSI 13.3-2013 ***Dosimetry for Criticality Accidents***. For the third burst, participants were required to report the dose values within 24 hours after the burst. Mount types and locations as well as target temperature increases (ΔT) for each burst pulse are provided in Figures 1 – 3. Table 1 provides the burst data actually achieved in exposing the dosimetry materials.

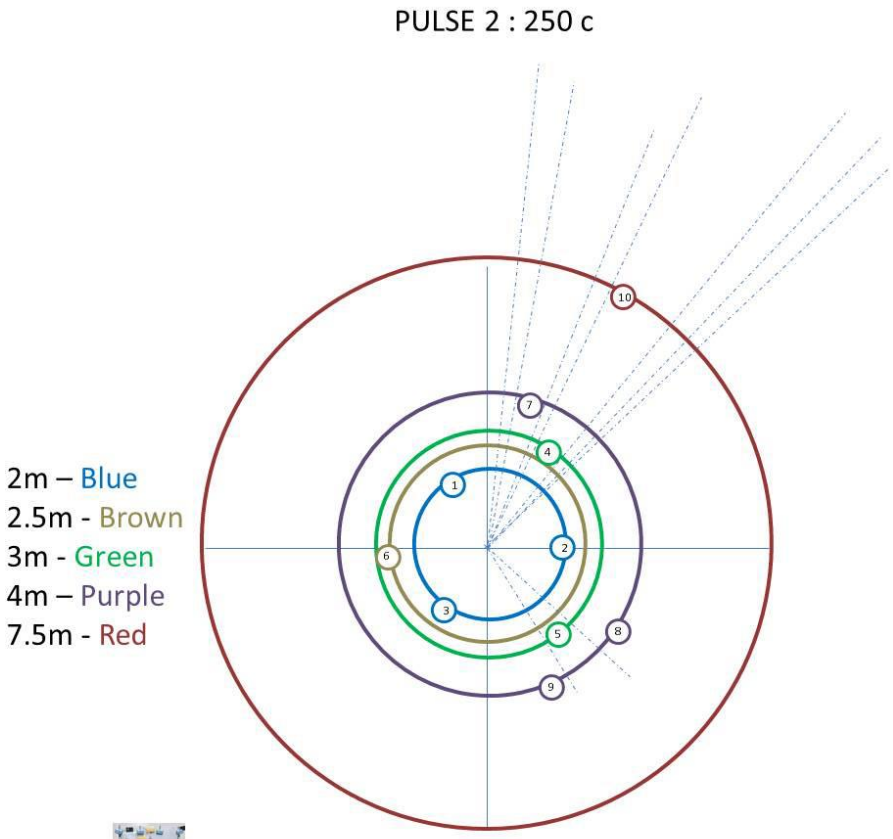
Initial Gamma data was obtained from calibrated Personnel Ion Chambers. Some participants were able to provide gamma doses within 24 hours, however most participants were not able to provide gamma doses until after they were able to return their dosimeters for processing at their respective facilities.

Figure 1.



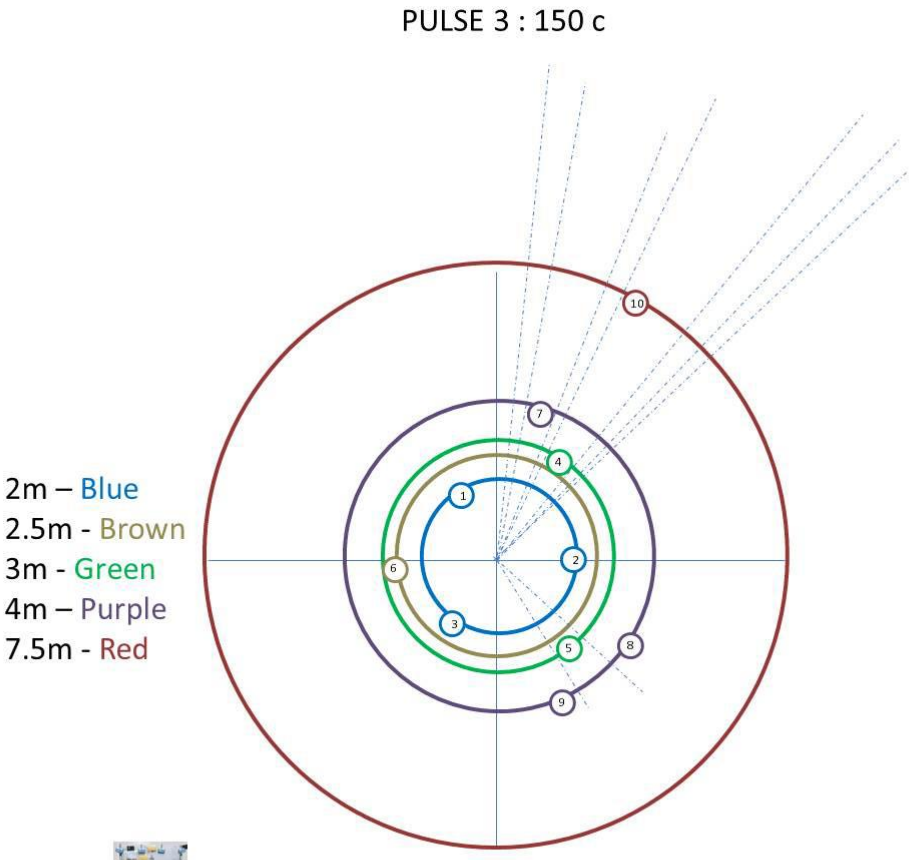
	Tree A-D	Position 1, 2, 3, 6
	Tree A-H	Position 8, 10
	BOMAB AP	Position 4, 5
	PMMA/Slab Phantom	Position 7, 9
	Passive Neutron Spectrometer (PNS AWE)	Position 10
	PNNL/Y-12 FNAD	Position 11, 12

Figure 2.



	Tree A-D	Position 1, 2, 3, 6
	Tree A-H	Position 8, 10
	BOMAB AP	Position 4, 5
	PMMA/Slab Phantom	Position 7, 9
	Passive Neutron Spectrometer (PNS AWE)	Position 10
	PNNL/Y-12 FNAD	Position 11, 12

Figure 3.



Tree A-D Position 1, 2, 3, 6

Tree A-H Position 8, 10

BOMAB AP Position 4, 5

PMMA/Slab Phantom Position 7, 9

Passive Neutron Spectrometer (PNS AWE) Position

PNNL/Y-12 FNAD Position 11, 12

Table 1. Actual Burst Data for Intercomparison Exposures.

Burst	Date	Time	ΔT (°C)	Period (μs)	Reactivity (cents)	FWHM (μs)
1	24-May-16	10:11	68.5	40.4	102.9	155.5
2	25-May-16	9:42	244.8	9.5	112.4	
3	26-May-16	11:35	147.7	14.3	108.3	

Evaluation of Dose Results

Preliminary Neutron KERMA Dose Results

Each participant was assigned a laboratory code (number). Some participants had multiple dose measurement methods/materials. When multiple methods were used an assigned alpha character (A-D) identified the method. Neutron KERMA doses as reports within the first 24 hours post irradiation are summarized in Figures 4-6.

Figure 4. Neutron KERMA results for Burst No. 1

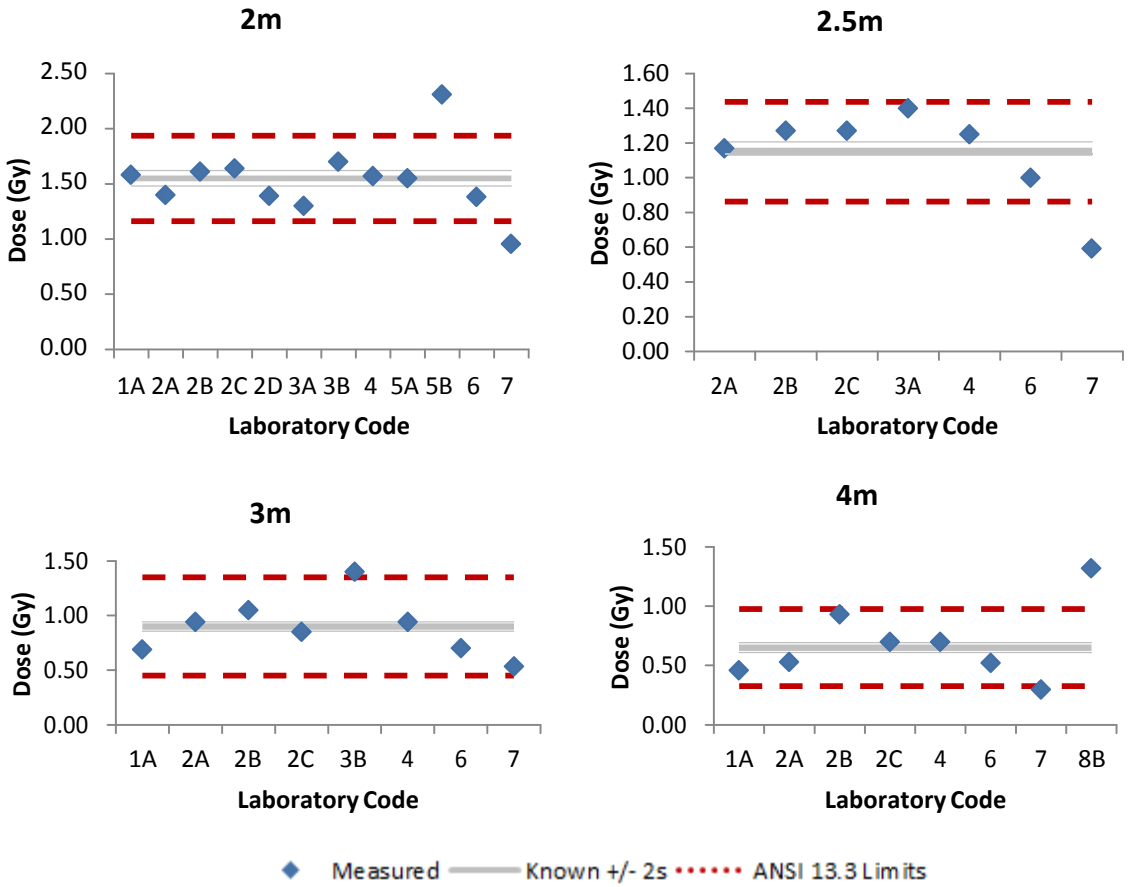


Figure 5. Neutron KERMA results for Burst No. 2

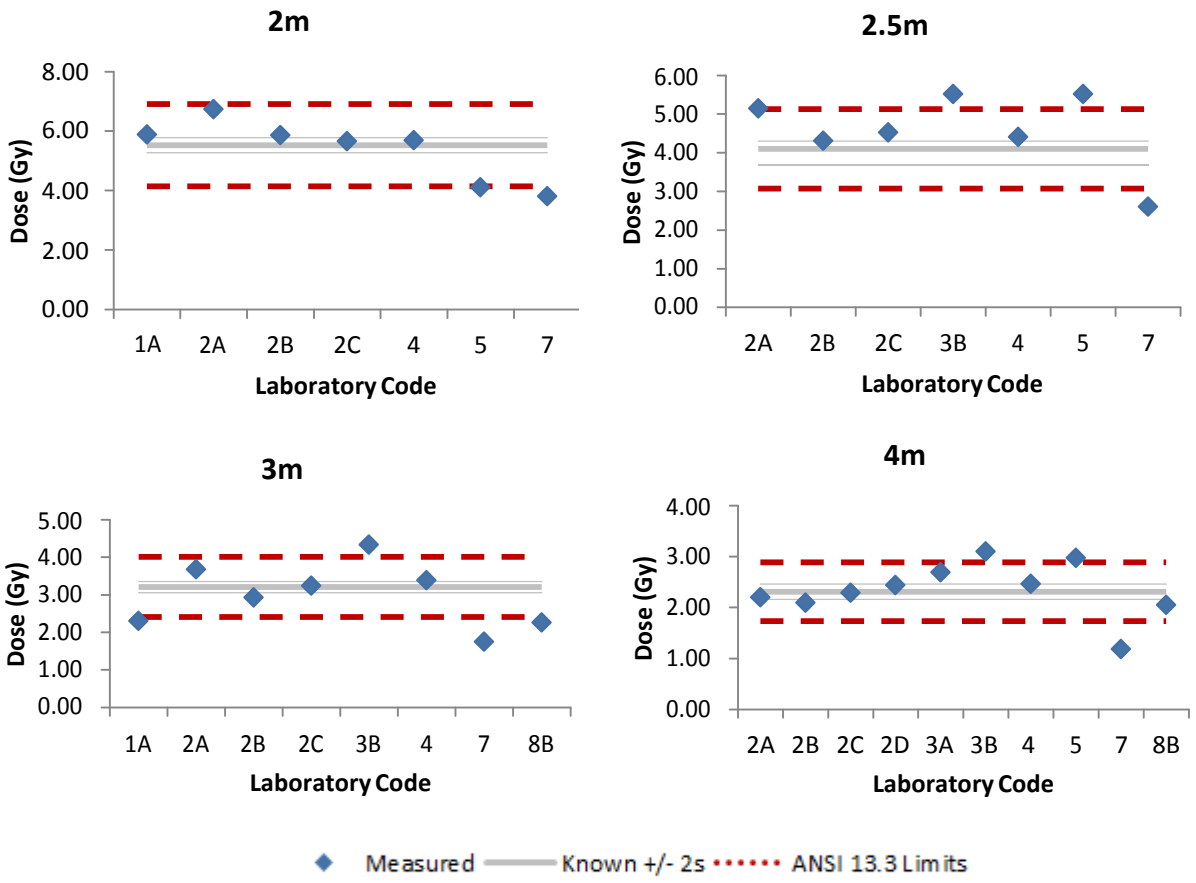
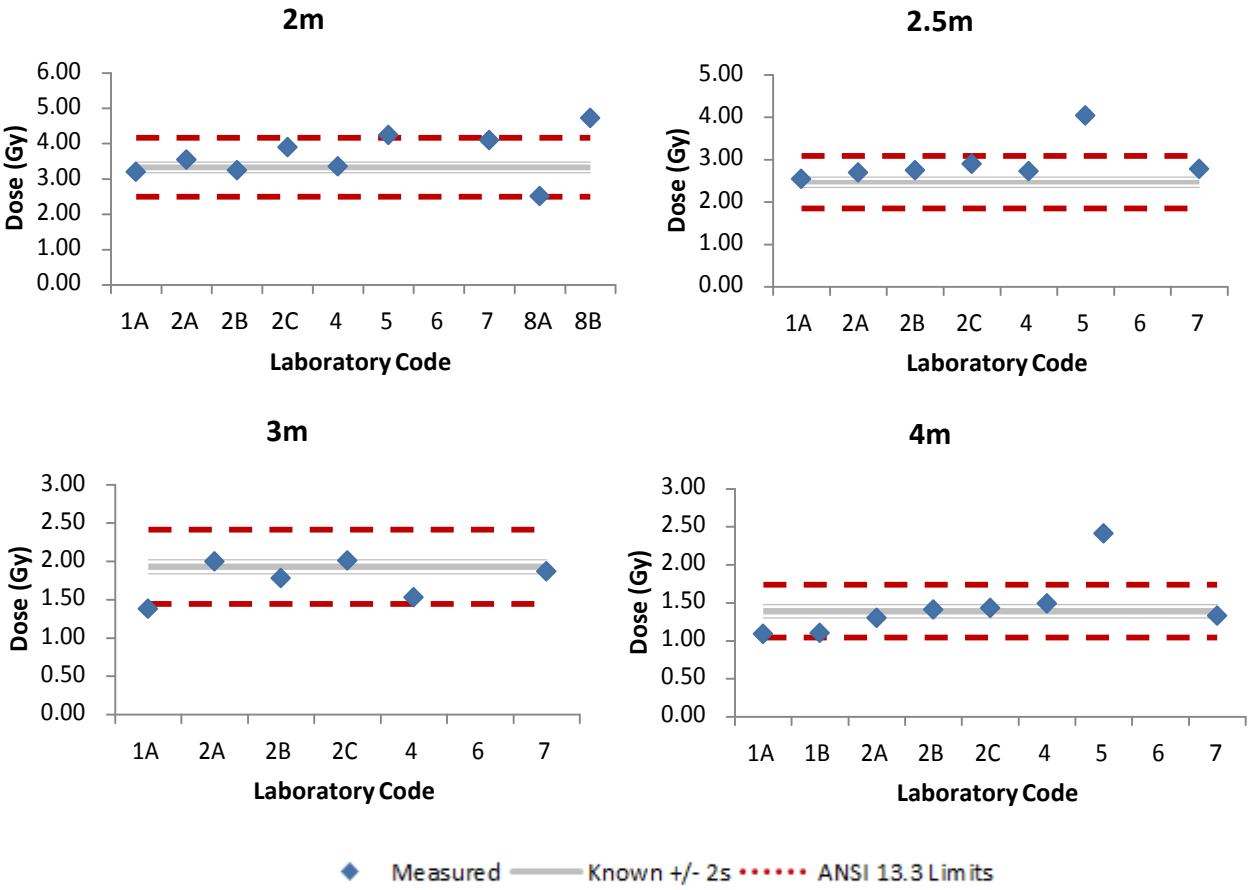


Figure 6. Neutron KERMA results for Burst No. 3



Note: Laboratory 6 is off-scale for all measurements

Preliminary Gamma Dose Results

Personnel Ion Chambers (PIC) were positioned at 2, 3, and 4 positions. Some laboratories were able to provide gamma dose results within 24 hours, however most laboratories needed to evaluate gamma doses using equipment based at their home laboratory. Not all laboratories are included in this preliminary data. The estimated known gamma dose value and errors are based on Godiva characterization studies performed in November 2014. Retrieval of the dosimeters took longer than when the characterization studies were performed, so the true gamma doses are expected to be larger than the estimated known gamma doses due to residual room activation after each Burst. Calcium fluoride TLDs were placed at several exposure locations and will be used to correct the estimated known values to a final known value.

Figure 7. Preliminary Gamma Dose Results for Burst No. 1.

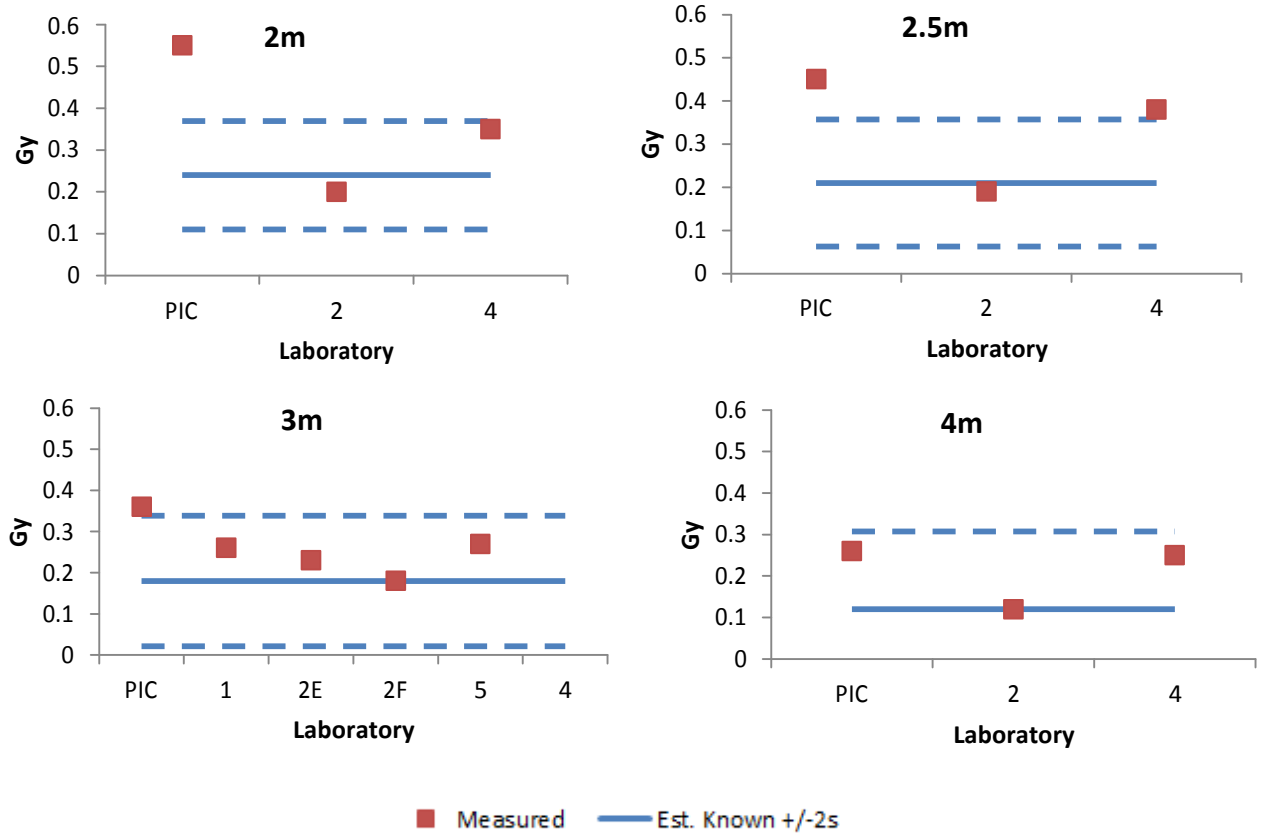


Figure 8. Preliminary Gamma Dose Results for Burst No. 2.

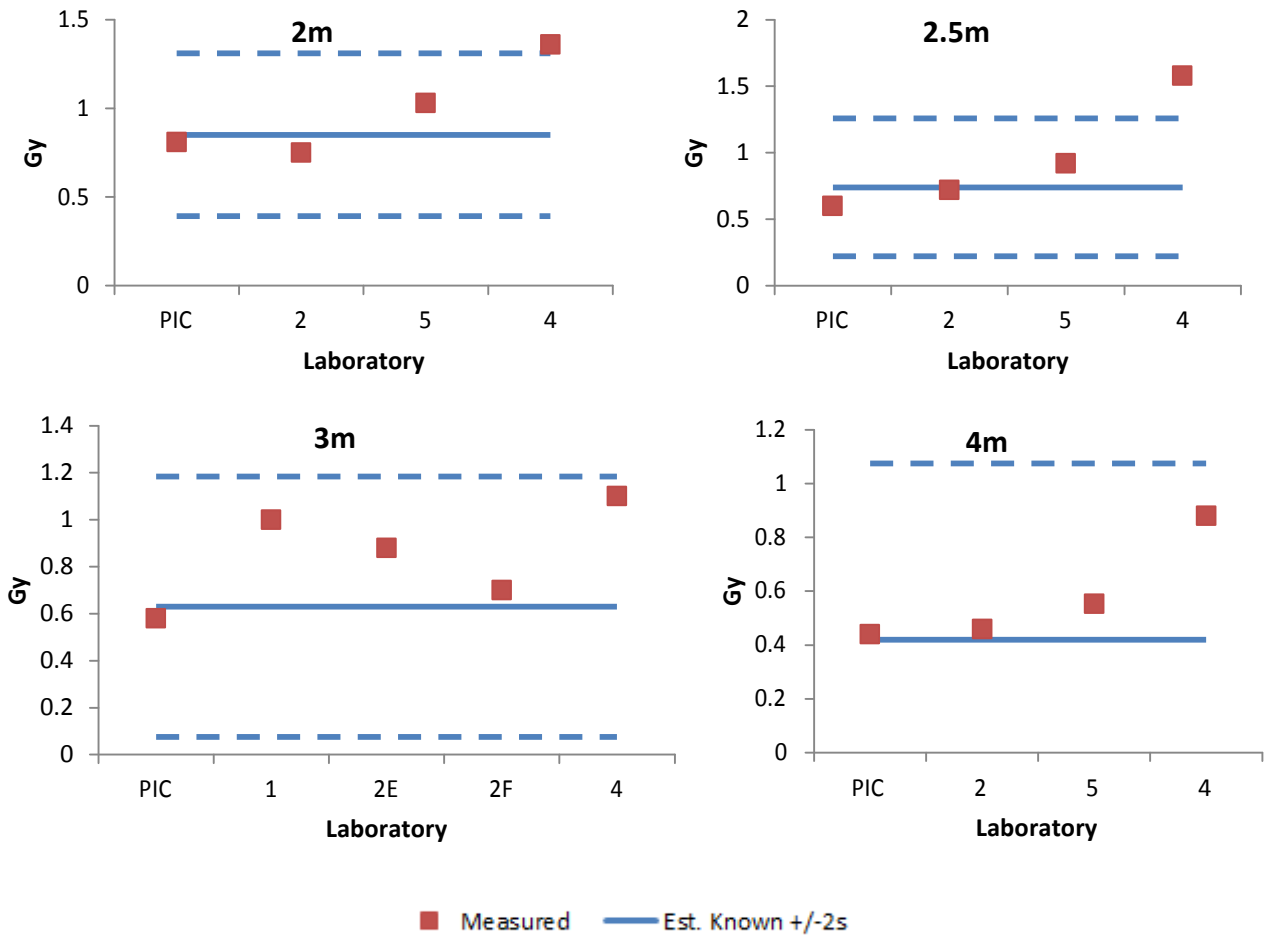
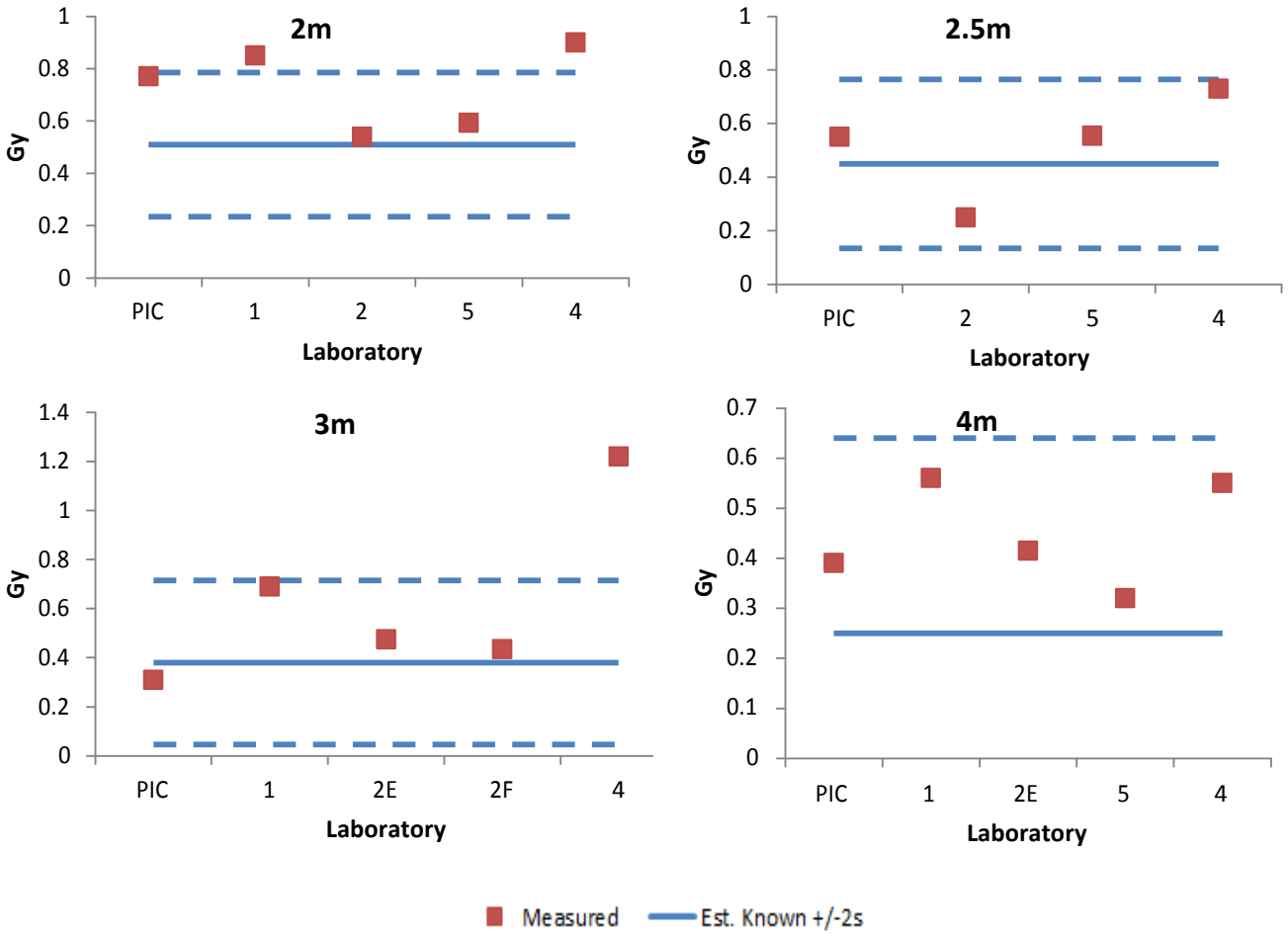


Figure 9. Preliminary Gamma Dose Results for Burst No. 3.

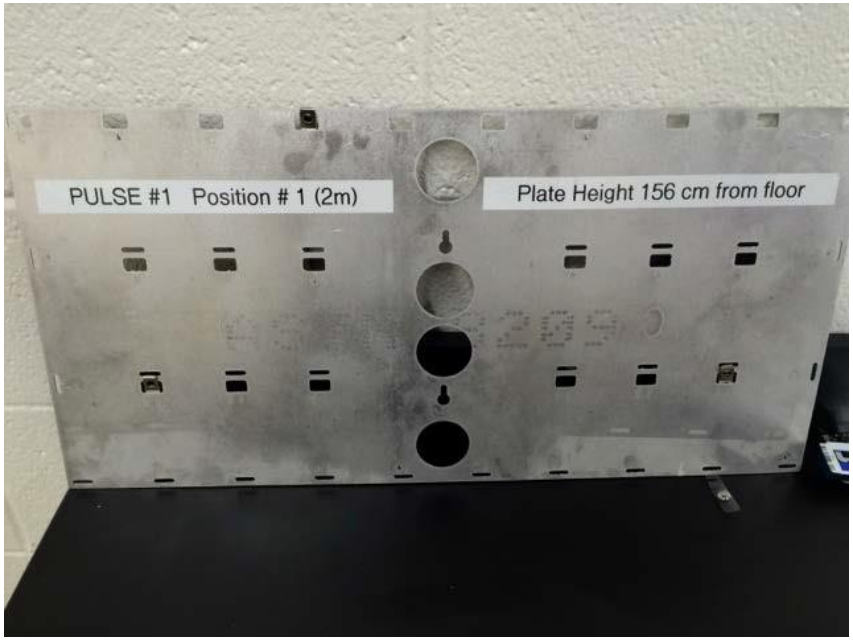


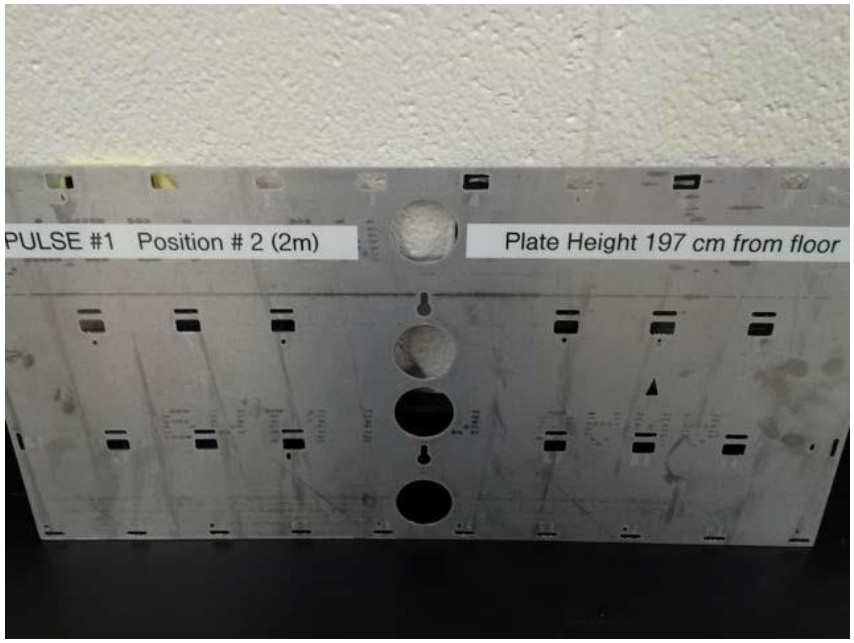
Final Results

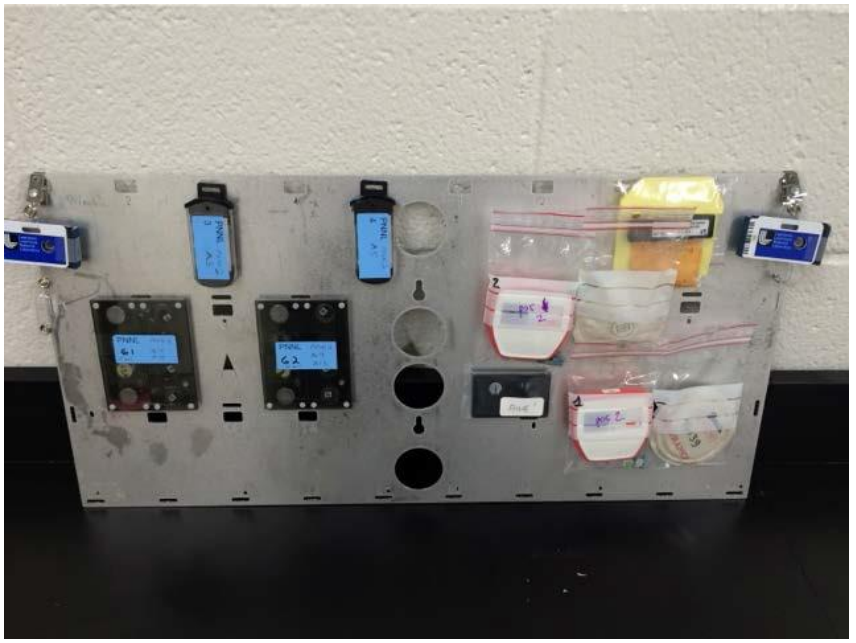
Each participating laboratory is responsible for completing a Final Report of their own results, which LLNL will upload to the IER-148 $C_E dT$ database.

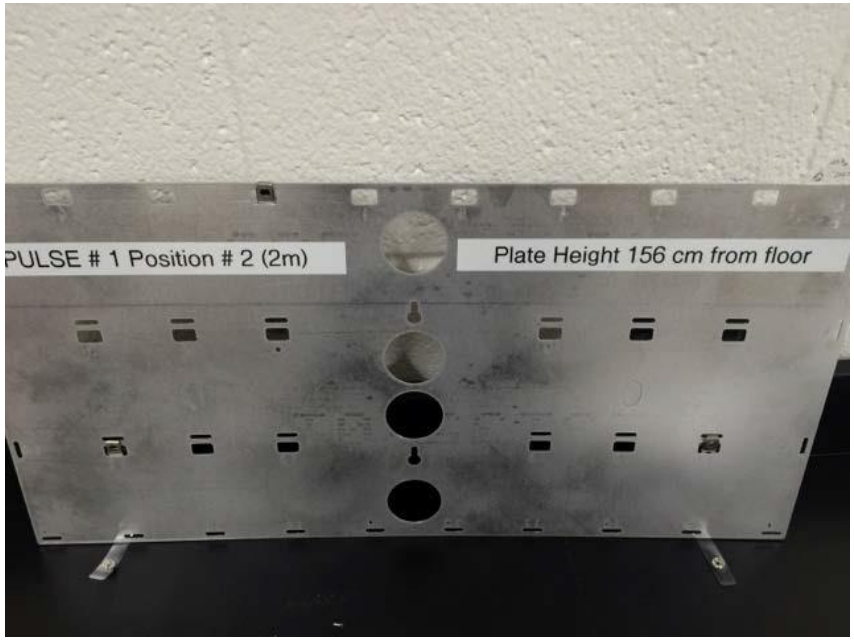
PHOTO NOTEBOOK

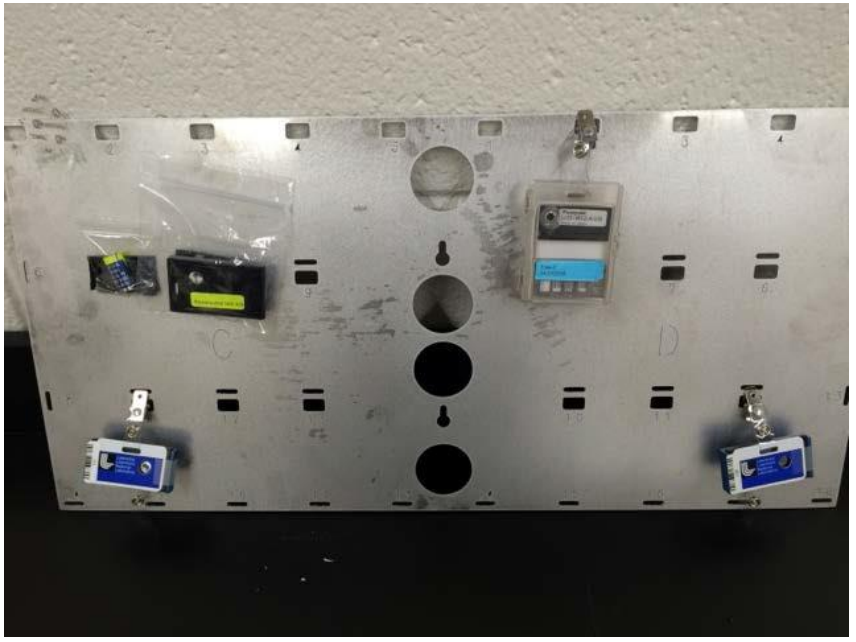
Pulse 1 Plate Loading




PULSE #1 Position # 2 (2m)
Plate Height 197 cm from floor




PULSE # 1 Position # 2 (2m)
Plate Height 156 cm from floor



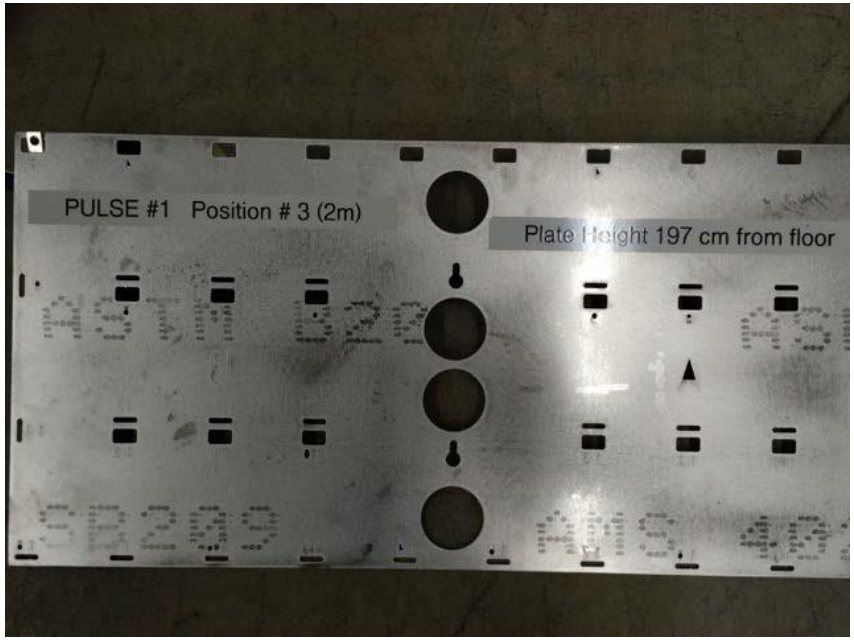

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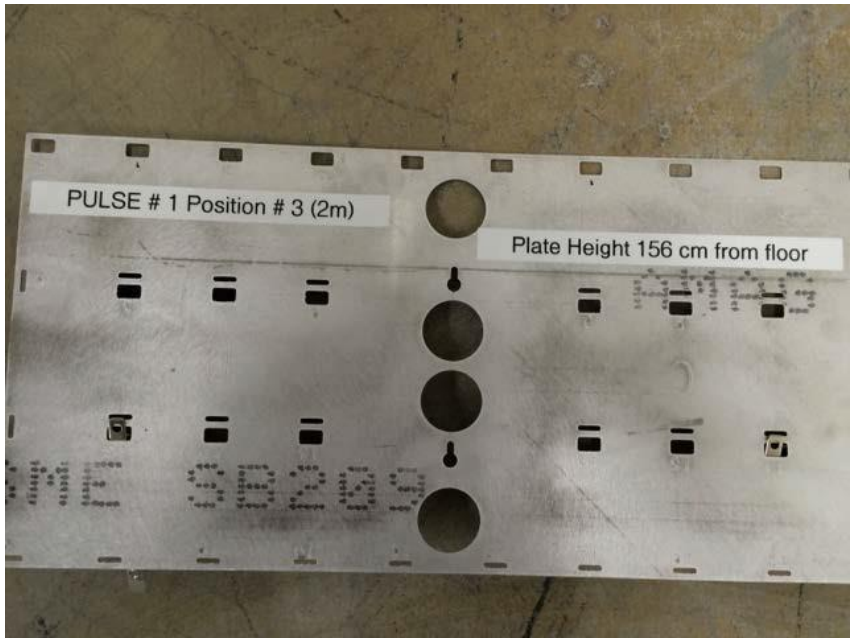
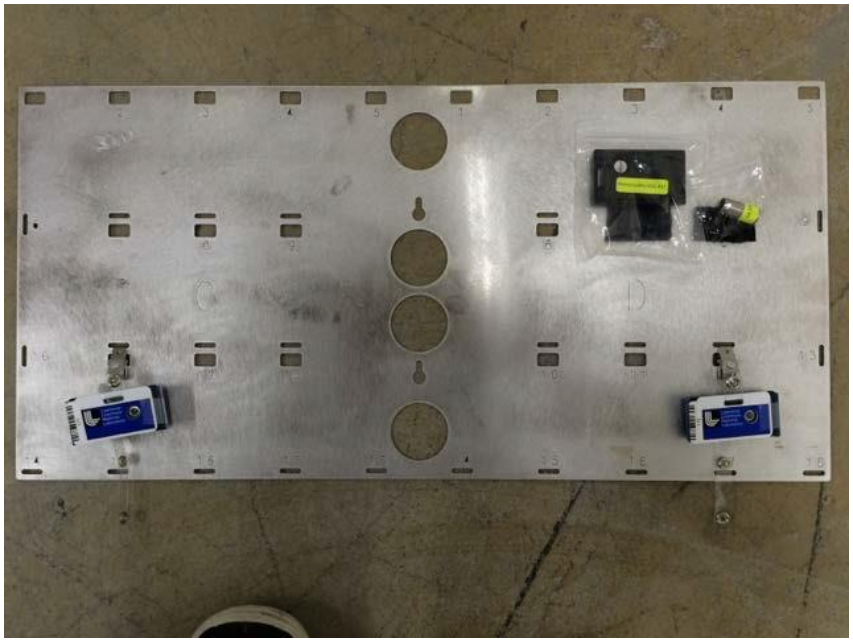
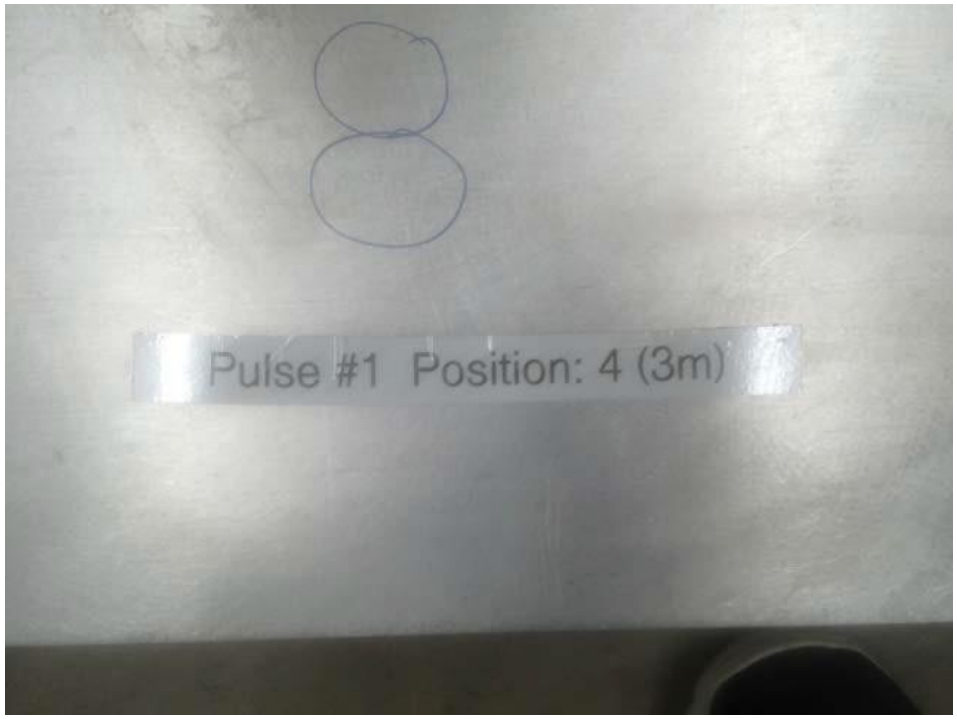
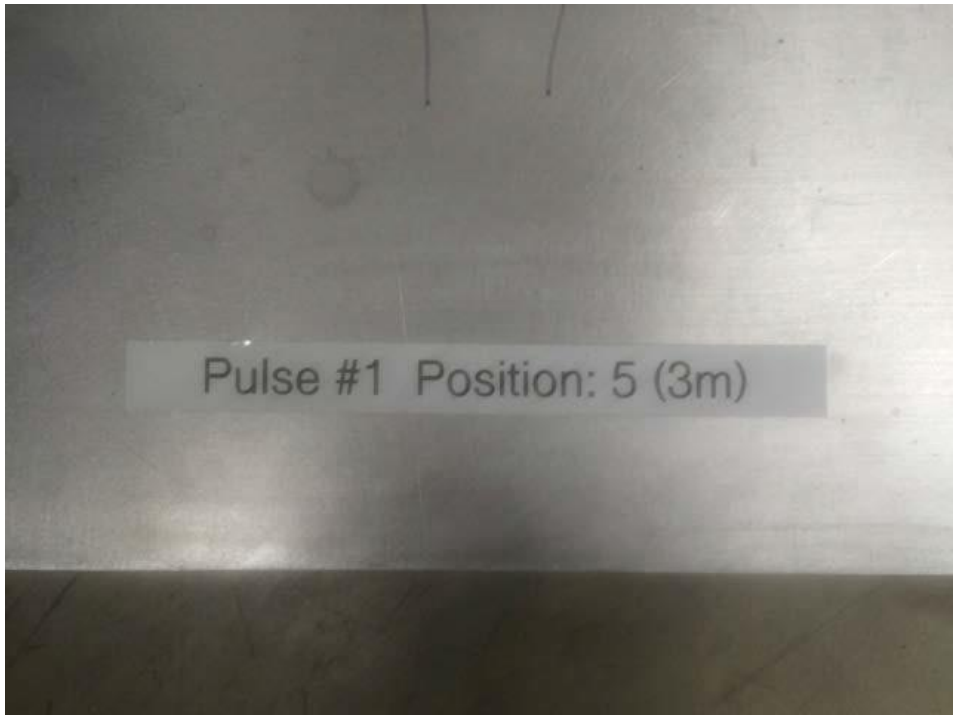
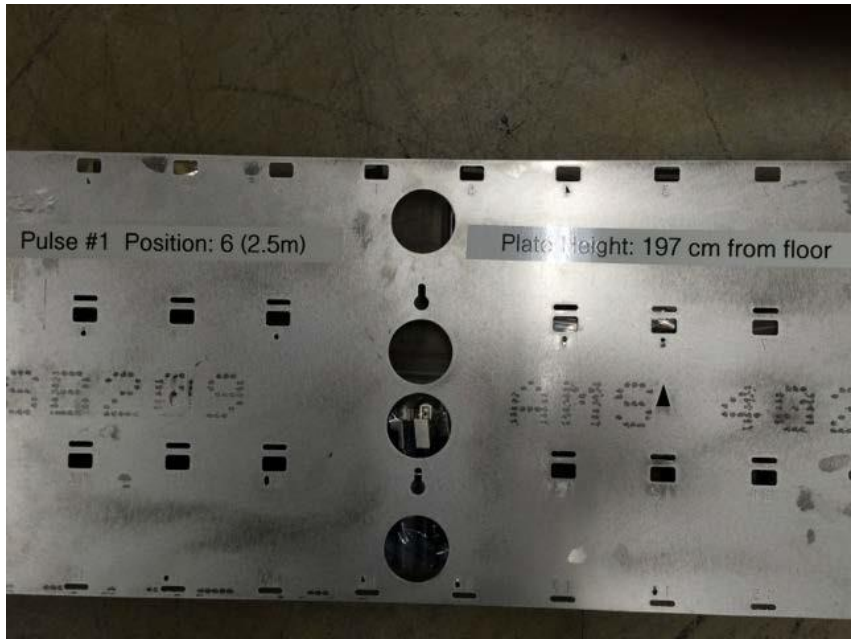
Plate Height 197 cm from floor

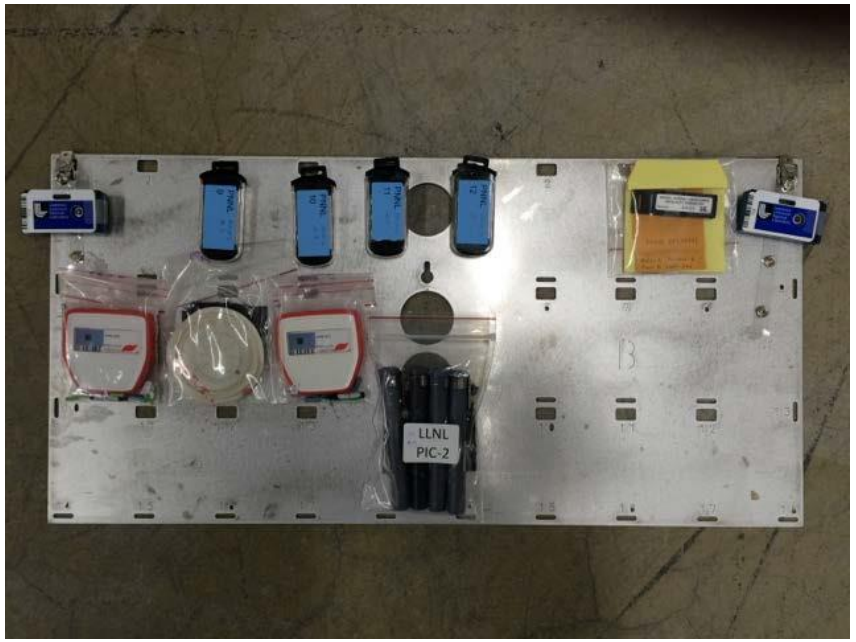

PULSE # 1 Position # 3 (2m)
Plate Height 156 cm from floor

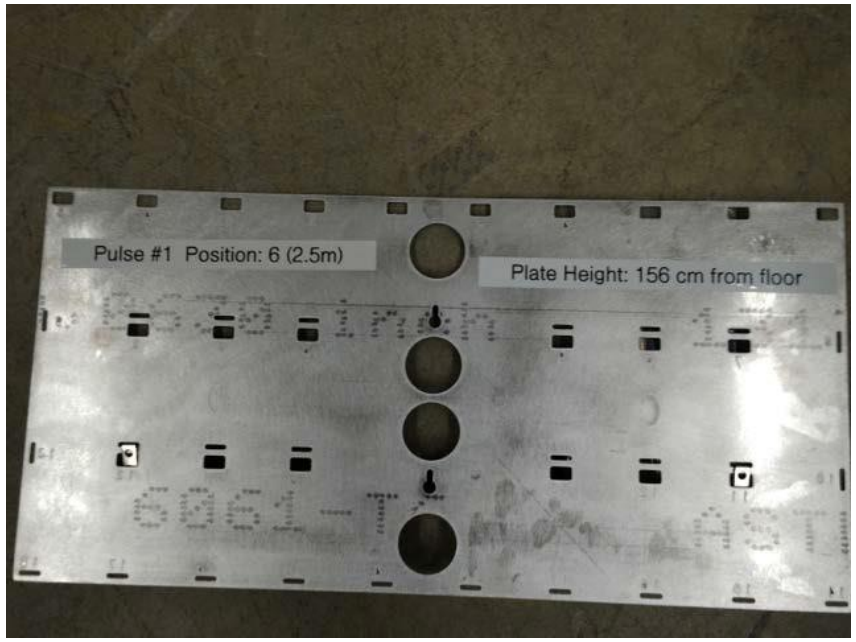


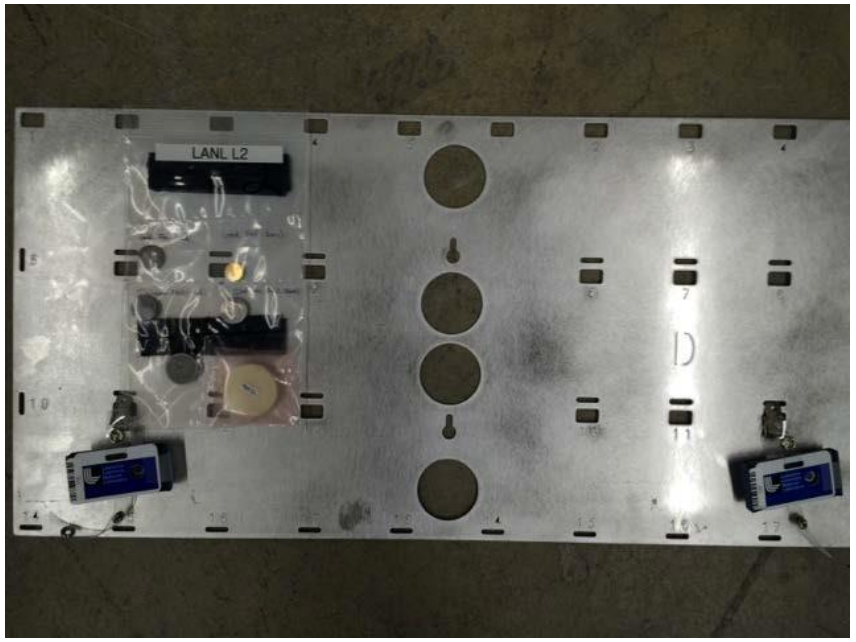

Pulse #1 Position: 4 (3m)


Pulse #1 Position: 5 (3m)


Pulse #1 Position: 6 (2.5m)
Plate Height: 197 cm from floor


LLNL
PIC-2

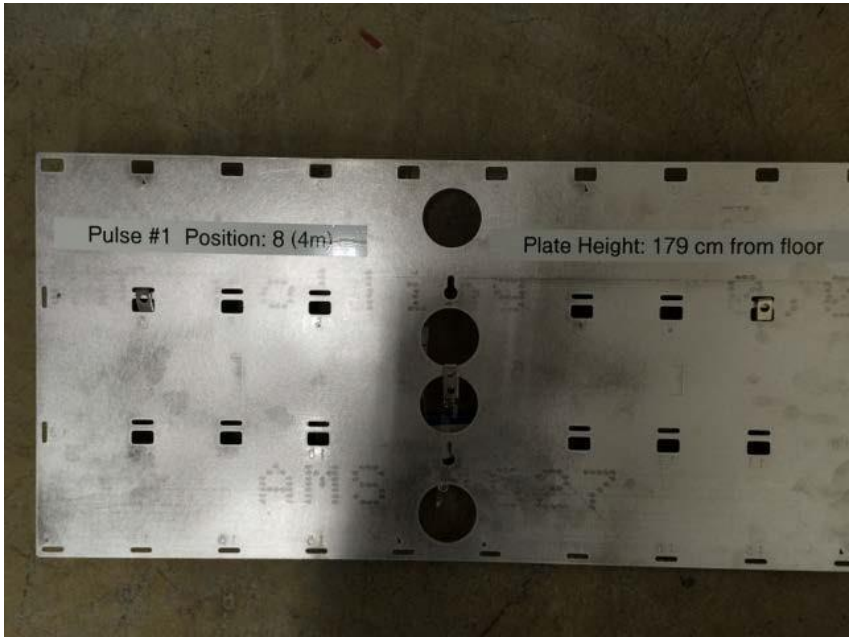

Pulse #1 Position: 6 (2.5m)
Plate Height: 156 cm from floor


LANL L2

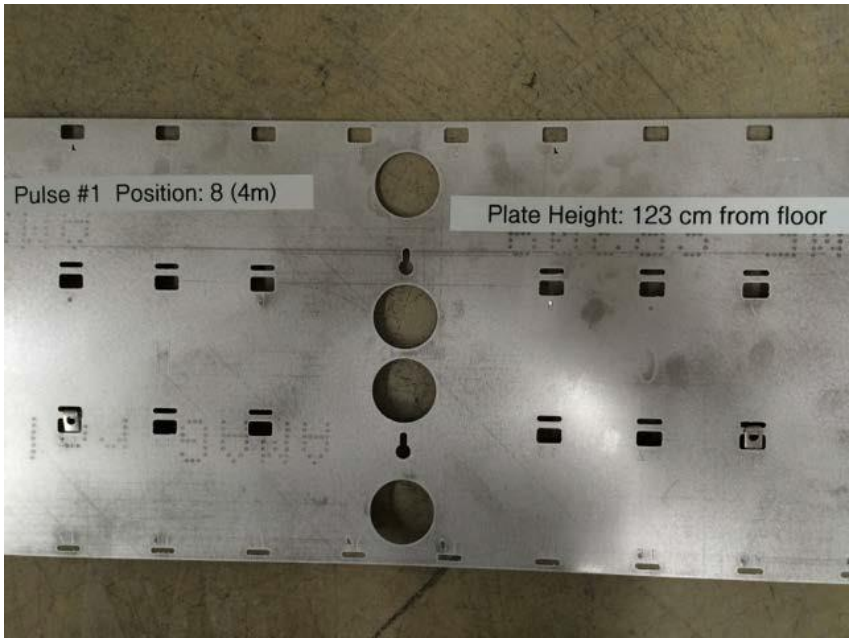
Pulse 1 Position 7 (4m)

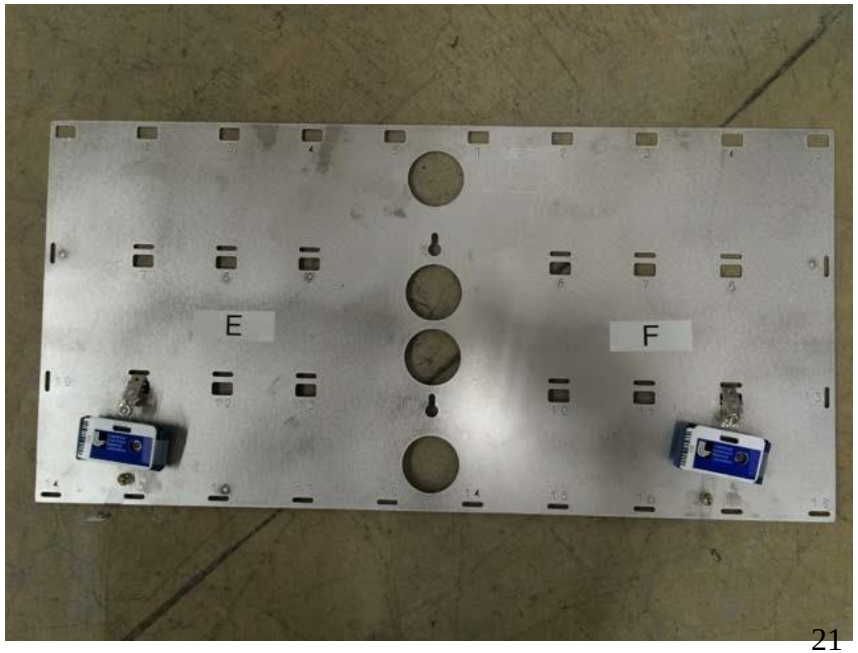
Front

Back

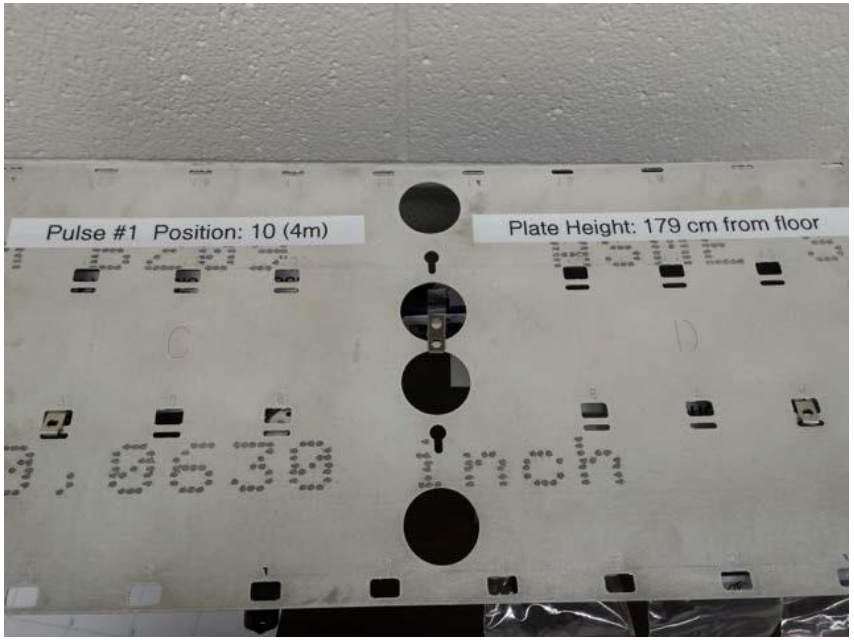

Pulse #1 Position: 8 (4m)
Plate Height: 179 cm from floor

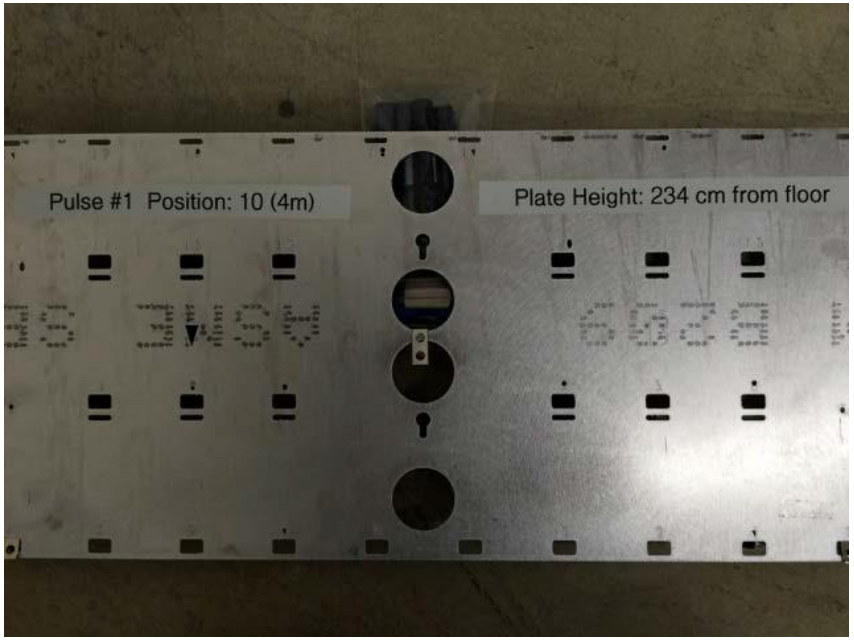

D

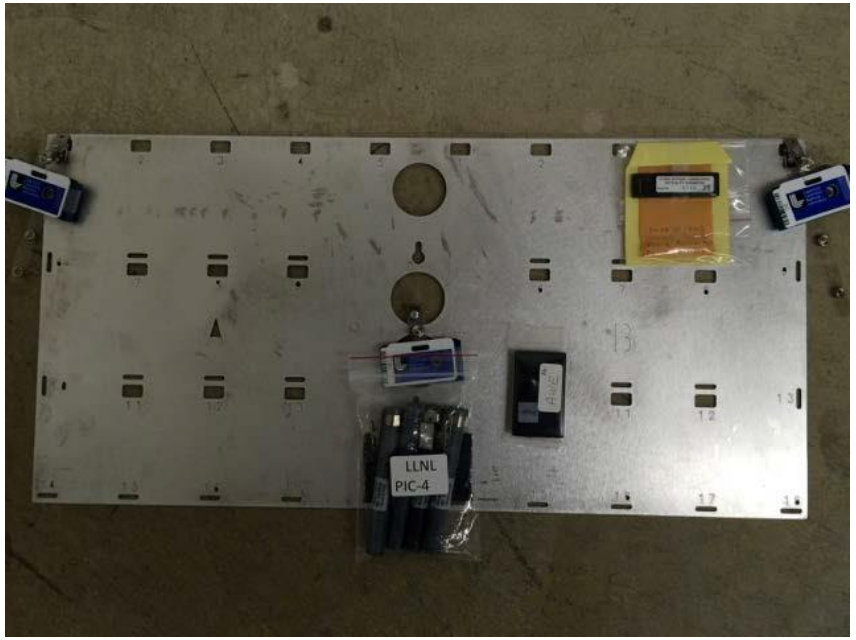

Pulse #1 Position: 8 (4m)
Plate Height: 123 cm from floor

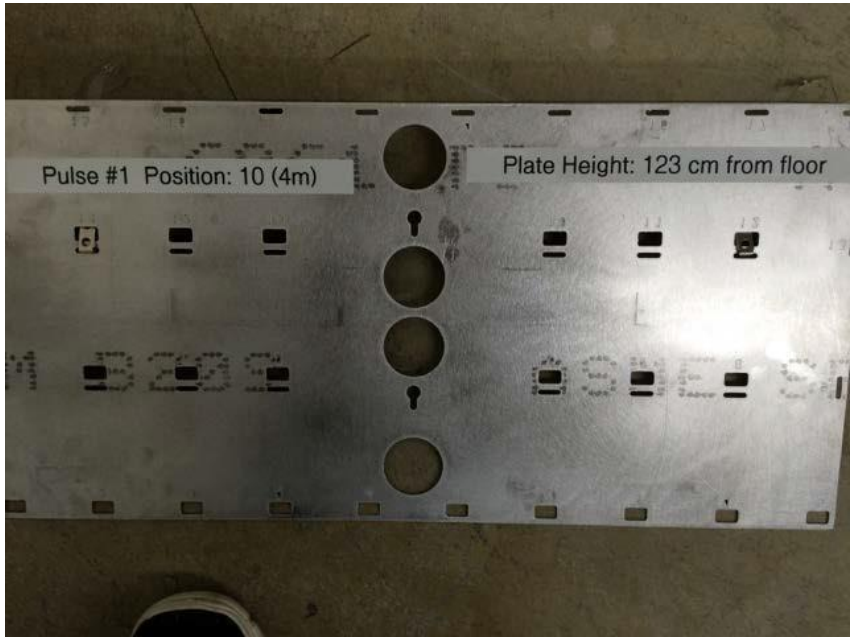

E
F

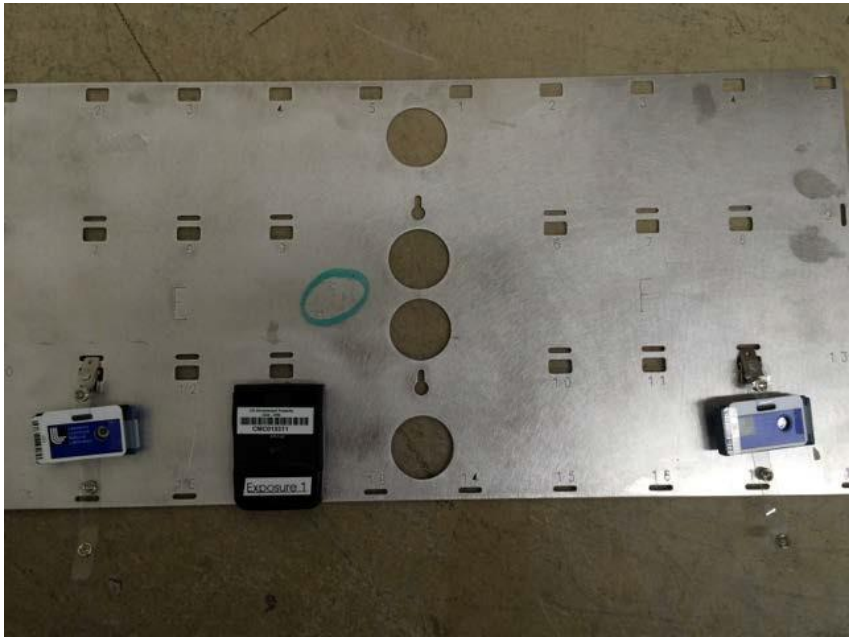
Pulse 1 Position 9 (4m)


Pulse #1 Position: 10 (4m)
Plate Height: 179 cm from floor

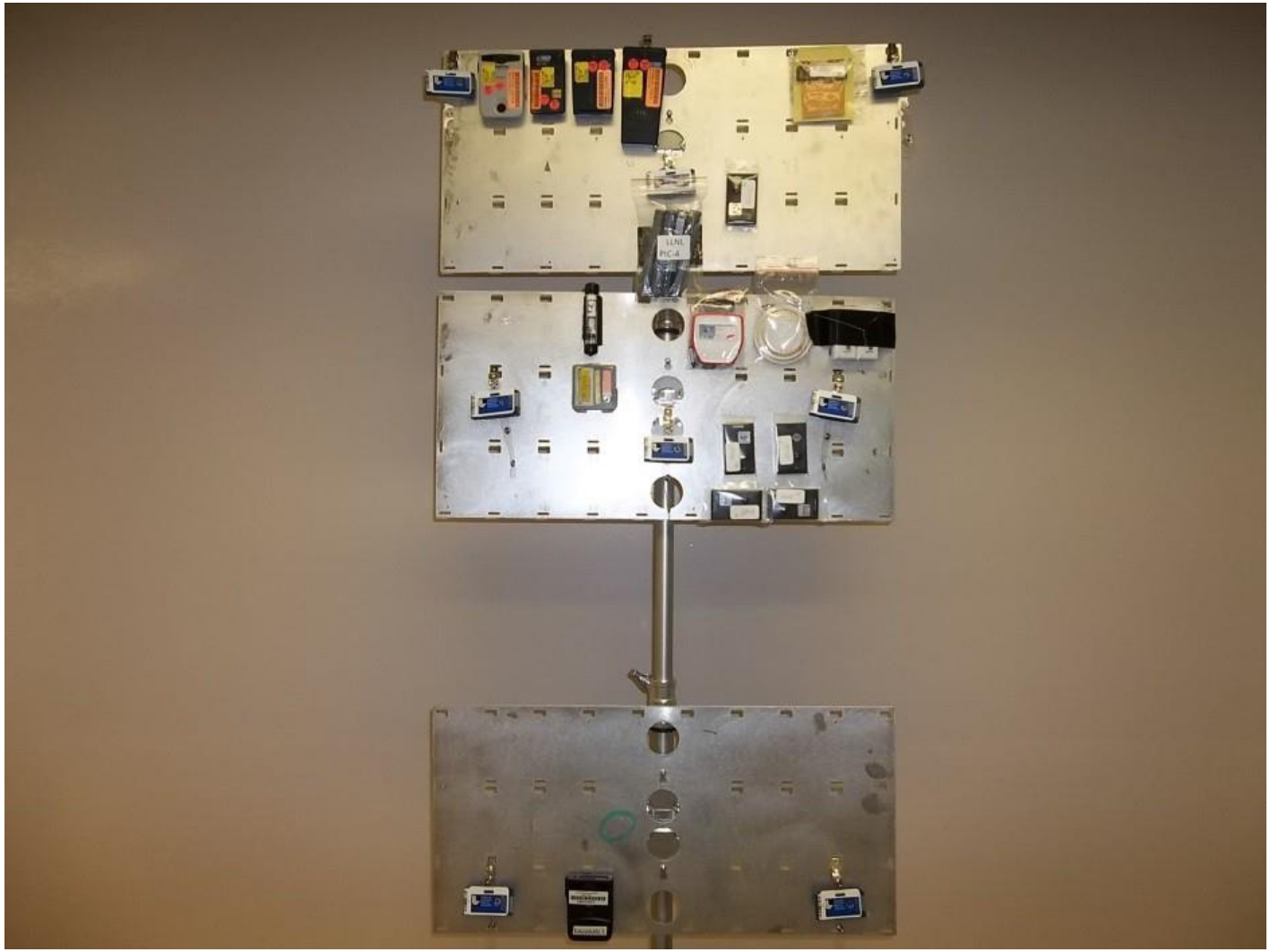

Pulse #1 Position: 10 (4m)
Plate Height: 234 cm from floor


LLNL
PIC-4


Pulse #1 Position: 10 (4m)
Plate Height: 123 cm from floor

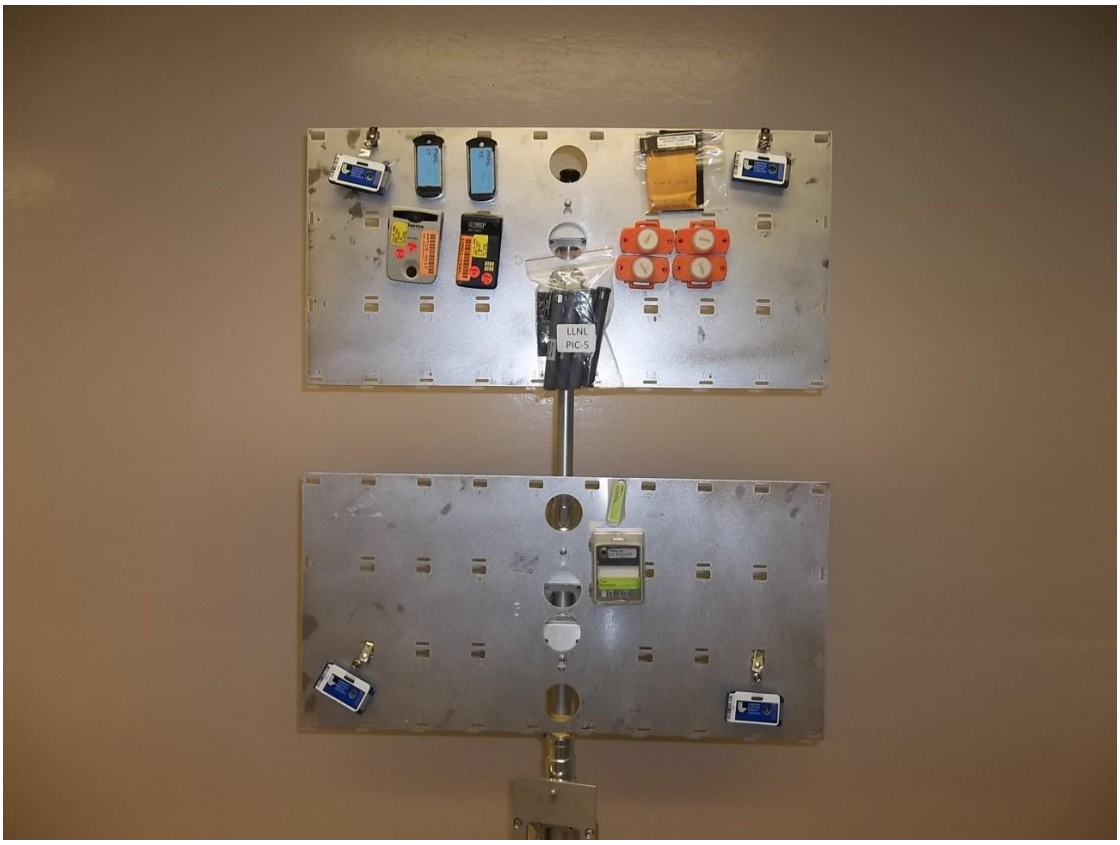

Exposure 1

Pulse 1 Position 10 assembled



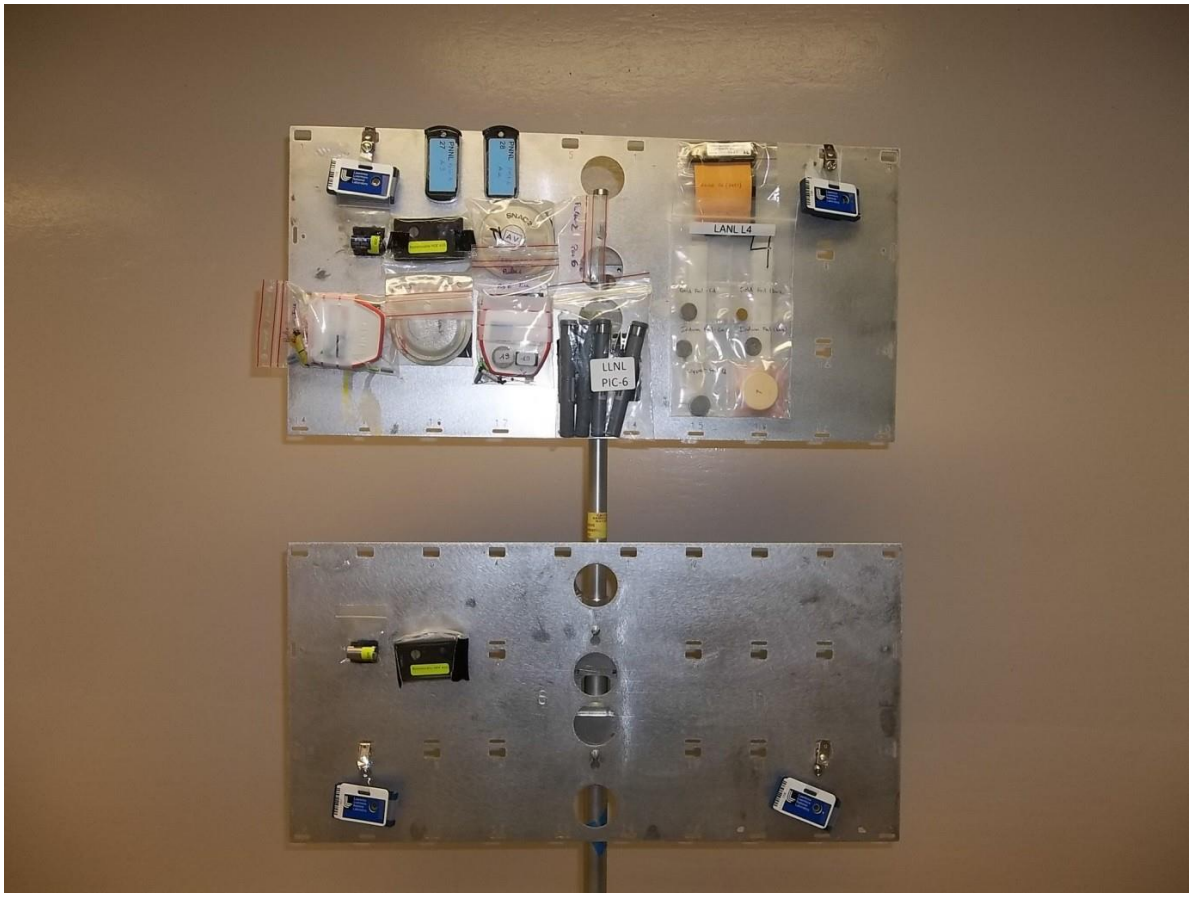

NOTICE
NOTICE

Pulse 2 Position 1 (2m)

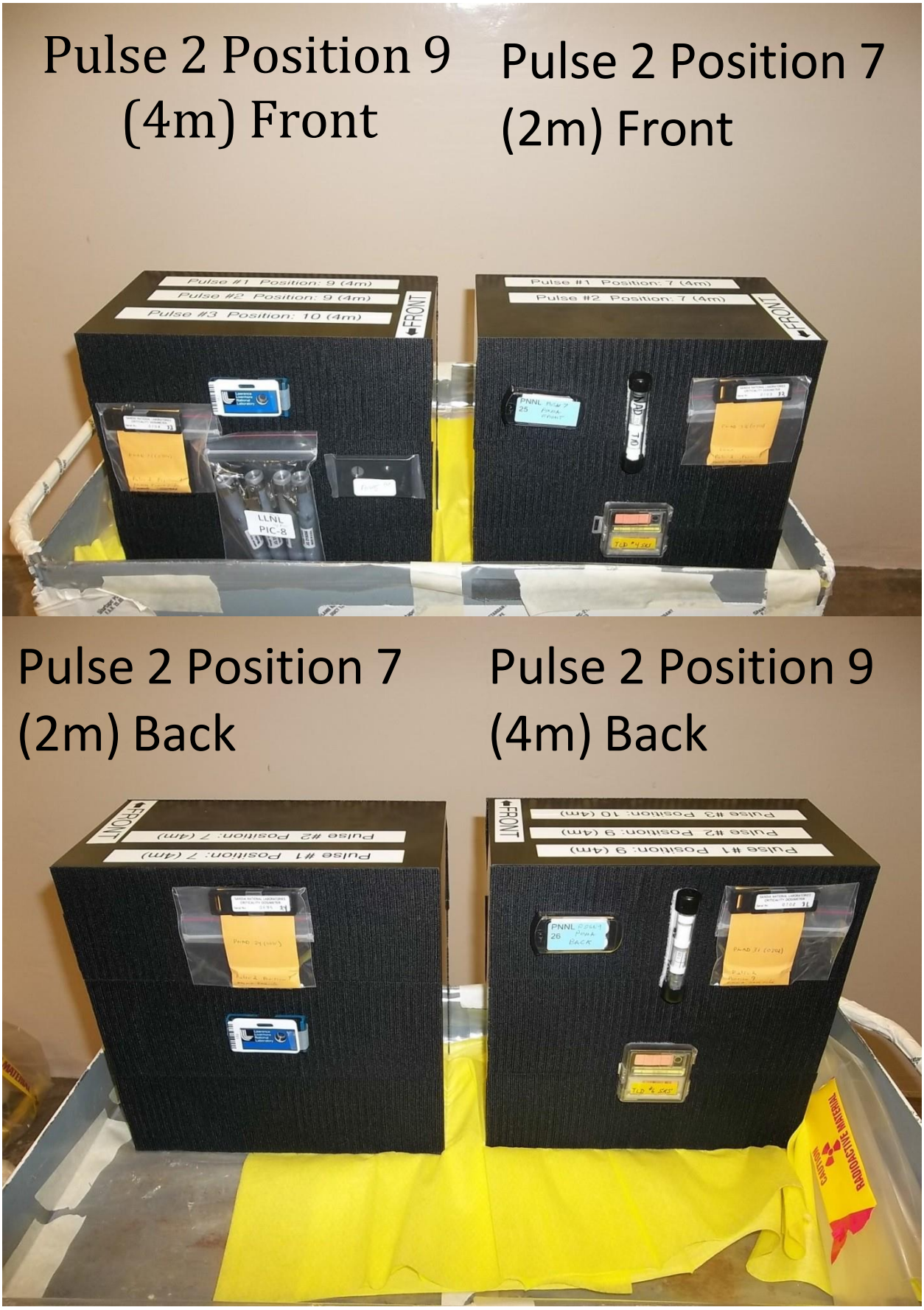


Pulse 2 Position 2 (2m)

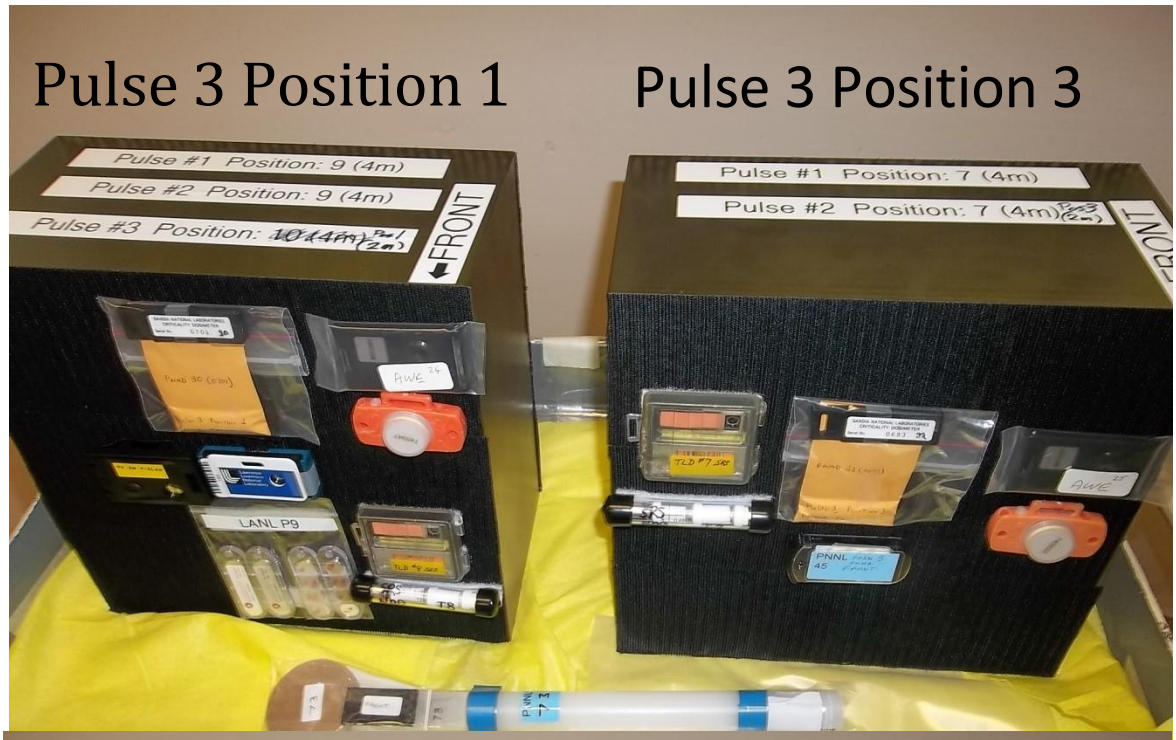
Pulse 2 Positon 6 (2.5m)

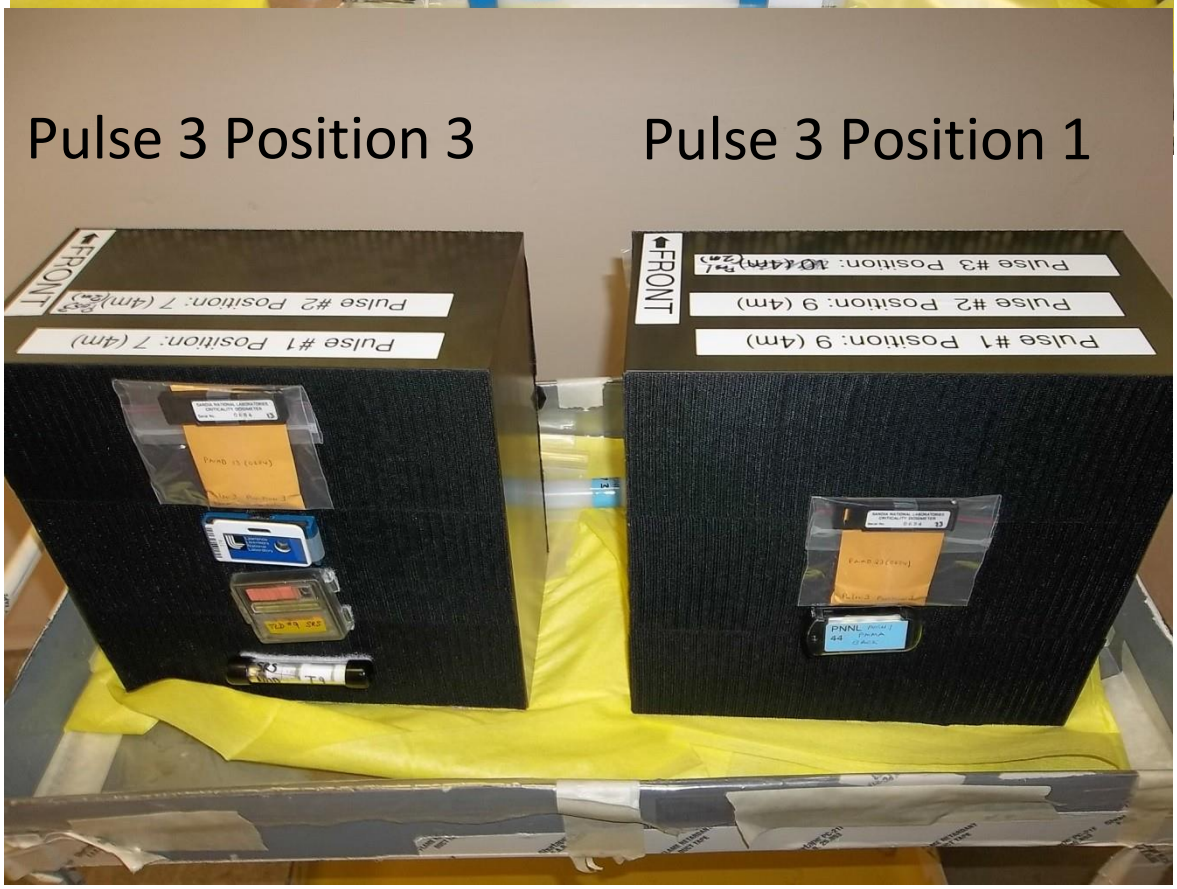


Pulse 2 Position 8 (4m)


Pulse 2 Position 9 (4m) Front
Pulse 2 Position 7 (2m) Front
Pulse #1 Position: 9 (4m)
Pulse #2 Position: 9 (4m)
Pulse #3 Position: 10 (4m)
FRONT
LLNL PIC-8
Pulse #1 Position: 7 (4m)
Pulse #2 Position: 7 (4m)
FRONT
Pulse 2 Position 7 (2m) Back
Pulse 2 Position 9 (4m) Back
FRONT
Pulse #1 Position: 7 (4m)
Pulse #2 Position: 7 (4m)
FRONT
Pulse #1 Position: 9 (4m)
Pulse #2 Position: 9 (4m)
Pulse #3 Position: 10 (4m)
RADIOACTIVE MATERIAL

Pulse 2 Position 10


Pulse 3 Position 1
Pulse 3 Position 3
Pulse #1 Position: 9 (4m)
Pulse #2 Position: 9 (4m)
FRONT
LANL P9
Pulse #1 Position: 7 (4m)
Pulse #2 Position: 7 (4m)


Pulse 3 Position 3
Pulse 3 Position 1
FRONT
Pulse #1 Position: 7 (4m)
Pulse #2 Position: 7 (4m)
Pulse #1 Position: 9 (4m)
Pulse #2 Position: 9 (4m)

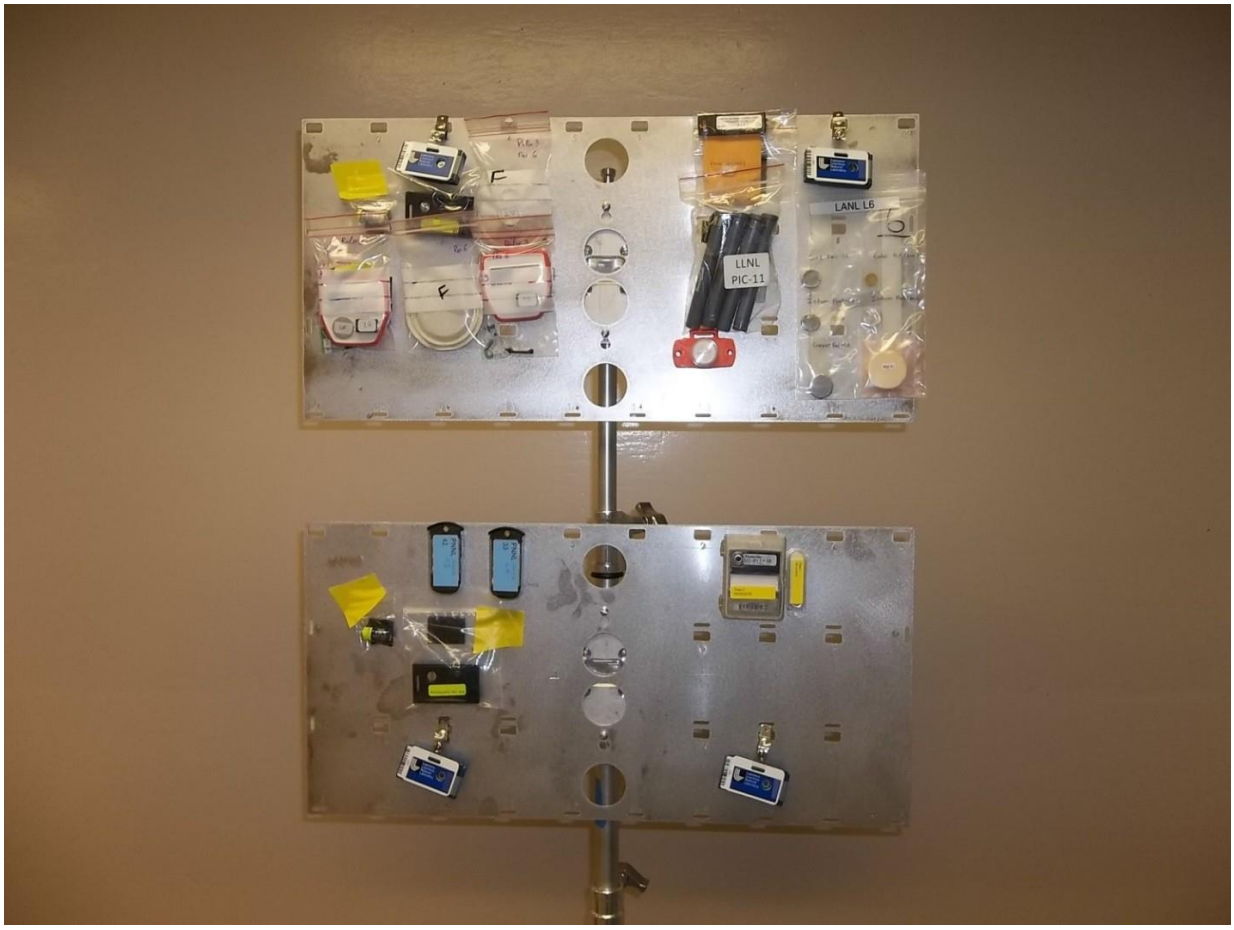
Pulse 3 Position 2 (2m)

Pulse 3 Position 4

Pulse 3 Position 4 (3m)
Back of Phantom

Pulse 3 Position 5 (3m) Front of Phantom Lateral Position

Pulse 3 Position 6 (2.5m)



Pulse 3 Position 7 (4m)
Back of Phantom

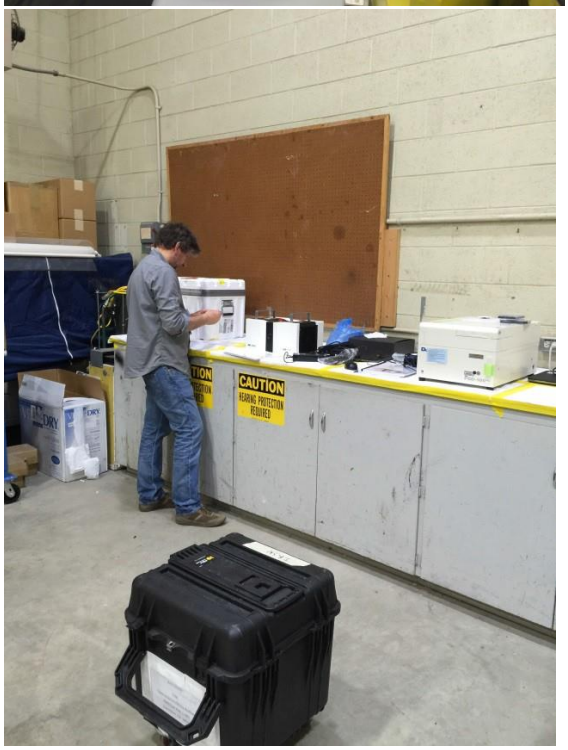
Pulse 3 Position 8 (4m)

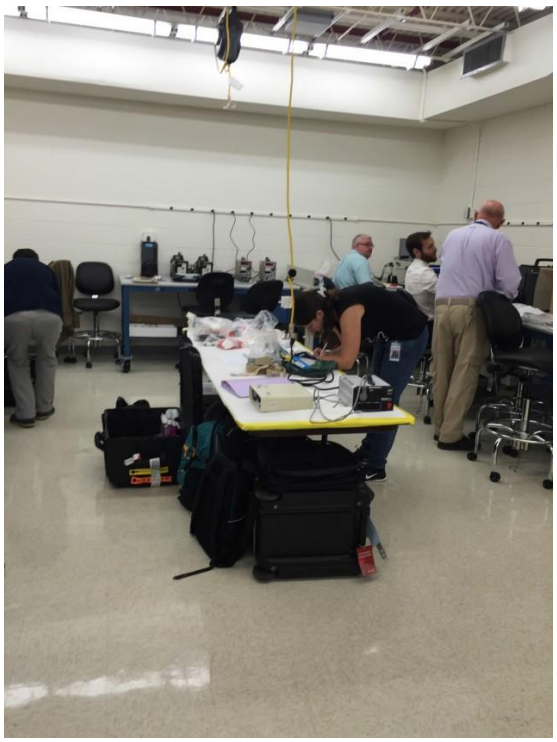
PREPARATIONS

Preparations occurred the week prior to the irradiations and on Monday May 23. Preparations included the loading of BOMAB phantoms with Ringers Lactate solution, mounting dosimeters onto the plates, and mounting of dosimeters onto the phantoms. The dosimeters had to be mounted and shipped to the DAF by Thursday May 26. Additional preparations needed to be made for the Passive Neutron Spectrometers and special dosimetry such as Fixed Neutron Dosimeters. Workstations were established and measurement equipment had to be assembled and calibrated.

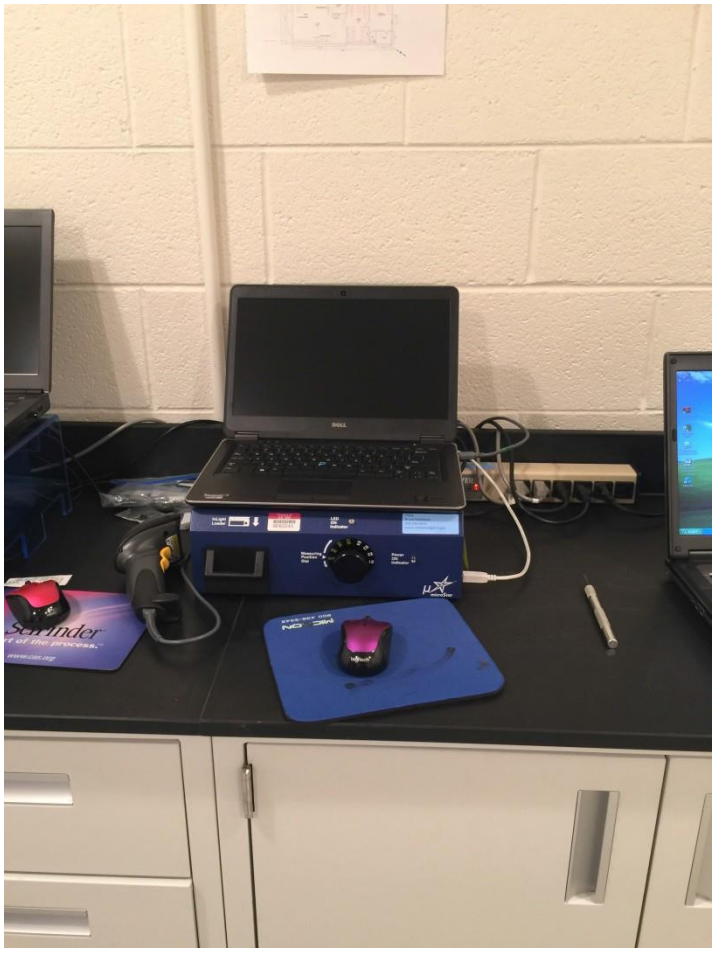
BOMABs

Equipment Setup



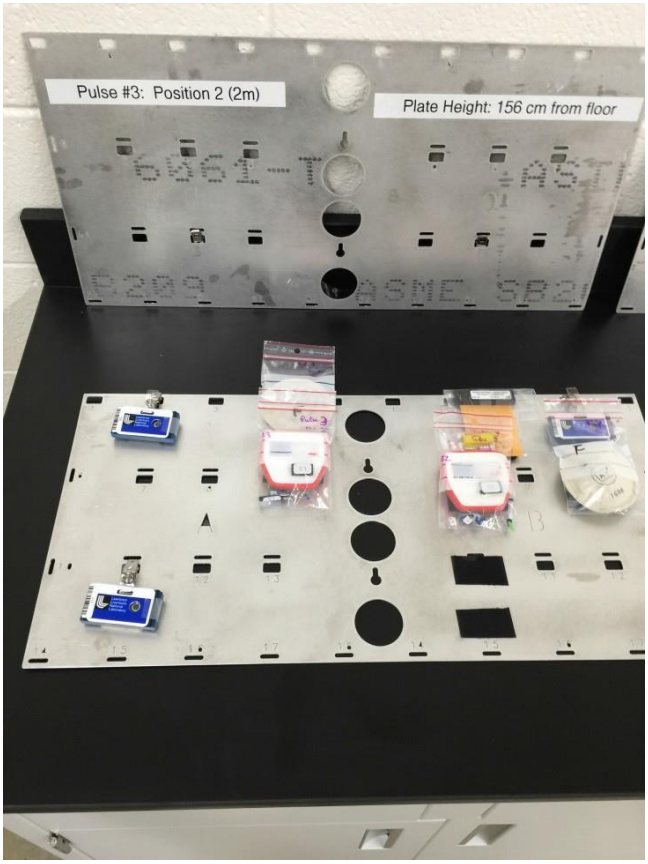


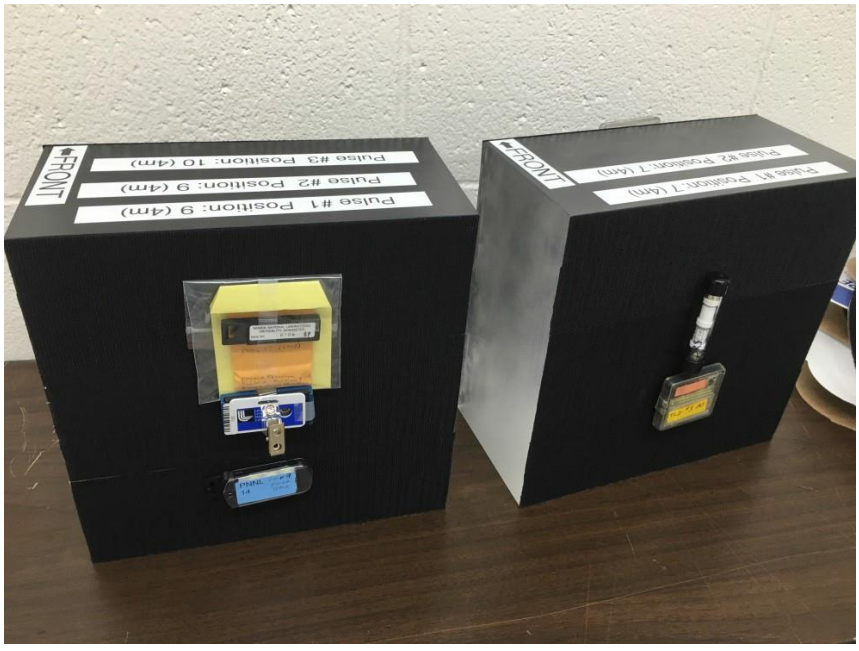
Equipment Setup



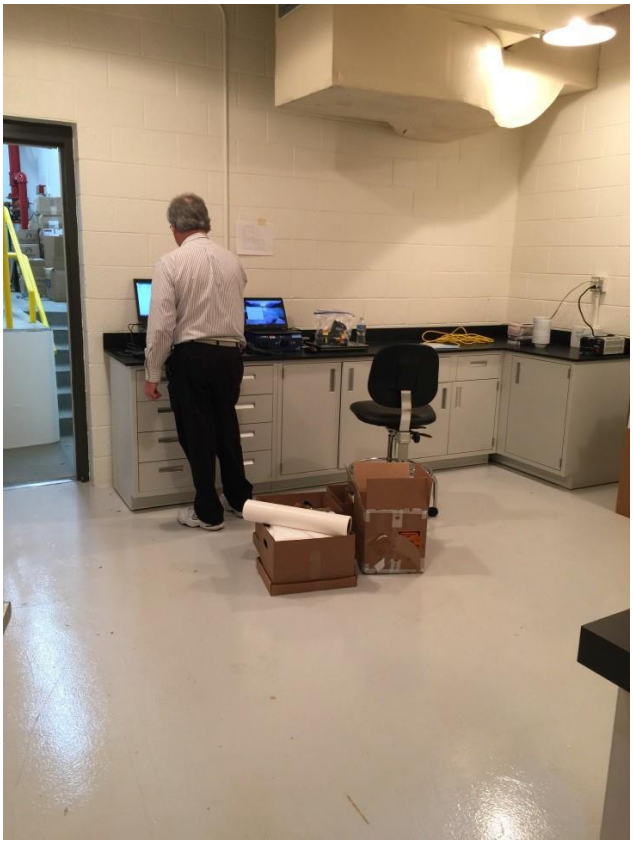
Passive Neutron Spectrometer

Loading Personnel NADs on Phantoms & Trees



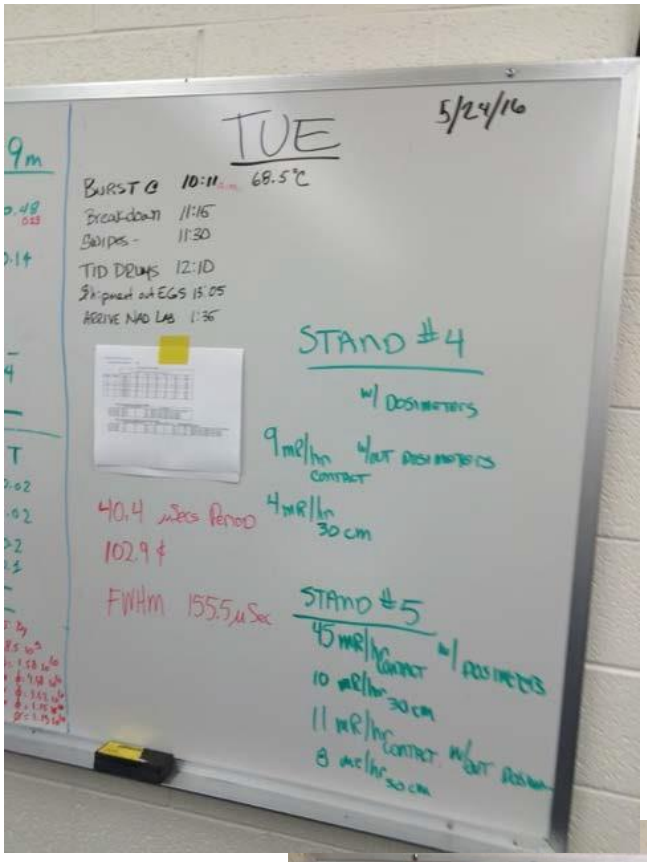


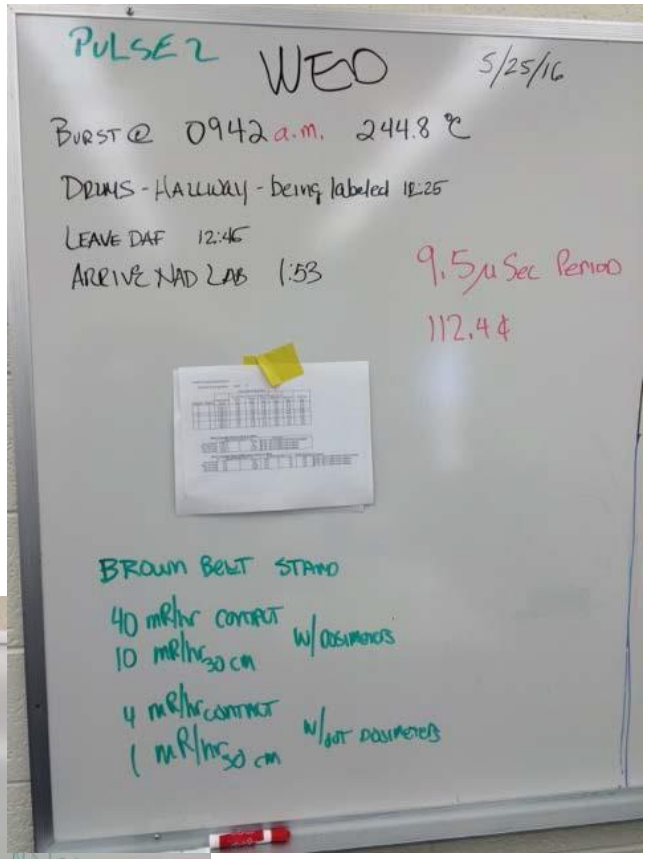
Prepare FNADs

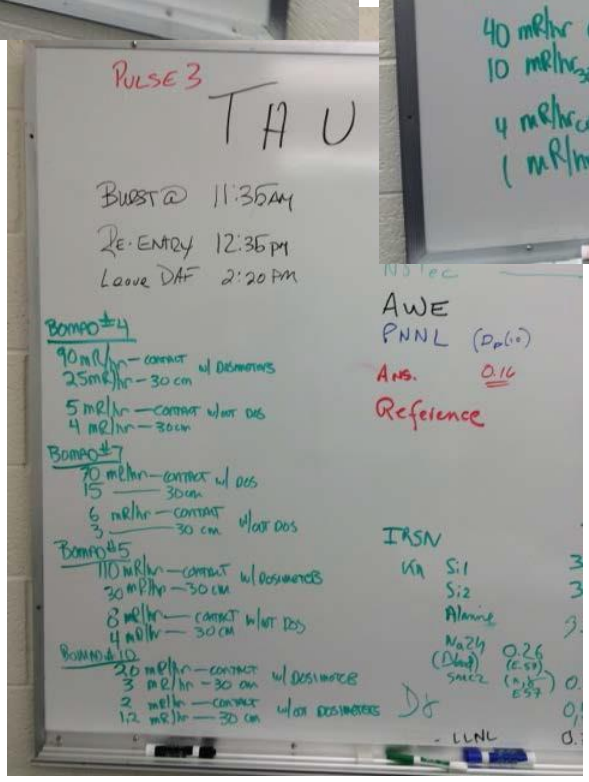


PACKING AND SHIPPING
TO DAF

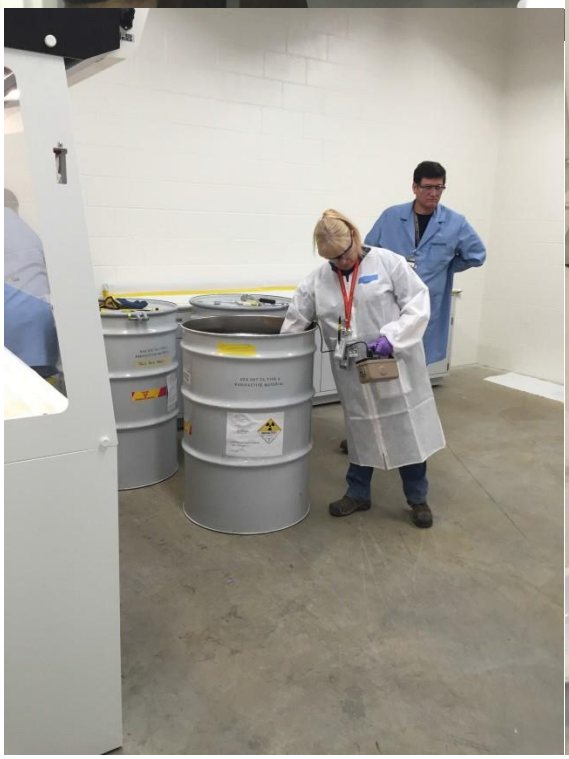
IRRADIATIONS





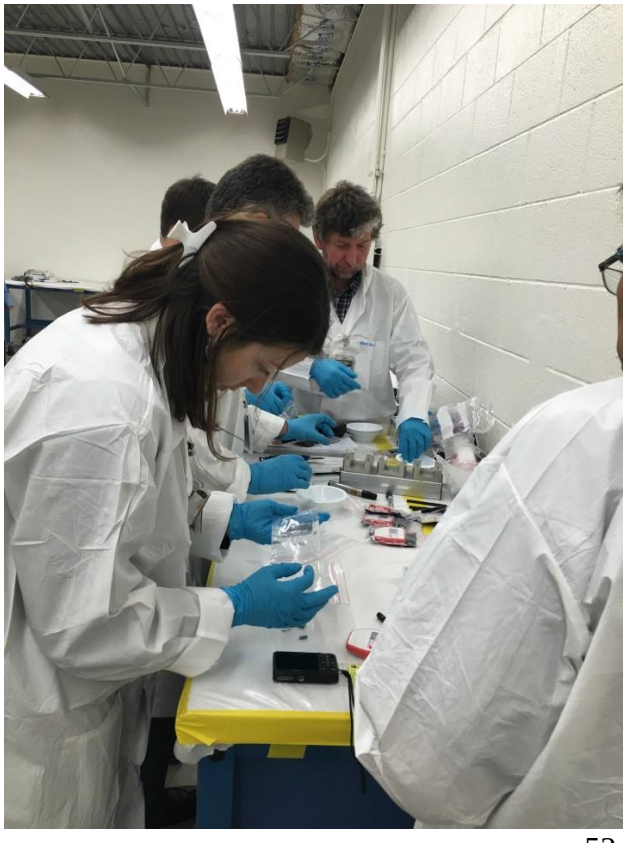


SAMPLE SHIPPING AND RECEIPT



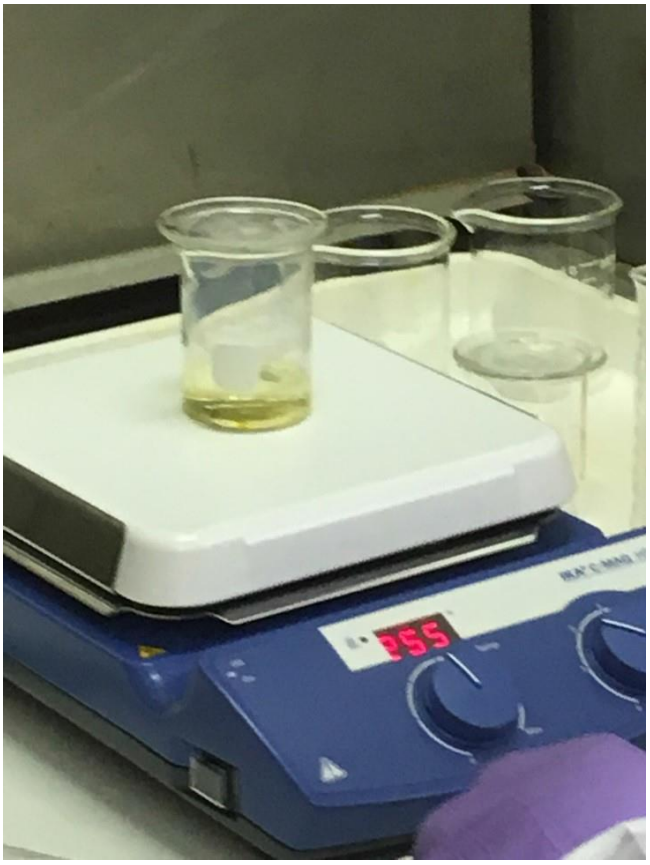
SAMPLE & MATERIAL DISTRIBUTION

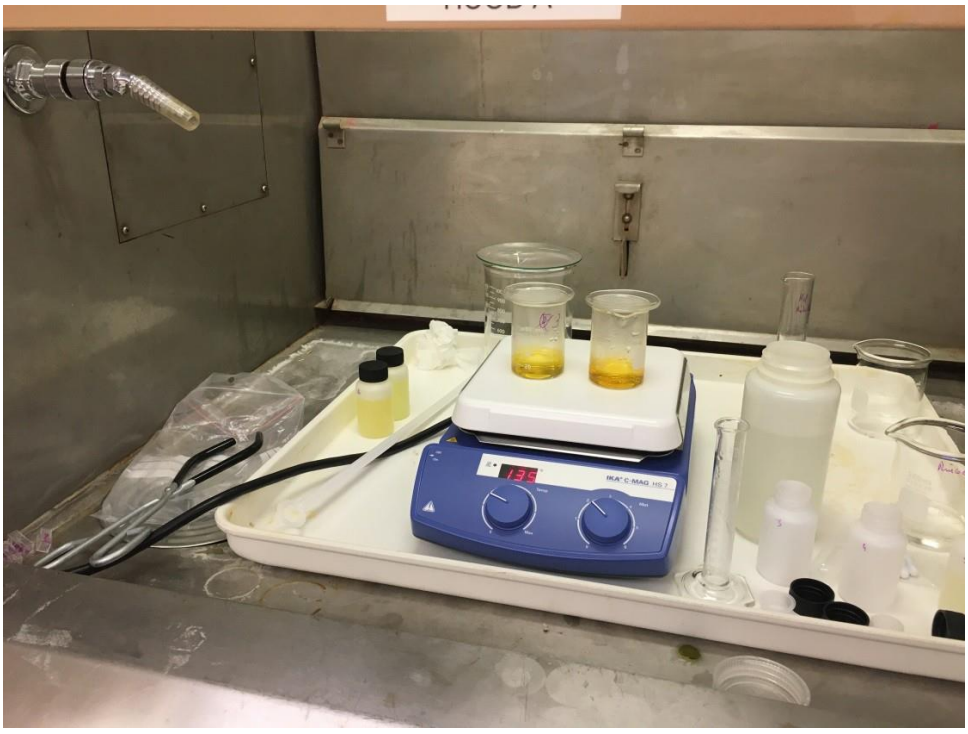
NAD & PNS BREAKDOWN



Breakdown (cont.)

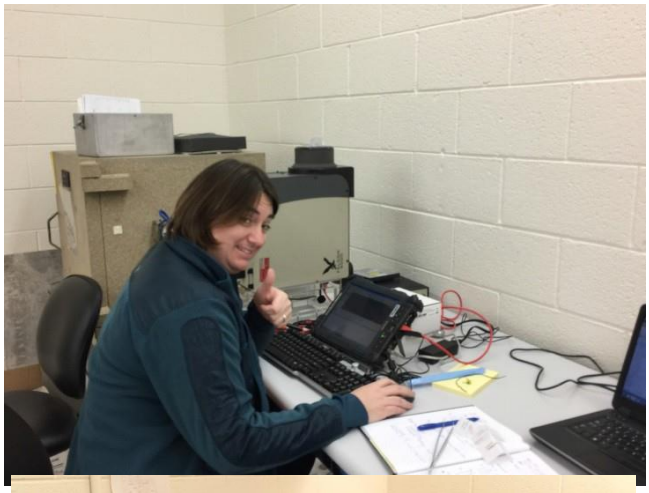
METAL DISSOLUTIONS

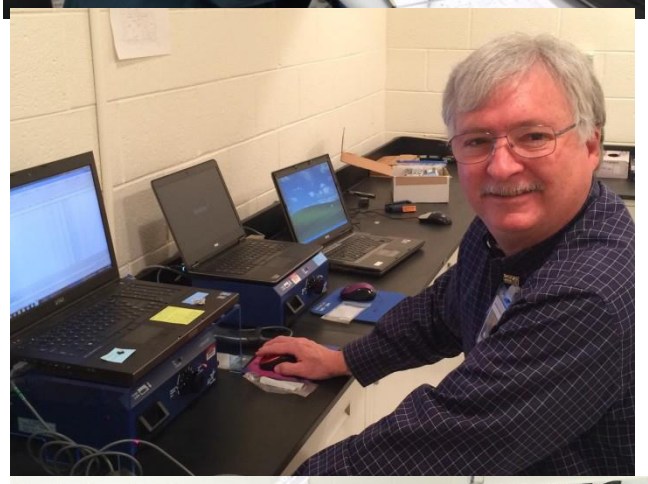


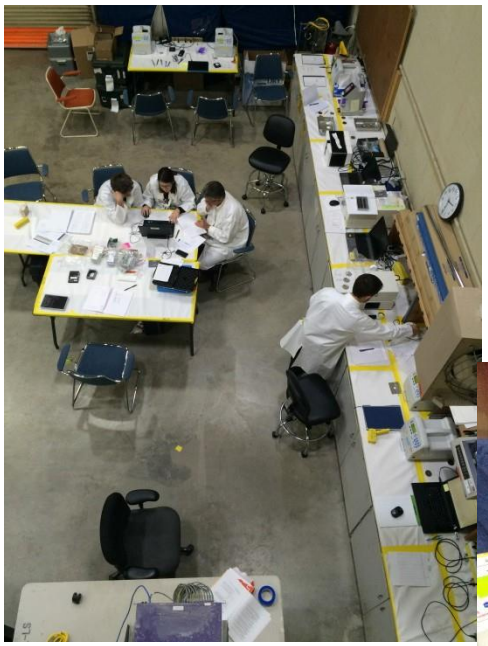


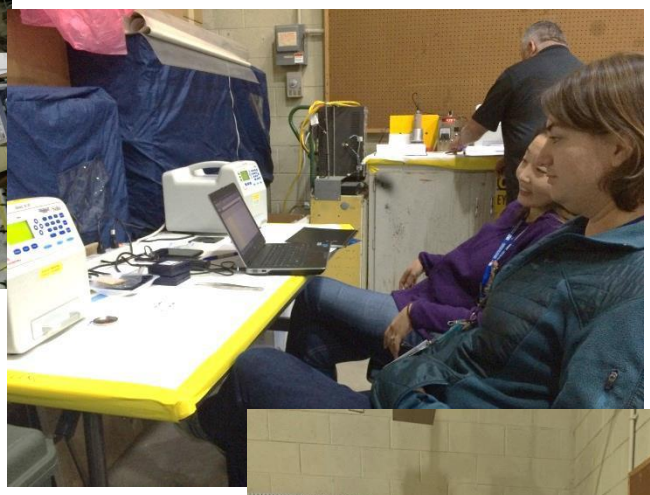
EXTRACTING RINGERS LACTATE BLOOD

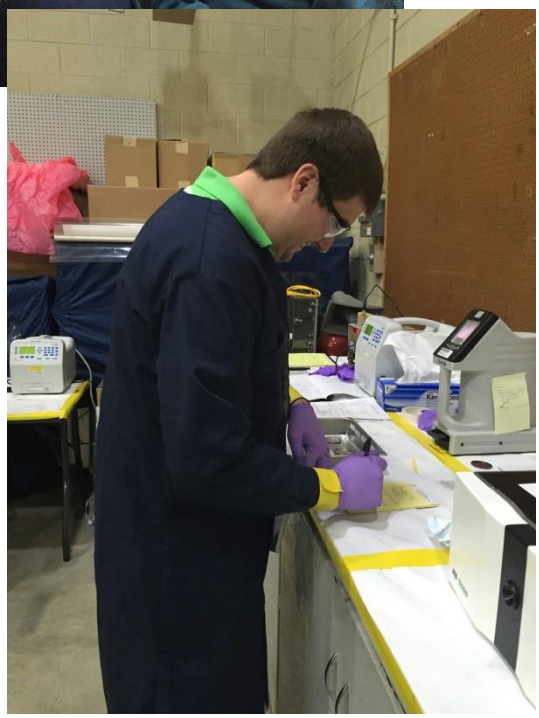
PERFORMING MEASUREMENTS



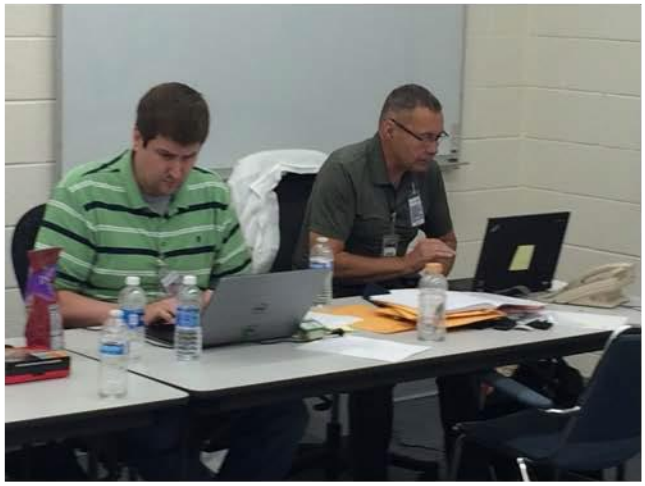


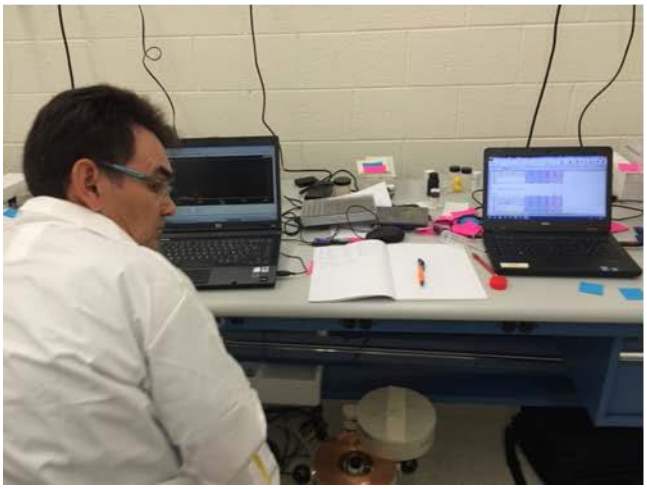




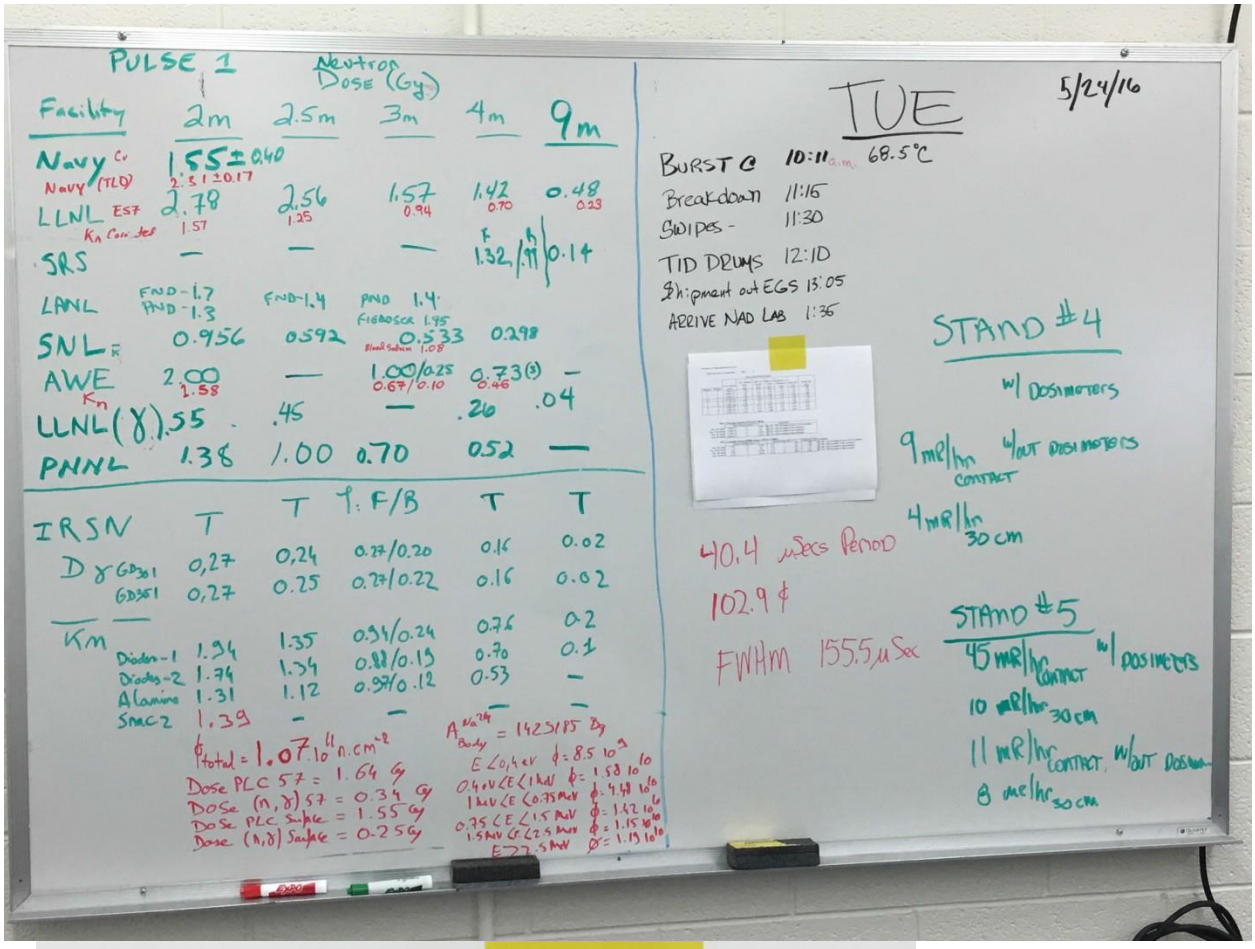


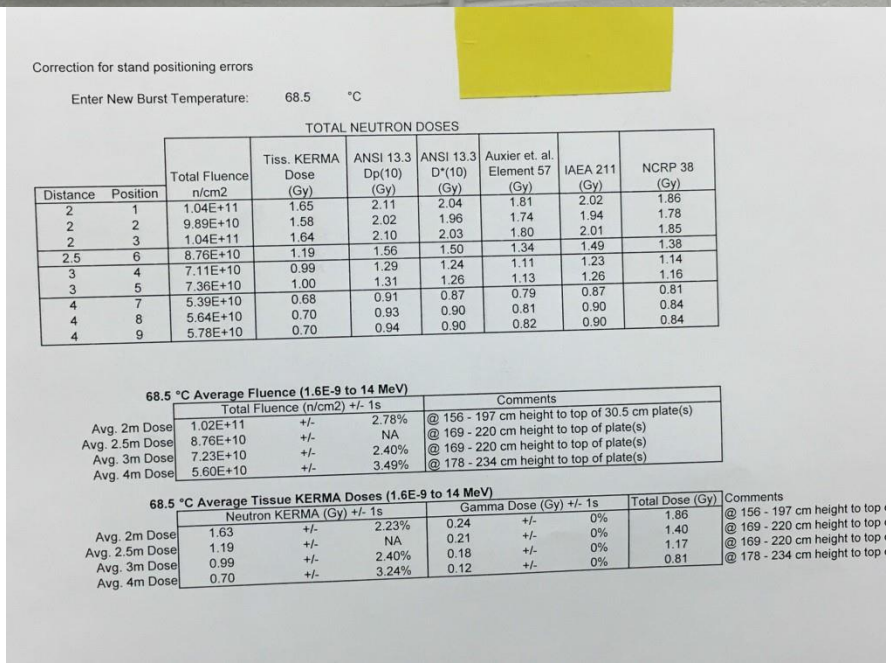
DATA ANALYSIS


PRELIMINARY RESULTS
Pulse 1





Correction for stand positioning errors

Enter New Burst Temperature: 68.5 °C

TOTAL NEUTRON DOSES

Distance	Position	Total Fluence n/cm2	Tiss. KERMA Dose (Gy)	ANSI 13.3 Dp(10) (Gy)	ANSI 13.3 D*(10) (Gy)	Auxier et. al. Element 57 (Gy)	IAEA 211 (Gy)	NCRP 38 (Gy)
2	1	1.04E+11	1.65	2.11	2.04	1.81	2.02	1.86
2	2	9.89E+10	1.58	2.02	1.96	1.74	1.94	1.78
2	3	1.04E+11	1.64	2.10	2.03	1.80	2.01	1.85
2.5	6	8.76E+10	1.19	1.56	1.50	1.34	1.49	1.38
3	4	7.11E+10	0.99	1.29	1.24	1.11	1.23	1.14
3	5	7.36E+10	1.00	1.31	1.26	1.13	1.26	1.16
4	7	5.39E+10	0.68	0.91	0.87	0.79	0.87	0.81
4	8	5.64E+10	0.70	0.93	0.90	0.81	0.90	0.84
4	9	5.78E+10	0.70	0.94	0.90	0.82	0.90	0.84

68.5 °C Average Fluence (1.6E-9 to 14 MeV)

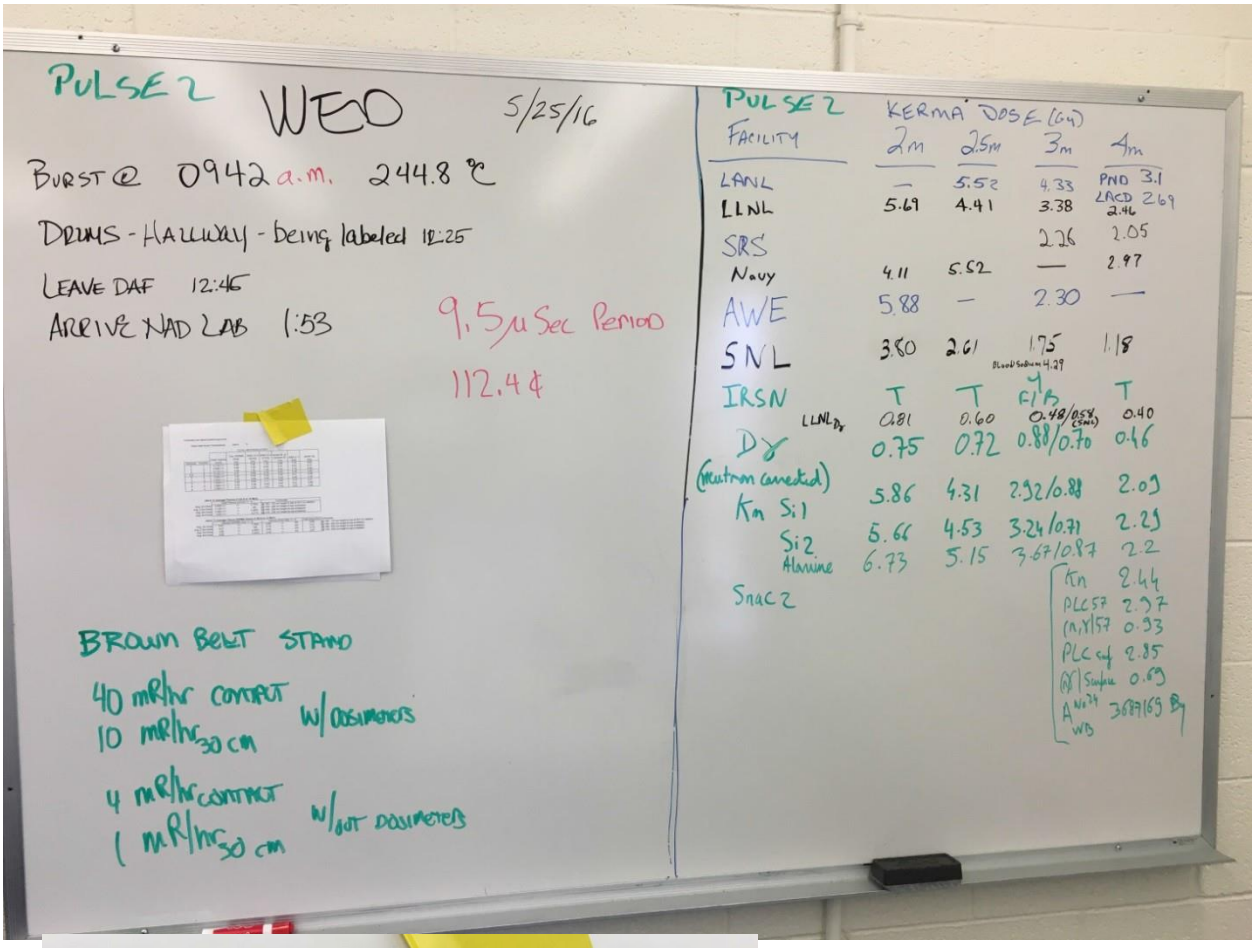
	Total Fluence (n/cm2) +/- 1s			Comments
Avg. 2m Dose	1.02E+11	+/-	2.78%	@ 156 - 197 cm height to top of 30.5 cm plate(s)
Avg. 2.5m Dose	8.76E+10	+/-	NA	@ 169 - 220 cm height to top of plate(s)
Avg. 3m Dose	7.23E+10	+/-	2.40%	@ 169 - 220 cm height to top of plate(s)
Avg. 4m Dose	5.60E+10	+/-	3.49%	@ 178 - 234 cm height to top of plate(s)

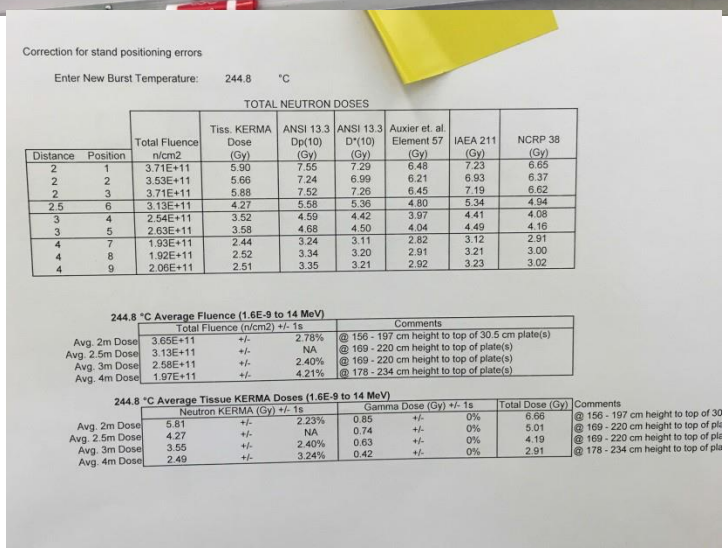
68.5 °C Average Tissue KERMA Doses (1.6E-9 to 14 MeV)

	Neutron KERMA (Gy) +/- 1s			Gamma Dose (Gy) +/- 1s			Total Dose (Gy)	Comments
Avg. 2m Dose	1.63	+/-	2.23%	0.24	+/-	0%	1.86	@ 156 - 197 cm height to top
Avg. 2.5m Dose	1.19	+/-	NA	0.21	+/-	0%	1.40	@ 169 - 220 cm height to top
Avg. 3m Dose	0.99	+/-	2.40%	0.18	+/-	0%	1.17	@ 169 - 220 cm height to top
Avg. 4m Dose	0.70	+/-	3.24%	0.12	+/-	0%	0.81	@ 178 - 234 cm height to top

Known Result

PRELIMINARY RESULTS
PULSE 2





Correction for stand positioning errors

Enter New Burst Temperature: 244.8 °C

TOTAL NEUTRON DOSES

Distance	Position	Total Fluence n/cm2	Tiss. KERMA Dose (Gy)	ANSI 13.3 Dp(10) (Gy)	ANSI 13.3 D*(10) (Gy)	Auxier et. al. Element 57 (Gy)	IAEA 211 (Gy)	NCRP 38 (Gy)
2	1	3.71E+11	5.90	7.55	7.29	6.48	7.23	6.65
2	2	3.53E+11	5.66	7.24	6.99	6.21	6.93	6.37
2	3	3.71E+11	5.88	7.52	7.26	6.45	7.19	6.62
2.5	6	3.13E+11	4.27	5.58	5.36	4.80	5.34	4.94
3	4	2.54E+11	3.52	4.59	4.42	3.97	4.41	4.08
3	5	2.63E+11	3.58	4.68	4.50	4.04	4.49	4.16
4	7	1.93E+11	2.44	3.24	3.11	2.82	3.12	2.91
4	8	1.92E+11	2.52	3.34	3.20	2.91	3.21	3.00
4	9	2.06E+11	2.51	3.35	3.21	2.92	3.23	3.02

244.8 °C Average Fluence (1.6E-9 to 14 MeV)

	Total Fluence (n/cm2)	+/- 1s		Comments
Avg. 2m Dose	3.65E+11	+/-	2.78%	@ 156 - 197 cm height to top of 30.5 cm plate(s)
Avg. 2.5m Dose	3.13E+11	+/-	NA	@ 169 - 220 cm height to top of plate(s)
Avg. 3m Dose	2.58E+11	+/-	2.40%	@ 169 - 220 cm height to top of plate(s)
Avg. 4m Dose	1.97E+11	+/-	4.21%	@ 178 - 234 cm height to top of plate(s)

244.8 °C Average Tissue KERMA Doses (1.6E-9 to 14 MeV)

	Neutron KERMA (Gy)	+/- 1s		Gamma Dose (Gy)	+/- 1s		Total Dose (Gy)	Comments
Avg. 2m Dose	5.81	+/-	2.23%	0.85	+/-	0%	6.66	@ 156 - 197 cm height to top of 30
Avg. 2.5m Dose	4.27	+/-	NA	0.74	+/-	0%	5.01	@ 169 - 220 cm height to top of pla
Avg. 3m Dose	3.55	+/-	2.40%	0.63	+/-	0%	4.19	@ 169 - 220 cm height to top of pla
Avg. 4m Dose	2.49	+/-	3.24%	0.42	+/-	0%	2.91	@ 178 - 234 cm height to top of pla

Known Result

PRELIMINARY RESULTS
PULSE 3 BLIND TEST