NUCLEAR CRITICALITY SAFETY PROGRAM

Intercomparison of Nuclear Accident Dosimetry using the Flattop Reactor at NCERC

IER-253 CED-4 Report

Presented at the NCSP Technical Seminar at Pantex on March 26-27, 2019

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LLNL-PRES-769622

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

Introduction

- Simulate dosimetry response to a real criticality event.
  - Participants blind to known doses
  - Limited information released during initial 24 hrs
- US/British/French collaboration in designing and executing the exercises.
  - Building on past exercises using Godiva, Caliban, and Silene reactors
  - Coordinators were independent of their respective laboratories
- 10 laboratories participated
  - DOE: LANL, LLNL, PNNL, SNL, SRS & Y-12
  - Navy: Naval Dosimetry Center & Norfolk Naval Shipyard
  - AWE & IRSN

Methods

- Two critical excursions at NCERC
- Dosimeters placed on BOMABs and Free-in-air stands
  - 3 and 4 meters from reactor
  - Locations and orientations noted by coordinators
    - Information kept private from participants
- Participants asked to provide results as available
  - 24hrs post irradiation provide best dose estimate
- Dosimeter and exposure information provided by coordinators after conclusion of the exercise
  - Participants asked to provide revised/final estimate within 3 weeks

Methods

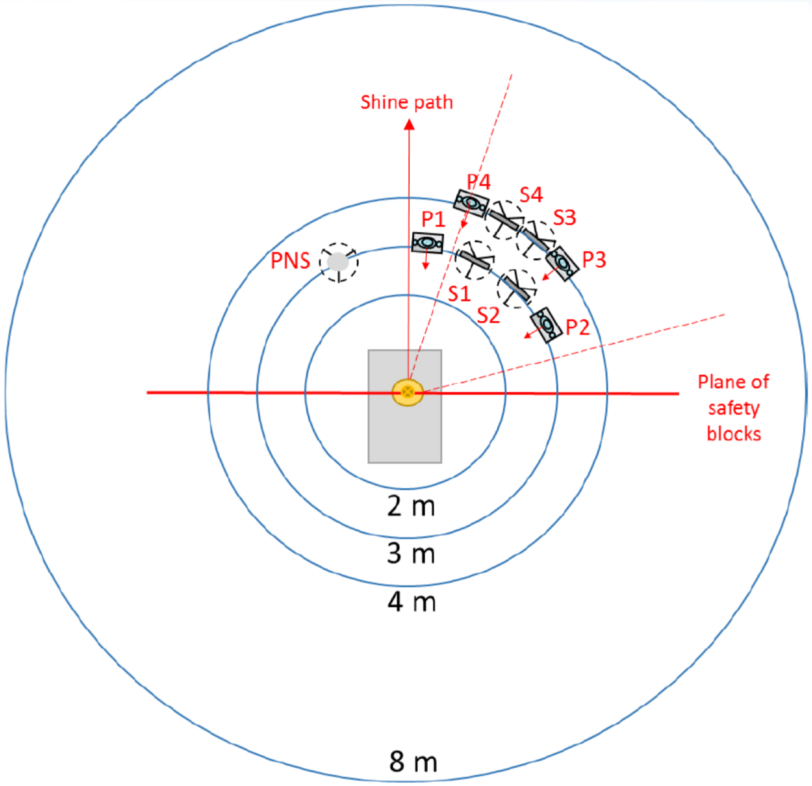


Figure 1: Location of dosimetry phantoms (P#) and stands (S#) for irradiation 1

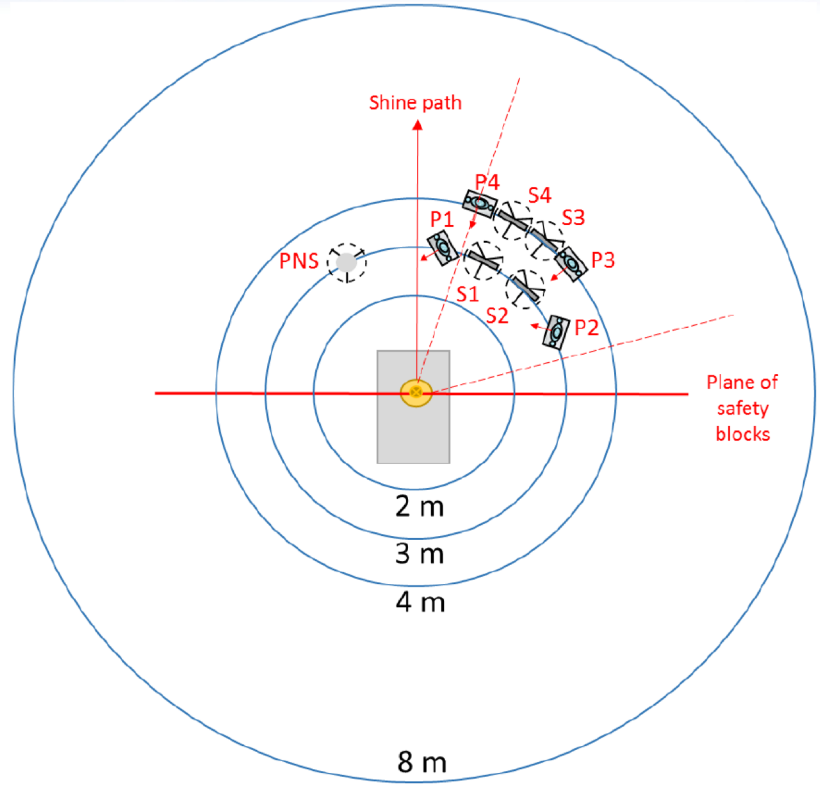
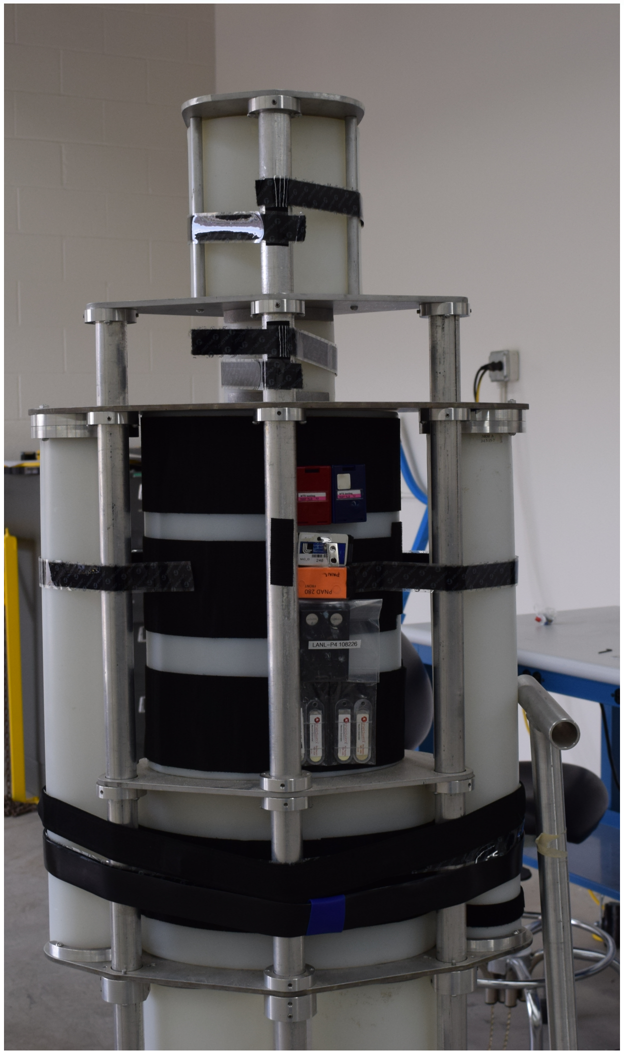


Figure 2: Location of dosimetry phantoms (P#) and stands (S#) for irradiation 2 (note phantoms 1 and 2 are rotated clockwise 45°)

Positioning and orientation of BOMABs and Free-In-Air stands

Methods



Methods

TOP
NTS testing
TEST TLD 28
NNSY 29
PNAD 297
FRONT
PNNL
Navy
PNAD 298

Methods

- Participants asked to submit dose results using ANSI/HPS N13.3-2013 dose conversion factors.
  - Some labs used IAEA Technical Series 211
- Performance compared to ANSI/HPS N13.3 requirements
- Test statistic: $B = \frac{(Measured\ Dose - Delivered\ Dose)}{Delivered\ Dose} \times 100$

Total absorbed dose range (Gy)	ANSI N13.3 Test Statistic
0.1 to 1	±50%
1 to 10	±25%

- DOE Laboratory performances also compared to DOE Standard on Radiological Control, Article 515 (DOE-STD-1098-2017)
  - *"Personnel nuclear accident dosimeters should be capable of measuring an absorbed dose in or on a phantom from 10 rads to approximately 1,000 rads with an accuracy of ± 20% for gamma radiation and ± 30% from neutron radiation."*

Results

- Reference doses based on Flattop characterization study
  - ANSI/HPS N13.3 $D_p(10)$ dose conversion values

	Distance (m)	Neutron Dose (Gy)			Gamma Dose (Gy)			Total Dose (Gy)		
		Known Value	+1s	-1s	Known Value	+1s	-1s	Known Value	+1s	-1s
Irradiation #1	3	0.92	0.08	-0.07	0.17	0.01	-0.01	1.09	0.08	0.07
	4	0.61	0.04	-0.04	0.15	0.01	-0.01	0.76	0.04	0.04
Irradiation #2	3	3.71	0.32	-0.3	0.67	0.05	-0.06	4.48	0.33	0.3
	4	2.5	0.16	-0.15	0.59	0.04	-0.04	3.09	0.16	0.15

Results

Percent of all dosimeter results outside the bias limits for all laboratories

	Irradiation #1		Irradiation #2	
Known Total Dose (Gy)	0.76*	1.09	3.09	4.48
% Outside ANSI Limits	12%	45%	52%	50%
% Outside DOE STD Limits	51%	53%	52%	48%

*ANSI/HPS N13.3-2013 limit for <1 Gy is ±50%

Results

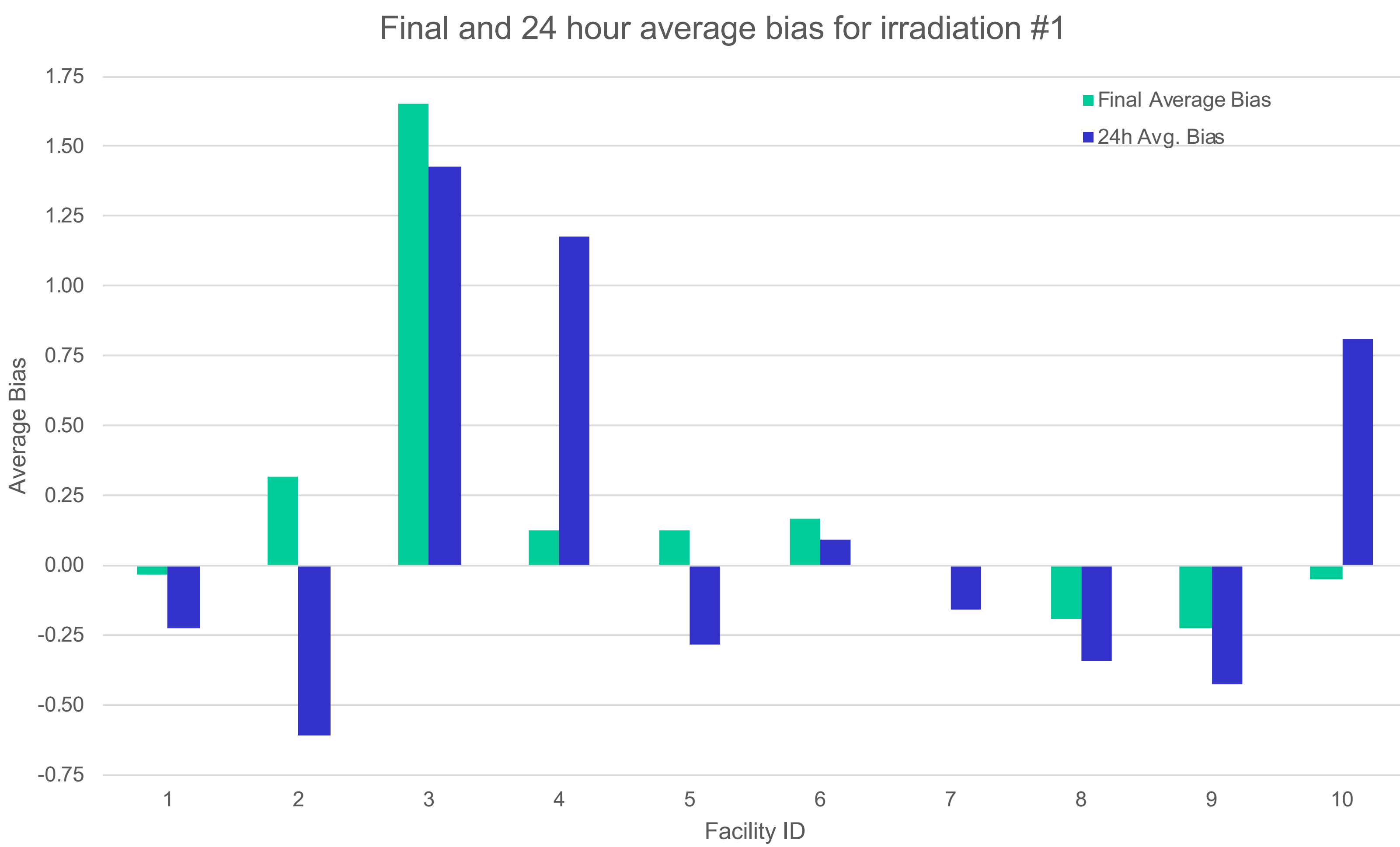
Percent of dosimeter results outside of bias limits by laboratory

LAB ID	% outside ANSI Limits	% outside DOE STD Limits
1	**2.8%**	**11%**
2	**47%**	**41%**
3	88%	81%
4	**33%**	**32%**
5	10%	23%
6	**27%**	**58%**
7	**50%**	**100%**
8	59%	26%
9	38%	36%
10	**57%**	**78%**

Labs highlighted in red are DOE Laboratories

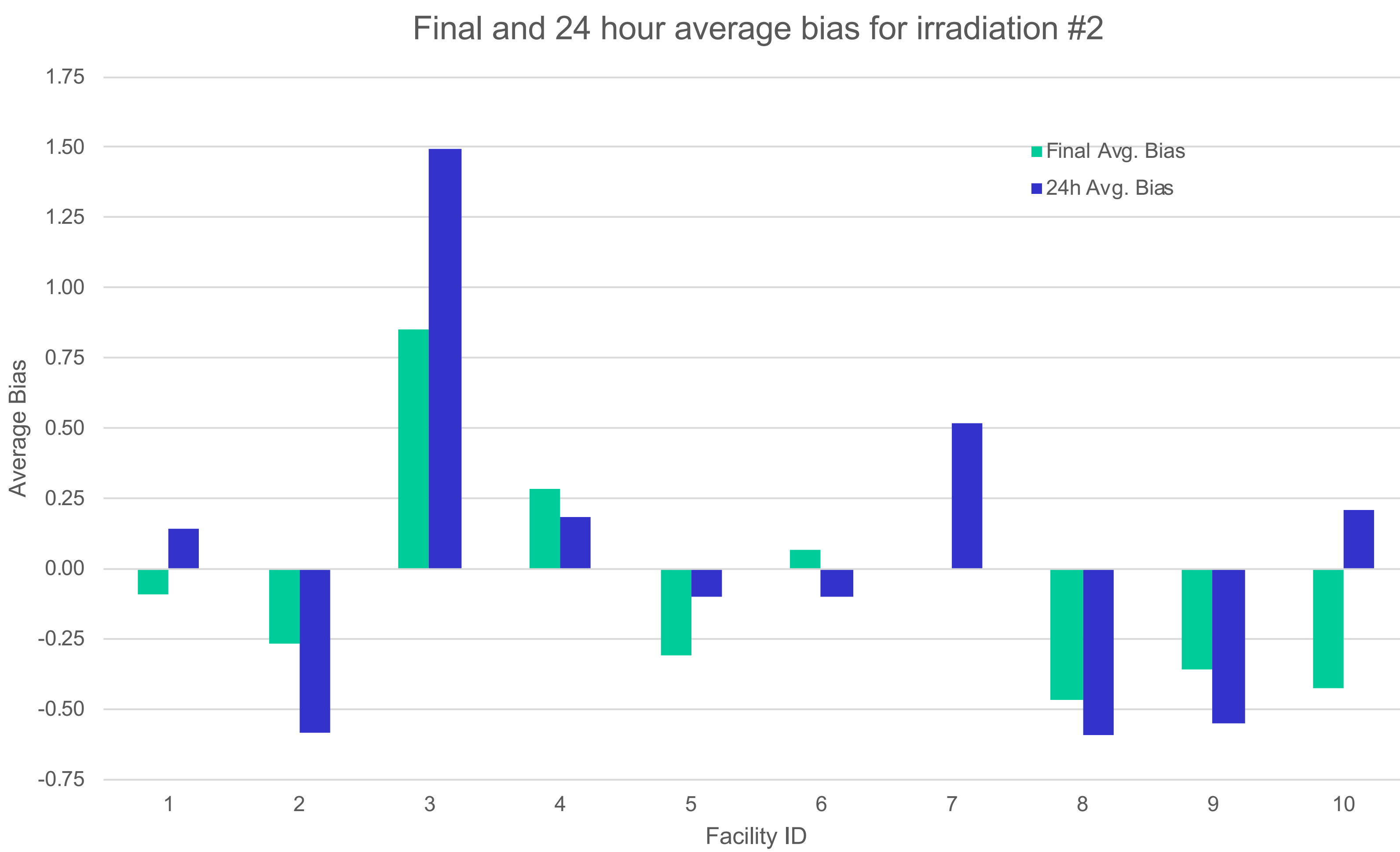
Results

24-hour vs Final Neutron Results



Results

24-hour vs Final Neutron Results



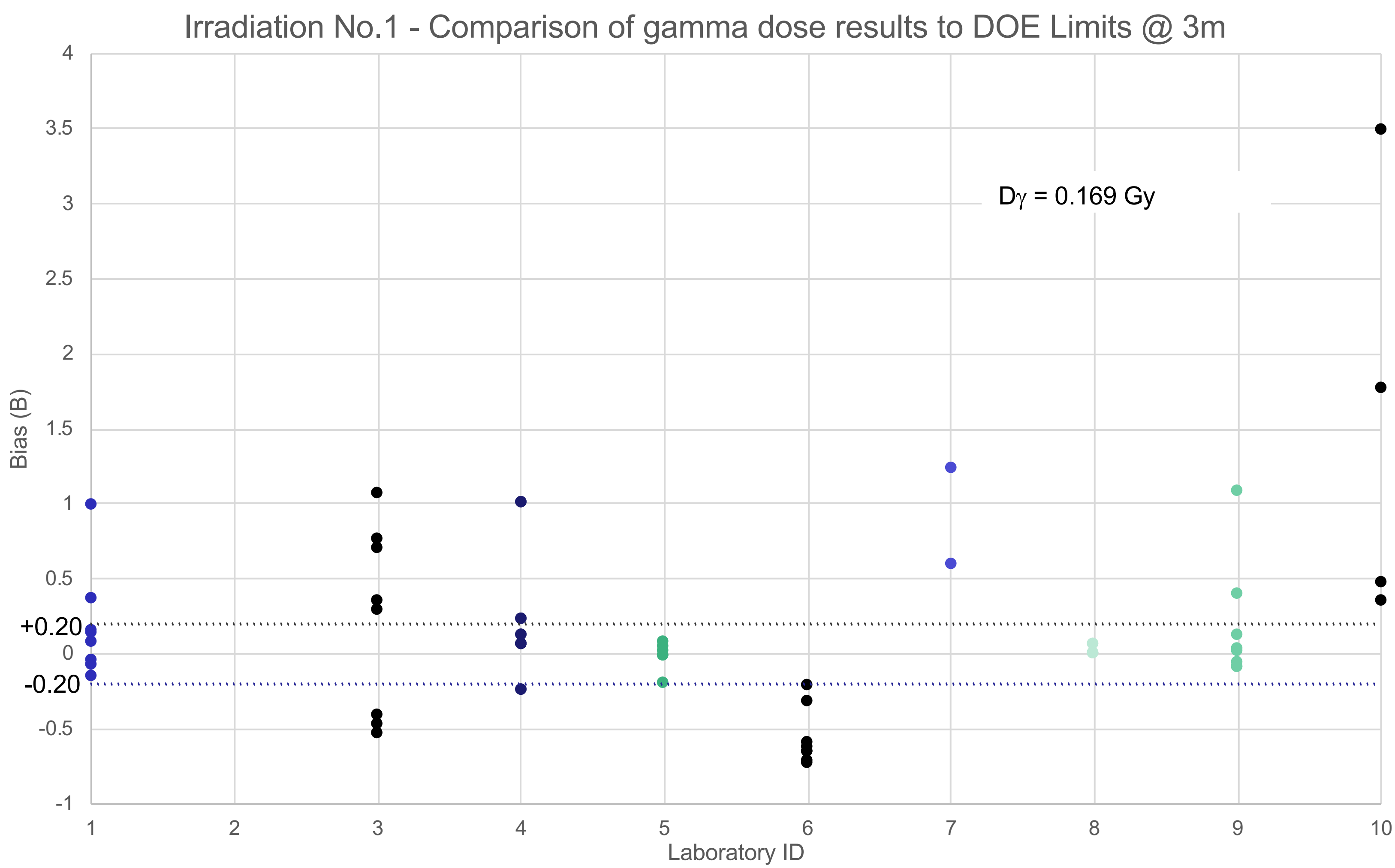
Results

Gamma Dose Results

- 6 labs provided gamma doses within the first 24hrs
- The remaining labs provided gamma doses with the final reported doses
- Several participants required gamma dosimeter processing at home laboratories
- Two laboratories were unable to report gamma doses
  - High dose dosimeter would risk damage to DOELAP accredited equipment
- One laboratory made refinements on 24hr result

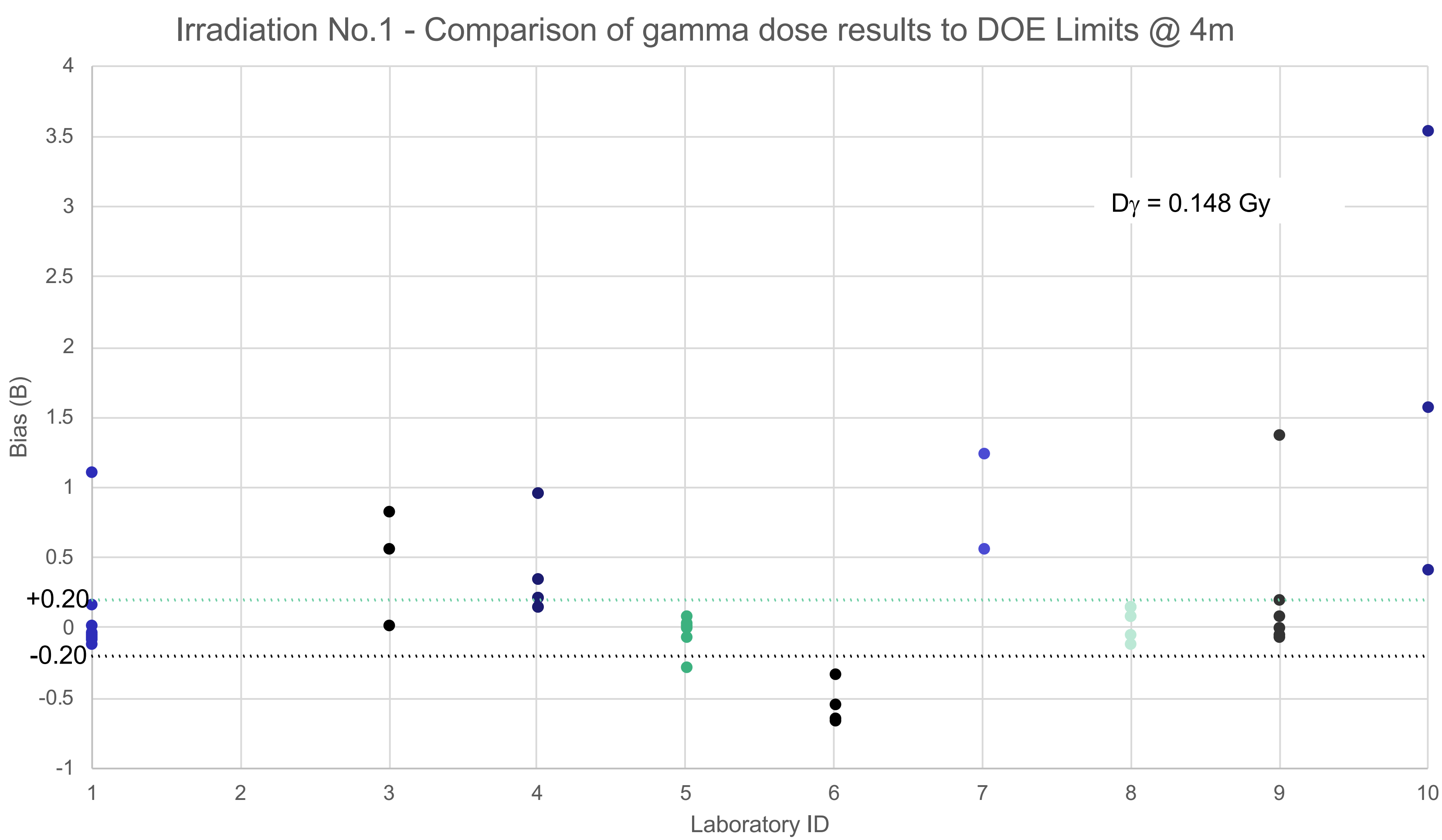
Results

Gamma Dose Results – compared to DOE Standard



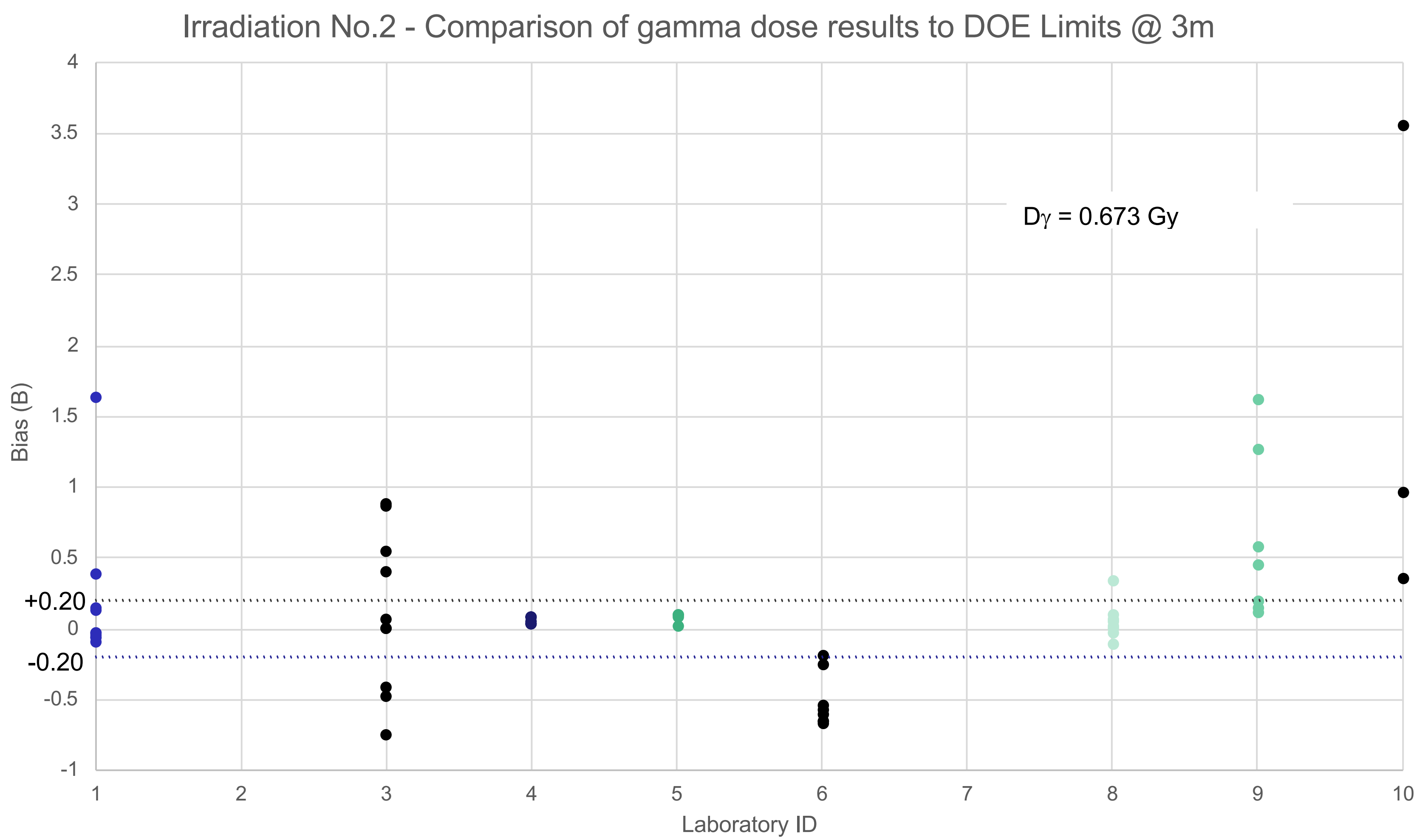
Results

Gamma Dose Results – compared to DOE Standard



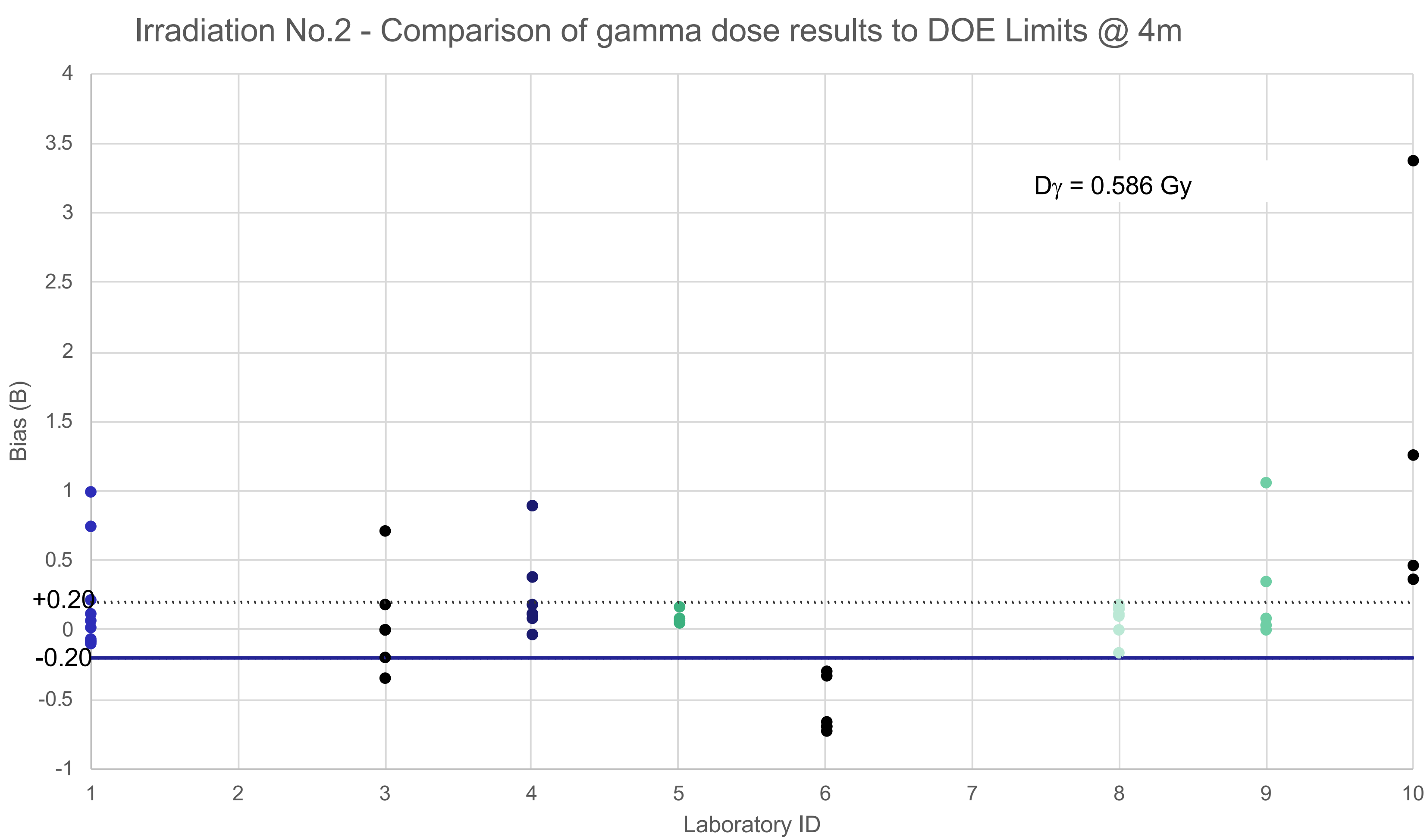
Results

Gamma Dose Results – compared to DOE Standard



Results

Gamma Dose Results – compared to DOE Standard



Results

Biological Dosimetry

- 4 participants provided neutron results using biological dosimetry
  - Hair and/or simulated blood
- Results significance limited by number of results and lack of one-to-one correspondence with any specific dosimeter result
- Number of dose results within ANSI and DOE standard limits appear to be better than doses predicted by other methods
- Percent of all dosimeter results outside the bias limits for all laboratories:

	Irradiation #1	Irradiation #2
% outside ANSI Limits	14%	33%
% outside DOE STD Limits	14%	17%

Results

Rotations

- Simulate personnel not facing the event
  - Irradiation 1 Phantom Rotations: 0°, 180°
  - Irradiation 2 Phantom Rotations: 45°, 180°, 225°
- Percent of all dosimeter results outside the bias limits for all laboratories with dosimeters on rotated phantoms:

	Irradiation #1		Irradiation #2	
Known Total Dose (Gy)	0.76	1.09	3.09	4.48
% Outside ANSI Limits	15%*	57%	27%	44%
% Outside DOE STD Limits	54%	57%	55%	81%

*ANSI/HPS N13.3-2013 limit for <1 Gy is ±50%

Results

Neutron Quick Sorting

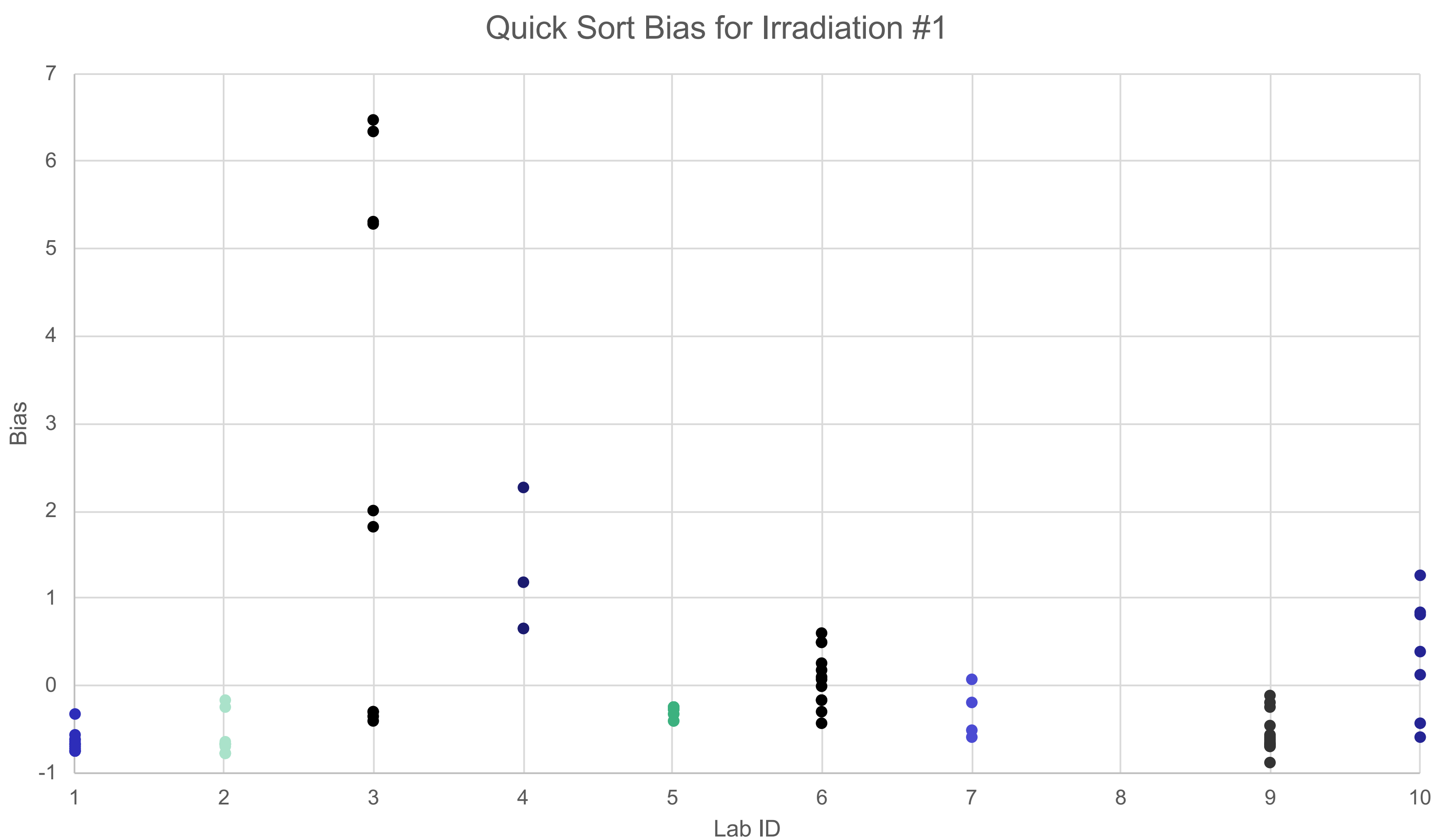
- ANSI/HPS N13.3 requires quick sort capability for:
  - Doses above 0.5 Gy
  - Sorting personnel according to total estimated dose.
- DOE standard requires a method to identify individuals who received medically significant doses.
- No accuracy requirements by ANSI or DOE

Results

Neutron Quick Sorting

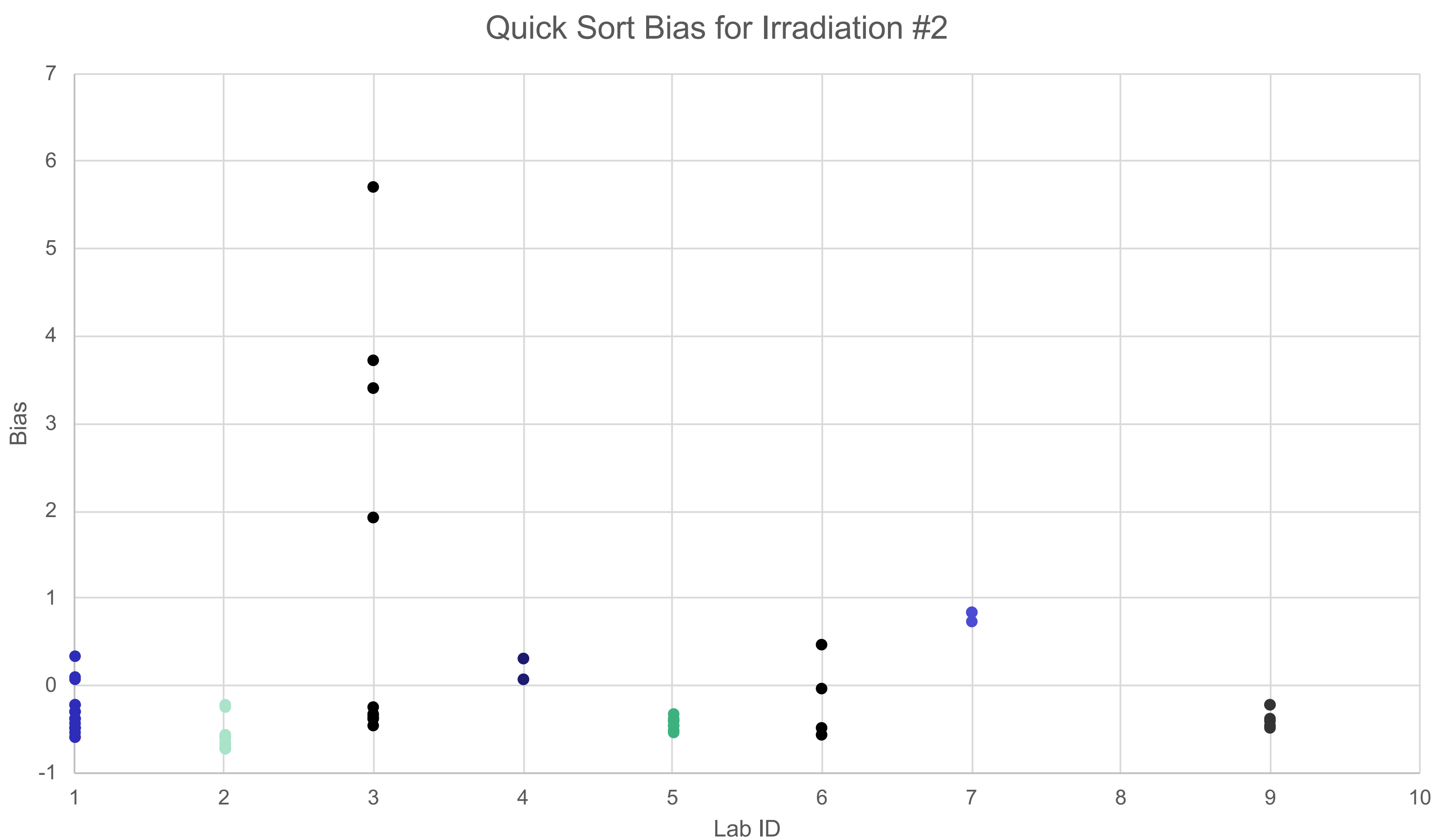
- Number of participants providing results within a few hours:
  - Irradiation 1: 9 of 10
  - Irradiation 2: 8 of 10
- One participant uses a triage priority ranking for potentially exposed individuals
  - Primary method using direct measurement of body Na activation
  - Also attempted triage using TLD holder of its dosimetry system.
- Another participant initially used incorrect dose conversion units for quick sort results
  - Corrections provided during the three weeks after the exercise

Results
Quick Sorting



Results

Quick Sorting



Discussion and Conclusions

Going forward

- Final total doses above 1 Gy were basically a 50:50 chance of being within limits
- Some laboratories had significant improvement between the 24 hour and final neutron results
- The applied gamma doses are within ANSI/HPS N13.11 accident category testing ranges
  - DOE laboratories are DOELAP accredited
  - This type of test field offers different test category than normally used
  - Standard improvements may be needed

Discussion and Conclusions

- Biological dosimetry
  - 67% to 90% of results within DOE and ANSI limits
  - Irrespective of rotation
  - tend to provide better compliance with the standard than the systems currently utilized
- Rotation Evaluations
  - Need to improve methods for determining rotational angles
  - Need to improve rotation correction methods/results
- Quick sort
  - Most laboratories relied on metal activation (ex. Indium)
    - Dependent on neutron energy spectrum >1 MeV
  - Unknown spectrum and rotation make sorting and triage difficult for highly moderated spectra (such as Flattop)
- Testing at AFRRI will be an even greater challenge

Any Questions?