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IER 557: Godiva IV Reproducibility

Joetta Goda, Travis Grove, Bruce Pierson, Danielle Redhouse, Rob Weldon

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IER 557 Godiva Reproducibility

Primary Goal -- Determine Reproducibility for 70°C bursts

In collaboration with

- Sandia Metrology Laboratory
- PNNL Counting Laboratory

Motivation

IER 498: Criticality Accident Alarm System Shielding Benchmark

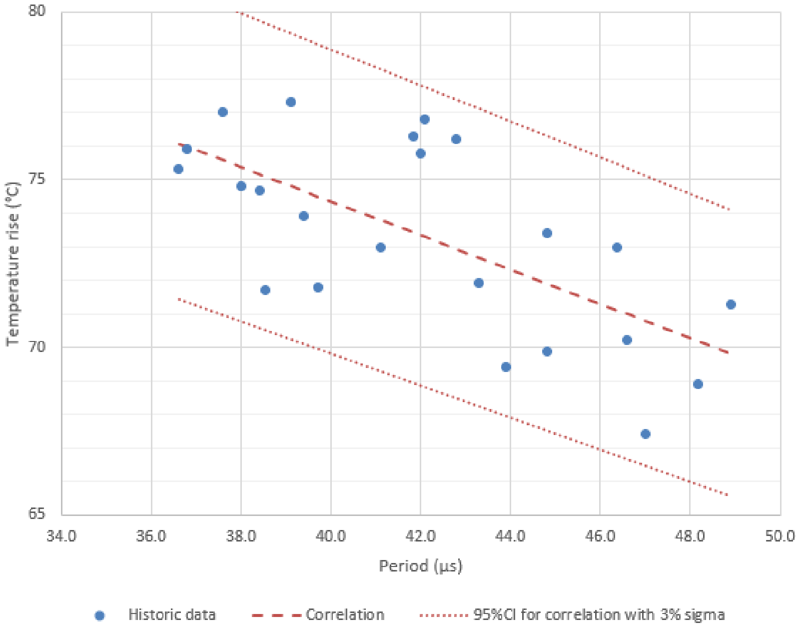
- A shielding benchmark using the Godiva IV critical assembly.
- SILENE shielding benchmark relied on absolute calibration of source intensity determined by calibrating fission chamber detectors to radchem analysis of SILENE solution.
  - Lots of effort expended during evaluation to reduce uncertainty.
- IER 498 Godiva shielding benchmark proposes to use two bursts for each measurement, one with shielding sample and one without.
  - Many effects cancel out.
  - Relies on variation in burst size being quantified and smaller than other sources of experimental uncertainty

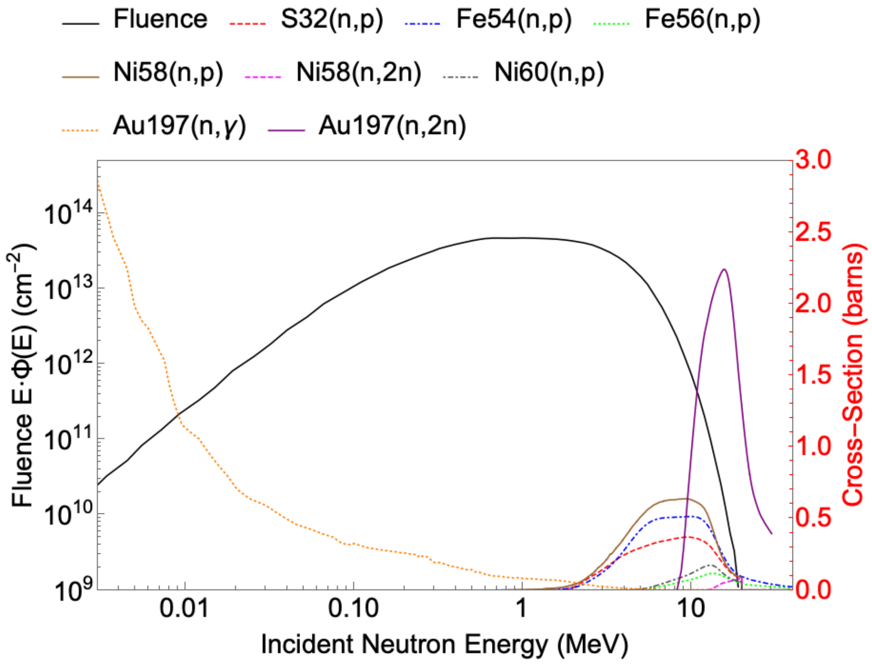
Reproducibility for 70°C bursts

Defined as variation in source term

Looked at historical data correlations

Activation monitor counting most direct measurement of fluence





Quantify and Account for Variation in Burst Size

Three Approaches

1. Activation Product Counting to Determine Variation
   - Perform “identical bursts” with activation foils in glory hole.
   - Determine inherent variation between bursts.
2. Detector Diagnostics and Correlation to Activation Products
   - Integrate detector signal, theoretically proportional to number of fissions.
   - Correlate to activation foil measurements.
3. Activation Product Counting to Normalize IER 498 Data
   - Use to scale source term or normalize IER 498 detector responses between bursts.
   - Sandia, et al. recommends deploying foils on every burst even if not counted.

Preliminary Measurements – January

Goals

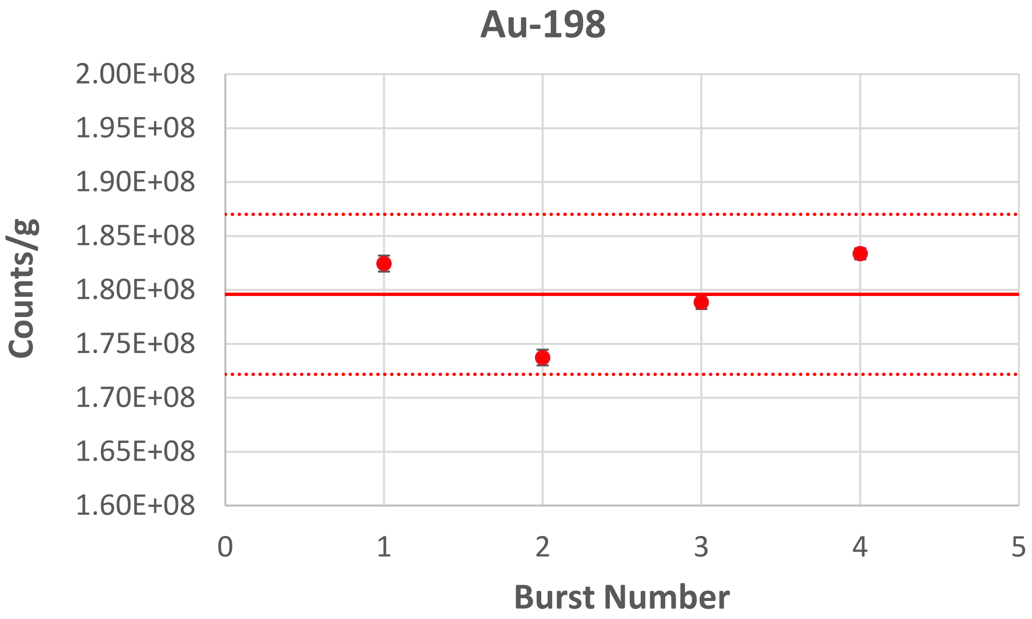
- Proof of principal
- 5-7% variation was acceptable
- Inter-comparison between labs
- 4 bursts performed
- Determine a set of foils or wires
  - PNNL activation packs
  - Sandia Ni and S
  - LANL Au and Fe foils and wires
- Learned a lot!

Burst	Date	Time	Delta T (°C)
#2069	1/12/22	11:35	75.8
#2070	1/12/22	15:27	71.4
#2071	1/13/22	10:23	74.7
#2072	1/13/22	14:09	77.3

Example Result from Preliminary Measurements

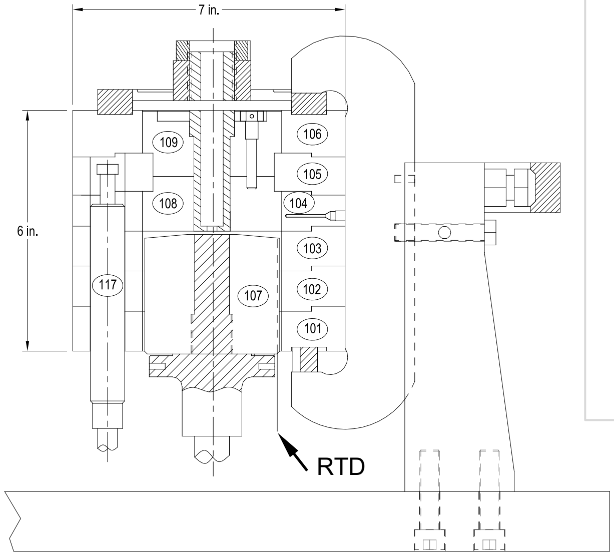
- Au-197(n,γ)Au-198
- Std Dev = 3.78E6
- Relative Error 2.1%

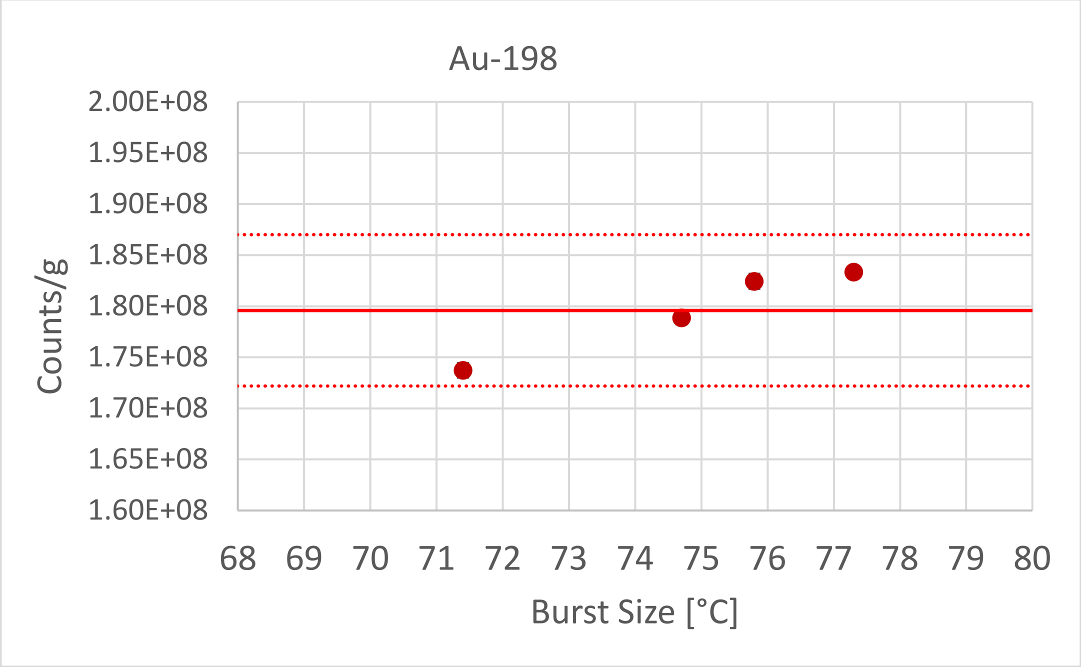
- 4 measurements is low to determine standard deviation
- Poor calibration affects absolute specific activity, but not relative emission



Temperature Correlation

- Plot versus temperature rise instead of burst number





Primary Measurements – May

- 12 bursts over 2 weeks

- 2 per day
- Godiva did not cool completely to ambient temperature between bursts.
- Will this affect results?
- Important for IER 498 which will need 2 bursts per day to maintain schedule

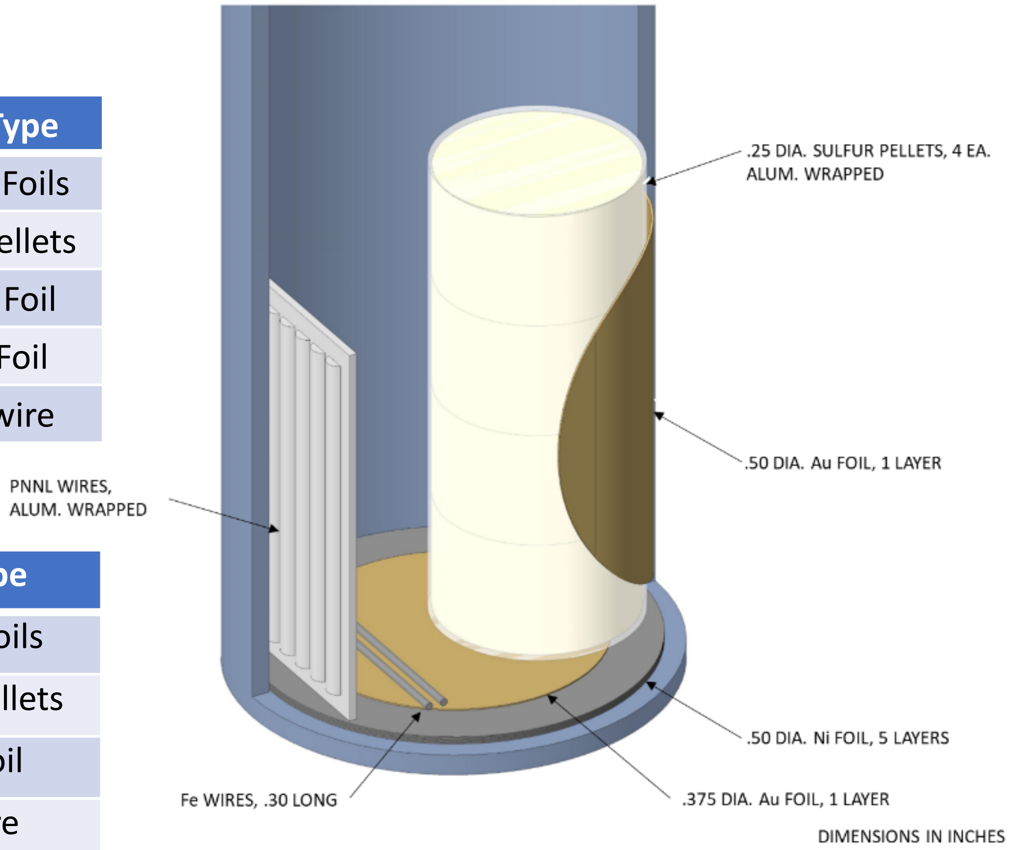
Burst #	Date	Burst time	Δ T (°C)
2081	5/10/2022	13:10:36	76.8
2082	5/10/2022	16:20:15	78.0
2083	5/11/2022	10:04:39	78.5
2084	5/11/2022	15:32:25	74.8
2085	5/12/2022	10:09:00	75.6
2086	5/12/2022	14:50:12	75.5
2087	5/16/2022	12:32:49	79.1
2088	5/16/2022	16:03:19	73.4
2089	5/17/2022	9:45:42	74.1
2090	5/17/2022	14:18:05	74.4
2091	5/18/2022	9:37:29	77.5
2092	5/18/2022	13:52:23	74.5

Week 1

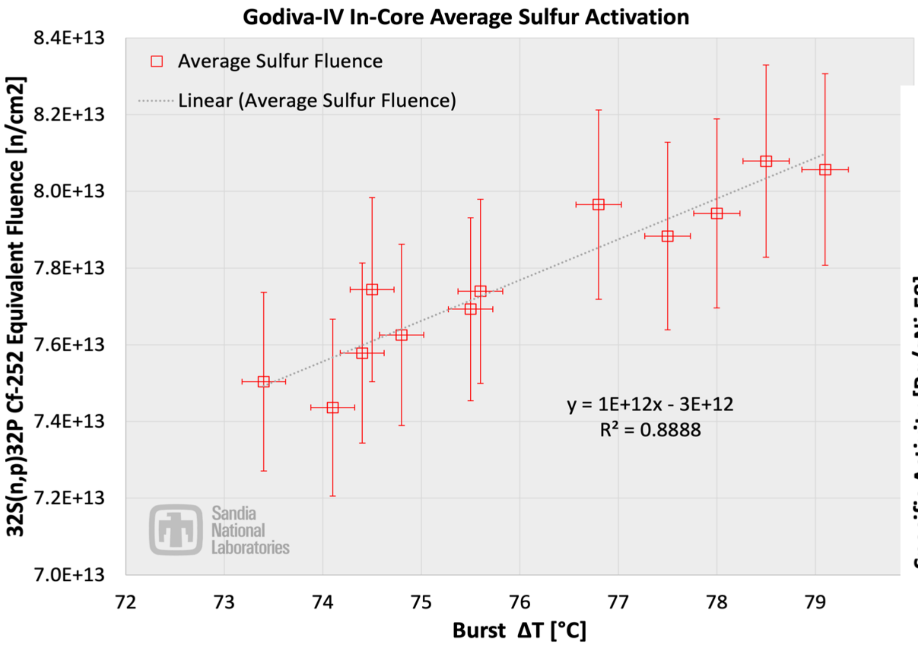
Organization	Quantity	Monitor Type
SNL	5	Nickel (Ni) Foils
SNL	4	Sulfur (S) Pellets
LANL	2	Gold (Au) Foil
LANL	1	Iron (Fe) Foil
LANL	1	Iron (Fe) wire

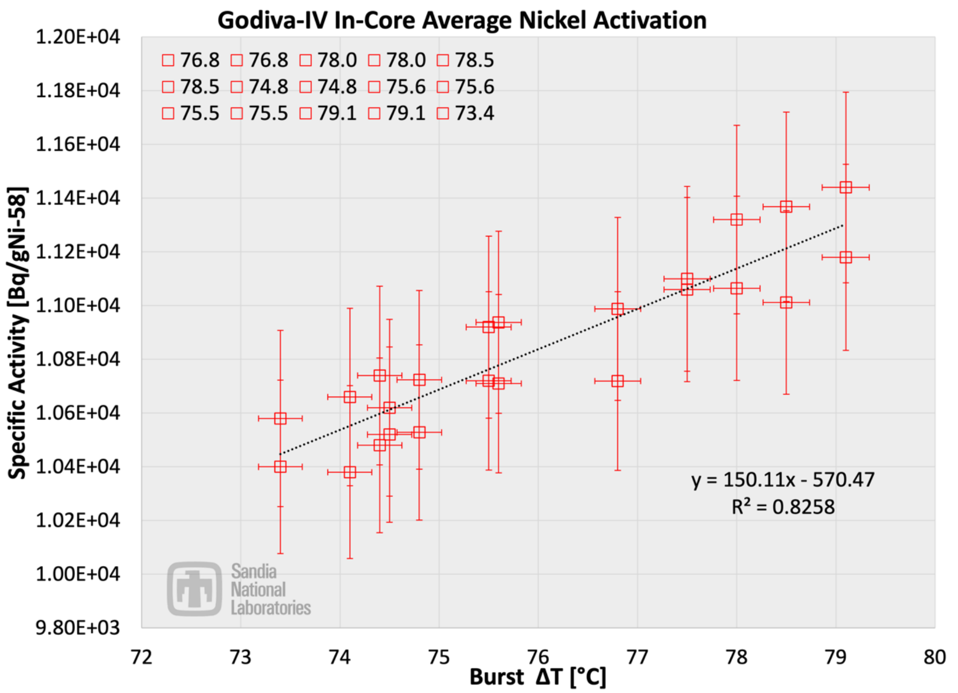
Week 2

Organization	Quantity	Monitor Type
SNL	5	Nickel (Ni) foils
SNL	4	Sulfur (S) pellets
LANL	2	Gold (Au) Foil
LANL	2	Iron (Fe) wire
PNNL	1	Monitor Set



Sandia Sulfur and Nickel Results

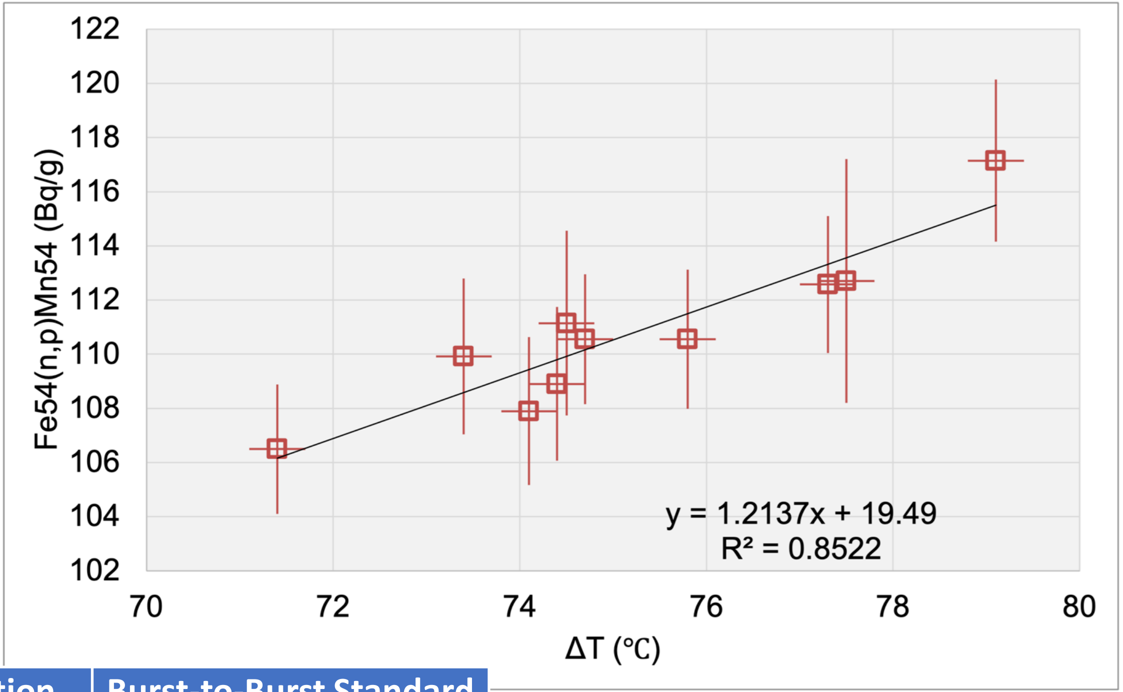




Measurement	Organization	Burst-to-Burst Standard Deviation (%)
S-32(n,p)P-32	SNL	2.56%
Ni-58(n,p)Co-58	SNL	2.56%

PNNL Iron Results

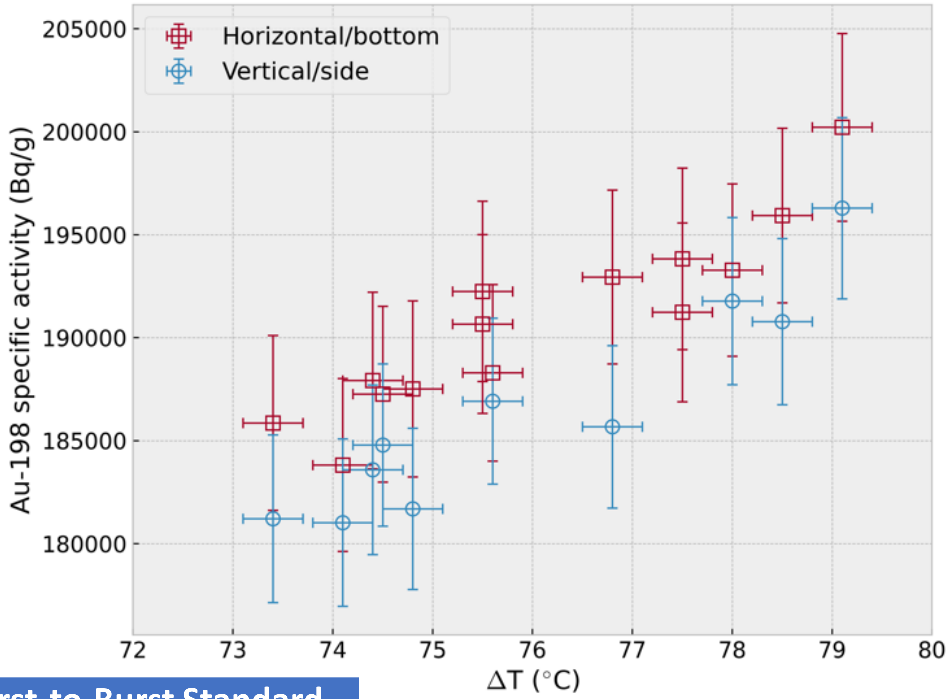
- Mn-56 had decayed by the time iron reached PNNL



Measurement	Organization	Burst-to-Burst Standard Deviation (%)
Fe-54(n,p)Mn-54	PNNL	2.53%
Fe-56(n,p)Mn-56	LANL	2.67%

LANL – NCERC Count Room Gold Results

- Positioning reproducibility better flat on bottom than standing.
- 2 foils in some bursts



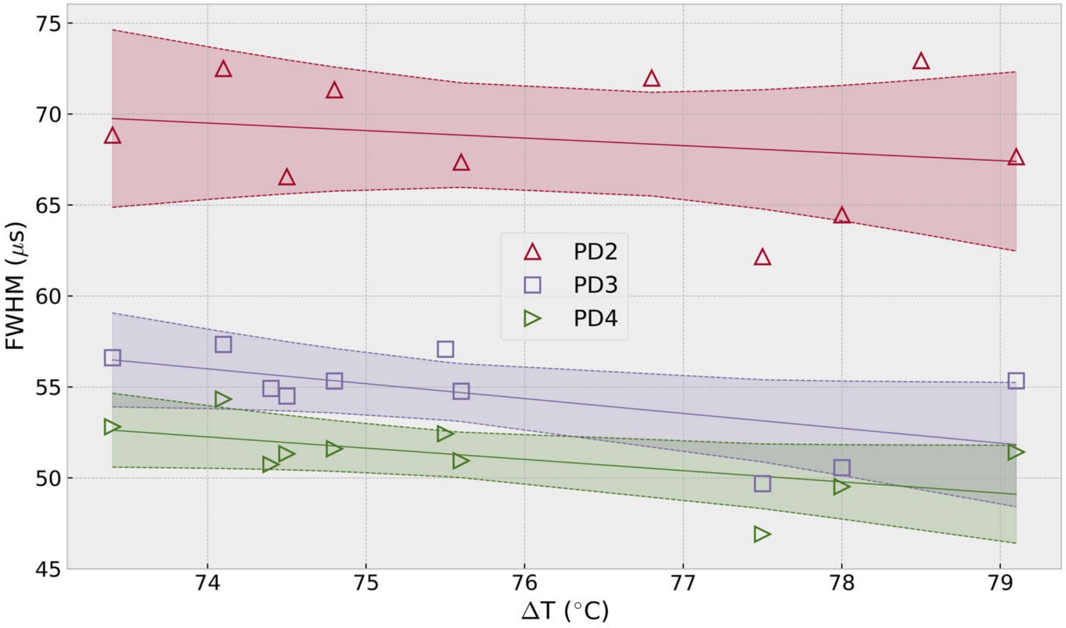
Measurement	Organization	Burst-to-Burst Standard Deviation (%)
Au-197(n,γ)Au-198	LANL	2.60%

Detector Diagnostics and Correlation to Activation Products

- New photodiode (PD)/scintillators deployed to measure burst
- Better precision in the measurement
- Sensitivity to a lower radiation level

Photodiode Results

- Goal was more immediate measurement of burst size than counting activation foils
- Clear trend of decreasing FWHM with increasing temperature rise
- Higher standard deviation than activation foils
- Shape of pulse difficult to fit
- Further work will be done
- Captured ringing signal

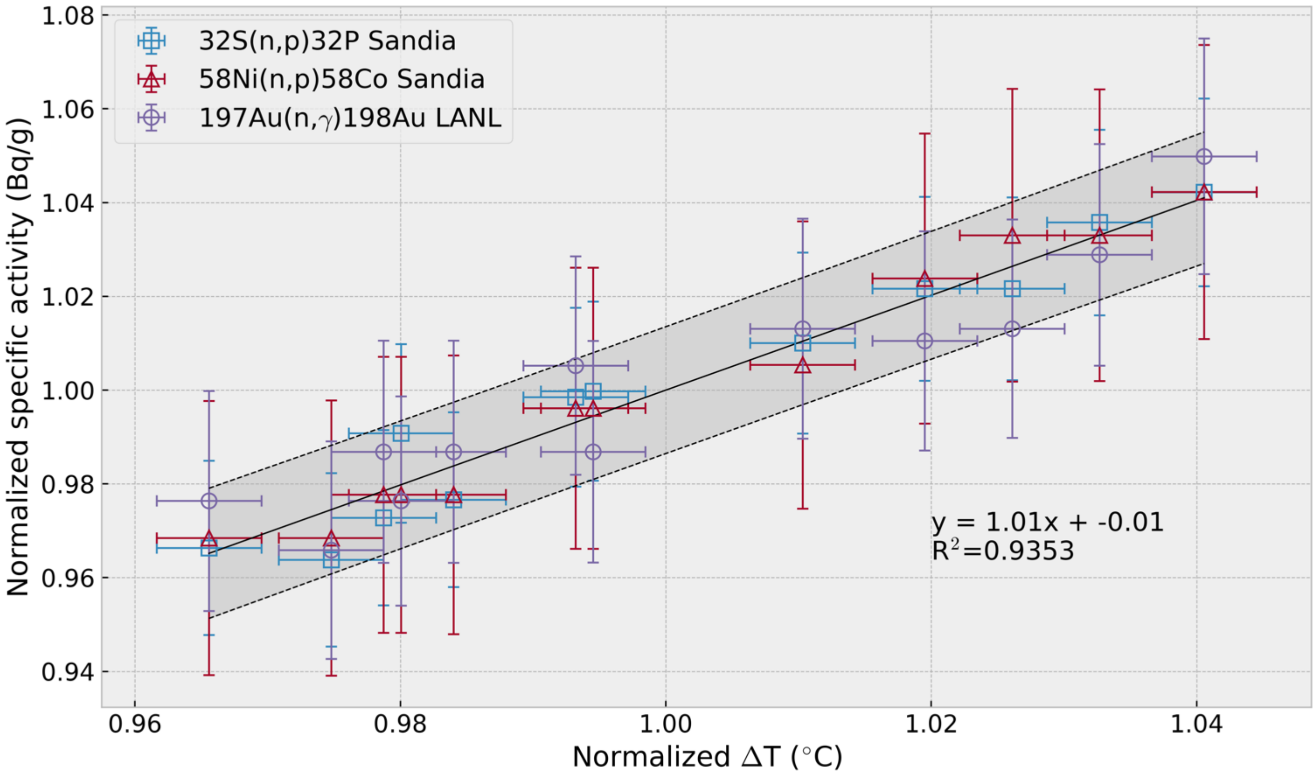


See talk by Rob Weldon

Activation Product Counting to Normalize IER 498 Data

- Originally, normalization was the back up plan if variation between bursts is higher than desired.
- Inherent variation between bursts meets criteria for IER 498
- Can be used in combination with temperature rise to further reduce uncertainty.
- Plan to deploy foils on all IER 498 bursts.

Normalized Sulfur, Nickel and Gold Data



Conclusions

- Multiple methods, independently evaluated, show that the standard deviations between the 12 bursts measured are in the range of 2-3%.
- The specific activity results support that the temperature change measured by the RTD deployed in Godiva is of similar precision to activation product counting.
- More work is required before detector diagnostics can provide better indication of burst size than temperature increase or foil activation measurements.
- The ratio between the specific activity or relative emission of the monitors can be used to scale the results of a given experiment.
- A standard set of monitors consisting of gold, iron and nickel is proposed.
- Plan to deploy foils on all IER 498 bursts and other bursts to build long-term data set.

Acknowledgements

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NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

NCERC
NATIONAL CRITICALITY EXPERIMENTS RESEARCH CENTER

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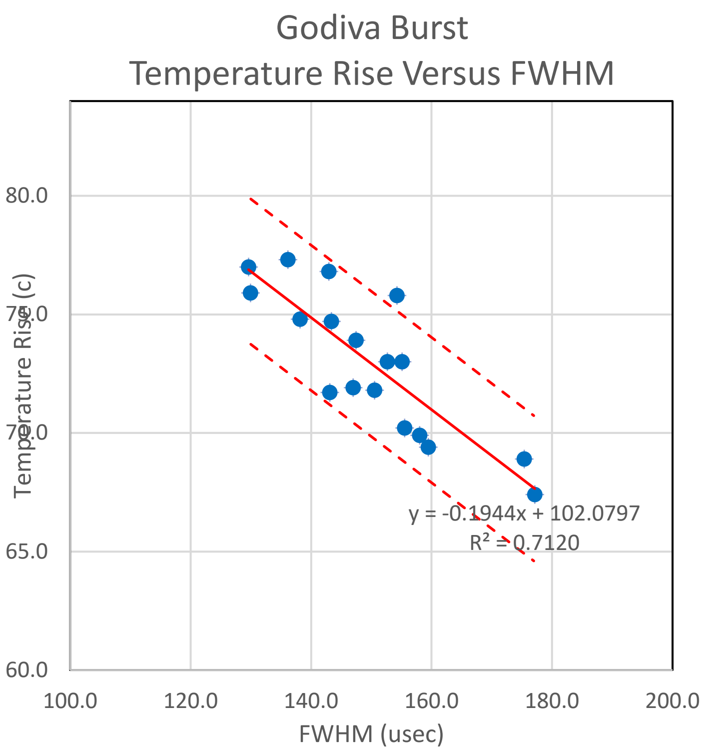
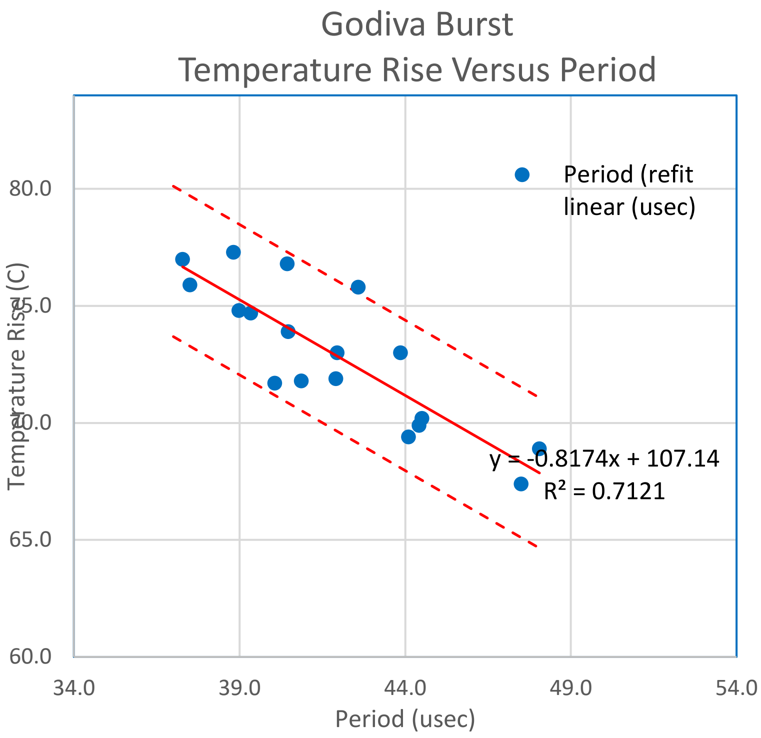
Additional Slides with Applicable Background Data

- IER 498 Discussion "Data we have" -- Prior to major expenditure for IER 498, reproducibility of burst intensity is in question. There is a lack of consensus on data supporting the reproducibility of burst size. The team recommends that burst size be reproducible to a standard deviation of 7% for the CED-3A to proceed.

- IER 498 CED-2 Report -- Specifically, the Godiva IV source intensity should be verified to be either reproducible or recordable with uncertainty sufficiently small to support the benchmark. Nominally a 5% one sigma uncertainty in source intensity should be sufficient, but this value could change.

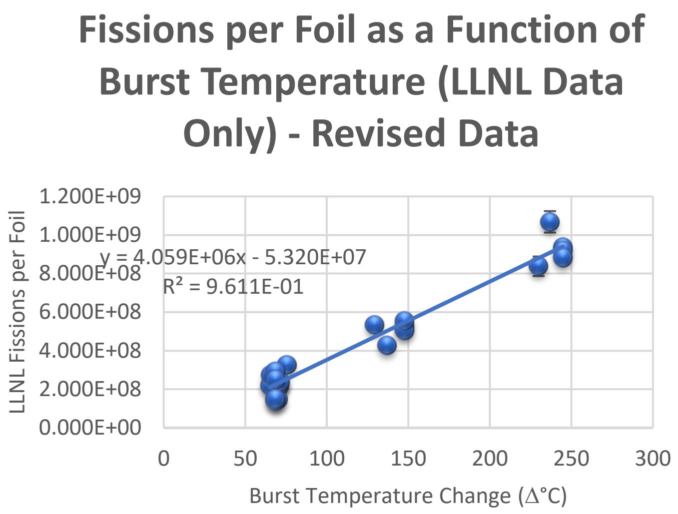
Historical Data

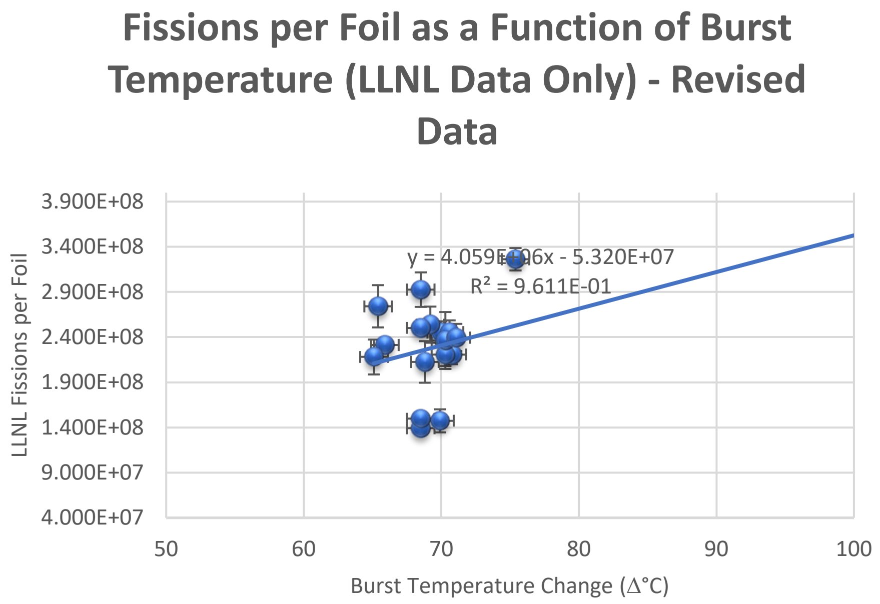




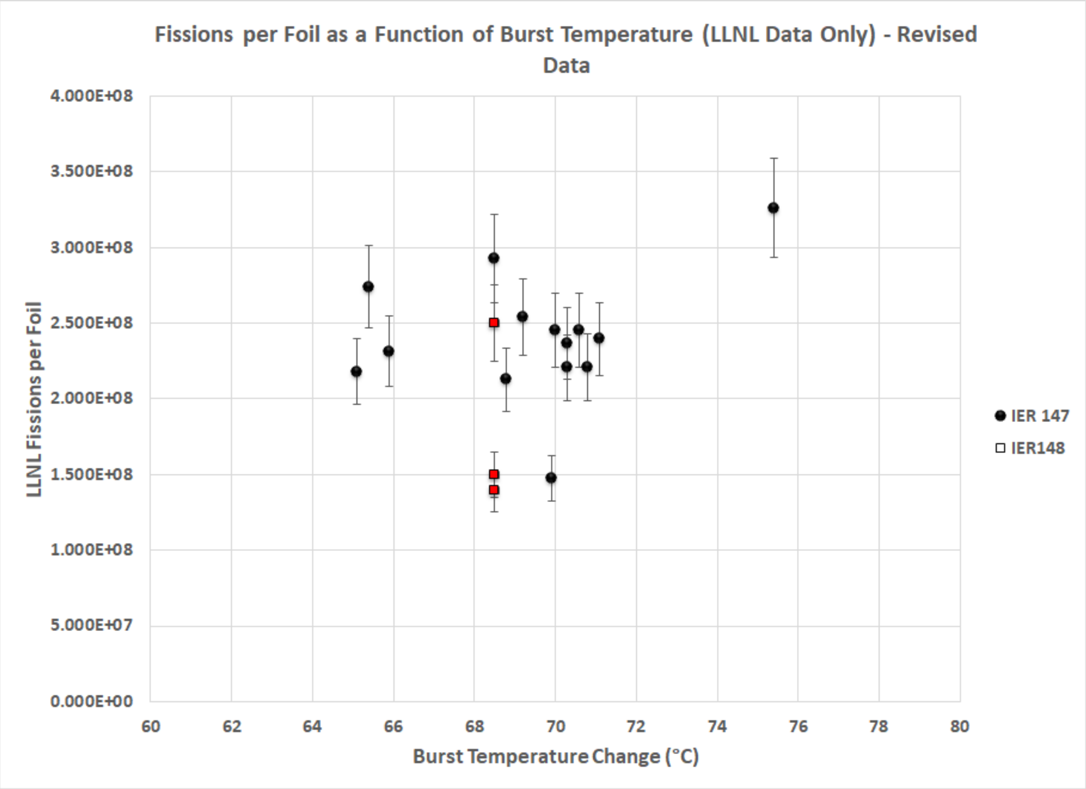
IER 147 Dosimetry around Godiva

- ~2013 Many “identical” bursts performed. Bonner spheres at 9 positions, etc.
- Fission foil/deposit in glory hole for each burst. Data shared by LLNL during IER 498 discussions in 2021.
- Largest set of data

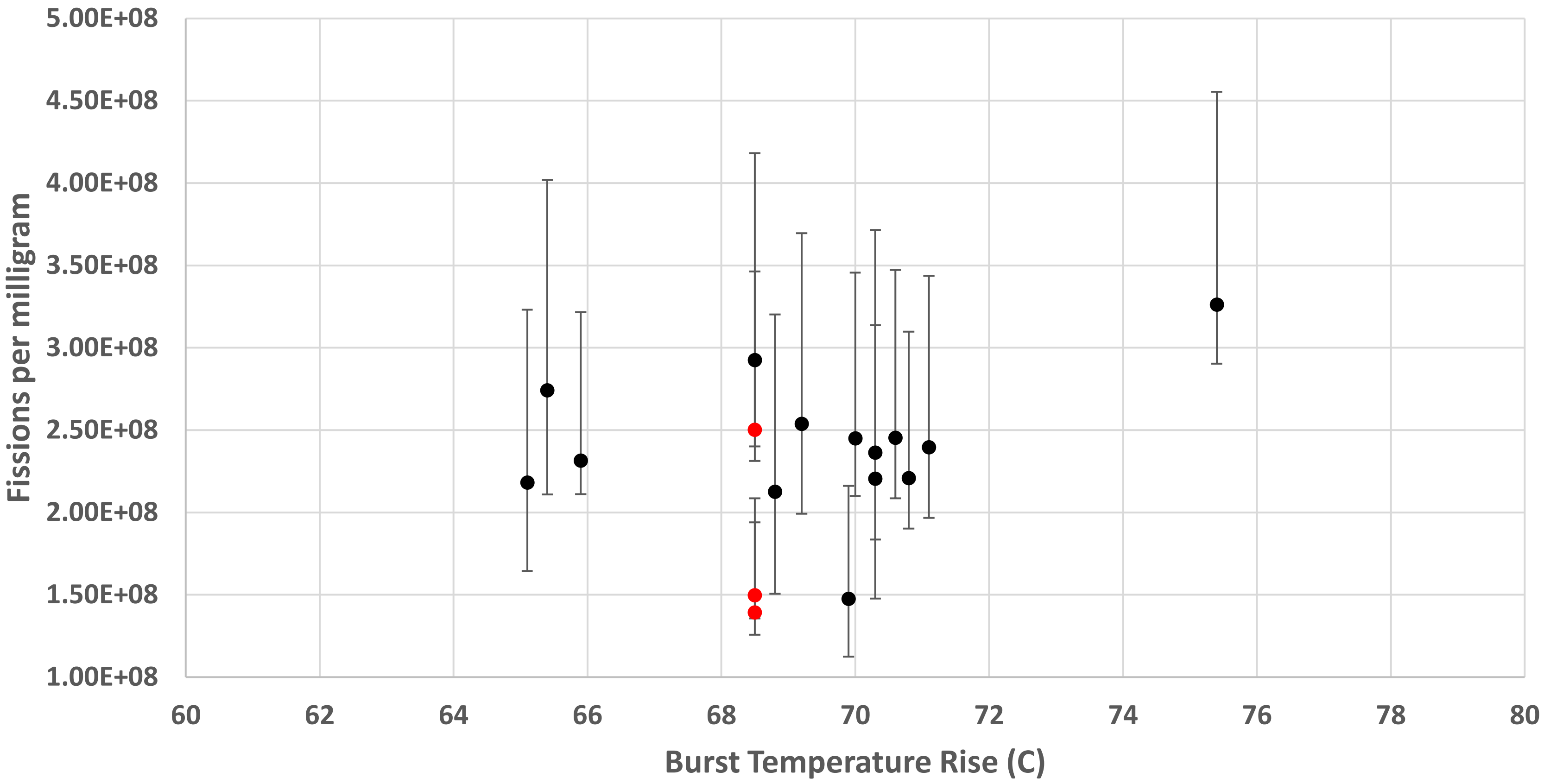




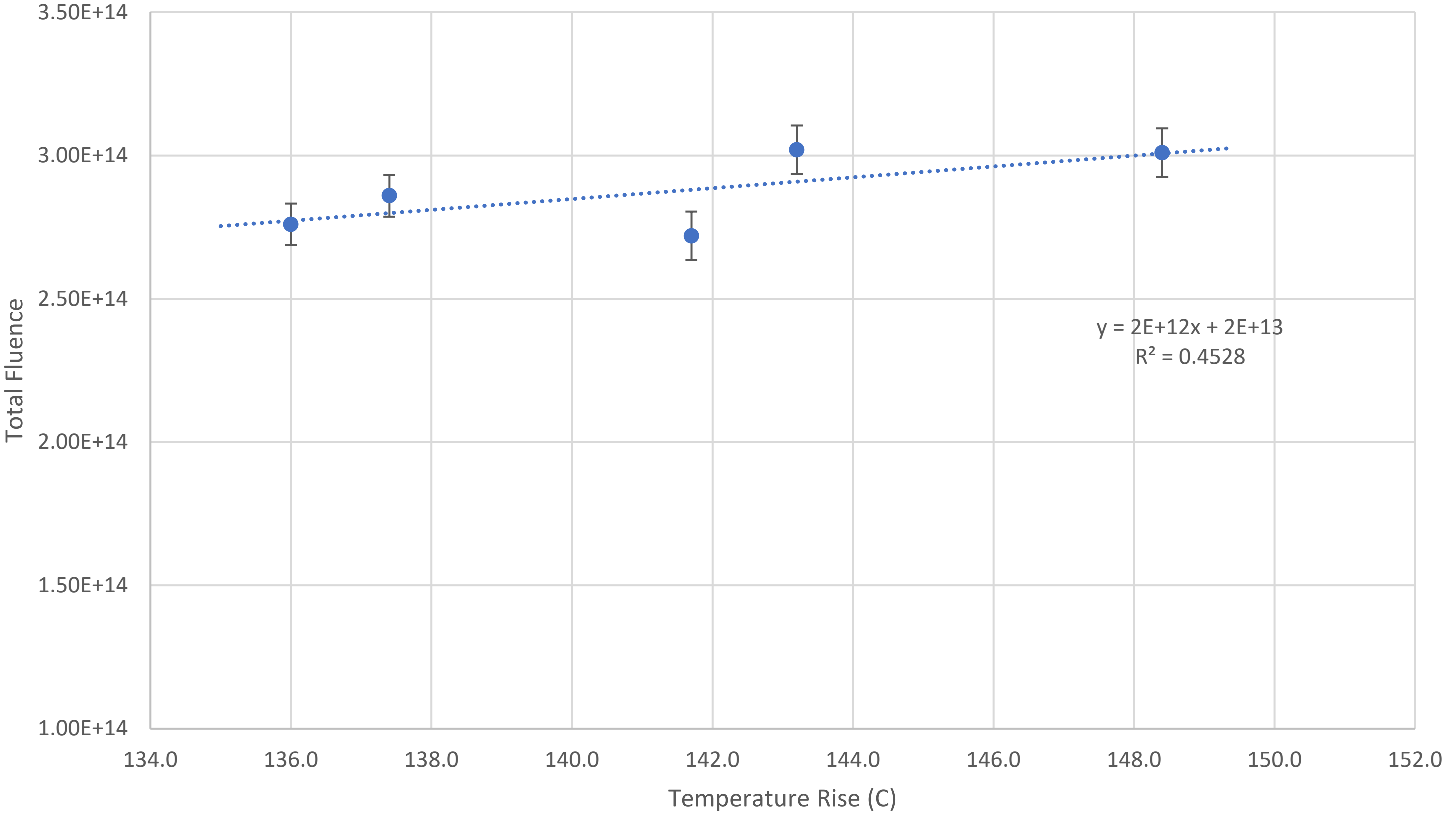
Fission Foil Data from IER 147/148



Including Mass Uncertainy



Fluence vs Temperature Rise
150 °C bursts from SLFPY



Summary of IER 557 Results

Measurement	Organization	Burst-to-Burst Standard Deviation (%)
S-32(n,p)P-32	SNL	2.56%
Fe-54(n,p)Mn-54	LANL	3.21%
Fe-54(n,p)Mn-54	PNNL	2.53%
Fe-56(n,p)Mn-56	LANL	2.67%
Ni-58(n,p)Co-58	SNL	2.56%
Au-197(n,2n)Au-196	PNNL	6.84%
Au-197(n,γ)Au-198	LANL	2.60%
Au-197(n,γ)Au-198	PNNL	4.33%
RTD #2	LANL	2.40%