

# Godiva IV Startup at NCERC Delayed Critical through Prompt Critical

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NEN-2

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# Godiva Assembly Overview



- Cylindrical uranium metal fast burst assembly
- 65 kg, 93% enriched
- 7-inch diameter (17.8 cm), 6-inch tall (15.2 cm)
- Core without safety block or control rods
  - Multiplication  $\sim 10$
  - $k_{\text{eff}} \sim 0.9$

# Timeline

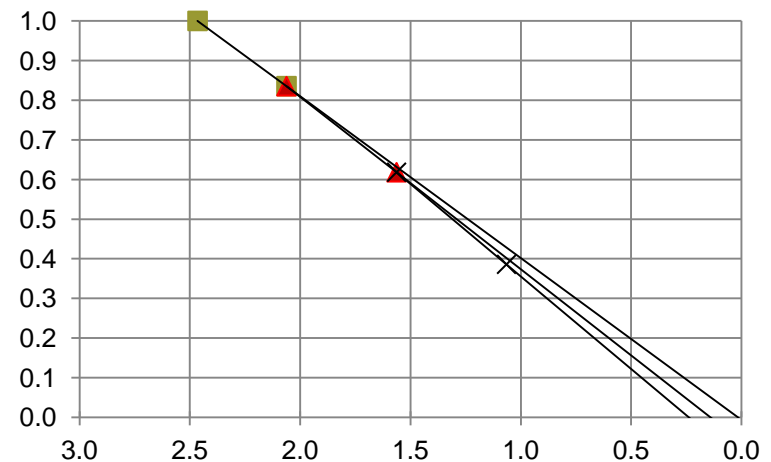
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- **Godiva IV was built in 1967 and operated at TA-18 until...**
- **July 2004—Last Prompt Burst**
- **August 2004—Last Critical Operation**
- **July 2005—Godiva was disassembled...**
- **April 2012—Godiva assembled**
- **October 2012—First Critical at DAF**
- **September 2013—First Prompt at DAF**

## Approach to Critical

- 1/M on Sum of Control Rod positions

Position (in)	Total Counts	1/M	M	Predicted Critical
2.47	52091	1.00	1.00	-
2.06	62355	1.20	0.84	0.02
1.56	84252	1.62	0.62	0.14
1.07	134989	2.59	0.39	0.24



- Excess reactivity \$1.07 compared to \$1.23 prior to disassembly

# Reproducibility of Control Elements

## Control Rod

- Insert CR 1
- Find DC with CR 2
- Record CR 2 position
- Remove CR 2
- Repeat

$0.250 \pm 0.001$  in

$\pm 0.04$  ¢

## Safety Block

- Establish positive period
- Measure period
- Remove SB
- Insert SB
- Repeat

$45.07 \pm 0.59$  sec

$\pm 0.15$  ¢

## Burst Rod

- Insert BR
- Establish positive period
- Measure period
- Remove BR
- Repeat

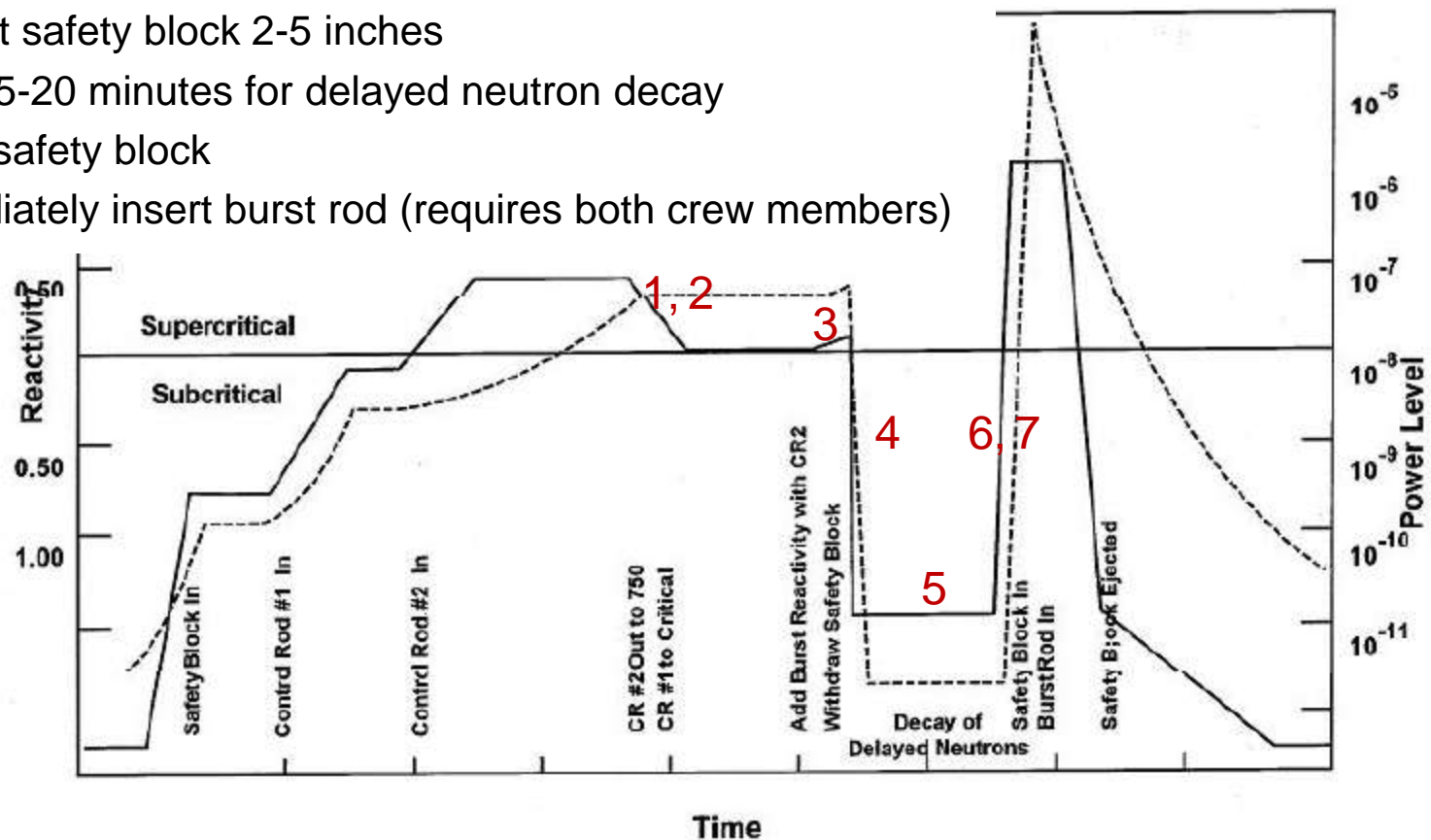
$21.34 \pm 0.41$  sec

$\pm 0.29$  ¢

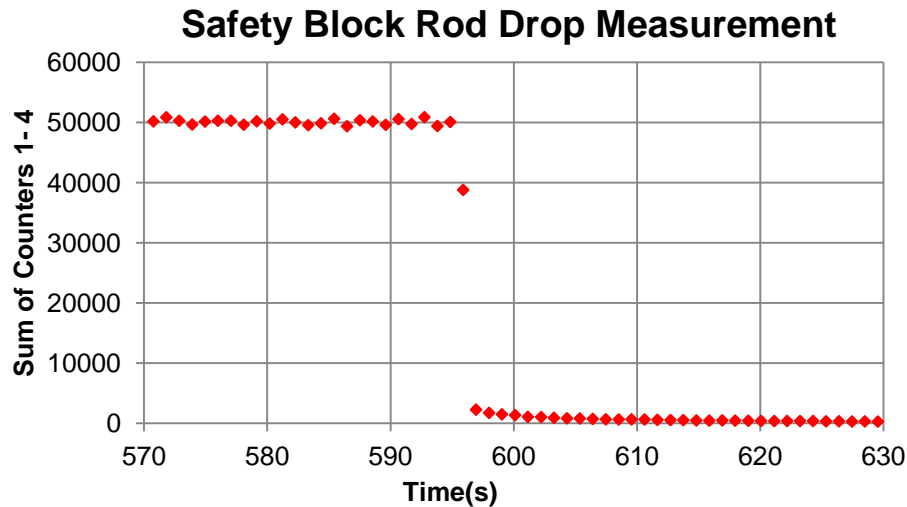
- Comparable to values measured during 1993 restart

# Burst Operation

1. Move Control Rod 2 to 0.250"
2. Find DC with Control Rod 1
3. Insert (or remove) burst increment with Control Rod 2
4. Retract safety block 2-5 inches
5. Wait 15-20 minutes for delayed neutron decay
6. Insert safety block
7. Immediately insert burst rod (requires both crew members)



# Safety Block Rate of Shutdown



$$\rho(\$) = 1 - \frac{n_0}{n_1}$$

$$\rho(\$) = 1 - \frac{50082}{2256}$$

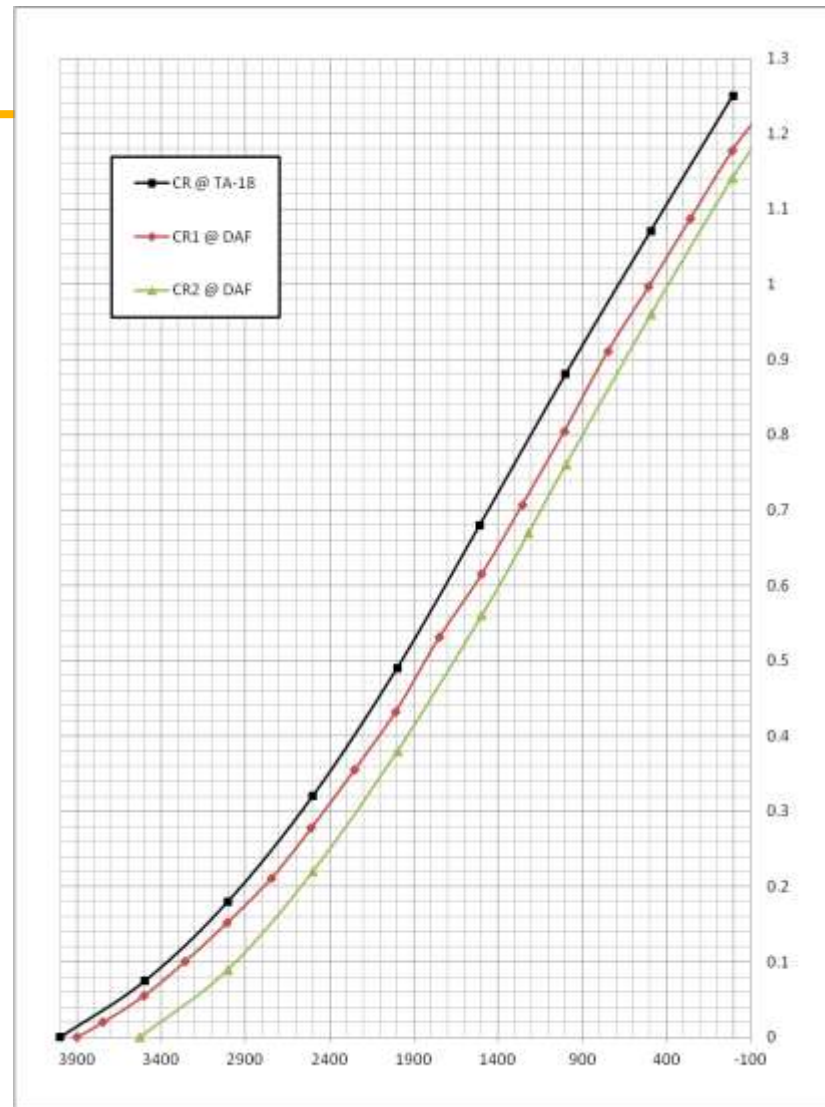
$$\rho(\$) = 1 - 22$$

$$\rho(\$) \approx -\$21$$

$$\Delta t = 2 \text{ s}$$

- Shutdown Rate is approx. -\$10/s

# Control Rod Calibration





# Worth of Burst Rod

Period (sec)	Desired Reactivity(\$)	Reactivity to Remove(\$)	CR 2 Position(in.)	Measured Period(sec)	Measured Reactivity(\$)	Burst Rod Worth(\$)
15	0.32	0.68	2.050	13.19	\$0.34	\$1.02
10	0.39	0.61	1.850	8.63	\$0.41	\$1.02
5	0.51	0.49	1.500	4.38	\$0.54	\$1.03
1	0.78	0.22	0.825	0.85	\$0.80	\$1.02
0.2	0.93	<del>0.07</del> 0.09	0.450	0.181	\$0.94	\$1.01+.02
0.1	0.96	<del>0.04</del> 0.06	0.296	0.0510	\$0.98	\$1.02+.02
0.05	0.98	<del>0.02</del> 0.05	0.279	0.0354	\$0.985	\$1.01+.03
0.012	0.995	<del>0.005</del> 0.045	0.261	0.0301	\$0.987	\$.992+.04

Burst Rod Worth

➡ \$1.032

# Burst Reproducibility



- Establish DC

- Remove burst increment

- Remove SB

- Wait

- Insert SB

- Insert BR/burst

- BR out

- Repeat

$90.69 \pm 0.13 \text{ } \phi$

- Establish DC

- Remove burst increment

- Remove SB

- Wait

- Insert SB



- Insert BR/burst

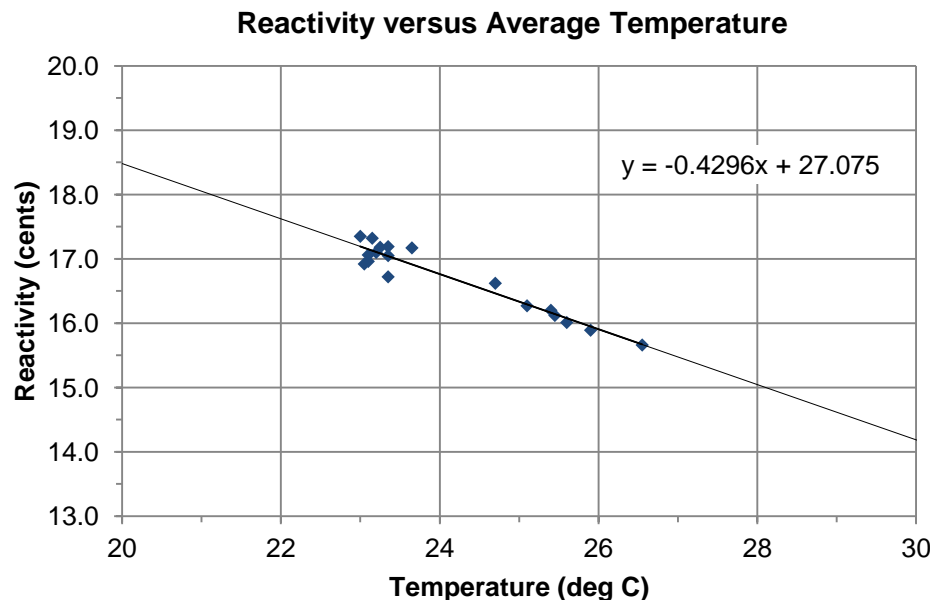
- BR out

- Repeat

$90.19 \pm 0.03 \text{ } \phi$

## Reactivity Quenching (Temperature Coefficient)

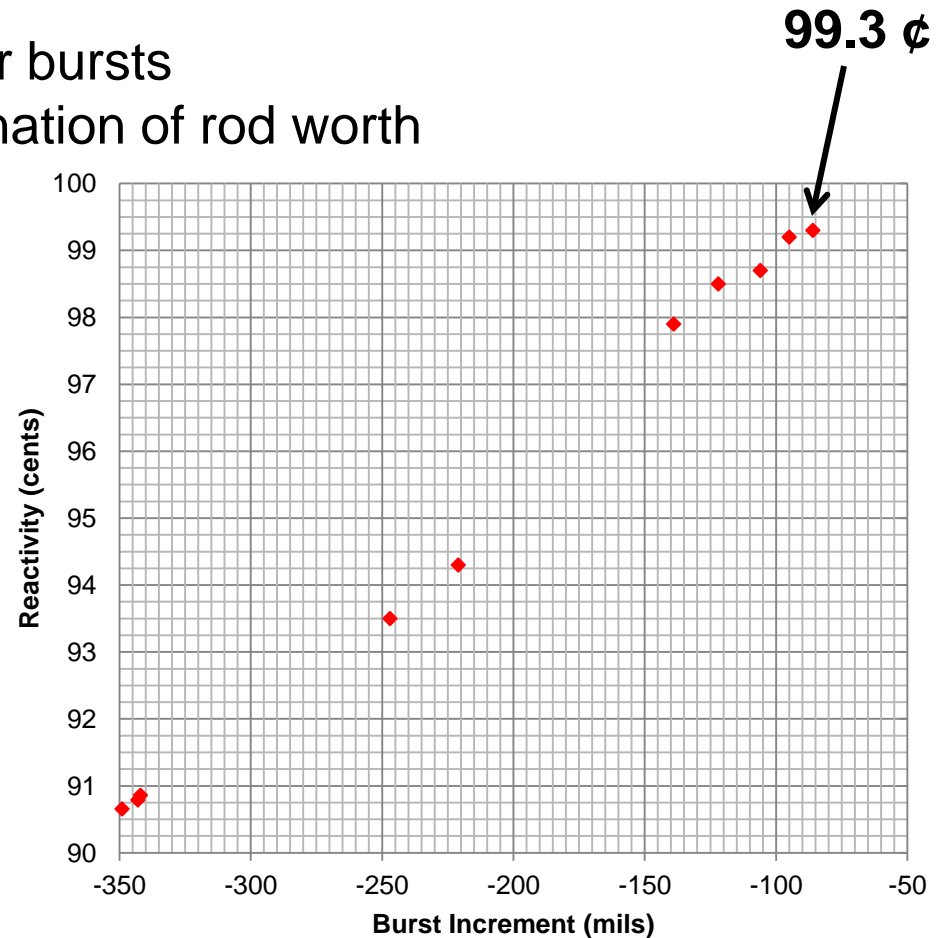
- For characterization plan, we started on a positive period and showed that as temperature increased, period decreased.
- A free run would also demonstrate a negative temperature coefficient.
- Enough variation in room temperature over characterization to plot excess reactivity versus temperature.



- 0.4 cents/ $^{\circ}$ C

# Approach-to-Prompt

- Perform successively larger bursts
  - Most accurate determination of rod worth
  - Demonstrates process



## First Super-Prompt Burst at DAF, September 2013



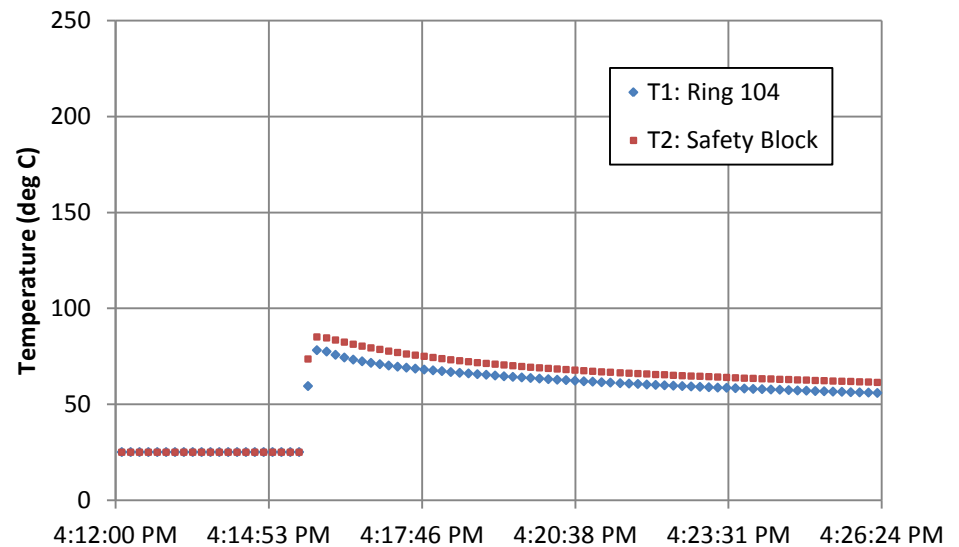
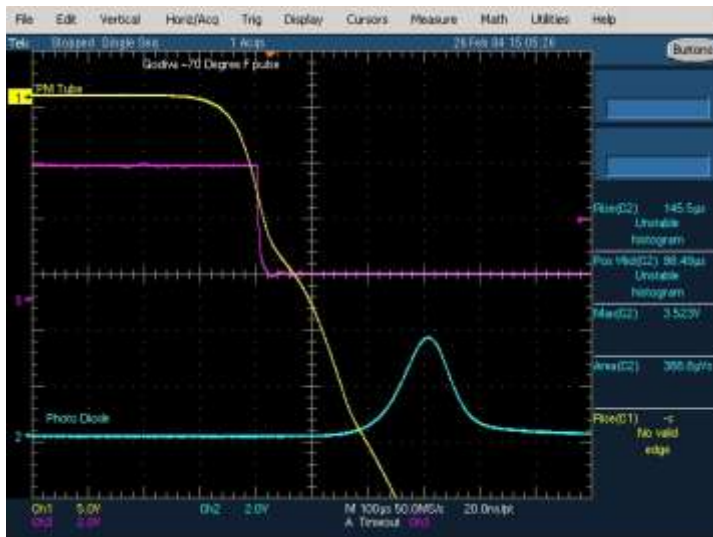
On September 10, 2013,  
Godiva IV burst for the first time in  
Nevada.

Burst #1963 had a temperature rise of  
60° C and a reactivity of \$1.03.

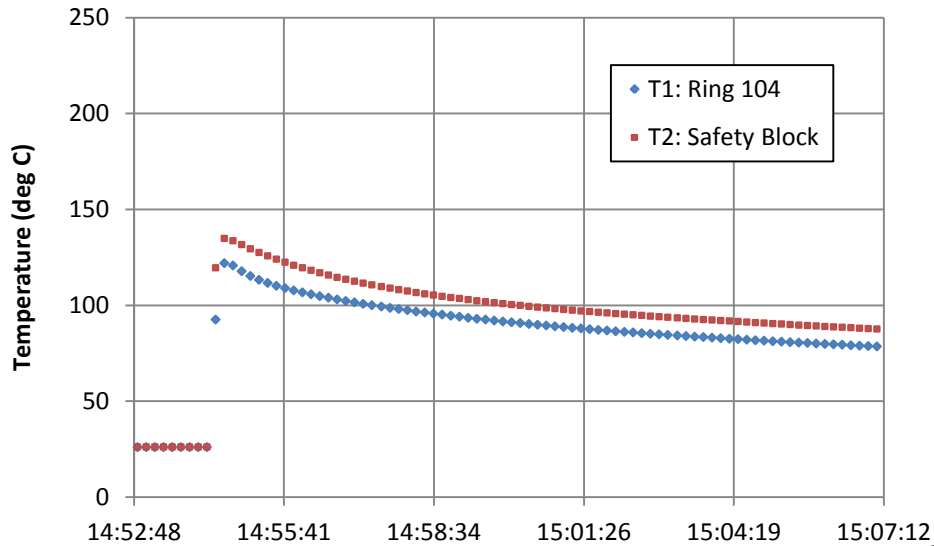
Three more bursts of increasing size  
followed over the next two days.

# Super-Prompt Bursts

- Burst Size Measured by:
  - Temperature Rise
  - Initial Period Measurement on PMT
  - FWHM on PD
  - Fission Foils



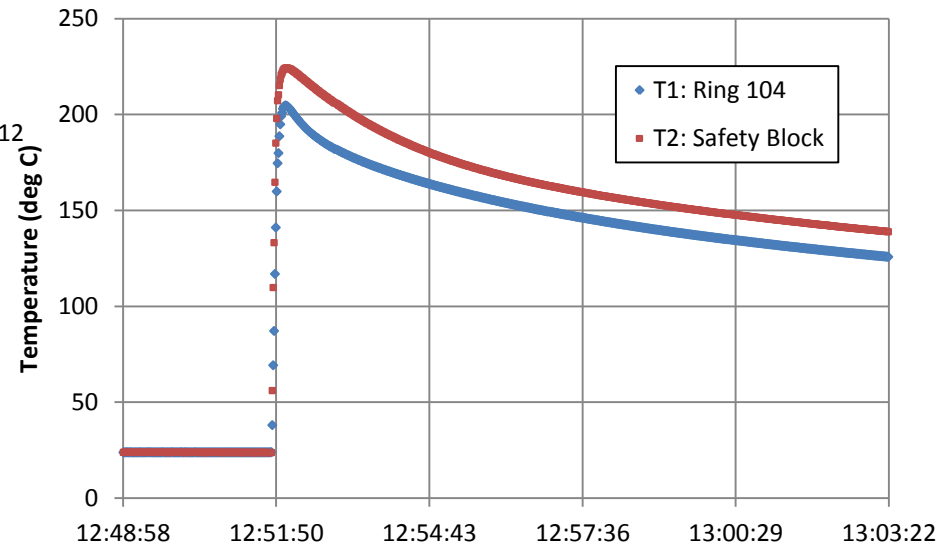
# Super-Prompt Bursts



- 108 °C Temperature Rise
- \$1.06 Reactivity



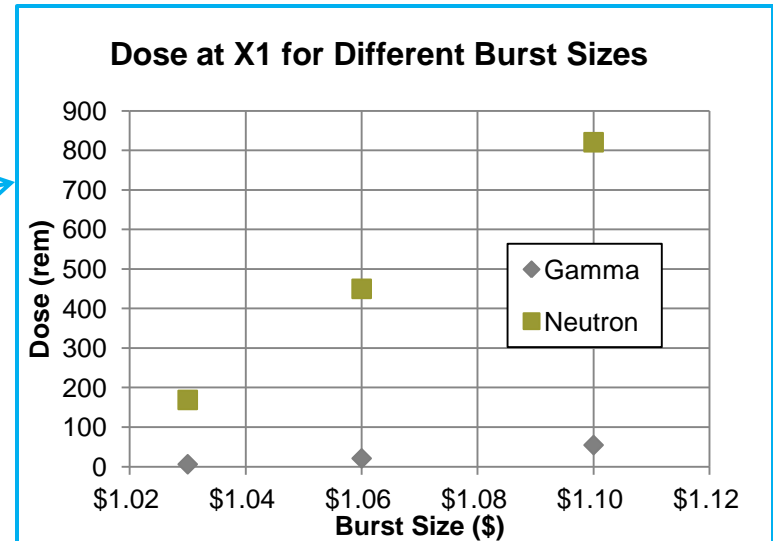
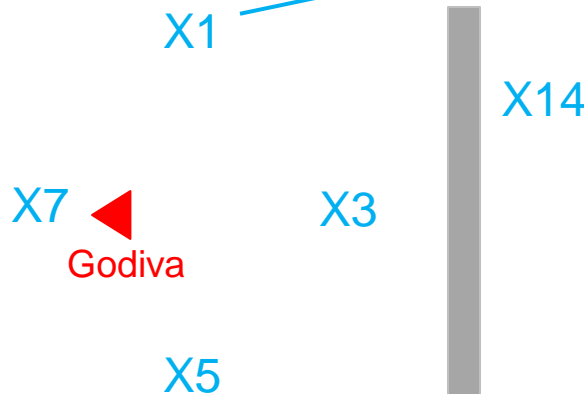
- 200 °C Temperature Rise
- \$1.10 Reactivity



# Dosimetry

## \$1.03/60° Burst

	Gamma Dose (rem)	Neutron Dose (rem)	Total Dose (rem)
X1	6	169	175
X3	7	134	141
X5	13	330	<b>343</b>
X7	17	272	288
X14	0	.1	.1



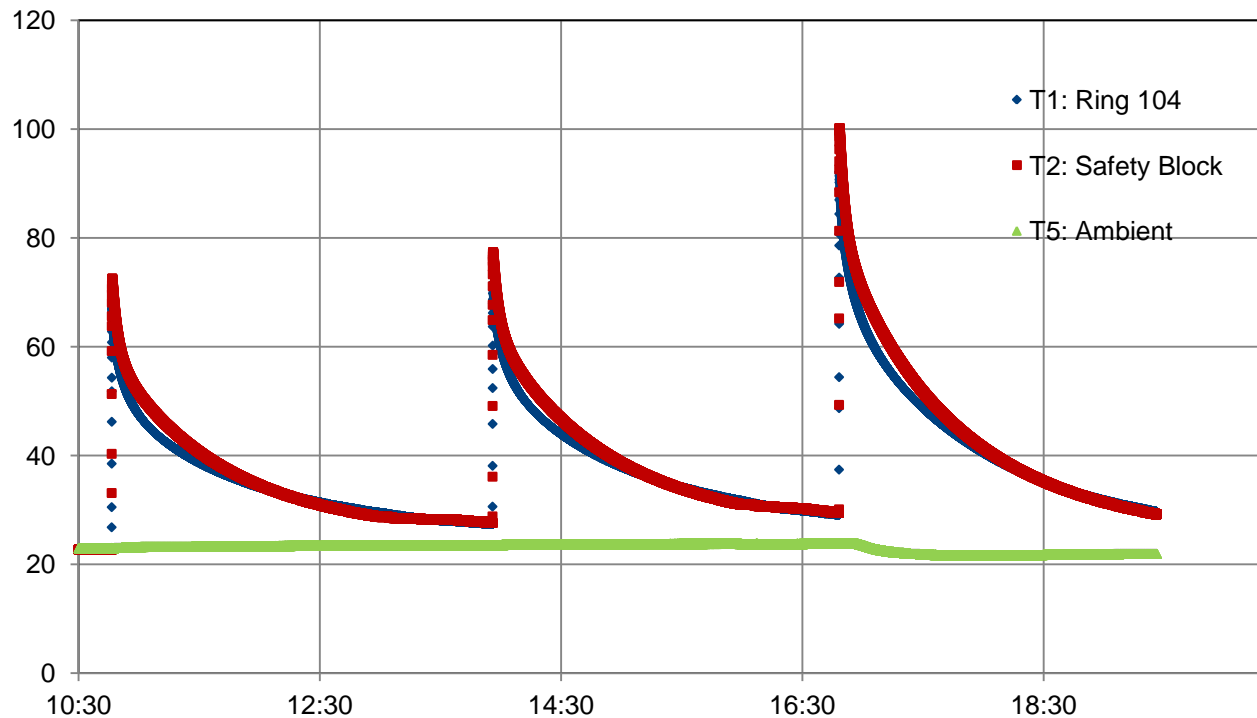


# Available Burst Sizes and Specifications

Delta T (C)	Mini-burst	70 degree	150 degree	250 degree
Reactivity	\$0.993	\$1.04	\$1.07	\$1.10
Initial Period	15 msec	30 $\mu$ sec	18 $\mu$ sec	11 $\mu$ sec
alpha	66/sec	33000/sec	55000/sec	91000/sec
FWHM	N/A	100 $\mu$ sec	55 $\mu$ sec	33 $\mu$ sec
# fissions		1 E 16	2 E 16	4 E 16

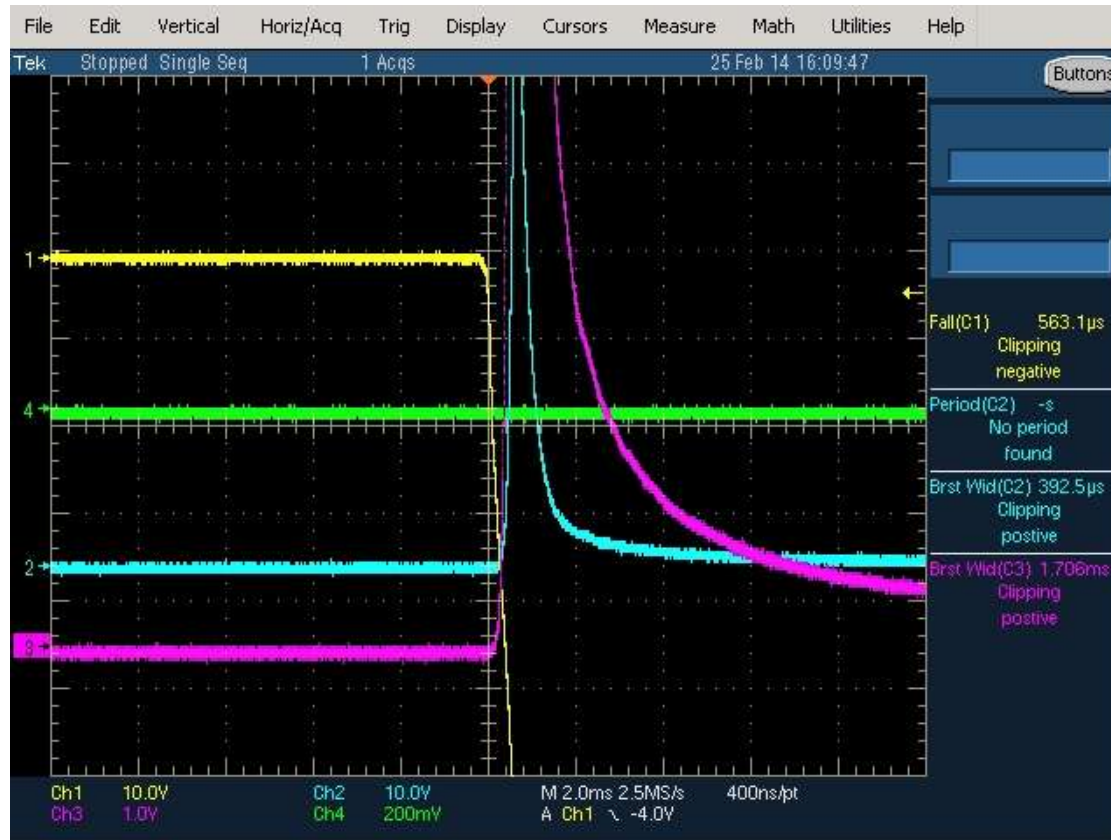
## Data – January 14, 2014

Three bursts in one day



## Data - January 25, 2014

### Photomultiplier and photodiode setup and checkout continue



# Acknowledgements

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