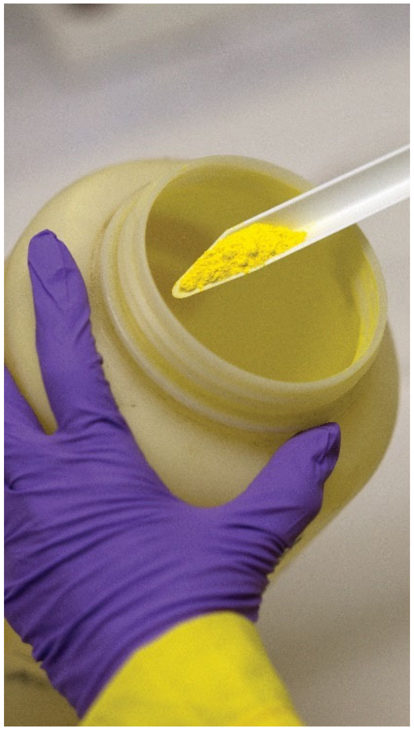

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PANTEX PLANT | Y-12 NATIONAL SECURITY COMPLEX

Qualification of Y-12 Legacy Criticality Accident Alarm System Detectors

Chris Haught, Troy McMillen, Chris Woodrow

Outline

- Configuration of Y-12 Legacy CAAS
- Historic Qualification and Range of Coverage
- Qualification Testing with Godiva
- Conclusions

Legacy CAAS Configuration

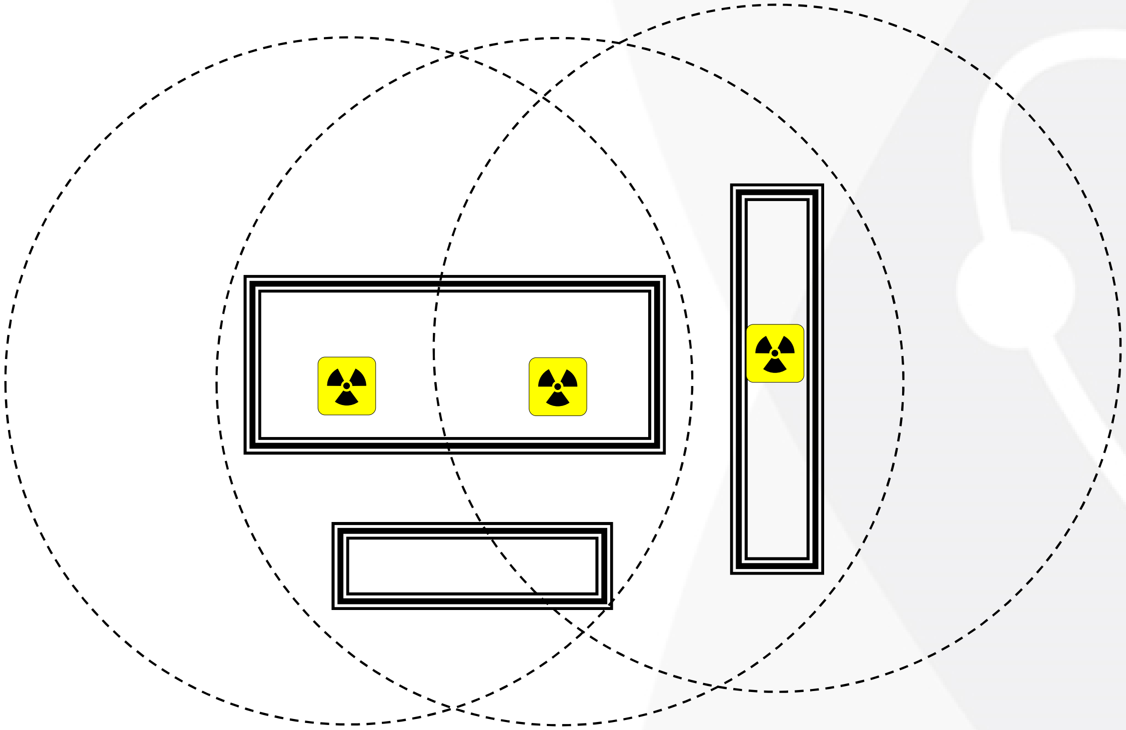
- Gamma sensitive NMC GA-6 detectors
  - Plastic scintillators
  - PMTs
  - 30 +2/-5 mR/hr setpoint
  - Light source creates ~1 mR/hr artificial background
- Detector states
  - Normal
  - “Fail” (< ~0.1 mR/hr)
  - “Hi Rad” (above setpoint)
- CAAS Station
  - 2 detectors
  - Control relay circuit
  - Alarms on 2 “Hi Rad” signals
- Accident Coverage
  - Generic 400-ft range of coverage
  - “Overlapping” coverage required

Overlapping CAAS Coverage

400-foot range of coverage for each station

All fissile material areas within the range of at least 2 stations

Each CAAS station  **has 2 detectors**

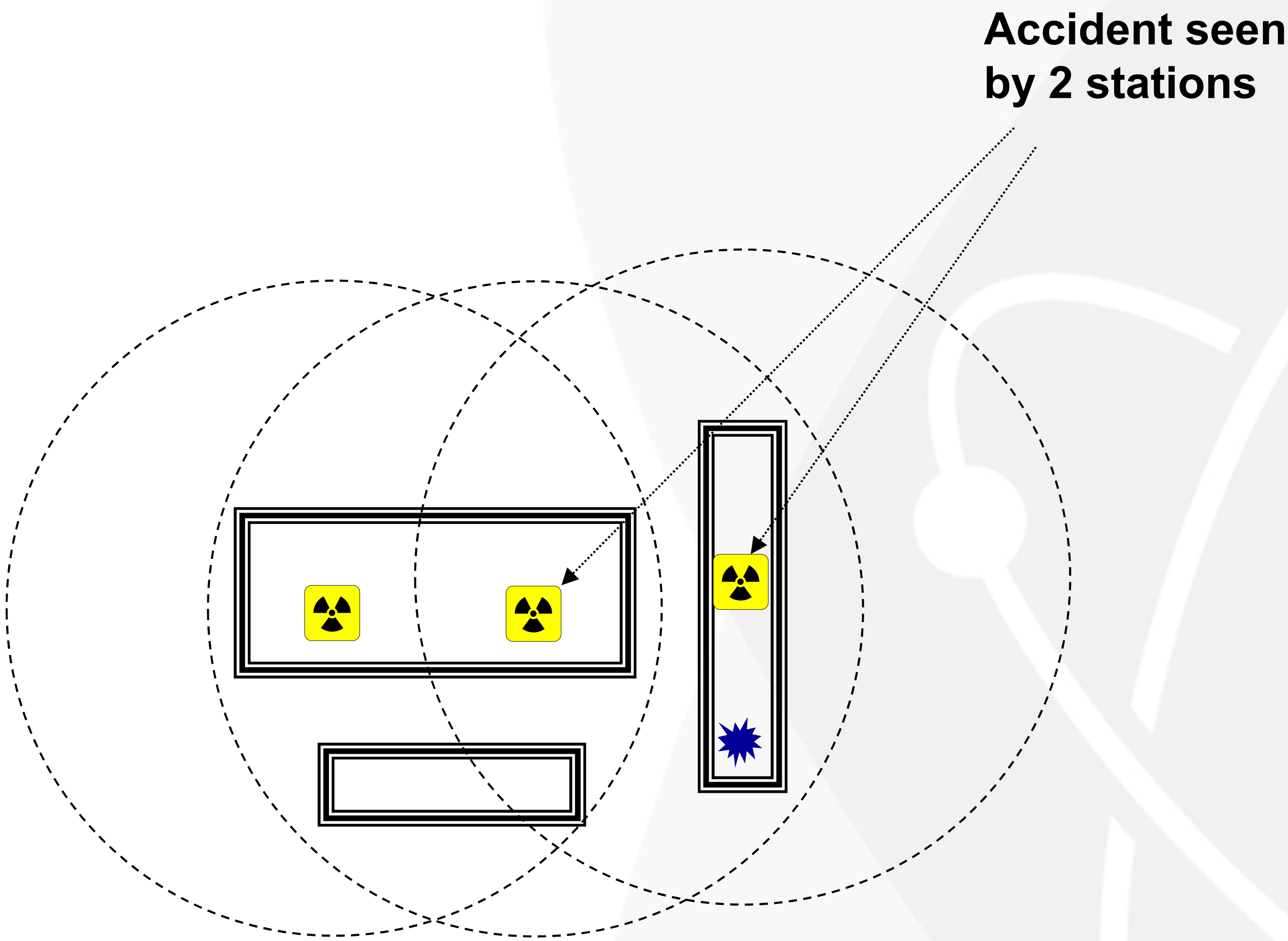


Overlapping CAAS Coverage

400-foot range of coverage for each station

Each CAAS station has 2 detectors

Postulated criticality accident



Overlapping CAAS Coverage

400-foot range of coverage for each station

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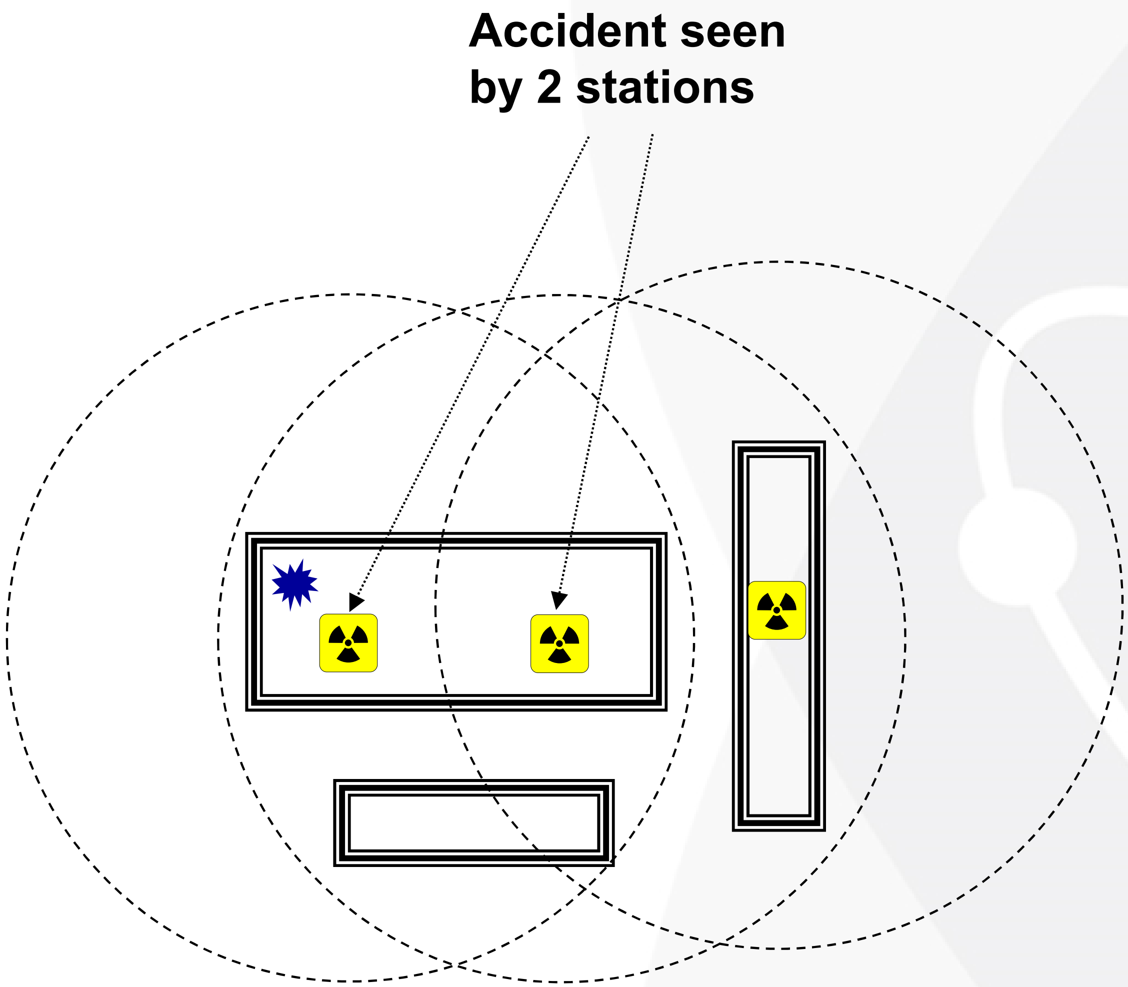
Postulated  criticality accident

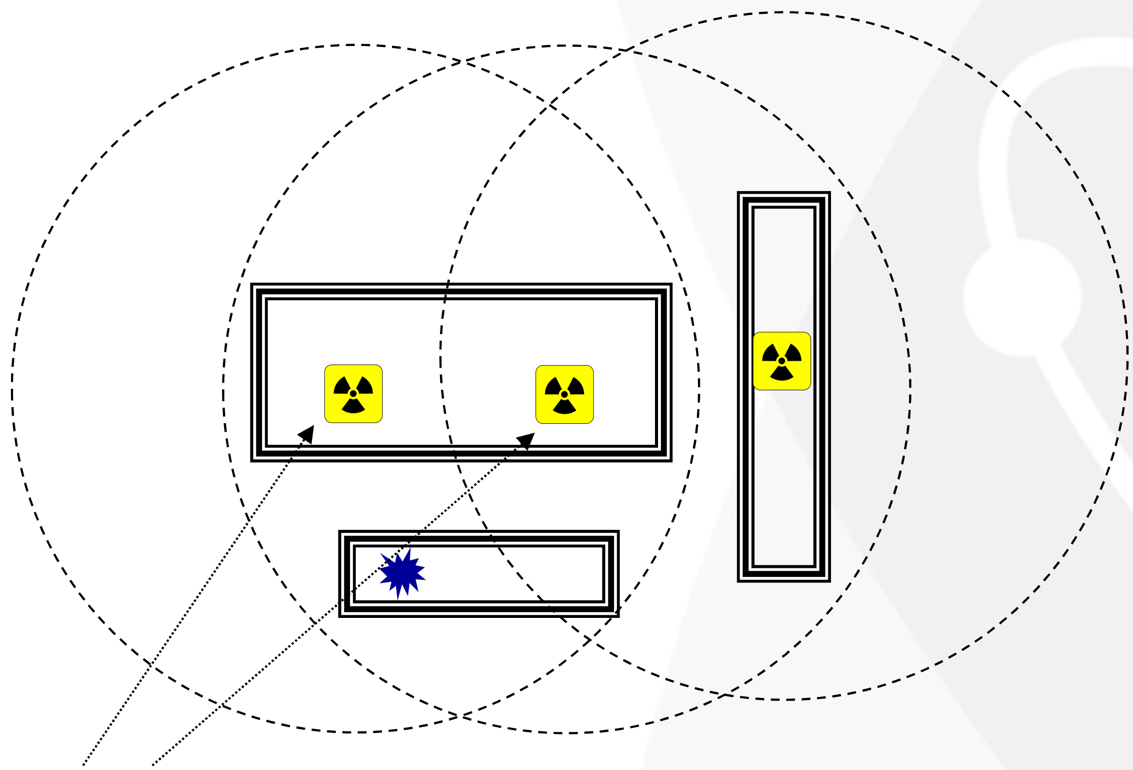


Overlapping CAAS Coverage

400-foot range of coverage for each station

Each CAAS station has 2 detectors

Postulated criticality accident



Accident seen by 2 stations

Historic CAAS Detector Qualification and Maintenance

History of pulse reactor testing dating back to 1950s

- Configurations involving shielding materials to test range of accident coverage
- Detector Qualification (ANSI/ANS-8.3)
  - Minimum accident of concern (20 rad/m @ 2 m or alternate)
  - Response to minimum duration transient (1 ms)
  - Tolerance to maximum radiation (10 rad/s)
- Detector qualification criteria from 1980s
  - 10^{15} fissions 800 feet from detector (distant pulse test)
  - 10^{17} fissions 14 feet from detector (intense pulse test)
  - Required for every detector

Historic CAAS Detector Qualification and Maintenance

- Detector checks
  - “Fail” indicator monitoring
  - Periodic visual checks
  - Periodic source checks
- Detectors require periodic calibration due to setpoint drift
  - Y-12 maintains an onsite calibration facility
  - Detectors periodically removed from service and replaced with ones recently calibrated
  - Removed detectors are recalibrated and queued reuse

Historic Detector Range Analysis

Y-12 has used hand calculation methods to estimate range of coverage

$$\dot{D}(r) = \frac{\dot{S}_o R}{4\pi r^2} B e^{-\mu r}$$

$\dot{D}(r)$ is the detector setpoint

- Only accounts for primary gammas and buildup (B)
- For a sustained source equivalent to 20 rad/min at 2 m:

$$\dot{D}(r) = \left(\frac{D_\gamma}{D_{\gamma+n}}\right)(20\, rad/min)\left(\frac{2\, m}{r}\right)^2 B e^{-\mu r}$$

Methodologies in ANSI/ANS-8.3, Appendix B

- For a rapid transient source equivalent to 20 rad at 2 m:

$$\dot{D}(r) = \left(\frac{D_\gamma}{D_{\gamma+n}}\right)\left(\frac{20\, rad}{pulse\ width}\right)\left(\frac{2\, m}{r}\right)^2 \varepsilon B e^{-\mu r}$$

ε is the detector sensitivity to a rapid transient

Historic Detector Range Analysis

Detector Sensitivity Estimates

- 1967 experiments using HPRR bursts
  - 7×10^{14} fissions to 1×10^{17} fissions
- NMC detectors at 1,000 feet from reactor
- Algorithm to estimate gamma dose rate @ 1,000 ft
  - Measured: pulse width and fissions (from ΔT)
  - Previously determined: gamma dose rate @ 1,000 ft per kW (steady-sate measurements)
- Detector response estimated
  - Detector trip at different setpoints
  - Observations of the detector meter

Historic Detector Range Analysis

Detector Sensitivity Estimates

Fissions	FWHM (ms)	Setpoint (mR/hr)	ε
7.13×10^{14}	1.0	50 (trip); 500 (no trip)	$\frac{50\ mR/hr}{9.51\times10^{4} mrem/hr} = \frac{1}{1900}$
9.66×10^{15}	1.0	50, 300, 500, 750 (all tripped)	$\frac{750\ mR/hr}{1.29\times10^{6} mrem/hr} = \frac{1}{1700}$
2.33×10^{16}	0.75	550 (recorder trace and calibration)	$\frac{550\ mR/hr}{3.07\times10^{6} mrem/hr} = \frac{1}{5600}$

- Less sensitive for high-energy burst, but interest is on the low end
- Concludes that 1/2500 is a conservative value to use
  - Included in ANSI N16.2-1969, Appendix A
  - Documented as Y/DD-113 in 1974 by E.C. Crume
  - Included in ANSI/ANS-8.3-1997, Appendix B

Historic Detector Range Analysis

Effect of Shielding from Walls

$$\dot{D}(r) = \left(\frac{D_\gamma}{D_{\gamma+n}}\right)\left(\frac{20\,rad}{pulse\ width}\right)\left(\frac{2\ m}{r}\right)^2 \varepsilon B e^{-\mu_{air} r_{air} - \mu_{shield} r_{shield}}$$

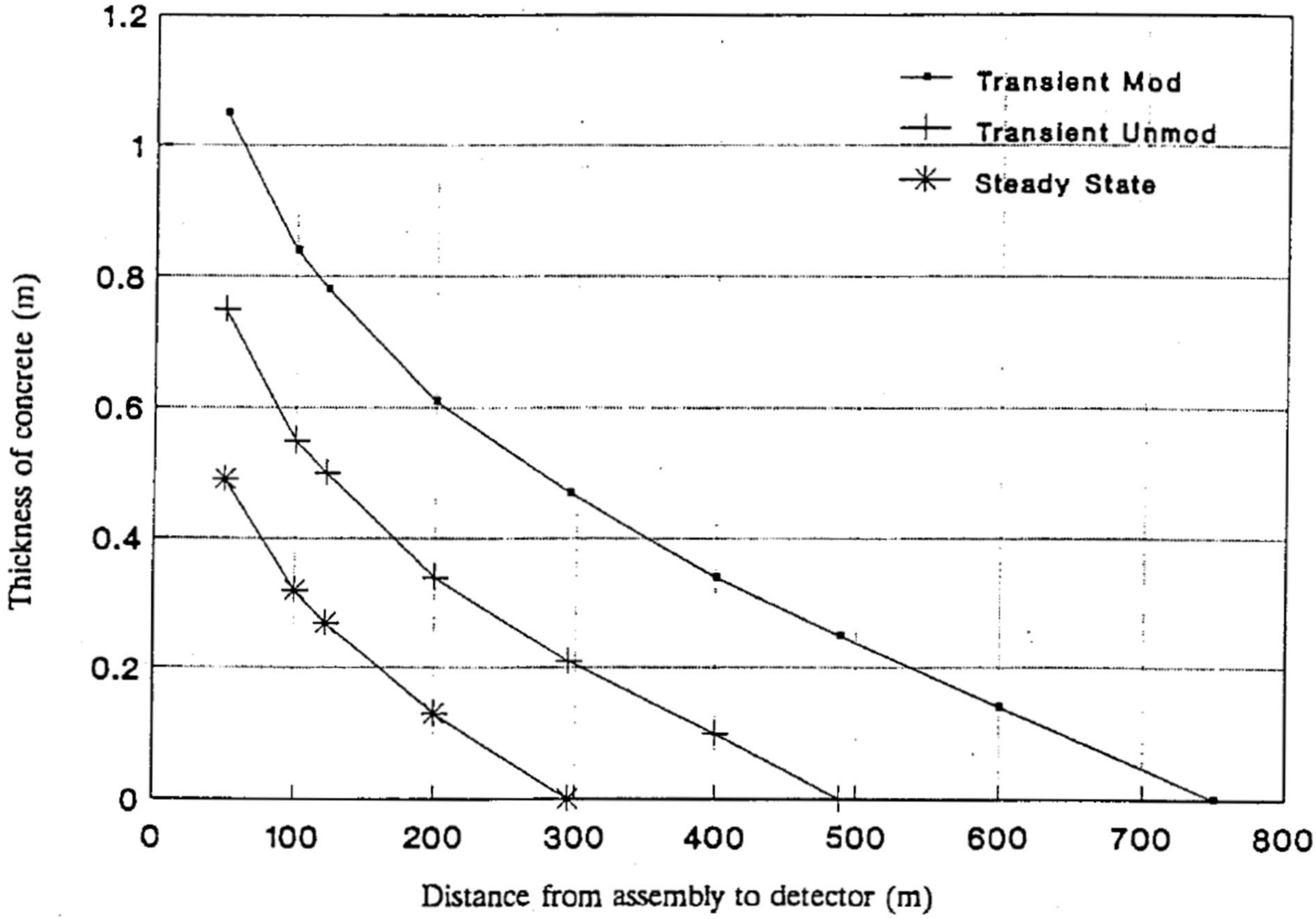
$$B = min[B_{air} + B_{shield}, B_{air} \times B_{shield}]$$

- Done for 10 discrete prompt gamma groups, total dose rate is the sum of all groups
- New estimate for detector sensitivity using above formulation and data from 1989 Godiva test

Fissions	FWHM (ms)	Detector Location	Setpoint (mR/hr)	Gamma Dose @ 2m (rad)
2.85×10^{14}	4.0	1600 ft.	25 (trip)	1.5 (derived)

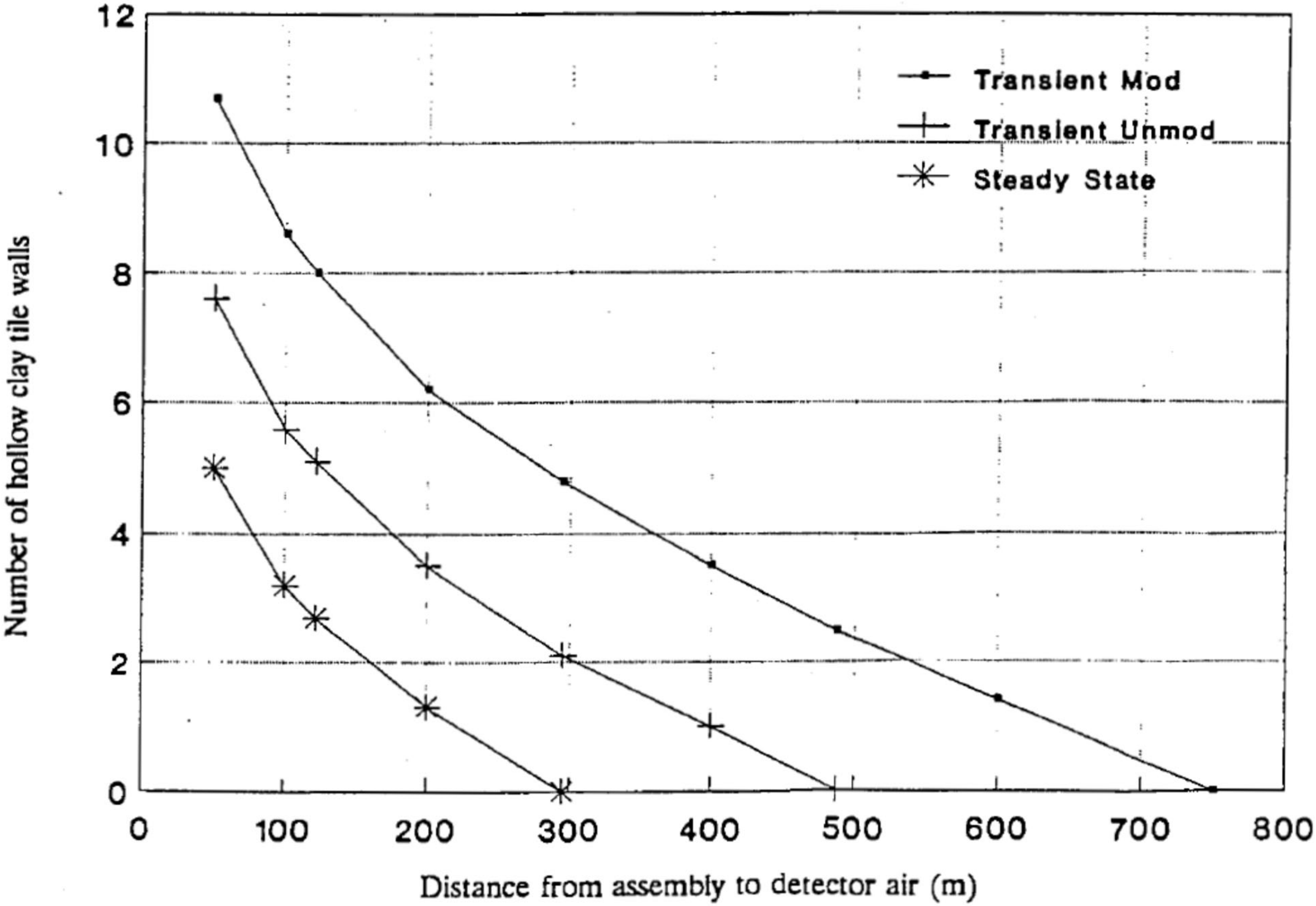
$$\epsilon = \frac{1}{140}$$

Historic Detector Range Analysis



- Sustained source (steady-state) is the most conservative
- At 120 m (400 feet), max shielding is 0.3 m (~12 in)

Historic Detector Range Analysis



- Sustained source (steady-state) is the most conservative
- At 120 m (400 feet), max shielding is 3 hollow-clay tile walls

Y-12 CAAS Post 1990s

- DOE no longer has an operational fast pulse reactor (until circa ~2010)
- New detectors purchased in 2005
- New PMTs purchased in 2016
- Detector qualification only involves passing calibration process
  - Setpoint equivalent to radiation level at 400 feet from a 20 rad/min @ 2m source (shielding from 3 hollow clay tile walls or 12 inches of concrete)
  - Lacking qualification for maximum radiation and minimum pulse width

Godiva IV Testing, July 2017

- Subject “sample” of detectors to an intense pulse at close range
  - Maximum expected radiation
  - Minimum pulse width
- 6 detectors initially tested in 2017
  - 2 new detectors
  - 4 existing detectors with new PMTs
- Data Logging
  - Data logger in control room
  - Output voltage from each detector connected to data logger
  - Contact closure signal from each detector connected to data logger
  - Signal from reactor shutdown acquired to record time of burst

Godiva IV Testing, July 2017

Burst #	Reactivity (¢ above prompt)	Burst Temp. (ΔT °C)	Fission Yield ($\times 10^{16}$ fissions)	Pulse Width FWHM§ (μsec)	Total Absorbed Air Dose* and Dose Rate at 2 m from Godiva IV		CAAS Alarm Response¥
					Dose (Rad)	Dose Rate§ (MRad/s)	
2025	0.8	47.5	0.63	970	28 (14 n + 14 γ)	.017	Immediate
2026	3.0	71.8	0.95	310	42 (20 n + 22 γ)	0.10	Immediate
2027	8.0	149.0	2.0	180	86 (42 n + 44 γ)	0.35	Immediate

- 149°C pulse adequate to qualify detector
  - Dose rate >> 10 rad/s criterion
  - Pulse width < 1 ms
  - Immediate response measured against shutdown trigger

Godiva IV Testing, May 2018

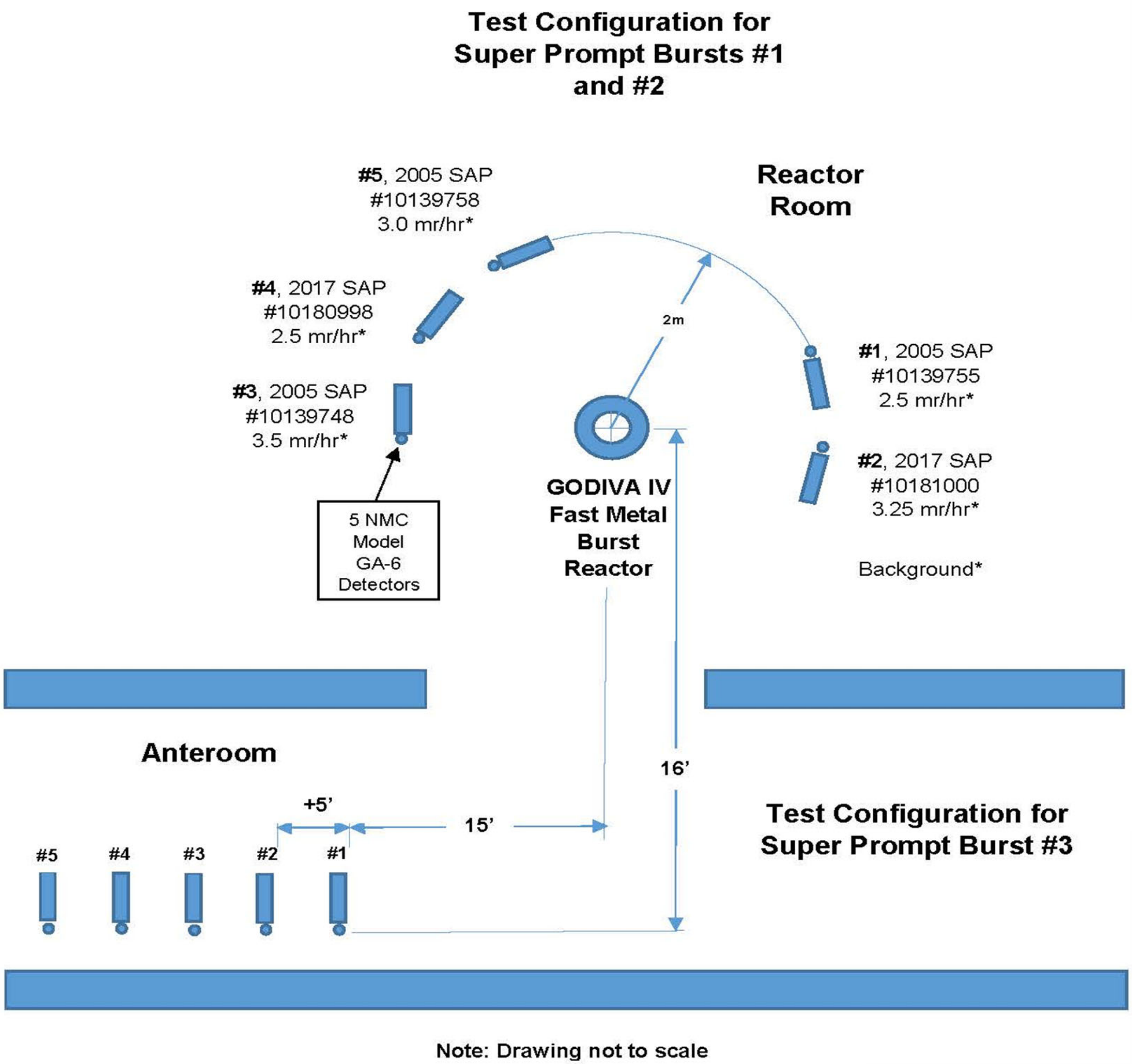
- Same general plan as before,
  - Lower intensity pulse to test equipment connections and performance
  - Only a 150°C pulse needed for qualification
  - New configuration to investigate attenuated response
- 5 detectors tested
  - 2 new detectors
  - 3 existing detectors purchased in 2005
- Data Logging
  - Data logger in control room
  - Output voltage from each detector connected to data logger
  - Contact closure signal from each detector connected to data logger
  - Signal from reactor shutdown acquired
  - Time of burst determined from observation of data

Godiva IV Testing, May 2018

- Configuration for Qualifying
  - Detectors positioned within an arc around the reactor
  - Power supplied to each detector
  - 180 cm above the floor
  - 2 meters from the reactor core centerline
  - NADs and CaF_2(Mn) dosimeters placed in similar locations

- Investigative Configuration
  - Detectors in reactor anteroom different distances from entrance
  - Two sets of NADs and CaF_2(Mn) dosimeters placed near detectors

Godiva IV Testing, May 2018



Godiva IV Testing, May 2018

- Schedule
  - Equipment set-up on day 1
  - Prompt pulse on day 2 to confirm detector operability and data connections
  - Prompt pulses of 150°C magnitude on days 3 and 4
- Data measurements
  - Temperature rise from RTDs
  - Reactivity and fission yield determined from relationship with ΔT
  - Pulse width (FWHM) from PD output trace
  - Dose from relationship with ΔT (IER-147)
  - Peak dose rate from total dose integrated over pulse shape (PD output trace)

Godiva IV Testing, May 2018

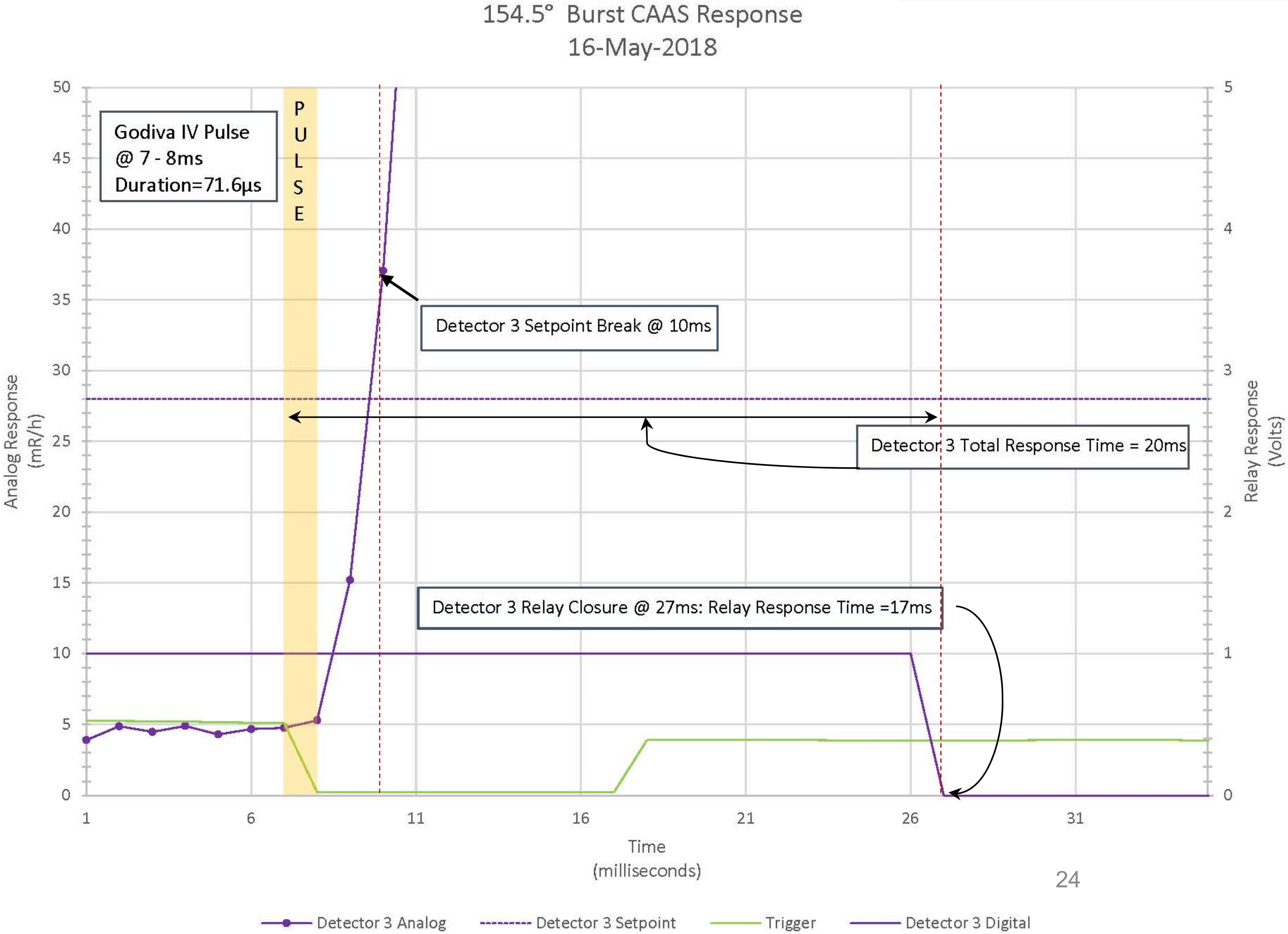
Reactivity (¢ above prompt)	ΔT (°C)	Fissions ($\times 10^{16}$)	Pulse Width (FWHM) (μs)	Total Absorbed Air Dose†	
				Dose (rad)	Dose‡ Rate (krad/s)
3.0	74.7	0.99	196	44	220
8.0	155	2.1	71.6	90	1,300
8.0	153	2.1	67.7	---	-----

† Combined gamma and neutron doses
‡ Estimated from dividing dose by FWHM

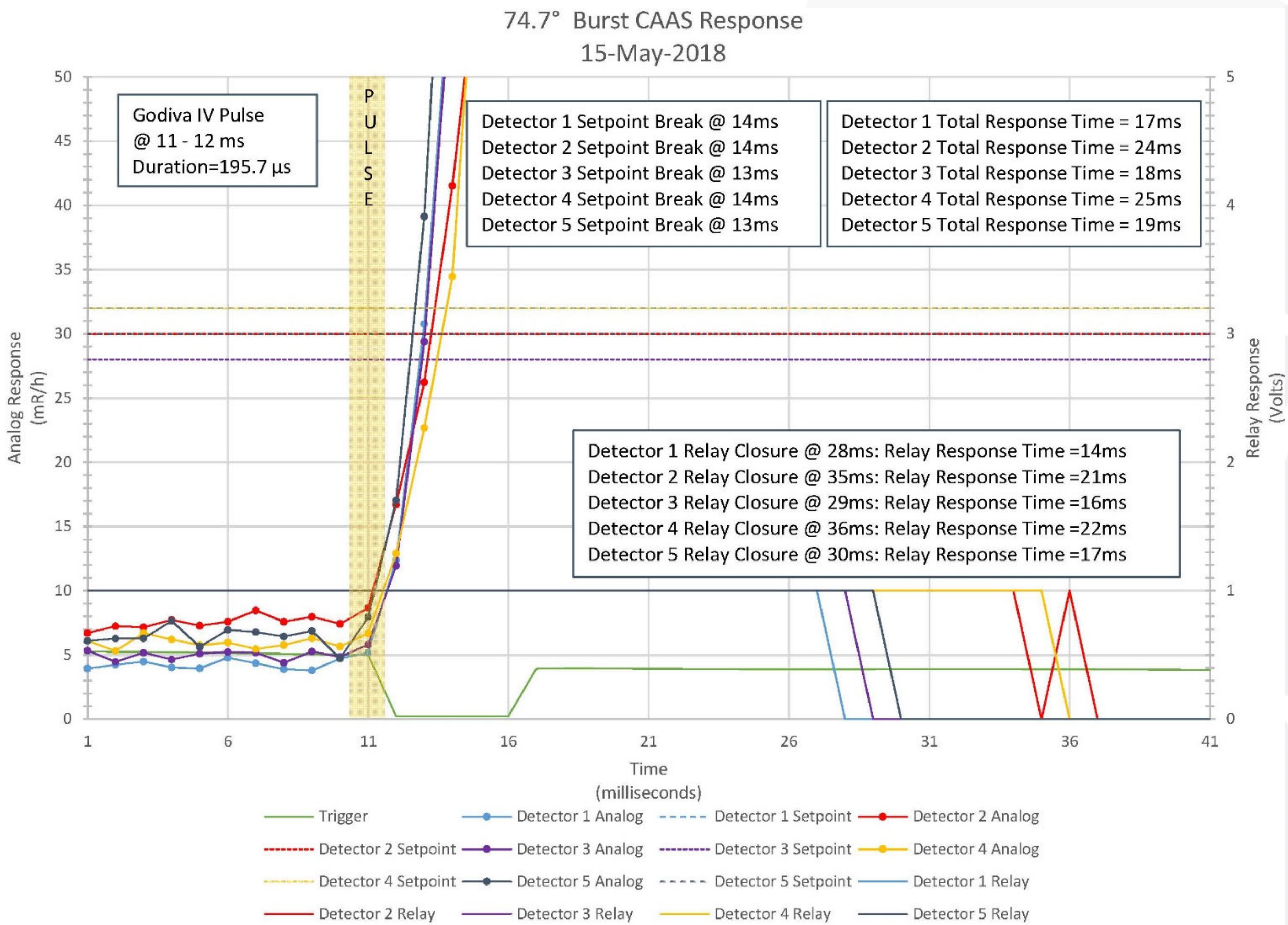
155°C pulse adequate to qualify detector

- Dose rate >> 10 rad/s criterion
- Pulse width < 1 ms
- Detector response measured from detector output and contact closure signal

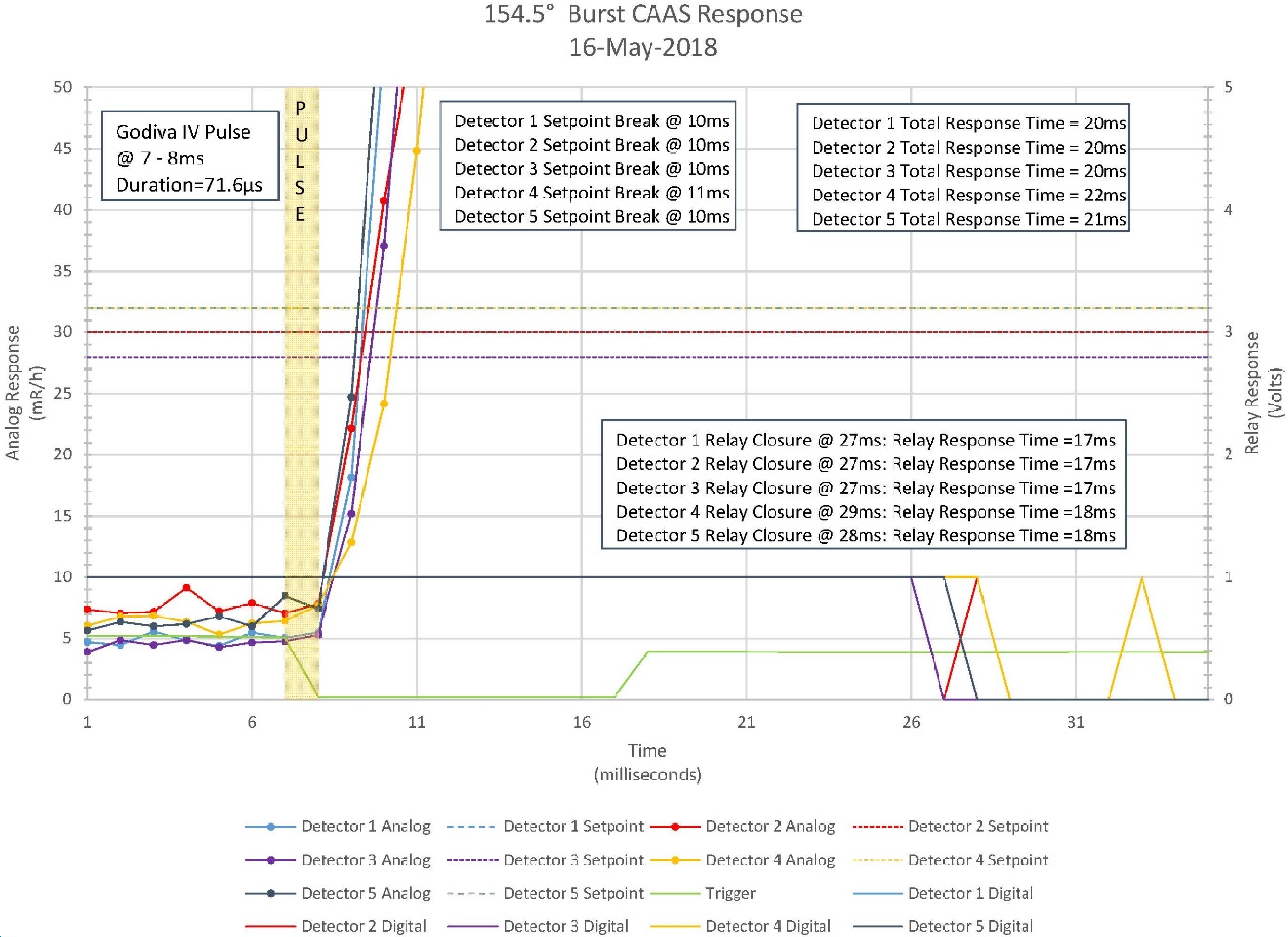
Typical detector response to a Godiva Burst



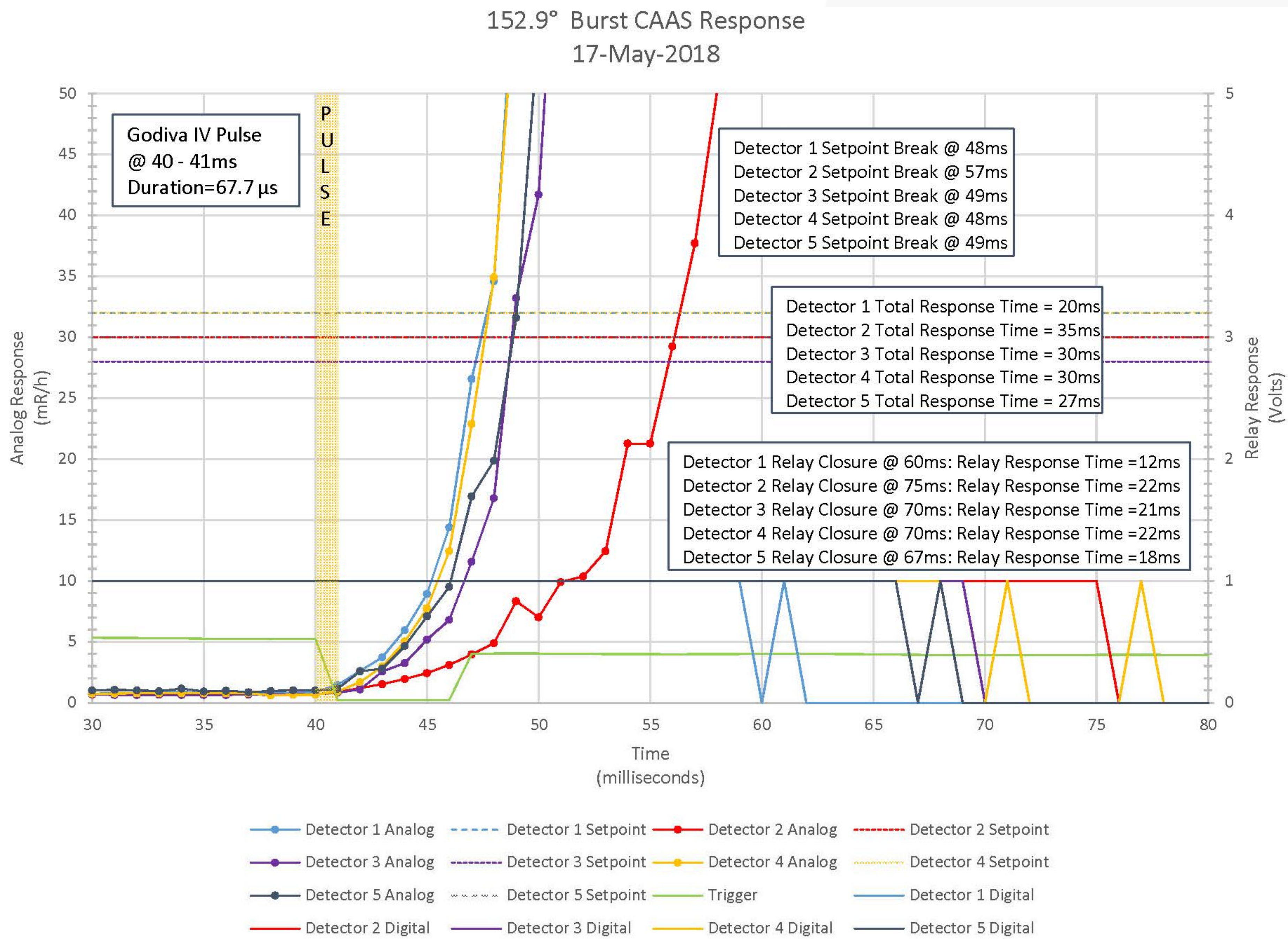
Detector Responses to May 15th 75° Prompt Burst



Detector Responses to May 16th 155° Prompt Burst



Detector Responses from Anteroom - May 17th



Conclusion

- Hand calculations can be useful for evaluating detector coverage
- Detector efficiency must be considered when modeling rapid transients
- Re-established DOE capability to test detectors with intense, short-duration mixed neutron and gamma field
- Established confidence that new detectors and existing detectors:
  - Will detect a minimum duration criticality accident
  - Are tolerant to maximum radiation
- Detector response ~20 to 25 ms, mostly due to contact closure in the alarm signal relay
- Lends confidence that the Y-12 CAAS system will generate an alarm signal within ½ second
- Fielded dosimetry agreed with IER-147 within 25%

Acknowledgments

- DOE NCSP for overall support and funding
- LLNL for planning, dosimetry, and results
- LANL for setting up equipment and operating reactor

Disclaimer