Qualification of Y-12 Legacy Criticality Accident Alarm System Detectors

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INTRODUCTION

The Y-12 National Security Complex has had a criticality accident alarm system (CAAS) capable to detect a criticality accident since 1945. With the exception of Y-12's new High-enriched Uranium Materials Storage facility (HEUMF), the system installed in Y-12's existing facilities dates to 1957. This legacy system has received many upgrades since installation and detector stations have been removed and relocated as enriched uranium operations have evolved, but the basic design and electronic configuration of the system is the same as that in 1957.

Historic Configuration

The legacy CAAS consists of multiple detector stations that provide a large area of accident coverage within enriched uranium facilities. Each station utilizes two model GA-6 gamma-sensitive detectors made by Nuclear Materials Corporation as shown in Fig. 1. The output signal from each detector at a station is connected to a control relay circuit that includes the logic for alarm annunciation. The detector utilizes a plastic scintillator sensitive to gamma radiation and is adjacent to a photomultiplier tube (PMT) that is used to convert the light signal from the scintillator into an amplified electronic signal. The detector is calibrated to a setpoint of 30 +2/-5 mR/hr. The maximum tolerance limit ensures a large radius of coverage and the lower tolerance limit minimizes false alarms from high background.

Each detector also has an LED light source attached to the PMT to artificially create a background of approximately 1 mR/hr. The combination of the artificial background and alarm setpoint allows for each detector to be identified as in a normal state, a fault state if the background drops below 0.1 mR/hr ("Fail"), and a high state if the alarm setpoint is exceeded ("Hi Rad").

The control relay circuit generates the alarm signal if both detectors at the station are in the high state. The control relay circuit will latch the alarm signal in place until the alarm is manually reset. The control relay circuit used to be configured to generate an alarm signal for combinations of high and fault detector states and even when both detectors are in the fault state. This configuration resulted in a series of false alarms from failure in the power supplied to the detectors and was changed circa 2000 to alarm only when both detectors are in the high state.

Fig. 1. Nuclear Materials Corporation GA-6 Radiation Detector.

Detector Calibration

These detectors are susceptible to alarm setpoint drift and must be periodically recalibrated. Detectors are calibrated on site using a gamma source and calibration device maintained specifically for CAAS detectors. A large enough supply of calibrated detectors is maintained so that an entire facility's detectors can be removed and replaced with minimal CAAS downtime. Removed detectors are recalibrated and kept ready for replacement when the next building's recalibration comes due.

Annunciation

Annunciation of the criticality accident alarm signal is accomplished through a combination of an audible alarm and strobe lights. The audible alarm is a 470 Hz tone (referred to as the clarion horn) emitted from a combination of CAAS system horns and the plant's Emergency

Notification System (ENS) speakers. In areas where the ambient noise level is high, strobe lights are installed to augment alarm annunciation. The strobe rate is approximately 80 flashes per minute with an effective candlepower rating of 1000.

Most nuclear facilities at Y-12 are equipped with multiple stations. If the control relay circuit in at least one station generates an alarm signal, the CAAS alarm will annunciate through the entire facility and exterior to the facility. In some nuclear facilities that are in close proximity to one another, a station in one facility also provides accident coverage for portions of the adjacent facility. Therefore, the CAAS is configured to generate the alarm throughout all clustered facilities when at least one station produces an alarm signal.

Historic Basis for Accident Coverage

Each station is credited as having a 400-foot radius of accident coverage. This coverage range was established well before the benefit of high-speed computing platforms and computer codes that allow for high-fidelity models of process facilities. The range of coverage is based primarily on testing at pulse reactor facilities and first-order adjustments of test results to generically account for shielding by facility walls. In order to compensate for uncertainties in this generic range of coverage, a requirement for coverage from at least two stations (i.e. "overlapping coverage") was established in the 1980s. In addition, CAAS stations in areas where thick shielding was in place, e.g. storage vaults, were considered to only have 100 feet of coverage.

Historic Qualification of Detectors

The testing at pulse reactor facilities was also done to qualify the radiation detectors for use in the CAAS. Criteria in versions of ANSI/ANS-8.3 in effect in the 1970s and 1980s required that detectors can initiate an alarm when subjected to a high radiation field, can initiate an alarm for transients with a minimum duration pulse, and are sensitive enough to immediately respond to a minimum accident of concern. Typically qualification was accomplished through a distant-pulse test to confirm sensitivity and an intense-pulse test to confirm both survivability and ability to respond to a narrow-width pulse. A typical distant-pulse test was a reactor pulse of 10^{15} fissions with the detector located ~800 feet from the reactor. A typical intense-pulse test was a reactor pulse of 10^{17} fissions with the detector located ~12 feet from the reactor. Detectors that successfully alarmed in both tests were considered qualified for use in the CAAS.

Qualification

Results of qualification testing performed at LANL in 1989 and SNL in 1992 were reported previously.[1] By the late 1990s the DOE had lost its capability to perform criticality alarm detector testing at pulse reactors with the shutdown of SPR-III at Sandia and the shutdown of TA-18 at Los Alamos. In 2005, Y-12 purchased new detectors to replace failing detectors and in 2016 purchased a new supply of PMTs to replace those in aging detectors. The only qualification testing performed for the new detectors and PMTs was a calibration at Y-12's CAAS detector calibration facility. While this test is reasonable and adequate for testing the sensitivity of detectors to a minimum accident, it does not simulate a narrow-width pulse nor does it test the detector for tolerance to the maximum expected radiation.

In order to address the deficiencies in detector qualification, two rounds of testing were conducted at the Godiva IV reactor now located at the National Criticality Experimental Research Center (NCERC) on the Nevada National Security Site (NNSS). The tests subjected CAAS detectors supplied by Y-12 to very intense and short duration mixed neutron and gamma radiation fields at a close distance from the reactor to establish compliance with maximum radiation and minimum pulse width requirements.

The first round of testing was performed in July 2017 and involved four previously purchased detectors with new PMTs installed and two recently purchased detectors. The results are reported in Table IV. The specific design requirements in place at Y-12 today promulgate from the DOE-approved safety analysis and state that detectors shall function in radiation fields up to a dose rate of 10 rad/s and further credits that alarm actuation will occur for transients with a duration less than 1 msec. The pulse widths and dose rates provided by each burst during the test far exceed those requirements. The CAAS detectors all provided an immediate alarm signal and remained operable after the bursts establishing compliance to the requirements and qualification for service in the CAAS.

The second round of testing was done in May 2018 and involved three detectors purchased in 2005 and two recently purchased detectors. Again, three separate bursts were conducted but with the detectors relocated to the anteroom for the last burst. Results are presented in Table V. The first two pulses were done for purposes of qualifying the detectors and again the pulse widths and dose rates provided by those bursts far exceed the aforementioned qualification requirements. The last burst was done with the detectors relocated to the anteroom in the configuration depicted in

TABLE IV. Godiva IV Test Results (July 2017)

Reactivity (¢ above prompt)	ΔT (°C)	Fissions (×10[16])	Pulse Width (FWHM) (μs)	Total Absorbed Air Dose†	
				Dose (rad)	Dose‡ Rate (krad/s)
0.8	47.5	0.63	970	28	17
3.0	71.8	0.95	310	42	100
8.0	149	2.0	180	86	350
† Combined gamma and neutron doses ‡ Estimated from photodiode output trace					

Fig. 2. This test was done for the purposes of collecting data and exploring the possibility of future test that could simulate conditions detectors would see from a distant pulse.

TABLE V. Godiva V Test Results (May 2018)

Reactivity (¢ above prompt)	ΔT (°C)	Fissions (×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					

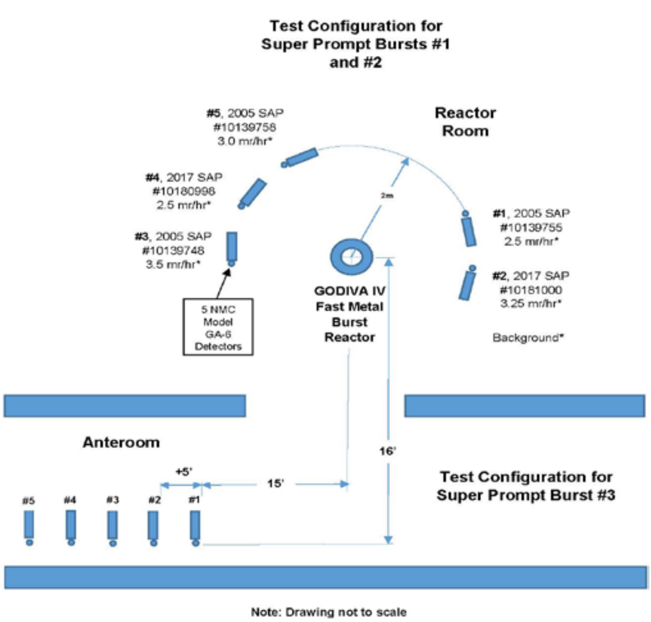

Fig. 2. Testing Configuration

The response of each detector's output signal and alarm relay were recorded and evaluated to determine the time required for the output to reach the alarm point. The response of one detector from the 155°C burst is shown in Fig. 3 and is indicative of all detectors tested.

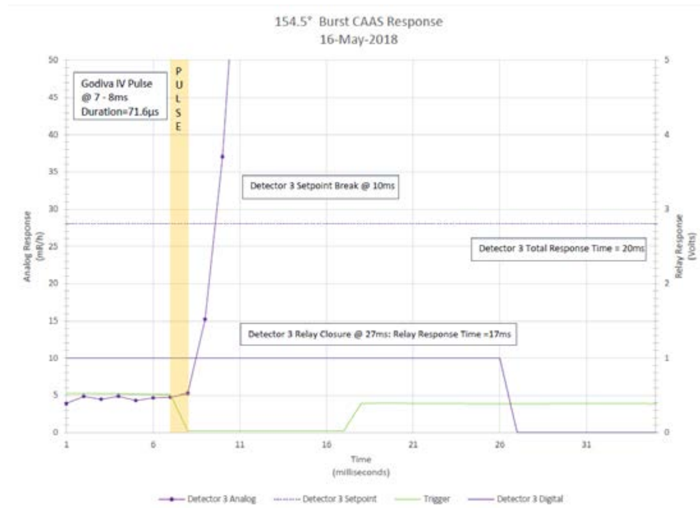

Fig. 3. Detector Response

The output clearly indicates that the alarm response is coincident with the reactor shutdown trigger signal (within one time bin) and also indicates closure of the alarm relay in 17 ms. The time between the detector signal exceeding the alarm setpoint (indicated on Fig. 3 as "setpoint break") and closure of the alarm relay is attributed to the mechanisms in the relay. This indicates that the electromechanical equipment that constitute the alarm circuit are capable of generating an alarm in well under 0.5 s and compliant with the ANSI/ANS-8.3 requirement for response time.

ACKNOWLEDGMENTS

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REFERENCES

1. C. F. HAUGHT and C. W. WOODROW, "The Y-12 Legacy Criticality Accident Alarm System," *Proc. Amer. Nuc. Soc (ANS 18)*, Philadelphia, Pennsylvania, June 18-24, p. xxx, American Nuclear Society (2018).

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