The Y-12 Legacy Criticality Accident Alarm System

Chris Haught,*

Chris Woodrow*Consolidated Nuclear Security, PO Box 2009, Oak Ridge TN 37831-8010, chris.haught@cns.doe.gov*
Consolidated Nuclear Security, PO Box 2009, Oak Ridge TN 37831-8006, christopher.woodrow@cns.doe.gov

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.

Previous Testing

Several tests were conducted between 1989 and 1994 at the Sandia National Laboratory and the Los Alamos National Laboratory. The tests at SPR-III and Godiva-IV were performed for detector qualification and the tests at SHEBA were performed for accident coverage determination. The testing at SHEBA included shielding from typical Y-12 materials of construction – that is hollow clay tiles shown in Fig. 2 and concrete blocks shown in Fig. 3. Results of these tests are presented in TABLES I-III below. While most detectors passed the tests, those detectors that didn't pass were typically repaired on site and retested.

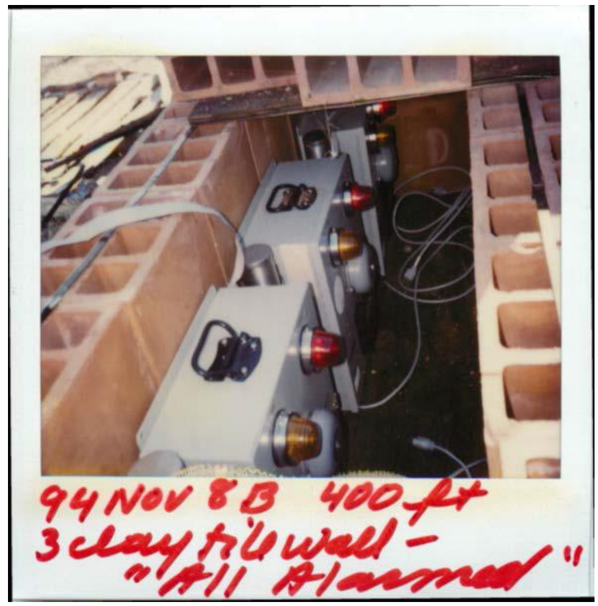

Fig. 2. Hollow Clay Tile Shield for CAAS Testing.

Fig. 3. Concrete Block Shield for CAAS Testing.

TABLE I. SHEBA Test Results (November 1994)

Dose[1] @ 2 m (rad)	Peak Dose[1] Rate @ 2 m (rad/min)	Distance (ft)	Shielding	Alarms[2]
38	38	800	None	3/3
4.3	12	400	2 clay tiles	3/3
7.2	43	400	3 clay tiles	3/3
11	37	400	2 concrete blocks	1/1
1: Combined gamma and neutron doses 2: Units that alarmed / units available to alarm				

TABLE II. SPR-III Test Results (March 1992)

Pulse Width (FWHM) (ms)	ΔT (°C)	Fissions[1]	Dose[2] @ 3 m (rad)	Dose[2] Rate @ 3m (rad/s)
Detectors located 12' 8" from reactor; 63 of 63 detectors alarmed				
2.59	41	2.73×10^{16}	101	3.88×10^{4}
2.79	42	2.80×10^{16}	103	3.70×10^{4}
1.54	50	3.33×10^{16}	123	7.94×10^{4}
Detectors located 722' from reactor; 54 of 63 detectors alarmed				
0.382	95	6.33×10^{16}	349	9.14×10^{5}
0.442	98	6.53×10^{16}	338	7.65×10^{5}
0.348	99	6.60×10^{16}	356	1.02×10^{6}
1: Based on 150°C corresponding to 1×10^{17} fissions 2: Combined gamma and neutron doses				

TABLE III. Godiva IV Test Results (April 1989)

Distance (ft)	Pulse Width (FWHM) (μs)	Fissions	Dose[1] @ distance (rad)	Dose[1] Rate @ distance (rad/s)
32 of 32 detectors alarmed				
12	40	3.23×10^{16}	133	3.31×10^{6}
1600	3,500	3.54×10^{14}	8.18×10^{-5}	0.0234
1600	2,000	1.57×10^{15}	3.64×10^{-4}	0.182
1: Combined gamma and neutron doses				

Current Qualification

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 addition to these qualification issues, a recent assessment discovered detectors in current service that were reported in the SPR-III 1992 testing report as having failed the tests. While anecdotal information suggests any detectors failing tests were repaired and retested, no documentation of successful testing can be found.

In order to address the deficiencies in detector qualification, several detectors were tested in July 2017 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 to establish compliance with maximum radiation and minimum pulse width requirements and 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.

TABLE IV. Godiva IV Test Results (July 2017)

Reactivity (¢ above prompt)	ΔT (°C)	Fissions ($\times10^{16}$)	Pulse Width (FWHM) (μs)	Total Absorbed Air Dose[1]	
				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
1: Combined gamma and neutron doses 2: All detectors responded within 0.02 s of the high radiation preset trigger					

ACKNOWLEDGMENTS

Successful completion of the recent tests was predicated on the collaborative efforts of several organizations and the authors wish to acknowledge those organizations. John Scorby of Lawrence Livermore National Laboratory (LLNL) provided logistical, technical and management support, prepared the test plan and coordinated with personnel who fielded supplemental dosimetry. Joetta Goda and Travis Grove of Los Alamos National Laboratory (LANL) managed the operation of Godiva IV and coordinated field support for CAAS detector placement and data acquisition. Ryan LeCounte of LANL did extensive wiring to prepare equipment for testing and Donnette Lewis of LANL facilitated approval of Y-12 equipment in NCERC. Angela Chambers of DOE's NCS Program was instrumental in directing DOE's resources to support planning and execution of these tests.

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