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ESTIMATING RADIUS OF COVERAGE OF THE Y-12 PLANT CRITICALITY ACCIDENT ALARM SYSTEM FROM EXPERIMENTS AT THE LOS ALAMOS CRITICAL EXPERIMENTS FACILITY

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**ESTIMATING RADIUS OF COVERAGE OF THE Y-12 PLANT
CRITICALITY ACCIDENT ALARM SYSTEM FROM EXPERIMENTS
AT THE LOS ALAMOS CRITICAL EXPERIMENTS FACILITY**

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INTRODUCTION

An operation at the Oak Ridge Y-12 Plant is considered to be covered by the Criticality Accident Alarm System (CAAS) if the operation is located within the radius of coverage of two detector stations. Experiments were performed at the Los Alamos Critical Experiments Facility (LACEF) to evaluate the radius of coverage for the detectors used in the Y-12 CAAS. Ideally, the detectors would be tested using a source term that is comparable to the minimum accident of concern as described in ANSI/ANS-8.3[1]. The minimum accident of concern that is suggested by ANSI/ANS-8.3 is an excursion that results in a dose of 20 rad at 2 meters from the reacting material within 60 seconds. The most limiting situation is when the 20 rad is delivered at a constant dose rate for 60 seconds. This steady state excursion produces the smallest radius of coverage. The peak dose rate that resulted from each excursion in this study was estimated so that the reactor source term could be compared to the minimum accident of concern. The reactor source term, distance from reactor, intervening shielding and status of detector alarms were used to evaluate the radius of coverage for the Y-12 CAAS detectors for a given alarm set point.

EQUIPMENT AND MATERIALS

The detectors were exposed to radiation fields provided by SHEBA, a cylindrical critical assembly operating at the LACEF. SHEBA is fueled with a uranyl fluoride solution that has been enriched to 5% ^{235}U . SHEBA has a well-moderated neutron spectrum. Reactivity is typically controlled by varying the solution level. SHEBA has three pumping speeds, three drain speeds and a poison safety rod. For these experiments, SHEBA was operated above ground and with the steel doors open to provide direct line of sight measurements.

The detectors used in the Y-12 Plant CAAS are NMC Model GA-6 detectors. These detectors indicate exposure rates and are set to alarm when the exposure rate exceeds a predetermined set point. The detectors are comprised of plastic scintillators, photomultiplier tubes, amplifiers, meters, relays and alarms. The detectors have a five-decade range from 0.1 to 10,000 mR/hr and were set to alarm at 25 mR/hr. When the exposure rate exceeded the alarm set point, the high radiation warning lights were illuminated. The warning lights were set to latch so that the lights remained lit after the radiation levels fell below the alarm set point.

The radius of coverage for the CAAS detectors is dependent on the type and amount of intervening shielding. Concrete and hollow clay tile block were used as the shielding materials because they are primary constituents of the buildings at the Y-12 Plant. The detectors were surrounded by up to three layers of hollow clay tile block or two layers of concrete block. The

clay tile blocks measure approximately $11\frac{1}{2}" \times 11\frac{1}{2}" \times 7\frac{1}{2}"$. The thickness of the shell is approximately $\frac{3}{4}"$ and the thickness of the webs is approximately $\frac{5}{8}"$, forming six openings that measure approximately $11\frac{1}{2}" \times 2\frac{3}{4}" \times 2\frac{3}{4}"$. Each clay tile block wall was $7\frac{1}{2}"$ thick. The primary constituent of the clay is SiO_2 . Other constituents are H_2O and oxides of Al, Ca, Cd, Fe, K, Mg, Na, and Ti. The clay has an average density of 2.35 g/cm^3 . Because almost 60% of the volume of the block is void, the block has an average density of 0.99 g/cm^3 . The concrete blocks are solid, measure approximately $15\frac{1}{2}" \times 7\frac{1}{2}" \times 5\frac{1}{2}"$ and have densities of approximately 2.3 g/cm^3 . Because the shielding walls were temporary, they were constructed without mortar. Individual blocks and adjacent layers were carefully placed to minimize openings.

MEASUREMENTS AND DOSIMETRY

Thermoluminescent dosimeters (TLDs) from the Y-12 Plant and Los Alamos National Laboratory (LANL) were used to estimate neutron and gamma doses from various SHEBA excursions. These dose values were used to relate the experimental results to the criteria in ANSI/ANS-8.3. The TLDs were placed on phantoms that were positioned at approximately midheight of the fuel and 3 m from the edge of the SHEBA assembly. The TLDs from Y-12 Plant were placed on phantoms comprised of 20 cm by 20 cm by 10 cm blocks of Lucite while the TLDs from LANL were placed on large plastic jugs filled with water. During some experiments, TLDs were also placed on the side of the SHEBA building at two meters from the vessel surface. Two configurations of Y-12 Plant TLDs were used to estimate neutron and gamma doses individually. The neutron TLDs were paired with beta/gamma TLDs for evaluation of each excursion. The TLDs were processed in accordance with an approved fixed nuclear accident dosimetry processing procedure. Neutron doses were evaluated using the calculated spectral correction factor for SHEBA. A single configuration of LANL TLDs was used to estimate both gamma doses and neutron doses from the various SHEBA excursions. Neutron doses were calculated by applying an appropriate facility-specific neutron correction factor. Neutron doses were also measured with a tissue equivalent proportional counter (TEPC). The TEPC is a gas proportional counter that responds to neutrons.

SHEBA uses a compensated ion chamber (CIC) for the linear channel for fission power. SHEBA was set to trip at a certain ion chamber current (e.g., $1\text{E-}5$ amp). The CIC provided a measurement of the current in amps and integrated current in amp-seconds for each excursion.

During each experiment, data was acquired from the signal used to drive the meter display for one detector. Because this signal was inherently noisy, it was averaged over one second intervals to smooth the data, while still providing good resolution of the transient. The data was recorded on a portable PC located next to the detector.

SETUP AND OPERATION

The SHEBA building is located on the floor of a canyon about 1200 feet from the building that houses the LACEF control rooms. The canyon floor is essentially flat. Detectors were placed at distances ranging from 400 feet to 1000 feet. Intervening shielding included two concrete walls, two clay tile walls, three clay tile walls, or air only. An attempt was made to build four

clay tile walls around the detectors but due to the limited number of clay tiles available only the top and wall facing SHEBA contained four clay tile walls; the remaining sides were made up of three clay tile walls. Three detectors were placed in the same location for the first three tests. Not only was the number of clay tile blocks limited, but time was also a constraint. Therefore, to avoid delays for reconstructing the walls, two inner walls were banded together on a large pallet that could be moved. This configuration could have only two detectors in the opening.

Uranyl fluoride solution was pumped into the cylindrical tank. As the assembly approached delayed critical, the speed at which solution was pumped into the tank was slowed. As SHEBA was brought to delayed critical, solution was added such that a positive period of no less than 20 seconds was achieved. After the assembly became critical, the excursion was terminated manually by an operator or automatically because an area monitor reached its preset limit.

RESULTS

The doses that were measured with TLDs and TEPC are presented in Table I.

Table I. Dose Estimates made from TLDs and TEPC placed 3 m from SHEBA					
Experiment	LANL TLD gamma dose (rad)	LANL TLD neutron dose (rad)	LANL TEPC neutron dose (rad)	Y-12 TLD gamma dose (rad)	Y-12 TLD neutron dose (rad)
94NOV7A	10.9	10.2	11.4	7.6	118
94NOV8A	1.2	1.2	1.2	0.8	13
94NOV8B	2.0	2.0	2.0		
94NOV9A	4.7	4.8	4.1		
94NOV9B	3.6	3.8	3.3		
94NOV10A	2.9	3.0	3.1		
94NOV10B	3.9	3.5	3.6		

The neutron doses that were measured using the Y-12 TLDs were much larger than expected. The neutron doses that were measured with the TEPC were very close to the neutron doses that were expected and measured using the LANL TLDs. Therefore, the neutron doses and gamma doses that were measured using the LANL TLDs were used for estimating the peak dose rate for each excursion.

The peak dose rate that resulted from each excursion in this study had to be estimated so that the reactor source term could be compared to the minimum accident of concern. It was assumed that the current measured by the CIC was proportional to the dose rate and the integrated current measured by the CIC was proportional to the dose; therefore, the ratio of the peak current to the integrated current equaled the ratio of the peak dose rate to the total dose for a given experiment. The SHEBA operators provided the integrated current and peak current for each excursion. The dose was estimated using TLDs. The TLDs were collected as soon as health physics

considerations would allow. Some of the dose measured by the TLDs was received after SHEBA tripped. The gamma doses were lowered by 20 per cent to subtract out the effects of the residual radiation following the reactor trip. Based on TLD measurements made at 2 meters and 3 meters, the gamma doses that were measured at 3 meters were doubled to estimate the doses at 2 meters. The neutron doses that were measured at 3 meters were doubled to estimate the doses at 2 meters. Based on past measurements made with bubble dosimeters, it appears as this will overestimate the dose to the detectors, giving a larger estimate of the peak dose rate than the detectors were actually exposed to. The gamma and neutron doses were then combined to give the total dose estimates at 2 meters from the assembly for each excursion. The total dose estimates were multiplied by the peak current and divided by the integrated current to calculate the peak dose rate. A summary of each test setup and selected results is provided in Table II.

Table II. Calculated and Measured Data from Detector Tests								
Experiment	Peak Detector Signal	Integrated Current (amp-sec)	Peak Current (amp)	Dose ¹ at 2 m (rad)	Peak Dose Rate ¹ at 2 m (rad/min)	Distance (feet)	Shielding	Alarms ²
94NOV7A	111	1.5E-3	2.5E-5	38	38	800	none	3/3
94NOV8A	108	1.5E-4	6.8E-6	4.3	12	400	2 clay tile	3/3
94NOV8B	111	2.6E-4	2.6E-5	7.2	43	400	3 clay tile	3/3
94NOV9A	116	5.4E-4	2.2E-5	17	42	400	3+ clay tile	2/2
94NOV9B	107	4.3E-4	2.2E-5	13	40	600	3 clay tile	1/2
94NOV10A	97	4.1E-4	2.3E-5	11	37	800	2 clay tile	0/2
94NOV10A	97	4.1E-4	2.3E-5	11	37	400	2 concrete	1/1
94NOV10B	103	4.7E-4	2.2E-5	13	37	600	2 concrete	0/1
94NOV10B	103	4.7E-4	2.2E-5	13	37	900	none	0/1
94NOV10B	103	4.7E-4	2.2E-5	13	37	1000	none	0/1
¹ combined gamma and neutron, adjusted to remove effects of residual radiation								
² detectors that alarmed / detectors available to alarm								

The calculated total dose at 2 meters shows that these experiments did provide a source term similar to that suggested by the ANSI/ANS-8.3 Standard. For the Y-12 Plant detectors, a dose rate criterion is more appropriate. It would be reasonable to propose a peak dose rate criterion of 40 rad per minute. That is equivalent to 20 rad per minute with a peak-to-average exposure rate of two. This peak-to-average value is conservatively low with respect to the known criticality accidents and the typical SHEBA transients. Fine control of such a system is necessary to achieve steady state conditions.

Table III provides the data from bench tests that were done to determine the relationship between the signal current (scaled to arbitrary units) and the indicated dose rate on the detector meter.

Table III. Detector Signal versus Indicated Dose Rate	
Dose Rate (mR/hr)	Detector Signal
1	50
25	114
300	157
2000	198

After each transient, the detector signal data was downloaded from the portable PC to another computer or disk for permanent storage. It was initially hoped that the detector signal would be useful for scaling the results to various combinations of distance, shielding and alarm set point. Unfortunately, the test results showed that the peak detector signal was not a precise indicator of whether the alarm signal would occur. There was insufficient data to quantify this uncertainty. Also, the logarithmic relationship yields a large change in dose rate for a small change in detector signal.

CONCLUSIONS

A peak dose rate of 40 rad per minute is a reasonable choice based on the physical phenomena. For a minimum accident of concern that is defined as resulting in 20 rad at 2 meters within 60 seconds and allowing for a peak dose rate of 40 rad per minute, the radius of coverage for an alarm set point of 25 mR/h is as follows:

- 400 feet with 2 concrete block walls, or
- 600 feet with 3 clay tile walls, or
- 800 feet with no shielding.

The detector signal data was helpful in that it showed approximately how close the detector came to its set point. However, the large uncertainty in the data does not allow it to be readily used for interpolating combinations of distance and shielding for a given set point and source term.

RECOMMENDATIONS

It is recommended that additional work be done to improve the dose estimates from the TLDs exposed during these experiments. Additional experiments with other combinations of distance and shielding would help in applying these results to specific facility applications.

REFERENCES

1. "Criticality Accident Alarm System," ANSI/ANS-8.3-1986, American Nuclear Society, 1986.

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