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Plan for IER-443 Testing of the Y-12 and AWE Criticality Accident Alarm System Detectors at the Godiva IV Burst Reactor

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Auspices

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Executive Summary

This document provides the scope and details of the "Plan for Testing the Y-12 and AWE Criticality Accident Alarm System Detectors at the Godiva IV Burst Reactor". Due to the relative simplicity of the testing goals, scope, and methodology, the NCSP Manager approved execution of the test when ready. No preliminary CED-1 or final design CED-2 reports were required or issued. The test will subject Criticality Accident Alarm System (CAAS) detectors supplied by Y-12 and AWE to very intense and short duration mixed neutron and gamma radiation fields. The goals of the test will be to (1) substantiate functionality, for both existing and newly acquired Y-12 CAAS detectors, and (2) the ability of the AWE detectors to provide quality temporal dose information after a hypothetical criticality accident. ANSI/ANS-8.3.1997 states that the "system shall be sufficiently robust as to actuate an alarm signal when exposed to the maximum radiation expected", which has been defined at Y-12, in Documented Safety Analyses (DSAs), to be a dose rate of 10 Rad/s. ANSI/ANS-8.3.1997 further states that "alarm actuation shall occur as a result of a minimum duration transient" which may be assumed to be 1 msec. The pulse widths and dose rates which will be achieved in this test will exceed these requirements.

Pulsed radiation fields will be produced by the Godiva IV fast metal burst reactor at the National Criticality Experimental Research Center (NCERC) at the Nevada National Security Site (NNSS). The magnitude of the pulses and the relative distances to the detectors will be varied to afford a wide range of radiation fluence and pulse widths. The magnitude of the neutron and gamma fields will be determined by reactor temperature rise to fluence and dose conversions which have been previously established through extensive measurements performed under IER-147. The requirements for CAAS systems to detect and alarm under a "minimum accident of concern" as well as other functional requirements specified in ANSI/ANS-8.3.1997, are not included in the test. Routine and periodic maintenance and calibrations performed at Y-12 and AWE are intended to provide adequate confirmation for meeting these requirements.

1.0 Motivation

Both the Y-12 and AWE CAAS systems are operated to the requirements specified in ANSI/ANS-8.3.1997. Demonstrating compliance to many of the requirements is accomplished through periodic maintenance, functional testing, and calibrations performed locally at the respective sites. The operability requirement under short duration, high radiation fields, however, requires rather unique conditions that can only easily and reasonably be achieved by subjecting the detectors to radiation from a pulsed reactor. Both the Y-12 and AWE CAAS systems have been subjected to burst reactor testing in the past[1,2]. However, since those tests, the Y-12 detector heads have had some component changes, principally substitution of a different PMT in some of the deployed systems. Y-12 is also in the process of procuring new detectors (head and electronics enclosure) of the same type. New burst reactor testing is desired in order to assure that the modifications to the existing detector heads has not negatively impacted operability and to performance test the newly acquired CAAS detectors. AWE is interested in using this opportunity to perform testing of

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1 Angelo, P.L., *Documentation of Past Y-12 Plant CASS Detector Tests at Los Alamos and Sandia National Laboratories*, Y/DD-955, NCSD, Y-12 Plant, Lockheed Martin Energy Systems, Inc., September 29, 2000.

2 Garbett, S., *AWE Radiation Testing Part 4: IS821 DHA White Sands Test Report*, Radiological Instrumentation and Calibration, EDMS/800BAA52/RI/043, AWE, Aldermaston, UK, February 2016.

their CAAS system, principally to investigate the ability of the detectors to provide useful dose information as a function of time after a criticality event. LLNL is providing logistical and management support for the testing, as well as fielding supplemental detection systems to confirm dose and burst widths. LANL is providing operation of the Godiva IV reactor and field support for detector head placement and data acquisition.

2.0 Test Method Overview

Radiation pulses of variable magnitudes and durations have been requested by Y-12 and AWE. The total fluence and dose for each pulse will be determined by reactor temperature rise to fluence and dose conversions determined at several locations, radially and vertically, within the Godiva IV cell from previous measurements performed under IER-147. Supplemental NADs, CaF_2 TLDs, and Personnel Ion Chambers (PICs) will be deployed adjacent to the CAAS detectors to provide an independent means to measure and confirm expected total neutron and photon fluence and dose. A single sphere passive neutron spectrometer (PNS) will also be deployed as an "add-on" to allow concurrent testing with the NADs. The activated elements of the NADs and PNS will be transported and measured at the LLNL NAD Lab in Mercury at the NNSS. The PICs will also be transported to the NAD Lab for readout and the TLDs will be shipped and measured at Sandia National Laboratory.

Pulse widths will be measured by LANL with a photodiode (PD) located on the Godiva IV assembly stand. The PD will also provide a measurement of initial reciprocal reactor period (alpha), thus providing a means to estimate prompt fission yield and peak fission rates by comparison to historical alpha to prompt fission yield data. Note that prompt yields differ somewhat from total yields (e.g. determined by temperature rise or NAD activation) due to fissions which occur during the early moments of the reactor SCRAM when the reactor is still in delayed critical and due to the contribution of delayed neutrons emitted up to many minutes after the burst.

The Y-12 and AWE CAAS detector heads will be positioned, as described later in Section 4, at various distances from Godiva IV to receive a range of neutron and gamma fluence. The signals from the detectors will be monitored and logged by data acquisition systems provided by Y-12 and AWE. The output of LANL Godiva IV monitoring detectors may be used to trigger the data acquisition systems. Details of the CAAS detectors, associated electronics, and data acquisition systems to be deployed are provided below:

CAAS Detectors and Data Acquisition

Y-12:

- Nuclear Measurements Corporation model GA-6 CAAS detector head and electronics enclosure.
- Omega OM-LGR-5327 data logger

The detector consists of a scintillator, photomultiplier tube, amplifier, and high voltage power supply. The electronics enclosure contains the electronics which compare the output of the detector to a reference level and closes a relay contact if the detector output exceeds the reference level. The data logger will be connected to two outputs on each detector to record: (1) the contact closure and (2) the 50 mV at 50 mR/hr output signal. An input signal from the reactor monitoring system to signal when the pulse is initiated is also needed to determine the time to alarm. A small DC power supply will be needed to supply voltage through the high radiation alarm contact. The GA-6 CAAS is shown in Fig. 1 and a schematic of the data acquisition plan is provided in Fig. 2.

Fig. 1 Nuclear Materials Corporation model GA-6 CAAS

(a)

(b)

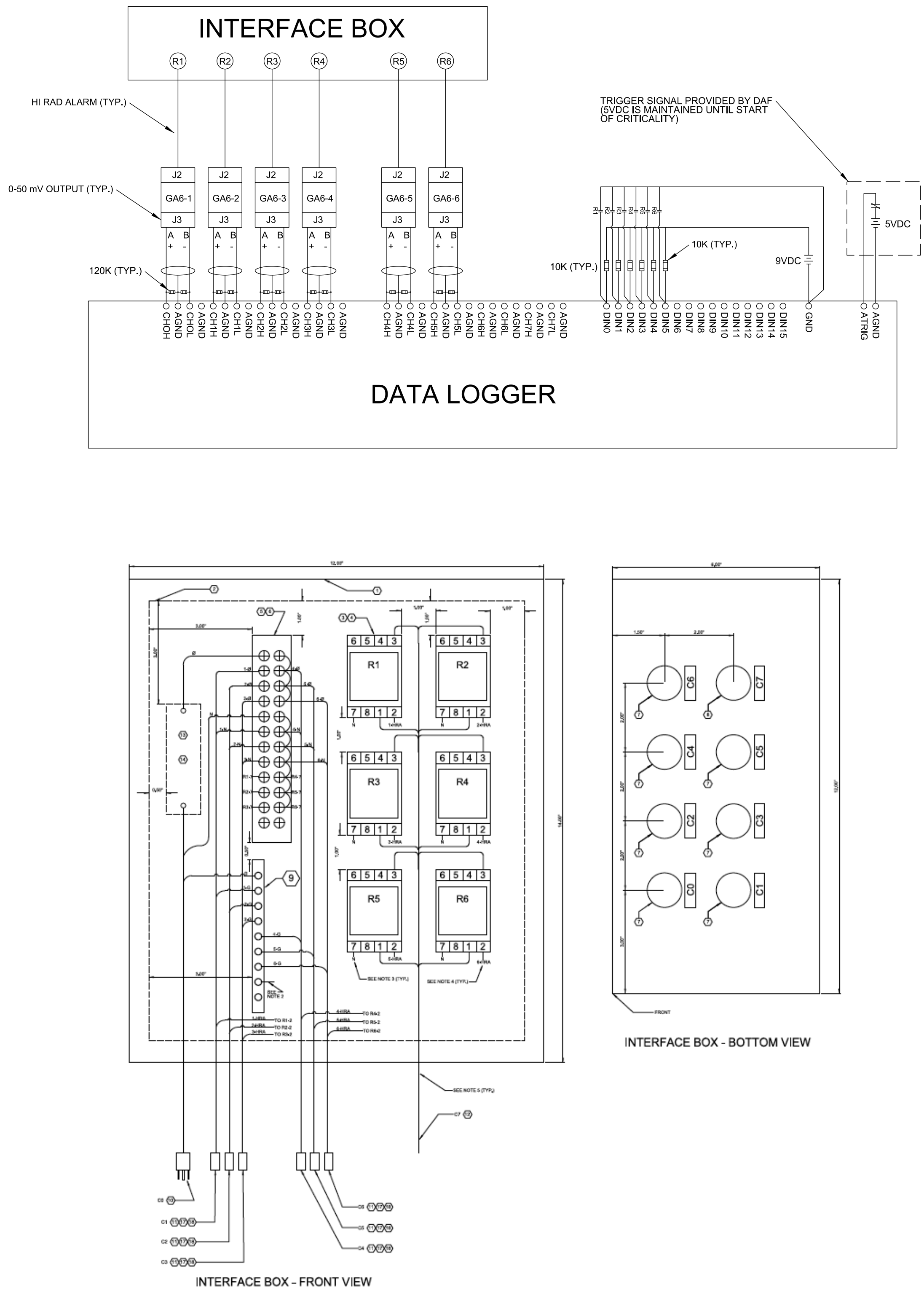


Fig. 2 Schematic of the Y-12 CAAS data acquisition plan including the (a) Omega OM-LGR-5327 data logger and (b) interface box.

AWE:

- One IS859 Mini Criticality Incident Detection System Rack
- Four IS821 Detector Head Assemblies

The Mini CIDS consists of an IS859 System Rack connected to one or more IS821 detector head assemblies (DHAs), pictured in Fig. 3. The DHAs utilize ion chambers (Centronic type IG32 parallel plate) together with signal processing electronics to measure gamma radiation to initiate an alarm when the dose exceeds a predetermined threshold in any period of one minute. The default alarm threshold is 4μGy (in ≤1min) which is equivalent to a dose rate of 240μGy per hour. The IS859 mini CIDS will gather real time data from up to four DHAs, if any two or more DHAs provide readings above the pre-set alarm threshold the system will illuminate a "Criticality" LED on the front panel. Three DHAs will be located within the cell and one will be used as a "live" spare located in the adjacent alcove.

The IS859 mini CIDS has a remote logging capability (via the Ethernet connection) to gather the data from the DHAs for a prolonged period of time after the pulse. Output from the IS859 will be routed to either the Godiva IV control room via the local cable junction box (located in the alcove) or directly to a laptop located in the alcove.

Neutron and Photon Activation

LLNL

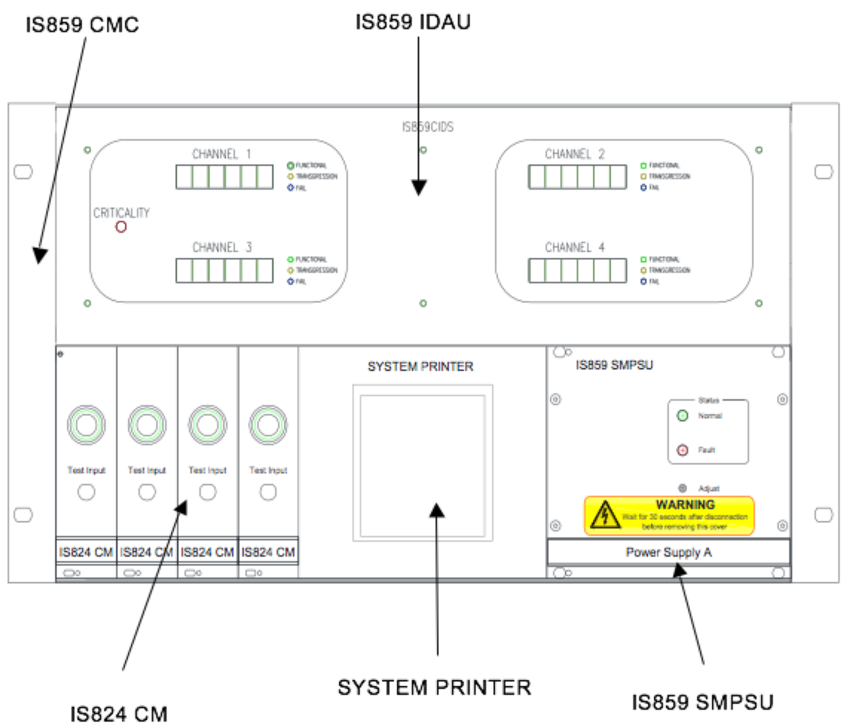
- NADs
- PICs
- Single Sphere Passive Neutron Spectrometer (PNS)
- Falcon 5000® Portable HPGe Based Radionuclide Identifier

Sandia

- CaF_2 TLDs

Neutron and photon activation analysis will be used to estimate total dose and fluence. LLNL NADs and Sandia TLDs will be positioned adjacent to the CAAS detectors. The PNS will be positioned at the 2m distance for all bursts. After irradiation, the NADS and activated PNS foils will be retrieved from the cell and transported to the NAD Lab in Mercury for counting. The NADS and PNS foil tubes will be disassembled and the individual activation elements measured by the HGPe detector. The CaF_2 TLDs will be retrieved after irradiation and shipped to Sandia for measurement. Previous use of NADs and CaF_2 TLDs in IER-147 and IER-148 have provided very reliable neutron and photon dose and fluence reconstruction.

(a)



(b)

Type	Chamber Designation	Fill Gas	Chamber Pressure	Polarising Voltage
IS821	Centronics IG32	Argon	3.1 atmospheres	-1000V

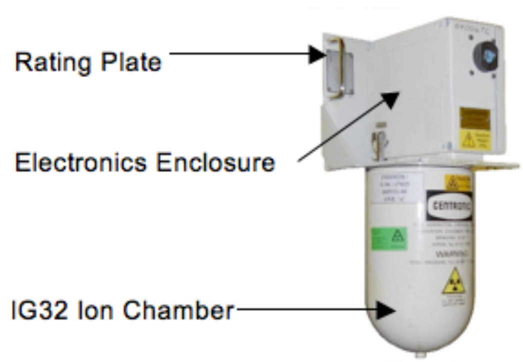


Fig. 3 AWE Mini CIDS (a) IS859 System Rack and (b) IS821 Detector Head Assembly.

3.0 Dose and Fluence as a Function of Godiva IV Fission Yield

Measurements under IER-147 have established total neutron and gamma fluence and dose as a function of Godiva IV fission yield at several locations within the Godiva IV cell. A schematic of the IER-147 measurement locations is provided in Fig. 4. It was found that the different measurement locations along the same radial arc all returned the same fluence and dose within the error of the measurements, i.e. there were no asymmetries found in the neutron and gamma fields in the Godiva IV cell. Variations as a function of vertical distance from the floor as well as deviations from a $1/r^2$ drop off in radiation intensity were seen and judged to be a result of "room return" scattering of radiation from the cell walls and floor. Measured radial changes in fluence and dose are provided in Figs 5 through 7. The combined neutron and photon absorbed dose in air for a 70°C burst is provided in Fig. 8. This data can be scaled linearly to any desired burst temperature. The data is accurate for a vertical distance between 115-220 cm above the floor. Adjustments can be made if CAAS detectors need to be positioned outside this vertical range. Note that air kerma is equivalent to absorbed dose in air (the unit of measure specified in ANSI/ANS-8.3.1997) to within a few percent for lower energy neutrons such as those produced in fission. Also, the photon absorbed dose in CaF_2 provided in Fig. 5 is expected to be within a few percent of the absorbed dose in air[3]. These minor differences between the measured doses and absorbed doses in air are essentially negligible in comparison to the magnitude of the excess doses the detectors will be subjected to beyond the Y-12 requirement.

Godiva IV fission yield as a function of temperature rise and excess reactivity is provided in Fig 9. The pulse width as a function of excess reactivity is provided in Fig 10. These relationships can be used to establish the burst yield and pulse width from the measured temperature rise. Conversely, the desired burst yield can be requested as a desired temperature burst and LANL can estimate the excess reactivity needed for that temperature burst with the data in Fig. 9.

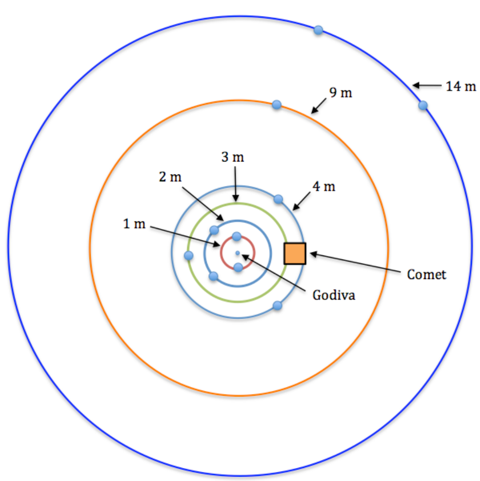


Fig. 4 Stylized schematic of the IER-147 measurement locations in the Godiva IV cell.

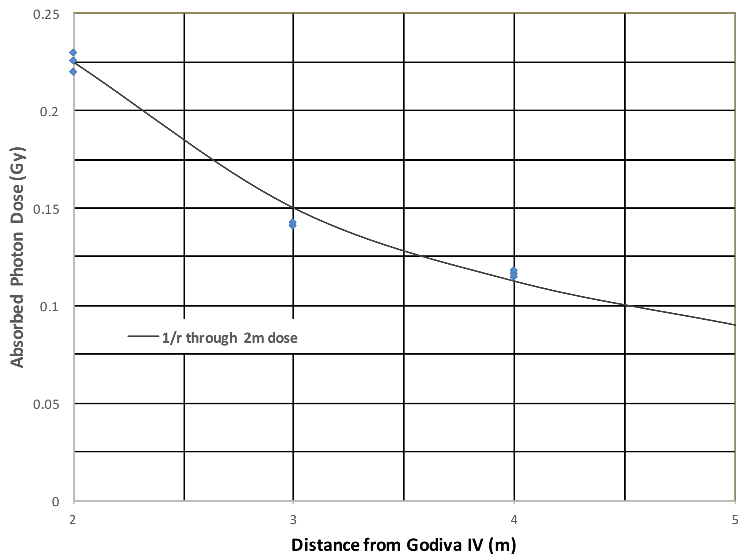


Fig. 5 Measured photon dose as a function of distance from Godiva IV. The results show that the photon dose falls off as 1/r rather than $1/r^2$ indicating a strong room return component to total photon fluence and dose. Data compiled[3] from CaF_2 TLDs for 70°C burst (IER-147 positions 1-9, panel C).

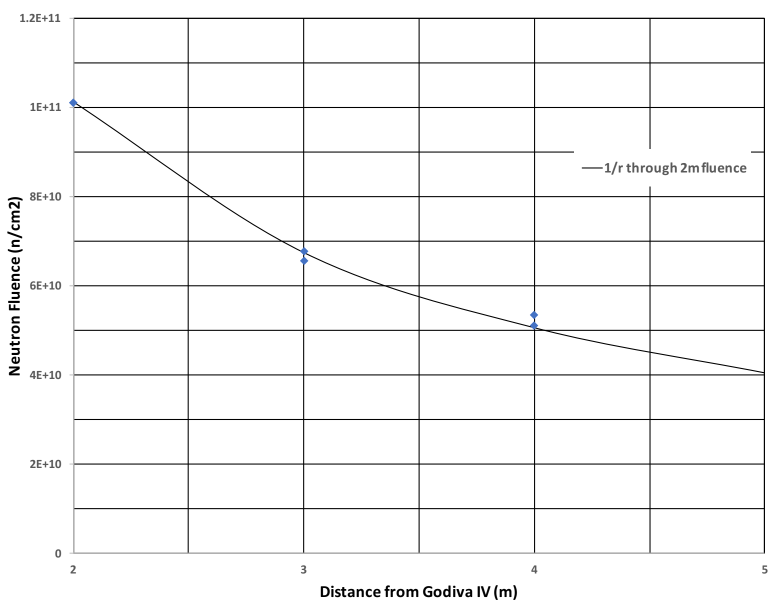


Fig. 6 Measured neutron fluence as a function of distance from Godiva IV. The results show that the neutron fluence falls off as 1/r. Data compiled[4] from passive Bonner Sphere Spectrometer (pBSS) measurements with Au activation normalized to a 70°C burst (IER-147 positions 1-9).

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[3] D. Ward, Sandia National Laboratory, private communication.

[4] Clark, L., and C. Wilson, AWE, private communication.

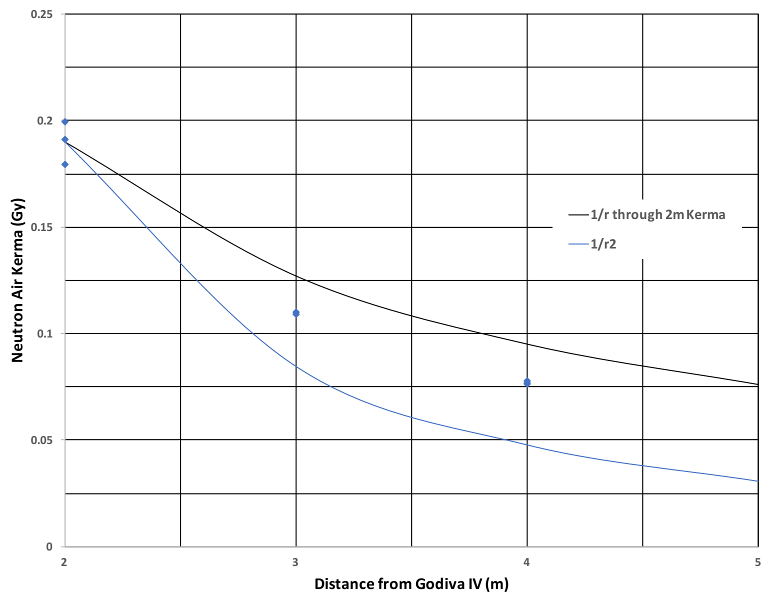

Fig. 7 Measured neutron air kerma as a function of distance from Godiva IV. The results show that the neutron kerma falls off slightly faster than the photon dose shown in Fig. 4. The drop off with distance is between 1/r and $1/r^2$. Data compiled[4] from pBSS detector measurements normalized to a 70°C burst (IER-147 positions 1-9).

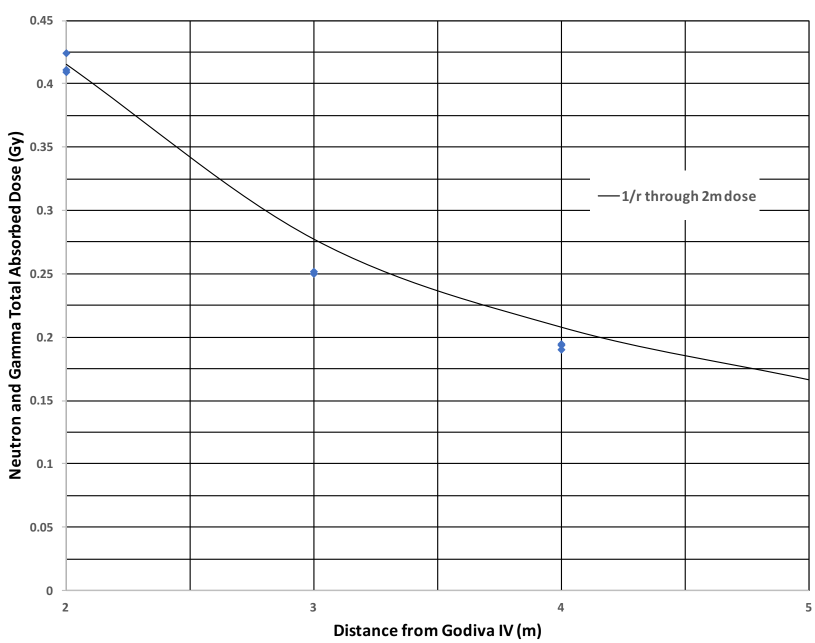

Fig. 8 Combined neutron and photon absorbed dose in air as a function of distance from Godiva IV. The drop off with distance is slightly larger than 1/r. The data is for a 70°C burst and can be scaled linearly to other burst temperatures.

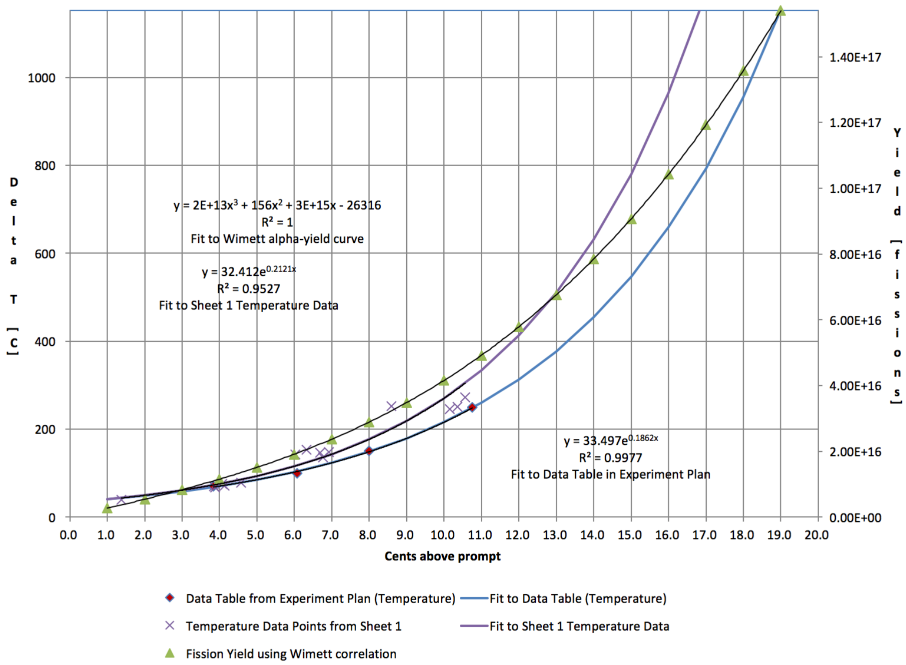

Fig. 9 Relation between fission yield, temperature rise, and excess reactivity for Godiva IV[5]

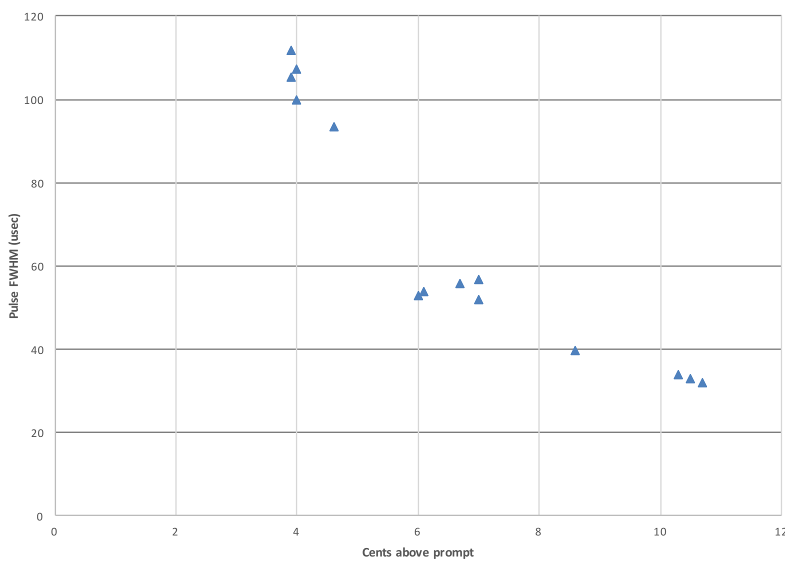

Fig. 10 Relation between burst width and excess reactivity for Godiva IV[5]

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[5] D. Hayes, LANL NEN-2, burst data for Godiva IV at NCERC provided by private communication.

4.0 Test Plan

CAAS Irradiation Plan

The CAAS irradiation plan is provided in Table 1. The duration of the testing is expected to be one week with 1 burst per day and one day for equipment set up and testing within the Godiva IV cell (note that NCERC and DAF typically operate on a 4 day/week work schedule so a total of 3 bursts are included in the plan). Additional testing beyond 1 week is desired to accommodate AWE and perhaps additional testing for Y-12. These tests are currently not scheduled and are pending Godiva IV availability and NCSP priority and funding.

CAAS detectors will be placed along arcs with distances of 2m and 4m from Godiva IV. NAD detectors and TLDs will be placed adjacent to the CAAS detectors. The PNS will be placed at 2m distance for all bursts. Fission yields for the selected burst temperatures have been estimated from Fig. 9. The expected dose and dose rates at 2m and 4m distances have been derived from the 70°C burst data in Fig. 8, where dose has been converted to Rads in air (1 Rad = 0.01 Gy) and scaled linearly to the selected burst temperatures. Dose rates have been estimated as the total absorbed dose delivered within the pulse widths, which have been estimated from Fig. 10. All the expected dose rates in Table 1 are far in excess of the 10 Rad/s dose rate tolerance level specified by Y-12 DSAs.

Loading of the PNS and placement of NADs, TLDs and PICs on mounting plates will be performed at the NAD lab the prior week. Shipment of these items to DAF will occur at the end of the prior week or on the Monday of the test week.

Any electronics equipment that may be sensitive to radiation may be positioned in the adjacent staging room. Measured air kerma values for photons and neutrons at 14 m distance are approximately 6.5 and 8.0 Rad respectively for the largest 220 °C burst with a direct line of sight to Godiva IV. Locations behind the concrete walls without line of sight are expected to have significantly lower radiation levels and should be safe for positioning of sensitive electronics.

The Y-12 CAAS alarm set point is 30 mR/hr. This is likely to be exceeded during the delayed critical calibration of Godiva IV which is part of the burst sequence. Delayed critical is precisely determined prior to each burst in order to establish the precise excess reactivity for the desired burst yield. However, after delayed critical is determined, the safety block is removed and Godiva IV becomes $20 sub-prompt critical and the dose rates drop quickly as delayed fission neutrons and gammas decay. The time period from removal of the safety block to the initiation of a prompt burst is typically 15 min or longer, sufficient for the radiation levels in the cell to drop below the CAAS alarm set point. The Y-12 CAAS detector does not latch into alarm and the alarm signal indicator will turn off once radiation levels fall below the set point. A remote reset of the Y-12 CAAS is therefore not necessary.

Table 1 Godiva IV Burst Irradiation Plan

Test Day	Burst Temp. (ΔT °C)	Fission Yield (x 10^{16} fissions)	Pulse Width (μsec)	Total Absorbed Dose and Dose Rate for Selected Distances			
				2 m		4 m	
				Dose (Rad)	Dose Rate (MRad/s)	Dose (Rad)	Dose Rate (MRad/s)
Monday	Equipment setup and testing, no burst						
Tuesday	**70**	0.93	105	**42**	**0.40**	**19**	**0.18**
Wednesday	**140**	1.9	55	**83**	**1.5**	**39**	**0.71**
Thursday	**220**	2.9	40	**130**	**3.3**	**61**	**1.5**

5.0 Support Equipment

Computers. Y-12 and AWE will supply laptop computers to aid in data acquisition and analysis as necessary. Laptops will be approved for use in DAF by NNSS computer security.

Electrical Test Equipment. Y-12 will supply a Fluke Model 87 Multimeter for testing of the CAAS.

Cables. Ethernet, coax and other necessary cables will be supplied by AWE and Y-12 to make connections between power supplies, detectors, data acquisition systems and the cable junction box located in the Godiva IV cell alcove.

Power Supply. Y-12 will supply two small DC power supplies to power the data logger. The CAAS detectors will be powered from an interface box which will require a 15 A, 120 V electrical supply. electronics enclosure. CAAS detectors and power supplies will be approved for use in DAF through required electrical inspections.

Adjustable Platforms and Stands. LANL will supply adjustable stands to which the CAAS and CIDs detectors can be positioned (equal to the vertical centerline of Godiva IV). LLNL will provide Avenger A5033 Roller 33 Folding Base support stands[6] with LLNL fabricated aluminum arms and support plates for placement of NADs, TLDs and PICS. LLNL will also supply an AWE fabricated PNS stand.

[6] http://www.avenger-grip.com/cms/site/avenger/home/search_product/product_user_search

6.0 Experiment Initiation and Execution (CED-3a,b)

Experiment initiation (CED-3a) will include:

- Obtaining equipment AHJ reviews and assist LANL in revising their NCERC work package to include CAAS detectors and associated test equipment as necessary.
- Assist in the transfer and receipt of equipment to the NNSS and DAF.
- Obtain personnel access and security plans, as necessary, and assist in required training for DAF access.
- Obtain review and approval for use of non-NNSS laptop computers in the DAF.
- Schedule CED-3b execution of prompt supercritical pulse measurements. Currently scheduled for the week of July 17, 2017.

7.0 Publication (CED-4)

The results of the testing will be published in internal Y-12 and AWE reports which may be issued externally at their discretion. A brief final summary report will be published by LLNL to document the testing results for the NCSP. There will be no ICSBEP publication.

8.0 Budget and Scope of IER 443

CAAS testing is one of the approved LLNL tasks under the FY17 NCSP IE budget. The costs for LLNL to provide management and logistical support and measurement of NADs is estimated to be $100k. The needed funding is well within the overall LLNL IE budget and relatively low due in large part to the extensive Godiva IV field measurements already performed under IER-147 and ready to deploy hardware. Participation of Sandia, Y-12 and AWE personnel will be funded by their respective sites. LANL and NSTec funding will come from their respective NCSP IE budgets.