UPF and Y-12 Criticality Accident Alarm System (CAAS) Radiation Testing Report

Uranium Processing Facility Safety Analysis Engineering
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UPF and Y-12 Criticality Accident Alarm System (CAAS) Radiation Testing Report

March 2021

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APPROVALS

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M. R. Buttrey, Preparer | Date

Timothy (TDJ) Jackson Digitally signed by Timothy (TDJ) Jackson
Date: 2021.03.21 07:30:59 -04'00'

T. D. Jackson, Preparer | Date

Jeff L (FQF) Goodman Digitally signed by Jeff L (FQF) Goodman
Date: 2021.03.22 10:54:05 -04'00'

J. L. Goodman, Manager, Enterprise Nuclear Analysis | Date

03/19/21

K. H. Reynolds, Project Engineering Manager, Nuclear Safety Engineering | Date

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0	03/19/2021	Initial Issue.	All

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CAAS	Criticality Accident Alarm System
DAF	Device Assembly Facility
FWHM	full width half maximum
HDPE	high density polyethylene
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
MSTS	Mission Support and Test Services
NAD	Nuclear Accident Dosimeters
NCERC	National Criticality Experiments Research Center
NNSS	Nevada National Security Site
PD	photodiode
PIC	personal ion chamber
rad	radiation absorbed dose
rad(Si)	radiation dose to silicon in rad
SNL	Sandia National Laboratory
TLD	thermoluminescent dosimeter
UPF	Uranium Processing Facility
Y-12	Y-12 National Security Complex

1. INTRODUCTION

This report documents the experimental conditions and results for the testing of the Mirion Technologies CAAS-3S Criticality Accident Alarm System (CAAS) for the Y-12 National Security Complex (Y-12) and Uranium Processing Facility (UPF). The testing was conducted at the Godiva IV Burst Reactor at the National Criticality Experiments Research Center (NCERC) at the Nevada National Security Site (NNSS) during the week of January 11, 2021. The testing was conducted in accordance with 25774-QL-POA-JR00-00002-VDE-27.0, *CAAS-3S Radiation Testing of Cabinet Components Test Plan*. The tests subjected the CAAS-3S system to intense and short duration mixed neutron and gamma radiation fields and to high integrated radiation doses. The purpose of the test was to environmentally qualify various CAAS-3S components in a radiation environment.

Successful completion of the tests was predicated on the collaborative efforts of several organizations. Sandia National Laboratory (SNL) and Lawrence Livermore National Laboratory (LLNL) provided dosimetry to estimate photon and neutron dose. Los Alamos National Laboratory (LANL) manages the NCERC facility, operated the Godiva IV reactor, and provided field support for CAAS-3S placement and communications interface for data acquisition systems supplied by Mirion Technologies. Throughout the test campaign, Y-12 and UPF personnel provided technical support in determining changes to the test schedule, as needed, interpretation of the results, and comparison between the measured dosimetry data and predicted results. Throughout the test campaign, Mirion personnel provided technical support in the operation of the CAAS-3S system itself.

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2. REQUIREMENTS AND SCOPE

The intent of the testing campaign was to test the function of the Mirion CAAS-3S system in a high radiation dose-rate and high integrated dose environment. The UPF requirement evaluated for this testing campaign is for the CAAS control cabinet components to be tested to demonstrate functionality when subjected to the minimums values shown in Table 1.

Table 1. UPF Cabinet Radiation Tolerance Requirements (25774-QL-POA-JR00-00002-VDE-27.0)

Requirement
Fluence: 1 MeV equivalent neutron fluence of at least 6.0 x 10^9 n/cm^2.
Dose: neutron dose of at least 0.5 rad(Si) and photon dose of at least 25 rad(Si).
Dose Rate: neutron dose rate of at least 4.0 x 10^2 rad(Si)/s and photon dose rate of at least 2.4 x 10^4 rad(Si)/s.

As part of the test plan, reactor operating parameters were set to meet all of the acceptance criteria and, to the extent possible, test the integrated fluence (and dose) criteria and dose rate criteria separately. Y-12 did not specify dose or dose rate criteria during procurement that required qualification during the testing campaign, and collaborated with UPF personnel in the determination of cabinet locations and reactor operating parameters in the test plan. In the selection of equipment location and reactor operating parameters, doses and dose rates exceeding the requirements were intentionally selected.

A specific detector probe location was not identified as part of the test-plan, although dosimetry was identified as included with the detector probes. A set of detector probes was placed in the criticality room, and the position of the probes recorded.

3. GODIVA DESCRIPTION

All irradiations were performed with the Godiva-IV reactor at the National Criticality Experiments Research Center (NCERC), located on the Nevada National Security Site (NNSS). Godiva-IV is located within the NCERC in the Device Assembly Facility (DAF) at NNSS.

Godiva-IV is a bare cylindrical assembly of approximately 65 kg of highly enriched uranium fuel (93.2% U-235 metal alloyed with 1.5% molybdenum for strength). The assembly is designed to perform controlled prompt critical excursions and can be used for controlled steady-state critical operations. The magnitudes of Godiva operations are typically described in different parameters (e.g. temperature rise and amount of reactivity insertion) than are generally used in the design and qualification of the CAAS system as Y-12 and UPF. As part of a previous experiment, the integrated fissions for two bursts were measured. From this, a relationship between temperature rise (ΔT in °C) and number of fissions was generated:

$$Fissions\ = 1E14 * \Delta T - 2E14$$

This is a derived value, not directly measured, but useful to rapidly convert reactor parameters in burst operations to units more applicable to analysis of CAAS systems.

For all operations, reactor parameters were measured using diagnostic equipment used as part of routine operations with Godiva-IV. In particular, the temperature rise during the pulse was measured by thermocouples attached to the fixed block and safety block, and the pulse width, measured in full width half maximum (FWHM). A Hamamatsu photodiode (PD) was used to measure the pulse width. Preliminary fits for FWHM were read on-site during the testing campaign, and more accurate readings for FWHM from the Hamamatsu PD were obtained by fitting the readout in an excel sheet. In practice, the fit and on-site read were nearly identical, and the fit is considered the official record of the pulse width.

Before the test, estimates of the integrated fissions per irradiation were generated based on historical test data with Godiva-IV. The number of fissions in each irradiation were provided by the Godiva-IV operators after the test campaign was completed.

For burst operations, super-prompt bursts are numbered sequentially in the log-book. The sub-prompt and steady state irradiations are not numbered, but are identifiable based on their date/time. The burst identification number does not impact the reactor parameters or radiation field, but is included for identification of the irradiation(s) and ease of communication between groups and organizations.

For some irradiations, the reactivity insertion was provided. Consistent with characterization of reactivity insertions, the units provided were in cents. Preliminary fits of the reactivity insertion were generated during the test campaign, and final values were provided after the test by LANL personnel.

4. EQUIPMENT CONFIGURATION

The CAAS cabinets (UPS, Processing, and Alarm cabinets) were positioned inside the reactor anteroom within the line of sight of Godiva. The back of the cabinets faced the Godiva reactor to allow personnel access to the front for equipment operation, readout, and diagnostics. A 2 in. thick high density polyethylene (HDPE) shield wall was placed between the cabinets and the entrance to the reactor room. The locations of the CAAS-3S equipment are shown in Figure 4.1.

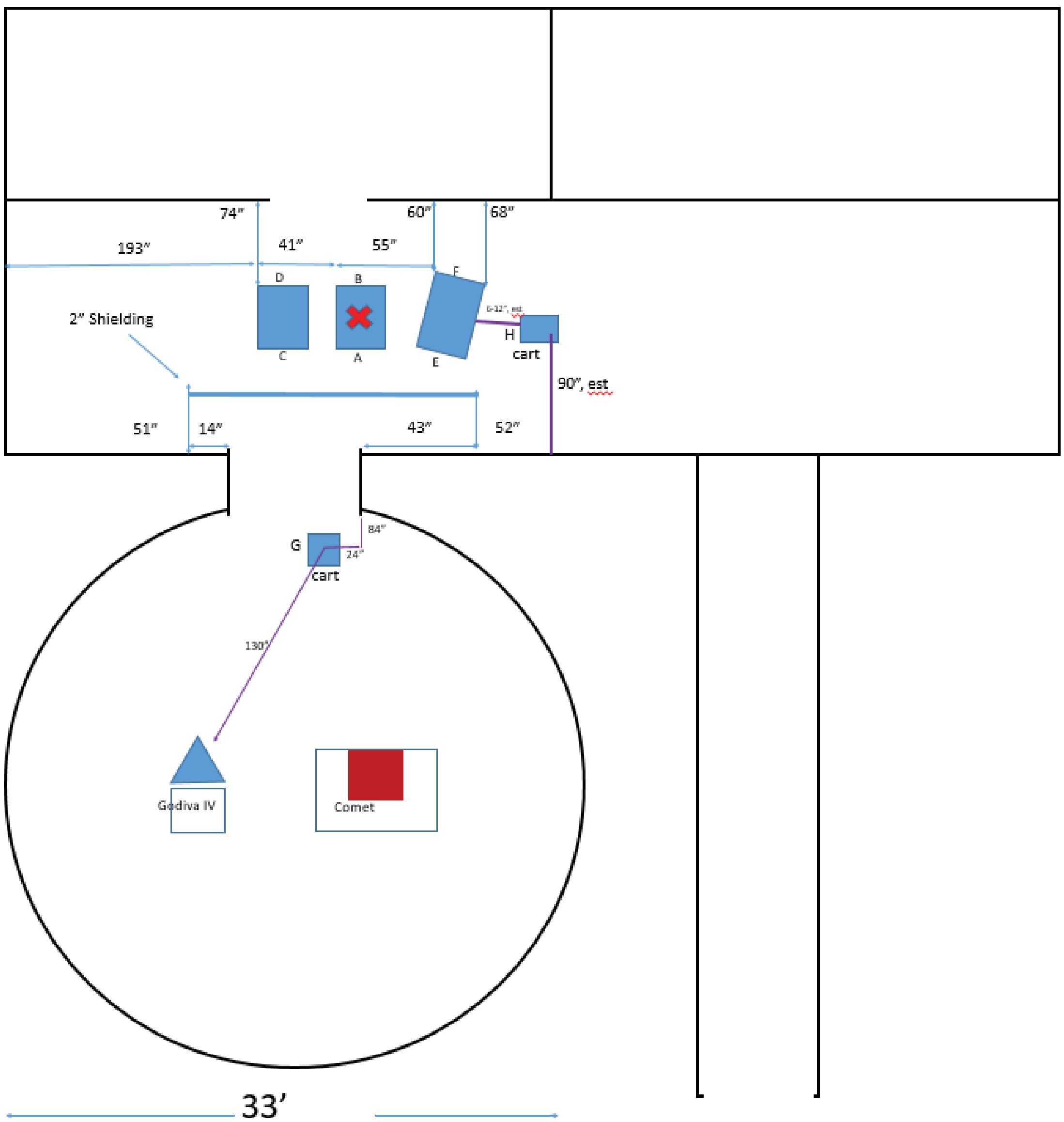

Figure 4.1. Equipment Locations, Positions Marked.

The specific locations of the cabinets and shield wall are shown in Figure 4.2, and pictures of the cabinet setup are shown in Figure 4.3.

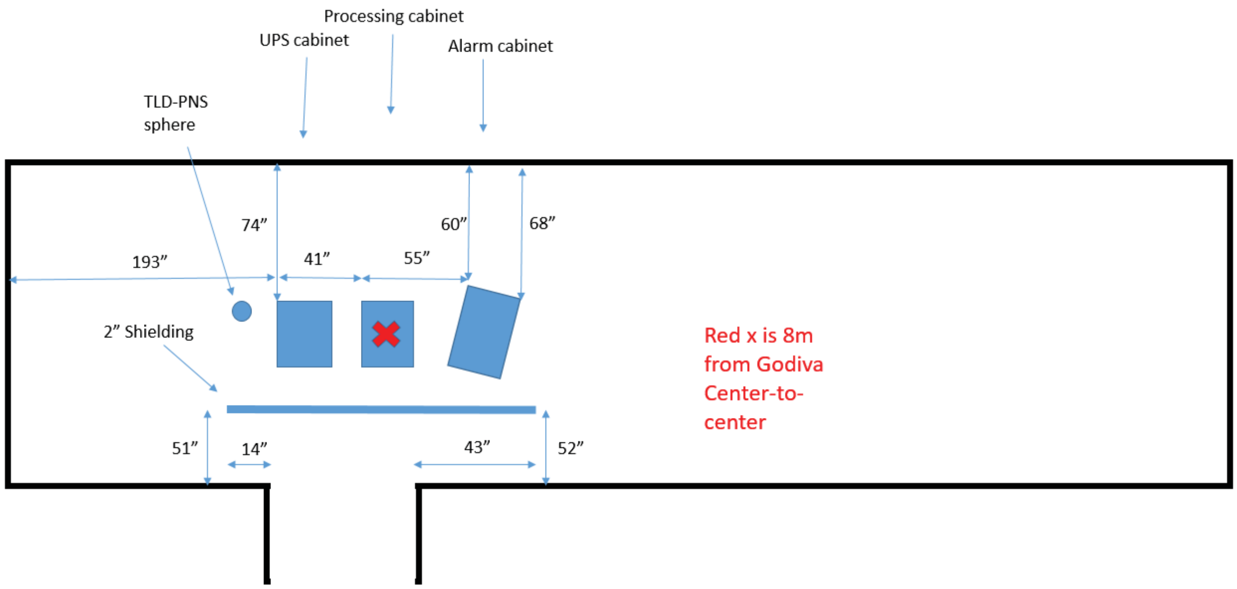

Figure 4.2. CAAS-3S Cabinet Locations in the Ante-room.

Figure 4.3. Pictures of Equipment Setup.

This equipment configuration was used for all irradiations except for Irradiation 4 (133°C burst), which relocated the cart, *G*, containing the detector probes, to outside of the reactor room. The equipment layout for Irradiation 4 is shown in Figure 4.4. This was done due to high background radiation above the alarm setpoint in the reactor room. The equipment configuration was returned to its original configuration for Irradiation 5 (250°C burst).

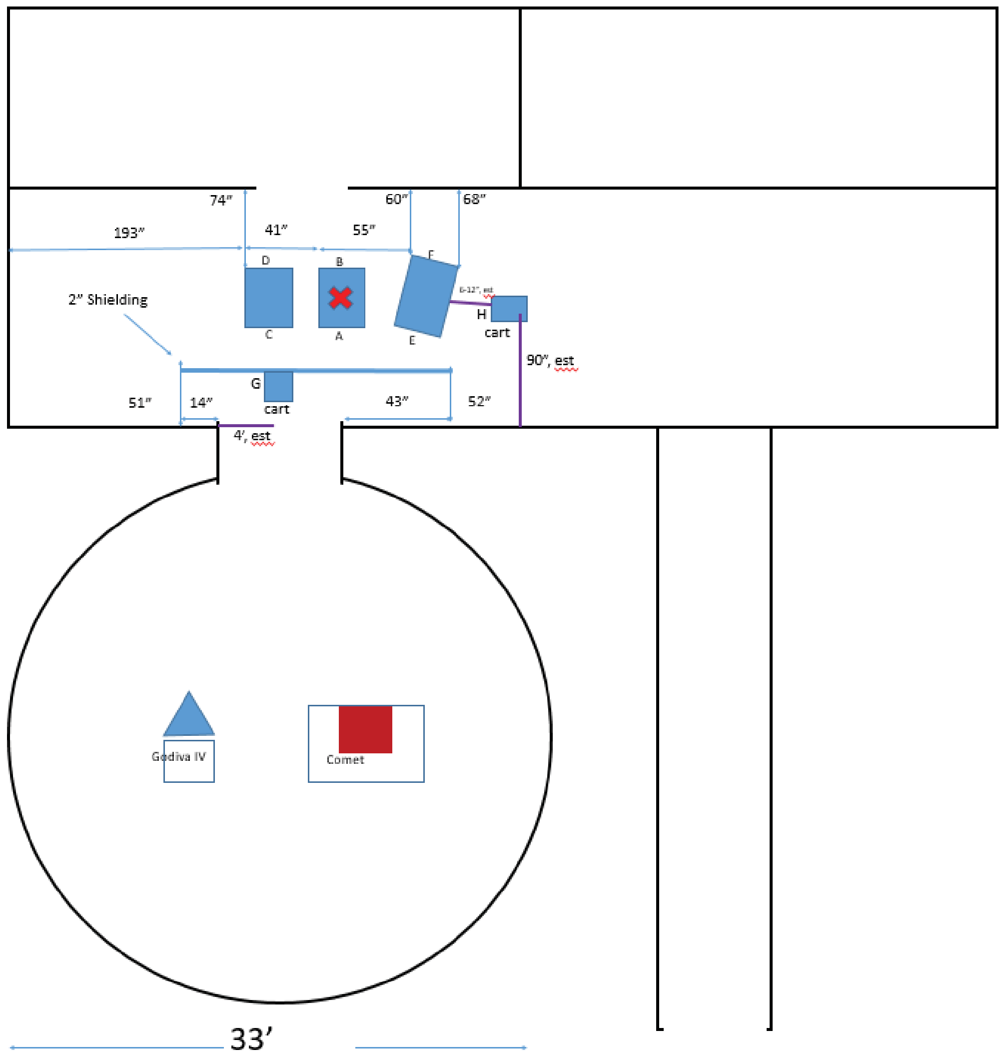

Figure 4.4. Equipment Layout for Irradiation 4.

For all operations, remote mirroring of the computer component of the processing cabinet allowed for monitoring of the dose rate detected by the probes and remote operation of the processing cabinet, including resetting of the system. A television monitor was setup on the morning of day 2 which allowed for additional visual confirmation of strobe activation beyond the field of view of the cameras normally used for Godiva operations.

Figure 4.5. Remote Monitor.

4.1 DOSIMETRY

Dosimetry was included at a number of locations, corresponding to equipment locations. The type and location of each dosimeter is included in Table 2. Each dosimeter provides different information about the radiation field and dose received to the equipment.

- LANL provided Pocket Ionization Chambers (PIC) for immediate measurement of dose.
- LLNL provided Nuclear Accident Dosimeters (NAD), Panasonic neutron thermoluminescent dosimeters (TLDs), and CR-39 personnel neutron dosimeters.
- Mission Support and Test Services (MSTS) provided combo dosimeters that measured effective dose for both neutrons and gamma-rays.
- SNL provided the CaF2 gamma detectors.

Table 2. Number of Dosimeters at Each Location

Location	Description	MSTS Combo (n, γ)	LLNL NAD (n)	LLNL Panasonic (thermal n)	LLNL CR-39 (fast n)	PIC (γ)	SNL CaF_2 (γ)
A	Processing Cabinet Back	3	3	3	3	2	5
B	Processing Cabinet Front	3	3	3	3	2	5
C	Power Supply Cabinet Front	3	3	3	3	2	5
D	Power Supply Cabinet Front						5
E	Alarm Cabinet Back	3	3	3	3	2	5
F	Alarm Cabinet Front						5
G	Probes on Cart		3	3	3		5
H	Horns, Strobes, and Probes on Cart	3					5
Total per Burst		15	15	15	15	8	40

Two personal ion chamber (PIC) dosimeters were included at each location, one scaled for 0-100 rad and the other scaled for 0-200 rad. The uncertainty in PIC measurement was not recorded, and it was assumed that the 0-100 scale PIC would provide more accurate data than the 0-100 scale PIC. In practice, differences between PIC readings were either negligible or attributed to not ensuring a set was zeroed in one instance. Some irradiations included PIC dosimeters in locations G or H.

The MSTS combination dosimeters were located in position G for the first irradiation.

Each dosimeter used provides different information about the radiation field at the dosimetry location, and the uncertainty in each dosimetry measurement was unclear. Furthermore, some dosimeters provide only limited information about a section of the spectra, such as CR-39 being only useful for considering the fast neutron dose, and other dosimeters are accurate only after a minimum threshold of radiation dose. The actual dose, particle ratio, and energy distribution received at each dosimetry location is based on not just a single dosimeter, but from review of the entire set of dosimetry data.

5. TESTS AND OBSERVATIONS

All operations with the critical assemblies at NCERC (Godiva, Planet, etc) are proceduralized, with everything documented in the log book. For Godiva burst operations, a basic procedure outline is:

1. Begin at a scrammed, strongly subcritical reactivity.
2. Raise the safety block to standard position.
3. Set control rod heights to a delayed critical.
4. Reset the control rod heights to a delayed super-critical position corresponding to the desired burst (<15 cents).
    a. Note: by this point, the dose rate generally exceeds the setpoint of the probes. It can be done at a lower power, but that requires high level of control by the reactor operators.
5. Drop the safety block, notify the facility operations control that burst operations have been entered, wait at least 15 minutes to reduce neutron background.
6. Raise the safety block to burst position, rapidly inset burst rod (1 dollar worth).
7. Burst happens, reactor scrams.

Steady state operations differ from burst operations in that only steps 1-4 are performed, with the reactor power controlled through the manipulation of control rod heights. During steady state operations, the primary source of feedback is due to temperature rise in the reactor which the operators compensate for by continuously adjusting the control rods. Therefore, the reactor power is not a constant value, and is referred to by an approximate value in this report.

Fissions were calculated from the temperature rise based on the relationship discussed in Section 3.

5.1 DAY 1 (1/11/2021)

The morning of Day 1 was spent performing logistical tasks, familiarizing testing campaign personnel with the facility and equipment, and verifying that the equipment setup was consistent with the test plan. Measurements of equipment locations, verification of facility dimensions, and other measurements were completed prior to any irradiations. Two cameras were initially included in the testing, one located within the criticality room and oriented to face the reactor, and one within the ante-room and rotatable to face a mirror allowing for indirect viewing of the reactor. The camera in the ante-room could rotate, and initially view one strobe. It was difficult to differentiate between the visible strobe and the reflection of a facility alarm strobe located on the wall of the ante-room. It was not apparent at this time that there was no visual confirmation, such as a camera that could see all of the strobes, that the system alarmed. Audio confirmation of an alarm (horns) was available through speakers located within NCERC.

The planned burst (Irradiation 1) for the afternoon of Day 1 was a 70°C burst. The measured parameters and reactor output for irradiation 1 are included in Table 3 and Figure 5.1. The dosimetry locations are shown in Figure 5.2.

Table 3. Measured Reactor Parameters for Irradiation 1

Parameter	Value
Pulse Number	2055
Temperature Rise	71.9 °C
FWHM (preliminary fit)	154 µs
FWHM (fit)	149 µs
Fissions	1.10E+16
Reactivity	102.7 cents

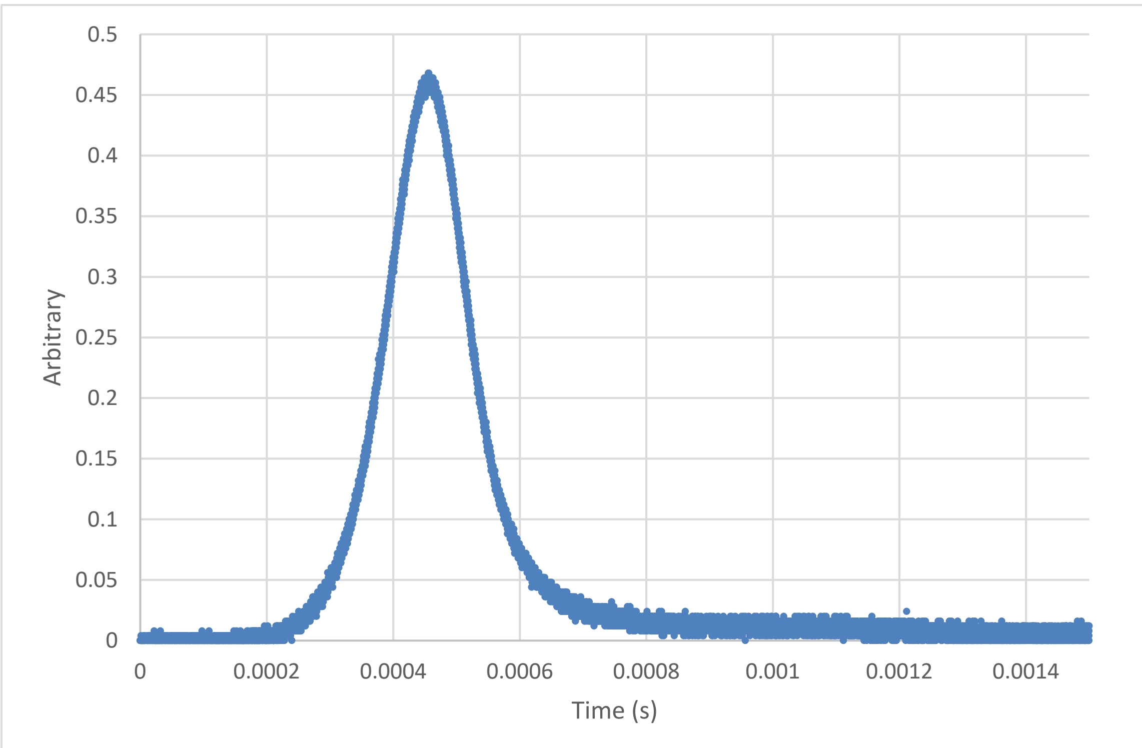

Figure 5.1. Reactor Output for Irradiation 1.

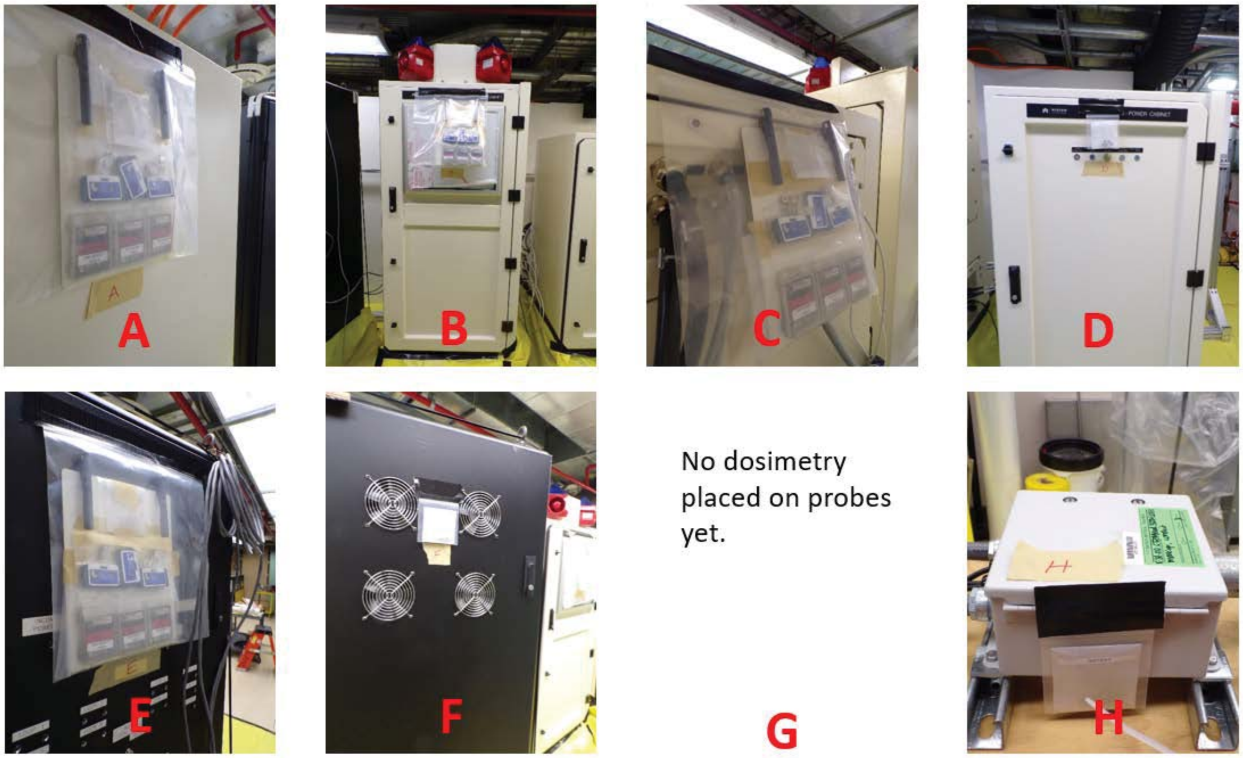

Figure 5.2. Dosimetry Locations for Irradiation 1.

The CAAS-3S system initialized an alarm (horns) during the setup criticality, which was remotely acknowledged and the system reset. The CAAS-3S system alarmed immediately after the pulse as confirmed by the horns alarming. The PC component of the system shut down after the pulse, and could not be remotely regained. LANL personnel entered the ante-room, terminated alarms, and placed the system into a non-alarming state for the next day.

5.2 DAY 2 (1/12/2021)

The status of the system was determined by Mirion personnel. They indicated that the PC rebooted without failure, that Safety PLC A was not functional, and that the system would be able to operate on Safety PLC B alone. It was determined to perform a sub-prompt burst in the morning and a steady-state irradiation in the afternoon.

The measured reactor parameters for the sub-prompt burst and reactor output are included in Table 4 and Figure 5.3.

For the sob-prompt bursts and steady-state runs, the number of fissions were calculated from the fission to amp-sec relationship (7E+18 fissions/amp-sec) discussed in Appendix A. The radiation components received from the sub-prompt bursts is negligible compared to the primary irradiations.

Table 4. Measured Reactor Parameters for Sub-Prompt Burst Day 2

Parameter	Value
Start Time (pst)	11:40 am
Integrated Power (amp-sec)	1.40E-07
Fissions	9.80E+11

The system alarmed immediately during the sub-prompt burst, as indicated by the PC in the processing cabinet and confirmed by the actuation of the horns. After the burst, the alarm was acknowledged and the system was remotely reset.

The measured reactor parameters and reactor output for the steady-state irradiation are included in Table 5 and Figure 5.3. The dosimetry locations are shown in Figure 5.4.

Table 5. Measured Reactor Parameters for Irradiation 2 (Steady-State)

Parameter	Value
Start Time (pst)	12:50 pm
End Time (pst)	13:31 pm
Integrated Power (amp-sec)	1.24E-03
Duration (min)	41
Fissions	8.68E+15

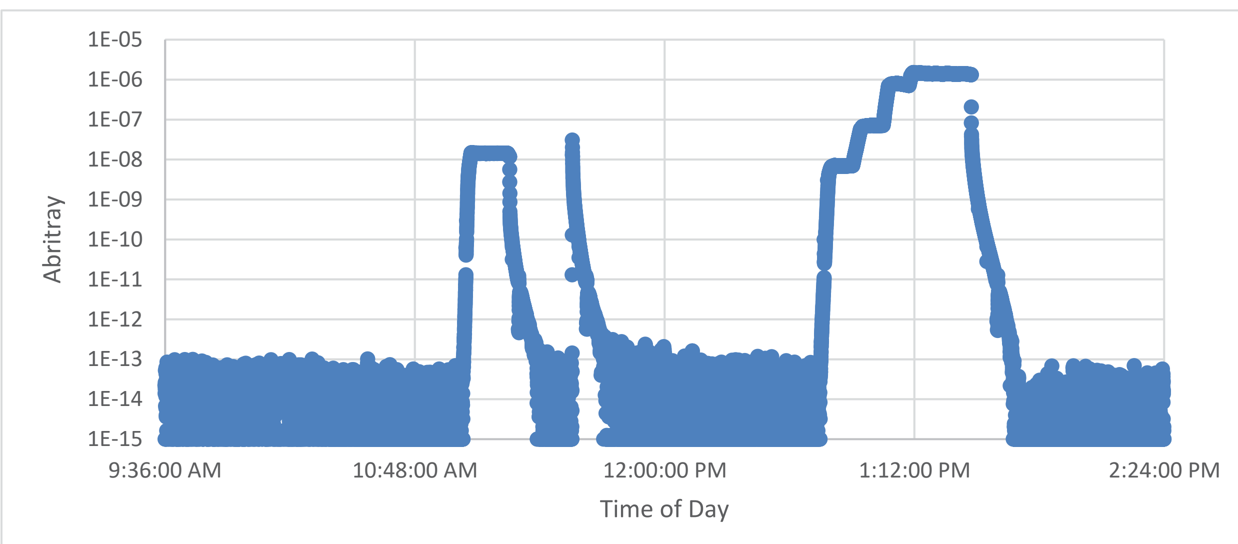

Figure 5.3. Sub-prompt Burst and Steady State Run on 1/12/21.

Figure 5.4. Dosimetry Locations for Irradiation 2.

During this steady-state irradiation, the power level was increased every few minutes as can be seen in Figure 5.3. After 40 minutes, the PC in the processing cabinet shut itself down, and the irradiation was terminated. When the dose rate exceeded the alarm setpoint, the system immediately initiated an alarm, as indicated by the PC in the processing cabinet and confirmed by the actuation of the horns. After the PC shut itself down, the system continued to alarm until the alarm was manually terminated.

5.3 DAY 3 (1/13/2021)

Prior to any irradiations, a camera was mounted in the ante-room, allowing for direct viewing of the processing cabinet and the table with horns and strobes, which was slightly moved to allow for viewing from multiple cameras. The PC in the processing cabinet was reset. It was decided to perform a sub-prompt burst and a steady-state irradiation up to the maximum allowed temperature rise in the morning and an intense burst of 130 °C in the afternoon.

The measured reactor parameters and reactor output for the sub-prompt burst are included in Table 6 and Figure 5.5.

Table 6. Measured Reactor Parameters for Sub-Prompt Burst Day 3

Parameter	Value
Start Time (pst)	10:22 am
Integrated Power (amp-sec)	1.30E-07
Fissions	9.10E+11
Reactivity	97.2 cents

The system alarmed immediately during the sub-prompt burst, as indicated by the PC in the processing cabinet and confirmed by the actuation of the horns. After the burst, the alarm was acknowledged and the system was remotely reset.

The measured reactor parameters and reactor output for the steady-state irradiation are included in Table 7 and Figure 5.5. The dosimetry locations are shown in Figure 5.6.

Table 7. Measured Reactor Parameters for Irradiation 3 (Steady-State)

Parameter	Value
Start Time (pst)	10:36 am
End Time (pst)	11:04 am
Integrated Power (amp-sec)	5.65E-03
Duration (min)	28
Fissions	3.96E+16

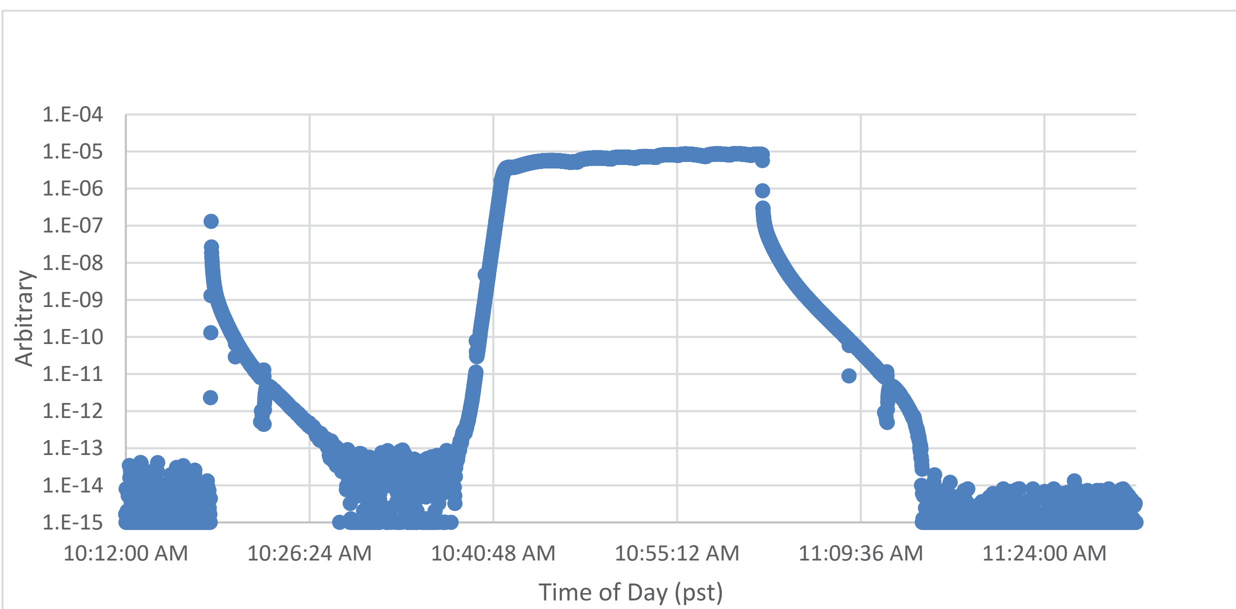

Figure 5.5. Sub-prompt Burst and Steady State Run on 1/13/21.

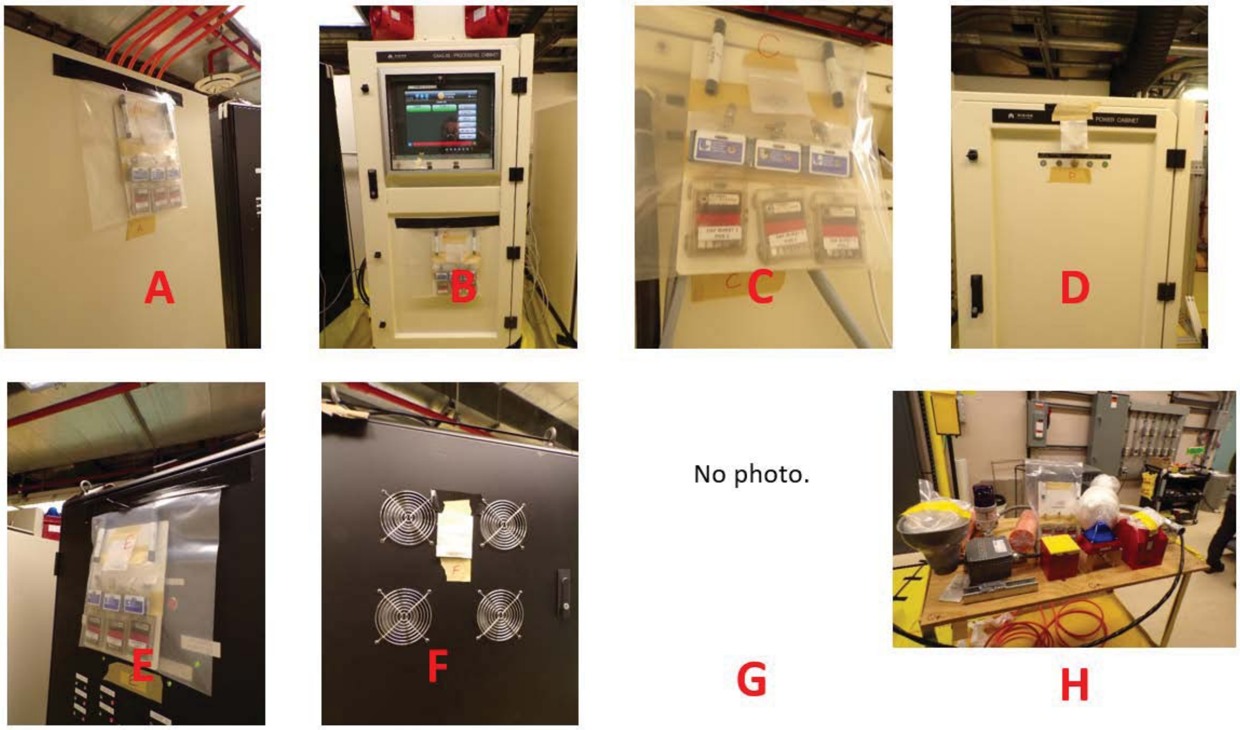

Figure 5.6. Dosimetry Locations for Irradiation 3.

After approximately 11 minutes of irradiation, the PC in the processing cabinet shut itself down. The irradiation continued until the reactor reached a temperature of 166°C. During this irradiation, when the dose rate exceeded the alarm setpoint, the system immediately initiated an alarm, as indicated by the PC in the processing cabinet and confirmed by the actuation of the horns. The strobes did not actuate during this irradiation. Because visual verification of strobe actuation was unavailable until this irradiation, it was concluded that strobe circuit or the strobes themselves were non-functional. After the PC shut itself down, the system continued to alarm until the alarm was manually terminated. The strobes were disconnected from the alarm cabinet and reconnected through a previously unused circuit (relay). After the irradiation, the dose rate in the criticality room remained above the setpoint for the probes. The probes in the criticality room were relocated to in the ante-room between the shield wall and the criticality room.

The planned burst (Irradiation 4) for the afternoon of Day 3 was a 130°C burst. The measured parameters and reactor output for irradiation 4 are included in Table 8 and Figure 5.7. The dosimetry locations are shown in Figure 5.8.

Table 8. Measured Reactor Parameters for Irradiation 4

Parameter	Value
Pulse Number	2056
Temperature Rise	133°C
FWHM (preliminary fit)	55.6 μs
FWHM (fit)	55 μs
Fissions	2.00E+16
Reactivity	106.8 cents

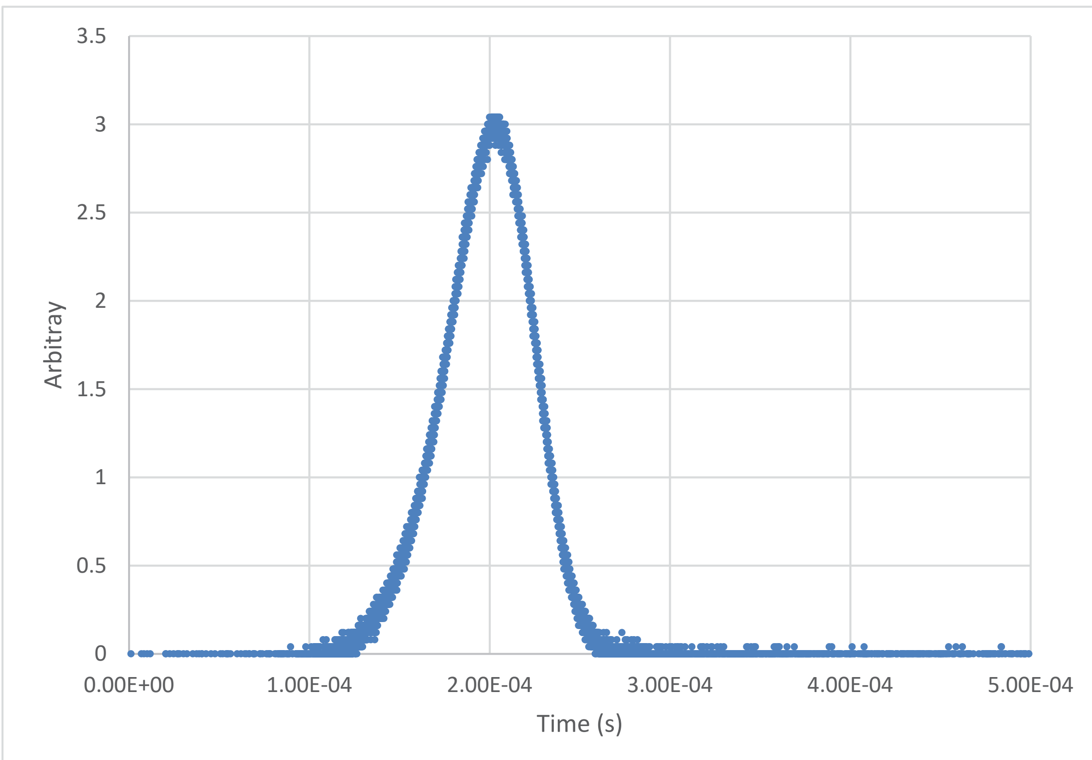

Figure 5.7. Reactor Output for Irradiation 4.

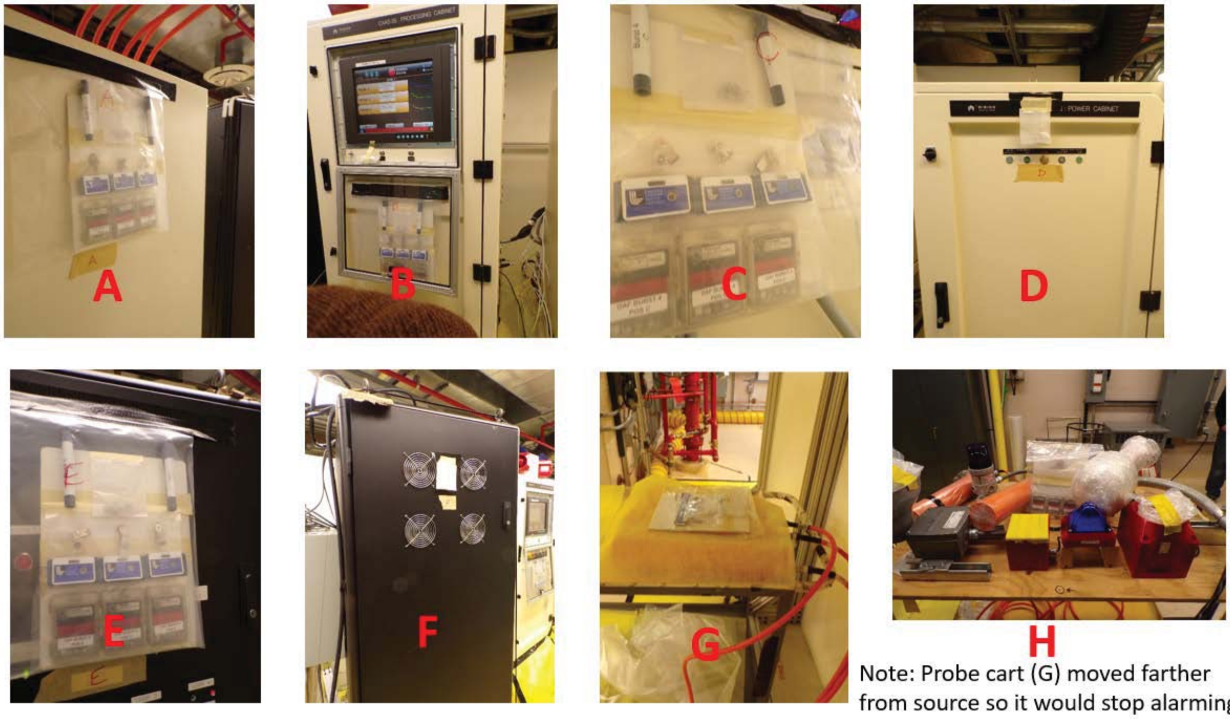

Figure 5.8. Dosimetry Locations for Irradiation 4.

The CAAS-3S system initialized an alarm (horns) during the setup criticality, which was remotely acknowledged and the system reset. The CAAS-3S system alarmed immediately after the pulse as confirmed by the horns alarming and visual confirmation of the strobes alarming. The PC component of the system shut down after the pulse, and could not be remotely regained. LANL personnel entered the ante-room, terminated alarms, and placed the system into a non-alarming state for the next day.

5.4 DAY 4 (1/14/2021)

Prior to any irradiations, the probes that were relocated for Irradiation 4 were returned to their original positions. The planned burst (Irradiation 5) for the morning of Day 4 was a 250°C burst. The measured parameters and reactor output for irradiation 5 are included in Table 9 and Figure 5.9. The dosimetry locations are shown in Figure 5.10.

Table 9. Measured Reactor Parameters for Irradiation 5

Parameter	Value
Pulse Number	2057
Temperature Rise	250 °C
FWHM (preliminary fit)	38.7 μs
FWHM (fit)	36 μs
Fissions	4.00E+16
Reactivity	111 cents

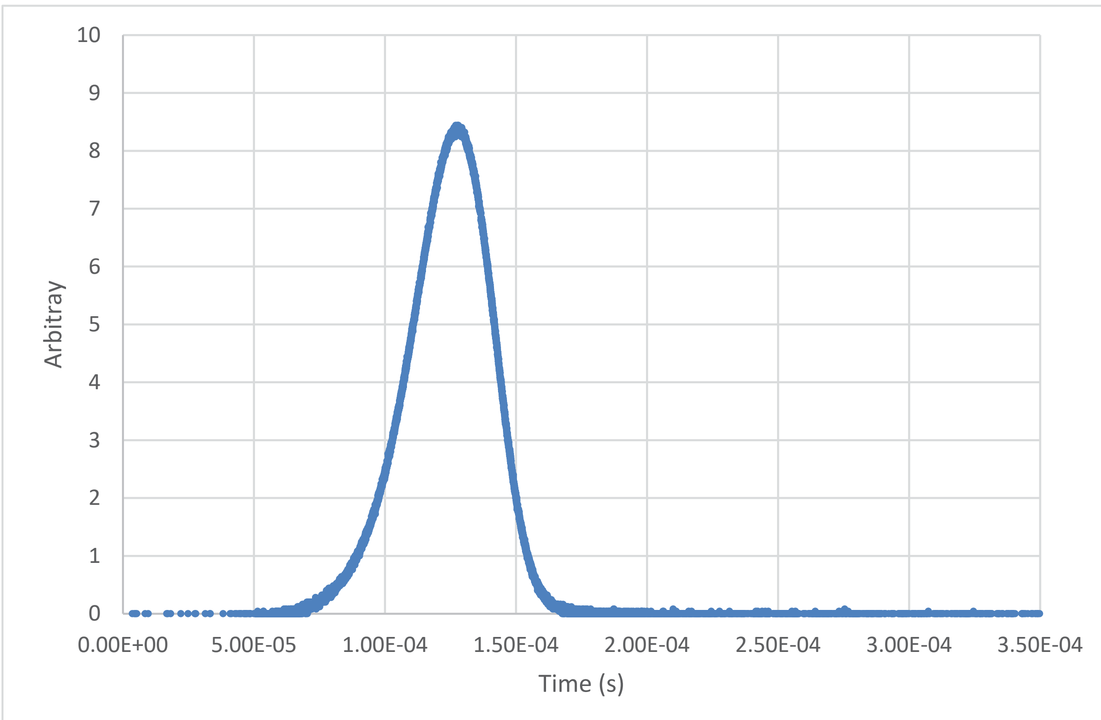

Figure 5.9. Reactor Output for Irradiation 5.

Figure 5.10. Dosimetry Locations for Irradiation 5.

The CAAS-3S system initialized an alarm (horns) during the establishment of delayed critical. The PC in the processing cabinet entered a fault state, and could not be remotely reset. After performing an auto-run out to shut down Godiva, personnel reentered the ante-room to reset the PC. A second establishment of delayed critical was performed, with the reactor power kept sufficiently low during this criticality so as to not initiate an alarm. Then, the burst was performed. The CAAS-3S system alarmed immediately after the pulse as confirmed by the horns alarming and visual confirmation of the strobes alarming. The PC component of the system shut down after the pulse, and could not be remotely regained. LANL personnel entered the ante-room, terminated alarms, and placed the system into a non-alarming state.

6. DOSIMETRY DATA

Dosimetry data was included for each irradiation. Some dosimetry data, specifically the PIC data, was immediately available, while other data (LLNL NAD was available shortly after the conclusion of the testing campaign. The measured dosimetry information for each irradiation are included in Table 10 through Table 14. Not all dosimetry types were included at each measurement location. For locations identified, "Proc" corresponds to the processing cabinet, "Powr" corresponds to the power supply cabinet, "Alrm" corresponds to the alarm cabinet, and "Reac" corresponds to the probes location in the criticality room. LL* indicates that the measured dose was below the lower limit of detectability.

Table 10. Irradiation 1 Dosimetry Data

		PIC	PIC	Sandia CaF_2		LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, rad-air	γ, Gy (Si)	%error	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem	fast n, rem
Location	Comment	0-100	0-200				rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	5	5	2.85E-02	6.5	0.840	3.7	3.7	3.1	37.6	2.3	23201	4.097	23.201	25.8
B	Proc, Front	2	2.5	1.09E-02	14	1.130	1.6	1.6	1.3	8.9	0.5	12006	2.081	12.006	17.0
C	Powr, Back	4	5	2.90E-02	6.4	0.269	4	4	3.4	42.6	2.6	31939	4.295	31.939	24.9
D	Powr, Front			8.43E-03	17.8										
E	Alrm, Back	1	2	1.75E-02	9.6	0.732	2.7	2.7	2.3	26	1.6	16124	2.863	16.124	21.0
F	Alrm, Front			8.03E-03	18.5										
G	Reac, Prob			1.40E-01	4.1	1.770	18.7	18.7	15.6	189.5	11.7	321786	20	321.786	
H	Horn/Light	0.5	0.5	LL*	N/A										

Table 11. Irradiation 2 Dosimetry Data

		PIC	PIC	Sandia CaF_2		LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, rad-air	γ, Gy (Si)	%error	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem	fast n, rem
Location	Comment	0-100	0-200				rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	3	3	1.41E-02	10.9	9.14E-01	2.5	2.5	2.1	23.4	1.4	40033	2.516	40.033	17.4
B	Proc, Front			5.69E-03	25.3	4.98E-01	1	1	0.8	5.6	0.3	7350	1.309	7.35	11.9
C	Powr, Back	2	2	1.40E-02	11.2	5.42E-01	2.5	2.5	2.1	27.7	1.7	19896	2.586	19.896	15.7
D	Powr, Front			LL*	N/A										
E	Alrm, Back	2	1	8.04E-03	18.5	3.77E-01	1.7	1.7	1.4	17.7	1.1	9212	1.732	9.212	13.3
F	Alrm, Front			LL*	N/A										
G	Reac, Prob	22	20	7.20E-02	4.24	1.03E+00	14	14	11.7	152.7	9.4				
H	Horn/Light			LL*	N/A							4784	0.617	4.784	

Table 12. Irradiation 3 Dosimetry Data

		PIC	PIC	Sandia CaF_2		LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, rad-air	γ, Gy (Si)	%error	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem	fast n, rem
Location	Comment	0-100	0-200				rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	13	12	8.25E-02	4.5	5.77E-01	12.4	12.4	10.3	111.9	6.9	63547	11.585	63.547	21.1
B	Proc, Front	5	8	4.22E-02	5.2	4.04E-01	4.6	4.6	3.8	27	1.7	29461	6.233	29.461	18.8
C	Powr, Back	12	12	8.69E-02	4.5	6.53E-01	12.9	12.9	10.8	118	7.3	86725	11.836	86.725	20.5
D	Powr, Front			3.32E-02	5.5										
E	Alrm, Back	11	10	5.86E-02	4.6	4.93E-01	7.4	7.4	6.2	71.3	4.4	39709	7.707	39.709	9.6
F	Alrm, Front			3.02E-02	5.8										
G	Reac, Prob			3.76E-01	3.8	5.45E+00	56.7	56.7	47.3	560.5	34.6				
H	Horn/Light	1	3	1.42E-02	8.6							19457	2.094	19.457	

Table 13. Irradiation 4 Dosimetry Data

		PIC	PIC	Sandia CaF_2		LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, rad-air	γ, Gy (Si)	%error	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem	fast n, rem
Location	Comment	0-100	0-200				rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	7.5	5	5.95E-02	4.4	1.11E+00	7.7	7.7	6.4	78	4.8	44206	8.026	44.206	12.2
B	Proc, Front	5	5	3.09E-02	6.1	3.00E-01	3.4	3.4	2.8	23.3	1.4	21773	3.897	21.773	38.1
C	Powr, Back	8	40	6.13E-02	4.3	1.72E+00	9.6	9.6	8	88	5.4	51422	9.312	51.422	18.6
D	Powr, Front			2.29E-02	7.8										
E	Alrm, Back	6	10	4.11E-02	5.3	3.07E-01	5.9	5.9	4.9	46.3	2.9	31228	5.723	31.228	15.8
F	Alrm, Front			2.30E-02	7.7										
G	Reac, Prob			1.08E-01	4.3	9.05E-01	16.1	16.1	13.4	187.3	11.6				
H	Horn/Light	0	0	1.08E-02	14							15236	1.603	15.236	

The two PIC dosimeters strongly disagree for location C. The cause of this is unlikely to be due to variation in the dose received by each dosimeter and is likely due to not zeroing a dosimeter. A similar behavior, although not as pronounced, is seen in location E. In this case, the 0-100 rad PIC data is assumed to be more reliable.

Table 14. Irradiation 5 Dosimetry Data

		PIC	PIC	Sandia CaF_2		LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, rad-air	γ, Gy (Si)	%error	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem	fast n, rem
Location	Comment	0-100	0-200				rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	11	15	1.16E-01	4.4	6.08E-01	17.8	17.8	14.9	158.2	9.8	78663	15.628	78.663	14.9
B	Proc, Front	6	5	5.56E-02	4.7	2.56E-01	5.9	5.9	4.9	35.3	2.2	41587	7.209	41.587	22.1
C	Powr, Back	10	10	1.19E-01	4.3	5.46E-01	19.1	19.1	15.9	157.5	9.7	99111	15.955	99.111	20.8
D	Powr, Front			4.25E-02	5.2										
E	Alrm, Back	9	10	7.52E-02	4.6	4.70E-01	10.6	10.6	8.8	86.6	5.3	50293	10.481	50.293	18.8
F	Alrm, Front			4.35E-02	5.2										
G	Reac, Prob			5.03E-01	3.9	6.21E+00	94.7	94.7	79	995.5	61.4				
H	Horn/Light	5	8	1.88E-02	7.7							24949	2.906	24.949	

The CAAS equipment received an integrated dose during the test campaign. The integrated doses, as determined by the dosimetry data, are included in Table 15. Due to limitations in data acquisition, including not all dosimeters being used or readable during each irradiation. The integrated dosimetry data is provided as a quick estimate of the total dose received by the equipment during the irradiations. Most of the dosimetry data cannot be directly compared to the qualification requirements, which are in rad-si or 1-MeV equivalent flux units.

Table 15. Integrated Dosimetry Data

		PIC	Sandia CaF_2	LLNL NAD	TLD					MSTS Combo			CR-39
		γ, rad-air	γ, Gy (Si)	n, rad(tissue)	n, rad(tissue)	γ, deep	γ, shallow	γ	n	n	n, mrem	γ, rem	n, rem
Location	Comment	0-100			rem	rem	Kerma, air	rem	Kerma, air				
A	Proc, Back	39.5	3.01E-01	4.049	44.1	44.1	36.8	409.1	25.2	249650	41.852	249.65	91.4
B	Proc, Front	18	1.45E-01	2.588	16.5	16.5	13.6	100.1	6.1	112177	20.729	112.177	107.9
C	Powr, Back	36	3.10E-01	3.73	48.1	48.1	40.2	433.8	26.7	289093	43.984	289.093	100.5
D	Powr, Front		1.07E-01										
E	Alrm, Back	29	2.00E-01	2.379	28.3	28.3	23.6	247.9	15.3	146566	28.506	146.566	78.5
F	Alrm, Front		1.05E-01										
G	Reac, Prob	22	1.20E+00	15.365	200.2	200.2	167	2085.5	128.7	321786	20	321.786	
H	Horn/Light	6.5	4.38E-02							64426	7.22	64.426	

7. CONCLUSIONS

The CAAS-3S system was environmentally qualified for high radiation dose and dose rate environments using the Godiva-IV reactor at NCERC. A total of five irradiations, representing high integrated doses and high dose rate environments, were performed on the CAAS-3s system. For these irradiations, the cabinets were located in the ante-room and shielded by a two-inch-thick HDPE shield. A set of probes were located in the reactor room with an unshielded line of sight to Godiva. For each reactor irradiation, including establishment of delayed critical, when the dose rate at the probes exceeded the setpoint, the CAAS-3S system immediately initiated an alarm as confirmed by audio confirmation of the horns actuating and by, when the PC component of the processing cabinet was functional, indication of alarm status on the PC. The strobes failed to actuate each time that the dose rate at the probes exceeded the setpoint until the strobes were disconnected from the alarm cabinet and reconnected through a previously unused circuit (relay), at which point visual confirmation of the strobes actuating when the dose rate at the probes exceeded the setpoint was achieved. During or immediately after every irradiation, the PC component of the processing cabinet either entered a fault state or shut itself down, requiring manual reset. During the first irradiation, Safety PLC A entered a fault state which never recovered during the testing campaign.

8. ACKNOWLEDGEMENTS

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This work was completed as a collaborative effort using personnel and resources from LANL, LLNL, MSTS, SNL, Y-12, UPF, and Mirion.

9. REFERENCES

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APPENDIX A

From: Goda, Joetta M (LANL)
Sent: Thursday, January 28, 2021 4:46 PM
To: Reynolds, Kevin <Kevin.Reynolds@cns.doe.gov>; Yugo, James <James.Yugo@cns.doe.gov>
Subject: [External] RE: Conversions

Kevin—how do you have time to remember that stuff.

Jim,

The conversion that I sent earlier was from Flattop because I couldn't find a Godiva one at the time, but it should be 10^18, not 16. I can't find where I emailed it to you guys so I hope I didn't email it wrong.

6.2×10^{18} Fissions/Amp-sec   Flattop

I later did find one we did specifically for Godiva and it is

7E18 fissions/Amp*sec.   Godiva

We have done fission foils for two different bursts at NCERC.

75.3 deg => 1.1(1)x10^16 fissions

237 degree => 3.5(3)x10^16 fissions

These line up well with the plots from the old Godiva papers. I usually just say E16 fissions for 70 deg, 2E16 fissions for 150 deg, 4E16 fissions for 250 deg.

You can pull intermediate numbers from the plot.

~Joetta