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PANTEX PLANT | Y-12 NATIONAL SECURITY COMPLEX

CAAS-3S Radiation Testing for Y-12 and UPF with Godiva-IV

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Nuclear Criticality Safety

Why we did this?

- Y-12 and the Uranium Processing Facility (UPF) have procured new CAAS
- Mirion CAAS-3S selected as uniform system for new procurements
- CAAS designs in facilities require a dose & rate qualification for probes
- CAAS electronics cabinets will be exposed to a high dose & rate for some accidents and locations

The Mirion CAAS-3S

- Up to ten clusters (3 probes/cluster) per processing cabinet
  - Alarm threshold 1 V (~50 mrad/h, gamma)
  - Neutron probes differ only in sensing material
- Three cabinets:
  - Power Supply
    - Primarily a series of batteries
  - Processing
    - PC I/O components, PLC's, etc
  - Alarm
    - Primarily a series of electric switches
- Processing cabinet has two safety PLC's to independently initiate alarm signal
- Features remote operation capabilities through the PC

System requirements

- **Preliminary UPF CAAS design identified system requirements**
  - Uniform requirements for every component
- **UPF Requirements exceeded previously-demonstrated CAAS-3S qualifications**
- **Y-12 did not set specific requirements, but need identified during design**
  - Physical layout similar to UPF layout
- **Notable characteristics: Units relevant to electronics, gamma dose dominating**

UPF System Requirements

Requirement
Fluence: 1 MeV equivalent neutron fluence of at least 6.0×10^{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 4.0×10^{2} rad(Si)/s and photon dose rate of at least 2.4×10^{4} rad(Si/s)

Godiva-IV Burst Testing

- **Performed January 2021 at the National Criticality Experiments Research Center (NCERC).**
- **Godiva-IV is well-characterized**
  - Detailed description in HEU-MET-FAST-086
  - Highly enriched uranium alloy fuel, and is reasonably representative of the radiation spectra anticipated during unshielded accident conditions at Y-12 and UPF
- **Primary Goal: Qualify the CAAS-3S system to a mixed-field radiation dose and dose rate.**
- **Secondary Goal: Extend the Y-12 Shielding MCNP Validation to rad-si**
  - Results consistent with a factor of 2.
- **This paper represents the efforts of Y-12 and UPF personnel, and their interpretation of the test results.**

System Functions

- **The CAAS-3S performs a variety of functions**
  - Alarms
  - Remote operation
  - Data Logging
  - Real-time dose rate monitoring
  - Many of these were identified as important in the selection process
- **For this testing, Safety vs Secondary Functions identified**
  - Safety - system alarming when at least two of three probes are exposed to a dose rate exceeding the alarm threshold
  - Everything else is secondary
- **As a system, secondary functions are required to be operational to reset from an alarm and prior to an accident, but can fail during the performance of the safety function.**

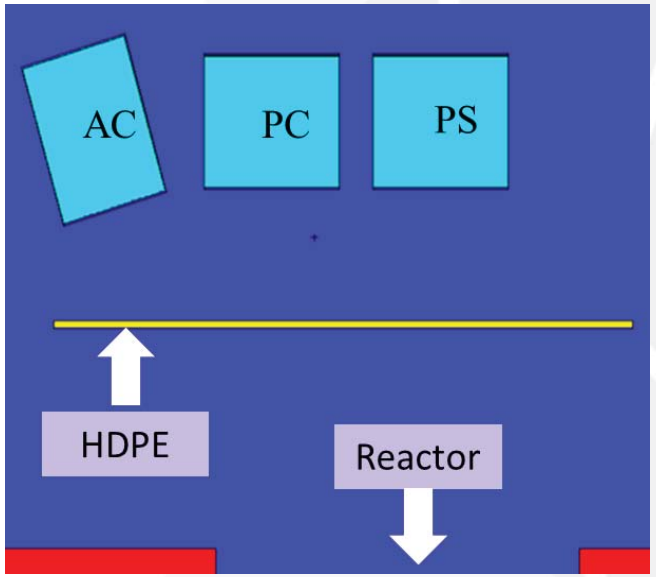
Simulation-Driven Design

- **Y-12 and UPF use MCNP extensively in their CAAS design**
- **By using the same simulation methodology in the design of the reactor testing, the effects of the assumptions, approximations, and biases can be consistent between the various analyses and directly compared against the measured data during the burst testing.**
- **Modeled the NCERC facility in MCNP, designed test layout based on the results**
- **To represent Godiva-IV, a metal HEU spherical accident was used**
  - difference in geometric buckling between the accident and a simplified Godiva-IV geometry
  - the modeled accident is anticipated to have ~70% of the leakage of Godiva-IV, and would be anticipated to lead to a negative bias in the calculation

Simulation Model

- Cabinets aligned in the ante-room 28-30 ft from Godiva
- 8 ft tall, 2 inch thick HDPE Wall, preliminary results showed gamma/neutron ratio of 20-25 (rad-si)
- Probes not modeled

Cabinet Tally Locations		
Cabinet	Designation	Location
Power Supply	PS	cabinet interior lower
		cabinet interior upper
		tally front
		tally rear
Processing	PC	cabinet interior
		tally front
		tally rear
Alarm	AC	cabinet interior lower
		cabinet interior upper
		tally front
		tally rear



Godiva Operations

- **Total of five (5) irradiations**
- **Irradiation 5 similar to Maximum intensity accident used at Y-12/UPF**
  - Dose Rate Qualification
- **Sum of irradiations became integrated dose**

Godiva-IV Operating Parameters						
Burst						
Irradiation	Date	Type	Pulse #	Temperature Rise (°C)	FWHM (μs)	Fissions
1	1/11/2021	Burst	2055	71.6	149	1.10E+16
4	1/13/2021	Burst	2056	133	55	2.00E+16
5	1/14/2021	Burst	2057	250	36	4.00E+16
Steady State						
Irradiation	Date	Type	Pulse #	Temperature Rise (amp-sec)	Length (min)	Fissions
2	1/12/2021	Steady State	n/a	1.24E-03	41	8.68E+15
3	1/13/2021	Steady State	n/a	5.65E-03	28	3.96E+16
Total						1.19E+17

Results During Testing

- **Every irradiation: the CAAS-3S system alarmed immediately when exposed to a dose rate exceeding the alarm threshold**
- **During each low-power delayed critical operation, the CAAS-3S system immediately alarmed when the dose rate at the probes exceeded the alarm threshold**
- **Irradiation 1: computer in Processing Cabinet entered fault state**
  - System continued to alarm
  - Secondary functions (ability to acknowledge alarm) lost
  - Returned to normal operations after manual reset
  - Safety PLC A failed, system only on Safety PLC B
- **Irradiation 2: computer in Processing cabinet shut down after 41 minute**
  - System continued to alarm
  - Secondary functions (ability to acknowledge alarm) lost
  - Returned to normal operations after manual reset

Testing Results

- **Every irradiation: the CAAS-3S system alarmed immediately when exposed to a dose rate exceeding the alarm threshold**
- **During each low-power delayed critical operation, the CAAS-3S system immediately alarmed when the dose rate at the probes exceeded the alarm threshold**
- **Irradiation 1 (71.6°C) : computer in Processing Cabinet entered fault state**
  - System continued to alarm
  - Secondary functions (ability to acknowledge alarm) lost
  - Returned to normal operations after manual reset
  - Safety PLC A failed, system only on Safety PLC B
- **Irradiation 2 (1.24E-03 amp-sec): computer in Processing cabinet shut down after 41 minutes**
  - System continued to alarm
  - Secondary functions (ability to acknowledge alarm) lost
  - Returned to normal operations after manual reset

- **Prior to Irradiation 3: No indication that strobes were flashing**
  - Alarm determined by audio confirmation
  - Facility strobe light visual interference
  - Determined strobes were not flashing
    - Reconnected strobes to alarm cabinet
    - Post-test diagnostics indicated that there was a wiring error preventing strobe actuation
- **Irradiation 3 (5.65E-03 amp-sec): computer in Processing cabinet shut down after 11 minutes**
  - Continued until planned integrated fissions
- **Irradiation 4 (133°C) : Same as 1**

Irradiation 5 (250°C) – Maximum Dose Rate

- During the low-power excursion prior to Irradiation 5, the system immediately alarmed, and the processing cabinet PC component entered a fault state, and could not be remotely reset
- 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
- 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 reset

- Conclusion: System performed its safety function throughout testing campaign
  - Anticipate loss of secondary functions during intense criticality accidents

Qualifications

- **Two-branch approach, dosimetry based and calculation based**
- **Dosimetry was provided by LANL, LLNL, SNL, and NNSS**
- **Each dosimeter was used for every irradiation**
- **Availability of rad-si dosimetry was only identified after campaign**

Dosimeters Used in Measurement Campaign		
Dosimeter	Particle Type	Unit
PIC	γrad(air)	rad(air)
Sandia CaF_2	γ	Gy (Si)
LLNL NAD	n	rad(tissue)
TLD	γ γ n n	rem kerma (air) rem kerma, (air)
MSTS Combo	γ n	rem rem
Cr-39	fast n	rem

Dosimetry-Based Qualification

- Rad(si) and Rad(air) neutron aren't comparable
- Dose rates > 1E5 rad/s
- Integrated doses 15-30 rad (cabinets)

Qualified Component Dose and Dose Rates Without Margin, Dosimetry-Based				
Component	Rad(si), g	Rad(air), n	Rad(si)/s, g	Rad(air)/s, n
Processing	3.01E+01	2.52E+01	3.22E+05	2.72E+05
Power Supply	3.10E+01	2.67E+01	3.31E+05	2.69E+05
Alarm	2.00E+01	1.53E+01	2.09E+05	1.47E+05
Probes	1.20E+02	1.29E+02	1.40E+06	1.71E+06
Horns/Strobes	4.58E+00		5.22E+04	

Calculation-Based Qualification

- **Gamma/neutron ratio > 90%**
- **For use with same calculation methodology (code, cross-section, geometry, materials, etc)**

Qualified Equipment Dose and Dose Rates Without Margin, Calculation-Based

Equipment	Rad(si), g	Rad(si), n	Rad(si)/s, g	Rad(si)/s, n
Processing	2.04E+01	9.52E-01	1.90E+05	8.89E+03
Power Supply	2.40E+01	1.04E+00	2.24E+05	9.75E+03
Alarm	1.45E+01	7.07E-01	1.35E+05	6.60E+03

Secondary Goal – Shielding Validation Extension

- Y-12's MCNP Shielding validation generically has a factor of two
- Rad(si),g and rad(air),n within 0.5-2.0
- Rad(tissue),n and mrem(n) response significant variation (1.95-28.9)
- Determined that rad(si),n calculation results acceptable
  - Actual safety bases calculations use factor of 4+

Rad(air), n, Calculation and Dosimetry Results and Comparison

Cabinet	Location	Calculated [rad(Si)]	CaF2 [rad(Si)]	Calc/Exp
Power Supply	front	5.26	9.7	**5.42E-01**
Processing	front	4.90	9.8	**5.00E-01**
Processing	rear	2.61	2.2	**1.19E+00**
Alarm	front	3.61	5.3	**6.80E-01**

Rad(si), g, Calculation and Dosimetry Results and Comparison

Cabinet	Location	Calculated [rad(Si)]	CaF2 [rad(Si)]	Calc/Exp
Power Supply	front	8.08E+00	1.19E+01	**6.79E-01**
Power Supply	rear	2.94E+00	4.25E+00	**6.91E-01**
Processing	front	6.84E+00	1.16E+01	**5.90E-01**
Processing	rear	4.03E+00	5.56E+00	**7.25E-01**
Alarm	front	4.87E+00	7.52E+00	**6.48E-01**
Alarm	rear	2.66E+00	4.35E+00	**6.11E-01**

Neutron Biologic Calculation and Dosimetry Results and Comparison

Cabinet	Location	Neutron Kerma, rad(tissue)	LLNL Nad rad(tissue)	Calc/Exp
Power Supply	front	1.21E+01	5.46E-01	**2.22E+01**
Processing	front	1.09E+01	6.08E-01	**1.79E+01**
Processing	rear	7.39E+00	2.56E-01	**2.89E+01**
Alarm	front	7.92E+00	4.70E-01	**1.69E+01**
		Neutron Dose Equivalent, mrem	**MSTS n, (mrem)**	**Calc/Exp**
Power Supply	front	1.93E+05	9.91E+04	**1.95E+00**
Processing	front	1.73E+05	7.87E+04	**2.20E+00**
Processing	rear	1.15E+05	4.16E+04	**2.77E+00**
Alarm	front	1.24E+05	5.03E+04	**2.47E+00**

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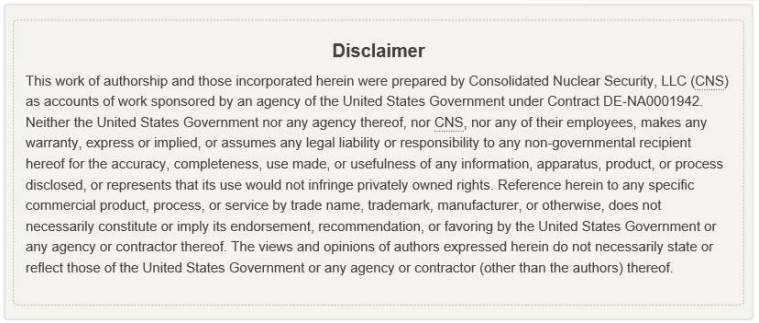

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