Godiva Experiments for the Nuclear Criticality Safety Program (NCSP)

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INTRODUCTION

Godiva IV is a fast burst critical assembly constructed of approximately 65 kg of highly enriched uranium (HEU) fuel alloyed with 1.5 percent molybdenum for strength. Godiva is one of the last such critical assemblies in the United States, and can be used for studies of super-prompt critical behavior as well as irradiations and demonstrations.

A demonstration of a Godiva burst is usually performed as a highlight of the hands-on portion of the Criticality Safety Training Classes [1] taught at the National Criticality Experiment Research Center (NCERC). The Godiva burst is used to demonstrate the concept of super-prompt critical and the time-scale of a criticality accident.

In addition, several NCSP projects have been conducted on Godiva IV over the past two years. One experiment focused on collecting data to support multiphysics simulations using Photo-Doppler Velocimetry (PDV) to measure surface movement and gamma detectors to measure the burst output as the burst develops from background to peak over ten orders of magnitude.

Another experiment was performed to demonstrate the functionality of the Criticality Accident AAlam=rm System (CAAS) system developed for installation in the Y-12 Uranium Processing Facility (UPF). The system must not only respond to a criticality event and alarm, but must also be shown to operate in a high dose environment.

MULTIPHYSICS MEASUREMENTS

Multiphysics models are developed by coupling neutronics calculations (e.g. MCNP®[i]) coupled with various types of finite element analysis (e.g. ANSYS Fluent) which calculate heat transfer, material expansion, etc.

In September and October of 2020, measurements were taken during a series of Godiva bursts and Godiva steady-state operations.

There were two types of systems deployed. One consisted of an MHD-240 detector-- a four-head photo-multiplier and photodiode detector with a common 6” plastic scintillator cube (BC-404) with each head designed for overlapping coverage spanning more than 10 decades in overall sensitivity. The channels are designated Ch1 through Ch4, with preset relative sensitivities (gains) of 10^6, 10^4, 10^2, and 1 respectively. Two other detectors (an MHD-241 and an Eljen EJ-325A) were used for reference as the MHD-240 detector was moved between two positions.

The other was a Photo-Doppler Velocimetry (PDV) system which used the reflection of laser light on the surface of the Godiva IV core. A visible laser signal was used to target the probes at the fuel rings as shown in Figure 1. The Class IV laser used for the actual measurements did not operate at a visible wavelength and was not turned on when personnel were present.

Figure 1: Visible Laser Indicating Target Positions on Godiva IV Core

Raw data from the reflection of the laser off the surface of Godiva is shown in Figure 2 [2]. This data is for the laser targeted on Ring 3 (the upper dot shown in Figure 1 during a 123 \degree C burst. Preliminary fitting of a damped sinusoid to the data indicates a frequency of oscillation of 7729 +/- 13 Hz is shown in Figure 3. Similar data was obtained for Ring 4 during the same burst. Both laser reflections were also captured during a 201 °C burst. The frequency agrees well with previous predictions [3]. Further discussion can be found in a paper by Lucas Snyder at tis same conference.

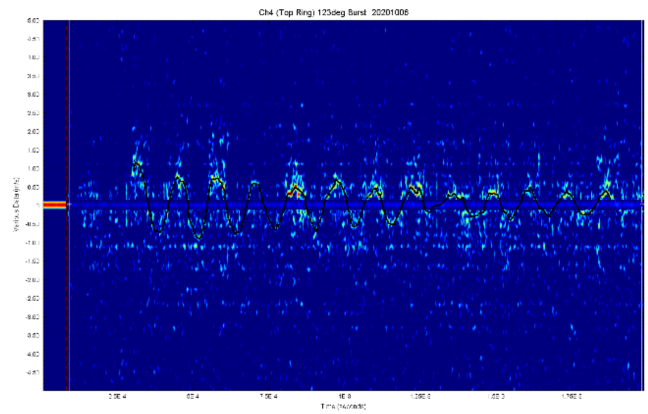

Figure 2: Raw data from PDV System

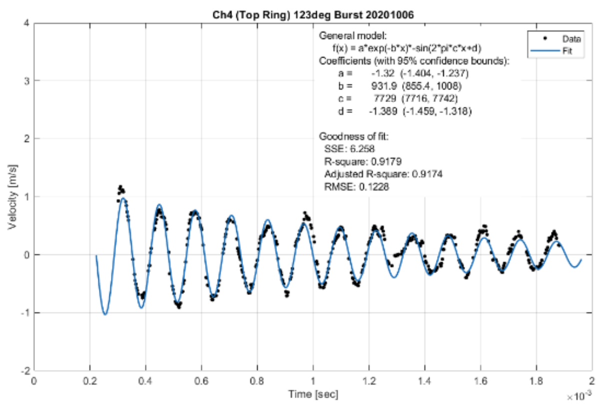

Figure 3: Fit to PDV signal

Figure \ref{fig:ChannelOverlay} shows the MHD-240 data for the same burst. Each channel is scaled and shows the coverage of the burst signal over ten orders of magnitude. The following week, MHD-240 data was taken during steady-state operation at various power levels with and without a borted poly and lead shield blocking the direct signal from Godiva. The results show the relationship between direct dose and room return [4].

TESTING OF CRITICALITY ACCIDENT ALARM SYSTEM (CAAS)

In January of 2021, testing was performed using Godiva on the new CAAS system supplied by Mirion Technologies and planned for installation at the Y-12 Uranium Processing Facility (UPF) currently under construction. The focus of the test was the performance of the cabinets in specified neutron and gamma dose fields.

The testing showed that the CAAS-3S control cabinet components successfully performed in the radiation levels specified in the UPF specification document. The system probes had previously been tested for response. However, one design basis accident postulated higher dose at the cabinet locations than they had been designed or tested.

Due to the large size of the cabinets, they were placed in the anteroom at approximately 8 meters from Godiva in direct line of sight as shown in Figure 4. A poly shield was constructed to decrease the neutron field while allowing the desired gamma exposure to be reached.

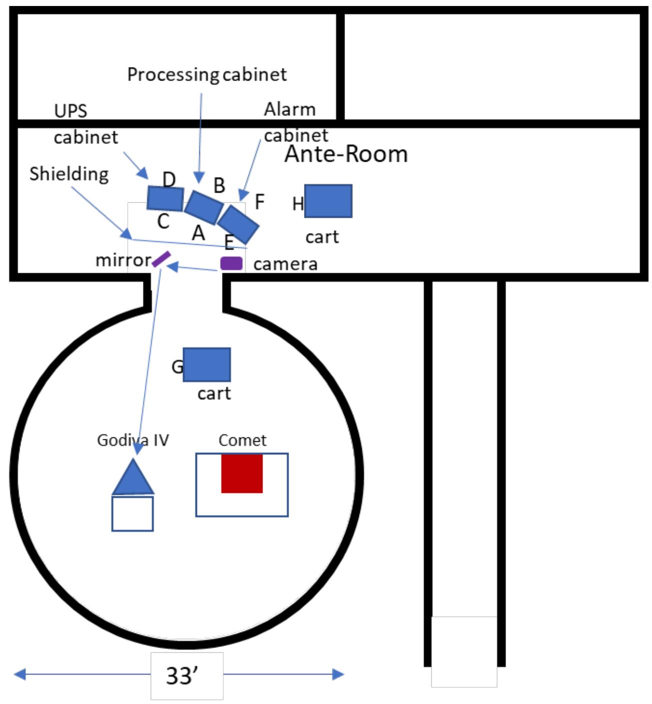

Figure 4:Position of CAAS Equipment During Godiva Bursts

A total of five separate irradiations were performed to test the system under various conditions and to supply the required dose. The system responded and alarmed to all bursts including the final 250 °C burst, which was conducted after the system had been subjected to the required neutron and gamma fields by three bursts and two steady-state runs. The system remained in alarm status until radiation levels had dropped and the reset key was turned. One of two redundant Programmable Logic Controllers (PLC) failed during the first burst. The other one never failed. The PLCs were returned to Mirion after the testing for examination. The computer in processing cabinet died during each irradiation, but rebooted later.

TABLE I. Irradiation Summary

Irradiation Number	Irradiation Type	Irradiation Description
1	Burst	72 °C
2	Steady state	15 minute
3	Steady state	30 minutes
4	Burst	133 °C
5	Burst	250 °C

The irradiations are summarized in Table I. Dosimetry was deployed to measure the gamma and neutron dose rates at the position of each of the components of the system. Testing with sufficient gamma dose was of most concern. The gamma dosimetry results from CaF2 crystals supplied by Dann Ward of Sandia National Laboratory are displayed in Figure 5. Based on dosimetry results, adequate dose was supplied.

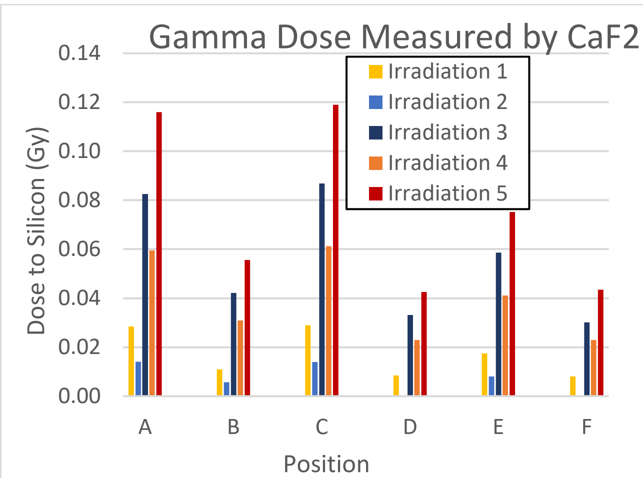

Figure 5: Gamma Dose at Equipment Positions During Irradiations. Positions G and H are not shown.

CONCLUSIONS AND FUTURE WORK

Godiva IV is one of few fast burst critical assemblies remaining in the United States and has been successfully operating at NCERC for over ten years with more than 100 bursts performed along with steady-state delayed critical operations. During the past two years, notable work included PDV and gamma measurements to support multi-physics simulation validation and direct testing of a CAAS system.

Upcoming experiments include a continuation of the NA-22 sponsored Short-Lived Fission Product Yield (SLFPY) project. The effort is methodically measuring the fission products from fissionable isotopes created under the same reactor conditions and counted with the same detector setup. [5] Uranium-235, uranium-238, Pu-239, and Np-237 have already been measured and a uranium-233 sample has been produced by Lawrence Livermore National Laboratory (LLNL) for the next irradiation.

Future work includes an update to the Godiva benchmark evaluation, HEU-MET-FAST-086, included in the International Criticality Experiments Benchmark Evaluation Project (ICSBEP) handbook. The update will incorporate details noted during re-assembly and include critical configurations measured in the existing NCERC building. The previous evaluation contains configurations performed at TA-18 in a different building. These updates will support all work that utilizes the Godiva IV critical assembly.

Work is progressing to use perform a shielding benchmark, where Godiva will be used as the radiation source to measure transmission through shielding samples with various radiation detectors and dosimetry. Extensive modeling has already been performed at Oak Ridge National Laboratory (ORNL).[ref]

Future International Dosimetry Inter-comparisons are also planned.

ENDNOTES

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