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Photo Doppler Velocimetry and Gamma/Neutron Yield Measurements of Godiva-IV Critical Assembly

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INTRODUCTION

The purpose of this experiment was to collect data for a dynamic benchmark of the Godiva-IV burst assembly [1]. Data were taken using two different measurement systems. The gamma & neutron flux was measured using a calibrated, high-dynamic-range scintillator detector, the MHD-240. The measurement will be used to determine the total fission yield and alpha throughout the burst and shutdown sequence of Godiva-IV. The Photon Doppler Velocimetry (PDV) measurement detected the surface motion of the burst assembly as a function of time. The combined data will be used in a multi-physics simulation of the Godiva-IV burst assembly.

Data were collected during two modes of Godiva-IV operations. First a series of four prompt critical bursts were measured with data collected on both the MHD-240 and the PDV. The MHD-240 was used to record the gamma & neutron output of Godiva over 8 orders of magnitude, which was used to infer the alpha from each burst. PDV data was successfully collected on two of the four bursts, the vibration frequency is reported. Secondly, a series of delayed critical (DC) operations were conducted with data collected on the MHD-240 to determine the room-return component of the measured neutron and gamma flux for analysis of the prompt critical bursts. Prior to the Godiva measurements the MHD-240 was calibrated separately for gamma and neutron response. The calibrations, in combination with input from an MCNP simulation and the DC measurements, will be used to determine the total fission yield.

We present herein the experimental setup, the acquired data, and a preliminary analysis of the results. This was the first successful attempt to collect PDV data on the Godiva-IV (henceforth Godiva) assembly.

EXPERIMENTAL SETUP

The general layout of the experiment is shown in figure 1. The PDV probes were located 0.6 m from Godiva. The probes were mounted using ThorLabs RC02APC-P01 Reflector collimators and KM05 kinematic mirror mounts. The probe assemblies were mounted behind lead shielding, with a line-of-sight left open for the lasers. Probes were aligned with four of the six Godiva rings, with data resolvable on only two of the rings. Figure 2 shows a schematic of the Godiva assembly and the location of the PDV probes.

The MHD-240 detector consists of a 6" cube of BC-404 scintillator with three PMTs and a photo diode arranged around four sides. Each of the four detectors are adjusted to cover a wide range of sensitivities, with about a factor of 100 separating each channel. A picture of the detector head is shown in figure 3. The gamma calibration was performed

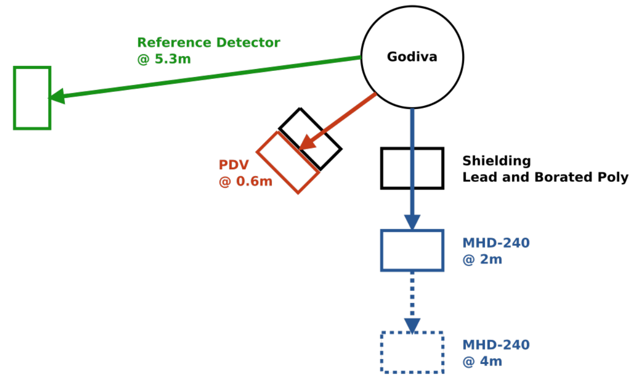

Fig. 1. The layout of the detectors relative to the Godiva assembly. The MHD-240 was located at 2 or 4 m, with and without shielding for the DC measurements, while the burst measurements were conducted with the MHD-240 located at 2 m with no shielding. The PDV was located 0.6 m from Godiva and a linear reference detector (compensated ionization chamber) was fixed at 5.3 m distance.

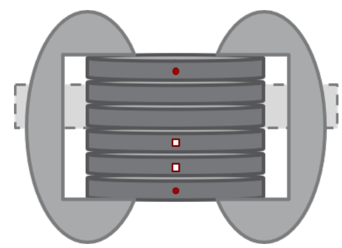

Fig. 2. A schematic of the Godiva rings and clamps. The red dots indicate the location of the PDV probes, on the top and bottom rings, for which resolvable data was successfully measured. The white squares also had probes, but the data was not resolvable.

by the Mission Support and Test Services (MSTS) at NNSS using the 1.17 MeV and 1.32 MeV γ-rays from a ^{60}Co source, MSTS source designation: RAA27208 (131). The neutron calibration of the MHD-240 was conducted at Ohio University's Edwards Accelerator Laboratory [2] and is detailed in reference [3].

The DC measurements were conducted to provide data for a room-return correction of the prompt critical analysis. The MHD-240 was located at distances of both 2 and 4 m with and without shielding. The shielded and un-shielded measurements provided data on the relative intensity at the detector with and without direct radiation from Godiva to determine the room-return component of the total flux. The shielding consisted of a matrix of alternating 1" plates of borated polyethylene and lead with a total of 6" of each. The prompt critical bursts were measured with the MHD-240 located at 2 m with no shielding in place.

Two detectors were deployed at a fixed position and used as reference monitors for the reactivity of various Godiva bursts. The first reference detector, termed MHD-241, has the same scintillator as the MHD-240 but with a single PMT variant with twice the photocathode area as those on the MHD-240. The second reference detector, termed LC1, is a nitrogen-helium filled proportional ion chambers, model number WL-23084 by Imaging and Sensing Technology.

Fig. 3. The MHD-240 detector head. The 3 PMTs and the photo diode are arranged on 4 sides of the 6" cubic BC-404 scintillator.

PDV RESULTS

PDV data was collected on two burst temperatures of 123°C and 201°C on the top and bottom of the six rings of the Godiva assembly (see figure 2). Figure 4 shows an example of one of the data sets from the bottom ring of the 201°C burst. Points are extracted from the raw data and then fit to determine the vibration frequency using custom analysis software [4]. Table I shows the results of all four measurements. Some general conclusions are that the top ring is consistently at a lower frequency than the bottom ring and the lower burst temperature has an overall higher frequency. While intuition might suggest the higher temperature would have more energy and therefore a higher frequency, the bulk material properties are what dictate the frequency so this simple assumption does not necessarily hold. Any further conclusions from this data will be part of the multi-phyiscs simulation that is planned to be conducted, which is however beyond the scope of this presentation.

MHD-240 RESULTS

Delayed Critical

The delayed critical data was collected to determine a room return correction for the prompt critical analysis. Five series of delayed critical data were collected. Two series of data at various power levels were collected with the MHD-240 located at 4 m, one with shielding and one without. Similarly,

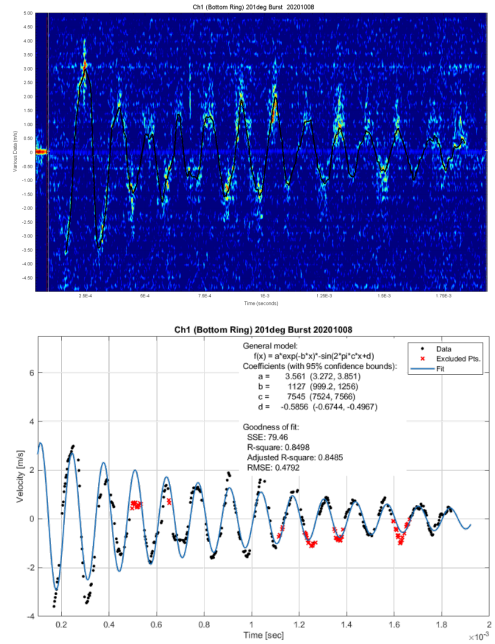

Fig. 4. Data collected on the bottom ring of Godiva during the 201°C burst. Data points are extracted from the raw data and then fit to determine the vibration frequency. The fit function and various fit parameters are listed in the legend.

TABLE I. The vibration frequency of each of the two rings for each of the two bursts. The measured frequency and the 95% confidence band are reported.

Temp. °C	Ring	Freq. (Hz)	95% Conf. (Hz)
123	Bottom	7881	7856-7907
123	Top	7729	7761-7742
201	Bottom	7545	7524-7566
201	Top	7317	7261-7327

two series of data were collected with the MHD-240 at 2 m, again one with and one without shielding. The shielded and un-shielded data are analyzed relative to one-another to determine the room-return component of the total flux, whereby the shielding is intended to block the direct radiation flux from Godiva to the MHD-240. Data were collected at 2 m and 4 m to determine if there was any radial dependence to the room-return. The two reference detectors were found to be very consistent, having good linearity over all levels of power, providing an unbiased reference for the absolute flux. During the fifth series, the plastic scintillator was removed from the MHD-241 reference detector to measure any potential response from the PMT and output cabling.

Figure 5 shows the output current measured on Ch. 2 & 3 of the MHD-240, the MHD-241 (Ref. 1) and the LC1 (Ref. 2) as the reactor is stepped up through several power levels. Ref. 2 is scaled be a factor of 60 to match Ref. 1 on the plot. The fact that the scaling factor is consistent over several orders of magnitude emphasizes that the two detector systems are very linear. Also shown in the figure is the scaling ratios between Ref. 1 and the MHD-240 channels. The dashes lines represent the dark level subtractions.

The general conclusion from the preliminary DC analysis is that the flux decreases for shielded measurements but are higher than they would be for a central source assuming no room return. This indicates that room return is substantial, which is to be expected for the Godiva configuration in a relatively small room with massive floor and walls. Furthermore, the supposition of $1/r^2$ for the 2 m and 4 m data sets does not hold, indicating a component of room-return from the opposite wall and/or the floor & ceiling, which is again to be expected. These data will provide a room return correction for the burst data analysis and a validation of MCNP simulations.

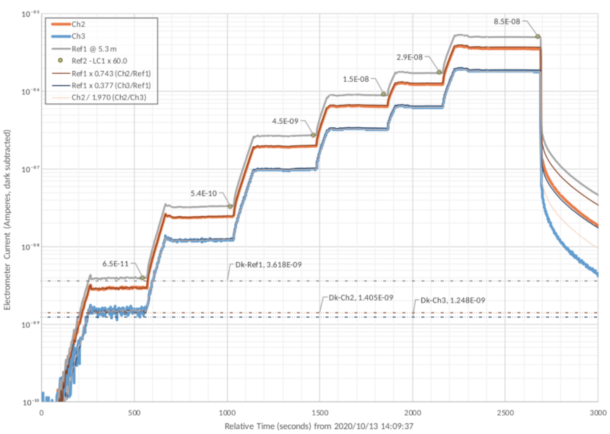

Fig. 5. Delayed critical data un-shielded at 2 m. The detector current levels are shown for Ch. 2 & 3 of the MHD-240, the MHD-241 (Ref. 1) and LC1 (Ref. 2). Ref. 2 is scaled by a factor of 60 to match Ref. 1. The dashed lines represent the dark level subtractions

Prompt Critical

Data was successfully collected on four prompt critical bursts of the Godiva assembly at various temperatures as measured by the Godiva instrumentation (see table II). Four channels were recorded on the MHD-240 and the detector was placed at 2 m from the assembly with no shielding in place. Initial data analysis indicates that the expected relative scaling factors for the four channels, which is based on the Co-60 calibration, do not hold. The least sensitive channel (ch. 4), equipped with the photo diode, has no optical filter and is operated such that the detector will not saturate at peak reactivity. For the analysis presented here, it is assumed that the ch. 4 scaling is accurate and that the three more sensitive PMT channels will have a similar logarithmic slope and can be scaled overall to match ch. 4. A fit search was performed over ch. 1-3 to find the region with the logarithmic slope that best matched that of ch. 4 and over which the data had a linear response, i.e. a good fit to an exponential. The data was scaled to match the constant of a fit to ch. 4, the result of one of the prompt critical data sets is shown in figure 6. The dashed lines shown in figure 6 are the fit results and also shown is the full-width-half-max (FWHM) of the peak reactivity. The vertical scale is adjusted to γ-MeV/s equivalent based on the Co-60 calibration. The initial alpha and FWHM for each burst are listed in table II.

While there are several possible causes of the scaling discrepancy between the 4 channels, it is likely a result of the sensitivity of the scintillator and/or optical filter changing since the calibration was performed several years ago. This change in sensitivity, or aging, has been observed in other MHD-240 detector systems. There are currently plans to verify the calibrations. The effects of asymmetric room return and down-scattering of the neutrons are also still being explored. The scaling discrepancy has no effect on the determination of alpha or the FWHM presented here. Further analysis however will be needed to resolve the overall scaling factors to determine the total fission yield.

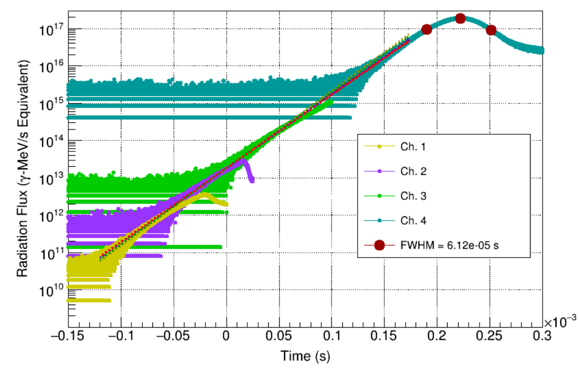

Fig. 6. Prompt critical data for the 123°C burst as measured by the 4 channels of the MHD-240. The vertical axis is scaled based on the gamma calibration. The neutron calibration was not considered in this plot. The dashed lines shown are the exponential fit results to each of the channels data.

TABLE II. The Godiva temperature, FWHM and alpha for each of the four prompt critical bursts measured by the MHD-240. The attenuation was adjusted on the 168° burst to focus on the low end of the curve and the peak of ch. 4 saturated the scope preventing the determination of the FWHM.

Temp. °C	FWHM (s)	Alpha (generations/μs)
70	2.08 E-4	0.018721
123	6.12 E-5	0.045316
168	–	0.070795
201	3.78 E-5	0.074613

CONCLUSIONS AND NEXT STEPS

The first successful PDV measurement of the Godiva-IV assembly was performed and the vibration frequency was measured for two prompt critical bursts. A measurement of the gamma and neutron flux of Godiva-IV of four prompt critical bursts were measured with the calibrated MHD-240 detector system. Delayed critical measurements were performed to determine the room return component of the measured Godiva-IV reactivity. The DC measurements and gamma/neutron calibrations will be used to determine the alpha and total fission yield of the Godiva-IV prompt critical bursts. The PDV and MHD-240 data will be used in a multi-physics simulation of the Godiva-IV assembly.

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