Godiva-IV dosimetry exercise 2022 preliminary results

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Abstract. Integral Experiment Request (IER) 538 is part of a series of dose characterization and nuclear accident dosimetry (NAD) exercises performed under the Department of Energy (DOE) Nuclear Criticality Safety Program (NCSP). This is the second NAD exercise using the Godiva-IV critical assembly and the third NAD exercise overall. The participating laboratories provided their own dosimeters that were mounted on the Lawrence Livermore National Laboratory (LLNL) BOttle Manikin ABsorption (BOMAB) phantoms and aluminum plates. The BOMABs and plates were placed at two, three, and four meters away from the center of Godiva. Alongside the NADs, there was a LLNL Passive Neutron Spectrometer (PNS), Atomic Weapons Establishment (AWE) PNS, and Y-12 Sphere present to measure the neutron dose from Godiva-IV. Two irradiations were conducted to test the NAD performance from each laboratory and assesses their performance to the DOE-STD-1098-2017 part 515 criteria. Neutron and gamma doses were measured prior to this exercise. This work presents a model for the neutron and gamma dose

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respectively to serve as the reference value. A code written in C/C++/ROOT was used to fit the measured neutron and gamma dose with the new models. It was assumed that the neutron and gamma doses are proportional to the change in temperature of Godiva after a burst irradiation. Uncertainties for the reference values were calculated using error propagation of the model's parameters. Preliminary results (within twenty-four hours) and final results were compared for each laboratory. On average of all the participating laboratories, 32% of neutron doses and 78% of gamma doses were outside the DOE standards. One laboratory did not report their dose readings and were not included in this average. There is a bias for a lower neutron dose and a higher gamma dose based on the distribution of results. In comparison with the past Godiva-IV NAD exercise, there is an improvement in neutron dose readings by 20%.

1 Introduction

In compliance with Title 10 of the Code of Federal Regulations Section 835.1304 (10 CFR §835.1304), an individual shall be issued a personal nuclear accident dosimeter (NAD) if there is a possibility for a nuclear accident to occur resulting in excessive exposure of radiation to the individual [1]. A NAD performance criterion is found in the ANSI/HPS N13.3-2013 (R2019) [2] and the DOE-STD-1098-2017 part 515 [3]. This work compared the performance of various institution's NAD to the Department of Energy's (DOE's) standard (listed in Table 1).

A NAD intercomparison was conducted in August 2022 utilizing two prompt burst irradiations from the Godiva-IV critical assembly [4]. Ten institutions participated in this exercise and nine institutions performed preliminary measurements at the Lawrence Livermore National Laboratory's (LLNL's) NAD lab. Nine institutions provided their results when they completed their analysis at their respective institution. These institutions were LLNL, Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), Savanah River Site (SRS), Hanford Site, Y-12 National Security Complex (Y-12), Naval Dosimetry Center (NDC), Atomic Weapons Establishment (AWE), and Institut de Radioprotection et de Sûreté Nucléaire (IRSN). The results were compared to the reference dose values provided in [5-7].

Table 1. DOE-STD-1098-99 part 515 criteria for personal NAD performance.

Particle	Absorbed dose in or on a phantom (Gy)	Required accuracy (%)
Neutron	0.1-10	30
Photon	0.1-10	20

2 Method

The NADs were placed on BOttle Manakin ABsorptions (BOMABs) phantoms to simulate dose to human and aluminum plates to simulate dose in free air. The BOMABs were filled with a saline solution to simulate human blood neutron activation. Each BOMAB was accompanied with two plates placed to the left and right of the BOMAB equidistant from Godiva-IV. LLNL, Y-12, and AWE provided spheres to measure the neutron spectrum for each irradiation. The position of the BOMAB/plate pairs and spheres are shown in Figure 1 for the two irradiations. Table 1 outlines the institution's NAD criteria, while Table 2 presents the dosimeters provided for this exercise.

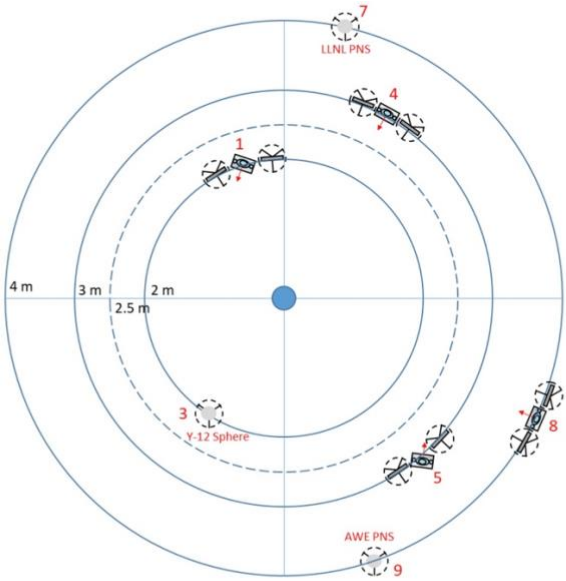

Figure 1. Placement of BOMABs, plates, and spheres during the Godiva-IV irradiation. The numbers shown are the designated position numbers, which are referenced in [5-7].

Table 2. Each institution provided their own NAD to be irradiated at Godiva-IV critical assembly.

Lab	Dosimeter
LLNL	Panasonic UD-810 TLD Thermo Scientific TLD-400 LLNL PNAD
LANL	LANL 8823 Dosimeter Los Alamos Criticality Dosimeter SWX-PNAD
SNL	SNL Criticality Dosimeter CaF_2:Mn TLD Arrow-Tech Direct Reading Dosimeter 740 Arrow-Tech Direct Reading Dosimeter 742
SRS	Criticality Neutron Dosimeter InLIght Model 2T Dosimeter nanoDot Dosimeter
Hanford Site	SWX-PNAD-2 Hanford Combination Neutron Dosimeter
Y-12	Harshaw Model 8805 Mirion DMC 3000
NDC	NCL-03
AWE	Harwell MKIV Criticality Locket Harshaw Model 8825
IRSN	SNAC2 SNAC50 IRSN Criticality Belt Technol Corp. RPL Dosimeter type 351 Silicon Diode

Following an irradiation, the BOMABs and plates are disassembled and transported to the NAD lab. The time between irradiation and arrival to the NAD lab was approximately three to four hours. Upon arrival the NAD lab, the NADs were recovered from the BOMABs and plates, then distributed to the institutions. Each institution provided preliminary results within 24-hours from irradiation and results after further analysis.

3 Preliminary Results

Because the leakage dose is proportionate to burst change in temperature, the neutron and photon dose for this exercise were extrapolated from a previous dose characterization establishing the reference dose values [5-7]. Results from each institution are compared to the reference value and are evaluated based on the DOE performance. On average, 32% of neutron doses and 78% of photon doses were outside of the DOE standard. There were two laboratories 100% within the DOE standard for the neutron dose, which indicates room for improvement in analysis or methodology for other institutions. On the other hand, there was a high bias for the photon dose results across all institutions except for one. This may have been caused by prolonged exposure from activated sodium in the BOMABs to the dosimeters between irradiation and disassembly at the NAD lab or prompt gamma rays produced from neutron thermal capture in the BOMABs. These results were provided in [6, 7].

4 Conclusion

Overall, two laboratories were 100% within DOE standards for neutron dose and majority were above the DOE upper limit for photon dose. Neutron dose calculation can be improved for other institutions. However, the bias in photon dose may be caused by procedural error in NAD exposure. According to the Godiva-IV dose characterization, the NADs were not intended on being left on the BOMABs between irradiation and arriving to the NAD lab. This caused a three-to-four-hour excess exposure of neutron activated sodium gamma rays to the photon dosimeters. The results from the exercise highlight the need to continue to host intercomparison exercises for NAD to allow for the improvement in dose predictions in case of an actual nuclear accident.

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