High-Fidelity Measurements for Flattop-HEU Benchmark Reevaluation

Kristin Stolte,* Theresa Cutler, Charlie Kiehne, Kelsey Amundson, Dave Hayes

*Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87544, kristins@lanl.gov

INTRODUCTION

Flattop was first built in the 1950's at Los Alamos National Laboratory. Flattop-HEU is composed of a sphere of highly enriched uranium (HEU) surrounded by a thick spherical natural uranium (NU) reflector. The reflector is composed of three parts: a stationary hemisphere and two movable quarter spheres. For fine control of the reactivity of the system, there are three control rods of natural uranium located in voids in the stationary hemisphere. The reflectors, control rods, and core are shown in Fig. 1 along with the glory hole. The final components that make Flattop a useful critical assembly are the glory hole and mass adjustment pieces. These pieces can be loaded in various configurations into the glory hole and the core pedestal to control the known worth of the system. The glory hole and mass adjustment pieces are mostly small pieces of HEU with some mass adjustment pieces fabricated from NU. This allows for the irradiation of samples to a specified level. [1]

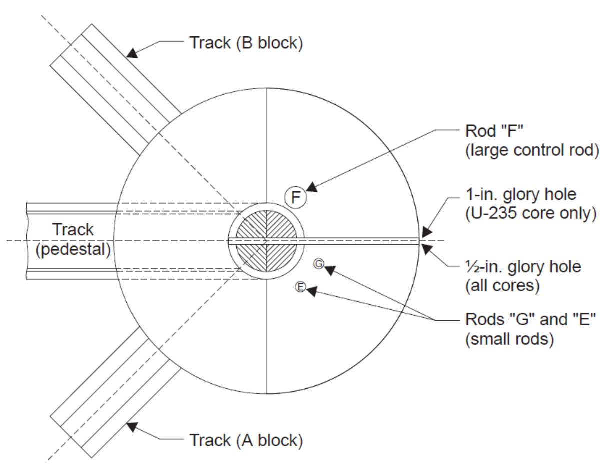

Fig. 1. Plan view of Flattop critical assembly showing location of control rods and quarter sphere tracks.

To better document the system, Flattop was evaluated and included in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook. [2] The original benchmark evaluation of Flattop-HEU was written in 1999 based on an experiment completed in the 1960's. [3] This original evaluation was written to provide a single diameter that defined critical mass; however, as computational capabilities have increased, the focus for benchmark evaluations has shifted to include detailed models with all physical dimensions. [1] Thus, as Flattop is a lynchpin in critical experiment work, the benchmark is being reevaluated at current standards. [4] This summary discusses some of the largest known uncertainties from the evaluation and the high-fidelity measurements taken to reduce these uncertainties.

KNOWN UNCERTAINTIES

In 2015, a preliminary reevaluation of the Flattop-HEU benchmark was completed. [5] This evaluation determined that the largest effects on the uncertainty were due to the masses and dimensions of the NU reflector pieces and HEU pieces for the glory hole. The uncertainty in the original benchmark evaluation was ±0.00300, and in the preliminary reevaluation, the total uncertainty was ±0.00157, primarily caused by the mass and volume uncertainty (±0.00137) of the NU parts.

It was deemed that for the Flattop-HEU benchmark to be as useful as possible, that it would be beneficial to perform new measurements to reduce the uncertainties. These measurements were focused on the dimensions of the NU reflector components, and the mass, volume, and dimensions of the HEU pieces. It was estimated in 2021 that the effects of high-fidelity measurements could potentially decrease the total uncertainty of the evaluation to ±0.00048. [5]

NEW MEASUREMENTS

The focus of the new measurements was to reduce the uncertainty associated with the dimensions and mass of most components since these were the highest contributors to the total uncertainty. To accomplish this goal, four different high-fidelity, calibrated measurement tools were used. The first was a high-precision balance with which to weigh the glory hole and mass adjustment pieces. The second was a coordinate measuring machine (CMM) to determine the diameter of the reflector components and core. To verify the CMM measurements on some components, a set of high-precision calipers with a digital read-out were also used. The last tool used was a pycnometer to measure the volume of the glory hole and mass adjustment pieces. The pycnometer also calculated the density of the pieces based on the provided mass.

Mass Measurements

For the small components, a Mettler Toledo NewClassic MF balance was used. This balance was calibrated and has a resolution of 0.1 mg. As the components measured were uranium, contamination was a large concern. Thus, each piece had to be cleaned and placed in a plastic bag before being measured. To ensure that the mass of the bag was accounted for, the empty bag was weighed three times, and the average mass computed. Then the piece was cleaned, placed in the bag, and weighed three times. The average mass for the bag was then subtracted from the average mass of both in order to calculate the mass of the piece.

For the midsize NU components of Flattop, a Mettler Toledo SB16001 and a Mettler Toledo NewClassic MS scale were used. These scales each had a resolution of 0.1 g, and the same procedure as described above was used when weighing each piece three times after weighing the bag separately. Lastly, a fourth scale, Mettler Toledo GmbH D-72458, was used to weigh the HEU core. This scale had a resolution of 0.001 lbs.

The large reflector pieces were not weighed at this time. This requires the complete disassembly of Flattop and the use of a crane, which was deemed not immediately justified given the level of effort and risk required. This measurement may be performed in the future if the uncertainty is not reduced to the desired level from the other measurements completed.

Dimension Measurements

To better understand the diameters of the reflector and core components, a CMM was used in two separate modes. The first mode was a scanning mode, which creates a 3D rendering of the scanned components. This image is voxelized in the software associated with the CMM, Inspire [6]. The dimensions can then be pulled from the image by comparing the locations of the voxels. Fig. 2 shows one of these scans being completed.

Fig. 2. CMM scan measurement of Flattop pedestal.

The second mode used with the CMM was point measurements made with a “ruby tip” probe. This mode used a probe attached to the end of the measurement arm. The probe touches the sample, in this case the reflector, and the software records the locations of the touches. The diameter of the reflector piece is then inferred from the locations of the touches. Careful attention was paid to ensure that the full span of each reflector piece was measured independently. This measurement was then verified by closing Flattop with the HEU core fully removed and repeating the same process to get the diameter of the closed assembly. Fig. 3 shows the CMM scan being performed on the closed Flattop configuration, and Fig. 4 provides the digital rendering of the scan. These two values agreed perfectly with each other, which also indicated the lack of a measurable gap in the closed configuration. The resolution of these measurements is ±0.001 in.

Fig. 3. CMM scan of Flattop while closed with HEU core removed.

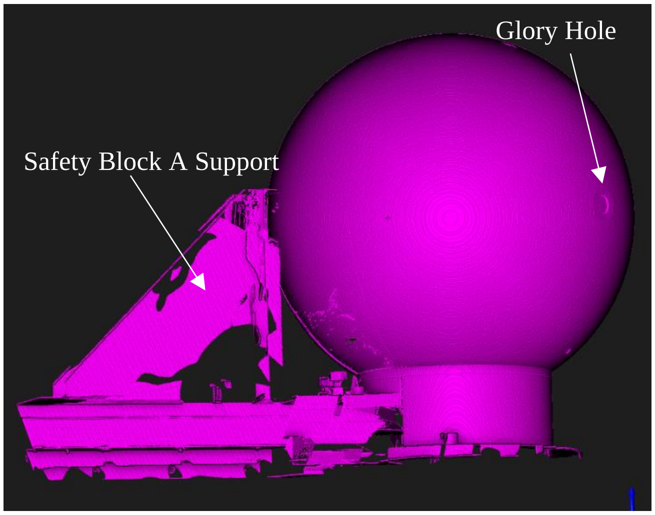

Fig. 4. Digital rendering of CMM scan for closed Flattop configuration showing support for safety block A and glory hole.

For the smaller glory hole and mass adjustment pieces, a high-precision set of calipers were used to verify the height and diameter, which were also measured by the CMM. The calipers had a resolution of 0.01 mm. Each of these dimensions was measured three separate times in varying locations across each piece to survey the whole piece. These measurements were also used as comparison points to verify the CMM was properly reporting. Preliminary analysis showed great agreement between the two sets of measurements.

Volume Measurements

The last set of measurements that were taken were volume measurements of the glory hole and mass adjustment pieces. These measurements were made using an Anton Paar Ultrapyc 5000 pycnometer, Fig. 5. [7] The temperature was set to 16ºC which corresponded to the building temperature, and the target pressure of the system was set to 10 psi. At the start of each set of measurements, the system was recalibrated to ensure accuracy of the results. Once the system was calibrated, each of pieces was wiped down and placed into the measurement chamber. The system was then set to measure the volume at least three times until the percent deviation in the volume measurement was below 0.05%. Typically, the sample required between three and five measurements to meet this requirement.

Fig. 5. Loading sample in small cell into pycnometer.

EFFECTS ON K_{EFF} AND UNCERTAINTY

It is expected that these measurements will greatly reduce the total uncertainty of the system to within acceptable levels of a modern benchmark. The estimated total uncertainty for the system after these measurements is ±0.00048. The model has not yet been fully updated to incorporate these alterations. However, initial adjustments are promising. Once these adjustments are made, the full benchmark will be reevaluated and presented to the ICSBEP Technical Review Group.

CONCLUSIONS

Flattop is one of the most used critical assemblies for the DOE. The original benchmark evaluation for the ICSBEP handbook had a much larger uncertainty than is currently acceptable for today's benchmark evaluations. To decrease this uncertainty, new physical measurements were taken of Flattop. These high-precision, calibrated measurements covered the mass, dimensions, and volumes of Flattop's major components. To capture these measurements, a CMM was used in conjunction with several scales, calipers, and a pycnometer. These high-precision measurements are expected to decrease the uncertainty of the benchmark evaluation and more closely match the computational model to the physical experiment. Flattop will be fully reevaluated for the ICSBEP handbook.

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REFERENCES

1. D. HAYES, T. BREDEWEG, T. CUTLER, J. GODA, T. GROVE, J. HUTCHINSON, J. LAMPROE, G. MCKENZIE, A. MCSPADEN, W. MYERS, R. SANCHEZ, and J. WALKER, "A New Era of Nuclear Criticality Experiments: The First 10 Years of Flattop Operations at NCERC," *Nuclear Science and Engineering*, **195**, sup1, S37–S54 (2021).
2. J. BESS, T. IVANOVA, L. SCOTT, and I. HILL, *The 2020 Edition of the ICSBEP Handbook*, Nuclear Energy Agency, Organization for Economic Co-Operations and Development (2020).
3. R. W. BREWER, T. P. McLAUGHLIN and V. DEAN, "Uranium-235 Sphere Reflected by Normal Uranium using Flattop," *International Handbook of Evaluated Criticality Safety Benchmark Experiments,* HEU-MET-FAST-028, Revision 1, Nuclear Energy Agency, Organization for Economic Co-Operations and Development (September 2015).
4. D. HAYES, T. CUTLER, J. FAVORITE, J. GODA, J. HUTCHINSON, R. LITTLE, and M. RISING, "Reevaluation of Flattop HEU Core Benchmark CEDT Phase-3A Measurement Plan," LA-UR-22-25798 (2022).
5. J. A. FAVORITE, "Preliminary Flattop-25 Reevaluation Results," LA-UR-15-29661 (2015).
6. HMI METROLOGY SOFTWARE, INC., "Inspire Reference Guide," (2018).
7. ANTON PAAR, "Ultrapyc 5000 Instruction Manual and Safety Information," I15IB012EN-D (2021).