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Trepanning Graphite Samples at a Shutdown Magnox Reactor: A US-UK Joint Exercise for Nuclear Verification

Authors:
B. Bowerman[1], R. Boyd[2], C. Finfrock[1], C. Gesh[3] (gesh@pnl.gov), R. Pires[3]
[1] Brookhaven National Laboratory
[2] Secured Transportation Services
[3] Pacific Northwest National Laboratory

ABSTRACT

In April 2022, a team sponsored by the US DOE Office of Nuclear Verification (ONV) shipped trepanning equipment to the nuclear power station at Trawsfynydd, Wales, UK to collect samples from the graphite moderator of Reactor 1. The sampling campaign to collect 48 graphite samples was completed in five weeks beginning July 11. Half the samples will be analyzed in the US to determine the total energy production of the facility. The other half will be analyzed by Magnox Ltd. to support decisions for options for the ultimate decommissioning path for the facility.

This paper provides a description of the equipment and the operations required to trepan, collect, and package the samples while controlling the small amounts of radioactive graphite dust entrained on and within the tool. The most important sample parameter needed is the precise location of the sample, to within ±6 mm in a fuel channel, while the tool is deployed to between 12 and 20 meters below the operations floor; our means of achieving this precision is given.

INTRODUCTION

In 2011, the US Department of Energy (DOE) established the capability to retrieve samples from graphite moderated reactors for the purpose of determining the total energy production of the facility. Brookhaven National Laboratory (BNL) maintains the equipment and hosts annual exercises for the US Graphite Sampling Team (GST). In 2022, the GST participated in a joint capability demonstration at a shutdown Magnox reactor in Trawsfynydd, Wales, UK. Following a review of the timing of Magnox decommissioning, Trawsfynydd is being prepared for the adoption of a continuous dismantling strategy by the UK Nuclear Decommissioning Authority (NDA) and the site operator, Magnox LTD. The US DOE provided primary funding for the US effort. Magnox provided logistics and health physics support. In addition to demonstrating the GST trepanning capability, the sampling campaign was developed to address two objectives:

1. Provide graphite samples for a graphite isotope ratio method (McNeece 1999) analysis in the US, and
2. Provide samples for analysis by the NDA in support of its long-term responsibility for the eventual decommissioning of all Magnox reactors.

This paper describes the plans and operations used to successfully complete the retrieval of 24 samples for each objective within the five weeks allocated.

SAMPLING PLAN

Decommissioning activities at Trawsfynydd Reactor 1 included removing fuel handling equipment used to lift standpipe closure assemblies (SCAs) from the standpipes that access the fuel channels. In addition, a weather tight capping roof was installed over the charge face of the reactor, preventing the removal of the standard SCAs. Access to a limited number of standpipes

was made possible with the installation of reduced-height SCAs in 16 standpipes. The locations of the reduced-height SCAs are denoted with letters in Figure 1, which provides a plan view of the total 241 standpipes in the Reactor 1 core. Based on the time limits and projected sampling rate, four channels were selected for sampling, one located at the center, two on the periphery, and one midway between these.

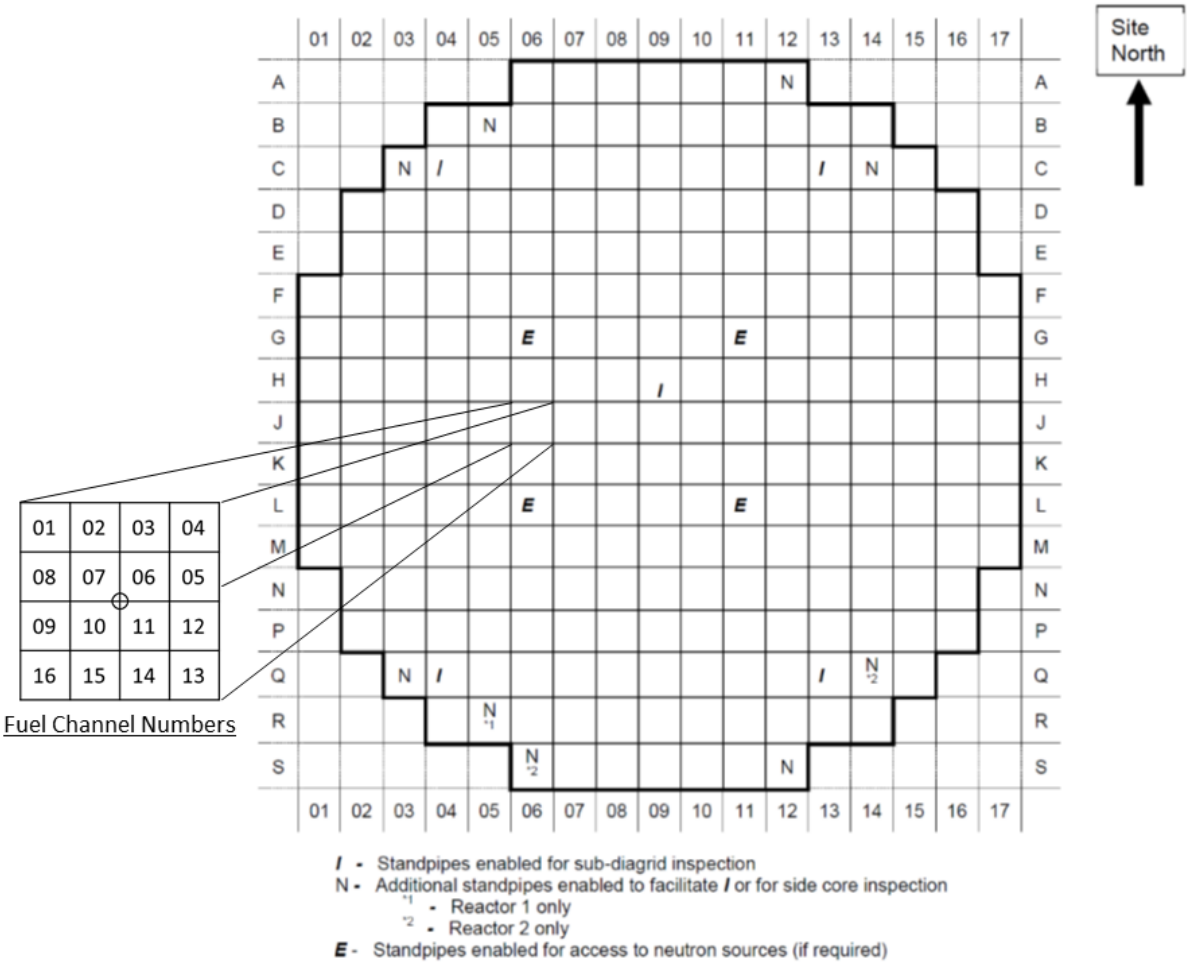

Figure 1 – Standpipe numbering scheme. The standpipes used for sampling were: H09 (center), L06 (midpoint), and C03 and Q13 (core periphery)

US and UK samples were collected from the same fuel channels. There are four fuel channels readily accessible, adjacent to the "X-hole" directly under the standpipe and designated by their compass direction from the X-hole. Thus, the fuel channels sampled are identified as H09/SW, C03/NW, Q13/NW, and L06/SW. (Note that NW and SW are fuel channel numbers 07 and 10 in the inset charge-pan key in Figure 1.) The azimuthal position of the samples was kept consistent for each set, with the UK samples being trepanned 90°around the channel from the US samples.

Fuel Support Struts (FSS), located near the bottom of each channel, served as the reference point for measurement of vertical position. There were nine vertical (axial) sampling positions specified in each channel, positioned as closely as possible to the centers of the nine Magnox fuel rods that occupied a channel during operation. US samples were taken from axial positions 1 to 9 in the H09 standpipe and from axial positions 1, 3, 5, 7, and 9 in the other three standpipes

sampled. The UK samples from the same four fuel channels were taken at the following axial positions:

a. UK sample 1 = US sample 1
b. UK sample 2 = US sample 5
c. UK sample 3 = the midpoint between fuel elements 5 and 6
d. UK sample 4 = US sample 9
e. UK sample 5 = Lowest available location in the upper reflector block
f. UK sample 6 = Mid-point of the upper reflector

The full list of samples is summarized in Table 1. In each channel, the US samples were collected first, followed by the UK samples.

Table1. Summary List of sample locations

Order	Standpipe	Channel	Azimuthal US/UK	US Axial Locations	UK Axial Locations
1	H09	SW	SW/NW	1-9	1-6
2	C03	NW	SW/NW	1,3,5,7,9	1-6
3	Q13	NW	NE/SE	1,3,5,7,9	1-6
4	L06	SW	NW/SW	1,3,5,7,9	1-6

The graphite sampling system consists of the sampling tool (or head) deployed into a reactor on an umbilical. The system is enclosed in a movable containment, shown in Figure 2, that limits the spread of contaminated graphite. Figure 3 shows a close-up view of the trepanning tool that is lowered into the standpipe and fuel channel on the umbilical for sample collection, while Figure 4 provides close-ups of the cutter (a) in the tool, (b) extended from the tool, and (c) in a Teflon storage pot. The diamond coated cutters were cleaned and stored under inert gas in these pots in 2019, to prevent corrosion until sampling, after which the cutters are returned to the pots for subsequent shipment for analysis. Each cutter has a tracking number engraved on the drive shaft, which is recorded during sampling along with the vertical position in the fuel channel.

Figure 2. The trepanning tool in the movable containment positioned over a standpipe

Figure 3. The Graphite Sampling Tool. The forward view camera, on the left, looks down the channel. The umbilical connects to the top of the tool above the sideview camera, which has green LEDs lit. The cutter extends from the hole that is approximately halfway between the forward and sideview cameras.

a)  **b)**  **c)** 

Figure 4. The trepanning cutter:
a) partially extended; b) fully extended with sample present; c) in Teflon storage pot

EQUIPMENT and TRANSPORT

In addition to the sampler, other items are needed to collect samples or conduct repairs and maintenance. These include the overview camera, maintenance glovebox, control consoles, compressed air system, deck cable connections, house electrical connections, and equipment spares. The equipment items were packaged into 20 wooden crates which were then loaded into four 20-foot ISO shipping containers. Team members secured all crates and direct-loaded equipment with bracing, cargo netting and strapping for transport, then inventoried, photographed, closed, and sealed the containers for transport from BNL to Trawsfynydd.

The route included truck and marine container ship transport modes, with minimal holdups for export at Port Newark, New Jersey, and to clear customs at Liverpool. The rapid clearances through ports were the result of careful planning and coordination between the US and UK.

SAMPLING CAMPAIGN OPERATIONS

Even 32 years after operations ceased, significant radiological hazards persist in the Trawsfynydd reactors. Sampling work took place within an access-controlled area identified as a C2 contamination area, following standard British Health Physics (HP) practice. In this area, surface contamination levels may exceed 4 Bq/cm^2, and Personal Protective Equipment (PPE) requirements included coveralls, gloves and boots which were removed on exiting. GST members carried out manual chores such as moving equipment to positions over a standpipe, raising/lowering the tool into a standpipe and fuel channel, and conducting and viewing functional checks of the tool. They manipulated the cutters to record cutter ID numbers in the video record, removed and installed cutters, re-packaged cutters containing samples in Teflon pots, and bagged these upon removal from the sampler. Bagged samples were surveyed, transferred out of the C2 area, and locked in a secure storage room.

Sampling work involved the operation of the overview camera, sampler, and use of the maintenance box within C2. The overview camera was inserted in a standpipe close to the sampling standpipe and deployed at a height to provide a clear view of the tool entering the desired fuel channel. The maintenance box provided a confined work space for maintenance and repair of the tool head's mechanical components. One of the routine maintenance operations was replacement of the carriage that held and powered the cutter. After 20 samples, the gears providing cutter rotation become worn leading to wobble in the cutter and unacceptable sample characteristics. Replacing the carriage replaces the gears and solves the problem.

The sampler and overview are controlled by consoles operated outside the C2 area and connected by 25-foot cables for pneumatic controls, electrical controls, and data transfer. Team members at the consoles follow strict procedures to assure rigorous reproducibility and precision in the measurement of sample locations.

The campaign consisted of three stages:

- Week 1: Unpacked, assembled, and staged equipment on the reactor refueling floor. Located and connected electrical supplies with transformers and distribution equipment. Certified air compressors and pressure equipment. Completed functional tests and calibrations. First fuel channel accessed, visually inspected, and metrology completed. In the metrology process, the team measured the heights of all the brick-tile joints above

the FSS. Metrology, also critical to confidence in the precision of the sample's vertical position above the FSS, was repeated at least twice for each fuel channel.

- Weeks 2, 3, and 4: Collected samples. Figure 5 shows the team with the first sample taken from Reactor 1. Weekly sample totals are shown in Table 2. Collection rates ranged from one to six samples per day, averaging 3.5 per day for the 14 days of sampling. Interruptions to sample collection operations are discussed below.
- Week 5: Dismantled systems and repacked releasable equipment in shipping crates. All crates were returned to the ISO containers, which were then locked and sealed by Magnox staff. Contaminated equipment (the sampler, maintenance box, and overview camera) was wrapped in plastic and will be stored in a C2 contamination area until decontamination or packaging as a radioactive shipment.

Table 2. Weekly Samples Tally

Week	Channel	US	UK	Total
2	H09/SW	9	6	15
	C03/NW	1	0	1
3	C03/NE	4	6	10
	Q13/NW	5	0	5
4	Q13/NW	0	6	6
	L06/SW	5	6	11
	Total	24	24	48

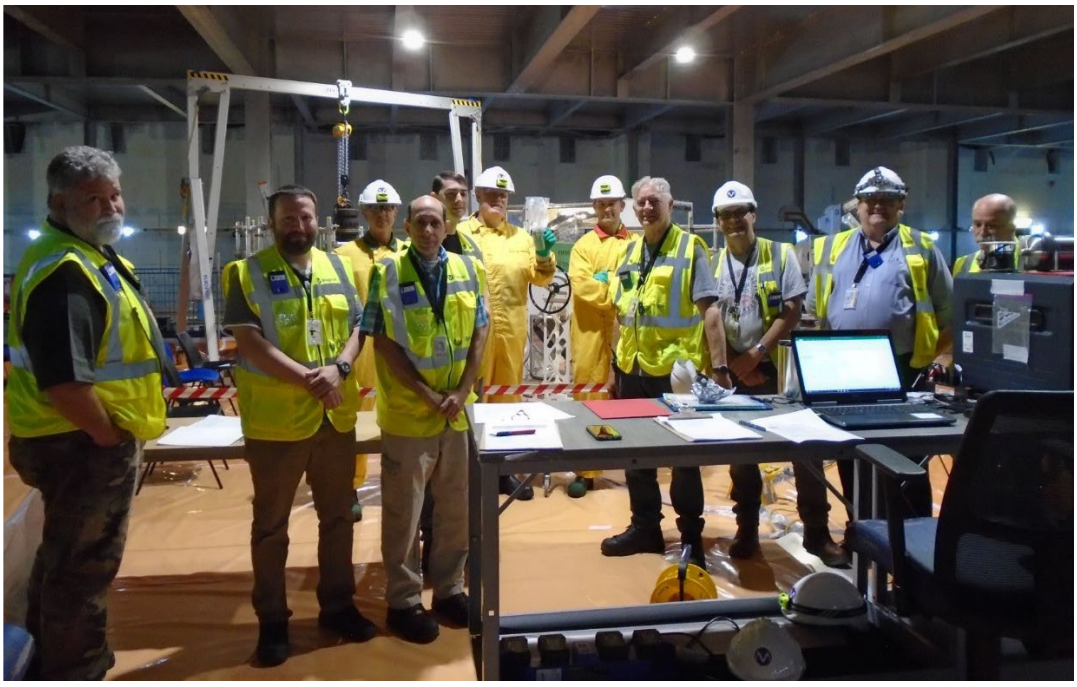

Figure 5. GST and Magnox Staff with the First Reactor 1 Sample on July 18, 2022.

Delays, both expected and unexpected, slow down sampling:

- Between standpipes, replacement/removal of SCAs must be completed. This required the use of the A-frame hoist seen in the background of Figure 5. For each standpipe two SCAs were removed, one each for the sampler and overview camera. Magnox staff completed this function, usually within an hour.

- Initial steps at a standpipe before the first sample included:
    - Positioning the sampler, lowering the bellows, which interface with the standpipe and provide a barrier between the work area and reactor atmosphere
    - Setting up the overview camera at an adjacent standpipe, and
    - Conducting two to three metrology runs.
    - GST standard procedure requires initial fuel channel visual inspections with a separate inspection camera. These were waived because the four channels had been inspected during a preliminary visit by the GST in January 2022.
- Post-sampling inspection with the sampler, which records the positions of all the sample in a single video file, is conducted when sampling is complete in a channel.
- Routine tool maintenance, e.g., replacing the carriage after 20 samples.
- Unexpected operational tool issues. For example, during sampling the second week, cutter rotation stopped short. The tool was removed from the reactor and moved into the maintenance glove box for assessment. A set screw, holding the cutter in the sampler, had not been tightened sufficiently. During rotation the set screw backed out until it hit the wall of the carriage, stopping rotation. Securely installing a new set screw solved the problem.

CONCLUSIONS

The US GST and Magnox staff successfully completed their joint mission to collect 48 samples in five weeks at the shutdown Trawsfynydd Reactor 1. Operations proceeded on schedule with only a few minor equipment problems that were resolved. Half of the collected samples will be used in the US to verify total energy production in Reactor 1.

The other half of the samples will be used to quantify graphite core physical and radiological properties 30 years after the reactor's shutdown. This characterization information is vital to the Magnox mission and shall underpin the reactor decommissioning methodologies, material treatment options, and ultimate volumes of waste to be produced at the site. Demonstrating the capability at a Magnox reactor site in this way, and having the ability to repeat the exercise in the future at other UK reactor sites, removes uncertainty from the cost and schedule for remediating graphite core reactor sites

ACKNOWLEDGMENTS

As noted in the title, the sampling campaign was a joint effort. The contributions to the sampling campaign by the staff of Magnox, LTD., are gratefully acknowledged. Magnox supplied logistical support in unloading and unpacking the equipment, and full health physics coverage, from PPE and dosimetry to radiation control staff. Without this support the sampling effort could easily have taken additional time. We also recognize the oversight and direction of the UK Nuclear Decommissioning Authority, who viewed this campaign as contributing to their understanding of the current physical status of the Trawsfynydd Reactor 1 core.

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