Abstract

The WRAPUP Project: Recovering Information from the Operation of WR-1

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The WRAPUP (Whiteshell Reactor Applied Physics data Utilization and Preservation) Project was established in response to an inquiry received in 2011 May from staff at the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) who are involved with the International Reactor Physics Benchmark Experiments (IRPhE) Project. TheIRPPhE Projectcollects, archives and evaluates integral reactor physics experimental data from measurements performed at various research laboratories, worldwide, and manages a handbook of evaluated experimental data and benchmark simulations pertaining to them.The IRPhEProjectwanted to know if AECL (Atomic Energy of Canada Limited) would be interested in contributing information from WR-1 (Whiteshell Reactor No. 1) physics experiments to its database. AECL – Chalk River Laboratories (CRL) is an active participant in the IRPhEProject, having contributed experimental data from the ZED-2 (Zero Energy Deuterium) reactor at the CRL, including CANDU (Canada Deuterium Uranium) related experimental data with the support of the CANDU Owners Group (COG), and having participated in the review of the contributions from other national laboratories (currently representing fourteen countries). AECL recognizes the value of this work to the global reactor physics community for testing the computer codes and nuclear data used in reactor simulations of every reactor type and thereby improving their reliability.

It was recognized that the provision of any WR-1-related information might help the IRPhE Project to fill a gap in its coverage for a now largely forgotten reactor type – Organic Cooled Reactors (OCRs). But, in addition, it was believed that the WR-1 data mightoffer a new dimension to the IRPhEProjectdatabase if enough operating data still existed. The experimental data in the current IRPhEProject handbook predominantly involvesnapshot (i.e., a single reactor state at a given instant of time), zero-power critical measurements using fresh (unirradiated) fuel at room temperature.In contrast, the WR-1 operating data mightchallenge the reactor physics codes to simulate more realistic and complex power reactor conditions at coolant temperatures up to ~425°C (and that varied with power manoeuvres), with a variety of irradiated fuel types (UO_2, UC, and $UThO_2$ in several geometrical configurations and at uranium enrichment levels up to 4.95 wt% ^{235}U), in various types of fuel channels (stainless steel and Zr-2.5Nb) and over extended periods of irradiation, during which significant isotopic changes occurred to the fuel composition andchanges to the core configuration occurred due to fuel management operations.

Being the most modern of AECL's research reactors to operate at high power (the earlier ones being the NRX (National Research Experimental) and,the still operating, NRU(National Research Universal) reactors at CRL), WR-1 was very well instrumented.In particular, calorimetric power measurements were available for each and every fuel channel (up to 54) in the reactor core. This meant that the measured

core radial power distribution could be determined with reasonable accuracy (to within a few %) and directly compared against computer code predictions. In turn, the fuel axial spatial burnup distribution could be estimated as as the irradiation proceeded. In addition, the axial flux profile could be measured (albeit infrequently) using a variety of self-powered travelling flux detectors in certain fuel assemblies consisting of fuel bundles mounted on a hollow central support tube.

Reactivity changes could be discerned with good precision in WR-1 based on changes in the average heavy water (D_2O) moderator critical height, since (as in ZED-2) the average moderator level could be determined accurately and the reactivity changed fairly slowly with moderator level.

Most of the operating history of WR-1 was routinely (at least daily) processed from the information produced by the online data logger and archived on various digital storage media. This was supplemented by periodic measurements of other quantities (such as boron concentration in the moderator, moderator purity, and organic coolant 'High Boiler' fraction) that would be needed to construct representative physics code simulations.

From initial inquiries to AECL staff at the CRL and the Whiteshell Laboratories (WL)who are responsible for the ongoing decommissioning and legacy information management activities at WL, it was found that an inventory of the WR-1 operational information had been created in 1997and that a substantial amount of material, such as engineering drawings, had been scanned and entered into AECL's electronic records management system, TRAK. Sometime after the 1997 inventory was recorded, it was decided to repackage the WR-1 information into cardboard boxes and move the boxes into Whiteshell storage Bbuilding 415.In 2011 July, a new record was drafted documenting the contents of the 752 boxes stored in Bldg. 415, with a cross reference to the previous cabinet/box record of 1997. Upon examination of these inventories, it appeared that the bulk of the WR-1 operating history record (e.g., reactor shift logs, power maps and burnup reports) might indeed be recoverable. However, the portions of greatest relevance to reactor physics simulations were intermixed with WR-1 records of low relevance as well as much non-WR-1 material. In addition to these paper records, there were indications that a variety of digital magnetic storage media still existed, which might contain the archived WR-1 operating history, but whose content and condition were presently unknown.

Based on the external interest from the IRPhEProject and the tantalizing preliminary indicationsof potential recovery of extensive and highly relevant WR-1 operating informationsuggested by the existing data inventories, the support of AECL management was secured to proceed with the WRAPUP Project, commencing in 2011 December. The basic mandate was to perform a limited, on-site evaluation of the status and extent of available physical records from the operation of WR-1 with a particular focus on those items that might be most relevant to the simulation of WR-1 operation and experiments using reactor physics codes. The initial focus was to examine the contents of the 752 boxes stored at the WL and attempt to sort out and document what was of potential interest to this project. The WRAPUP Project was undertaken with a certain sense of urgency given that AECL funding would be available only until 2012 March 31, the condition of some of the paper documents, such as line printer output, was deteriorating, due most likely to its long-term storage in an uncontrolled environment in an unheated warehouse, and the remaining firsthand knowledge base of WR-1 physics (principally the authors of this paper) and its operation was nearing a point of no return due to retirements and fading recollections.

A number of items of potential historic interest were recovered during our investigations, including the signature page from the reactor logbook for WR-1 initial criticality on 1965 November 1 (most of the 34 signatures were positively identified) and several pictures of reactor commissioning staff in the reactor control room. In addition, complete sets of design and commissioning manuals were located and portions were scanned and stored as electronic files.

The following summarizessome of the main highlightsfrom the WRAPUP Project from a reactor physics modelling point of view:

- In Core Components: The dimensions and materials of the calandria vessel and the fixed components associated with it are documented in commissioning manuals, reactor vault component specifications, and "master copy" drawings of reactor components in the WR-1 registry folders. Fuel channels, hanger assemblies and fuel assembly loadings can all be identified for the complete operating history of WR-1. The exact dimensions and initial compositionsfor all of the fuel assemblies were not identified during this review, however composition records for the initial core loading were identified (specified to the nearest one-hundredth of a gram ^{235}U and total U for each fuel bundle). We have confidence that most of this information can be found in the Purchase Order Files and post irradiation experimental reports that were not contained in the boxes investigated during this project.
- Reactor Operating Parameters: Control parameters like moderator height, ion chamber response, boron (^{10}B) concentration and coolant chemistry were identified, we believe, for most of the period of WR-1 operation.Handwritten records of coolant circuit conditions, reactor power, etc. were identified from the fourteen reactor logbooks that span the entire WR-1 operating history. Thermalhydraulic conditions of the coolant and moderator exist on line-printer output for all data logger scans taken after 1967 April (reactor loading 31). Line printer output from WR-1 start~~-~~up (1965 November 1) to 1967 April range from scant (early 1966) to numerous by the end of the period. Core Average Summariesfor each reactor loading exist~~s~~ in electronic form from 1968 June (reactor loading 46) to the end of reactor operation (reactor loading 318). These summaries supply the time-weighted average of the flow, pressure, and temperature in each site as well as circuit and loop averages. They also contain averages of moderator height and ion chamber response. Fuel string and bundle definition for each site in core are~~is~~ also contained in the summaries.Archiving of processed scan data was started in 1973 June (reactor loading 137) and continued until the end of WR-1 operation. This electronic record was stored on 10-inch-reel magnetic tapes written by a PDP10 computer. To date we have not found the architecture/software to extract the scan data from these tapes, although we are confident that such data could be recovered if appropriate hardware is located or appropriate software is obtained to translate the hexadecimal data from these tapes into a comprehensible form. Such data were successfully recovered from a few tapes that were in a form and format that could be read by existing hardware maintained by the thermalhydraulics research group at the ~~active~~ RD-14M experimental loop facility still operating at WL. In addition, monthly branch

progress reports and reactor shift logs were recovered that supplement the numerical records with verbal commentary and greatly aid the understanding of the basis for the ongoing changes made to the WR-1 core and its operation.

- Operational Results: Total power developed and fuel string and bundle burnup exist on line-printer output for all fuel irradiated in WR-1 with the exception of one period of about 20 core loadings. It is believed that the missing Burnup volume is misplaced and will be found and returned.
- Axial neutron flux scans: numerous axial flux scans were recovered that provide detailed axial neutron flux profiles using a variety of travelling, self-powered neutron flux detectors (e.g., Pt, Rh, Vn, Inconel, etc.). Such data could conceivably be used to verify the estimates of bundle end-flux peaking for power ~~CANDU~~ reactor core simulations.
- Startup physics measurements: likely the most significant reactor physics finding was the Canadian General Electric (CGE) 1967 report, R67CAP9, by O.J. Hahn, "WR-1 Startup Physics Measurements", which provides key data, such as coolant void reactivity measurements, at well defined initial core conditions, and forms the starting point for subsequent simulations of WR-1 operations. Fittingly, the copy of R67CAP9 obtained from the CRL library was that of W.B. Lewis, widely recognized as the father of the CANDU reactor concept.

The findings of this review suggest that most of the operational data that could be used to form a reactor physics validation database exist, however the form of some data (e.g., line-printer output) would not be digitized easily.

Routine operation of the WR-1 reactor was simulated using the LATREP/HEX code system (later the WIMS-AECL/HEX code system), in which LATREP (Lattice Recipe, similar tothe CANDU lattice cell code POWDERPUFS-V) provided the lattice cell parameters for each radial lattice site and axial plane (ten were used, two for each fuel bundle) as a function of fuel burnup. The lattice cell parameters were used by the two-group thermal neutron diffusion code HEX (the main version used was HEX3BR, for which a user manual was recovered), which performed a neutron diffusion theory calculation to determine the core eigenvalue and the relative, three-dimensional, spatial neutron flux and power distributions. No computer code source listings or executable data files for LATREP or HEX were recovered during the WRAPUP Project.

An effort was made to develop a~~n~~modern MCNP (Monte Carlo n-Particle) model of the initial WR-1 startup core, however this could not be completed during the WRAPUP Project. Simulation of an extended period of WR-1 operation might best be attempted using modern multigroup neutron diffusion codes such as DONJON or 3DDT, for which significant Canadian experience exists.

To conclude, the WRAPUP Project has been an interesting exercise in modern-day 'reactor-physics archaeology' for the authors of this paper, who are among those few remaining individuals who were intimately involved with the operation of WR-1 for a portion of its history. It remains to be seen whether sufficient interest exists to expend the additional effort that would be needed to extend the WRAPUP investigationand potentially revive the simulation of extended periods of WR-1 operation. Some careful thought should be given to this possibility since the additional effort needed may be small in comparison with the several billion dollars of Canadian taxpayer investment and several decades of technical research and development that would be needed just to replicate the remarkable accomplishments of WR-1.