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Idaho National Laboratory

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Modernization of the Radiation Measurements Laboratory at the Advanced Test Reactor Complex

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Abstract. The Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL) is a unique, water-cooled, high-flux test reactor capable of performing tests prototypical of PWR operating conditions. The Radiation Measurements Laboratory (RML) was founded in the 1960s to support reactor operations and to conduct independent scientific research. For nearly six decades RML has performed four primary functions: monitoring of radioactivity by gamma-ray spectroscopy of routine reactor samples, fluence rate determinations for irradiation cycles, fission-rate measurements for the ATR-Critical (ATR-C) Facility, and independent research and development of radiation detection systems and applications. Through the decades, RML has seen technological advancements that have been integrated into each of the critical functions of the laboratory. However, many of the measurement and analysis systems employed to this day can be improved by modernization. Recent progress at RML is improving reliability and accuracy of the radiation measurements performed in support of nuclear energy research for the U.S.A. Department of Energy. The control and data collection systems supporting ATR-C have been upgraded. New High-Purity Germanium (HPGe) spectrometers have been procured with liquid nitrogen recycling capabilities to improve up-time and reduce measurement uncertainties. Fluence-rate measurement techniques are also being improved to ensure accuracy, avoid systemic errors, and identify biases. In a parallel effort, new scientific research avenues are being explored which will provide an opportunity to further enhance the utilization of ATR and ensure the sustainability of the RML as nuclear research continues to evolve. The RML is improving the effectiveness of irradiation services provided by ATR while ensuring a sustainable future for nuclear energy research.

Key Words: Reactor Dosimetry, Radiation Measurement, Advanced Test Reactor

1. Introduction

The Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL) has unparalleled nuclear irradiation capabilities for nuclear technology research and development, supporting a variety of stakeholders. The routine operations of the ATR are supported in part by the on-site Radiation Measurements Laboratory (RML). Founded in the early 1960s to support multiple test nuclear reactors at INL (known by several other names in the past), the RML performs 4 core functions. Short irradiation experiments are conducted at the ATR Critical facility (ATR-C) before each full ATR cycle in order to verify the safe configuration of the reactor geometry with a new experiment inserted. The fission-rate profile in ATR-C is determined by irradiating fission wires which are analysed by RML [1]. Routine gamma-ray spectroscopy measurements are conducted by RML to determine the isotopic abundance and activity of samples associated with reactor operation such as coolant samples, stack-gas samples, and filter samples. The RML also determines the fluence-rate for each reactor cycle by measuring the activation of dosimetry wires [2]. Finally, independent research projects leverage the capabilities of RML with the proximity to ATR and ATR-C to develop and test new radiation detection systems and applications. The RML has supported three different test reactors and has seen many improvements in radiation measurement capabilities. It is imperative to maintain a system of modernization, continually improving RML, to enable effective and sustainable utilization of ATR.

2. A Parallel Approach to Radiation Measurement Laboratory Modernization

The present state of the RML presents both challenges and opportunities to improve effectiveness and sustainability. The challenges are related to the aging hardware and support systems in the laboratory which must be addressed in order to ensure that the core functions of the RML are maintained. At the same time, opportunities exist to develop innovative approaches to these challenges and to integrate RML into larger research efforts, ensuring a sustainable research mission for the laboratory. A parallel approach to modernization has therefore been adopted at RML where challenges are addressed with the specific intention to leverage the work into new scientific contributions that can support further research. This method is being applied to the three main roles of the RML: fission-rate measurements supporting ATR-C, gamma-ray spectroscopy of routine ATR complex samples, and neutron fluence-rate measurements supporting ATR. Independent research and development opportunities are also being pursued to support the main mission areas and to bring new resources into the RML.

2.1. Fission-Rate Measurements at ATR-C

The ATR-C at INL is a low-power version of ATR primarily used to qualify experiment configurations for the ATR to ensure the safe operation of the higher-power ATR [3]. Experimental configurations are tested first by modelling the full ATR-C reactor core and then confirming these models using a standardized method of irradiating uranium-aluminium (U-Al) alloy fission wires which are strategically located through the reactor core [4]. Following irradiation, the gross-beta-particle activity of the U-Al fission wires is measured to determine the average fission-rate of the wires. The measurement results are used to develop a map of the fission rate throughout the ATR-C core. Typically, these irradiations produce between 300 and 900 activated fission wires. A method was developed in 1965 to determine the average fission-rate of each sample by measuring the gross beta-particle activity using a 4-channel counting system with automatic sample changers, shown in Fig. 1 [4].

FIG. 1. The 4-channel counting system utilizes original sample-changing hardware and proportional gas detectors to measure the gross beta-particle activity of irradiated fission wires [1].

The beta-particle counting system has been in service for over 50 years, incorporating numerous upgrades during that time. However, many of the upgrades are necessarily unique applications which do not presently have commercial support. The natural transition of personnel in RML has created a challenging situation where many of the custom improvements could not be replaced in a timely manner if they failed. To that end, a development effort was initiated which would replace the control and data-collection mechanisms with commercially available hardware, using a modern programming language. National Instruments (NI)-based hardware has been procured and integrated with LabView to replace the custom hardware and software which was previously in service.

The transition to new hardware and control software provided a unique opportunity to assess the accuracy of the measurement method. First, a comparison was made between data acquisition of standard beta-particle sources using the legacy system and the NI-based system independently. After observing statistically identical results with the standards, a parallel measurement system was devised which would allow both the legacy and NI-based system to be used at same time to measure the activity of irradiated fission wires. Once again, the results were statistically the same [1]. Finally, the absolute accuracy of the system was assessed by comparing beta-particle measurement results using the calculations from the original system calibration with modern gamma-ray spectroscopy [1]. The large number of samples, low activity of each isotope within the samples, and short half-lives of many fission products limits the effectiveness of gamma-ray spectroscopy in this particular application. However, the assessment of a sub-section of the wires showed that both the legacy and NI-based system provided un-biased results of the average fission-rate for the activated wires.

The improvements which have been made to the beta-particle counting system at RML are an example of the parallel modernization effort where a system which was a failure risk was improved in a manner that enabled new scientific efforts. The new system not only improved the capabilities of the RML by reducing the risk and potential impact of hardware failures, but also provided an avenue in which the accuracy of the system could be assessed and reported to the greater scientific community [1].

2.2. Improvements to Gamma-Ray Spectroscopy Systems

One critical function of the RML at ATR is to support routine assay of radioactive samples in order to identify and quantify man-made contamination. These samples come in various physical forms, from liquid draw samples to real-time stack-gas monitoring. A collection of High-Purity Germanium (HPGe) detectors are maintained at the RML in order to perform gamma-ray spectroscopy measurements in a timely manner. Historically, RML has been a major contributor to the understanding of the science of gamma-ray spectroscopy, helping to develop many of the fundamental measurements in the area. However, as the scope of operations has changed for ATR over the years (a common challenge for research reactors), the focus of RML has shifted to operational support. Challenges in the area of gamma-ray spectroscopy at RML include aging hardware and software as well as a disconnect from commercial suppliers. A clear opportunity existed to improve vendor relations while simultaneously replacing aging hardware. Until recently, the HPGe detectors at RML were supported by analog measurement hardware (high-voltage power supplies, amplifiers, multi-channel analyzers, digital-to-analog converters, etc.). All-in-one commercial support hardware has been acquired to replace the aging hardware. A thorough investigation of the performance of the new DSPEC502 modules has concluded that all the requirements of the RML can be met by the digital systems.

Additionally, five new HPGe detector systems have been procured to replace the primary measurement systems at RML for routine samples analysis and for continuous monitoring of the stack gas exhaust. The new detectors include a liquid nitrogen (LN_2) condensing system which will substantially reduce LN_2 consumption at RML. The acquisition of new detectors has also provided an opportunity to replace the shielding and re-assess the efficiency calibration of each of the new detector configurations. The re-calibration will improve the effectiveness of RML in quantifying radioisotopes. Custom software has been historically used to perform analysis of gamma-ray spectra in order to determine absolute activity of the samples and identify radioisotopes within the samples. The replacement of aging hardware also enabled the exploration of modern, commercial software for spectrum analysis and sample processing. An assessment of commercial options is ongoing, but the eventual selection will improve the sustainability of RML by eliminating the need to support customized software for gamma-ray spectroscopy.

2.3. Neutron Fluence-Rate Measurements at ATR

A combination of Ni and Co/Al activation wires are deployed during every ATR irradiation cycle in order to determine the axial neutron fluence-rate distribution during the cycle. Accepted ASTM Standard Practices are followed in order to determine the neutron fluence-rates by measuring the activity of the irradiated Ni [5] and Co [6]. The activation of natural nickel by the ^{58}Ni(n,p)^{58}Co reaction is measured to determine fast-neutron fluence-rate while the activation of cobalt by the ^{59}Co(n,g)^{60}Co provides a measurement of the thermal-neutron fluence-rate. The system that is employed for these measurements includes two primary components. First a submerged NaI spectrometer is used in the ATR canal to determine a normalized activity rate for each irradiated wire. This is completed by using a mechanical scanning mechanism to scan the activated wires across the face of a columnated shield. The gamma-ray interaction rate at each of several intervals across the wire is recorded and normalized to the highest activity for that wire. Then, a technician manually removes a portion of the wire from the highest activity region. The wire segment is taken back to the RML for an absolute activity measurement using a calibrated ionization chamber. These measurements are combined to determine the average axial neutron fluence-rate at various locations within ATR during the cycle, shown in Fig. 2.

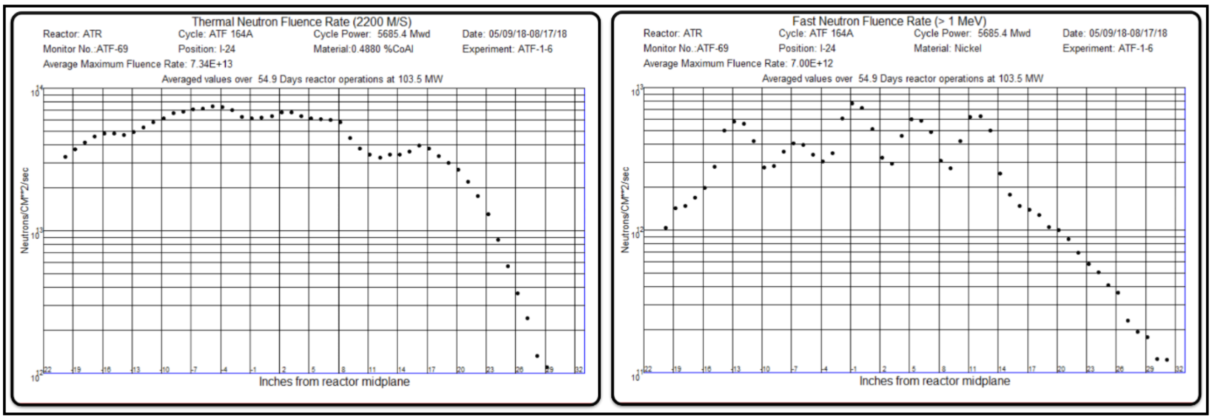

FIG. 2. Cobalt and Nickel flux wires are deployed within the ATR core during every cycle. The radioactivity of the wires is assessed by RML in order to determine the spatial distribution of fast and thermal neutron fluence rates for experimenters [2].

Several challenges are presented by the ATR neutron fluence-rate measuring system. First, the mechanical hardware associated with the wire-scanning process is aging poorly. Replacement hardware has been necessary in the past to support continual functionality, however a failure in key support systems could render the hardware inoperable for an extended period. There are also disadvantages to the physical methods that are used to remove the wires from their aluminum holders, scan them over the collimator, and remove a segment to be measured at RML. The ionization chamber, which has been in continual service for over 50 years has a slow leak which must be routinely assessed in order to provide a correction factor to activity measurements. The parallel modernization approach is being applied to address the challenges presented by the existing system while leveraging opportunities to innovate.

In the short-term, a new electrometer was procured to provide averaged current measurements with standard deviations for absolute activity measurements of wire segments. This has improved the precision of the measurement when compared to the previous digital system that only provided a real-time readout that had to be interpreted by a technician in order to obtain an approximate average value. The new hardware was also more recently calibrated, and a regular calibration schedule has been created to ensure reliable performance. The stability of the measurement system is also routinely measured by monitoring the decay of numerous activated Ni wire samples. This serves two purposes. First, the decay-rate can be used to measure the recombination effect to assess how this phenomenon has changed with the slow leak of the ionizing gas from the ionization chamber. Second, it provides a long-term quality assurance measurement for the system.

A parallel effort has sought to replace the wire-scanning hardware entirely, and in doing so improve the capabilities of ATR. An ATR Non-Destructive Examination (NDE) System (ANDES) has been designed with several non-contact NDE functions for a variety of ATR specimens, including driver fuel, light water reactor rodlets, capsules, plate-type experiment and dosimetry flux wires, illustrated in Fig. 3. These ANDES functions include underwater gamma spectroscopy, remote specimen handling, high-resolution visual inspection, computed gamma tomography and underwater laser metrology. If installed, ANDES would provide an unparalleled PIE capability that would benefit ATR from both an operational and experimental programmatic perspective.

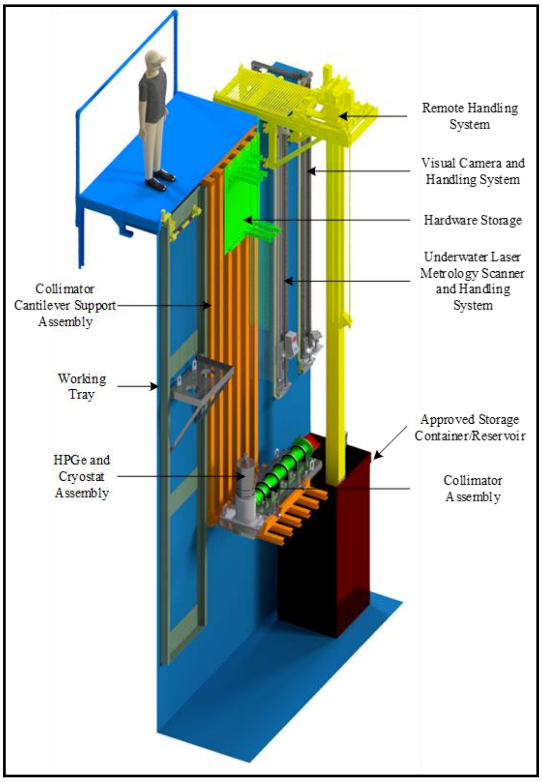

FIG. 3. The ANDES system would improve existing capabilities of PIE at ATR as well as providing new opportunities.

ANDES would improve ATR operations effectiveness in two ways: (1) collecting and validating more recent driver fuel burnup data and (2) improving flux wire dosimetry measurements. ATR reactor dosimetry measurements are currently made using a combination of flux wires made of nickel and cobalt alloys to measure experiment, safety rod, and beryllium reflector fluence. These wires are scanned by RML technicians via a laborious process of disassembling the flux wire holders and scanning each wire individually along its total length, using a sodium-iodide (NaI) underwater detector. The high-purity germanium (HPGe) detector used by ANDES would not require disassembly of the flux wires from their holders. A magazine that holds several flux wire holders simultaneously would offset the lower efficiency (i.e., increased count time) of the HPGe detector relative to the current NaI detector. The improved system would reduce technician exposure to radiation and improve ergonomic conditions while also enhancing the quality of data collected from reactor dosimetry measurements at ATR.

2.4. New Opportunities for Sustainable Operation

Integration of the RML into other research programs at INL and other national laboratories is helping to ensure sustainable operation of the laboratory. The ATR requires a complete changeout of the internal core components on a regular basis. The RML has taken a leading role in helping to design the physics testing procedures and in supporting dosimetry measurements that will be used to validate the new configuration. This is a role RML performed in the past, and one for which it is especially well-suited. However, RML faces a challenge faced by many similar facilities today related to the turnover of experienced staff. The capabilities of the highly specialized research scientists previously at RML are being filled by new staff. This provides opportunities for professional development of staff, but also challenges the scientists to rapidly develop the skills necessary for successful completion of the required tasks.

The ATR supports irradiation experiments for several customers. The Nuclear Science User Facility (NSUF) is a growing contributor to irradiation experiments at ATR. Many of the drop-in style experiments supported by the NSUF include dosimetry packages that are used to determine the neutron fluence-rate in the area of the experiment, and to correct the neutron energy spectrum estimate. Measurement of these dosimetry packages is presently conducted at an off-site facility, increasing the cost and time required to analyze the irradiation experiments. The RML is working with the NSUF to build the capacity to support experiment dosimetry measurements on-site to further accelerate nuclear energy research capabilities. The RML is also expanding the research capabilities offered to NSUF researchers by supporting irradiation experiments in the ATR Gamma-Tube, a dry irradiation port surrounded by recently irradiated ATR fuel. The high gamma-ray activity in the Gamma-Tube can be of particular use for experiments which require a very high gamma-ray dose without requiring an in-core nuclear reactor irradiation. Real-time dose-rate measurements are possible using specialized ionization chambers which have been procured for the RML.

Independent research is also being conducted which benefits from the routine activities at the RML. The ATR-C fission-rate measurements have built a strong tie between the ATR-C operations team, ATR nuclear engineering team, and the RML. Through this relationship a new collaborative research proposal was developed to fabricate and deploy a prototype real-time axial neutron flux monitor in the ATR-C to measure the changes in neutron flux while the control mechanisms in the reactor are moving. These measurements will be compared to simulation results to identify past and potential future biases in the past and future modeled data that cause discrepancies in irradiation experiment results. The knowledge gained from this experiment will improve the analysis capabilities of reactor experimenters and reduce uncertainties in irradiation experiments. The success of this proposal has also laid the groundwork to integrate RML into other radiation measurement activities at INL which relate to the calibration of real-time neutron flux sensors.

3. Conclusion

The RML at ATR has taken a parallel approach to addressing challenges and capitalizing on opportunities to ensure effectiveness and sustainability. The challenges that RML faces are common in the research reactor community, and the success that has been realized by this parallel approach can be shared by other laboratories in similar situations. A dedication to purpose has helped to keep the RML on-track in continuing to support routine measurement activities, and an enthusiasm for growth has made it possible to leverage these improvements into new scientific results which can be shared with the nuclear research reactor community. These modernization efforts will guarantee that the routine gamma-ray spectroscopy measurements, neutron fluence-rate, and fission-rate measurements at RML continue to support the daily operations of the ATR. Simultaneously, opportunities to expand into new areas of research that leverage these capabilities are being pursued to ensure a sustainable future for RML.

4. Acknowledgement and Disclaimer

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