APPLICATION OF THE MITR SIMULATOR FOR LICENSED OPERATOR REQUALIFICATION AND TRAINING

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The MIT Nuclear Reactor Lab (NRL) has developed two digital twin simulator units for use in nuclear engineering education, operator training and requalification, public outreach, and research development activities. The MITR-II Simulator (MITR-Sim) encompasses benchmarked RELAP5 models, realistic reactivity control and feedback parameters, industry grade I&C and logic controls with Western Services Corporation, Inc. (WSC)'s 3Keymaster software suite [1]. The replica simulator with touch screen interface allows the users to closely experience many important aspects of the operator duties and responsibilities on the control room console. Recent challenges with long term unanticipated outages of the reactor has created opportunities for supplementary simulator training that can fill the gaps of licensed operator requalification. The MITR Requalification program includes lecture and review material in addition to on-the-job training (OJT) [2]. In March 2023, a lecture fulfilling the review requirements was given using the MITR-Sim, covering a wide range of content. Time was provided for operators to manipulate simulator reactivity controls, gain familiarity with the digital interface, and compare model response to personal operating experience. Operator feedback was extremely positive and steps are being taken to schedule required quarterly reactivity control manipulations on the MITR simulator to maintain the active license status.

1. MITR and Simulator Overview

The Massachusetts Institute of Technology (MIT) Research Reactor (MITR) is a multi-purpose research reactor located on the MIT campus, see Fig 1. It was constructed and achieved first criticality in 1958 (MITR-I) and upgraded in 1975 (MITR-II) with a new core tank and housing. The reactor is licensed for 6 MWth operation and is the second highest power university research reactor in the U.S. The tank-type reactor design consists of a compact core with power density similar to a Light Water Reactor, with light water primary coolant, and heavy water and graphite reflector. The MITR is the major experimental facility of the Nuclear Reactor Laboratory (NRL), and is utilized in education, training, nuclear science, fuel and materials irradiation tests, and advanced nuclear reactor research [3]. The MITR uses high enrichment uranium (HEU) fuel and is one of the five High Performance Research Reactors in the U.S being evaluated for low enrichment uranium (LEU) fuel conversion [4,5]. The MIT Nuclear Reactor Laboratory (MIT-NRL) in conjunction with Western Services Corporation, Inc. (WSC) successfully developed and deployed a digital twin of the MIT Research Reactor for the purposes of education, training, and research [6]. The MITR Simulator (MITR-Sim) completed initial Facility Acceptance Testing in May 2021, with delivery of a second unit and LEU core model in June 2022 and a touchscreen hardware upgrade in December 2022.

Figure 1: Overview of NRL containment dome (blue) in Cambridge. Photo courtesy of T. Tracy.

1.1. Simulator Capabilities

The MITR Simulator possesses benchmarked RELAP5 input decks for both main primary and secondary system loops, validated point kinetic core model, empirical fission product poison reactivity feedback data, and calibrated absorber worth curves. The synthesis of these components allows a very realistic operator experience in terms of reactor behavior and response. The graphical reproduction of console instrumentation and indication was mapped using photos of the physical equipment and intended to facilitate realistic reactor manipulations [6].

Instrumentation readings also reflect signal noise and bias based on the most recent calibration or recorder data. Not only is the true value predicted from the simulator model, but the display indication to the operator can be tailored to match actual control room conditions. The logic and control interlocks and startup circuitry were incorporated into the model to provide for a representative startup sequence and also the ability to simulate a failure in any of those control components. The two glass top units with associated instructor stations are shown in Fig 2.

1.2. Previous Use

The simulators have both been heavily utilized for outreach and education. Users included professional training course participants, MIT Nuclear Science and Engineering Department students, visiting research collaborators, and a wide variety of general public members. The response and feedback have been overwhelmingly positive and the simulators have become a valuable asset to the NRL. However, up until recently only a handful of users have been intimately familiar with the MITR design and operation and possessed some idea of what typical instrument response looks like under transient conditions.

Figure 2: Dual glass top units and instructor stations launched with LEU model (left) and HEU model (right)

2. Operator Training

Reactor Operators must undergo both initial training in compliance with 10 CFR 55 to obtain an operating license granted by the Nuclear Regulatory Commission (NRC) and continuous requalification training in order to maintain that license [7]. Both components of training require specified minimum time performing shift duties, reactor control evolutions, and demonstration of knowledge pertaining to reactor physics, operating characteristics, feedback mechanisms, and transient behavior. The MITR usually maintains between 20 and 25 staff and students with RO (Reactor Operator) or SRO (Senior Reactor Operator) licenses. There are up to 5 new student operators in training each year and 1-2 full time staff trainees.

2.1. Extended Outages

Unanticipated outages affect every reactor, but when they extend beyond the duration of required surveillance frequencies, training requirements, and operational needs it can compound an existing problem with a bottleneck in the training pipeline as large numbers of staff need to undergo requalification or meet OJT criteria [8]. Two recent unplanned, extended outages have disrupted the normal training cycle at the MITR. The COVID-19 pandemic in 2020 and the primary system leak in 2022, each resulting in at least 6 months of reactor shutdown time. The MITR has many quarterly training requirements that lapse for all licensed operations staff. While it is not an impossible task to solve, it does increase the administrative workload for the NRL and for the NRC to approve special procedures and oversight for extenuating circumstances. Operations staff does not have the ability to meet those requirements at another facility, but with the high-fidelity performance of the simulators, usage for licensed staff training is an acceptable substitute in lieu of the physical reactor.

2.2. Initial Training

The initial training program encompasses intensive classroom study of facility characteristics and operation protocols as well as hands-on practical factors and supervised startups and reactivity control manipulations. Trainees are required to perform a minimum number of reactor startups, control manipulations, and estimated critical position (ECP) calculations [2,7]. For a training class that can be as many as 7 candidates, scheduling in at least 28 reactor startups can become disruptive to the operating schedule and place pressure on the trainees to not request for more practice opportunities before the licensing exam. While the simulator cannot take the place of the reactor console for an operating exam, it allows trainees to take advantage of a low stakes, easily accessed, method for practicing reactivity control and increasing familiarity with proper startup procedure, control room communications, and logbook entry requirements.

2.3. Requalification and OJT Requirements

Licensed operators must satisfy continuous training requirement in order to maintain proficiency on facility operations, review changes to equipment and procedures, and ensure knowledge does not atrophy after initial training. Operators must perform a minimum of 10 reactivity control manipulations and one reactor startup in each two-year requalification cycle, among other drill and exam requirements [2]. At the NRL, much of the technical and management staff also possess and maintain active RO/SRO licenses even if licensed duties are performed infrequently. Performance of startups on the simulator can be used either to satisfy some of those OJT requirements, or simply for staff to refamiliarize themselves with the procedure in the event of long periods between startups. Additionally, many SRO's meet the startup OJT requirement by acting as the Supervisor in the control room rather than moving the control rods themselves and having ample availability for performing the operator actions during a startup will be a benefit to the requalification program.

3. Demonstration and Training

In place of the annual requalification lecture covering reactor physics, as shown in Fig. 3, the simulator was used for the training in order to accomplish two main goals: familiarize a wider variety of operators to the simulation software and demonstrate transient consequences that otherwise remain purely hypothetical. The two scenarios selected were chosen to highlight key points where the reactor would not necessarily provide the operator with advance warning before violating an administrative requirement or Standard Operating Procedure (SOP). This is meant to address issues of reliability not reactor safety, which remains preserved.

The first of these was demonstrating a "cold-slug accident" wherein the flow of secondary water is halted and then restarted during operation, resulting in an over-cooled flow of water to the main heat exchanger, causing a sudden temperature dip in the primary water and subsequent reactivity addition. To avoid this inadvertent reactivity insertion, all abnormal operating procedures related to secondary pump failure direct the operator not to restart the pumps unless all neutron absorber are fully inserted (i.e. the reactor is shutdown). However, there is no interlock or annunciator alarm that would prevent an operator from restarting a secondary pump by mistake.

Figure 3: Annual reactor physics requalification training for licensed personnel. Still taken from training video recorded for off shift operators and those unable to attend in person.

The second scenario demonstrated was a reactivity insertion via neutron poison decay, specifically Xenon-135. MITR-II is typically loaded with enough fuel each cycle to prevent becoming xenon precluded but there are times where abnormally long cycles or large installed negative experiment worth makes preclusion possible towards the end of an operating cycle. In the event that an operator attempts a reactor startup and cannot attain criticality before all absorbers are fully withdrawn, procedure directs the operator to lower the blades and recalculate the estimated critical position while likely means having to wait for fission product poisons to decay before attempting another startup. Per SOP 2.3 the reactor is declared critical on a +50 sec period, usually at 50kW. In the event of a xenon precluded startup, the reactor will not be able to reach a stable +50 sec period but may be able to continue subcritical multiplication [9]. The shutdown xenon worth peaks around 6 hours after a reactor scram, and if this happens after operating at steady state full power, there is a lot of xenon worth that can be lost from decay and burnup. If the operator does not lower the absorbers, subcritical multiplication will continue and as the xenon concentration decreases, positive reactivity is added to the core. When demonstrated on the end of cycle initial conditions loaded into the simulator, the core eventually does reach a stable positive period but it does not ever become shorter than +175 sec. If the operator is not watching power or period indications, the first alarm they will receive will likely be the High Power Warning at 6.1 MW. The operator could then potentially recover control and lower power or the reactor safety system will initiate a scram at 6.5 MW, both of which do not undo the violation of startup procedures (which specify a maximum power step of 1 MW and minimum soak time of 5 min) but do maintain the safety of the reactor [10].

After a period of discussion and time for questions about the simulators, operators were encouraged to perform reshims, test interlocks, and attempt startups and provide feedback on experience as well as suggestions for improvement.

3.1. Benefits

The biggest benefit of the MITR Simulators is the easy access to a representative experience of operation without the oversight requirements. Many operators commented on the realism of the interface, the similarity in instrument behavior, and surprise at how instantaneously transferrable years of physical reactor operation experience was to a completely digital touchscreen interface. The demonstration of reactivity effect and feedback was also reported as a more useful learning experience than the normal lecture format and there was a general sentiment of viewing the simulators as a valuable asset to the NRL.

3.2. Upgrades

Input from a larger pool of licensed operators, many of which have decades of experience, helped identify targeted areas for improvement in order to maximize effectiveness of initial training and alleviate strain on the reactor operating schedule. A few minor changes were requested, related to unit displays on channels, a graphics needle “sticking” and location of audio source. Larger requests for the next major upgrade included the addition of neutron counter displays and associated audio and the configuration of a simulator logbook to mimic the official digital record of control room entries.

4. Expansion

Further integration of MITR Simulator capabilities into the training program has become a key point of interest for NRL Operations, specifically for applications where evolutions must be performed for satisfying a qualification card but are not typically needed outside of training (e.g. a 1/M startup). Approval of changes to the initial operator training program must go through the usual safety review process and the proposed inclusion of the simulator as an alternative to meet a subset of training requirements will be drafted up and circulated amongst the MIT Reactor Safeguards Committee for review and comment before the next annual meeting.

Acknowledgements

The authors wish to thank WSC staff Oussama Ashy, Sergei Korolev, and Mark Terry for their support on MITR-Sim development. The MITR-Sim LEU system is sponsored by the U.S. Department of Energy National Nuclear Security Administration, Office of Material Management and Minimization through Argonne National Laboratory under Contract No. DEAC02-06CH11357

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