UTILIZING RESEARCH REACTOR SIMULATORS FOR REACTOR OPERATOR TRAINING AND LICENSING

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ABSTRACT

Experience is fundamental to engineering education, especially to nuclear engineering education. An important yet still unique, even after over 50 years of world-wide experience, a subset of such learning and training is becoming a research reactor operator. For these trainees, the opportunities to get extensive hands-on operational experience is usually limited and subject to time added on to strictly guided reactor procedures. Simulation then becomes a supplement to an operator's training by providing a far less restrictive environment. Additionally, such simulator-based learning provides a unique learning for students who do not have opportunity to experience hands-on training at real research reactor facility. A number of training simulators are available through the simulator library of the International Atomic Energy Agency (IAEA). This library specifically includes PCTRAN (Personal Computer Transient Analyzer) that can simulate a few conditions in research reactors. In this paper we show a comparison of this simulator to the University of Utah simulator developed for its TRIGA reactor (UUTR). Students and staff at the Utah Nuclear Engineering Program (UNEP) use both simulators in training the students to obtain their Reactor Operator and Senior Reactor Operator licenses – the exams being administrated by the U.S. Nuclear Regulatory Commission (NRC). In addition to this comparison, an outline of the recently conducted novel pilot training course based on combining these simulators with real reactor operation is also described.

1. Introduction

The Utah Nuclear Engineering Program operates a 100 kW TRIGA Reactor used for research, training, and education. Included in the nuclear engineering curriculum are two courses designed to train students in earning operating licenses from the Nuclear Regulatory Commission [1], [2]. The training for reactor operator license and training of students in reactor physics and reactor fundamentals, is enhanced with the use of PC-based basic principle reactor simulators from the IAEA database. Additionally, the students at the University of Utah Nuclear Engineering Program (UNEP) developed its own UUTR Simulator. The purpose of basic principle simulators such as PCTRAN is to assist in understanding the fundamental concepts of reactor technology and its response to various operation conditions [3], [4]. PCTRAN is the collective name for a set of basic principle simulators. Specifically, the PCTRAN Pool Reactor and PCTRAN Two-loop Pressurized Water Reactor (PWR) are of interest for training purposes. In addition to this a student-coded UUTR simulator is used alongside with the PCTRAN simulators for training and educational exercises.

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2. The Role of PC Based Basic Principle Simulators in Training on Reactor Fundamentals

Historically, training for UUTR operators consists of a classroom overview of reactor theory followed with hands-on operational experience. The hands-on portion of this training is limited with the availability of the US NRC regulated UUTR and is restricted to well-defined procedures of operation. This limited the class size and availability. Another issue was if the UUTR were not operable for maintenance or repairs, students would be missing the opportunities for reactor operation lessons and training. Basic principle simulators serve to solidify concepts from the classroom training as well as provide supplemental hands-on experience on the UUTR operational specifics.

The PCTRAN Pool Reactor simulator is beneficial in training basics on reactor fundamentals. The interface is shown in Figure 1. The reactivity trends and response to operator actions can be well studied using this simulator. Many of the simulator parameters available to study, such as neutron multiplication factor or reactivity effect of single components, are not typically available during actual reactor operation. While helpful for education on basic reactor theory and concepts, the PCTRAN simulator does not match fully the actual operating conditions of the UUTR.

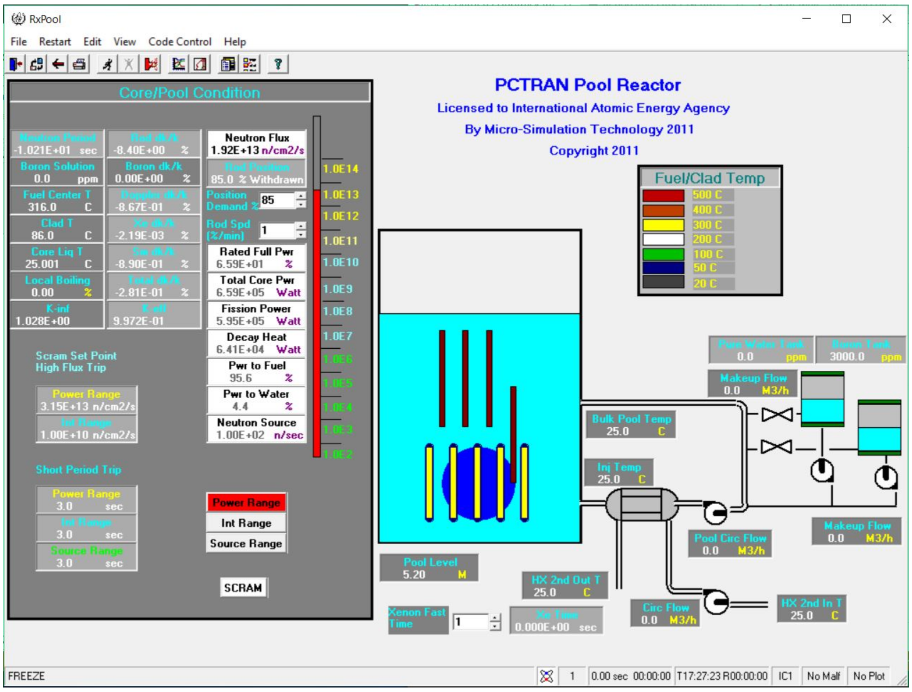


Figure 1: PCTRAN Pool Reactor interface

The UUTR simulator is a student-coded, Python-based basic principle research reactor simulator. It is designed to replicate in full the control console and behaviour of the UUTR. Parameter channels of the UUTR simulator are the same as those, which appear on the UUTR console itself. Capabilities of individual control rod manipulation and scram testing are well available. This functionality allows the trainees to practice UUTR procedures including start-up and control rod worth calibration in a nearly step-by-step manner. The UUTR simulator provides typical behaviour and relationships of UUTR parameters. The trainees are able to visualize and develop the exact expectations of what the operators should see during normal operating conditions. Due to changes in the UUTR over time, it is necessary to update the simulator in regular frequency to optimize this functionality.

The UUTR simulator complements the PCTRAN Pool Reactor simulator by providing a realistic operation experience. Unlike the PCTRAN Pool Reactor simulator, the UUTR simulator displays only the parameters, which appear on the real UUTR console. The resemblance between the UUTR Simulator and the UUTR console is observed in Figure 2 and Figures 3 – 6 with the matching colour boxes. Figure 3 shows the UUTR radiation monitoring systems. Operators can simulate exposing the area radiation monitors to an external radiation source and see the response on the meters with the associated alarms and lights.

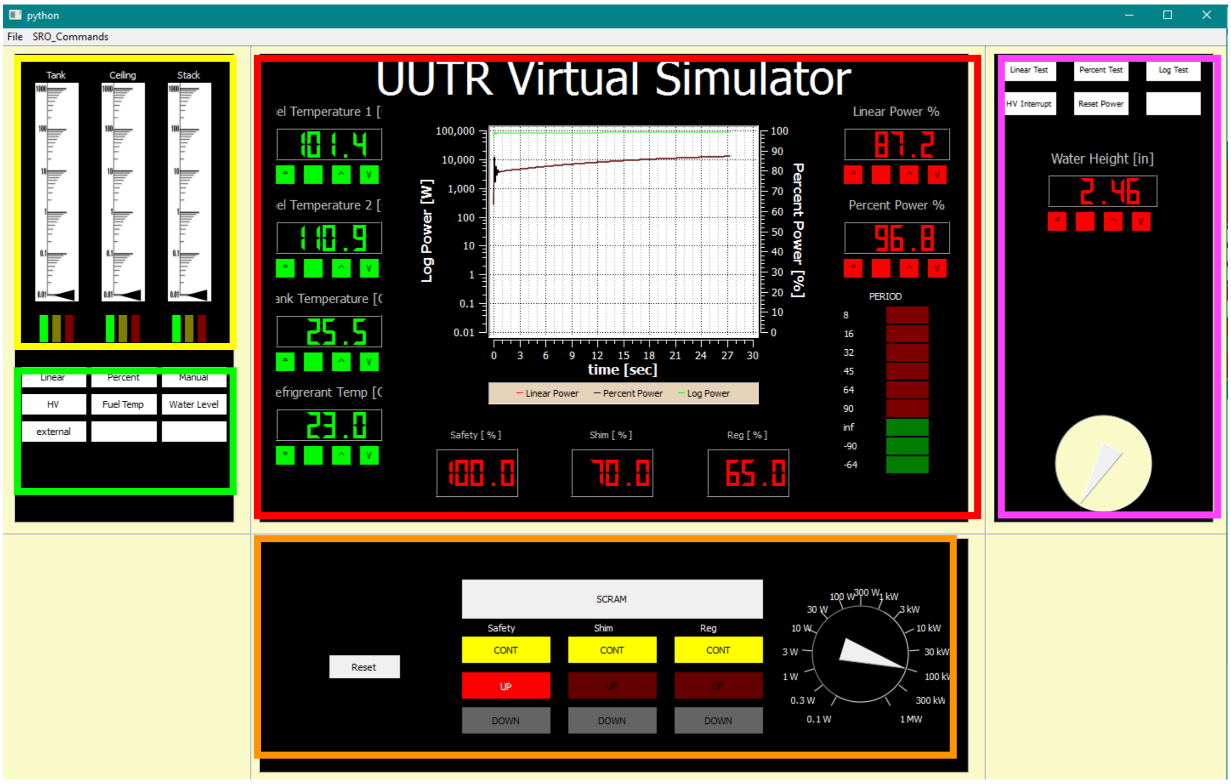


Fig 2: UUTR Simulator interface

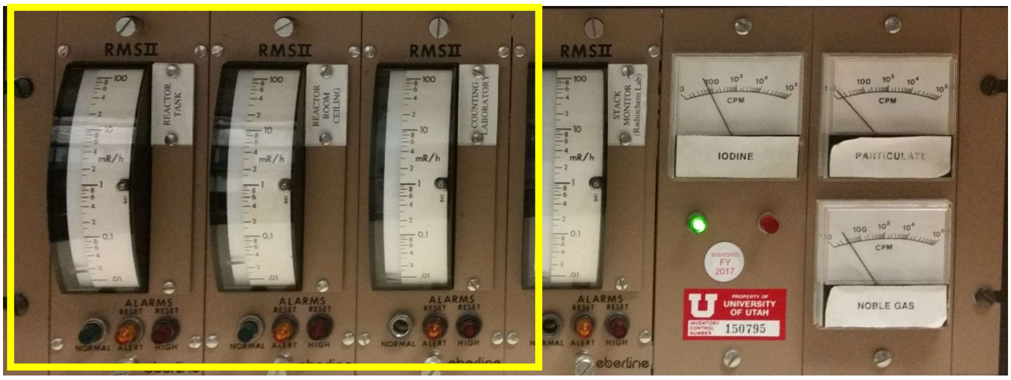


Fig 3: UUTR Radiation Monitors, Left Panel

Figure 4 shows the central panel of the UUTR console. On the left are scram annunciators, which appear in the left display of the simulator. Other information including power, temperatures and rod positions appear in this central panel and in the central display of the UUTR simulator.

Fig 4: UUTR Central Panel

Fig 5: UUTR Right Panel

Figure 5 shows the right UUTR console panel. This panel allows for the introduction of test signals, as well as summarizes information about water level, conductivity and pH. The simulator also has the capability to introduce test signals and indicates water level on the right display. It does not have displays for conductivity or pH.

Fig 6: UUTR Lower Central Controls

Shown in Figure 6 are rod manipulation controls as well as the linear power scaling dial. These appear in the lower display of the UUTR Simulator.

The PCTRAN Two-loop PWR, Figure 7, may be used to provide an introduction to the theory and operation of power-scale reactors. It is functional in simulating normal and transient operation as well as accident scenarios. This includes power control, pressure control, water level control, steam generator, reactor protection, emergency core cooling and containment systems which do not appear in the PCTRAN Pool Reactor simulator [5]. While operation of this simulator differs greatly from the UUTR operation, which students are training for, it serves as a platform for students to consider reactor theory as it applies to larger reactors. It also allows for training to be conducted on severe accidents and demonstration of emergency actions and procedures.

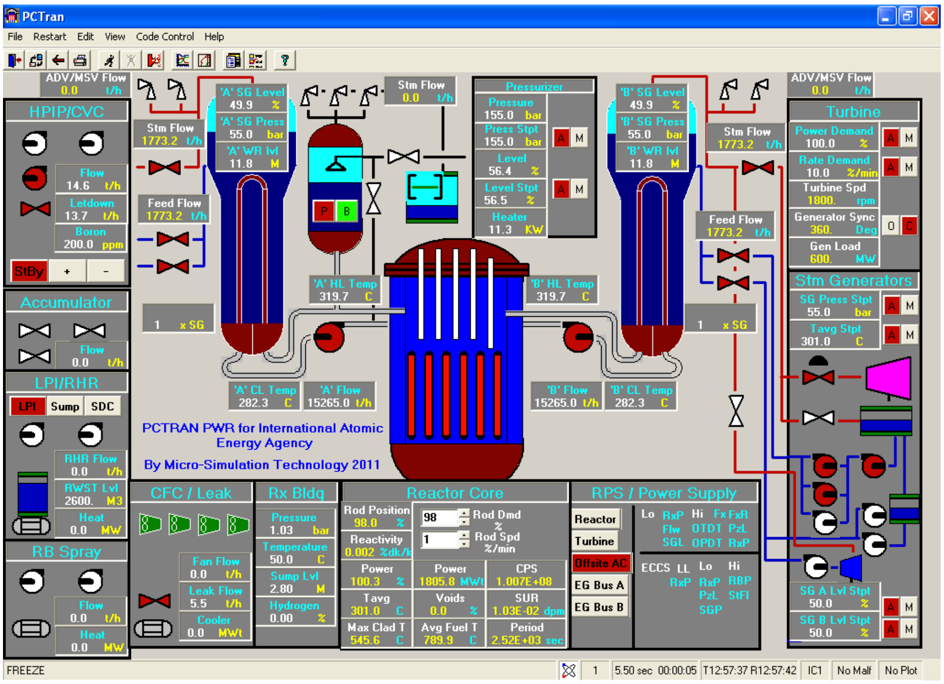


Fig 7: PCTRAN Two-loop PWR interface

3. Pilot Training

In February of 2017, the University of Utah hosted a pilot training course on reactor technologies and severe accidents, which included classes on PCTRAN simulators and the UUTR simulator. Participants in the simulator portion of the pilot training course included Japanese nuclear industry professionals, students from Okayama University in Japan, students from Brigham Young University and hosting UNEP students. Participants backgrounds ranged from no experience in nuclear fields to years working in the nuclear power industry.

3.1 PCTRAN Pool Reactor in Pilot Training

The objective of PCTRAN Pool Reactor lessons in the pilot training course was to allow participants to visualize the response parameters of a research reactor. This lesson introduced students coming from non-nuclear or non-reactor background to reactor theory through running the PCTRAN Pool Reactor simulator. This was accomplished by an overview of the operation and capabilities followed by participant operation of the simulator. Three examples were included to demonstrate the simulator's capability in solidifying the concepts learned in the classroom. This includes an observation of the negative eighty second period following a scram, an observation of subcritical multiplication, and the creation of a 1/M plot from simulator data. Plots from these examples are shown in Figure 8, Figure 9 and Figure 10 respectively.

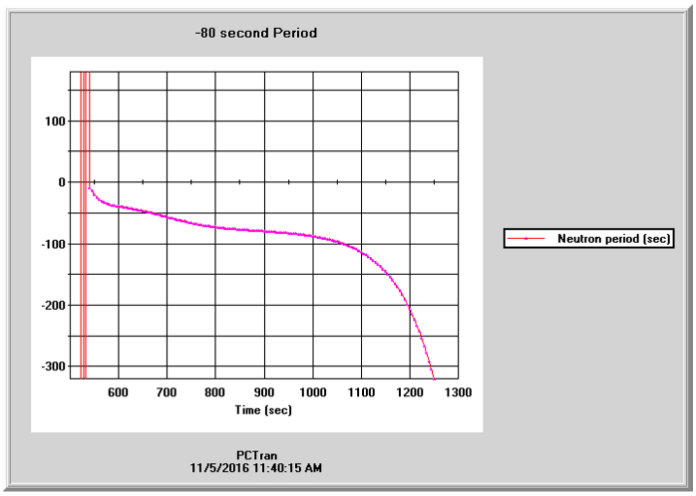


Fig 8: PCTRAN Pool Reactor, neutron period vs. time following scram

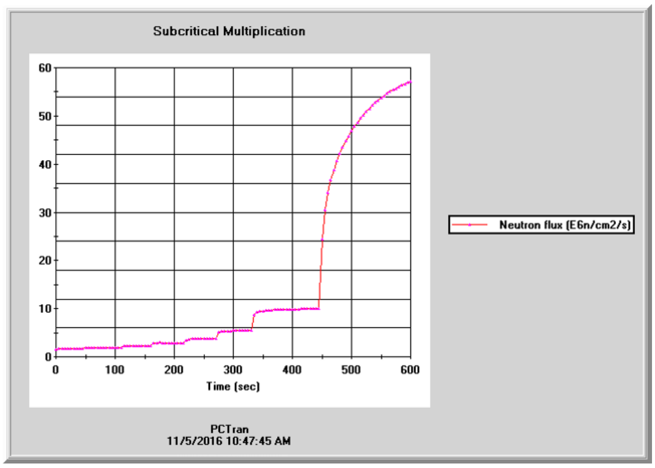
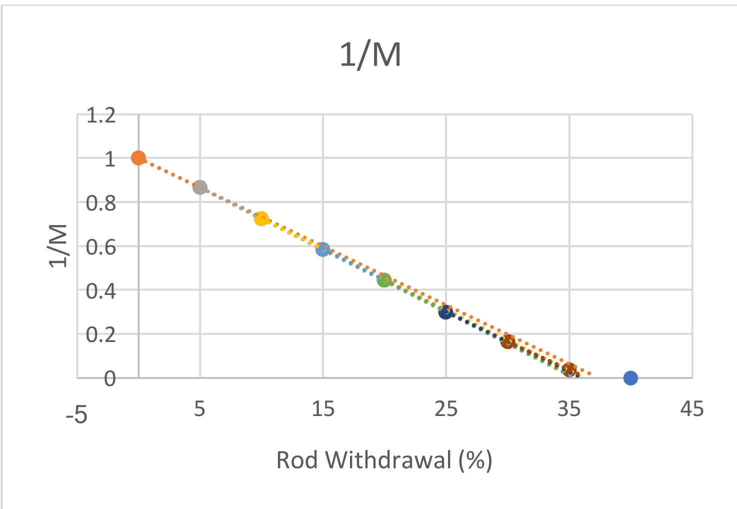


Fig 9: PCTRAN Pool Reactor, subcritical multiplication with equal reactivity steps



Criticality Predicted at Rod Withdrawal %
37.3
35.5
36.2
35.7
35.4
36.0
36.3
Critical at 40.0

Fig 10: PCTRAN Pool Reactor, 1/M plot generated from simulator data

The PCTRAN Pool Reactor simulator lesson was supplemented with operation of the actual UUTR. Participants found the combination to be a useful learning tool and noted that actual operation solidified the concepts they had initially learned through the PCTRAN Pool Reactor simulator.

3.2 PCTRAN Two-loop PWR in Pilot Training

The PCTRAN Two-loop PWR simulator lessons built upon the basic reactor theory that was demonstrated by the PCTRAN Pool Reactor. These lessons consisted of an introduction to the operation of a PWR as well as the capability of the simulator to introduce accident scenarios. Participants were tasked with observing the reactor response and trends following accidents including rod bank failures, loss of coolant and a reproduction of the Three-Mile Island accident.

3.3 UUTR Simulator in Pilot Training

The UUTR simulator lessons consisted of an overview of the capabilities of the simulator followed by participant operation and comparisons to the operation of the PCTRAN Pool Reactor as well as actual UUTR operation. During simulator operation, participants were asked to attempt the three same examples from the PCTRAN Pool Reactor lessons. In doing so, students observed the significant differences between the simulators. The negative eighty second neutron period could only be observed qualitatively since UUTR simulator neutron period display, like the actual UUTR console, lacks a precise measurement of this parameter. Subcritical multiplication and the neutron count necessary to construct the 1/M plot are impossible to observe using the UUTR simulator. Participants found that these different capabilities helped make the distinction between basic principle simulation and actual operation. They also found the use of the UUTR simulator was particularly helpful in understanding the actual UUTR operation. Participants compared temperature data taken from both the UUTR and the UUTR simulator and found the simulation to be acceptably accurate in replication. Through this observation, participants gained confidence in the capability of the simulator and its benefit for use in training. Throughout the training program, participants identified several areas where improvements to both PCTRAN simulators and the UUTR Simulator may be made. PCTRAN simulator source-code is closed and does not have the capacity for major changes to its operation. The UUTR simulator is flexible in this aspect and may be edited to add functionality and make significant changes as the UUTR console is upgraded.

4. Conclusion

PCTRAN simulators in combination with the UUTR simulator offer a broad set of capabilities to aid in the training of reactor operators. The PCTRAN Pool Reactor simulator functions as an introduction to reactor theory and the trends resulting from basic operations. The UUTR simulator provides a realistic operating experience for the UUTR that is both operationally flexible and consistently available. The PCTRAN Two-loop PWR supplements research reactor training with an introduction to reactor principles and safety systems as they apply for power-scale reactors. The pilot training program hosted by UNEP served to validate the use of reactor simulator lessons as a component of operator training. Reviews of the simulator lessons were wholly positive, and participants observed them to be helpful in understanding theory and operation as a supplement to the actual reactor operational experience gained.

Students have demonstrated improved retention of skills and theory practiced and observed by operating the PC based simulators. The positive feedback given from the simulator training includes allowing the students to learn by doing and teach each other the nuclear theory concepts while running the simulators. UNEP will continue to implement and seek for new and innovative ways to use PC based simulators in licensed operator training.

5. References

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