Modernization of the INL ATR Simulator
INL ATR - Introduction Features and Capabilities
- John Durrant

Studsvik - Reactor Core Model - Jeffrey A. Borkowski

WSC - INL ATR Simulator Upgrade Project - Sergei Korolev and Oussama Ashy
• In September 2018 INL awarded to WSC a contract to upgrade the existing 30 years old plant simulator used for training of the ATR plant operators

• The Full Scope Simulator was delivered in September 2019
Advanced Test Reactor – Training Simulator Upgrade

Meeting international nuclear energy research challenges

Presenter: John Durrant, Project Manager
January 2020

ATR's simulator room.
INL’s capabilities center around the Advanced Test Reactor (ATR), located at the ATR Complex on the INL Site 47 miles west of Idaho Falls, Idaho.

ATR is the only U.S. research reactor capable of providing large-volume, high-flux neutron irradiation in a prototype environment, and the thermal test reactor makes it possible to study the effects of intense neutron and gamma radiation on reactor materials and fuel.
The ATR is a pressurized water test reactor that operates at low pressure and low temperature. It contains a beryllium reflector to help concentrate neutrons in the core, where they are needed for fuels and materials testing.

Experiments conducted at ATR provide a critical look at reactor components and systems; this supports planning for the long-term operation of the reactors as well as DOE-NE’s mission. Testing at ATR support reactor research around the world to extend the life of current nuclear plants, develop design for the reactors of the future and test new types of nuclear fuels that reduce waste generation and proliferation risks.
Design Features

ATR has a unique serpentine core allowing the reactor’s corner lobes to be operated at different power levels, making it possible to conduct multiple simultaneous experiments under different testing conditions.

ATR's core.

ATR's canal area.
**Advanced Test Reactor**

Confinement Structure
Operating Conditions:
- 360 psia
- 160° F (250 MW thermal)

Reactor Core:
- 4 feet x 4 feet (50 cubic feet)
- 95 pounds of uranium

**Commercial Reactor**

Containment Structure
Operating Conditions:
- 2250 psia
- 600° F (3,400 MW thermal)

Reactor Core:
- 12 feet x 12 feet (1700 cubic feet)
- 200,000 pounds of uranium

*Key ATR parameters compared with those of a commercial pressurized water reactor.*
ATR Simulator Usage

- Initial reactor operator qualifications and requalifications and specialty training/simulation for other work groups require simulation training
- Usage of the simulator is >70% on a weekly basis
- Future training classes to increase in size and frequency to meet operational needs
- Complex manipulations necessitate the use of a high-fidelity simulator for the experiments conducted.
Original Instructor Simulator Screen Prior to Upgrade

A screenshot from the instructor’s PC of the original simulator program.
Upgraded Simulator Screen

A screenshot from the instructor’s PC of the upgraded simulator program.
ATR’s core

- Large test volumes – up to 48 inches long and 5 inches in diameter
- 77 testing positions
- High neutron flux
- Fast/thermal flux ratios ranging from 0.1 – 1.0
Glasstop Screenshots
Our Future

- Emulate or imitate the Reg Rod System
- Emulate the CDS (Computer Display system)
- Emulate the DCS (Distributed Control system)
- Emulate the DRMS (Digital Radiation Monitor system)
- Full integration of audio-visual recording system in sync with simulator model

A complete software package will then be placed on a glassstop display:

- Displays will be placed in classrooms facilitating higher student throughput
- Displays will be placed within the ATR building to allow for running scenarios and prerunning complex or infrequent activities for the on-shift operating crew. Additionally, they could be used for OJT by the on-shift operating crews
- This will provide opportunities for effective human performance improvements with the availability of multiple simulators.
CORE MODELING FOR THE ATR SIMULATOR UPGRADE

Jeffrey A. Borkowski
RAMONA5/HELIOS?

• HELIOS like CASMO but for generalized geometry
• RAMONA5 like S3R but set up to talk to HELIOS
• More flexibility for one-of-a-kind models without a commercial fuel management system
ACTUAL NODALIZATION

- Central four nodes “as built”
- Minor adjustments around drums 1 & 4
- Quadrant symmetry maintained
- Outer nodes are combinations of reflector, vessel, and water
RAMONA5 DATA NEEDS FOR ATR

- Subset of standard LWR data set
  - Diffusion, absorption, removal XS and flux for all nodes
  - Fuel nodes have additional requirements
    - Nu-fission, fission XS, nu/kappa ratio
    - Average energy per fission
    - Delayed neutron data (yields and decay constants, average neutron velocity)
  - Microscopic cross sections and fission yields for main fission products (I, Xe, Pm, Sm)
PRIMARY REACTOR CORE INPUTS

- Safety Rod Positions
- Outer Drum Positions
- Neck Shim Position
- Fission Chamber Positions
- Thermal Hydraulic Values for each node
  - Fuel Temperature
  - Coolant density (active fuel)
  - Test space density (density inside each flux trap)
  - Beryllium reflector temperature
PRIMARY REACTOR CORE OUTPUTS

- Direct Power Data
  - Active fuel elements (power deposited in the fuel meat)
  - Active coolant
- Derived Power Data
  - Total thermal power
  - Lobe powers
  - N16 based power data
- Detector signals
IMPORTANT DIFFERENCES TO POWER REACTORS

• Multiple control methods (drums, neck shims, shutdown rods)
• Relatively smaller reactivity coefficients
• Relatively smaller changes in feedback variables
• “Reg Rod” and its controller respond to hold power
• Delayed Photo-neutron effect important for operational events
• Lots and lots of measured measurements for detectors
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$^{140}$Ba* $\rightarrow$ $^{140}$Ba + $\gamma$

$^9$Be + $\gamma$ $\rightarrow$ $\{^8$Be$\} + n$

for $\gamma > 1.67$ MeV
CONTRIBUTION FOR LOW POWER OPS

Asymptotic photo-neutrons will impede the **Slow Set Back on the Reg Rod**, which lower the power to “0.0”

No photo-neutrons will impede a fast restart due to inadequate source counts.

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Studsvik
• Scope of the Model Upgrade
  - Reactor Core Neutronics (by Studsvik)
  - Primary Coolant System
  - Secondary Coolant System
  - Experimental Loop (1D-N)
  - Balance of Plant Systems
  - Electrical Systems
  - Reactor Logic and Control
  - Interfaces with ATR stimulated systems (MaxDNA, CDS, RRCS)
Teamwork was essential in the success of the simulator upgrade
Primary Coolant System Nodalization

- Nominal operational power is 110MW (while maximum is 250MW); reactor core heat is removed by subcooled water flow
- Large flow (5800 gpm) through the reactor core is maintained by six pumps
- Heat is removed by five heat exchangers to the secondary system and next by the cooling tower
- Medium pressure (~400 psia) and temperature (120 degF) in the system
• Flow (~24 gpm) through the specimen is maintained by three pumps
• Loop temperature is controlled by three heat exchangers and 4 line heaters
• High pressure (~2000 psia) and temperature (530 degF) in the Loop
• All plant electrical components are simulated (AC/DC buses, diesel generators, UPS systems)
• Model simulates loss of both commercial and diesel power supply
• Four different reactivity control components, absorber material is Hafnium
  ▪ Safety Rods (6)
  ▪ Outer Shim Control Cylinders (OSCC) (16)
  ▪ Neck Shim Rods (24)
  ▪ Regulating Rods (2)
• Lobe Power Calculation and Indication System (LPCIS)
  ▪ There are five lobes, four corner and one center
  ▪ There are 11 N-16 power readings and 4 quadrant thermal powers
  ▪ Power split is very important in ATR operation
  ▪ LPCIS uses complex algorithm to calculate lobe powers as a function of N-16 and thermal powers
  ▪ Operator adjusts and balances core power split with Neck Shim Rods and OSCC
• MaxDNA DCS
• Console Display System (CDS)
• Regulating Rod Control System (RRCS)
• National Instruments Arcaus IO System
• Digital Radiation Monitoring (DRMS)
• Soft Panel I/O Counts
  - 380 DO’s
  - 224 DI’s
  - 140 AO’s
  - 36 AI’s
Challenges

• Regulating Rod Control System (RRCS); was unstable in both manual and auto mode:
  ▪ delay in the communication between the 3KEYMASTER model and the RRCS controllers
  ▪ existing stimulated RRCS was tuned to the old core model
• Lobe Power Calculation and Indication System (LPCIS); real plant Fortran application was converted to C++ code and next to 3KM Tool
• Four different applications to communicate with existing simulator plant control and display systems (MaxDNA, CDS, DRMS, IO)
• Core Testing (many different types of reactivity control mechanisms)
• Large scope of ATP’s
• During SAT - Tested the Simulator Against Data and the Plant Procedures
  ▪ Steady State Tests
  ▪ Normal Operation – Startup/Shutdown
  ▪ Transient Tests
  ▪ Malfunction Tests – Total of 176 MF’s
  ▪ Core Physics Tests
  ▪ Common Tests - Instructor Station, Real-Time, Repeatability Test
The upgraded high-fidelity simulator fully supports the INL ATR staff training requirements for years to come.

New Simulator Benefits in Summary:

- Superior Training with advanced models
- Lower Maintenance cost with up to date software and hardware
- Future support of plant upgrades and improvements

Simulator Upgrade Phased vs. Full Upgrade
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Phased or Full Upgrade approach

- Incompatibility between Upgraded and Existing Systems
- Data or System Inconsistencies
- Simplified Modeling of Interface Systems
- Interfaces Omitting or Missing
- Repeatability of New or Existing Models
- Ability to Change/Modify Existing Models
- Scope Drift During Project Execution
- Multiple/Repetitive Testing Requirements
- General Expectation of the Upgrade

Full Upgrade
Reactor Engineering Development Launches Heat Transfer Tests

The first successful test run of the Reactor Physics and Engineering heat transfer experiments was made on January 18 after a year of preparation. The purpose of the tests is to improve heat transfer from flat plate (MTR-ETR type) fuel assemblies. Many advantages may be derived from learning how heat transfer efficiencies can be improved. This information can lead to increased reactor power operation, a longer operating cycle between refueling shutdowns, or a decrease in coolant flow. If the volume of coolant flow through the reactor core could be decreased, it would make more water available for experimental loops. In some reactor situations the cooling towers and pump facilities are running to capacity and this situation may limit further expansion until greater heat dissipation techniques are evolved. Efficient cooling is an integral part of efficient and safe reactor operation. Any time that more heat is built up within a fuel assembly due to carryover, the water may be caused to boil around that "hot spot," and the hot spot may go into a meltdown state with highly undesirable complications.

In assembling equipment for out-of-pile heat transfer tests attempts are made to simulate the reactor conditions existing in a fuel element where the fissioning of U-235 generates large quantities of heat, which on the case of the MTR and ETR, is removed by passing water over the surface of the fuel plates. The uniform heating is replaced by electrical heating in the out-of-pile experiments. Thousands of amperes of alternating electric current are instead used, by means of heavy duty bars, and passed through a thin-wall tube section which is heated much like the considerably lower-power electric heaters found in many homes. Water flowing into the test section removes the heat as it would be capable of carrying away a reactor. A pump, water reservoir, heat exchanger, piping, and flow, pressure, and temperature measuring devices complete the necessary equipment for such tests. The relationship of electrical power, water flow velocity, and the temperature of the test section and the water entering and leaving the test section provide the data which are later evaluated to determine safe operating limits for present reactors and for designing reactors of the future. Bob McPherson (Division Engineering) had performed most of the design engineering work on the heat transfer test equipment when the reactor was built and the study showed the heat exchanger design and the construction of a mockup assembly, i.e., high electrical resistance and high melting point. This alloy was also selected for safety reasons since nickel, in even the smallest amount will react explosively with water. The alloy material selected for these tests has a net in rectangular conduits — or even in cylindrical cooling tubes of a specialty fabricating firm in Kirkland, Washington, finally agreed to form the material into welded tubes. It was mutually recognized that this material would be excessively difficult to seam-weld and this belief was borne out in practice. Many feet of tubing fabricated but only six feet met specifications. The next hurdle was to get some fabricators to commit the tubing into flat conduit according to the exacting specifications. These requirements stipulated that the inside of the rectangular conduit must be 0.100 by 1.254 ft, and that the 0.010 in wall thickness be reduced, on the two smaller sides to exactly half of their original thickness. A half dozen specialty fabricators were invited to bid on the job, but each one removed the invitation stating that the specifications were too exacting for their equipment and techniques.

Lila the U. S. Marina, the C. F. Machine Shop will conclude that the impossible task only a little longer. After a couple of weeks of study, a forming jig was built, and the finished job was turned out to perfection. The C. F. Machine Shop also made the brass bus bars which were fabricated as half-cylinders with machined channels cut down the middle of the flat surfaces. The two surfaces were then joined with silver solder with an integrity capable of containing 300 pounds of internal pressure from the circulating coolant. A six inch section of chromed nickel conduit was then silver soldered between the two cylindrical bus bars in a manner that permits the unescapable flow of coolant from the circulating loop into the bus bars, through the conduit, and on through the other bus bar for discharge into the circulating loop. The exterior surface of the comparatively fragile conduit is supported on all four sides by a ceramic core so that it can withstand the internal pressures at all working temperatures. Inside experimenting with heat transfer efficiency under various combinations of flow, temperature, pressure, and conduit dimensions, tests will be run to determine if additional heat transfer can be obtained by roughening the inside surface of the coolant channel to increase turbulence. A series of runs employing 200 kw of electrical energy will include variations into the boiling range and possibly a de- nitrifying melt down. With the redundant information on record, a new unit will be msed up for larger test sections and higher power and later for a pile tests.

Supervisor Warren Francis has this to say about the program to date: "We are proud of the ingenuity and resourcefulness shown by the men who designed and built this equipment. Some of the bottleneckers have been real "stickers" but the fellows are and solved each problem as it came up. As a result, we have a testing system which was built on a relatively small budget and we expect to derive much valuable information on nucleate technology from the projected testing program."
THANK YOU

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