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Advanced Test Reactor – A National Scientific User Facility

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ADVANCED TEST REACTOR - A NATIONAL SCIENTIFIC USER FACILITY

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ABSTRACT

This presentation and associated paper provides an overview of the research and irradiation capabilities of the Advanced Test Reactor (ATR) located at the U.S. Department of Energy Idaho National Laboratory (INL). The ATR which has been designated by DOE as a National Scientific User Facility (NSUF) is operated by Battelle Energy Alliance, LLC. This paper will describe the ATR and discuss the research opportunities for university (faculty and students) and industry researchers to use this unique facility for nuclear fuels and materials experiments in support of advanced reactor development and life extension issues for currently operating nuclear reactors.

The ATR is a pressurized, light-water moderated and cooled, beryllium-reflected nuclear research reactor with a maximum operating power of 250 MW_{th}. The unique serpentine configuration (Fig. 1) of the fuel elements creates five main reactor power lobes (regions) and nine flux traps. In addition to these nine flux traps there are 68 additional irradiation positions in the reactor core reflector tank. There are also 34 low-flux irradiation positions in the irradiation tanks outside the core reflector tank.

The ATR is designed to provide a test environment for the evaluation of the effects of intense radiation (neutron and gamma). Due to the unique serpentine core design each of the five lobes can be operated at different powers and controlled independently. Options exist for the individual test trains and assemblies to be either cooled by the ATR coolant (i.e., exposed to ATR coolant flow rates, pressures, temperatures, and neutron flux) or to be installed in their own independent test loops where such parameters as temperature, pressure, flow rate, neutron flux, and chemistry can be controlled per experimenter specifications. The full-power maximum thermal neutron flux is ~1.0 x10^{15} n/cm^2-sec with a maximum fast flux of ~5.0 x10^{14} n/cm^2-sec.

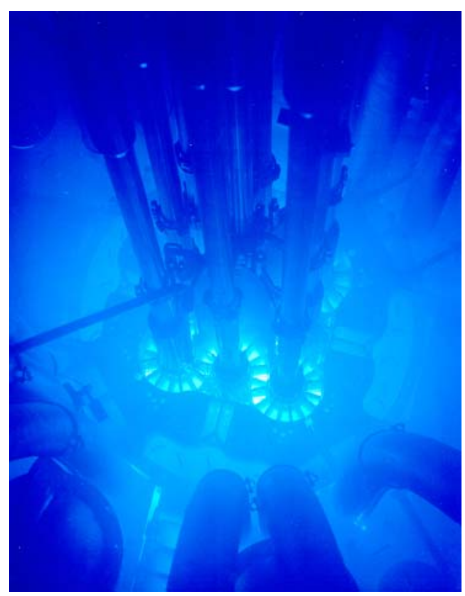


Figure 1. Advanced Test Reactor Core.

The Advanced Test Reactor, now a National Scientific User Facility, is a versatile tool in which a variety of nuclear reactor, nuclear physics, reactor fuel, and structural material irradiation experiments can be conducted. The cumulative effects of years of irradiation in a normal power reactor can be duplicated in a few weeks or months in the ATR due to its unique design, power density, and operating flexibility.

Keywords: advanced test reactor, research reactor, test reactor, nuclear reactor, national scientific user facility, idaho national laboratory, nuclear fuel testing, nuclear materials testing, ATR, INL.

INTRODUCTION

This presentation and paper provides an overview of the research and irradiation capabilities of the Advanced Test Reactor (ATR) (Fig. 2) located within the Reactor Technology Complex at the Idaho National Laboratory (INL). The ATR which has been designated by the U.S. Department of Energy (DOE) as a National Scientific User Facility (NSUF) is operated by Battelle Energy Alliance, LLC under contract for DOE.

Figure 2. Advanced Test Reactor located within the Reactor Technology Complex (RTC) at Idaho National Laboratory (INL).

The ATR NSUF includes the ATR itself, the Advanced Test Reactor Critical (ATRC) facility, facilities for post-irradiation examinations such as the Hot Fuel Examination Facility (HFEF), and science and engineering technical support for experiment design, fabrication, and operation.

ADVANCE TEST REACTOR DESCRIPTION [1, 2, 3]

The ATR is a pressurized, light-water moderated and cooled, enriched uranium fueled, beryllium-reflected nuclear research reactor with a maximum operating power of 250 MW_{th}. General design information and operating characteristics for the ATR are presented in Table 1. The unique serpentine configuration of the fuel elements, as shown in Figures 1 and 3, create five main reactor power lobes (regions) and nine flux traps. In addition to these nine flux traps there are 68 additional irradiation positions in the reactor core reflector tank. There are also 34 low-flux irradiation positions in the irradiation tanks outside the core reflector tank.

Table 1. ATR General Design and Operating Nominal Full-Power Data[1,2]

Advanced Test Reactor (ATR) Data	
Reactor	
Thermal Power (Maximum Design Power)	250 MW_{th}
Power Density	1.0 MW/liter
Maximum Thermal Neutron Flux	1.0 $x10^{15}$ n/cm^2-sec
Maximum Fast Flux	5.0 $x10^{14}$ n/cm^2-sec
Number of Flux Traps	9
Number of Experiment Positions	68
Core	
Number of fuel assemblies	40
Active length of Assemblies	1.2 m (4 ft)
Number of fuel plates per assembly	19
Reactivity Control Drums/Rods	Hafnium
Coolant	
Design Pressure	2.7 MPa(390 psig)
Design Temperature	115°C (240°F)
Reactor coolant	Light water
Maximum Coolant Flow Rate	3.09 m^3/sec (49,000 gpm)
Coolant Temperature (Operating)	Inlet: < 52°C (125°F) Outlet: < 71°C (160°F)

The unique design of ATR control devices permits large power variations among its nine flux traps using a combination of control cylinders (drums) and neck shim rods (Fig. 3). The beryllium control cylinders contain hafnium plates that can be rotated toward and away from the core, and hafnium shim rods, which withdraw vertically which can be individually inserted or withdrawn for minor power adjustments. Within bounds, the power level in each corner lobe of the reactor can be controlled independently to allow for different power and flux levels in the four corner lobes during the same operating cycle.

Figure 4 shows a typical symmetrical axial distribution of neutron flux for five different energy groups in the center flux trap. These data are for a total reactor power of 125 MW_{th}.

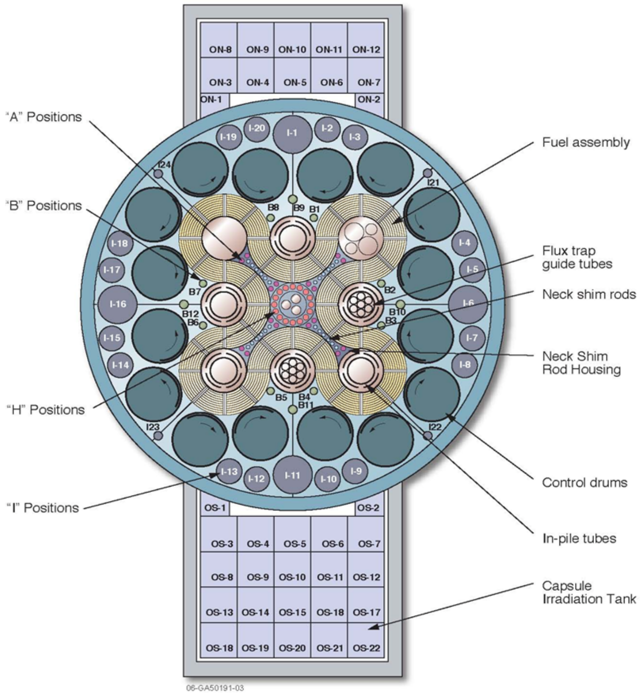


Figure 3. ATR core and irradiation tank layout.[1, 2]

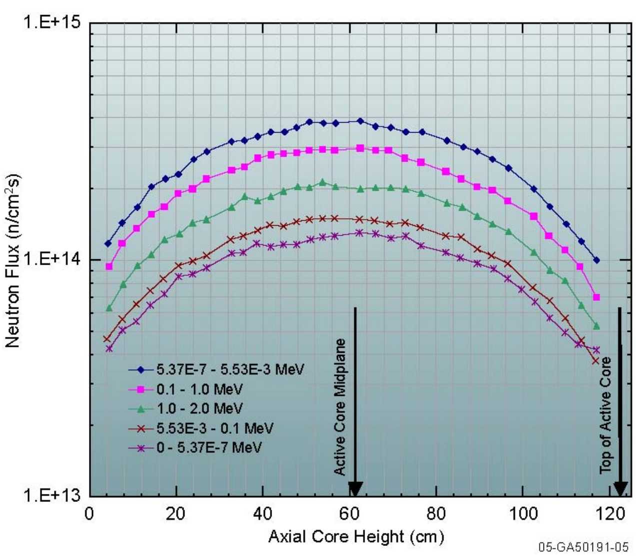


Figure 4. Unperturbed five-energy-group neutron flux intensity profiles over the active core length of the ATR center flux trap for a total reactor power of 125 MW_{th}.

The ATR also contains a separate facility referred to as the Advanced Test Reactor Critical (ATRC) facility (Fig. 5), which is a full-size replica of the ATR operated at low power (5 kW maximum) and used to evaluate the potential impact on the ATR core of experiment test trains and assemblies. Mock-ups of experiments can be inserted in the ATRC, and such parameters as control rod worths, reactivities, thermal and fast neutron distributions, gamma heat generation rates, ATR fuel loading requirements, and void/temperature reactivity coefficients can be determined prior to experiment insertion into the ATR.

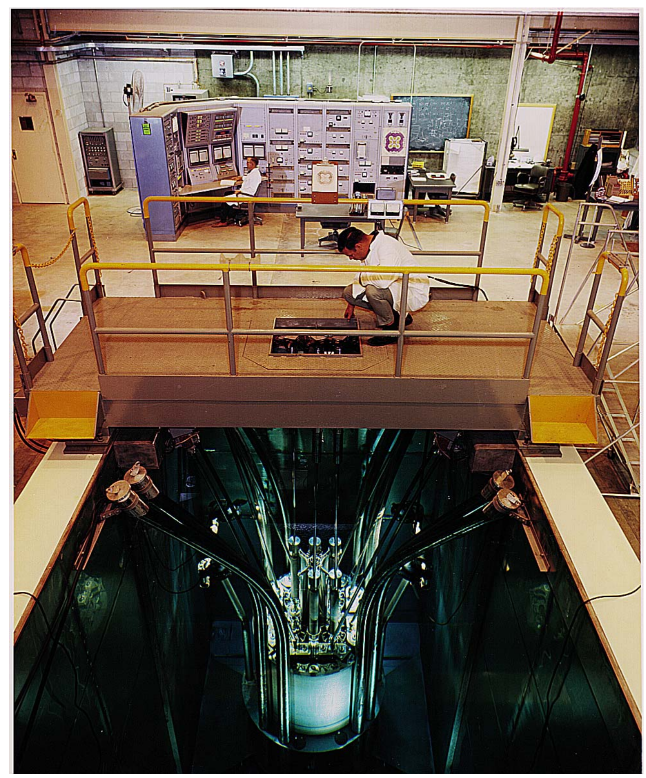


Figure 5. Advanced Test Reactor Critical (ATRC) Facility used to verify reactivity of experiments and core configurations.

EXPERIMENT CAPABILITIES [1, 2, 3]

The ATR is designed to provide a test environment for the evaluation of the effects of intense radiation (neutron and gamma) on material samples, especially nuclear fuels. Due to the core design (fuel layout and control material positioning), each of the five lobes can be operated at different powers and controlled independently. Options exist for the individual test trains and assemblies to be either cooled by the ATR coolant (i.e., exposed to ATR coolant flow rates, pressures, temperatures, and neutron flux) or to be installed in their own independent test loops where such parameters as temperature, pressure, flow rate, neutron flux, and chemistry can be controlled per experimenter specifications.

The irradiation positions associated with the ATR are divided into five groups: flux traps, A-positions, B-positions, H-positions, and I-positions. Table 2 contains nominal data for each of these irradiation positions.

The physical dimensions of the available test positions in the ATR range in size from ~0.659 inches in diameter to ~5 inches in diameter. Sizes and typical flux levels for positions in flux traps, neck shim housing and reflector are listed in Table 2. Fluence achieved in each cycle is the integral of the lobe power curve over the days of operation.

Targets are inserted into the ATR inside "experiment assemblies." The components of these assemblies are the targets, the capsule, and the basket. The capsule serves to provide a boundary to contain the target material and isolate it from the reactor primary coolant. The capsule is designed with an internal annulus generally filled with an inert gas such as helium or argon. The basket serves as the housing of the capsule(s) and is designed to mate with the irradiation position in the reactor.

For the initial set of NSUF tests scheduled for insertion in Fiscal Year (FY) 2008, users will use baskets and capsules supplied by INL. Designs for these baskets and capsules have already been qualified within the ATR safety and operational envelope. In the future, users may work with the INL to develop new capsule and basket designs; however, each of these will have to be analyzed to ensure that the experiment does not compromise the ATR safety basis.

POST-IRRADIATION EXAMINATION FACILITY

In addition to ATR irradiation facility access, the ATR NSUF work encompasses the post-irradiation examination (PIE) work. Below are summarized some of the capabilities available to NSUF users.

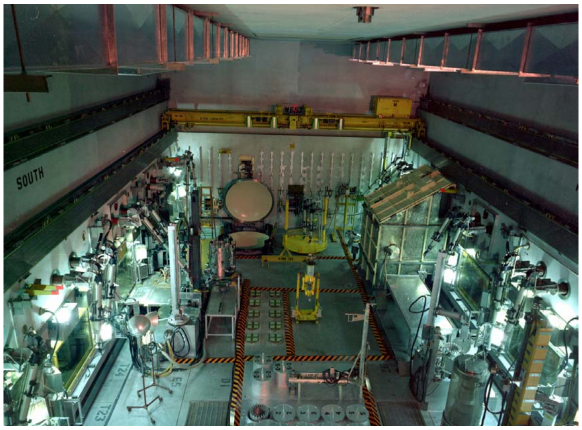
The Hot Fuel Examination Facility [4] (HFEF) (Fig. 6) located within the Materials and Fuels Complex (MFC) at Idaho National Laboratory is a large alpha-gamma multi-program hot cell facility (Fig. 7) which is designed to remotely characterize highly irradiated fuel and structural materials. The wide range of fuel handling and measurement capabilities at HFEF, coupled with the INL's experience in testing and analyzing fuel behavior make HFEF an ideal facility in which to perform post-irradiation and spent nuclear fuel characterization activities.

Figure 6. Hot Fuel Examination Facility (HFEF) located at the within the Materials and Fuels Complex at Idaho National Laboratory (INL).

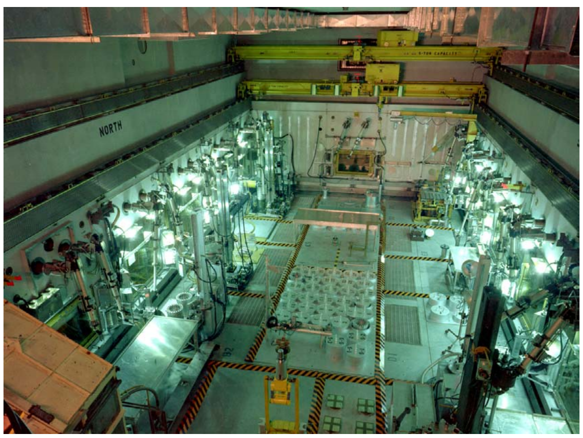
HFEF which became operational in 1975 has supported programs centered on post-irradiation examinations (i.e. characterization) of fuels and materials irradiated in the Experimental Breeder Reactor II, the Transient Reactor Test Facility at MFC, and the Fast Flux Test Facility at the Hanford Engineering Development Laboratory near Richland, Washington, all in support of the Liquid Metal Fast Breeder Reactor Program.

Other support work at the HFEF has been performed on designs and materials investigated in the Light Water Breeder Reactor Program, the Light Water Reactor safety program, high level waste vitrification studies, Waste Isolation Pilot Plant (WIPP) test, and the U.S. Air Force and Army among others.

In addition to the HFEF, there are several analytical radiochemical labs at MFC that can also be used to perform PIE activities. These lab capabilities include glove boxes, shielded hot cells, and hooded wet chemistry areas. Fuel characterization capabilities include isotopic analysis of irradiated fuel, hydrogen analysis, pellet density, burnup analysis, and others.



HFEF Main Cell (West View)



HFEF Main Cell (East View)

Figure 7. Hot Fuel Examination Facility (HFEF) main hot cell

SUMMARY

The Advanced Test Reactor and associated facilities at the INL, now a National Scientific User Facility, is a versatile tool in which a variety of nuclear reactor, nuclear physics, reactor fuel, and structural material irradiation experiments can be conducted. The ATR is the highest power research reactor operating in the United States. The cumulative effects of years of irradiation in a normal power reactor can be duplicated in a few weeks or months in the ATR due to its unique design, power density, and operating flexibility.

NOMENCLATURE

ATR	Advanced Test Reactor
ATRC	Advanced Test Reactor Critical Facility
C	Celsius
cm	centimeter
F	Fahrenheit
ft	feet
g	gram
gpm	gallons per minute
HFEF	Hot Fuel Examination Facility
in	inch
INL	Idaho National Laboratory
kg	kilogram
m	meter
MeV	Million electron Volts
MFC	Materials and Fuels Complex
MPa	Mega Pascal
MW	Million Watts
MW_{th}	Mega Watts thermal
n	neutron
NE	northeast
NSUF	National Scientific User Facility
NW	northwest
psig	pound per square inch gauge
sec	second
W	Watt

REFERENCES

1. "FY-2008 Advanced Test Reactor National Scientific User Facility Users' Guide," INL/EXT-07-13577, Idaho National Laboratory (2007).

2. "INL's Unparalleled Advanced Test Reactor," Fact Sheet 05-GA50506, Idaho National Laboratory (2005).

3. "Upgraded Final Safety Analysis Report for the Advanced Test Reactor," SAR-153, Idaho National Laboratory (2006).

4. "Hot Fuel Examination Facility, The Evolution of a National Asset", Idaho National Laboratory (2007).

TABLE 2. Approximate Peak Flux Values for ATR Experiment Positions for a Reactor Power of 110 MW_{th} (22 MW_{th} in each Lobe).[1]

ATR Experiment Position Characteristics[f]				
Position	**Diameter (cm/in)[a]**	**Thermal Flux (n/cm^2-s)[b]**	**Fast Flux (n/cm^2-s)[c]**	**Gamma Heating (W/g - graphite)[d]**
Flux Traps				
NE and NW Flux Traps	13.3/5.250	4.4×10^{14}	2.2×10^{14}	
Other Flux Traps[g]	7.62/3.000	4.4×10^{14}	9.7×10^{13}	
Irradiation Positions				
A – Positions:				
A-1 thru A-8	1.59	1.9×10^{14}	1.7×10^{14}	8.4
A-9 thru A-16	1.59/0.625	2.0×10^{14}	2.3×10^{14}	8.8
B - Positions				
B-1 thru B-8	2.22/0.875	2.5×10^{14}	8.1×10^{13}	6.4
B-9 thru B-12	3.81/1.500	1.1×10^{14}	1.6×10^{13}	5.5
H - Positions				
H-1 thru H-14	1.59/0.625	1.9×10^{14}	1.7×10^{14}	8.4
I - Positions:				
Large (4)	12.7/5.000	1.7×10^{13}	1.3×10^{12}	0.66
Medium (16)	8.26/3.500	3.4×10^{13}	1.3×10^{12}	
Small (4)	3.81/1.500	8.4×10^{13}	3.2×10^{12}	
Outer Tank Positions (Capsule Irradiation Tank)				
Outer North (12)				
ON-4	Variable[e]	4.3×10^{12}	1.2×10^{11}	0.15
ON-5	Variable[e]	3.8×10^{12}	1.1×10^{11}	0.18
ON-9	Variable[e]	1.7×10^{12}	3.9×10^{10}	0.07
Outer South (22)				
OS-5	Variable[e]	3.5×10^{12}	1.0×10^{11}	0.14
OS-7	Variable[e]	3.2×10^{12}	1.1×10^{11}	0.11
OS-10	Variable[e]	1.3×10^{12}	3.4×10^{10}	0.05
OS-15	Variable[e]	5.5×10^{11}	1.2×10^{10}	0.02
OS-20	Variable[e]	2.5×10^{11}	3.5×10^{9}	0.01

a. Capsule diameter must be smaller
b. Neutron Average Speed = 2200 m/s
c. Neutron Energy > 1 MeV
d. Depends on Configuration
e. Can be either 2.22, 3.33, or 7.62 cm (0.875, 1.312, or 3.000 in)
f. Actual neutron flux and gamma heating values will vary depending on the number and types of experiments and the number and locations of fresh and recycled fuel elements in the core.
g. East, Center, and South flux trap configurations contain seven guide tubes each with an inside diameter of 1.76 cm (0.694 in).