ATR

NATIONAL SCIENTIFIC USER FACILITY

FY 2009 Advanced Test Reactor National Scientific User Facility Users' Guide

Idaho National Laboratory

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ACRONYMS

AFCI	Advanced Fuel Cycle Initiative
AGR	Advanced Gas Reactor
AL	Analytical Laboratory
ATR	Advanced Test Reactor
ATRC	ATR Critical Facility
DOE	Department of Energy
DOE-ID	Department of Energy Idaho Operations Office
DOT	Department of Transportation
EML	Electron Microscopy Laboratory
ESAP	Experiment Safety Assurance Package
FY	fiscal year
GASR	gas assay, sample, and recharge
HFEF	Hot Fuel Examination Facility
HSIS	Hydraulic Shuttle Irradiation System
INL	Idaho National Laboratory
ITP	Irradiation Test Plan
IU	irradiation unit
LANL	Los Alamos National Laboratory
LWR	Light Water Reactor
MFC	Materials and Fuels Complex
NE	Office of Nuclear Energy
NR	Naval Reactors Program
NRAD	neutron radiography reactor
NRC	Nuclear Regulatory Commission
NSUF	National Scientific User Facility
ORNL	Oak Ridge National Laboratory
PALM	powered axial locator mechanism
PCS	primary coolant system
PI	principal investigator
PIE	post-irradiation examination
PM	project manager
QA	quality assurance
R&D	research and development

RERTR	Reduced Enrichment for Research and Test Reactors
SEM	scanning electron microscopy
SORC	Safety and Operations Review Committee
TEM	transmission electron microscopy
TFR	technical and functional requirements
TIG	tungsten inert gas
TRIGA	Training Research Isotope General Atomics
TTAF	test train assembly facility
USQ	unreviewed safety question
UWG	Users' Working Group
V&V	verified and validated

1. INTRODUCTION

Collaborative development of nuclear energy science and technology by three major sectors—academia, the commercial nuclear power industry, and the federal government—is key to meeting challenges in the development of nuclear energy. All three share a common need for experimental capabilities, whether for basic science investigations, applied research in nuclear fuels and materials or validation of data. In April 2007, to fill this need, the U.S. Department of Energy (DOE) Deputy Secretary of Energy designated the Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL) as a National Scientific User Facility (NSUF). The Office of Nuclear Energy (NE), the Office of Science, and Office of Naval Nuclear Propulsion Programs, or Naval Reactors (NR) strongly endorsed the action. While functioning as a NSUF, the ATR will continue to support its current national missions.

The ATR (Figure 1) is located at the ATR Complex on the INL site and has been operating continuously since 1967. The primary mission of this versatile facility was initially to serve the U.S. Navy in the development and refinement of nuclear propulsion systems, however, in recent years the ATR has been used for a wider variety of government- and privately-sponsored research. Even though the ATR now also serves a range of other research and isotope production customers, it currently operates at approximately 60% of its experiment loading capacity. DOE's designation of the ATR as a NSUF enables DOE to facilitate research that would not have been feasible for many researchers and allows for fuller utilization of the ATR as a government asset.

Figure 1. Advanced Test Reactor facility.

This document provides a guide for prospective experimenters interested in performing irradiation research in the ATR. The following contains a brief discussion of the NSUF objectives, a description of the ATR and its experiment capabilities, the ancillary capabilities of the INL to support irradiation experiment development and Post Irradiation Examination (PIE), the process for users to follow to conduct an irradiation experiment, the conditions that apply to experimenters, and the technical requirements for materials inserted into the ATR test positions. This document is not intended to provide all the necessary information required to perform an experiment in the ATR, but will serve as a guide to concept development and initial experiment planning. An experienced team of INL researchers will work with experimenters to ensure that all experiments comply with all INL and ATR requirements.

2. OVERVIEW OF THE ATR NATIONAL SCIENTIFIC USER FACILITY

The designation of the ATR as a National Scientific User Facility (NSUF) provides a resource for meeting national imperatives to secure reliable energy sources and protect the environment. The ATR NSUF includes the ATR itself, facilities for post irradiation examinations such as the Hot Fuel Examination Facility (HFEF), and science and engineering support for experiments.

The ATR NSUF will be a center for nuclear fuels and materials research. It will attract and promote collaboration among nuclear energy, science, and technology researchers conducting cutting-edge materials and fuels Research and Development (R&D). Programs to enhance nuclear engineering and science education in the U.S. are also an important element of the ATR NSUF.

The mission of the ATR NSUF is to provide nuclear energy researchers access to world class facilities to support the advancement of nuclear science and technology in the United States. The ATR NSUF will accomplish this mission by offering state-of-the-art experimental irradiation testing and PIE facilities and technical assistance in design and safety analysis of reactor experiments.

The ATR NSUF will be a premier facility for scientific investigation of nuclear fuels and materials for nuclear energy systems. The user facility will:

- Support both basic and applied research and development
- Increase the effectiveness and decrease the uncertainty associated with development of new fuels and materials for existing and advanced reactor concepts
- Facilitate the development and validation of new analytical models to improve nuclear energy systems
- Encourage research collaboration on high-quality scientific experiments using the ATR and assure that unique research capabilities are made available to a broader scientific community using traditional collaborations
- Provide access to the ATR for production of medical, research, and industrial isotopes including the production of short-lived isotopes
- Provide a platform for educating and training nuclear scientists, radiochemists, engineers, and the various technical trades critical to the nuclear industry
- Support new nuclear programs at universities that do not have a dedicated research reactor, and augment those programs that do have research reactors.

3. ATR DESCRIPTION

The following sections present design and operating information about the ATR that would be helpful to prospective experimenters. Experimenters are encouraged to contact INL personnel (listed on the ATR NSUF home page) if they need additional information during proposal development.

3.1 Pertinent ATR Design Features

The ATR design exploits a unique serpentine core configuration that offers a large number of test positions. The primary operating characteristics are listed in Table 1.

Table 1. ATR General Characteristics.

Reactor:	
Thermal power	250 MW_{th}[a]
Power density	1.0 MW/L
Maximum thermal neutron flux	1.0×10^{15} n/cm^2-sec[b]
Maximum fast flux	5.0×10^{14} n/cm^2-sec[b]
Number of flux traps	9
Number of experiment positions	68[c]
Core:	
Number of fuel assemblies	40
Active length of assemblies	4 feet
Number of fuel plates per assembly	19
Uranium-235 content of an assembly	1,075 g
Total core load	43 kg[d]
Coolant:	
Design pressure	2.7 Mpa (390 psig)
Design temperature	115°C (240°F)
Reactor Coolant:	
Light water maximum coolant flow ra	3.09 m^3/s (49,000 gpm)
Coolant temperature (operating)	<52°C (125°F) inlet, 71°C (160°F) outlet

a. Maximum design power. ATR is seldom operated above 110 MWth
b. Parameters are based on the full 250 MWth power level and will be proportionally reduced for lower reactor power levels.
c. Only 66 of these are available for irradiations.
d. Total U-235 always less due to burn-up.

The ATR has large test volumes in high-flux areas. Designed to permit simulation of long neutron radiation exposures in a short period of time, the maximum thermal power rating is 250 MW_{th} with a maximum unperturbed thermal neutron flux of 1.0×10^{15} n/cm^2–s. Since most contemporary experimental objectives generally do not require the limits of its operational capability, the ATR typically operates at much lower power levels. Occasionally, some lobes of the reactor are operated at higher powers that generate higher neutron flux.

The ATR is cooled by pressurized (2.5 MPa [360 psig]) water that enters the reactor vessel bottom at an average temperature of 52°C (125°F), flows up outside cylindrical tanks that support and contain the core, passes through concentric thermal shields into the open upper part of the vessel, then flows down through the core to a flow distribution tank below the core. When the reactor is operating at full power, the primary coolant exits the vessel at a temperature of 71°C (160°F).

The unique design of ATR (Figure 2) control devices permits large power variations among its nine flux traps using a combination of control cylinders (drums) and neck shim rods. The beryllium control cylinders contain hafnium plates that can be rotated toward and away from the core, and hafnium shim rods, which withdraw vertically, 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.

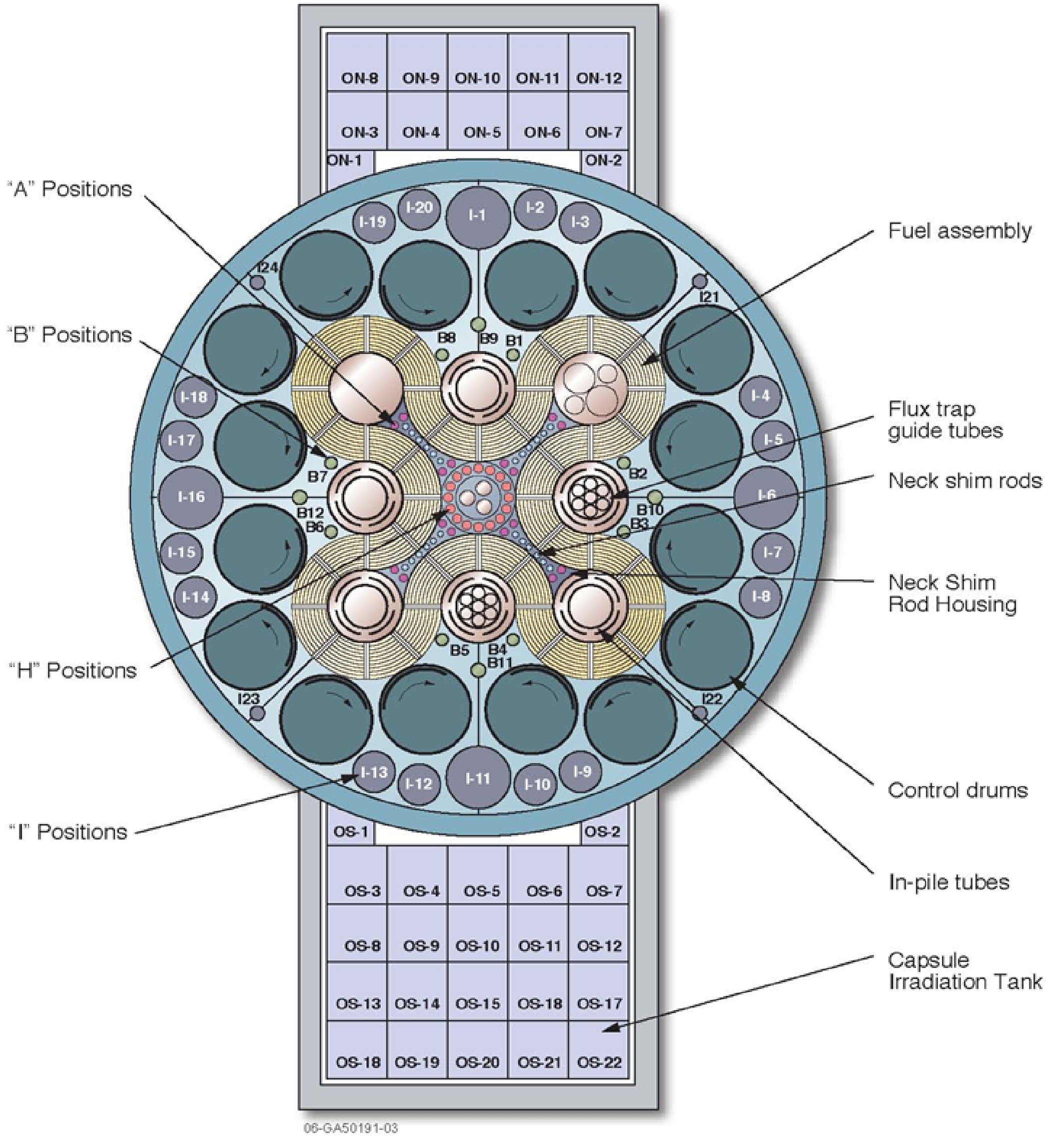

Figure 2. ATR Core Cross Section.

3.2 ATR Thermal Power and Flux

Neutron flux in the ATR varies from position to position and along the vertical length of the test position. It also varies with the power level in the lobe(s) closest to the irradiation position. Thermal and fast flux intensity values listed in Table 2 are at the core midplane for a reactor power of 110 MW_{th} and assume a uniform reactor power of 22 MW_{th} in each lobe.

Table 2. Approximate peak flux values for ATR capsule positions at 110 MW_{th} (22 MW_{th} in each lobe).

Positions		Diameter (in.)[a]	Thermal Flux (n/cm^2-s)[b]	Fast Flux (E>1 MeV) (n/cm^2-s)	Typical Gamma Heating W/g (SS)[c]
Northwest and Northeast Flux Traps		5.250	$4.4x10^{14}$	$2.2x10^{14}$	
Other Flux Traps		3.000[d]	$4.4x10^{14}$	$9.7x10^{13}$	
A-Positions					
	(A-1 - A-8)	1.590	$1.9x10^{14}$	$1.7x10^{14}$	8.8
	(A-9 - A-12)	0.659	$2.0x10^{14}$	$2.3x10^{14}$	8.8
*	**(A-13 - A-16)**	**0.500**	**$2.0x10^{14}$**	**$2.3x10^{14}$**	8.8
B-Positions					
*	**(B-1 - B-8)[f]**	**0.875**	**$2.5x10^{14}$**	**$8.1x10^{13}$**	6.4
*	**(B-9 - B-12)**	**1.500**	**$1.1x10^{14}$**	**$1.6x10^{13}$**	5.5
H-Positions					
	(H-1 - H-16)	0.625	$1.9x10^{14}$	$1.7x10^{14}$	8.4
I-Positions					
*	**Large (4)**	**5.000**	**$1.7x10^{13}$**	**$1.3x10^{12}$**	0.66
*	**Medium (16)**	**3.500**	**$3.4x10^{13}$**	**$1.3x10^{12}$**	
*	**Small (4)**	**1.500**	**$8.4x10^{13}$**	**$3.2x10^{12}$**	
Outer Tank Position					
	ON-4	Var[e]	$4.3x10^{12}$	$1.2x10^{11}$	0.15
	ON-5	Var[e]	$3.8x10^{12}$	$1.1x10^{11}$	0.18
	ON-9	Var[e]	$1.7x10^{12}$	$3.9x10^{10}$	0.07
	OS-5	Var[e]	$3.5x10^{12}$	$1.0x10^{11}$	0.14
	OS-7	Var[e]	$3.2x10^{12}$	$1.1x10^{11}$	0.11
	OS-10	Var[e]	$1.3x10^{12}$	$3.4x10^{10}$	0.05
	OS-15	Var[e]	$5.5x10^{11}$	$1.2x10^{10}$	0.20
	OS-20	Var[e]	$2.5x10^{11}$	$3.5x10^{9}$	0.01

a. Position diameter. Capsule diameter must be smaller

b. Average speed 2,200 m/s.

c. Depends on configuration

d. Current east, center, and south flux trap configurations contain seven guide tubes w ith inside diameters of 0.694 in.

e. Variable; can be either 0.875, 1.312, or 3.000 in.

f. B-7 is the location of the Hydraulic Shuttle Irraidation System

* Positions available for experiment irradiation in FY-2009

Figure 3 shows the symmetrical axial distribution of neutron flux for five different energy groups in the center flux trap. These data are for a slightly higher total reactor power of 125 MW_{th}. Figure 4 shows the average unperturbed neutron energy spectrum for the same reactor power of 125 MW_{th}. Figure 5 illustrates the lateral variation in flux intensity at the mid-plane in the east quadrant of the core for a much higher reactor power of 220 MW_{th}. Lines of constant flux intensity for thermal neutrons are shown with a contour interval of 4×10^{13} n/cm^2–s.

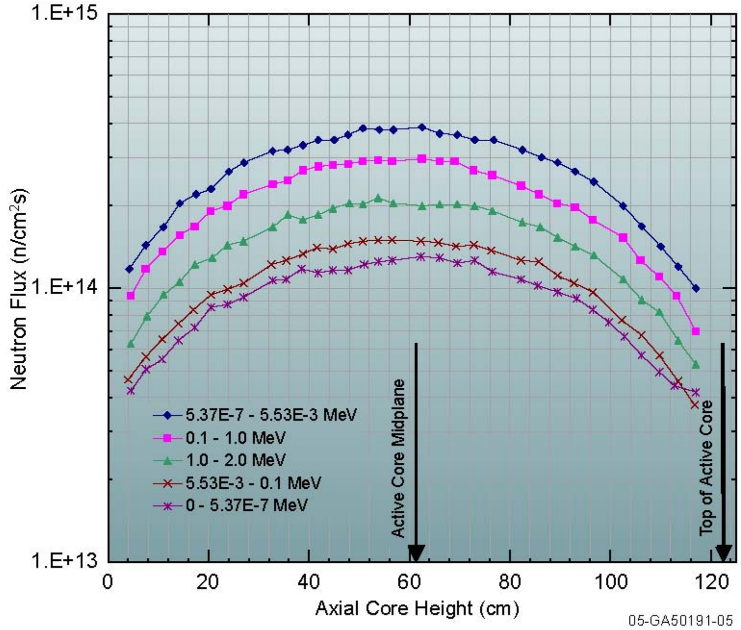

Figure 3. Unperturbed five-energy-group neutron flux intensity profiles over the active core length of the ATR center flux trap for total reactor power of 125 MW_{th}.

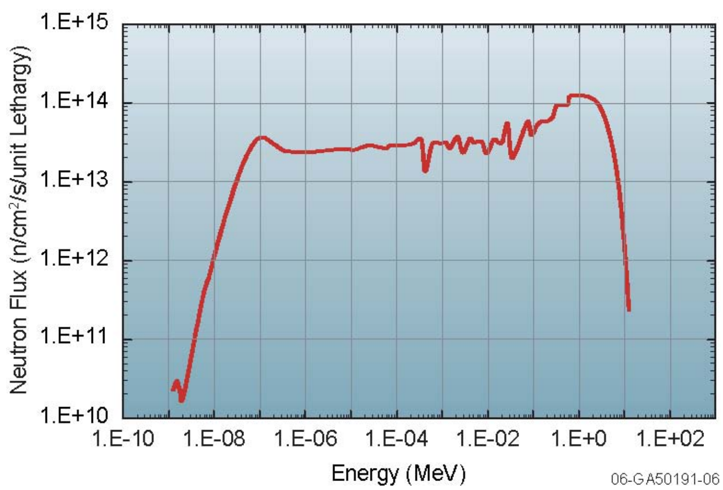

Figure 4. Unperturbed neutron energy spectrum for the center flux trap with the reactor operating at 125 MW_{th}.

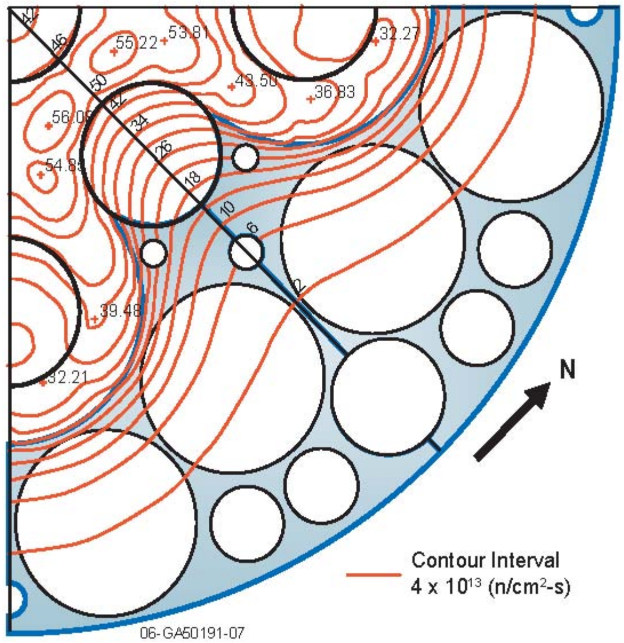

Figure 5. Unperturbed thermal neutron flux intensity distribution at the midplane in the east quadrant of the ATR for a reactor power of 220 MW_{th}.

Gamma heating in the ATR core is highest at the core midplane. It falls off with a cosine distribution to the top and bottom of the core where the fuel elements end, then decays exponentially outside of the core. Figure 6 shows typical gamma heating profile for a small (0.875 in.) B position with the reactor operating at 125 MW_{th}.

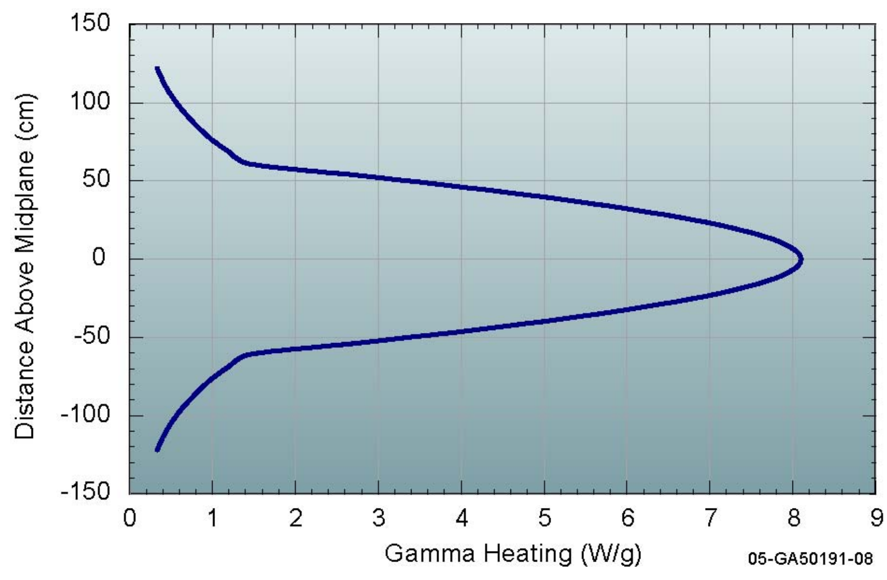

Figure 6. Typical gamma heating profile in a small B position with the reactor operating at 125 MW_{th}.

3.3 Experiment Positions

The curved fuel arrangement of the ATR places reactor fuel closer on all sides of the flux trap positions than is possible in a rectangular grid. The ATR has nine of these high-intensity neutron flux traps and 68 additional irradiation positions inside the reactor core reflector tank, each of which can contain multiple experiments. This is further complemented by two capsule irradiation tanks outside the core with 34 additional low-flux irradiation positions (Figure 7). The positions colored red are those available for NSUF experiments in FY 2009.

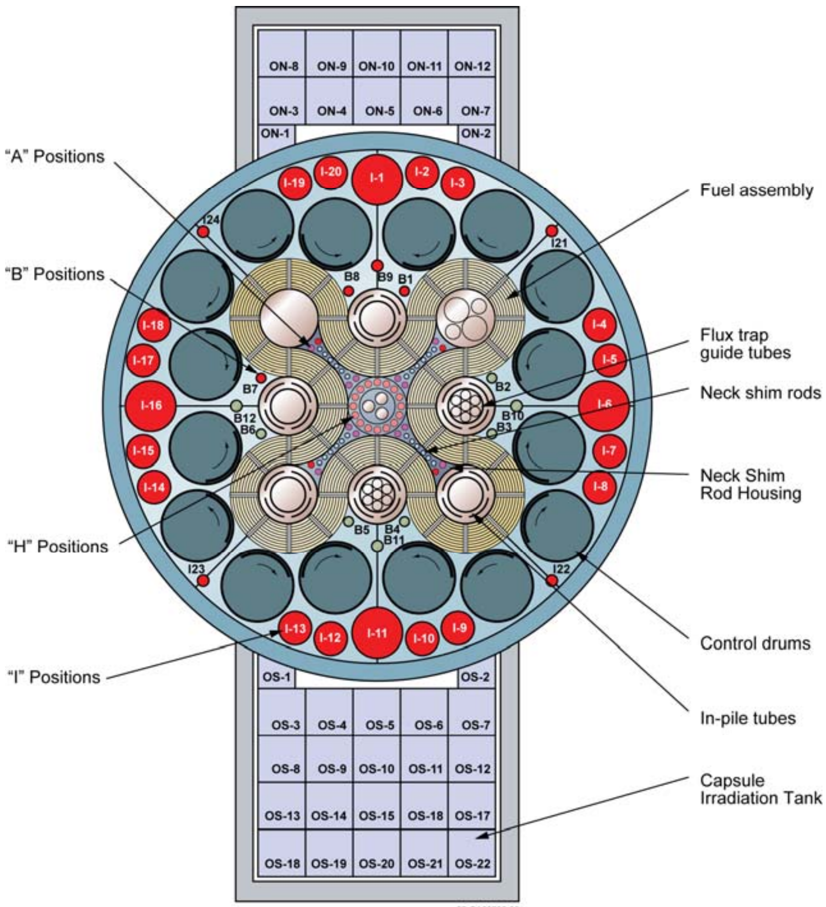

Figure 7. ATR flux traps and other irradiation test positions in or near the core.
● = Positions Available for NSUF Experiment Irradiation in FY 2009

The physical dimensions of the available test positions in the ATR range in size from 0.659 inches in diameter to 5.00 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 positions offered in the Fiscal Year (FY) 2009 solicitation, users will use baskets and capsules supplied by INL where feasible. 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.

In FY 2009 NSUF-funded experimenters are encouraged to design and/or manufacture targets to fit within the capsule designated for the position(s) into which the targets are intended to be inserted. Further details about these positions are in Section 6 of this Guide. The following experiment positions will be available for NSUF experiments in FY 2009:

- Group A positions are in the cruciform-shaped neck shim rod housing (see Figure 8); the inner eight positions (A-1 to A-8) are used mainly for long-term irradiations due to limited accessibility. Positions A-13, A-14, A-15, and A-16 are available in FY 2009.

- Group B positions are located in the beryllium reflector surrounding the core (Figure 7), inside the rotating control cylinders. The smaller B positions are located close to the fuel elements and, as Table 2 indicates, have considerably higher neutron flux than the larger B positions. Positions B-1, B-8, and B-9 are available in FY 2009.

- The I positions are in the periphery of the beryllium reflector, outside the rotating control cylinders, thus the flux is lower than the other ATR positions, but these positions are larger than most others in the ATR. All of the I positions, 1-24 are available in FY 2009.

- The Hydraulic Shuttle Irradiation System (HSIS) will be operational in FY 2009 in ATR position B-7. This system will enable test samples to be inserted into, and removed from the ATR during operations. There are a total of 16 capsules in the HSIS "train" that will be inserted and removed together. Each capsule is 2.25" long, and 0.625" outer diameter, and all the capsules are titanium. It is anticipated that most uses of the shuttle system will be for durations of a few hours to a few days.

The following positions may be available in future years if there is a demand:

- Group H positions are in the center flux trap assembly (Figure 8). Positions H-3 and H-11 are used for N-16 monitors and are not available for irradiations. The other 14 H positions extend 6.0 in. below the active core for a total length of 107 in. They are all being used at this time and there is no H unused irradiation space at this time. No H positions are available for the NSUF experiments in 2009.

- The Outer Irradiation Tank positions (ON-1 to ON-12 and OS-1 to OS-22) are constructed with three variable diameters to enable simultaneous irradiation tests of differing dimensions. No ON or OS positions are available for NSUF irradiations in FY 2009.

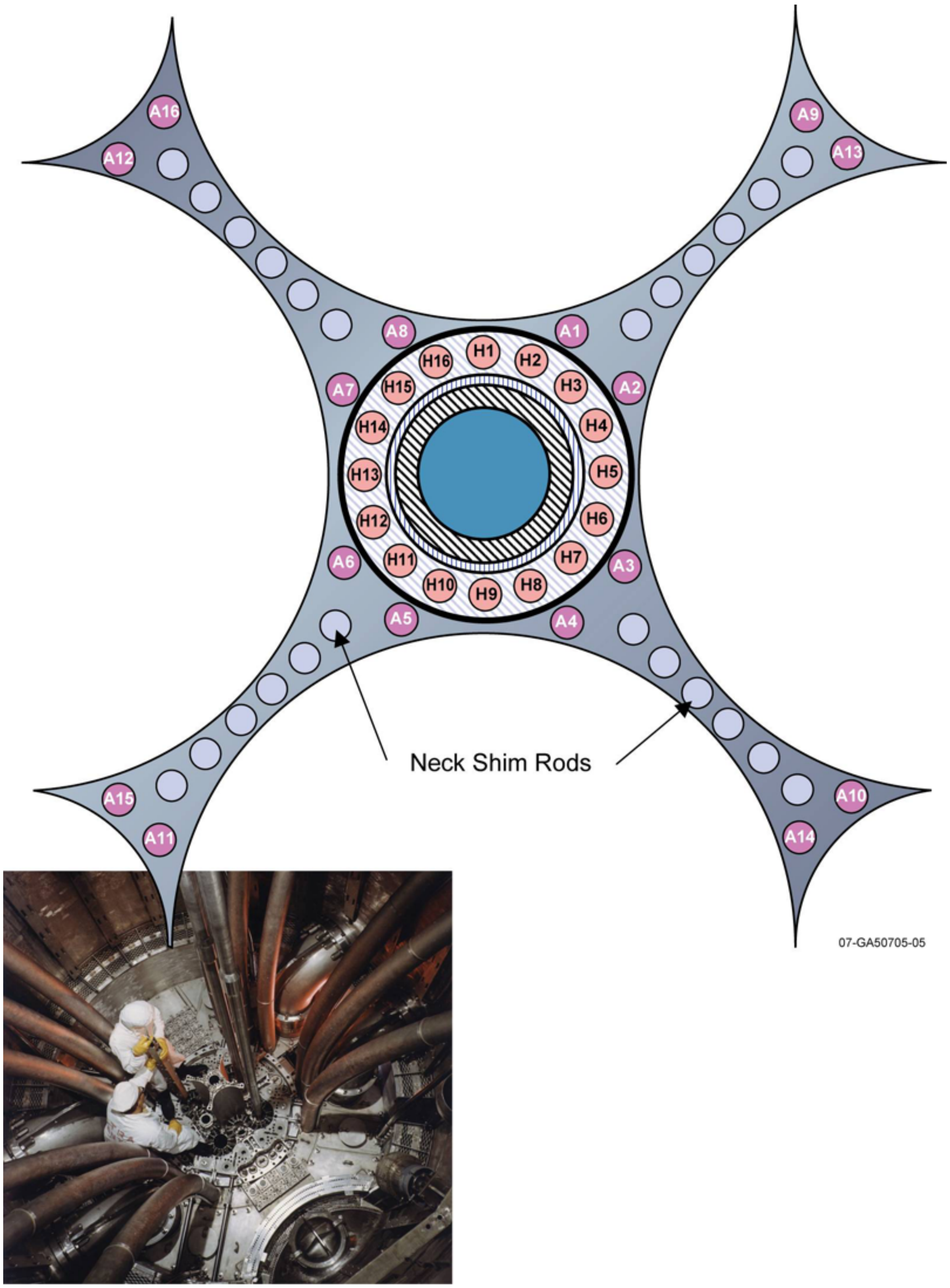

Figure 8. Group A positions in neck shim housing and Group H positions in center flux trap.

3.4 Operating Practice

The ATR operates in cycles that typically range in duration from 6 to 8 weeks of operating time, preceded by an outage that is typically one to two weeks in duration. Experiments may be inserted or removed only during the scheduled shutdowns (outages) that occur between the operating cycles. Experiments are inserted through the top head and removed (Figure 9) via the discharge chute shown in Figure 11.

Figure 9. Top Head of the ATR.

The top head itself is not removed during routine refueling outages. Following reactor shutdown and primary system depressurization, cover plates are removed from five elliptical ports in the top head. Long-handled tools are used to reach through these ports to transfer fuel, irradiation capsules, and core components through a discharge chute in the side of the vessel slightly above the top of the core (Figure 11) to the adjacent canal (Figure 10). These irradiated items can be manipulated and returned to the reactor for further irradiation or remain in the canal until they have cooled sufficiently to be loaded into an appropriate shipping container and transported for PIE.

In addition to the regular 6 to 8 week cycles, high power cycles identified as Powered Axial Locator Mechanism (PALM) are occasionally scheduled for short durations. These cycles typically run from 7 to 14 days with lobe powers as high as 50 MW. An approved ATR Test Plan is published which identifies specific cycle identifications, lobe powers and operating lengths. Any requests to deviate from the approved ATR Test Plan can be submitted to the ATR Users' Working Group (UWG) for review. Table 3 shows the proposed operating schedule, as a sample of what experimenters may expect for operational time, however, experimenters need to keep in mind that this schedule may change somewhat due to different operational needs in the future.

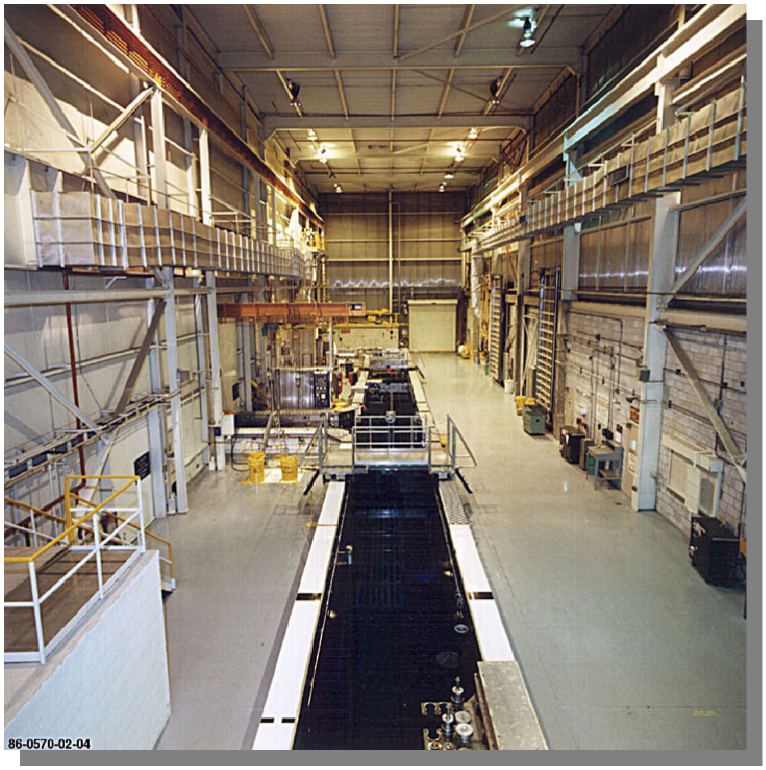

Figure 10. ATR storage canal.

Table 3. Operating history and proposed operating schedule, with lobe powers.

Cycle #	Cycle Start Date	Outage Days	Operating Days	Lobe Powers[a]			
				NW	NE	SW	SE
140A	9/29/07	14	49	18.0	18.0	23.0	23.0
140B	12/1/07	20.5	35.6	18.0	17.7	23.7	23.0
141A	1/26/08	9.6	32.4	18.0	18.0	23.0	23.0
142A	3/8/08	57	48	23.0	18.0	24.8	23.0
142B	6/21/08	18	52	23.0	18.0	25.0	25.0
143A	8/30/08	21	56	18.0	18.0	25.0	25.0
143B	11/15/08	21	56	18.0	18.0	25.0	25.0
144A	1/31/09	14	49	18.0	18.0	23.0	25.0
144B	4/4/09	14	49	18.0	18.0	23.0	23.0
145A	6/6/09	56	56	18.0	18.0	23.0	25.0
145B	9/26/08	14	49	18.0	18.0	23.0	25.0
146A	11/28/09	14	56	18.0	18.0	23.0	25.0
146B	2/6/10	14	49	23.0	18.0	23.0	25.0
147A	4/10/10	49	49	23.0	18.0	23.0	23.0
147B	7/17/10	14	14	18.0	18.0	50.0	30.0
148A	8/14/10	7	56	18.0	18.0	23.0	23.0
148B	10/16/10	14	49	18.0	18.0	23.0	23.0
149A	12/18/10	14	56	18.0	18.0	23.0	23.0

a. Powers listed for Northwest (NW), Northeast (NE), Southwest (SW), and Southeast (SE) reactor lobes

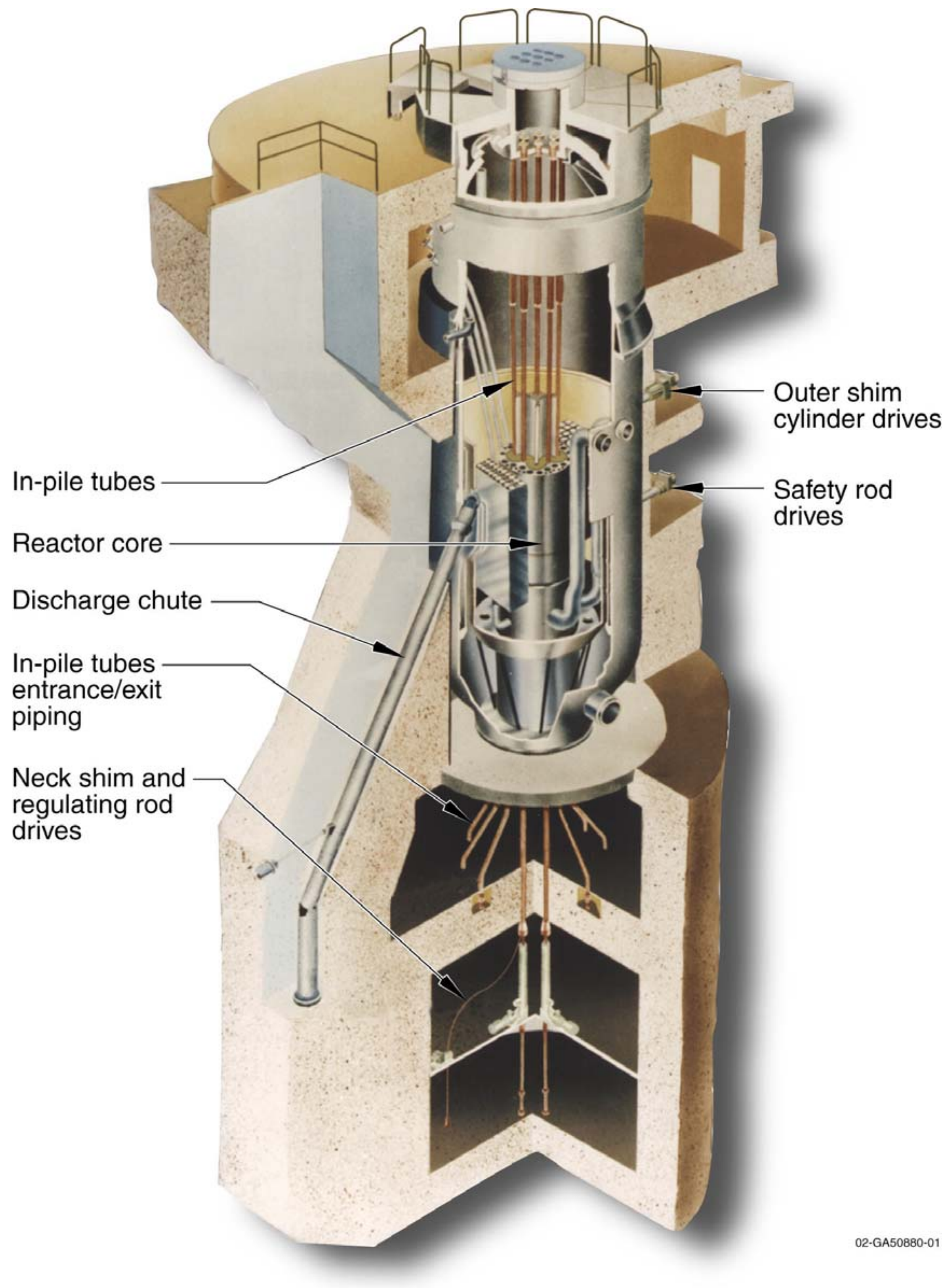

Figure 11. Cut-away view of the ATR.

4. AVAILABLE SUPPORT SERVICES, EQUIPMENT, AND SPECIALIZED FACILITIES

In support of ATR operations, the INL has developed extensive technical capabilities and specialized facilities. These are available to prospective users in accordance with need.

4.1 Target/Capsule Design and Engineering

Targets must be designed and fabricated to fit inside the capsules provided for particular test positions. Generally the test matrix must be physically axially uniform and free of unidentified contaminants. Manufacturing tolerances are necessarily tight—targets must not only fit inside the capsule but must also conform to the specifications used to perform the neutronic and thermal analyses of the experiment assembly as a whole. If prospective users do not have access to design expertise needed to ensure that targets meet specification, the INL will provide this service.

4.2 Chemical Analysis

After fabrication, the exact chemical composition of the as-built target must be determined within allowable uncertainties using appropriate and certified analytical chemistry methods. The user has the option to submit certified chemical compositions, which will be reviewed by the INL quality engineer. Additionally, the Analytical Laboratory located at the INL Materials & Fuels Complex (MFC) has a complete suite of analytical instruments housed within gloveboxes and hot cells and is available to users to perform such elemental chemistry and isotopic determinations.

4.3 Target Fabrication

Targets for irradiation frequently contain materials (such as fissile or high activity isotopes) that require special handling and machinery. Consistency in production quality and tolerances is critical to obtaining representative experimental results from which reliable conclusions can be drawn.

The INL has several facilities where ATR experiments can be fabricated and/or assembled. At the MFC, there are fuels and materials facilities for fabricating nuclear fuels and non-fissile targets. The Test Train Assembly Facility (TTAF), which is a portion of the ATR Complex Hot Cell Facility Building, serves as a location for the mechanical assembly for both test capsules and test trains that will be inserted into the ATR. The TTAF has a 25-ft long table to facilitate the assembly of long test train assemblies. The facility contains power equipment including induction brazing equipment, tungsten inert gas (TIG) welders, spot welder, drying ovens, drill presses, vacuum systems, and electro-plating equipment.

Cooperative agreements with Los Alamos National Laboratories (LANL) and Oak Ridge National Laboratory (ORNL) can provide access to additional capabilities for other specialized target fabrication. The INL can arrange for target fabrication in one of the specialized facilities within the system of National Laboratories or its qualified vendors.

4.4 Packaging and Transportation

Unirradiated targets that contain radioactive constituents cannot be transported over public highways unless packaged in Department of Transportation (DOT) approved containers and appropriately manifested. Irradiated capsules containing target materials are typically transported in a Nuclear Regulatory Commission (NRC) licensed transport cask after cooling. INL staff can provide support for shipping activities for users that lack qualified shipping personnel.

4.5 Quality Assurance

The INL's Quality Assurance (QA) requirements and procedures govern work at the ATR and all nuclear facilities at the INL. The INL's program meets NQA-1 requirements. The INL NSUF staff will work with the users to ensure that work performed by users will meet the necessary INL QA requirements, or will arrange for INL staff to perform the work. Typically, a quality plan specific to each experiment project will be included in the Project Execution Plan, written during the first stage of work. All materials, parts, and components will undergo receipt inspection by a quality engineer, and any non-conformances must be resolved before inserting those items in the ATR.

Archiving and retrieval of records and data at the ATR is broken into two major groups: the reactor operating data and the test data. Specification of which data to archive, in what medium, and for how long will be determined by the user and documented in the experiment Quality Program Plan.

4.6 Post Irradiation Examination

Post-irradiation examination capabilities available to ATR NSUF users are included in three primary facilities at the MFC:

- The Analytical Laboratory (AL), focused on analysis of irradiated and radioactive materials
- The Electron Microscopy Laboratory (EML), a radiological facility containing optical, scanning, and analytical microscopes
- The Hot Fuel Examination Facility (HFEF), a large alpha-gamma hot cell facility designed to remotely characterize irradiation fuels and structural materials.

More information about the PIE capabilities is available in the PIE Capabilities Guide, available off the ATR NSUF home page. PIE capabilities available at HFEF are detailed in the following sections.

4.6.1 Visual Examination

Upon receipt, the capsule can be visually examined to determine its mechanical integrity and surface appearance, and the mass of the capsule can be measured. During the examination, deviations from the as-built condition are recorded. Of note are capsule tube and end cap failures, cracks, deformations, blisters, areas of discoloration, corrosion, and loss of material by wear. Deviations from as-built conditions will be examined by close-up photography prior to performing subsequent PIE tasks.

4.6.2 Neutron Radiography

Neutron radiography can be used to examine the internal condition of the capsule assembly prior to disassembly. This non-destructive technique is able to detect the presence of water or bonding material within the capsule cavity indicating a leak or containment failure. Data are available on the general condition of the specimens, including axial position, radial position and gap, distortion or bow, and the fuel column length within the capsule.

Neutron radiography is performed at the MFC Neutron Radiography Facility which interfaces through the floor of the HFEF Main Cell (Figure 12). The neutron beam is generated by a 250 kW Training Research Isotope General Atomics (TRIGA) reactor located below the Main Cell. The capsule and fuel rodlets are imaged at the East Radiography Station (Sub-Cell Area).

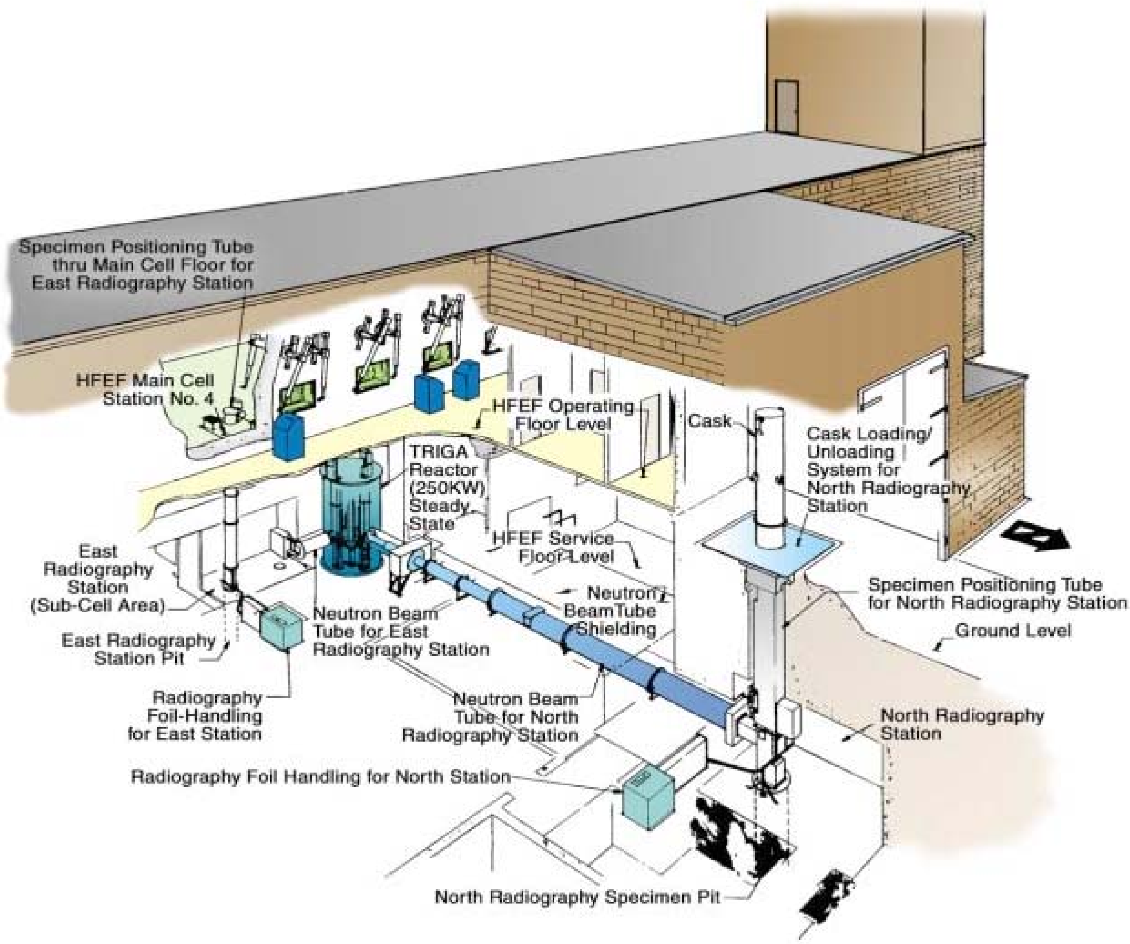

Figure 12. Neutron radiography facility at MFC.

4.6.3 Internal Gas Pressure and Void Volume Analyses

The Gas Assay, Sample, and Recharge (GASR) System can be used to puncture the capsule assembly, to measure the free volume and internal gas pressure and to collect samples for gas composition and isotopic analyses and total elemental composition.

The GASR system provides internal void volume and gas pressure data to an accuracy within ± 5% in a pressure – volume range of 0.03 to 60 liter-atmosphere. The system is comprised of a 150 W pulsed laser, shielded cell-wall penetrations for optics and gas lines, a mechanical vacuum pump, calibrated volumes, gauges and controls. A neoprene gasket is used to form the leak tight seal between the object to be assayed and the sealing/puncture chamber.

4.6.4 Assembly Dimensional Inspections

The diameter profile of an experimental component can be measured using the Element Contact Profilometer (ECP), a remotely operated, continuous-contact profilometry gauge for measuring axial and spiral diameter profiles of cylindrical elements and capsules. This is capable of measurements to an accuracy of ±0.0003 in. (7.6 μm) and can measure percentage swelling over a range of 0.13 – 8.7%. The length of the rodlet can be measured with an accuracy of ±0.010 inches and the bow of the fuel rodlet can be measured to an accuracy of ±0.020 inches.

4.6.5 Gamma Scan

Experimental components can be gamma scanned over their entire accessible length to measure total activity and isotopic activity of select fission products and activation products in structural materials. Gamma spectra can be used to determine fuel pellet or fuel pin separations in the fuel column, fuel redistribution, fission product migration, and the relative axial burnup profile.

4.6.6 Optical and Electron Microscopy and Radiochemical Analyses

Optical and electron microscopy are used to analyze microscopic features such as fuel restructuring, pore density and size distribution, fuel-cladding chemical interaction, grain size and structure in the fuel and cladding, precipitates, and cladding integrity. Rodlet samples are prepared in transverse and longitudinal sections to perform the optical and scanning electron microscopy analyses.

The fuel burnup of a representative number of fuel samples can be determined by radiochemical analyses on samples supplied to the Analytical Laboratory.

Sample preparation is performed in an inert, argon atmosphere sub-cell of the HFEF Main Cell equipped with an independent atmosphere control system (see Figure 13). The sample preparation sub-cell has facilities for sectioning, mounting, grinding, polishing and etching. The optical microscopy, scanning electron microscopy and radiochemistry samples are transferred by a pneumatic transfer system.

Optical microscopy is performed using a Leitz metallograph equipped with a projection screen and high resolution digital camera for recording images.

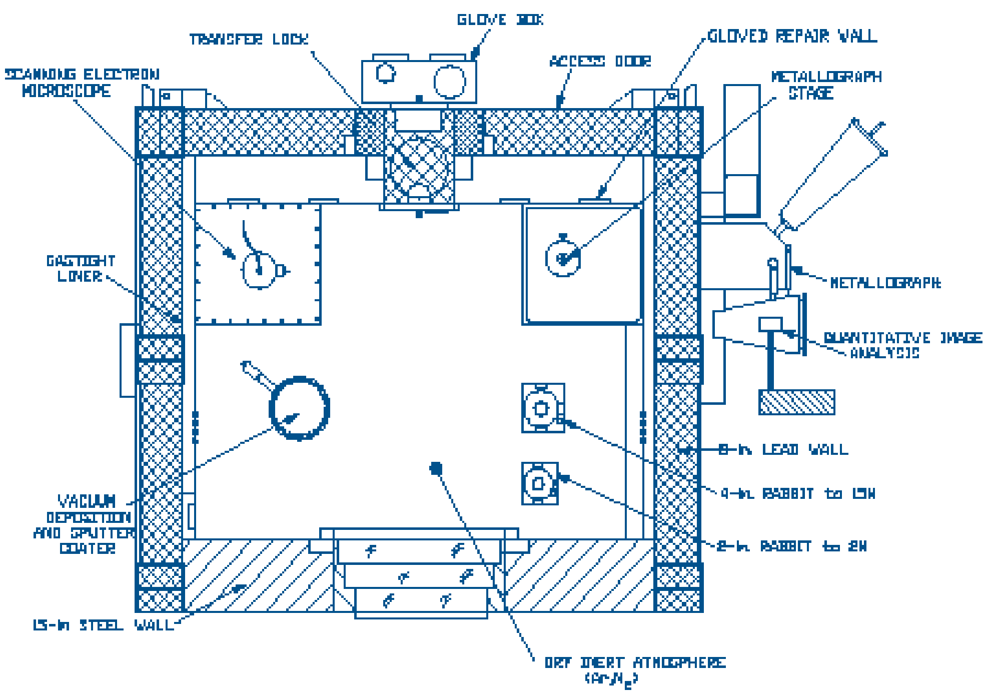

Figure 13. Inert atmosphere hot cell used for optical microscopy.

4.6.7 Mechanical Property, Phase Distribution, Microchemistry and Microstructure Examinations

Hardness testing, tensile testing, and analytical electron microscopy can be used to evaluate the mechanical properties, phase distribution, microchemistry and microstructure of the fuel forms and cladding. Micro-hardness measurements are performed using a Vickers-type diamond indenter hardness tester.

Samples are reduced in size for transfer to the EML (Electron Microscopy Laboratory) for SEM(Scanning Electron Microscopy) and TEM (Transmission Electron Microscopy) examination, including microchemical analysis using wavelength and energy dispersive spectroscopy. Transmission electron microscopy samples of fuels or materials specimens can be prepared and analyzed for irradiation-induced microstructure such as, dislocations, defects, voids, and precipitates.

5. OVERVIEW OF NSUF PROCESS FOR EXPERIMENT INSERTION

This section contains an overview of the experiment process, from inception of a user experiment to final disposition of the target and capsule. In order to provide context for the timeline for execution and to highlight critical opportunities for technical and strategic collaboration during the process, all steps of this process are discussed here, not just those that directly involve the user.

The central tenet of the NSUF is collaborative innovation between INL and user organizations. To fully realize the potential of this approach, the work must be performed by integrated task teams. Target design should be a combined exercise with input from INL experts; safety analyses should include user input and comment; and post irradiation examination should be represented by experts from both the INL and user. Similarly, interpretation of results and the planning of follow-on work should be a joint enterprise.

Figure 14 is a roadmap of the process for performing user experiments. The following subsections provide a brief discussion of each step, including purpose, party responsible for execution, typical order of events, general methodology, and location at which each element takes place. The length of time to complete an experiment will vary depending on the complexity of the irradiation test (i.e., capsule design), irradiation duration, and PIE complexity. As a matter of routine, the minimum time necessary to complete the initial experiment definition, design, and fabrication for a simple static capsule experiment is six months. Use of standard hardware and previously analyzed configurations can shorten this process, however, changes during the design phase of the project will tend to extend this schedule.

5.1 Proposal Process

Proposals will be requested annually from prospective users for experiments to be conducted in the ATR. Evaluation against clearly defined criteria and selection will be performed by a peer review team. The purpose of conducting this exercise annually is to stimulate creative thinking and to expand the opportunities to participate as widely as possible. Most experiments will require more than one year for completion.

Because industry and academic capabilities and interests are generally quite different in scope and available resources, solicitation and selection of proposals for these two user groups may be treated separately.

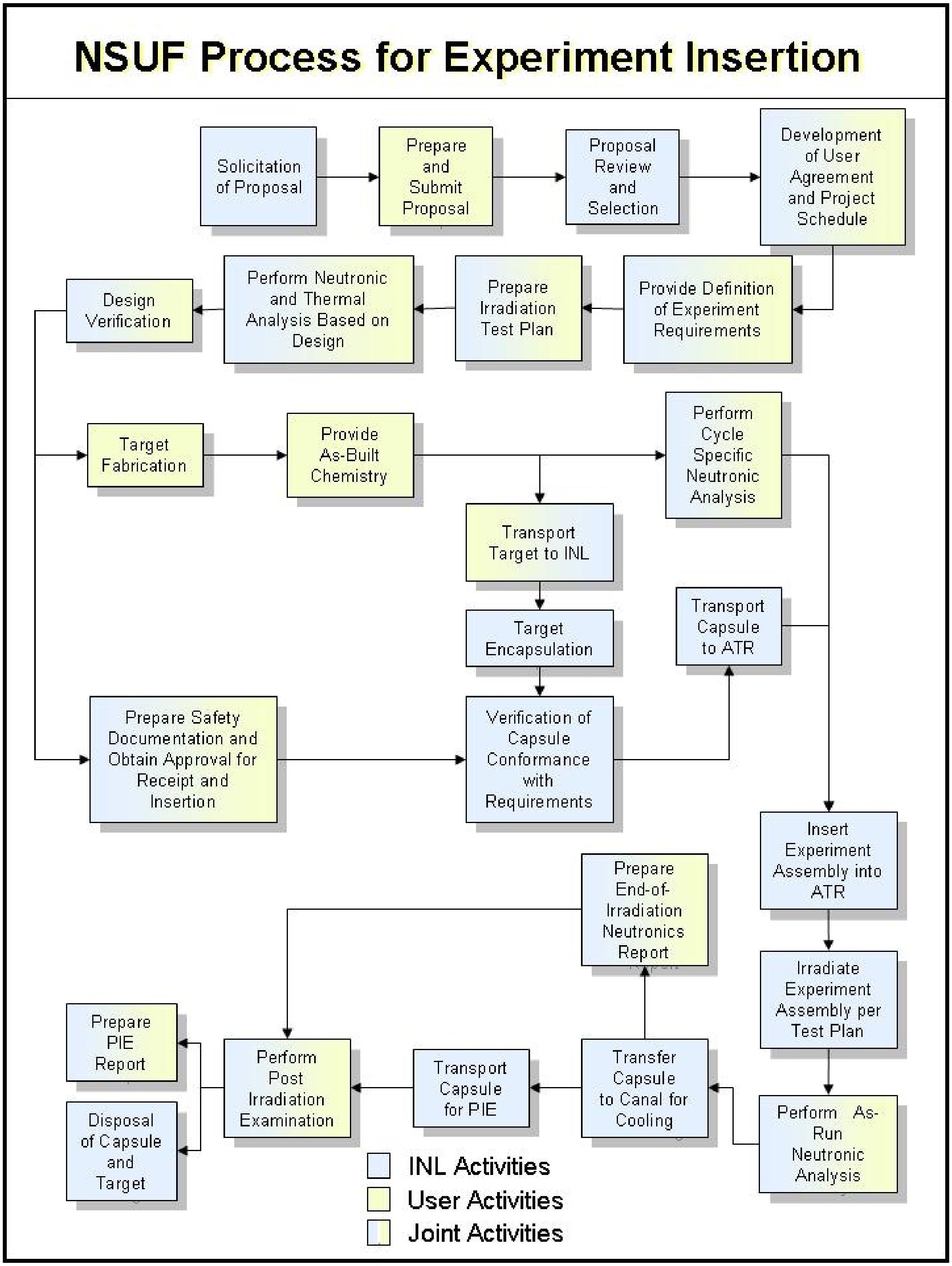

Figure 14. Process for Experiment Irradiation.

5.2 Prepare and Submit Proposal

Proposals must conform in content and format to specifications in the solicitation. Proposal due dates may be extended but proposals received after the published due date will not be considered. Clarity of purpose and potential experimental value are of greater weight in eventual selection than over elaboration of credentials or prior accomplishments of the user. Emphasis in proposals should be given to explaining the phenomena or attributes to be tested and verified or disproved. Meaningful performance metrics and practical means of accurate measurement are important to clearly convey to the selection team. Prospective users may propose irradiation in a specific position, however, the INL project team, in consultation with the user, will make the final determination in consideration of all relevant operating factors. Users are also encouraged to consult the INL staff in proposal preparation to ensure that the experiment proposed can be performed as envisioned.

5.3 Develop User Agreement and Project Schedule

After proposals are awarded, ATR NSUF management and the awardees will jointly develop a user agreement. The user agreement contains standard language required to perform work with (and at) the INL, and also contains a statement of work which includes specific information about the preparation and delivery of test specimens, and a budget spreadsheet. The user agreement (and corresponding documents) must be signed prior to the INL staff starting the technical design work. This information will be sent to the ATR NSUF Program Administrator.

An INL project manager (PM), principal investigator (PI), and key project team members will be identified; the INL PM and PI will work with the user PI to establish the preliminary schedule in parallel with the negotiation of the user agreement. Technical assistance (engineering, neutron physics analysis, development of the safety case, irradiated fuel shipments, procedures, etc.) will be provided by the INL experiment project team as required and delineated in the user agreement. Membership in the experiment team should remain as consistent as possible for the duration of the experiment. The irradiation schedule will be established by working with the ATR UWG to ensure that the individual experiment needs are aligned with the ATR integrated operating schedule. The INL PM will be the interface between the INL project team and the UWG. Some of the preliminary schedule information will be included in the user agreement, to be sure that both parties agree on the proposed schedule, so the user agreement and preliminary schedule will be developed simultaneously.

5.4 Definition of Experiment Requirements

Although general information regarding available irradiation positions and the corresponding assemblies is provided in this document, target design requires an exact definition of requirements. INL staff, with the user, will identify the ATR irradiation location where the experiment will be placed and the reactor cycle(s) during which the experiment will be irradiated. Once this determination is made, the INL project team, in conjunction with the user, will compile a detailed list of requirements, including capsule dimensions, expected flux and fluence, and safety limits. These will be formally documented, in the Technical and Functional Requirements (TFR) and Irradiation Test Plan (ITP) for the experiment, in accordance with INL design control processes.

Irradiation location and cycle determination in turn defines the capsule and basket that will comprise the complete experiment assembly. The INL project team formally documents all relevant requirements ranging from capsule inside dimensions to temperature and pressure limitations and communicates these in writing to the user. Users will proceed with detailed target design based on this information. Additional considerations and restrictions, per ATR safety requirements are discussed below.

5.4.1 Target Materials Requirements

The following material requirements will apply.

5.4.1.1 Prohibited Materials

The following materials are not permitted in an ATR experiment or loop facility within the reactor biological shielding.

- ***Unknown Materials*** – No experiment shall be performed unless the material content, with the exception of trace constituents, is known.
- ***Explosive materials with an equivalent of $\geq$ 25 mg of TNT.*** (Explosive material is a solid or liquid which has an explosion hazard in water or steam, as defined in Lewis [1990], and is used in a configuration that can detonate and produce a shock wave.
- ***Cryogenic liquids.***

5.4.1.2 Evaluation of Material

The following materials are not used in experiments unless such usage is shown to be in compliance with the primary experiment safety analyses criterion and the compliance analyses are completed prior to insertion in the reactor vessel or canal.

- Radiologically hazardous activation products, if post irradiation handling cannot be performed within facility and personnel safety limits.
- Radiation sensitive materials, if the radiation effects result in a challenge to the safety basis (such as a structural deformation leading to a capsule failure).
- Highly flammable or toxic materials, per se or as by-products of radiation sensitive materials.
- Reactive materials which are defined as any solid or liquid which has a reactivity index of 2 in National Fire Protection Association Publication 704 (NFPA 2001) or has a disaster or fire hazard indicating detrimental reactions in water or steam (Lewis 1990).

5.4.1.3 Containment of Materials

Materials that are incompatible with the reactor fuel element cladding, the reactor primary coolant, canal water coolant, or with the reactor Primary Coolant System (PCS) structural materials must be contained to ensure they are not released to the PCS or canal.

Incompatible materials must be secured to minimize the likelihood of being released into the reactor PCS. The following are examples of materials which are chemically incompatible with the PCS: mercury, gold, copper, silver, and chlorides. Gold, silver, or other properly reviewed materials may be used as activation monitors, provided they are secured so that the material cannot be released into the reactor PCS. The preceding materials list is not all inclusive, as there are other materials not listed that are incompatible with the reactor fuel element cladding. As experiment designs are finalized, all material interactions will be evaluated to ensure compliance with applicable safety basis documentation.

5.4.2 Margins between Test Goals and Safety Limits

Users are advised that experiment condition targets will be set below Safety Limits. Positions and cycles that provide adequate safety margin will be selected in conjunction with the user.

5.4.3 Dimensional Limitations by Position

Once a position has been assigned for irradiation of a specific experiment, the irradiation capsule will be designed. The target size will depend on the capsule size and the need for temperature insulation. Once the target specimens size has been determined, target fabrication must conform to these dimensions.

5.4.4 Limits on Fissile and Fertile Elements

Certain ATR positions offered have specific limitations on fissile and fertile elements that can be contained in target materials. Limitations are noted and clearly defined.

5.5 Preparation of Irradiation Test Plan

After award, the INL PI, working with the user PI, prepares the ITP to identify experiment objectives, milestones, and decision points. In their proposals, prospective users outlined the phenomena of interest, expected results (with reference to the bases for these results), proposed metrics (and required level of accuracy) for determining results and the means necessary for practical measurement, materials to be used to construct the target, fabrication parameters critical to achieving desired results, irradiation parameters required, and any relevant considerations for handling or analysis, and an irradiation strategy to meet experimental objectives. The ITP should correspond to the material provided in the proposal that formed the basis for selection, however, the level of detail required in the ITP goes well beyond that requested in the proposal. All relevant parameters that are expected to change as a consequence of irradiation should be described. Metrics for calibrating effects must be provided, along with tolerances on measurement accuracy. Means and methods for performing measurements must be described. The ITP will be formally checked and certified by an authorized user representative as accurate and complete.

The user PI works with the INL project team to determine detailed technical information such as neutron energy, total fluence, pressure, temperature, linear heat generation rates. Known uncertainties will be identified and potential impacts (schedule, cost, data quality, operating conditions, etc.) will be evaluated. User work elements are defined and commitments are mutually agreed upon prior to commencement of the project. This information will enable the INL project team to identify and perform the necessary activities to ensure that the all INL and user requirements are met. This plan is the primary reference document for managing and coordinating activities associated with the irradiation experiment. The INL PM is responsible for ensuring that the INL project team successfully executes the requirements within this Test Plan and reports progress on a monthly basis. The following subsections provide more detail about the parameters that need to be defined to enable the INL project team to design and irradiate the material to achieve the scientific objectives.

5.5.1 Target Material Composition and Physical Characteristics

The chemical composition of all proposed target materials must be described in terms of chemical element or compound, tolerances on respective proportions, and allowable levels of trace contaminants. Physical characteristics such as crystal structure, porosity, friability, malleabilitiy, compressibility, tensile strength, and thermal properties need to be identified.

5.5.2 Flux, Fluence, and Neutron Energy Requirements

Specific requirements or constraints on instantaneous flux, total fluence, and/or neutron energy must be defined. This information is used by the INL project team to determine optimal test position in the ATR and the plausibility of achieving spectral adjustments to meet experimental requirements.

5.5.3 Geometric and Configurational Requirements

User intentions to examine unique geometric alignments (for example, to exploit the reactor flux profile) or target orientations must be clearly defined in terms of spatial relationships and allowable tolerances for the target material.

5.5.4 Special Shielding, Selective Absorption, or Dispersion Requirements

Phenomena that require special shielding, selective absorption to shift neutron spectra, or devices to disperse or diffract neutrons may be of limited plausibility in the ATR. Users requiring these to achieve specific irradiation effects must clearly define ranges to enable the INL project team to determine if achievable through use of absorptive material in baskets.

5.6 Neutronic, Thermal, and Structural Analysis

Neutronic performance predictions are necessary to ensure that programmatic and safety objectives can be achieved during irradiation. Users are encouraged to perform their own calculations, however, final validation that experiments meet reactor safety requirements will be performed by INL staff. Each experiment assembly is modeled in the designated irradiation position at planned reactor conditions for the particular cycle to predict performance characteristics. Verified and Validated (V&V) computer codes are used to calculate burn-up, gas generation, fluence, linear heat generation rates and other experiment parameters. If capsules and baskets selected for a specific experiment have not been previously analyzed, hydraulic parameters and core physics parameters must be calculated and compared to the reactor operating and safety envelope.

The INL project team is responsible for the adequacy and accuracy of supporting analyses submitted by experimenter organizations. The operation of each experiment is compared with the design specification to ensure that it is properly enveloped. Each experiment is compared to the safety envelope identified in the Experiment Safety Assurance Package (ESAP) to ensure consistency with the assumptions made in the analyses.

5.7 ATR Critical Facility

For some experiments, a “pre-test” is required to validate the reactivity estimate for the experiment. This is performed in the ATR Critical facility (ATRC), by the INL Nuclear Engineering staff. The determination of whether this test is required for a specific experiment is also the responsibility of the Nuclear Engineering staff. The ATRC core is a heterogeneous, pool-type reactor, dimensionally proportional to ATR, and typically operates at power levels of 600 watts or less. If an ATRC test is required, the INL project team will work with the users to ensure necessary information is obtained and that the ATRC work is scheduled in the experiment planning.

5.8 Preparation of Experiment Safety Assurance Package

An ESAP, prepared for all irradiation experiments at the ATR, addresses safety basis requirements. The purpose of the ESAP is to provide information needed to determine whether the proposed activities conform with applicable facility safety documentation (i.e., Technical Safety Requirements for the Advanced Test Reactor, Safety Analysis Report, Design Analyses), or pose an Unreviewed Safety Question (USQ).

For the FY 2009 user experiments, some of the capsules and baskets have been analyzed and documented in a previously approved ESAP. Use of these experiment configurations will reduce the experiment preparation time.

5.9 Design Verification

Once the necessary analyses and the design documents are completed, the INL project team will verify that the approved design meets the experiment specification and that the as-built experiment is within the appropriate safety limits for insertion into the ATR.

5.10 Target Fabrication and As-Built Chemistry

Targets for irradiation will be fabricated by the user unless other arrangements are negotiated with the INL and agreed to in the User Agreement. Finished targets must meet specifications agreed to in the experiment description documents (e.g., ITP and TFR). Extra targets may be required for destructive testing to determine the as-built chemistry, the uniformity of composition, and other key parameters. The as-built chemistry analysis will be compared to the design specification to ensure that the bounding uncertainties have not been exceeded so that the ESAP is not invalidated.

5.11 Nuclear Safety Documentation and Approvals

All experiments must meet the established nuclear safety requirements for ATR. INL personnel are responsible to ensure that all ATR insertion requirements are met. The analytical results are compiled in required formal safety documentation, the ESAP, reviewed by the Safety and Operations Review Committee (SORC), and, subject to resolution of comments, approved. The SORC reviews all safety and support documentation to ensure compliance with nuclear safety requirements.

5.12 Target Encapsulation

The target specimens will be encapsulated at the INL by INL staff. The INL will procure the materials for construction and fabricate the capsule(s) and basket(s) in accordance with the schedule required to insert the target in the designated operating cycle. Because the capsule also fits inside a basket that provides the experiment interface and support within the reactor position procurement of materials to make the basket and fabrication are conducted in parallel with the activities for building the capsule. Users will have the option of encapsulating their own target material and providing the sealed capsules to the INL if adequate QA requirements are in place for materials that will be in contact with the ATR primary coolant system.

No experiment may be inserted into the ATR without demonstration of capsule integrity to ensure that there are no leaks or mechanical flaws. The INL will perform required pressure and leak testing and will prepare associated confirmatory documentation.

5.13 Target Packaging and Transport

Unless provided for by agreement with the INL, users are responsible for shipment of experiment material in appropriate containers to the INL. Experiments should arrive at INL one to two months before insertion into the ATR, depending on reactor operating schedule, experiment complexity, and ESAP approval schedule.

5.14 Insertion of Experiment Assembly into ATR

ATR Operations staff inserts experiments into assigned positions during ATR outages. These insertions are documented in the reactor loading record.

5.15 Irradiation

A continuous record of operating power in each ATR lobe is maintained throughout the cycle including any adjustments required. This information is then used by INL analysts to calculate as-run irradiation parameters (including burn-up if the target contains fissile material) for each cycle and to determine the number of irradiation cycles required to achieve experiment objectives. If there are any specific operating instructions (e.g., power level different from the plan or power limit at a specific time during the irradiation) for a single experiment, the user, in conjunction with the INL project team, must communicate this to the ATR Operations staff to ensure that experiment objectives are met.

5.16 As-run Target/Capsule Neutronic Analysis

Using the as-built data obtained from physical and chemical analysis of user supplied representative targets, along with the actual ATR cycle operating data, INL staff will calculate the as-built expected performance of the full experimental assembly in the designated position during the assigned cycle(s). These results are compared to the design predictions and to identify specific limits that may reflect anomalies in fabrication.

5.17 Experiment Assembly Removal from Reactor

Experiments that have completed irradiation are transferred to designated positions in the ATR canal for cooling. ATR Operations staff performs handling of experiments and fuels during shutdown. During outages, visual examination of experimental assemblies can be performed. Completed tests remain in the ATR canal until activation and fission product decay is sufficient to permit loading into a cask for transport to PIE facilities. INL packaging and transportation personnel are responsible for determining and verifying when radiation levels from the experiment assembly are sufficiently low to allow for safe handling and transport.

5.18 Transport of Irradiated Capsule for PIE

After experiment assemblies have cooled sufficiently to permit safe handling and transport, the capsule is removed from the basket and placed inside an NRC approved shipping container by ATR Canal Operations. This cask is provided by the INL; loading and transport to PIE facilities are conducted by INL staff in accordance with the Transportation Plan for the specific experiment. If the user desires that the PIE will be performed outside the INL, this information needs to be included in the user agreement and the ITP, so the appropriate plans can be incorporated into the schedule.

5.19 End of Irradiation As-Run Neutronics Report

Proper interpretation of PIE results is only possible with a knowledge of the actual irradiation conditions experienced in the ATR. INL technical personnel calculate the expected neutronic effects using the same codes employed for predicting performance and the as-run irradiation analysis from the ATR. These calculations are documented in a report after irradiation is complete.

5.20 Postirradiation Examination

PIE performed at the INL (in the HFEF or other labs) is carried out by INL personnel using the instruments appropriate for determination of irradiation effects. It is normally possible for users to participate in PIE data reduction and to observe and direct examinations. This work is done within shielded remote cells in the HFEF that are equipped with proper remote access devices. Examinations are performed in isolation from other experiments to prevent unintended effects or cross-contamination. Alternatively, examination at another PIE facility can be arranged by the user.

5.21 Disposition of Capsule and Target

Capsules, targets, and baskets are activated during the irradiation process and require disposition as radioactive waste unless re-used. During the proposal development and feasibility review process, verification that there is a disposition path for any waste generated by the experiment will be performed. Normally, wastes from the experiments can be inserted into the ATR Complex or MFC established waste streams. If there are other waste disposal paths needed for specific experiment material, the user will be required to identify the approved waste disposal path and fund the disposition of the materials. The user is responsible for proper disposition of the target materials unless separate prior arrangements have been made through the user agreement.

5.22 Preparation and Submittal of PIE Report

The INL PI, in conjunction with the user PI, will interpret the PIE results in the context of the as-run data. All conclusions, calculations, rationale, and supporting data are compiled in a PIE report that is subject to peer review and comment prior to formal issuance. Unless designated as proprietary in accordance with the user agreement with the ATR NSUF, this report is published and made available to the general public.

6. REACTOR POSITIONS OFFERED IN FY 2009

The following sections describe the ATR experiment positions that will be offered to non-proprietary, peer-reviewed selected proposal experiments in FY 2009. The information provided in this section reflects experiments that have been previously performed in these experiment positions. There are some ATR experiment positions that have not been used for experiments, thus there is neither specification information nor an ESAP. This will require the INL project team to perform all the required safety analyses for the experiment. Final specification of the irradiation position will be determined following proposal selection during experiment design.

6.1 Positions A-13, A-14, A-15, A-16

- Fissionable material is not allowed
- Target materials capable of producing off-gases as a result of being irradiated are not allowed
- The capsule void volume is normally filled with helium at one atmosphere during fabrication. Other inert fill gases at one atmosphere may be acceptable but will require evaluation.
- Target materials must be designed such that neither thermal nor radiation induced expansion will cause mechanical stresses in the encapsulation material

6.2 Irradiation Positions B-1 and B-8

- Fissionable material is allowed in the target, however, the peak allowable heat flux for the capsule will apply and associated gas release into the capsule will require evaluation of the capsule integrity for potential internal gas pressure. Any target material capable of causing gas release into the capsule requires a capsule integrity evaluation and must not result in a potential internal gas pressure exceeding 235 psig
- The target material must be contained in a single capsule and be essentially uniform over 18.0 in. in the capsule

- The capsule inside diameter is nominally 0.288 in. and the nominal length of the space in the capsule is 18.25 in.
- The experimental capsule will be irradiated with the capsule center located slightly below the ATR core midplane
- The capsule void volume is normally filled with helium at one atmosphere during fabrication. Other inert fill gases at one atmosphere may be acceptable but will require evaluation.
- Target materials must be designed such that neither thermal nor radiation induced expansion will cause mechanical stresses in the encapsulation material
- Document the maximum allowable indicated adjacent lobe power, calculated by multiplying the ratio of the allowable peak heat flux (23.7 W/cm^2) to the calculated peak heat flux (at a given lobe power) by the lobe power used in calculating the peak heat flux, divided by factors of 1.085 and 1.18
- Target materials must not create an unacceptable radiological hazard and adequacy of the specified shipping container for the irradiated experiment must be demonstrated
- The maximum allowable peak heat flux from the outside surface of the 0.324-in. diameter capsule is 23.7 W/cm^2 (7.52E + 04 Btu/hr/ft^2).

6.3 Irradiation Position B-9

- Fissionable material is allowed in the target, however, the peak allowable heat flux for the capsule will apply and associated gas release into the capsule will require evaluation of the capsule integrity for potential internal gas pressure. Any target material capable of causing gas release into the capsule requires a capsule integrity evaluation and must not result in a potential internal gas pressure exceeding 235 psig
- The target material must be contained in a single capsule and be essentially uniform over 48.0 in. (the ATR active core height) in the capsule. Deviation from a uniform capsule loading over 48.0 in. may prove to be acceptable but will require justification, e.g., to demonstrate adequate capsule pressure boundary structural integrity and total experiment energy production within the current FIR envelope
- The capsule void volume is normally filled with helium at one atmosphere during fabrication. Other inert fill gases at one atmosphere may be acceptable but will require evaluation.
- Target materials must be designed such that neither thermal nor radiation induced expansion will cause mechanical stresses in the encapsulation material
- Document the maximum allowable indicated adjacent lobe power, calculated by multiplying the ratio of the allowable peak heat flux to the calculated peak heat flux (at a given lobe power) by the lobe power used in calculating the peak heat flux, divided by factors of 1.085 and 1.05
- Target materials must not create an unacceptable radiological hazard and adequacy of the specified shipping container for the irradiated experiment must be demonstrated

6.4 Irradiation Positions I-21, I-22, I-23, I-24

- Fissionable material is allowed, however the peak allowable heat flux requirement will apply and associated gas release into the capsule will require verification that the potential internal gas pressure is within capsule design envelope. Any target material capable of causing gas release into the capsule must not result in a potential internal gas pressure exceeding 235 psig
- The target material must be contained in a single capsule and be essentially uniform over 48.0 in. (the ATR active core height) in the capsule. Deviation from a uniform capsule loading over 48.0 in. may

prove to be acceptable but will require justification, e.g., to demonstrate adequate capsule pressure boundary structural integrity and total experiment energy production within the current FIR envelope

- Target material must be contained in a single capsule that extends from the ATR gear box support beam vertical support base (at ATR reference elevation of 82 ft 10.94 in.) downward through the I irradiation position. The capsule will be designed by the ATR NSUF and will have a total length of 60.25 in. The available target space in the capsule will be at least 48 in. in length and will be positioned such that the 48-in. target is centered at approximately the elevation of the ATR core mid-plane. The capsule inside diameter is to be determined but is not expected to exceed 1.345 in.
- The capsule void volume is normally filled with helium at one atmosphere during fabrication. Other inert fill gases at one atmosphere may be acceptable but will require evaluation
- Target materials must be designed such that neither thermal nor radiation induced expansion will cause mechanical stresses in the encapsulation material
- Document the maximum allowable indicated adjacent lobe power, calculated by multiplying the ratio of the allowable peak heat flux (39.4 W/cm^2) to the calculated peak heat flux (at a given lobe power) by the lobe power used in calculating the peak heat flux, divided by factors of 1.085 and 1.05
- Target materials must not create an unacceptable radiological hazard and adequacy of the specified shipping container for the irradiated experiment must be demonstrated
- The maximum allowable peak heat flux from the outside surface of the 1.450-in. diameter capsule is 39.4 W/cm^2 (1.25E + 05 Btu/hr/ft^2)

6.5 Irradiation Positions Summary

Table 4, below, displays a summary of the previous irradiation position limits, specifications and parameters listed in the previous sections. Where there is no information provided, individual experiment parameters will need to be developed for new experiments and the INL project team will confirm compliance with safety requirements.

Table 4. Irradiation Position Summary.

Experiment Parameter	A-13, -14, -15, -16	B-9	B-1, -8	I-1 – I-20	I-21, -22, -23, -24
Fissile Material allowed	No	Yes	Yes	Yes	Yes
Capsule inside diameter (in.)			0.288		1.345
Capsule inside length (in.)			18.25		60.25[a]
Maximum internal pressure during irradiation (psig)		235	235		235
Fill gas	Helium	Helium	Helium		Helium
Maximum heat flux at capsule surface (W/cm^2)	49.5		23.7		39.4
Maximum linear heat generation rate (400 W/cm)					
Maximum total energy production (kW)					
Irradiation limit (effective full power days)					
Instrumented lead experiment acceptable	No	Yes	Yes	Yes	Yes

a. Actual target will be only 48 inches

7. ATR EXPERIMENT CONFIGURATIONS

The following information provides details on the different experiment configurations that can be inserted into the ATR. Not all experiment configurations are available for all operating cycles. It is the responsibility of the ATR UWG to plan and schedule the experiments to be performed in each location, using the available experiment configurations, for each operating cycle. The INL PM for each experiment project will serve as the interface between the project team and the UWG. Detailed information for target design will be provided to users after proposals are selected and final irradiation positions are assigned. While sufficient for concept development and initial planning, the information provided in this Users' Guide is not suitable for final design and fabrication of targets.

7.1 Static Capsule Experiment

A static capsule experiment may contain a number of small samples, or, particularly if a large 'I' position is used, it may contain engineered components. Temperature within the capsule is usually controlled by providing a gas gap with a known thermal conductance (Figure 15). Peak temperature can be indicated using a series of temperature sensitive paint spots or melt wires. Thermal bonding media such as liquid metals may be used in capsule experiments to keep temperatures uniform inside the experiment. Flux-wire monitors in the experiments can give good measurements of neutron fluence at particular locations.

Static capsule tests cost much less than either instrumented-lead or loop tests, but provide less flexibility and no dynamic control of the irradiation environment. Capsules may be any length up to 122 cm (48 in.) and may be irradiated in any of the positions in the core, including the flux traps. The sections below describe some of the capsule experiments that have been performd in the ATR.

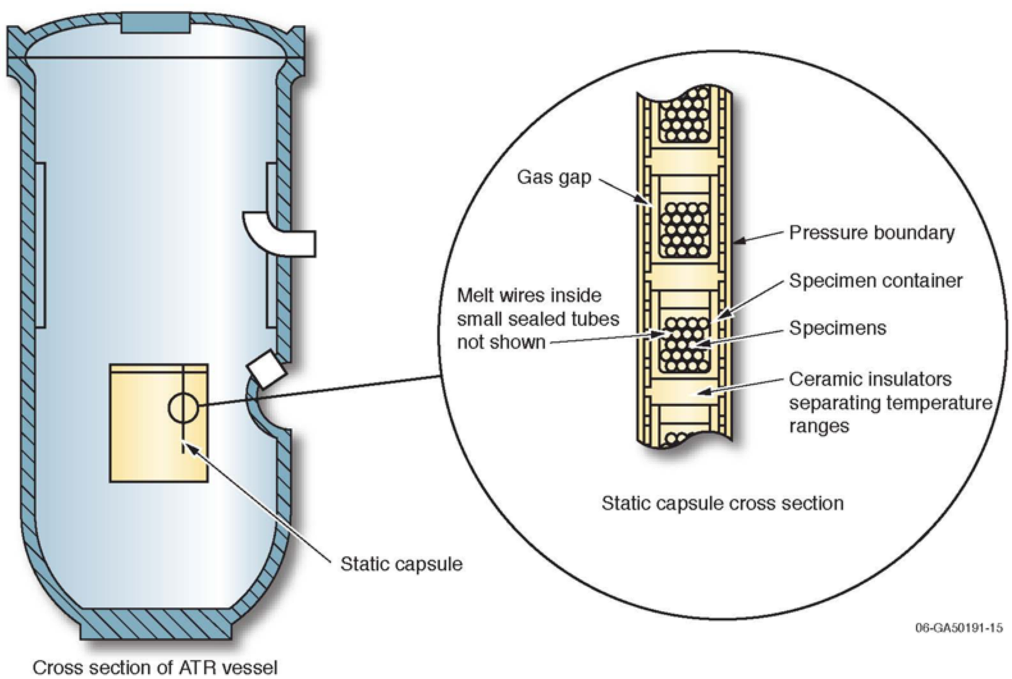

Figure 15. Static capsule experiments are often stacked in aluminum baskets.

7.1.1 Mixed Oxide Fuel

As part of the nuclear non-proliferation initiatives, it was proposed that weapons grade plutonium could be mixed with commercial uranium oxide and burned in current light water reactors (LWR). As part of that initiative, however, some testing was needed on the mixed oxide fuel (“MOX”). A simple capsule was prepared to contain nine fuel samples; the samples were exposed to a variety of burnups to simulate LWR burnup profiles. These test capsules were moved from one experiment position in the ATR to another position during the irradiation duration to enable a more stable fuel burnup rate during the course of the experiment. Preliminary fuel analysis results were sufficient to enable commercial nuclear power companies to pursue fabrication and use of MOX fuel in commercial LWR power plants. Figure 16 is a picture of the MOX static capsule experiment.

Figure 16. Picture of MOX static capsule experiment.

7.1.2 RERTR Plate Testing

As part of the Global Threat Reduction Initiative, high-enriched uranium fuel is discouraged in all research and test reactors. The Reduced Enrichment for Research and Test Reactors (RERTR) program was initiated to develop and qualify new fuels. ATR has been used as the primary testing location for the new fuel types and will continue to be used until all reactor fuel development is completed and new fuels are fabricated, around 2014. These tests are considered static capsule configurations, however these fuel specimens are in a plate geometry rather than cylindrical pellet, and the fuel plate cladding is in contact with the ATR primary coolant system. These tests are being performed in reflector and flux trap positions. Figure 17 shows the “miniplate” configuration used in the large B test reflector positions for the RERTR tests. The plates are nominally 1”x4”.

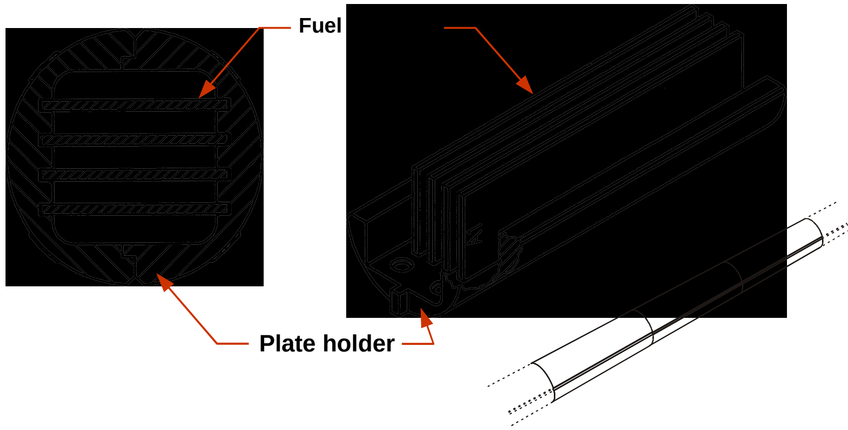

Figure 17. RERTR miniplate test configuration.

7.1.3 Advanced Fuel Cycle Initiative Fuel

The Advanced Fuel Cycle Initiative (AFCI) is currently irradiating different fuel types in the East Flux Trap of the ATR, and plans to continue to irradiate fuel specimens for several more years. The objective of the tests is to support development of fuels to minimize the spent fuel volume needed to be stored in a long term repository. Since the experiments are being conducted in one of the high thermal flux positions of ATR and have a maximum linear heat generation rate similar to existing power reactors, a cadmium lined basket is utilized to reduce the thermal flux and therefore reduce the fission rate in the fuel. This approach also increases the fast to thermal flux ratio to be more representative value of future fast reactors.

These tests are static capsule type experiments, consisting of short internal capsules (called rodlets) containing the fuel specimens. The rodlets are filled with sodium to provide good heat transfer and temperature equalization within the capsule and fuel. An inert cover gas plenum is also included in the top of the rodlet to provide room for swelling and collection of any fission gas releases. Several rodlets are loaded in an outer capsule with a precisely designed gas gap between the rodlets and the capsule wall. The gas gap is filled with a suitable gas to control the heat transfer from the rodlets to the capsule wall and into the ATR primary coolant, which determines and controls the temperatures in the fuel rodlets. The capsules are loaded into an open top basket that positions the capsules in the proper vertical location within the selected position within the East Flux Trap in ATR.

7.1.4 Reactor Pressure Vessel Steel

Several stainless steel samples were irradiated in multiple ATR positions to simulate commercial power plant neutron damage. Some samples were welded prior to being irradiated and some samples were welded after the irradiations. The experiment objectives were to determine particle migration, and to perform stress corrosion cracking studies of the irradiated samples. One of the experiments required some additional flux enhancement, so additional fuel was included as part of the experiment in one of the outer "I" test positions to ensure that the flux received by the experiment was appropriate for the test data needs. This fuel booster provided approximately three times the flux in the test position than would have been provided by the ATR driver fuel alone.

7.2 Instrumented Lead Experiment

Some capsules have lead tubes attached for carrying instrument wires and temperature control gases in and out of the reactor vessel. These are referred to as instrumented lead experiments. Figure 18 shows conceptually how an instrumented lead experiment is installed in the ATR.

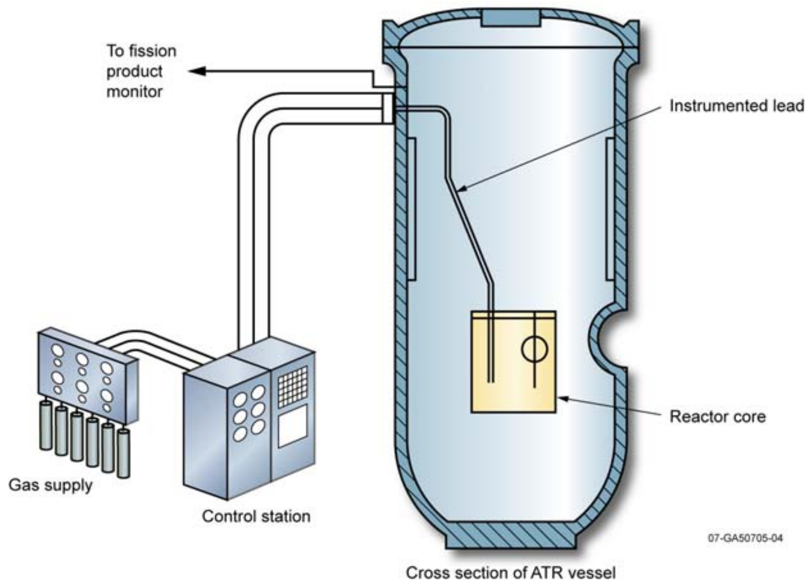

Figure 18. Illustration of an instrumented lead experiment.

Instrumented lead experiments are more complex than simple static capsules. They may have a relatively large number of thermocouples, for example, connected to individual capsules, or single specimens. There may be active control and sampling of atmospheric composition inside the capsule. Experimenters can control temperature in individual zones by varying the gas mixture (typically helium and neon) in the gas gap that thermally links the capsule to the water-cooled reactor structure. Other electrical or pneumatic connections may also be used, subject to reactor safety requirements. With the added complexity of these experiments, the time required for installing and removing the experiment is not as flexible as for static capsules. Costs for installing and operating the experiments are also higher.

Examples of instrumented lead experiments are discussed below.

7.2.1 Magnox Graphite

Graphite samples were irradiated to high-density losses due to radiolytic oxidation in a gas controlled, high temperature environment for Magnox, in support of life extension studies. This was a temperature controlled instrumented experiment, and a new temperature control system was developed that was the basis for subsequent temperature control experiments. The temperature was controlled nominally within a 5° C temperature band. Some samples were irradiated in an inert environment, and others were in a CO_2 environment to assess the environmental effect on the density loss. The experiment successfully achieved the results the customer wanted - one set of samples was extremely degraded due to oxidation, and the other set of samples in the inert environment was relatively intact.

7.2.2 Advanced Gas Reactor Fuel

The Advanced Gas Reactor (AGR) Fuel Development and Qualification Program irradiation tests were initiated in 2006, and there will be a total of eight different fuel irradiations for the program. The test train for AGR-1 (shown in Figure 19) consists of six separate capsules vertically centered in the ATR core, each with its own custom blended gas supply and exhaust for independent temperature control. Each of the six capsules is approximately 1.3” in diameter and 5.2” long, and will contain 12 prototypical fuel compacts approximately 0.5” in diameter and 1.0” long. The fuel compacts are made up of 780 µm diameter TRISO-coated fuel particles in a graphite matrix compact. The compacts are arranged in four layers in each capsule with three compacts per layer nested in a triad configuration. A graphite spacer surrounds and separates the three fuel compact stacks in each capsule and also provides the inner boundary for the insulating gas jacket. The graphite spacer also contains boron carbide as a consumable neutron poison to limit the initial fission rate in the fuel, providing a more consistent fission rate during the planned two-year irradiation. In addition to the boron carbide, a thin hafnium shroud is located around the outside portion of the capsule located toward the center of the ATR core to provide additional neutron absorption and provide more control of the experiment fission rate.

There are three thermocouples in four capsules (top capsule has five and the bottom capsule has only two due to space limitations) located in the top, middle, and bottom of the graphite holder to measure temperatures during irradiation. For the initial test, high temperature thermocouples were developed that enabled precise temperature control of the experiment up to 1200° C.

Gaseous fission products are monitored by routing the outlet gas from each capsule to an individual fission product monitor system, which include a High Purity Germanium (HPGe) spectrometer for identifying specific fission gases and a gross gamma (sodium iodide crystal scintillation) detector to provide indication when a small cloud of fission gases passes through the monitor. This small cloud or wisp of fission gases typically indicates when a TRISO fuel coating failure may have occurred.

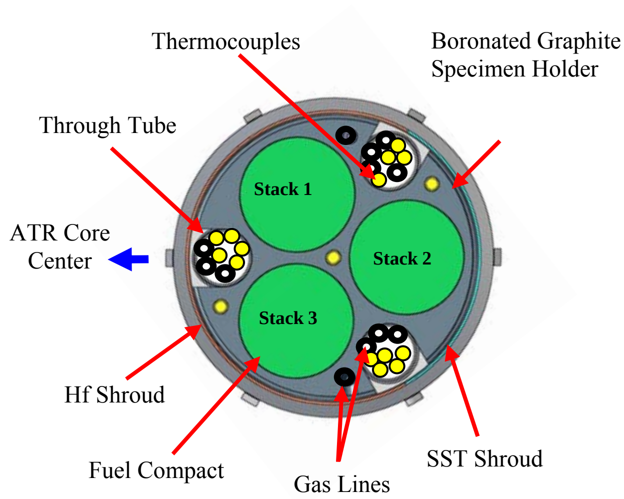

Figure 19. AGR-1 Capsule Cross Section.

7.3 Pressurized Water Loop

Five of the nine flux traps in the ATR are equipped with pressurized water loops, which are used for materials and fuels testing. Each of the five water loops can be operated at different temperatures, pressures, flow rates or water chemistry requirements. These loops can operate above the standard temperature and pressure of a current commercial pressurized water reactor power plant. The great advantage of loop tests is the ease with which a variety of samples can be subjected to conditions specified for any pressurized water reactor design. Many samples can be tested at once (in several loops or one loop, depending on the size of samples) with variation in the samples, thickness of cladding, etc., and the samples can be compared afterward for optimum design. Materials and fuels designers rely heavily on such tests.

Figure 20 is the cross section of a typical loop design. Three concentric tubes form the piping assembly for each water loop in the ATR. The assembly penetrates the vessel's bottom closure plate and has an inlet and an outlet below the vessel. Coolant comes up through the innermost tube, the flow tube, and passes the sample. Near the top of the vessel, on four of the five loops, the coolant passes through positions in the flow tube into the annulus enclosed by the pressure tube and returns down that annulus to the outlet. On the fifth loop, the water passes only one way, up through the in-pile tube and out through the side of the reactor vessel.

Helium flows through the annulus enclosed by the outermost tube, which also serves as the insulating jacket. Insulation is essential because the inside of the pressure tube is in contact with loop coolant at temperatures up to 360°C (680°F), whereas the outside of the insulating jacket is in contact with primary system coolant at 52°C (125°F). The helium is monitored for moisture to detect any leaks in the tubes.

Loop cubicles and equipment occupy the space around the reactor on two basement floors. The pressurized water loop equipment includes piping within the reactor vessel and pumps, heat exchangers, a pressurizer, and demineralizers within a shielded cubicle (Figure 21). The line heaters are capable of raising the loop coolant temperature from 38–360°C (100–680°F) in 3 hours. Normally, these heaters are used to capacity only when preparing the loop for startup. After the reactor comes into operation, fission and gamma heating of the samples provides much of the required heat.

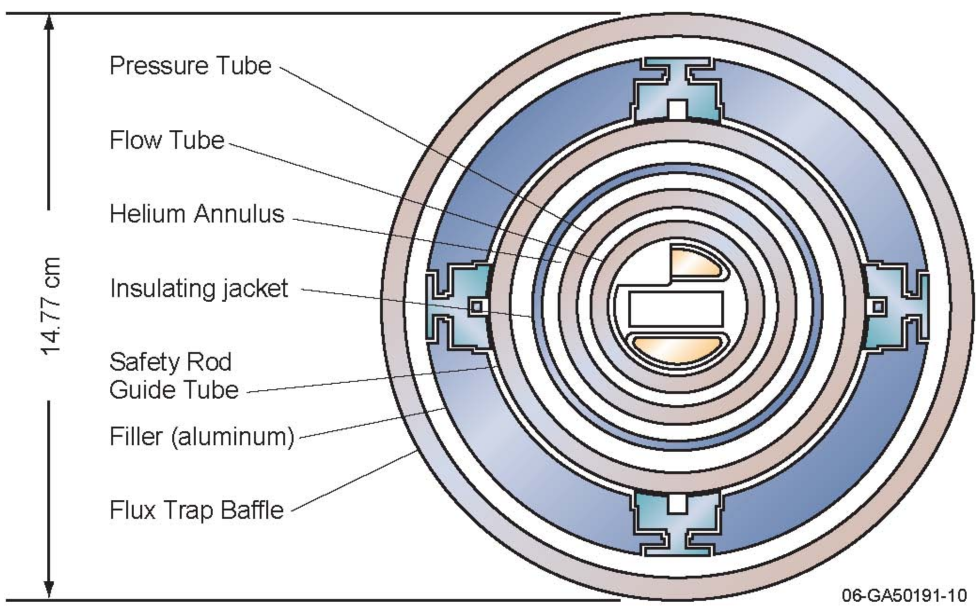

Figure 20. Cross section of the in-core portion of a typical pressurized water loop experiment.

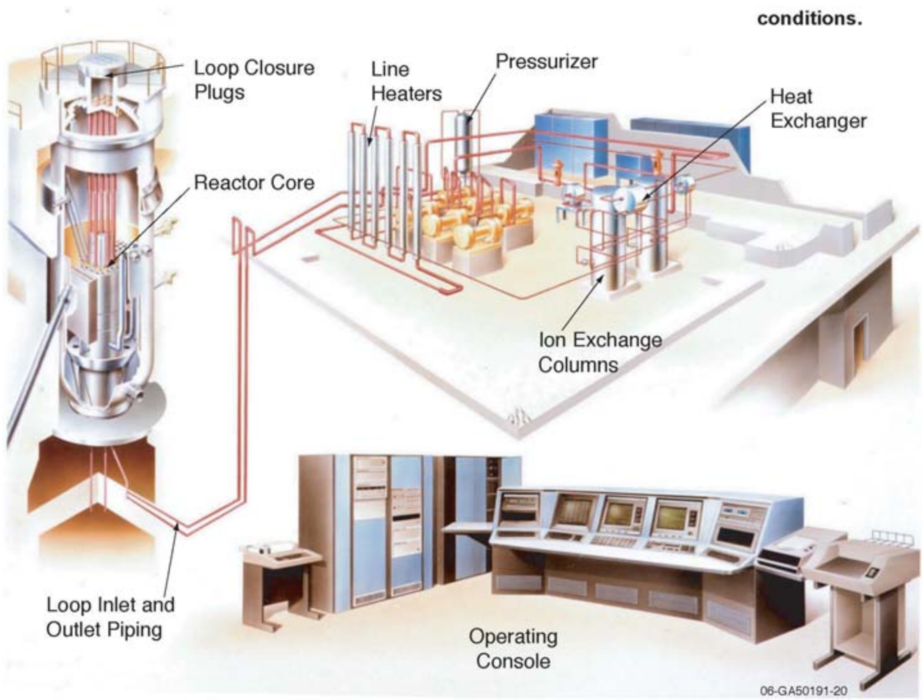

Figure 21. Pressurized water loop experiments provide environmental simulations for many different reactor conditions.

No loop instrumentation or control is duplicated in the reactor control room. However, loop parameters are displayed on the Loop Data Acquisition System located in the reactor control room. Setpoints in the loop circuitry such as loop pump failure, low coolant flow, or high temperatures are capable of causing reactor power reductions or scrams to protect the experiments. When any of these problems occur, trouble lights or annunciators on the panel in the reactor control room light up to indicate which loop is having trouble.

The ATR in-pile tubes can be subjected to high neutron fluxes, and the fluxes can be controlled. An added refinement is the ease of adjusting the neutron energy spectrum. The ability to produce different neutron energy spectra in ATR loops can be valuable.

Another advantage of ATR loops is the ease with which samples can be changed. To remove a sample, it is necessary only to remove a shield plug from the transfer plate, disconnect the lead wires to the sample, unlock the closure plug, install a transfer sleeve, and draw the sample up into a removal cask.

Due to planned use of the pressurized water loop experiment positions, the experiment configuration will not be offer to NSUF users until at least FY 2010.

7.4 Hydraulic Shuttle Irradiation System

The hydraulic shuttle irradiation system (HSIS) will enable insertion and removal of experiment specimens during ATR during operational cycles. The HSIS is installed in the B-7 reflector position, and will have a similar flux profile as a static capsule installed in the same position. The shuttle capsule inner dimensions are 0.495” ID, and 2.07” length, and are titanium. Up to 16 capsules can be used for irradiations simultaneously, although a user does not need to fill all 16 capsules for a test. The maximum allowable weight of each shuttle contents is 27.0 grams. Prior to placing materials in the capsules, the material will need to be evaluated for reactivity to ensure that insertion of the material will be within the

HSIS safety authorization. Some materials have been evaluated and are within the safety authorization in some configurations. INL staff will work with experimenters to ensure that desired test materials are within the safety bases.

8. SUMMARY

The ATR has a variety of experimental options and opportunities provided by the ATR NSUF. The first experiments were offered in FY 2008. Initial experiments were limited to the positions currently available and by the qualified capsules and baskets. In FY 2009, position offerings and experiment configurations have been expanded, and, as resources for qualifying new capsule and basket designs are acquired, a broader variety of experiments will be accommodated in the future.

Prospective experimenters interested in the ATR NSUF may contact Dr. Todd Allen by telephone at 208-569-2566 or by email at allen@engr.wisc.edu. Direct dialog between users and the INL is encouraged at all stages. User suggestions and input will be made available to all interested parties by posting on the ATR NSUF web page https://inlportal.inl.gov/portal/server.pt?open=512&objID=402&mode=2.

All users sponsored by the NSUF program will be required to participate in User Agreements. In general, the results from ATR NSUF experiments will be publicly disclosed unless prior arrangements are made to treat as the proprietary or confidential interest of the user. In this event, a Non-disclosure Agreement between the INL and the user must be executed that clearly indicates which information is covered and how it will be marked. If discussions with INL personnel include any disclosure of such information, it is the responsibility of the user to declare which information is sensitive and obtain acknowledgement of understanding before disclosing.

A call for ATR NSUF proposals is expected to be issued every fiscal year. The proposal solicitation will indicate the type of experiments of greatest interest and will contain the criteria that will be used for bid evaluation.