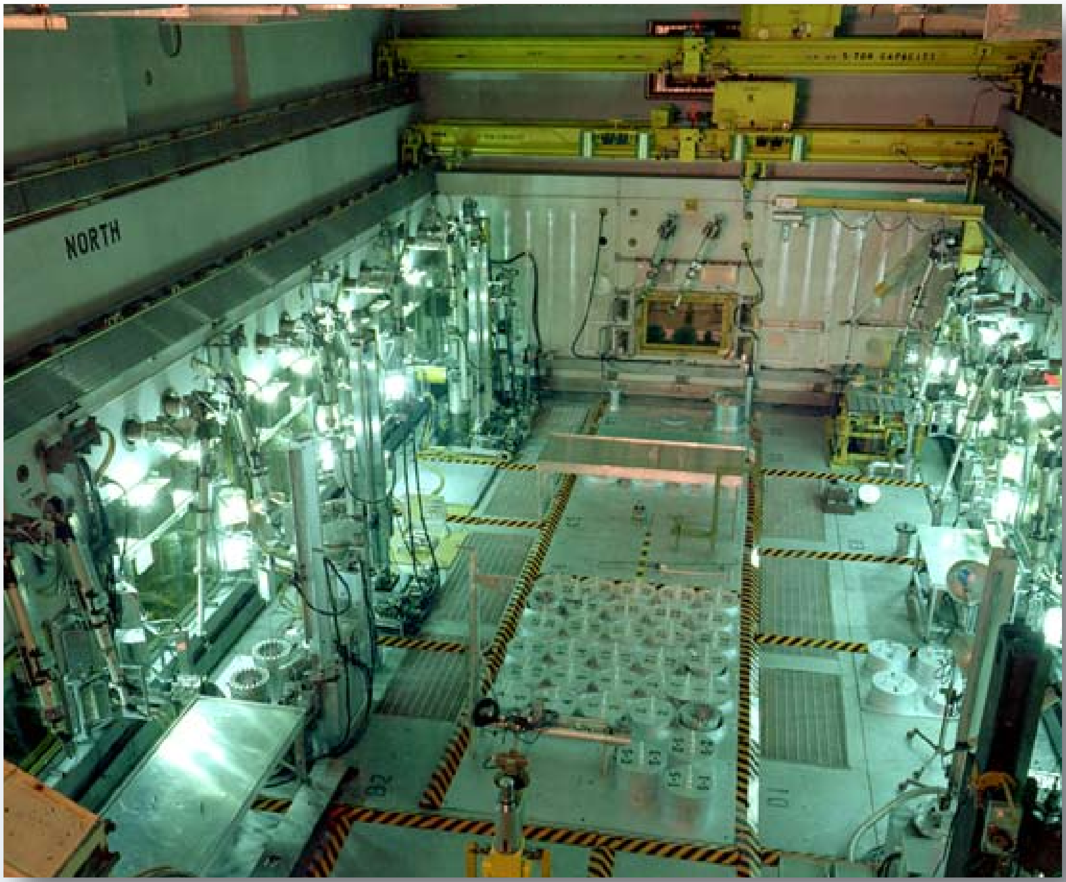

The Hot Fuel Examination Facility Guide

ATR

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INL

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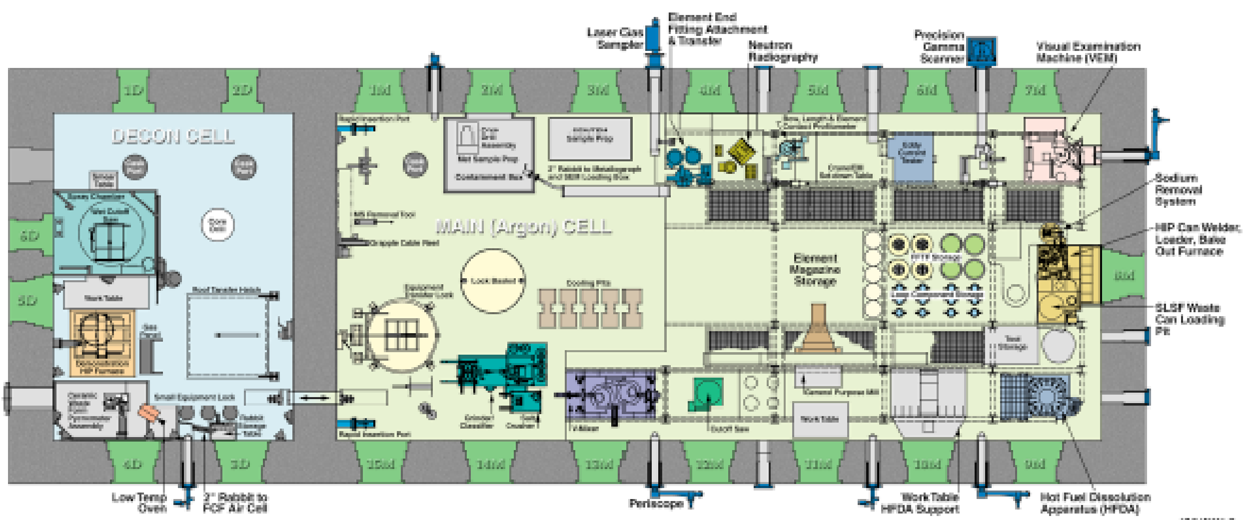
When the U.S. Department of Energy created the Advanced Test Reactor National Scientific User Facility (ATR NSUF) at the Idaho National Laboratory (INL) in April 2007, it provided important new resources to advance the nation's energy security. The designation opened the Hot Fuel Examination Facility (HFEF) to new users – universities, laboratories and industry – for basic and applied nuclear research and development. HFEF makes available to academic, industrial and federal researchers one of the world's outstanding post- and interim-irradiation examination capabilities. ATR NSUF combines these HFEF resources with the materials and fuels irradiation and isotope production capabilities of the ATR, making it the premier facility in the world for scientific investigation of nuclear fuels and materials for nuclear energy systems.

For over 30 years, HFEF has supported liquid metal/fast reactor research and dozens of sponsor organizations, domestic and foreign. Located at the INL Materials and Fuels Complex, HFEF is a large, heavily shielded, alpha-gamma hot cell facility designed for remote examination of highly irradiated fuel and structural materials. Its capabilities include nondestructive (dimensional measurements and neutron radiography) and destructive examination (such as mechanical testing or metallographic/ceramographic characterization). It can accept full-size light water reactor assemblies and fuel elements.

General Description

Operated by Battelle Energy Alliance at the INL, the HFEF comprises two adjacent large, shielded hot cells in a three-story building, as well as a shielded metallographic loading box, an unshielded hot repair area and a waste characterization area. The main cell (argon atmosphere) has 15 workstations, each with a viewing window and a pair of remote manipulators. A decontamination cell (air atmosphere) has six similarly equipped workstations. The cells are equipped with overhead cranes and overhead electromechanical manipulators. Cell exhaust passes through two stages of HEPA filtration. The facility is linked to analytical laboratories and other facilities by pneumatic sample transfer lines.



HFEF Process Areas and Equipment Locations

Major and minor facility upgrades, both completed and in progress, have contributed to the range of unique HFEF capabilities. One upgrade, for example, installed connected alpha glove boxes to support the examination and characterization of materials in hundreds of waste-containing drums to prepare them for disposal at the Waste Isolation Pilot Plant in New Mexico.

Each main cell work station has removable electrical and lighting feed-throughs that can be changed to accommodate the mission of the station. The main cell is equipped with two rapid insertion ports for quick transfer of small tools and items into the cell.

The decontamination cell contains a spray chamber for decontaminating equipment and non-fissile material using a manipulator-held wand. Material handling takes place via a 750-lb electro-mechanical manipulator, a 5-ton crane and six sets of master-slave manipulators.

The hot repair area is available for contact maintenance on cell equipment; it can also be used for transfer of equipment and materials to or from the decontamination cell.

The waste characterization area is used for the intrusive characterization and sampling of contact-handled transuranic waste for the Waste Isolation Pilot Plant performance assessment. It consists of a 16 X 8 X 8 ft. alpha glovebox equipped with shielded viewing windows for personnel protection from low-level gamma and beta-radiation. A data acquisition system housed on an adjoining mezzanine documents the waste handling operations.

HFEF also has a 250 kW Training Research Isotope General Atomics (TRIGA) reactor, for neutron radiography irradiation to examine internal features of fuel elements and assemblies.

Material Transfers

Transfer of radioactive materials from shipping casks to the hot cells generally takes place using the cask tunnel and cart. Large shipping casks greater than 17 ft. long, 56 in. diameter or 30 tons use the Loop Insertion Cell and main cell roof penetration. Small casks weighing less than 5 tons can be transferred through the cart room and hot repair area into the decontamination cell, where it can be unloaded remotely. The maximum weight and dimensions for transferring items through the cask tunnel are as follows.

Maximum Weight and Dimensions for Cask Tunnel Transfers

Large lock	6 ft. diameter X 12 ft. long
Small lock	12 in. wide by 18 in. high by 60 in. long
Two-cask tunnel transfer penetrations	21 $^{9/16}$ in.
Rapid insertion port	3 in. diameter by 18 in. long
Pneumatic transfer line to HP office	Standard carrier (Rabbit) 2 in. diameter X 3.5 in.
Pneumatic transfer line to FCF	Standard carrier (Rabbit) 2 in. diameter X 3.5 in.
Decontamination cell roof hatch	7 ft. square sliding door to hot repair area
Ceiling penetration to hot repair area	6 in.
Sealed roof penetration over 5D	25 in.

Examination Equipment

HFEF was primarily designed as a non-destructive examination facility for cylindrical fuel elements and structural items. The examinations that are performed and available equipment are given below.

HFEF NDE Capabilities

Non-Destructive Examinations	Equipment Used
Neutron radiography	250 kW TRIGA reactor
Element/capsule diameter measurements	Element Contact Profilometer
Element/capsule gas sampling	Gas Assay Sample and Recharge
Element/capsule weight	Element/Capsule Balance (Mettler)
Element/capsule fission and activation product distribution	Precision Gamma Scanning
Element/capsule bowing and length	Bow and Length Machine
Element/capsule visual exam	Visual Exam Machine
Macro photography	High resolution digital photography
High precision specific gravity measurements	Pycnometer

Neutron Radiography

The TRIGA reactor enables neutron-radiography irradiation to verify materials behaviors such as:

- Fuel pellet separations
- Fuel central-void formation
- Pellet cracking
- Evidence of fuel melting
- Material integrity under normal and extreme conditions

Equipped with two beam tubes and two separate radiography stations, the neutron-radiography capability is one of the finest in the world for irradiating small components, a process not possible using conventional x-ray methods. Neutron radiography of elements, capsules and loops is performed in the main cell at workstation 4M. Specimens are placed into a radiograph holder that is lowered into the TRIGA reactor neutron beam located below the floor. The holders optimally position the specimen for radiography without excessive neutron scattering.

Both indium and dysprosium are used as neutron detector foils; these are irradiated in the neutron beam, then transferred to a film cassette and allowed to decay for three to four half-lives against ordinary X-ray film to form the image. The dysprosium foils, used for thermal neutron radiographs of low-enriched fuels and thin structural materials, produce excellent detail, but specimen thickness and fuel enrichment is limited. The indium foils are used for epithermal neutron radiographs of highly enriched fuels and thicker structural materials. These do not show as much specimen detail, but they can be used for thicker specimens and more highly enriched fuel. In many cases, both foils are used to gain an outline of the fuel as well as its internal structure. Other methods, including Polaroid and track-etch radiography, are available for special applications.

A neutron generator (14.3 MeV neutrons at 1.0×10^{11} neutrons/sec) on the north beam tube is available for development of non-destructive assay techniques for fissionable material waste forms.

System Limits for Neutron Radiography

Item	Limit
Maximum specimen length	152 in.
Maximum specimen diameter	6.5 in. (round) or 4.5 X 8.5 in. (rectangular)
Specimen weight	600 lbs

Element Handling and Positioning Equipment

Special equipment is available for handling cylindrical fuel elements and capsules; these minimize the amount of damage that might occur from using manipulators during examination. The system allows handling and examination of magazine loads of up to 20 elements and increases the throughput during the examination process. Use of the element handling equipment also enables safe handling of elements up to 152 in. long.

Element Handling Equipment Parameters and Limits

Parameter	Value
Total vertical travel	139 in.
Fast vertical speed	Variable 18 to 30 in. minimum/maximum
Slow vertical speed	Variable 0 to 6 in. minimum/maximum
Vertical step travel	0.001 in./step
Lift force	3000 lb maximum
Positioning repeatability	+ 0.005 in.

Precision Gamma Scanner

This equipment measures fission and activation-product activity distribution in fuel elements or capsules, providing valuable information about how reactor operation and storage affect components. These measurements can provide data about

- Relative fuel burnup and power profiles of reactor fuels
- Structural activation profile of core components
- Position and dimension of internal structures within fuel assemblies
- Relative distribution of various isotopes of interest in fuel
- Breached elements or capsules

The gamma scanner can be used for scanning large components such as test loops, as well as reactor components and fuel elements. Two types of gamma scans are generally performed:

- Gross gamma scans to determine the distribution of activity over the component’s length or width
- Isotopic gamma scans to determine the isotopic distribution of activity over a component’s length or width.

HFEF has an extensive isotope library that can be expanded to meet a user’s particular needs.

Gamma Scanner Limits

Parameter	Limit
Maximum count rate	86,000 cps
Maximum weight	500 lb
Slit dimensions	0.875-in. long X 0 to 0.099-in wide
Maximum vertical travel	152 in. (nominal)

Element Contact Profilometry

This continuous-contact profilometry gauge measures axial and spiral diameter profiles of elements and capsules. Horizontally opposed linear transducers contact the element as it is pulled vertically through sapphire-tipped probes. Guide rollers positioned above and below the transducers maintain the element vertical with respect to the transducers.

Measurement range is for element diameters between 0.174 in. and 0.840 in., with a maximum diametral swelling of 0.02 in. The swelling range is limited by the linearity of the probes for the size of elements handled. Certified calibration standards for each element size are used for zero, mid-span and full-span calibration. Measurement accuracy through this range is within 3×10^{-4} in. (7.6×10^{-3} mm). Data output of the element profile is in the form of a Microsoft Excel file and paper strip chart, and data are provided on a compact disk.

Gas Assay Sample and Recharge

This equipment provides the ability to puncture cylindrical capsules or fuel elements in their plenum regions to measure free volume and pressure and gather a sample for gas composition and isotopic analyses. After puncturing and measurement, the element may be refilled with any specified gas and rewelded. Although primarily for contamination control rather than in-reactor service, these welds are well characterized and have been tested to 100 psia. Reactor quality welds could be produced with further characterization.

The system is comprised of a 150-W pulsed laser, shielded optical and gas cell-wall feed-through, a mechanical pump, calibrated volumes, gages and controls. Fuel elements or capsules are positioned on the laser by a clamp onto a neoprene gasket. The gasket provides a seal between the element and laser seal head.

Gas Assay Sample and Recharge System Specifications

System Limits and Capabilities	
Parameter	**Limit**
Element diameter range	0.174 to 0.832 in.
Element length range	1 to 152 in.
Cladding thickness	0.010 to .125 in.
Observed accuracy	Better than ± 5% for pressure and volume
Laser	
Type	Neodymium - YAG
Element diameter range	0.174 to 0.832 in.
Maximum energy per pulse	20 Joules
Rated average power	150 W
Pulse repetition rate	1 to 150 pulses per second (pps)
Beam width	0.25 in.
Final lens focal length	4 in.
Minimum spot diameter	~0.005 in.
Pressure and Vacuum Instrumentation	
Sealing head pressure	l 0 to 200 ± 0.1 psia
Manifold pressure	0 to 50 ± 0.01 psia
Manifold vacuum	1 atm to 10 millitorr ± 5 millitorr
Sample line vacuum	1 atm to 10 millitorr ± 5 millitorr
Sample line pressure	0 to 50 ± 0.01 psia

Bow and Length Machine

The element bow and length machine measures the distortion (bow) and actual length of irradiated cylindrical fuel elements and capsules. It can be used to determine fuel element or core component length and bow, as well as the direction of the plane of the bow.

Bow and Length Machine Limits

Item	Limit
Element/Capsule Length	18 to 139 in.
Element/Capsule Diameter	1 in. max
Accuracy of Bow Measurements	0.020 in.
Accuracy of Length Measurements	0.010 in.

Visual Exam Machine

This machine provides a dedicated workstation for performing visual examination on fuel elements, capsules and other irradiated items. It comprises a standard in-cell examination stage and a modified Kollmorgan through-wall shielded periscope, designed for full-surface inspection and photo-documentation of irradiated fuel elements or capsules. Its commercial photographic strobe lights are used exclusively for photography, while built-in halogen modeling lamps are used for both viewing and photography.

The Kollmorgan periscope provides controls for aiming the objective (i.e., pointing the line-of-view), selecting among three magnifications, and focusing the image. The standard (spherical) optics of the periscope have been replaced with special planar optics that maintain the entire surface of a flat object (oriented normal to the optical axis of the system) in focus at the film plane.

Destructive Examination Equipment

HFEF has destructive examination capabilities useful for characterizing spent nuclear fuel and other irradiated materials. The following table lists the destructive examinations and the equipment used to perform the examinations. Brief descriptions of the equipment follow.

HFEF Destructive Exam Capability

Destructive Exams	Equipment Used
Sample cutting and preparation	Containment box in main cell Zone 2M
Mounting samples in metallographic mount	Containment box in main cell Zone 2 M
Fuel sample visual exam and photography	Leitz metallograph in metallographic loading box
Detailed photography of sample	High resolution digital photography
Scanning Electron Microscopy	SEM in metallographic loading box
Microhardness	Leitz metallograph in metallographic loading box
Punch samples TEM sample preparation	Subassembly Hex-Can punch/sample thinning Zones 3M and 2M

- Containment Box

Irradiated fuel, cladding and structural materials are sectioned, mounted into metallographic bases, ground and polished in the containment box located in the HFEF main cell. The containment box has its own argon atmosphere and atmosphere control system to prevent cross contamination with the main cell. The pneumatic transfer system (rabbit) transfers prepared samples to the met loading box for electron or light microscopy

- Metallographic Loading Box, Leitz Metallograph and Amray Scanning Electron Microscope

The Leitz metallograph is located in the metallographic loading box, a shielded containment box with an argon or nitrogen atmosphere and atmosphere control system that allows detailed examination and photomicrographs of irradiated samples. Irradiated samples prepared in the containment box are pneumatically transferred to the box, where they are examined by either the Leitz metallograph or the Scanning Electron Microscope. The remotely operated Leitz metallograph is used to perform microscopic examination, photography and microhardness testing on metallographic samples. It is equipped with a Vickers-type diamond indenter hardness tester, a projection screen and both low-voltage tungsten and xenon lights.

Leitz Metallograph Limits

Item	Limits
Magnification range of microscope	20X to 800X
Hardness tester magnification	400X
Minimum hardness tester weight	5 gm
Maximum hardness tester weight	400 gm

- Shielded Scanning Electron Microscope

The shielded Amray 1200-B microscope provides the ability to examine materials for fractures, wear surfaces, or other conditions. Both radioactive and non-radioactive materials can be examined with this unit. Its magnification range is 15X to 30,000X, and the specimen size limit is 1.5 in. by 1.5 in.

- Transmission Electron Microscopy Sample Preparation Equipment

A special device has been designed to obtain samples of metallic components less than 80 mils thick for characterization such as immersion density, microscopy or chemical analysis. The device can be used on any thin-walled metallic component as long as it is flat enough to fit under the punch assembly. The unit is portable and it can be moved to different locations in cell as needed.

Upgrades and Enhancements

Looking to the future, the state-of-the-art post-irradiation examination capabilities at HFEF will continue to play a vital role in nuclear energy development. The INL is pursuing the following updates or replacements in the near term:

- Shielded Electron Microprobe

Designed to assess fission product distribution in irradiated fuels, this new instrument performs micro-structural and micro-chemical analysis of fresh and irradiated fuels and waste forms. As a specialized scanning electron microscope, it can also analyze localized micron-scale chemical composition data of irradiated fuels and materials.

- Thermal Ionization Mass Spectrometer

Replacing an existing instrument that has reached the end of its operational life, this instrument will perform elemental assay and isotopic composition on plutonium, uranium and minor actinides prepared from fresh and irradiated fuels.

- Focused Ion Beam Instrument

This new instrument has the ability to analyze the three-dimensional structure and chemistry of materials on a submicron scale. The goal is to characterize irradiated nuclear fuels to detect submicron-level damage, which would make the INL instrument unique in the world. A better understanding of this process has significant potential to improve in-reactor fuels and materials performance.

- Micro-scale X-Ray Diffractometer

The purpose of this device, which performs micro-scale phase identification, small-sample powder diffraction and texture determination, is to track the evolution of fuel structure during irradiation.

- Modifications to AL Rooms B-50/51

Extensive modifications will increase room size, enhance the HVAC system, add electrical interfaces to support new instruments, and install a high-mass, vibration-isolated floor to maximize the resolution at which instruments operate.

- Mechanical Test Equipment and Sample Preparation Equipment

Funded by Battelle Energy Alliance, these upgrades include new mechanical test and sample preparation equipment in the HFEF hot cells – specifically a mechanical test load frame, power supply and an out-of-cell control console as well as sample cutting and preparation tools.

- TN-FSV Cask NRC License Modification

This work comprises modifying the Certificate of Compliance for the TN-FSV transportation cask to include payloads important to the mission of INL fuels research and reactor development. Also funded by Battelle Energy Alliance, the scope includes fabrication of a new inner-shielded cask insert.