

Construction of a Post-Irradiated Fuel Examination Shielded Enclosure Facility

2008 EFCOG Safety Analysis Working Group

Boyd D. Christensen
Michael A. Lehto

May 2008

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U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance



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Boyd D. Christensen
Battelle Energy Alliance, Idaho National Laboratory
P.O. Box 1625
Scoville, Idaho 83415-6110
208-533-7914/208-533-7239(fax)
boyd.christensen@inl.gov

Michael A. Lehto
Battelle Energy Alliance, Idaho National Laboratory
P.O. Box 1625
Scoville, Idaho 83415-6110
208-533-7295/208-533-7239(fax)
michael.lehto@inl.gov

Abstract

The U.S. Department of Energy (DOE) has committed to provide funding to the Idaho National Laboratory (INL) for new post-irradiation examination (PIE) equipment in support of advanced fuels development. This equipment will allow researchers at the INL to accurately characterize the behavior of experimental test fuels after they are removed from an experimental reactor also located at the INL. The accurate and detailed characterization of the fuel from the reactor, when used in conjunction with computer modeling, will allow DOE to more quickly understand the behavior of the fuel and to guide further development activities consistent with the missions of the INL and DOE.

Due to the highly radioactive nature of the specimen samples that will be prepared and analyzed by the PIE equipment, shielded enclosures are required. The shielded cells will be located in the existing Analytical Laboratory (AL) basement (Rooms B-50 and B-51) at the INL Material and Fuels Complex (MFC).

AL Rooms B-50 and B-51 will be modified to establish an area where sample containment and shielding will be provided for the analysis of radioactive fuels and materials while providing adequate protection for personnel and the environment. The area is comprised of three separate shielded cells for PIE instrumentation. Each cell contains an atmosphere interface enclosure (AIE) for contamination containment. The shielding will provide a work area consistent with the as-low-as-reasonably-achievable (ALARA) concept, assuming a source term of 10 samples in each of the three shielded areas. Source strength is assumed to be a maximum of 3 Ci at 0.75 MeV gamma for each sample. Each instrument listed below will be installed in an individual shielded enclosure:

Shielded electron probe micro-analyzer (EPMA)

Focused ion beam instrument (FIB)

Micro-scale x-ray diffractometer (MXRD).

The project is designed and expected to be built incrementally as funds are allocated. The initial phase will be to fund the construction activities, which will include facility modifications and construction of one shielded enclosure. Follow-up activities will be to construct two additional shielded enclosures to complete the suite of three separate but connected remote-operated examination areas. Equipment purchases are to be capital procurement spread out over several years on a funded schedule.

This paper discusses safety and operational considerations given during the conceptual design phase of the project. The paper considers such things as project material at risk (MAR), new processes and equipment, potential hazards, and the major modification evaluation process to determine if a preliminary Documented Safety Analysis (PDSA) is required. As part of that process, an evaluation was made of the potential hazards with the new project compared to the existing and historical work and associated hazards in the affected facility.

1. INL/MFC Background

The INL is a government-owned reservation located in southeastern Idaho (see Figure 1), approximately 25 miles west of Idaho Falls, Idaho. The INL was first established in 1949 as the National Reactor Testing Station (NTS) used for a construction and testing area for various experimental and research reactor programs, reactor fuels, structural components, materials, and reactor safety programs. The INL site covers an area of approximately 890 mi². The INL is currently operated by Battelle Energy Alliance, LLC (BEA) under a 10-year contract with DOE. Current missions of the INL include developing nuclear reactor technologies and supporting national security programs, advanced fuel development, spent fuel treatment, and other science and technology programs.



Figure 1. Location of the INL Site.

MFC is the easternmost facility located on the INL. Formerly known as Argonne National Laboratory –West and operated by the University of Chicago, the MFC site covers an area of approximately 890 acres. Construction of the MFC site began in the mid-1950s with the Experimental Breeder Reactor-II (EBR-II) and support facilities, following the successful

demonstration of the EBR-I reactor which is also located on the INL reserve. The EBR-II program, which is no longer in operation, was developed for research and development of liquid metal fast breeder reactor technology. Facilities currently operated at MFC include the following:

- The Fuel Cycle Facility (FCF) is adjacent to the EBR-II facility. During EBR-II operations, this inert atmosphere hot cell facility was used as a support facility for subassembly dismantling, as well as fuel reprocessing and fuel pin casting for return to the reactor. The current mission of FCF is to process and stabilize blanket fuel from reactor programs.
- The Hot Fuel Examination Facility (HFEF) is an inert atmosphere hot cell facility. HFEF was constructed to support irradiated fuel and hardware examination programs for EBR-II and other DOE complex-wide projects. The Neutron Radiography Reactor (NRAD) is a 250 KW Training, Research, and Isotope, General Atomics (TRIGA) reactor located within HFEF. HFEF is also the home of the Waste Isolation Pilot Program (WIPP) verification project for performing visual examination of contact handled transuranic waste being shipped to the New Mexico WIPP repository.
- The Transient Reactor Test Facility (TREAT) located one mile west of the main MFC compound, is an air-cooled uranium-oxide reactor, which was used in reactor fuels and materials safety experiments using short, controlled bursts of high power nuclear energy. TREAT is currently maintained in standby pending further project identification.
- The Zero Power Physics Reactor (ZPPR) is currently in non-operational standby status. This reactor was designed for studying the properties of liquid-metal reactor cores at low power. When operational, experimental cores were built in ZPPR by hand-loading plates of reactor material into drawers. These reactor materials include uranium, plutonium, sodium, and stainless steel.
- The Laboratory and Office (L&O) Building consists of small hot cells, gloveboxes, waste-form-development equipment, and general-purpose chemistry laboratories. The AL is located within the L&O. The mission of the AL is to provide chemical, radiochemical, and physical measurements in support of MFC and INL nuclear and environmental programs.
- The Fuel Manufacturing Facility (FMF) was constructed in 1986 to house fuel manufacturing operations in support of EBR-II. Since the shut down of EBR-II, FMF has been converted to a multiuse research and development (R&D) facility.
- The Space and Security Power Source Facility (SSPSF) provides the capability for assembly and acceptance testing of radioisotope power systems (RPS) to be used in National Aeronautics and Space Administration (NASA) deep space missions and other security applications relying on an integral, secure, and long term power source.

- The Radioactive Liquid Waste Treatment Facility (RLWTF) processes low-level radioactive liquid waste generated at MFC. The facilities supported by RLWTF are EBR-II, HFEF, TREAT, ZPPR, FCF, and the AL. RLWTF is capable of evaporating approximately 227,000 L (60,000 gal) of radioactive liquid annually; the resulting residue is low-level radioactive solid waste which is packaged and stored in an environmentally acceptable form for interim-storage or shallow-land burial.

Figure 2 is an aerial view showing the major MFC facilities discussed above.



Figure 2. MFC Major Facilities.

The irradiated fuel examination shielded enclosures discussed in this paper will be built in the lower level of the AL. The project consists of receiving small samples of irradiated fuel prepared in another MFC hot-cell facility. The samples will be transported into the shielded enclosures via a pneumatic transfer system.

2. Analytical Laboratory Facility Description

Facility Description

The AL occupies the main floor of the north wings (A- & B-wings) of the Laboratory & Office (L&O) Building 752 and includes the Nondestructive Analysis (NDA) Laboratory located at the east end of the B-wing. The AL also includes two counting rooms and a storage room in the B-wing basement, in addition to the ventilation exhaust filter areas in the A- and B-wings of the basement. The AL complex consists of the following:

A-wing

- Six shielded hot cells and attached gloveboxes
- A decontamination and manipulator repair room
- Two storage vaults
- One general chemistry/instrumental laboratory
- Gloveboxes and analytical instruments

B-wing

- Eight general chemistry laboratories
- Analytical glovebox laboratories
- Mass spectrometry laboratories
- Three counting rooms, two located in the basement
- One chemical storage room
- One experimental fuel casting laboratory
- An NDA laboratory
- Basement utility area including B-50/51.

The L&O Building also contains a number of tenant activities including major office areas, a cafeteria, and a library, none of which contain radioactive or extremely hazardous substances.

The AL contains both chemical and radiological hazards with the potential for localized consequences. The hazardous materials are contained in the hot cells, gloveboxes, or hoods. Hazardous chemicals are stored in the chemical storage room. It is the potential release of these materials that constitutes the potential hazard to workers. Based on analysis consistent with the classification methodology of DOE-STD-1027-92,¹ the AL is categorized as a Hazard Category (HC) 3 facility. Due to the limited amounts of fissionable material allowed in each zone in the AL, a criticality accident in the AL is considered an incredible event according to the AL SAR.²

Facility Background

The AL was built in the late 1950s and was operational in the early 1960s. The work initially performed in the hot cells supported the recycle of EBR-II fuel during the late 1960s. The hot cells underwent functional and safety upgrades in 1993 and 1994.

The historic function of the AL has been to provide

- Chemical, radiochemical, and physical measurements
- Nondestructive assay measurements
- Engineering development activities, such as preparation of irradiation samples, all in support of nuclear and environmental programs at MFC.

As a result of its capabilities, the AL receives a variety of analytical samples from various INL facilities and from contractors outside of the MFC and INL. These samples are the source of data for research and development, nuclear accountability, radiation control, routine process control, and environmental monitoring.

One activity of the AL has been the performance of chemical analyses and experiments on analytical samples of highly irradiated nuclear fuels and materials. The safe and efficient performance of this activity requires this work to be carried out in the AL hot cells.

Another activity at the AL was the destructive and nondestructive analysis of analytical samples of irradiated and reprocessed uranium fuel, fission products, and miscellaneous reprocessing samples as part of the Fuel Cycle Demonstration projects. Following completion of the Fuel Cycle Demonstration, the AL hot cells supported a surveillance program that required analysis of EBR-II driver fuel and blanket samples. The unique capabilities of the hot cells made the facility useful for the analysis of other reactor fuels such as mixed oxides (UO₂-PuO₂). The analysis of surveillance samples and experimental reactor fuels continued through the 1970s and 1980s. During this time period, analytical samples from reactors such as the General Electric Test Reactor and the Shippingport Nuclear Power Station were handled and analyzed. In the late 1980s, analytical samples cut from Integral Fast Reactor subassemblies were analyzed. These samples included both the binary U-10Zr and the ternary U-Pu-Zr alloys. During this time period, analytical samples from a small fuel electrorefiner, operated at the HFEF, were handled and analyzed. This small electrorefiner produced analytical samples identical to samples expected from the large electrorefiner during the processing or conditioning of spent nuclear fuel. These samples included electrorefiner salt, cadmium, and cathode deposits.

In summary, historical analytical samples processed in the AL contained:

- Fertile, fissionable, and fissile material
- Fission and activation products
- A variety of nuclear reactor fuels.

3. Proposed Project Description

The proposed activity being developed is to modify AL rooms B-50/51 into a shielded suite laboratory to be used for additional examination and analysis of irradiated experimental fuel samples from the advanced fuel cycle initiative (AFCI) program. The project is funded by the DOE Office of Nuclear Energy, Science and Technology to support the primary mission of the INL in developing fuels and materials for a new generation of commercial nuclear power plants.

The AFCI is a multi-laboratory collaborative research and development effort supporting an advanced nuclear fuel cycle concept expected to provide transition from the current once-through fuel cycle used in commercial nuclear power reactors to concepts consistent with the advanced reactor programs being developed. The AFCI is considered essential to reestablishing viability in commercial nuclear power production by addressing several major industry issues. The program seeks to reduce the generation of and management costs of high level nuclear

waste, delay the need for a second geologic waste repository, and reducing proliferation concerns by recovering useable fissile material from spent nuclear fuel. The technology being developed with the AFCI will enable long term growth of the nuclear power industry by removing technical barriers, resulting in an increased national energy security position.

The INL has been designated by the DOE as the focal point of nuclear energy research and development and is expected to take a lead role in this fuel cycle development. Existing facilities together with new modifications will be combined with new facilities to provide the needed capabilities.

As envisioned, experimental fuel types prepared in the MFC Fuel Manufacturing Facility will be irradiated for a period of time in the Advanced Test Reactor (ATR) at the INL Reactor Test Complex (RTC). After the predetermined irradiation, the fuel will be removed from the reactor experiment port and transported via shielded cask to the MFC HFEF. After initial examination in the HFEF hot cells, a sub-sample may be prepared and transported by an existing pneumatic transfer system to the AL where it will be loaded into one of the shielded enclosures discussed in this paper. Once in the shielded enclosure, the samples will be analyzed using sensitive analytical equipment. Results of these analyses are important in the development of the new reactor programs. Research aspects of particular interest are; fuel types and efficiencies, fuel and cladding performance, fuel burnup rates, and transmutation of actinides.

4. Project Requirements for the AL

DOE has committed to provide funding to the INL for new PIE equipment in support of advanced fuels development. This equipment will allow researchers at the INL to accurately characterize the behavior of experimental test fuels after they are removed from a reactor. The accurate and detailed characterization of the fuel from the reactor, when used in conjunction with computer modeling, will allow DOE to more quickly understand the behavior of the fuel and to guide further development activities consistent with the missions of the INL.

Due to the highly radioactive nature of the specimen samples which will be prepared and analyzed by the PIE equipment, shielded enclosures are required. The shielded enclosures will be located in the existing AL basement (Rooms B-50 and B-51) at the INL MFC.

AL Rooms B-50 and B-51 will be modified to establish an area where sample containment and shielding will be provided for the analysis of radioactive fuels and materials while providing adequate protection for personnel and the environment. The area is comprised of three separate shielded enclosures for PIE instrumentation. Each enclosure contains an AIE for contamination containment. The shielding will provide a work area consistent with the ALARA concept assuming a source term of 10 samples in each of the three shielded areas. Source strength is assumed to be a maximum of 3 Ci at 0.75 MeV gamma. Each instrument listed below will be installed in an individual shielded enclosure:

- Shielded electron probe microanalyzer (EPMA)
- Focused ion beam instrument (FIB)
- Micro-scale x-ray diffractometer (MXRD).

The following lists relevant project assumptions used in developing the conceptual design for the facility modifications:

- Modifications to the existing facility to support shielded cell installation do not significantly impact other facility operations.
- In-cell fire protection is not required at this stage of design.
- Existing power supply to the facility has sufficient capacity to meet the added load demands of the new PIE and supporting equipment.
- All three PIE instruments noted above will require their own separate concrete pad(s) for vibration isolation from the AL basement floor.
- The pneumatic transfer system components are identical to the existing system, and the proposed transfer system to the B-50/51 area is based on the existing transfer system from HFEF to AL.
- The new equipment and operating personnel will not have a need for water in the modified B-50/51 area (i.e., eye wash, safety shower).
- The existing NDA addition of the AL facility is equivalent to a seismic performance category (PC)-2 based on a qualitative technical evaluation performed on the AL.³ The modifications to the facility will also be designed and constructed to meet this performance category to provide flexibility in locating future missions in this area.
- Shielding performance requirement for normally occupied areas and at the operating gallery is <0.5 mrem/hr, measured at 15-20 cm. This includes the AL main floor above B-50/51.
- Shielding performance requirement for areas entered occasionally by trained radiation workers in accordance with a Radiation Work Permit is <5 mrem/hr, measured at 15-20 cm.
- The shielding analysis assumes a point source since sample dimensions are not known at this time but are believed to be small, resembling a point source.
- Samples are received in sealed containers free of external smearable contamination; alpha contamination is limited to small confinement boxes.
- Samples are received via a rabbit system (pneumatic sample transfer) from HFEF or AL in clean, sealed containers.
- The shielded enclosures will remain relatively free of contamination and accessible to personnel for routine maintenance without interrupting work in adjacent cells. This also assumes that samples will be transferred out of the enclosures prior to entry.
- The shielded suite ventilation system will interface with the existing ventilation system. The existing system may require resizing or modification for new high-efficiency particulate air (HEPA) filter housing, air sampler, fans, motors, and temperature/pressure control systems.
- Ventilation systems are designed for particulate constituents, and gas ventilation is not fully defined at this stage.
- The size of the AIE is based on master/slave manipulator Central Research Laboratories (CRL) model G-LD.

The project is designed and expected to be built incrementally as funds are allocated. The initial phase will be to fund the construction activities, which will include facility modifications and construction of one shielded enclosure. Total cost for this phase is estimated at \$2.7 M. Follow-up activities will be to construct two additional shielded enclosures for an estimated \$900 K each. Equipment purchases are to be capital procurement costs and are not included in the above estimates.

Facility Modifications

In order to install the PIE equipment and associated support equipment, various existing electrical and mechanical utilities and services require relocation. Additionally, structural modifications will be required to accommodate and operate the equipment.

The first structural modification required is the partial removal of a 10-in.-thick concrete, load bearing wall which supports the AL main floor above the PIE area. An existing door cutout will be moved and a new door cutout will be provided to allow access to the shielded enclosures. Calculations supporting this modification are provided as Appendix D to the conceptual design report (CDR).⁴

The second structural modification is the removal of the floor area, where the enclosures and equipment will be located, and the installation of enclosure wall support footings and a vibration isolation pad for each enclosure. The combined weight of the enclosures, including shielding, will exceed the allowable floor loading in the B-50/51 area with the cut outs for the vibration isolation pads. Thus new footings and stem walls are required to adequately support the walls and roof.

Area Layout

An operating gallery is located on the enclosure front side. This is typically where normal operations will be conducted. The operating gallery will house the analytical equipment controls and displays as well as desks and chairs to support equipment operation. The planned gallery is approximately 8 ft wide from cell face to facility wall and will extend from the north facility wall to the support equipment room wall on the south. Figures 3 and 4 illustrate the existing and anticipated facility layout of the area.

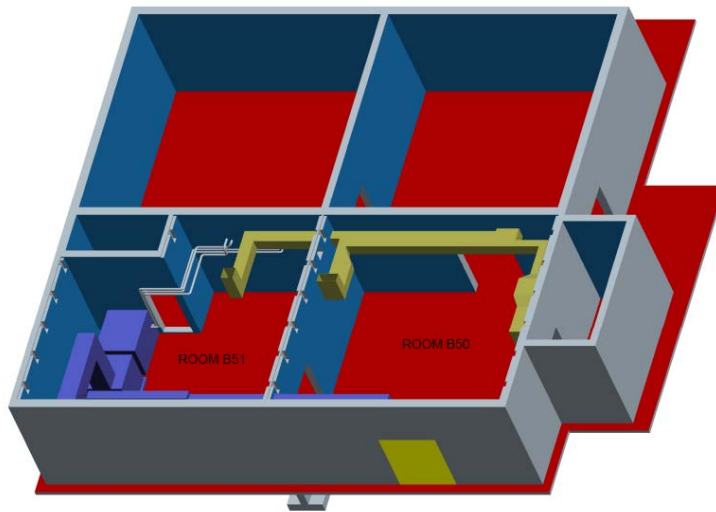


Figure 3. Existing facility structure.

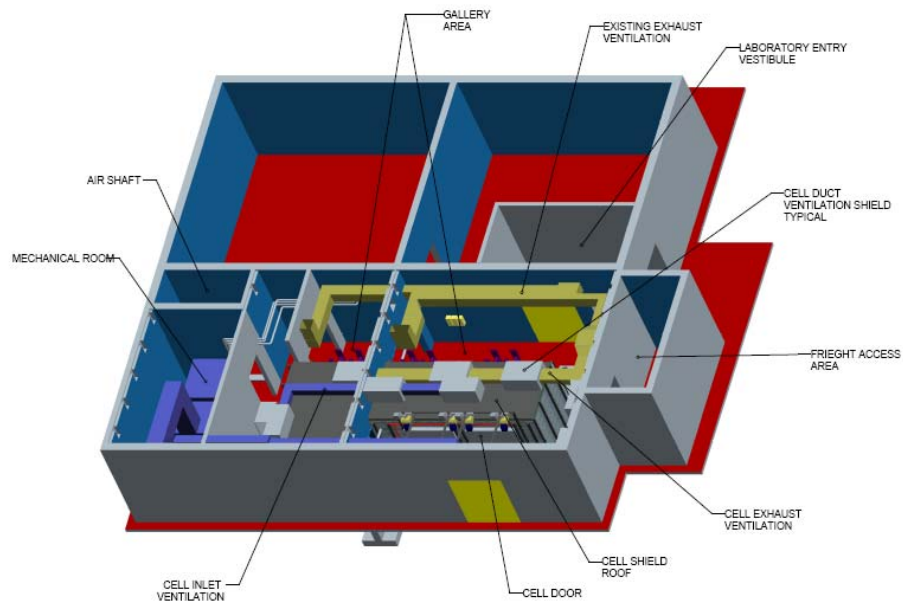


Figure 4. Facility Concept Model.

All cell walls are planned to be modular and configured as 1/2-in.-steel hot-side liner, lead, and 1/2-in.-steel cold-side cover. The manipulator wall configuration is slightly different from the others, providing a steel manipulator interface and containing windows as well as the manipulators.

The windows planned for use in the shielded enclosures are an assembly of selected panes from windows that were excessed by the Naval Reactors Facility (NRF). A typical shielded window consists of several panes of leaded shielding glass sandwiched between a cold-side and hot-side borosilicate glass pane. The window thickness is approximately 13.4 in. and was based on a shielding evaluation for the anticipated PIE fuel samples. The windows will extend out of the cold-side wall by as much as 4 to 5 in. due to the less efficient shielding of the leaded glass and the additional hot- and cold-side covers.

A pair of CRL model G-LD manipulators will be installed at the operating face of each of the cells. These manipulators are designed for gloveboxes and small volume work stations. Sufficient clearance will be provided to remove the manipulators into the operating gallery for repair and maintenance as needed.

The enclosure roof is supported by the shield wall structure. The roof design utilizes inverted T-style structural steel tied with 1/4-in. steel plates. Lead bricks are placed between the T-legs, which are covered on top with steel plates enclosing the lead.

The enclosure door structure consists of the same steel/lead/steel configuration as the walls. The lead thickness will be 4 in., which meets the applicable performance requirements of <5 mrem/hr for occasionally occupied areas.

Other support structures include an inert AIE box (with a gas purification system), pneumatic transfer system (PTS) rabbit, and inter-cell transfer system (ICTS). Each of these systems will be consistent in form and function with industry and existing MFC systems to the extent possible under this modification.

Shielding Design

Shielding calculations were performed using Monte Carlo N-Particle Transport Code (MCNP) for the manipulator wall, end walls, back walls and doors, inter-cell walls, roof, and windows. The design basis for the shielding is a source term of 3 Ci of 0.75 MeV photons per sample. A total of 10 samples may be present in each of the enclosures. In addition, the required minimum allowable dose rates for the analysis, based on the 30 Ci of 0.75 MeV photons, is <0.5 mrem/hr in the operating gallery area in front of the manipulator wall and <5.0 mrem/hr in the areas on the enclosure exterior sides as well as the maintenance area at the rear of the cells. The roof is designed such that the maximum dose from anywhere within the AL through the roof is <0.5 mrem/hr.

These calculations are made on very preliminary designs and conservative, enveloping source term concepts. As the design progresses, program refinements may emerge which could change the basis or assumptions on which the current design was made.

Dose rate calculations and performance requirements resulted in a manipulator wall and roof configuration of 1/2-in.-carbon steel hot-side-liner, 8 in. of lead (bricks), and 1/2-in.-carbon steel cold-side cover.

The end wall, back wall, and door configuration is 1/2-in.-carbon steel hot-side liner, 4 in. lead, and 1/2-in.-carbon steel cold-side cover. The modeled resultant dose rate from this configuration is 0.91 mrem/hr, meeting the performance requirement of <5 mrem/hr.

Window configuration consists of a 9.25-in.-thick pane, a 2.75-in.-plate, and 0.60- and 0.75-in.-borosilicate hot- and cold-side cover plates for a total thickness of approximately 13.4 in. The resultant calculated dose rate is 0.40 mrem/hr, which meets the applicable performance requirement of <0.5 mrem/hr.

Ventilation

Enclosure ventilation is provided by the following modifications to the existing facility ventilation system:

- A new duct branches off the inlet system and routes to the three work enclosures
- An outlet duct routes from the three work enclosures to merge with the existing outlet system
- An extension is added to the existing outlet system.

These modifications also include replacement of the existing HEPA filter and housing located at the north end of the modified area. The inlet and outlet ventilation ducts are equipped with a HEPA filter and an automated louver with motor where the work enclosures are breached. The HEPA filters assure contamination control, and the louvers/motor assemblies control the pressure in the enclosures. In addition, this air flow control system will maintain enclosure temperatures and humidity according to the in-cell equipment operating requirements.

5. Analytical Process Equipment

Focused Ion Beam Detector (FIB)

The FIB system is a dual beam characterization instrument used to image and characterize the composition of solid materials, as well as perform nano-machining of samples to prepare them for further analysis. The first beam is an electron beam, enabling the instrument to function as a scanning electron microscope. The second beam is an ion beam, enabling the instrument to perform nano-machining of samples. The instrument consists of a 1 ft³ vacuum chamber surrounded by sensors for imaging and material characterization. The sample is housed in the vacuum chamber during operation. The sample enters and exits through an air-lock on the side of the vacuum chamber. The FIB instrument is remotely operated from computer consoles once the sample is loaded into the vacuum chamber.

Prior to characterization, the sample is handled in the inert AIE, which will contain any contamination that may be present on the samples. Tele-manipulators will be used for handling samples in the confinement box.

Imaging is performed using a Schottky Field Emitter, which produces a beam of electrons that interact with the sample on a very small scale. Depth of penetration of the beam into the sample depends on the material and the electron energy but is generally less than 100 nm. Interaction of the electrons with the sample material results in the production of backscattered electrons, secondary electrons, and characteristic x-rays. Detectors are situated around the FIB to detect the signals and allow for interrogation of the sample. Backscattered and secondary electron signals are used primarily for image analysis. Spectrometry of excitation-released gamma rays is analyzed to determine elemental composition of the sample.

The ion beam can also be used to locally remove or mill away material from the sample. This is accomplished by sputtering atoms from the sample because of the large mass collision of the ion collision compared to an electron impact.

Electron Probe Micro-analyzer (EPMA)

The EPMA is an instrument used to quantitatively measure the composition of solid materials from elements with an atomic number as low as 4 (Be). The application of current to a filament (typically tungsten) produces a beam of electrons which interact with the sample on a small scale, typically a circle 1 to 300 μm in diameter. Depth of penetration of the beam into the sample depends on the material but is generally around 1 μm . Interaction of the electrons with the material results in the production of backscattered electrons, secondary electrons, and characteristic x-rays. Detectors are situated around the EPMA to detect these signals and allow for interrogation of the sample. Backscattered and secondary electron signals are used primarily for image analysis. X-rays pass through crystals of varying d-spacing, which allows for discrimination of specific wavelengths from the x-ray continuum. These are processed by a gas proportional detector and a matrix correction algorithm, allowing for quantitative chemical analysis of the material.

Sample material can be either solid or particulate but must undergo a specific preparation procedure to use the EPMA's analytical capabilities. For a typical sample holder, the volume of the sample is limited to about 11 cm^3 . Samples must be cut to size to fit, must be polished to a 1 μm finish, and must be coated if they are not conductive. Often samples (both solids and particulate) are mounted in a metallographic mount (a hollow cylinder or ring) with epoxy, exposed to a vacuum to outgas the sample, and then polished and coated. This allows for samples far smaller than 11 cm^3 to be appropriately mounted in the sample holder so that the sample top is flat and parallel to the top of the sample holder. In addition, particulate samples prepared in this fashion become fixed in epoxy and are far safer to handle.

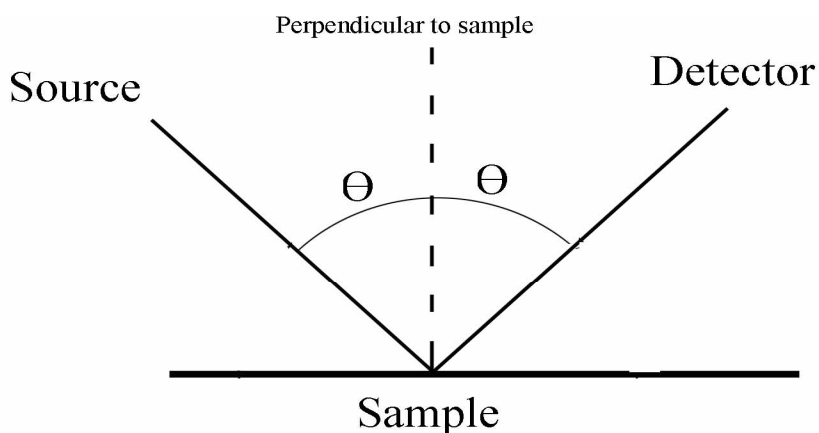
In the case of radioactive samples, it is unlikely that it will be feasible to handle an 11 cm^3 sample, the largest size physically possible. A radioactive sample with an activity of 100 Ci/g and density of 12g/ cm^3 will need to be reduced in size to about 2.2 mm^3 to remain below the 3 Ci limitation for shielding in the Cameca shielded EPMA. This type of sample will be mounted in a metallographic mount with epoxy, polished, and coated as described above.

Once the sample is prepared, the sample is placed into a sample holder. The sample must then be grounded to the sample holder by the addition of conductive paint (graphite or silver paint in an isopropanol suspension), or by anchoring the sample to the holder with conductive

tape. The sample holder is then put onto the EPMA sample shuttle. The shuttle is a device that carries the sample to the interior of the EPMA chamber. The shuttle is then placed into the sample introduction chamber of the EPMA. After closing the door to the chamber, the vacuum is activated. When sufficient vacuum has been achieved in the sample introduction chamber, the gate valve is opened, and the shuttle is pushed into the instrument via a metal hook on the end of an extension pole that attaches to the shuttle and extends through the sample introduction door. Once the sample is in the instrument, the extension pole is retracted back through the door and the gate valve is closed. Analysis of the sample then proceeds with the sample under vacuum in the EPMA. Removal of the sample is accomplished by reversing the steps taken to introduce the sample into the instrument. The sample is chemically and radiologically unchanged by the examination process.

Micro-scale X-ray Diffractometer (MXRD)

The MXRD generates x-rays at a source, directs them into a sample, and uses a detector to measure the intensity of the x-rays diffracted by the sample as a function of the angular relationship between the source and the detector (2θ). In a theta-theta diffractometer, the source and detector both change angles, and the sample doesn't.



The MXRD is expected to use two kinds of samples: powders and solids. When dealing with nonradioactive samples, powders are typically either glued to some kind of surface or contained in a depression in a thicker sample holder. Powders contained in depressions may be covered by x-ray transparent covers.

X-ray diffractometers come in two basic geometries: horizontal, in which the sample is held horizontal, and the source and detector move in a vertical plane; and vertical, in which the sample is held on a vertical plane (on its side relative to the picture above), and the source and detector move in a horizontal plane.

MXRDs follow the description above but have specialized design features that allow them to produce a very finely focused beam and position it on the sample.

6. Hazard Considerations

The AFCI post irradiation fuel examination project involves structural and utility service modifications in the B-50/51 area of the AL and constructing a shielded enclosure complex, which will then be used to receive fuel sample metallographic mounts to be analyzed using instruments which will allow researchers to accurately characterize the behavior of experimental test fuels after they are removed from a reactor. The characterization will be used in conjunction with computer modeling to quickly understand the behavior of fuel for reactor development programs.

Material at Risk

The material at risk (MAR) for this project is irradiated fuel samples, which will be received into the facility via the rabbit transfer system. The sample holder and the shielded enclosure provide a measure of confinement as a primary margin of safety. Due to the radiosensitivity of the characterization instruments, the inventory in any of the shielded cells is limited. Manufacturer recommendations are that a sample not exceed 3 Ci of 0.750 MeV gamma emitting isotopes. An operational decision to allow up to 10 samples per cell to provide program flexibility gives a total inventory of 90 Ci in the entire shielded suite area. Given the experimental nature of the AFCI fuel to be evaluated, a precise isotopic breakdown is not practical. However, it is established that the fuel composition will consist of uranium and plutonium with the associated transmutation products, such as americium and neptunium isotopes. Since the fuel will be resident in a reactor environment for some amount of time, fission products will also be present in the samples. Current AL programs involve similar samples consisting of fuel, transmutation, activation, and fission products. Of the isotopes anticipated in the AFCI PIE project, americium-241 is the most significant in terms of consequences to workers and the public from a release.

The source term anticipated in AFCI PIE project samples is small relative to the existing facility source term from both a committed effective dose and direct radiation dose perspective.

Spill Hazards

The existing AL safety analysis report (SAR)² evaluates spills outside gloveboxes or hoods as an anticipated event. Consequences of such an event are low or negligible to workers and the public due to the limited MAR and to training and procedure responses. The risk is classified as acceptable to co-located workers and the public in the AL SAR. This event would be less likely to happen in a shielded enclosure than elsewhere in the facility because the samples will enter the enclosure via the pneumatic transfer system and will remain within the shielded enclosure, thus reducing the potential for the sample material to spread. This type of hazard has been previously addressed in the existing AL safety documentation and spill analyses.

Natural Phenomena Hazard

Natural phenomena, including earthquakes and tornados, resulting in breach of confinement and failure of operational equipment are potential hazards to the facility and the shielded enclosure. These types of accidents were evaluated in the AL SAR and given a frequency of “unlikely” or “extremely unlikely.” Internal doses associated with uptake of airborne material from materials in the shielded enclosure are judged to be negligible to facility workers, co-located workers, or the public. The direct radiation exposures also fall below evaluation guidelines for facility workers, taking into account that the structure is not severely compromised and assuming evacuation of the affected area.

Major Facility Fire

A major fire in the facility would have the potential to damage confinement barriers and operating systems and to release the MAR. This type of accident is prevented or mitigated through facility fire detection and suppression systems and through the rapid response of the on-site fire department. Though unlikely, a major fire is considered to result in the most serious consequences of the events evaluated in the AL SAR. A catastrophic fire was used as the design basis accident for the AL. This accident was conservatively evaluated using an assumed MAR of 20 g of americium. The HC-2 threshold quantity for americium is 16 g. Since the AL contains a large number of different isotopes at any given time, it would not be practical to try to evaluate an accident against all possible inventory combinations. Using the 20-g americium quantity as a surrogate conservatively bounds any potential inventory and accident scenario in the AL.

The americium inventory expected from the AFCI PIE project is expected to be in the milligram quantities rather than the gram quantities evaluated in the AL design basis accident. The dose consequences would therefore be much lower for this type of accident in the PIE shielded suite than for other areas in the AL. Once again, the risk associated with the AFCI PIE is enveloped by the risk previously evaluated in the AL SAR.

Hydrogen Gas in the Shielded Enclosure

A commercially available gas purification system is recommended for maintaining purity of the inert atmosphere of the AIE. A double regeneration system will be used to provide continuous operation, with one column regenerating while the other is in use. Such purification systems typically use hydrogen as an oxygen “getter.” The project documentation has identified a regeneration system that uses an inert premixed gas with hydrogen concentration in the range of 3 to 5%. All off-gas will be vented through the facility HEPA filtration system. Using hydrogen or a hydrogen mixture for purification introduces a potential for a hydrogen fire/explosion in the purification system or hydrogen supply lines. For such an accident to occur, several conditions would have to align as precursors to the event: hydrogen present in an explosive concentration, loss of passive ventilation, sufficient oxygen concentration present, and ignition source. Considering the multiple failures required for this to occur, such an event would be deemed unlikely or extremely unlikely. The consequences of this event are deemed low to negligible due to the confinement of the MAR in the examination area. As needed, operating controls will be identified to further reduce the risk, such as automatic shut off valves, gas detectors, and oxygen monitors.

Hydrogen is currently used in the AL in a similar manner as is anticipated for the PIE project. The use of hydrogen gas in the AL is discussed in the SAR. As part of the hazard and accident analysis in Chapter 3 of the SAR, the potential for a major fire in the AL was identified with ignition of flammable gas as the initiator.

7. Major Modification Evaluation

10 CFR 830, Subpart B, “Nuclear Safety Management” states that a preliminary documented safety analysis (PDSA) is required for major modifications to HC-1, -2, or -3 DOE nuclear facilities as well as DOE approval prior to material or component procurement or beginning construction.⁵ An evaluation for this project against the 10 CFR 830 major modification criteria was made to determine if the project constituted a major modification. 10 CFR 830 defines a major modification as those changes that “substantially change the existing safety basis for the facility.” In an attempt to gain more consistency throughout the DOE complex in determining what meets this subjective definition, a new standard, DOE-STD-1189,⁶ has been drafted. The draft standard includes a table (included herein as Table 1, “PDSA Evaluation Criteria”) which aids in identifying a major modification. The draft guidance for applying the table states that in applying the criteria, the intent is not to automatically trigger the need for a PDSA if one or more of the criteria are met. Rather, it is intended that each criterion be assessed individually and then an integrated evaluation be performed based on the collective set of individual results. In performing this evaluation, the focus should be on the nature of the modification and its associated impact on the existing facility safety basis. Even a project that results in changes that ripple through the safety basis documents does not “substantially change the existing safety basis for the facility” solely because many parts or pages of the safety basis documentation need to be revised.

Table 1. PDSA needs evaluation.

PDSA Needs Evaluation		
<u>Project Information</u>		
Criterion No.	Evaluation Criteria	Evaluation
1	Add a new building or facility with a material inventory \geq HC 3 inventory limits or increase the HC of an existing facility?	The project does not involve the addition of a new building or facility. It will not change the hazard categorization of the facility. The AL is a HC-3 facility, and it will remain so.
2	Change the footprint of an existing HC 1, 2, or 3 facility with the potential to adversely impact any credited safety function?	The building size will not change. The B-50/51 area of the AL is currently not used as a radiological material examination area, so the usage of that area <i>will</i> change. Appropriate changes will be made in the existing safety basis documents. There are no safety structures, systems, and component (SSCs) derived in the current SAR that prevent hazards that could exceed evaluation guide criteria; therefore, there is no potential to impact any credited safety function.
3	Change an existing process or add a new process resulting in a Safety Basis change requiring DOE approval?	The project will add a process to the existing and evaluated processes in the AL. The added process is similar to the evaluated processes in that small irradiated fuel samples containing both actinide and fission products will be examined in a shielded remote-operated environment. It is expected that the new PIE process will require changes to the safety basis (such as an addendum) and DOE approval.
4	Utilize new technology or GFE not currently in use or not previously formally reviewed / approved by DOE for the affected facility?	The equipment which will be installed and used in the AFCI PIE is not new technology and is not government-furnished equipment (GFE). Instruments with similar technology such as an x-ray diffractometer and scanning electron microscope are currently in use in the affected facility.
5	Create the need for new or revised Safety Basis controls (hardware or administrative)?	The AFCI project scope and activities are similar to existing work being performed in the AL. The hazards are similar to existing facility hazards. As the project develops, further evaluations will determine the need for any additional controls. As noted in the response to Question No. 3, these controls could be addressed in an addendum to the existing facility SAR.
6	Involve a hazard not previously evaluated in the DSA?	The hazards involved with examination of samples of irradiated fuel sections are very similar to hazards previously evaluated under the AL SAR.

The results of the major modification evaluation against the above criteria for the AFCI PIE project determined that although the project involves modification to existing rooms in an active and operating HC-3 nuclear facility and installation of new equipment and structural

shielded enclosures for analysis and evaluation of irradiated fuel samples, the facility will continue to operate as a HC-3 nuclear facility with no significant increase in radioactive material inventory. Hazards associated with the new project are similar in type and severity with existing hazards associated with programs being performed within the facility. An evaluation of the project conceptual design does not indicate a need for significant upgrades to existing SSCs or significant new SSCs to properly mitigate the hazards associated with the project. Thus it was concluded that this project does not involve a major modification per DOE-STD-1189 and 10 CFR 830 criteria, and no PDSA is required. The changes to the existing SAR and technical safety requirements (TSRs) to reflect this project will be made following the normal unreviewed safety question (USQ)/SAR/TSR change processes or as an addendum to the existing SAR as the project moves forward

8. Summary

A facility is being designed with capability to receive and analyze remote handled experimental irradiated fuel samples in the MFC AL. This project is needed to support the DOE initiative to research, develop, design, and license a new generation of commercial nuclear power reactors to provide a cost effective carbon-free energy source for large scale national deployment in the coming years.

The experimental fuel will initially be prepared at the INL MFC in fuel program gloveboxes. The fuel pins will then be sent to the INL RTC where they will be placed in the reactor core for irradiation to test fuel performance under actual reactor conditions. The fuel pins will then be removed from the reactor and shipped via shielded cask back to the MFC and placed in an inert atmosphere hot cell facility. The samples will there be prepared by cutting a thin slice of the fuel pin and mounting it in an epoxy metallurgical mount. The sample will then be transferred through a pneumatic transfer system to the MFC AL where the samples will enter the shielded enclosures discussed in this paper. At the AL, analyses will be conducted to determine fuel and material performance.

It was determined that the project will not add any significant new hazards beyond what has already been evaluated for work being performed in the MFC and does not constitute a major modification. Work may commence on the project without completion of a PDSA. It is expected that a SAR addendum will be created to address the new aspects of this project.

9. References

1. DOE-STD-1027-92, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, 'Nuclear Safety Analysis Reports,'" U.S. Department of Energy.
2. W0660-0055-KH, "Analytical Laboratory Safety Analysis Report," Revision 5, February 2007.
3. TEV-59, "Qualitative Analysis of the Seismic Capacity of the NDA Laboratory Addition to MFC Building 752," February 2008.
4. ANNA-MFC-RPT-013, "Conceptual Design Report for Modification of Rooms B50 and B51 of the MFC Analytical Laboratory at the Materials and Fuels Complex (MFC)," Revision B, December 2007 draft.
5. 10 CFR 830, Subpart B, "Nuclear Safety Management," *Code of Federal Regulations*, Office of the Federal Register.
6. DOE-STD-1189, "Integration of Safety into the Design Process," draft.