APPENDIX A

P-04169

Post-Irradiation Hot Cell Examination of North Anna Fuel Rods

Work proposed by:

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The statement of work supplied by EPRI for which Argonne National Laboratory is proposing to complete this 'work for others' is in Attachment A.

Argonne responded to the EPRI SOW in Attachment A with a capabilities statement as shown in Attachment B.

The cost estimate for performing the scope of work is shown in Attachment C.

Argonne's policies for environmental, health, safety, and quality assurance are part of this proposal as stated below:

Environmental, Health and Safety Policy

The policy of ANL is that its activities will be conducted so that worker and public safety are given the highest priority. ANL will comply with all applicable federal and state laws, regulations, and orders to protect the health and safety of workers and the public and to minimize accidental damage to property. The ANL environment, health and safety policy is implemented through a number of manuals and handbooks. Compliance is assured through formal assignment of responsibilities, by the establishment of pertinent committees, and by conducting internal appraisals and audits that meet Department of Energy requirements for independence and frequency.

Quality Assurance Policy

ANL is committed to adherence to high standards of quality in its research by implementation of an effective quality assurance program.

Attachment A

EPRI STATEMENT OF WORK

"North Anna M5 Shipment and Hot Cell Examination"

EPRI will contract with a hot cell facility to execute the following activities on 4 fuel rods and 2 guide tube segments. The 4 irradiated (~71 GWd/mtU) nuclear fuel rods are approximately 152 inches in length. The diameter of the rods is 0.374 inches. The rods utilize zirconium - 1% niobium cladding alloy M5®. Each rod is estimated to have, after 6 months of cooling, an activity of less than 9110 curies (337 TBq) and a decay heat of 46 W. In addition, the 2 guide tube segments (also alloy M5®) will be approximately 36 inches in length, with a diameter of 0.482 inches.

Fuel Shipment

Supplier shall provide equipment and services to transport irradiated nuclear fuel rods and fuel assembly components from North Anna Nuclear Power Station to a hot cell facility located in the United States, Canada or Europe as set forth and defined below.

1. Equipment – Provide adequate approved and licensed shipping containers and related equipment to transport spent fuel rods and fuel assembly components. The shipping containers should be designed to minimize contamination of the container and to facilitate easy removal of contamination upon completion of the shipment.

    - Description and quantity of irradiated nuclear fuel rods and fuel assembly components:
        - Supplier shall provide appropriate containers to accommodate four (4) irradiated (~74 GWd/mtU) nuclear fuel rods of approximately 153 inches in length but not to exceed 154.5 inches. The nominal diameter of the rods is 0.374 inches. The rods utilize zirconium - 1% niobium cladding alloy M5®. Each rod is estimated to have, after 11 months of cooling (cycle shutdown April 30, 2004 and shipping in March 2005), an activity of 6300 curies (233 TBq) and a decay heat of 32 W. The SNM information for the rods will be provided on Form 741. In addition, the containers shall accommodate two (2) guide tube segments of approximately 32 inches in length (also alloy M5® but having a 2.5 inch 300 series (austenitic) SS sleeve on one end), with a diameter of 0.482 inches. The activity levels of these segments will be about 13.3 curies (.49 TBq) for each M5 GT and SS sleeve, a small fraction of the fuel rod activity. Note: the container license must cover M5® material and guide tube segments.

2. Services –
    - Shipment Origination Site Assistance
        - Supplier shall provide appropriate site assistance from the time of the initial handling or the arrival of the shipping container at site, up to and including the loading of the irradiated nuclear fuel rods and fuel assembly components and subsequent release of the container for shipment. Assist in preparation of shipping documentation.

- Shipment Destination Site Assistance
  - Supplier shall be present at the hot cell destination and shall provide appropriate site assistance from the time that the shipping container arrives, up to and including the unloading of the shipping container at the site.
- Shipment Planning and coordination
  - Supplier shall participate in periodic conference calls and meetings relative to the coordination and planning of this shipment.

3. Transportation Services – Supplier shall arrange and provide transportation of all shipping container equipment.
   - Transport of one shipping container and related equipment to shipping site.
   - Transport of loaded shipping container from site to hot cell facility. If facility is located outside the U.S., charter appropriate vessels as appropriate to complete the transportation process.
   - Return of shipping container and related equipment from destination site to supplier facility.

4. Transportation Assistance
   - Obtain a USNRC approved route for shipment of the loaded shipping container within the U.S. from shipping site to the hot cell facility, if within the U.S. or to the port of embarkation if the hot cell facility is outside the U.S.
   - Arrange all inland transportation, port handling formalities, and import license requirements as appropriate.
   - Coordinate with all concerned parties, USNRC, state and foreign governmental authorities, as needed to obtain licenses and approvals.
   - Perform a detailed route assessment.
   - Prepare and submit a Spent Fuel Route Plan to the appropriate governmental agencies.
   - Prepare a transportation plan and a security plan that details all transportation and security measures relative to the shipment.
   - Prepare and disseminate required Driver Instructions relative to the shipment.

5. Title to Fuel

The roles and responsibilities with respect to the ownership of the fuel rods and assembly components shall be clearly stated. It is advantageous to EPRI and Dominion for the shipper or hot cell facility to take title to the fuel at the boundary of the North Anna site.

Fuel Receipt

The hot cell shall receive the fuel rods and guide tube segments described above, survey the shipping cask for external contamination, unload the fuel, decontaminate the fuel canister, decontaminate the shipping cask, and support removal of the cask from the contractor's hot cell facilities. The contractor shall remove the fuel rods from their capsules.

Hot Cell Examination Workscope

The following is the expected scope of work to be performed by the hot cell facility. The final scope may vary slightly. Individual examinations should also be estimated on a per sample basis.

1. Conduct non-destructive hot-cell examinations as follows:
    - Perform visual examination and provide full length color video recordings (all samples)
    - Perform gamma scan surveillance (1 to 4 fuel rods).
    - Perform fuel rod length measurement (4 fuel rods).
    - Perform eddy current oxide and profilometry measurements (1 to 4 fuel rods).
    - Perform neutron radiography measurements (up to 4 fuel rod sections)

2. Perform destructive hot-cell examinations as follows:
    - Fission Gas Release: Puncture analysis will be performed on each of the 4 fuel rods for fission gas pressure and composition.

    - Metallographic Examination: Samples will be prepared from spans 2 and 7 (see note below) of each of the 4 fuel rods and from each of the 2 guide tube segments (span 2) for examination in both the as-polished and as-etched condition. Samples will also be prepared from fuel rod and guide tube welds. Examination will include characterization of the cladding microstructure, and crud and oxide layer(s). Both the ID and OD of the oxide layer will be measured with the samples in the as-polished condition. For the guide tube samples, this will be done on both the interior and exterior surfaces. Afterwards, part of the samples (from two different spans in one rod and a single span in the other three rods) will be etched to characterize the morphology of the hydrides in the metal. Also, the size and distribution of second phase particles in the span 2 samples from 2 of the fuel rods will be measured. An archive sample will be provided for a baseline measurement.

    - Ceramographic Examination: 4 of the samples mounted for metallography will be prepared for ceramography to characterize the pellet microstructure, including grain size, porosity, and the rim region. Measurements will be performed on fuel pellets from span 2 of each of the 4 fuel rods.

    - Hydrogen Analysis: The concentration of hydrogen in the fuel rod cladding and guide tubes will be measured by a hot vacuum extraction technique or its equivalent. Samples from spans 2 and 7, or welds, of each of the 4 fuel rods and span 2, or welds, of each of the two guide tube segments will be prepared for hydrogen analysis. Defueling will be performed mechanically followed by acid etching (note: some of the hydrogen samples may come from tensile, burst, or creep test specimens).

    - Tensile Testing: Tensile testing will be conducted in both the transverse (hoop) and longitudinal directions on samples from span 2 of each of the 4 fuel rods. From defueled cladding, precision ring-stretch and axial tensile specimens will be prepared. Tensile tests will be conducted at room temperature and at 350-400°C. Fractographic examination will be done using a scanning electron microscope (SEM).

- Burst Testing: Burst tests will be conducted with defueled cladding sections from span 2 of each of the 4 fuel rods at both constant pressure with ramping temperature and at constant temperature with ramping pressure. The constant-temperature tests will be conducted with ramping pressures until the cladding ruptures. The constant-pressure tests will be conducted at pressure near the PWR system pressure with slow temperature ramps until the cladding ruptures. Fractographic examinations will be done with a SEM.

  The biaxial tests will be performed on 120 mm long specimens with cold crimped Swagelok fittings at both ends. The specimens will be pressurized with high temperature oil and tested inside a resistance furnace that can heat the specimen up to 400 °C. The ZrO_2 layer will be removed at both ends by abrasive grit blasting or other approved procedure before the Swagelok fittings are attached. The pressurization rate will be 100 bars/minute.

- Thermal-Creep Testing: The diameter profiles of the samples from span 2 of each of the 4 fuel rods will be determined. Time-to-rupture and failure strain will be determined if rupture occurs. Creep rate as a function of time and temperature will be determined. Fractographic examination will be conducted with a SEM should the sample rupture. The test is to be done at 400 C and 130 MPa for 240 hours.

- Fuel Composition Profiles: The composition of pellets will be characterized radially on a pellet cross-section by "micro gamma scan" or Electron Probe Micro Analysis (EPMA), including the radial burnup distribution. The ability to obtain U and Pu isotopics as a function of radius would be beneficial. Measurements will be performed on 2 of the specimens prepared for ceramography (although EPMA may require new specimens). Profiles should be performed across the entire diameter to capture any gradient effects.

- Fuel Isotopics: Rod isotopics shall be obtained for a mid-plane elevation along the 4 fuel rods. An entire slice should be used as the sample to remove radial and azimuthal variations. The measured uncertainty should be determined by an accepted method. The U and Pu isotopes, U234, U235, U236, U238, Pu 238, Pu 239, Pu 240, Pu 241 and Pu 242 will be sufficient. The burnup of each slice should be determined. Slices should come from approximately the 6 foot elevation of the active fuel column and between the spacer grids and/or mid span mixers.

- Pellet Density: The density of a representative sample of a pellet shall be obtained. Since at this burnup the pellet will most likely have cracks and be bonded to the cladding, obtaining a whole pellet is unlikely. A reasonably sized particle of a pellet will be acceptable for determining the density. The method to be used and the expected uncertainty shall be described.

Note: The spans are between the 8 spacer grids. Spans are numbered from the top of the rod; span 7 is at the bottom.

A table is included below summarizing the North Anna hot cell workscope.

Waste Disposal

The hot cell contractor shall take title to the fuel rods, capsules, and any other waste generated as a result of this examination, and will have responsibility for disposing of that waste. Unless otherwise negotiated, all samples shall be designated as waste and may be discarded 1 year after the final report is submitted to EPRI. The contractor shall have responsibility to complete all required transportation documents for return of the empty shipping container to its owner.

Reporting

The hot cell contractor shall provide short biweekly status reports to EPRI that include progress to date, significant issues, schedule performance, and project costs. These biweekly status reports may be sent via e-mail to Kurt Edsinger (kedsinger@epri.com), or provided by telephone conference call. A telephone conference call will also be held after the non-destructive examination is completed and before the start of the destructive examination. The contractor shall also provide a final report that describes the results of all testing and analysis completed for this project.

Hot Cell Scope Summary (R = Required, O = Optional)

	Selection of Fuel Assembly Components for Hot Cell Examination			
	Fuel Rod Selection	R	4 Rods	Corner rod, center peripherial rod, rod adjacent to the instrument tube and a rod adjacent to a guide tube will be selected for hot cell examination.
	Guide Tube Selection	R	2 Guide Tube Segments; 3 Samples per GT Segment	One 3rd Cycle and one 4th Cycle guide tube segments will be sectioned at hot cell for subsequent examination.
Test No.	**Non-destructive Examinations Examination**	**Class**	**Quantity**	**Test Objective/Result**
1	Receipt Inspection	R	4 Rods	
2 2a	Gamma Scan Surveilence Gamma Scan Surveilence	R O	1 Rod 4 Rods	Check for gaps in the fuel column and determine the axial and azimuthal burnup distribution
3	Fuel Rod Length Measurement	R	4 Rods	
4 4a	Eddy Current Oxide Measurements Eddy Current Oxide Measurements	R O	1 Rod 4 Rods	
6	Neutron Radiography	O	4 sections (1 meter in length each)	Check for cladding defects or hydride concentrations
	Destructive Examinations Examination	**Class**	**Quantity**	**Test Objective/Result**
7	Fission Gas Puncture and Analysis	R	4 Rods	Gas pressure and composition
8	Metallographic Examination of Cladding	R	8 (4 Rods, 2 samples per rod for oxide, spans 2 & 7)	Oxide thickness (ID & OD) on all 8 samples; Hydride morphology and orientation from four span 2 samples and one span 7 sample.
9	Microstructural Examination of Cladding	R	2 (2 rods, 1 sample per rod, span 2)	Characterize SPP size and distribution.
10	Metallographic Examination of Guide Tubes	R	2 (1 from 3rd cycle GT and 1 from 4th chcle GT)	Characterize the microstructure, ID and OD oxidation. Hydride morphlogy in Weld region
11	Ceramography Examination of Fuel	R	4 (4 rods, 1 sample per rod, span 2, can utilize mounts from Test 8)	Grain size, porosity, rim characterization.
11a	Radial Isotopic Distribution	R	2 (2 rods, 1 sample per rod, same specimen as Test 11 or directly adjacent)	Obtain radial profiles of fission products, burnup distribution by micro gamma scan or EPMA.
12	Isotopic Analysis of Fuel	R	4 (4 rods, 1 sample per rod)	Obtain pin isotopics on a slice of fuel at ~6 ft. elevation of the active fuel column of each rod. Obtain burnup of each isotopic slice. Slice must not be near or under grid locations.
13	Cladding Hydrogen Analysis	R	8 (samples from Item 8-9 or	Hot vacuum extraction technique or equivalent
14	Guide Tube Hydrogen Analysis	R	2 (samples total from Test No. 10 or 19-20)	Hot vacuum extraction technique or equivalent
15	Room Temperature Axial Tensile Test of Fuel Rod Cladding	R	4 (4 rods, 1 sample per rod, span 2)	Mechanical Properties - YS, UTS, UE and TE
16	Elevated Temperature Axial Tensile Test of Fuel Rod Cladding (350C)	O	2 (2 rods, 1 sample per rod, span 2)	Mechanical Properties - YS, UTS, UE and TE
17	Room Temperature Ring Tensile Test of Fuel Rod Cladding	R	4 (4 rods, 1 sample per rod, span 2)	Mechanical Properties - YS, UTS, UE and TE
18	Elevated Temperature Ring Tensile Test of Fuel Rod Cladding (350C)	O	2 (2 rods, 1 sample per rod, span 2)	Mechanical Properties - YS, UTS, UE and TE
19	Room Temperature Axial Tensile Test of Guide Tubes	R	2 (2 Guide Tube sections, 1 sample per guide tube section)	Mechanical Properties - YS, UTS, UE and TE
23	Burst Test	R	4 (4 rods, 1 sample per rod, span 2)	Mechanical Properties - YS, UTS, UE and TE from near system pressure. SEM miscroscopy of fracture surfaces.
24	Thermal Creep Test	R	4 (4 rods, 1 sample per rod, span 2)	Determine Creep Rate
25	Pellet Density Test	R	4 (4 rods, 1 sample per rod, span 2)	

R = Required
O = Optional

Postirradiation Hot Cell Examination of North Anna Fuel Rods

ANL Technical Capability & Approach

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Postirradiation Hot Cell Examination of North Anna Fuel Rods

ANL Technical Capability

Executive Summary

Argonne National Laboratory (ANL) has received a copy of a Request for Proposal (RFP) issued by the Electric Power Research Institute (EPRI) in which EPRI solicits interest in a contract to perform post-irradiation hot cell examination (PIE) on high-burnup fuel rods and guide tube segments from the North Anna plant. As a U.S. Department of Energy laboratory, ANL cannot compete with the U.S. private sector for hot cell examination work. However, we do wish to make our broad capabilities available to help advance understanding of nuclear energy technology and to help improve the safety and reliability of U.S. nuclear power plants. Therefore, this statement of approach and capability for examination of the North Anna M5 fuel rods has been prepared for EPRI consideration. If EPRI so desires, then ANL can contract to provide technical examination services as part of a Work-for-Others agreement.

ANL can receive at the ANL-West location (soon to be incorporated into the new Idaho National Laboratory) irradiated fuel rods and assemblies shipped in commercial casks and transfer them into a large hot cell. The EPRI RFP describes shipment of the PWR fuel rods using the NAC LWT cask. Receipt and handling of this cask can be accommodated at ANL-West facilities using current facility fixturing and procedures and unloading of the cask internals can be accommodated with some additional planned fixturing. A complete range of non-destructive examination capabilities for full-length rods and a complete set of destructive characterization capabilities have been established and used previously for fuel examination. Some additional provision for fixtures and interface hardware may be necessary and are planned to facilitate examining the longer high-burnup LWR fuel rods.

The destructive characterization capabilities available include metallographic sample preparation, examination using optical and scanning electron microscopy (SEM), bulk chemistry analysis for elemental species and radionuclides, microchemical analysis using

Energy-Dispersive Spectroscopy (EDS) and Wavelength Dispersive Spectroscopy (WDS) in conjunction with SEM and/or Transmission Electron Microscopy (TEM), microstructural anlaysis using x-ray diffraction and TEM electron diffraction techniques. Additional techniques, such a microgamma scanning and, for example, radial coring for analytical chemistry can be established if desired. Tensile testing, burst testing with temperature ramp and creep testing are available. Burst testing with pressure ramp can be developed.

Discussions with the U.S. Department of Energy (DOE) and with the State of Idaho to address institutional issues associated with receipt of commercial materials into the State and with the long-term management and disposition of associated waste are in progress. We are confident that the discussions will result in agreement to conduct technical investigations of the type described in the White Paper.

1 APPROACH

1.1 Background

The Department of Energy and nuclear utility industry have established a strategic plan for improving and expanding current nuclear plant performance and achieving the longest safe and economic operating life possible. Argonne National Laboratory (as will the soon-to-be-established Idaho National Laboratory) supports the Department in the execution of its role in this regard.

The nuclear industry continues to develop advanced fuel designs for increased reliability and higher burnup operation. Fuel rods irradiated to a burnup of ~71 GWd/mtU and guide tube segments from a lead use assembly have been discharged from the North Anna Nuclear Plant. The rods utilize zirconium - 1% niobium cladding alloy M5, which has been developed by Framatome ANP. In a recent solicitation, EPRI has expressed a desire to obtain fuel characterization data to support qualification of the cladding material at high burnup.

ANL-W has many capabilities that can assist in developing these data and models, beginning with Post Irradiation Examination (PIE) and assessment. The primary purpose of the PIE described in the EPRI RFP is to provide characterization and performance data for the fuel rod cladding– specifically, oxidation, hydriding, changes in dimensions and mechanical properties and their dependence on neutron fluence.

Section 1 of this white paper summarizes the technical approach to obtaining the data that are required for the fuel rod hot cell examination described by EPRI. Greater details of the cask handling and examination capabilities are presented in Sections 2-5. Section 2 describes cask handling capabilities and preparations for shipment. Section 3 provides an overview of ANL hot cell capabilities for examining LWR fuel rods, while Sections 4 and 5 describe the non-destructive and destructive examination capability, respectively. Section 6 addresses schedule and Section 7 addresses anticipated waste issues associated with such work.

1.2 Conduct of Requested Workscope

Therefore, the following describes how ANL would conduct the described workscope.

Cask Receipt and Handling

ANL would receive fuel rods using the NAC LWT cask for transferring and handling such rods in the Hot Fuel Examination Facility (HFEF). ANL would develop some additional fixturing for the shipping package configuration. Details and considerations regarding cask selection and receipt are provided in Section 2.

North Anna M5 Hot Cell Examination

The technical approach and capabilities of ANL for conducting the hot cell examination of the North Anna fuel rods are summarized in Table 1. Further details can be found in subsequent sections of this document.

Waste Disposal and Handling

Discussions with the U.S. Department of Energy (DOE) and with the State of Idaho to address institutional issues associated with receipt of commercial materials into the State and with the long-term management and disposition of associated waste. We are confident that the discussions will result in agreement to conduct technical investigations of the type described in the White Paper. ANL is capable of meeting schedules similar to that specified in the EPRI RFP.

Table 1 ANL Technical Approach for North Anna M5 Hot Cell Examination

	Selection of fuel Assembly Components for Hot Cell Examination	Class	Quantity	Comments
	Fuel rod selection	R	4 rods	TBD by Framatome and EPRI. Specifics to be communicated to ANL.
	Guide tube selection	R	2 guide tube segments; 3 samples per segment	TBD by Framatome and EPRI. Specifics to be communicated to ANL.
Test No.	**Non-destructive Examination**	**Class**	**Quantity**	**Proposed Method and Expected Result**
1	Receipt Inspection	R	4 rods	Visual exam via periscope, documented with digital photography
2 2a	Gamma Scan Gamma Scan	R O	1 rod 3 additional rods	Axial isotopic gamma scan system established in cell.
3	Fuel Rod Length Measurement	R	4 rods	Length measurement (< 0.01 in. accuracy) using existing bow and length measurement device, with inversion to accommodate length in existing equipment
4 4a	Eddy Current Oxide Measurements	R O	1 rod 3 additional rods	Measurement possible using Framatome-supplied coil and electronics. Installation required.
6	Neutron Radiography	O	4 sections 1 meter in length	Full-rod lengths possible using inversion. Up to all 4 rods possible. Contrast resolution estimated at around 0.05 in.
Test No.	**Destructive Examination**	**Class**	**Quantity**	**Proposed Method and Expected Result**
7	Fission Gas Puncture and Analysis	R	4 rods	Established technique for gas sampling using existing in-cell system (< 5% accuracy for P & V) and gas analysis in analytical chemistry laboratory.
8	Metallographic Examination of Cladding	R	8 samples (4 rods, 2 samples per rod for oxide, spans 2 & 7))	Metallography of cladding using existing in-cell sample preparation and metallograph/SEM.
9	Metallographic Examination of Cladding	R	2 samples (one span-2 sample from each of 2 rods); SPP size and distribution	Metallography of cladding using existing in-cell sample preparation and metallograph/SEM.
10	Metallographic Examination of Guide Tubes	R	2 samples (one from 3rd-cycle GT and one from 4th-cycle GT); μ-structure, ID/OD oxidation, hydride morph'y in weld region.	Metallography of cladding using existing in-cell sample preparation and metallograph/SEM.
11 11a	Ceramography Examination of Fuel Radial Isotopic Distribution	R R	4 samples (4 rods, one span-2 sample each,) 2 samples (2 rods, one span-2 sample each,)	Metallography of cladding using existing in-cell sample preparation and metallograph/SEM. Assume same samples as used for test 11, or sections immediately adjacent.

12	Isotopic Analysis of Fuel	R	4 samples (4 rods, one sample per rod); samples taken per specification	Analytical chemistry determination of specified isotopes and burnup.
13	Cladding Hydrogen Analysis	R	8 samples – assume from tests 8 or 9.	Use of LECO hydrogen analyzer after in-cell installation.
14	Guide Tube Hydrogen Analysis	R	2 samples – assume from tests 10 or 19-20.	Use of LECO hydrogen analyzer after in-cell installation.
15	Room Temperature Axial Tensile Test of Fuel Rod Cladding	R	4 samples (4 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
16	Elevated Temperature Axial Tensile Test of Fuel Rod Cladding (350°C)	O	2 samples (2 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
17	Room Temperature Ring Tensile Test of Fuel Rod Cladding	R	4 samples (4 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
18	Elevated Temperature Ring Tensile Test of Fuel Rod Cladding (350°C)	O	2 samples (2 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
19	Room Temperature Axial Tensile Test of Guide Tubes	R	2 samples (2 guide tube sections, one sample per guide tube)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
23	Burst Test from near system pressure	R	4 samples (4 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
24	Thermal Creep test to determine creep rate	R	4 samples (4 rods, one span-2 sample per rod)	Can be performed at AGHCF at ANL in Illinois; YS, UTS, UE, and TE
25	Pellet Density Test	R	4 samples (4 rods, one span-2 sample per rod)	Can be determined using immersion density technique in Analytical Laboratory
R = required O = optional				

1.3 Scope and Conduct

The approach to postirradiation hot cell examination of North Anna fuel rods is described in this document. The PIE workscope would be conducted as appropriate at the Hot Fuel Examination Facility (HFEF), Analytical Laboratory (AL), Electron Microscopy Laboratory (EML) and Alpha Gamma Hot Cell Facility (AGHCF).

The PIE tasks would be performed according to approved procedures. Work would satisfy the requirements of NQA-1, being conducted in accordance with the ANL-W Quality Assurance Program, W0001-0929-QM and appropriate facility quality assurance plans. All work at ANL-West is performed in accordance with the appropriate facility ES&H guidelines and facility and division Conduct of Operations requirements.

2 CASK HANDLING AND TRANSPORTATION SERVICES

Argonne National Laboratory-West has facilities for handling Legal Weight Truck sized shipping casks up to 17 ft. in length, 56 in. in diameter, and 32 tons in weight. Argonne National Laboratory-West would use a NAC LWT cask for shipping the fuel rods (see Figure 1). The cask handling capabilities specific to LWR fuel rod payloads are discussed in this section. The transportation services available are also discussed.

2.1 Shipping Cask for Intact Fuel Rods

The NAC LWT cask is the preferred option for shipping intact (full-length) fuel rods. The NAC LWT maximum loaded weight of 52,000 lb, 200 in. length and 44 in. diameter with cavity dimensions of 13.4 in. diameter and 178 in. length. The NAC LWT uses a standard LWR Basket, which can accommodate the intact control rods.

ANL-W has existing cask interface equipment and procedures for receipt of the NAC LWT. Since 1997 ANL-W has handled the cask 6-10 times as part of the Tritium Production Burnable Absorber Rod (TPBAR) Lead Use Assembly (LUA) Program. Handling experience includes receipt and unloading of standard Westinghouse skeleton assembly with burnable absorber rods and a double encapsulated payload configuration for shipping sectioned TPBAR.

For supporting the shipment of the LWR fuel rods, ANL will need to develop a handling grapple for the NAC LWR Basket, a two-piece transfer lid for on-site unloading operations and the associated operations and procedures. Development of the revised operations and procedures includes performing out-of-cell qualification (Mockup) and in-cell qualification (Dry Run) prior to receiving and unloading a fuel shipment using the LWR Basket payload configuration.

2.2 Shipping Cask Option for Future Programs

The TN-FSV is a DOE-owned cask with physical dimensions capability of accommodating a LWR fuel rod shipment. The cask has a 47,000 lbs maximum loaded weight, 31 in. diameter and 207 in. length and cavity dimensions of 18 in. diameter and 199 in. length.

ANL-W has existing cask interface equipment and procedures for receipt of the TN-FSV. ANL-W has handled the cask three times since 1999 as part of the Dry Cask Storage Characterization Program. The payload configuration was PWR fuel rods in an INEEL designed shipping container. The shipments were performed out-of-commerce under a Transport Plan.

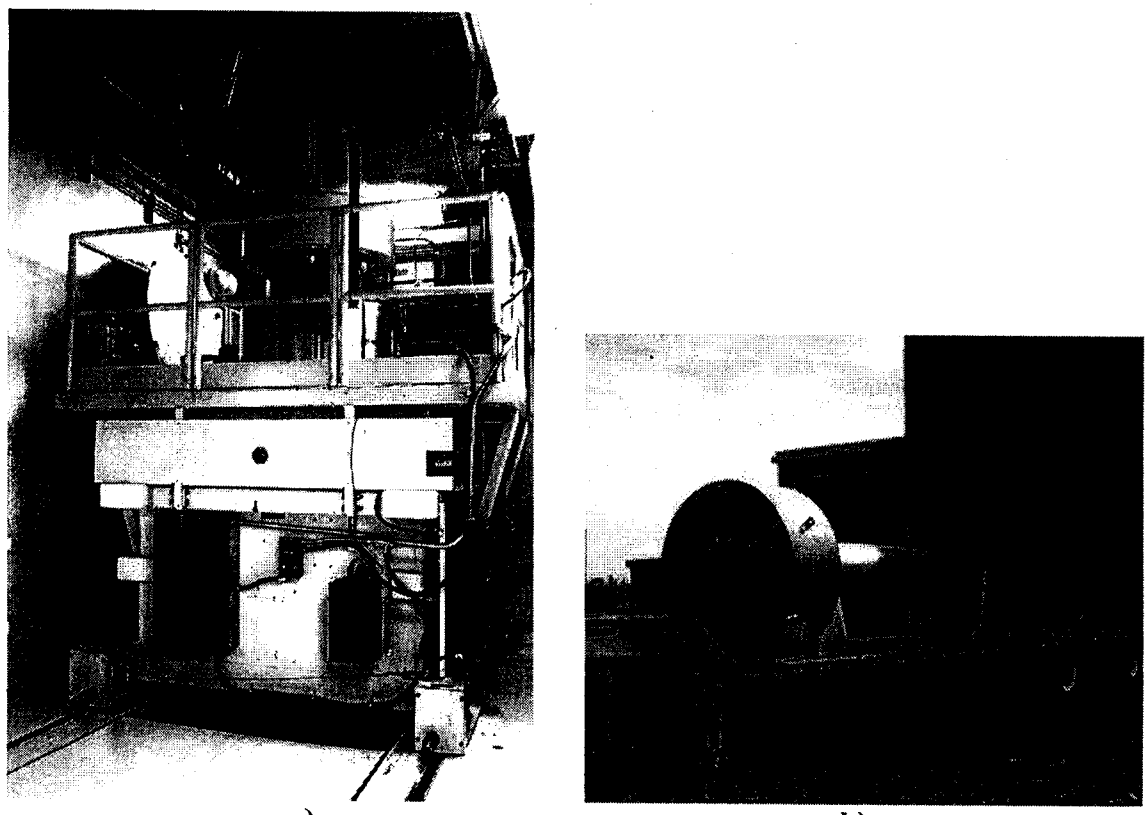
For supporting LWR hot cell examinations, ANL will need to design and fabricate a payload configuration to ship LWR fuel rods and assemblies and amend the Certificate of Compliance to authorize a LWR fuel shipment. Currently, there is no commitment to perform these preparations.

2.3 Transportation Services

The laboratories and the Department of Energy at Idaho have the expertise to provide transportation services and assistance for shipping nuclear fuel and irradiated materials. There is extensive experience, in a role as shipping agent or shipper of record,

arranging for these types of shipments from both USNRC and DOE licensee facilities to the laboratories.

The role of the laboratory and the Department of Energy will be defined in consultation with hot cell examination team to satisfy the specific utility requirements and to provide the most cost effective approach. The transportation services that can be provided include assisting in preparation of shipping documentation, obtaining a USNRC approved route for shipment within the U.S. from shipping site to the laboratory, arranging all inland transportation, performing a detailed route assessment, and preparing a transportation plan and a security plan.



a) b)

Figure 1 Cask handling capability for shipping intact LWR fuel rods: a) NAC LWT Cask and b) TN FSV

3 HOT CELL EXAMINATIONS OF LWR FUEL RODS

Argonne National Laboratory has a number of hot cell and radiological facilities for performing fuels and core components examinations of interest to the LWR industry. At the ANL-W site in Idaho Falls, Idaho are Hot Fuels Examination Facility (HFEF), Analytical Laboratory (AL), Electron Microscopy Laboratory (EML), Fuel Assembly and Storage Building (FASB), Fuel Manufacturing Facility (FMF) and at ANL-E site in Chicago, IL are Alpha Gamma Hot Cell Facility (AGHCF), and Irradiated Materials Laboratory (IML).

The facilities at ANL-W accommodate examination of full-length commercial LWR assemblies, as indicated in Figure 3. (See Section 2 for cask handling capability.) A comprehensive set of non-destructive and destructive examination capabilities is available and is summarized in the next three sections. The non-destructive examination capabilities include visual inspection, neutron radiography, gamma scan, and dimensional inspection. The destructive examination capabilities include metallography, hardness testing, scanning electron and transmission electron microscopy, radial chemical composition analyses, radiochemical fluence measurements, microgamma scanning, immersion density, phase identification, electric discharge machining, tensile testing, creep testing, and post-failure fractography.

Figure 2 Photograph showing the handling of a PWR assembly skeleton in ANL-W HFEF Hot Cell.

4 NON-DESTRUCTIVE EXAMINATION CAPABILITY

4.1 Visual Examination

The visual inspection capability includes digital video, composite digital still photography and a detailed visual inspection station. For routine visual inspection, through-the-cell-window digital photography is performed using a Leaf Volare digital still/video camera (with 3072-x-2048 pixel resolution for still images).

The detailed visual inspection station consists of a standard in-cell examination stage with a modified Kollmorgan throughwall shielded periscope coupled to a high-resolution Leaf Volare digital camera back. The apparatus has three levels of optical magnification (N.B., nominally 4X, 10X, and 25X) and a digital resolution of 3072 x 2048 pixels. The apparatus is equipped 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; commercial photographic strobe lights with built-in halogen modeling lamps; and a dimensional grid background for optics alignment and specimen dimensional scaling.

Visual inspection provides observations to determine mechanical integrity and surface appearance of fuel rods and in-core components. The inspection will record deviations from the as-built condition. Deviations to be noted include weld and end cap failures, cracks, deformations, blisters, areas of discoloration, corrosion, and loss of material by wear. Inspections are performed under the direction of the research staff. Observations are used to plan subsequent hot cell examination tasks. The inspection results will be documented according to approved procedures using controlled logbooks or project forms.

4.2 Gamma Scan

The segment or intact fuel rods will be gamma scanned over the entire accessible length. The total activity and isotopic activity of select activation and transmutation products in the absorber and cladding materials will be measured. The gamma spectra will be used to determine defects, cracking in the absorber rod and the relative axial fluence profile in thermal, epithermal and fast neutron spectra.

Figure 3 illustrates the gamma scanner apparatus (Precision Gamma Scanner III). The major components of the apparatus are a solid germanium crystal detector surrounded by a sodium-iodide (NaI) crystal detector to eliminate background due to Compton scattering, a collimator with an adjustable slit width for optimizing count rates, a multichannel analyzer and software for spectra collection and analyses, and a positioning stage with four degrees of freedom (X-Y-Z and theta). A dedicated, secure computer is used to remotely operate the positioning stage and record the spectra data.

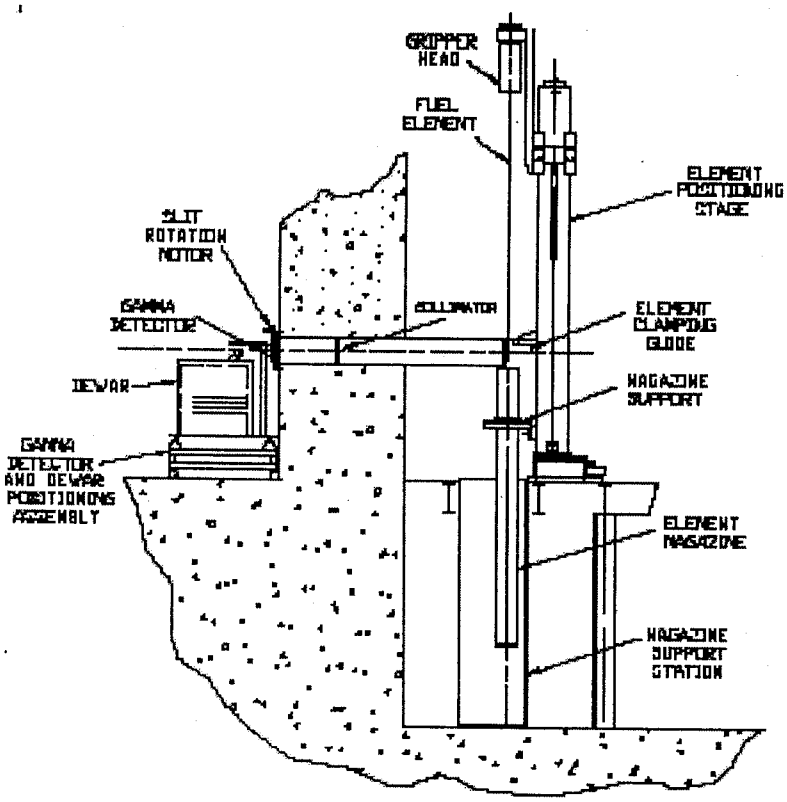


Figure 3 Precision Gamma Scanner III.

4.3 Dimensional Inspections

The dimensional inspection capability includes length, diameter, and bow. An eddy current tester for oxide layer and cladding integrity determination is currently under development. Dimension inspection is performed with the Element Contact Profilometer (ECP), which is a remotely operated, continuous-contact profilometry gauge for measuring axial and spiral diameter profiles of cylindrical elements and capsules. Figure 6 illustrates the diameter inspection instrument (N.B. the element positioning stage is not shown). The segment or intact control rod is inspected vertically using an element positioning stage. The diameter signal is sensed by horizontally opposed contact probes connected to linear transducers. The spring loaded guide rollers maintain the vertical alignment between the fuel rod and the contact probes.

The dimensional inspection instrument can accommodate rods between 4.42-21.3 mm (0.174-0.840 in.) in diameter and up to 3962 mm (156 in.) in length with a maximum diametral range of 0.51 mm (0.020 in.) The diameter profile of the fuel rods is measured to an accuracy of ±7.6 μm (±0.0003 in.) at a minimum vertical interval of 0.254 mm/step (0.01 in./step) with ±0.127 mm (0.005 in.) positioning repeatability. The diameter inspection instrument is calibrated to NIST traceable standards. There are typically four diameter profiles 45 degrees apart measured on each fuel rod to detect ovality.

The length dimension is measured with an accuracy of ±0.254 mm (±0.010 in.) The bow of the fuel rod is measured to an accuracy of ±0.51 mm (±0.020 in.) The inner diameter inspections will be determined by metallography.

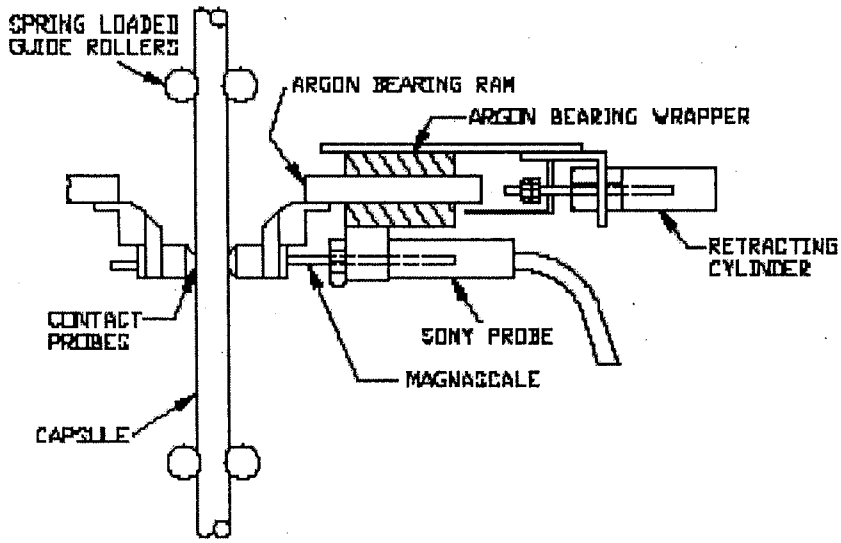


Figure 4 Illustration of diameter inspection instrument (Element Contact Profilometer)

4.4 Eddy Current Oxide Measurement

ANL-W will install a state-of-the-art eddy current measurement system. The system components will be supplied by AREVA Framatome-ANP as part of a CRADA. AREVA Framatome-ANP will also provide engineering and training to support installation of the instrument. The eddy current measurement system tester provides the capability to non-destructively detect flaws in the fuel rod cladding and to measure the oxide layer thickness. Similar systems are deployed in poolside postirradiation examinations at the nuclear plant.

Hot Cell Wall Feedthrough

ANL-W will design and fabricate a standard instrumentation feedthrough that will support the eddy current system. The feedthrough will have connections on the out-of-cell and in-cell interfaces. AREVA Framatome-ANP will provide engineering development to modify system for this setup. The system currently has a hardwired cable from the probe to the data acquisition and analysis console.

Exam Stage Interface

ANL-W will design, engineer and fabricate a bracket to mount the eddy current equipment to the stage or magazine support at the gamma scan station. AREVA Framatome-ANP will provide a vertical system design that minimizes the engineering effort by ANL-W. ANL-W will design and engineer a rod support fixture to

accommodate PWR rod lengths. The rod support fixture may be incorporated as a feature on the eddy current bracket. The ANL-W costs for this task consist of materials and supplies and the effort for mechanical engineering, machine shop, drafting, out-of-cell qualification and installation.

4.5 Neutron Radiography

Neutron radiography is offered as an option for nondestructive examination of the geometry of the as-irradiated rods. ANL-W is equipped with a neutron radiography facility that interfaces through the floor of the HFEF Main Hot Cell (Figure 5). The neutron beam is generated by a 250-kW Training Research Isotope General Atomics (TRIGA) reactor located below the Main cell. Irradiated LWR fuel rods and control rods are imaged at the East Radiography Station (Sub-Cell Area) using an elevator mechanism and specimen holders fabricated of neutron transparent material. The neutron flux at the East Radiography Station can be varied between 0.05-4 x 10^7 n/cm^{2}s.

The specimens are imaged using an indirect radiography method, which eliminates the effects of the high gamma-ray background emitted from the radioactive fuels and components. Two types of neutron detector foils are used to image details of structural materials and fuel features.

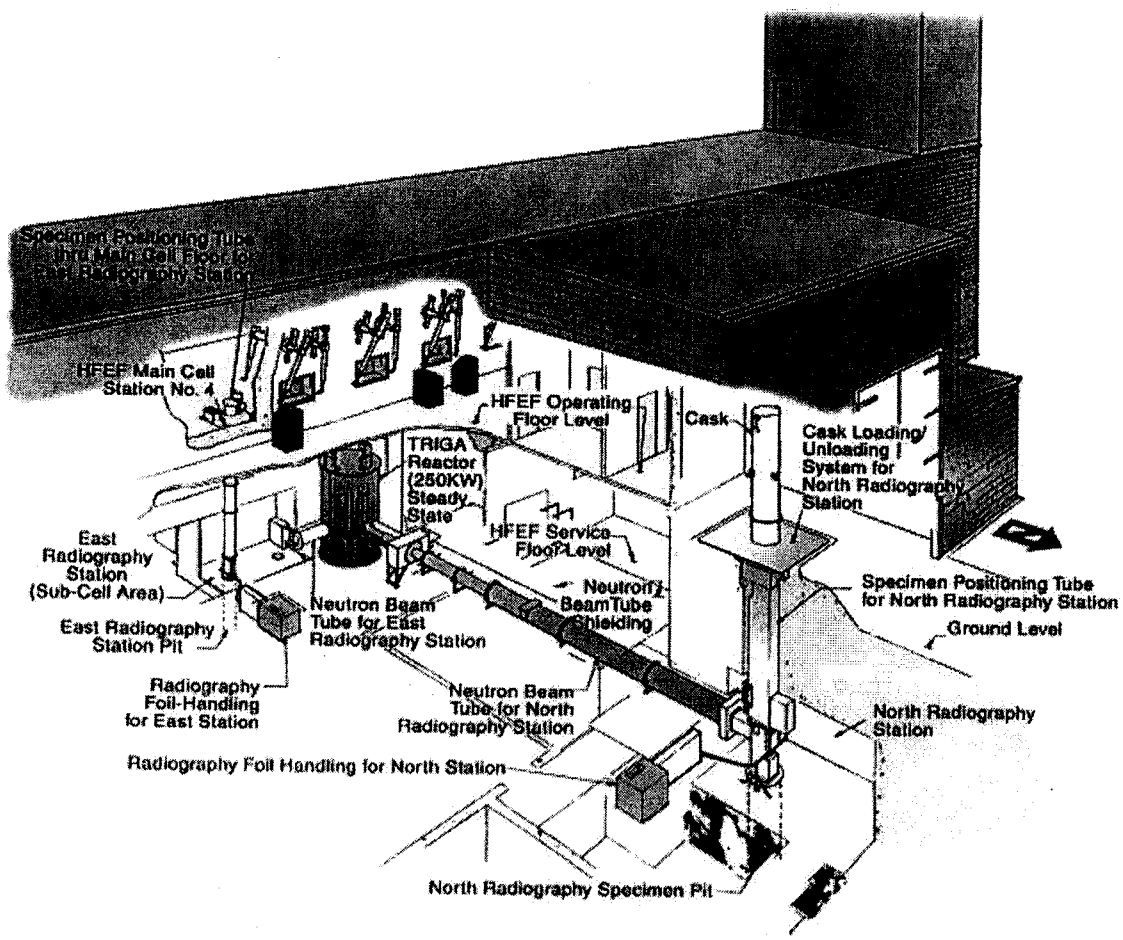


Figure 5 Neutron radiography facility at ANL-W.

Full-length radiography of LWR fuel rods is performed by inserting the fuel rod into a support holder and inverting the fuel rod. The support holder typically accommodates up to two rods. The rods are typically imaged at 2-4 azimuthal positions depending on the specific physical feature of interest.

Neutron radiography provides non-destructive examination of the general integrity of the fuel pellet column and cladding and the internal features of the fuel rods, specifically, fuel pellet chipping and cracking, pellet stacking irregularities, fuel pellet to pellet interface, axial growth, fuel pellet cracking, radial gap, and hydride blisters and cladding integrity. Figure 6 provides an example of the ANL-W neutron radiography capability.

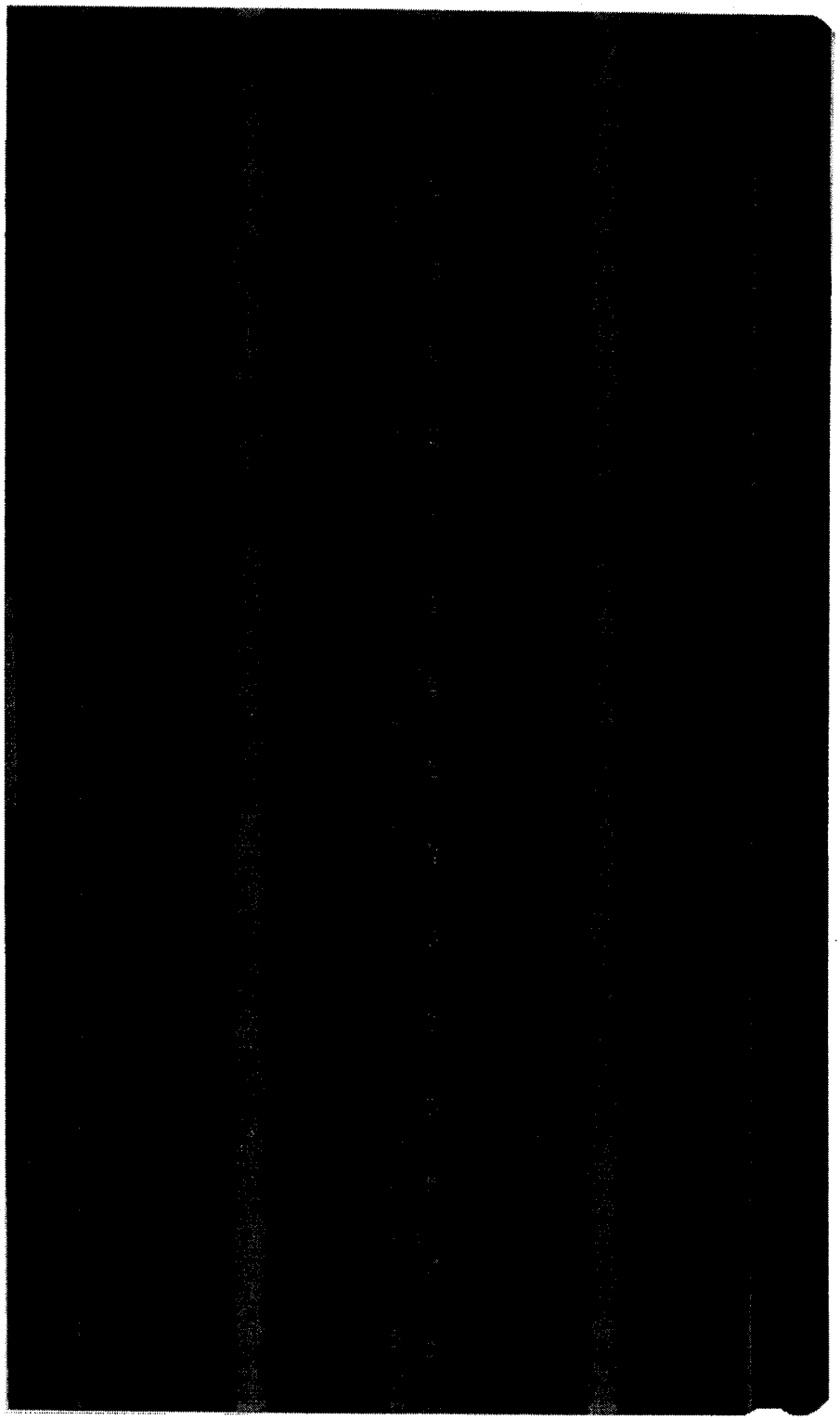


Figure 6 ANL-W neutron radiograph of two PWR fuel rods irradiated to ~30 GWd/t burnup and after 15 years dry storage, revealing the internal condition of fuel pellets and pellet to pellet interfaces.

5 DESTRUCTIVE EXAMINATION CAPABILITY

5.1 Fission Gas Puncturing and Analysis

The fuel rods will be laser-punctured to determine the internal gas pressure and internal void volume and collect samples for radiochemistry analyses. The fission gas samples will be analyzed for elemental and isotopic composition using a gas mass spectrometer. The fission gas release will be derived from the isotopic composition and the fuel burnup and independently from the elemental gas composition using the internal void volume, internal gas pressure, and the fuel burnup. The system will provide 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 illustrated in Figure 7. The system is comprised of a 150 W pulsed laser, shielded cell-wall feed-throughs for optics and gas lines, a mechanical vacuum pump, calibrated volumes, gages and controls. A neoprene gasket is used to form the leak tight seal between the object to be assayed and the sealing/puncture chamber.

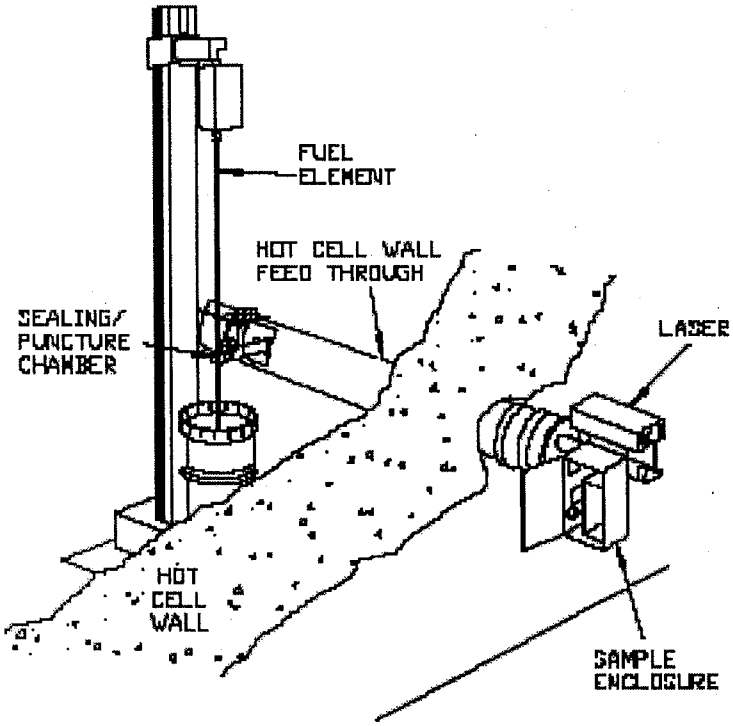


Figure 7 Illustration of apparatus used to determine capsule and rodlet assembly internal gas pressure and void volume (Gas Assay, Sample and Recharge System)

5.2 Metallography – Oxide Layer and Hydriding

The metallography capabilities include a separate sub-cell for sample preparation and a Leitz metallograph and scanning electron microscope (SEM) in a shielded hot cell (see Figure 8) and modified for remote operation. The sample preparation sub cell has an independent atmosphere control system and facilities for sectioning, mounting, grinding, polishing and etching. The optical microscopy, scanning electron microscopy and radiochemistry samples are transferred by a pneumatic transfer system. The Leitz metallograph is equipped with a projection screen and high resolution digital camera for data acquisition.

Cladding features characterized by metallography will include microstructure, crud and oxide layer thickness, and the inner and outer diameter of the oxide layer. Hydride density, orientation and distribution will be characterized after etching.

5.3 Metallography – Second Phase Particles

The size and distribution of second phase particles of the fuel rods are measured by scanning electron microscopy. The Zeiss 960 A Scanning Electron Microscope can operate at accelerating voltages up to 40 keV with a resolution limit of about 3 nm.

As an option, ANL has the capability for transmission electron microscopy (TEM) to conduct high resolution structure and composition analysis of cladding, both in plane view and cross section. Plane view analysis allows the determination of size and density distributions of second phase particles (SPP). TEM in conjunction with energy dispersive x-ray (EDX) analysis allows detailed information of the composition and crystal structure of these SPP. The JEOL 2010 200 kV advanced analytical electron microscope is equipped with an Oxford Link Isis energy dispersive x-ray spectrometer (EDS) for chemical analysis of elements higher than boron in the periodic table with a resolution of about 0.5 wt%. Quantifying changes in SPP during in-service exposure may be important in identifying cladding degradation mechanisms.

Cross section TEM analysis can be employed to analyze the interface between the cladding and oxide corrosion products that may have formed on the surface of the cladding during service. Oxide structure and compositional changes through the oxide can provide important information on the influence of cladding chemistry and structure on oxidation behavior.

Sample preparation equipment includes a Gatan precision ion polishing system, Gatan dimpler, South Bay tripod polisher, core drill, ultrasonic disc cutter, slurry drill core cutter, and eletropolishing equipment.

5.4 Ceramography

Fuel features characterized by ceramography will include grain size, porosity, microstructure, the rim region and fuel cladding interaction layer. Microhardness analyses can be performed with the Leitz Metallograph, if desired.

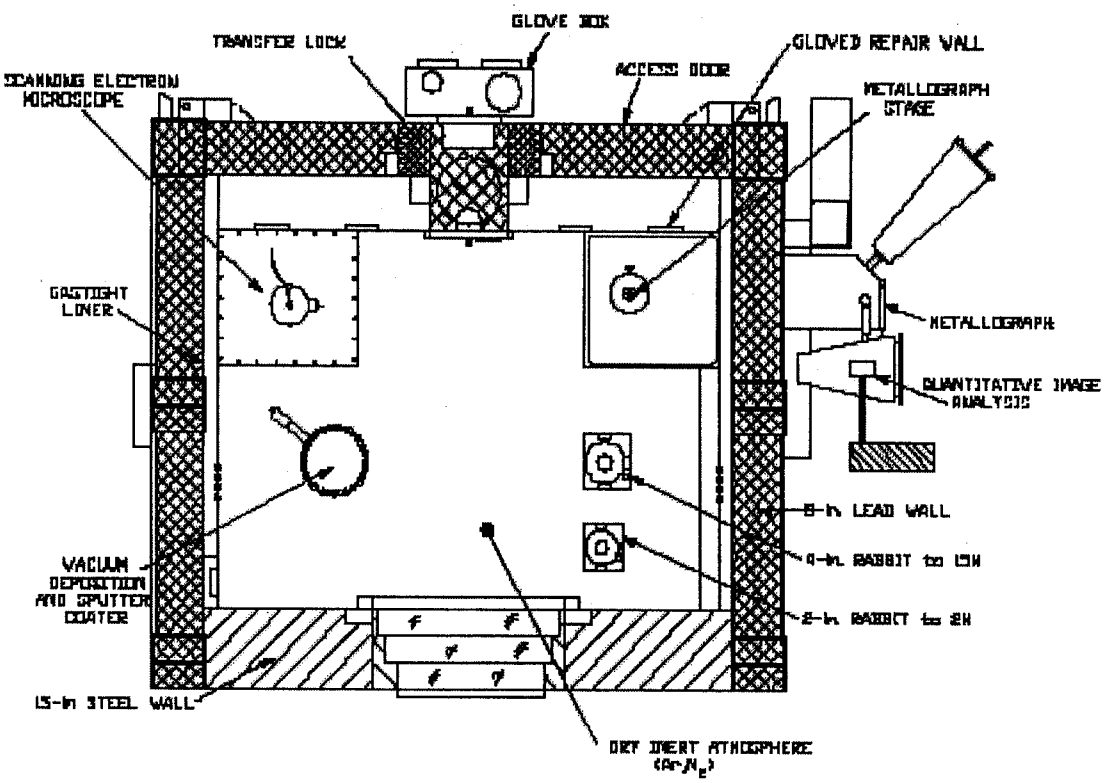


Figure 8 Inert atmosphere hot cell used for optical and electron microscopy.

5.5 Fuel Composition Profiles

A microgamma scan system will be used for determining radial isotopic and burnup profiles of fuel and in-core component samples. This system is comprised of a remotely operated precision motorized stage for positioning a sample and shield/collimator interfaced with an in-cell gamma counting system. ANL will measure the profile across the entire diameter of the sample.

5.6 Fuel Isotopics

Uranium and plutonium isotopics will be determined for U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240 and Pu-242. Burnup for each slice will be reported. Accurate determination requires the destructive dissolution of the sample followed by necessary radiochemical separations and radiation counting for the specific isotope of interest. Accurate determination of the total composition of the samples is also required. This work is carried out in a shielded analytical laboratory facility capable of performing acid digestions and radiochemical separations. Instrumentation used to perform the actual measurements includes lithium drifted germanium detectors and/or inductively-coupled plasma mass spectrometry (ICP-MS) for measuring activation products and inductively-coupled plasma-atomic emission spectrometry (ICP-AES) for elemental analyses. The two-sigma uncertainties range from 0.5% for major isotopes, 1 to 5 % for non-major isotopes depending on the amount of analyte present, and 5% for burnup..

5.7 Hydrogen Analysis

Hydrogen analysis of cladding and guide tube samples is performed with a LECO RH404 Hydrogen Analyzer modified for remote hot cell operation. The sample columns, furnace and thermal conductivity sensor components are separated from the electronics and reassembled in-cell. Measurement accuracy is ±10 ppm hydrogen.

5.8 Tensile Testing – Axial and Ring

ANL has a Charmille Andrew Electric Discharge Wire-Cutting Machine for remote machining of precise test specimens from irradiated materials. The precision of the machining is ±0.0127 mm (±0.0005 in.).

Tensile testing capability comprises an Instron 8511 servohydraulic driven tension/compression/cyclic testing machine that can be operated under vacuum or inert atmosphere up to 800°C. There is extensive experience testing both axial and ring tensile specimens and interpreting the data.

5.9 Burst Testing

Burst testing with temperature ramp is available. Burst testing with pressure ramp can be developed.

5.10 Thermal-Creep Testing

ANL has developed a thermal creep test system for cladding samples comprised of high temperature furnace, inert gas pressurization line, on-line temperature monitoring and remote controlled software program. Dimensional inspections are performed at interim periods. Creep-rupture tests of tensile specimens is can be conducted under vacuum or inert atmosphere up to 800°C using an Instron 8511 testing machine.

5.11 Pellet Density

Density measurements on irradiated fuel are performed using an immersion density apparatus located in the shielded hot cells in the Analytical Laboratory. The density apparatus includes an analytical balance equipped with a device to weigh a sample in air and submerged in a liquid, generally water. The equipment is designed for remote operation using manipulators. Measurement accuracy is determined based on NIST standards. Uncertainties of less than 0.1 % can be expected. Density of larger sections can be measured with gas pycnometry.

6 SCHEDULE

ANL can receive shipment of the fuel rods and guide tube segments in March 2005. ANL is capable of completing the statement of work within a two year performance period. If certain data are critical for an earlier delivery date, we can establish that during contract negotiations with the sponsoring organizations. The statement of work will be organized according to a work breakdown structure, with associated schedules and costs. ANL will provide periodic and final Hot Cell data reports. .

7 WASTE DISPOSAL

We will accept the fuel rods and guide tube segments. We will perform non-destructive examinations, then section and prepare test samples for destructive examinations. Recognizing the scientific value of the material, we will retain test material and remnants for, as long as reasonable, so further testing can be performed. Incidental material (e.g., curf and solidified waste from dissolution) will be handled with other similar waste streams generated on site. Eventual disposition will be disposed in a federal waste repository along with other similar fuel.

Attachment C

Cost Estimate

Activity	Quantity	Results/Comments	ENT Exempt	ENT Non-Ex	ENT M&S	NT Exempt	NT Non-Ex	NT M&S	FAC Exempt	FAC Non-Ex	FAC M&S	ET Exempt	ET Non-Ex	ET M&S	Drafting	Mach. Shop	MachSh Mat	Total
Fuel Shipment																		
Issuance of Project Plan			0	0	0	38899	0	0	0	0	0	0	0	0	0	0	0	38899
Project Review Meeting			0	0	0	19450	0	101563	0	0	0	0	0	0	0	0	0	121012
Empty Cask Depart NAC's facility			0	0	0	4862	0	112572	0	0	0	0	0	0	0	0	0	117435
Loaded Cask Depart N. Anna			0	0	0	4862	0	101563	0	0	0	0	0	0	0	0	0	106425
Cask Unloading			0	0	0	4862	0	101563	0	0	0	0	0	0	0	0	0	106425
Fuel Receipt																		
Fuel Receipt			0	0	0	0	0	0	14430	21179	0	0	0	0	0	0	0	35609
Non-destructive Examination																		
Write PWS-NDE			0	0	0	0	0	0	7215	580	0	0	0	0	0	0	0	7795
Neutron Radiography	1	Full length exam at 2 angles. Exam fixture accommodates 1-2 fuel rods for same price.	0	0	0	0	46	0	2345	9284	0	0	0	0	0	0	0	11675
Install End Fittings	6		0	0	0	0	0	0	2886	1161	2286	0	0	0	0	0	0	6332
Receipt Inspection	4	Full length exam by video and high resolution digital still photography	0	0	0	0	0	0	10101	4642	14286	0	0	0	0	0	0	29029
Gamma Scan Surveillance	1		0	0	0	0	0	0	6854	2901	0	0	0	0	0	0	0	9756
Dimensional Data	4	Diameter and length data obtained simultaneously.	0	0	0	0	0	0	5483	5106	0	0	0	0	0	0	0	10590
Eddy Current Oxide Measurement	1		0	0	0	0	0	0	2886	2901	0	0	0	0	0	0	0	5787
Destructive Examination																		
Write PWS-Destructive Exams			0	0	0	0	0	0	7215	580	0	0	0	0	0	0	0	7795
Fission Gas Puncture & Analysis	4		0	0	0	8754	0	8571	10101	6963	571	0	0	0	0	0	0	34961
Section rods in Main Cell	4		0	0	0	0	0	0	1443	2611	0	0	0	0	0	0	0	4054
Metallography Setup Saw			0	0	0	0	0	0	1443	2321	0	0	0	0	0	0	0	3764
Cladding Metallography Exam	8	8 oxide thickness. 5 hydride morphology and orientation.	0	0	0	0	0	0	19932	21614	357	0	0	0	0	0	0	41903

Activity	Quantity	Results/Comments	ENT Exempt	ENT Non-Ex	ENT M&S	NT Exempt	NT Non-Ex	NT M&S	FAC Exempt	FAC Non-Ex	FAC M&S	ET Exempt	ET Non-Ex	ET M&S	Drafting	Mach. Shop	MachSh Mat	Total
Cladding SPP Exam	2	TEM analysis. SEM analysis also available	0	0	0	60829	0	0	30	1475	0	0	0	0	0	0	0	62334
Guide Tube Metallography Exam	2	2 oxide thickness. 2 hydride morphology and orientation.	0	0	0	0	0	0	6133	6383	214	0	0	0	0	0	0	12730
Fuel Ceramography Exam	4	Grain size, porosity.	0	0	0	0	0	0	6133	7543	143	0	0	0	0	0	0	13819
Microgamma scan	4	Radial burnup profile	0	0	0	10614	0	0	60	629	0	0	0	0	0	0	0	11303
Isotopic Analysis & Burnup	4	Uranium and plutonium assay and isotopic analysis. Burnup analysis.	0	0	0	21083	0	1714	60	2950	0	0	0	0	0	0	0	25807
Cladding Hydrogen Analysis	8	H2 measurement (LECO RH-404 H2 analyzer)	0	0	0	22979	0	1286	120	5899	0	0	0	0	0	0	0	30284
Guide Tube Hydrogen Analysis	2	H2 measurement (LECO RH-404 H2 analyzer)	0	0	0	3283	0	429	30	1475	0	0	0	0	0	0	0	5216
Pellet Density Test	4	Archimedes Immersion Test	0	0	0	11891	0	1714	60	2950	0	0	0	0	0	0	0	16615
Ship Samples to ANL-E			0	0	0	0	0	0	14430	35395	10000	0	0	0	0	0	0	59826
Cladding Axial Tensile Tests - RT	4	YS, UTS, UE and TE. Fractography post-tensile test	0	0	0	0	0	0	0	0	0	33618	33618	11043	0	0	0	78278
Cladding Axial Tensile Tests - 400˚C	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladding Ring Tensile Tests - RT	4	YS, UTS, UE and TE. Fractography post-tensile test	0	0	0	0	0	0	0	0	0	39221	39221	12883	0	0	0	91325
Cladding Ring Tensile Tests - 400˚C	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guide Tube Axial Tensile Tests - RT	2	YS, UTS, UE and TE. Fractography post-tensile test	0	0	0	0	0	0	0	0	0	16809	16809	5521	0	0	0	39139
Guide Tube Axial Tensile Tests - 400˚C	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladding Plane Strain Ring Tensile Tests - RT	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladding Plane Strain Ring Tensile Tests - 400˚C	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladding Burst Tests - T ramp/const P	4	Fractography post-burst test included.	0	0	0	0	0	0	0	0	0	39221	39221	12883	0	0	0	91325
Cladding Burst Tests - P ramp/const T	4	Fractography post-burst test included.	0	0	0	0	0	0	0	0	0	74239	74239	24386	0	0	0	172864
Cladding Thermal Creep Test	4	Fractography post-creep test included.	0	0	0	0	0	0	0	0	0	56030	56030	18404	0	0	0	130464

Activity	Quantity	Results/Comments	ENT Exempt	ENT Non-Ex	ENT M&S	NT Exempt	NT Non-Ex	NT M&S	FAC Exempt	FAC Non-Ex	FAC M&S	ET Exempt	ET Non-Ex	ET M&S	Drafting	Mach. Shop	MachSh Mat	Total
Waste Handling & Packaging																		
Waste Handling & Packaging			0	0	0	8754	0	0	29582	27562	67143	55000	55000	0	0	0	0	243041
Reporting, Technical & Project Engineering																		
Technical Reporting & Travel ANL-E			0	0	0	0	0	0	0	0	0	112059	0	2000	0	0	0	114059
Technical Reporting & Travel ANL-W			0	0	0	146040	0	5714	0	0	0	0	0	0	0	0	0	151754
Project Engineering Management			0	0	0	146040	0	0	0	0	0	0	0	0	0	0	0	146040
[illegible]			0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]
S&S Services & Non-DOE Taxes			0	0	0	48486	[illegible]	41257	14075	16449	8975	18054	13307	3690	0	0	0	[illegible]
TOTAL			0	0	0	561689	50	477946	163047	190554	103976	444250	327444	90811	0	0	0	2359767