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Fissile Materials Disposition Program Light Water Reactor Mixed Oxide Fuel Irradiation Test Project Plan Revision 2

B. S. Cowell
S. A. Hodge

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Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
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B. S. Cowell

S. A. Hodge

Concurred by	John M. Ryskamp (INEEL)	7/7/97 Date
Concurred by	David Alberstein (LANL)	7/2/97 Date
Submitted by	Sherrell R. Greene (ORNL)	7/15/97 Date
Approved by	Patrick T. Rhoads (DOE/MD)	7/22/97 Date

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
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Fissile Materials Disposition Program Light Water Reactor Mixed Oxide Fuel Irradiation Test Project Plan

1.0 Introduction

The United States Department of Energy Fissile Materials Disposition Program (FMDP) has announced that reactor irradiation as mixed uranium-plutonium oxide (MOX) fuel is being pursued for disposal of surplus weapons-usable plutonium (Pu). Although MOX fuel is not currently utilized domestically, it is widely employed in a number of foreign countries. MOX fuel utilization is supported by a large body of MOX fuel irradiation experience that has been generated through research, development, and deployment programs since the mid-1950s. MOX fuel has been utilized domestically in test reactors and on an experimental basis in a number of commercial light water reactors (CLWRs). Over 300,000 MOX fuel rods have been successfully irradiated in the United States and Europe. Most of this experience has been with reactor-grade plutonium, which is derived from spent low enriched uranium (LEU) fuel. To pursue disposition of surplus weapons usable plutonium via reactor irradiation, it must be demonstrated that the unique properties of the surplus weapons-derived or weapons-grade (WG) Pu do not compromise the applicability of this MOX experience base.

2.0 Purpose and Scope of the Irradiation Test Project

One of the challenges facing the FMDP is to demonstrate that substitution of WG Pu for the reactor-grade (RG) Pu in commercial MOX fuel does not affect deleteriously the fuel performance, and that the commercial MOX experience base is therefore applicable. It is the purpose of this test project to contribute new information concerning the response of WG Pu under irradiation. The philosophy behind most MOX fuel development and qualification efforts is that MOX fuel is 95 percent UO_2, and from a materials standpoint, should therefore behave similarly to UO_2 fuel. This philosophy has been adopted and modified for the FMDP mission—plutonium constitutes but a small fraction of the material in MOX fuel, so WG MOX fuel behavior should be similar to that of both RG MOX fuel and UO_2 fuel.

The MOX fuel irradiation demonstration described herein is an initial step toward confirmation of this assertion. The primary focus of the irradiation tests is to address some important outstanding technical issues for the deployment in CLWRs of MOX fuel cycles based upon weapons-derived plutonium. Initial test planning included the provision that the technical objectives of the demonstration project would be limited to those generic issues that could be addressed without biasing programmatic procurement activities.

The LWR MOX fuel irradiation tests will irradiate MOX fuel produced in the TA-55 facility at the Los Alamos National Laboratory (LANL). Two types of MOX fuel pellets are being irradiated in order to investigate some unresolved generic fuel development/qualification issues. Simple, uninstrumented, drop-in capsules with local flux monitor wires are inserted in the Advanced Test Reactor (ATR) at the Idaho National Engineering and Environmental Laboratory (INEEL). Postirradiation examination (PIE) of this fuel is performed in the Irradiated Fuels Examination Laboratory at the Oak Ridge National Laboratory (ORNL).

The project's goals, assumptions, and requirements are described in Section 3. Section 4 contains a discussion of the technical issues addressed in the demonstration. Section 5 explains the organizational roles and responsibilities. Technical details of the project test matrix are provided in Section 6. Section 7 describes the hierarchy of project documentation and the methods for document control. Cost and schedule estimates are outlined in Section 8. Finally, Section 9 provides a brief summary of the overall project.

3.0 Goals, Assumptions, and Requirements

The four top-level ***goals*** of this Project are:

1) Demonstrate the utilization of Pu derived from weapons components* in a light water reactor (LWR) environment.
2) Contribute experience with irradiation of gallium-containing fuel to the data base required for resolution of generic LWR WG MOX fuel design issues.
3) Initiate irradiation of LWR WG MOX fuel in CY 1997.
4) Exercise the infrastructure necessary to promote WG MOX fuel irradiation by successfully demonstrating abilities to convert Pu metal from weapons components to oxide, fabricate MOX fuel, transport the fresh fuel, irradiate the fuel, transport the irradiated fuel, and perform the postirradiation examination.

The test will emphasize the development of additional information toward the resolution of generic performance issues to assist in mission fuel licensing and utility acceptance. Several additional ***requirements*** imposed on the test activity are summarized below:

1) All test fuel will be produced in the TA-55 facility at LANL.
2) The test will not assess issues related to inclusion of burnable poisons in MOX fuel.
3) The test fuel will be fabricated to meet a generic LWR MOX fuel pellet specification developed by ORNL using process specifications developed by LANL.
4) The test will include a comparison of the behaviors of test fuels with and without thermal treatment for removal of gallium.

* The surplus plutonium inventory contains other WG Pu material besides the weapons components, but all references to WG Pu in this plan pertain only to material derived directly from dismantled weapons components.

5) The plutonium for the test fuel will be derived from one or more weapons components. At least a portion of this material will be derived from components containing the maximum available gallium concentration (~1 weight percent).
6) Test conditions will reproduce LWR operating temperatures (clad and centerline) to the extent possible, as explained in the detailed Design, Functional, and Operational Requirements Document. (The thermal gradient across the fuel is implicitly determined by the specified values for the pellet surface temperature and the linear heat generation rate.)
7) The selection of fuel dimensions, cladding, fuel specifications, and burnup will be accomplished in a manner that does not bias future programmatic procurement activities.
8) The test fuels can be removed from the reactor at selected points within a range of burnups.
9) Domestic facilities will be used for fabrication, irradiation, and PIE.

4.0 Technical Issues Addressed

Several issues must be resolved prior to implementation of WG MOX use in CLWRs. Because this demonstration project was initiated before selection of a mission fuel design and fabrication process, only generic issues are addressed here. Three generic issues that must be considered in the final fuel design are: (1) the effects of gallium, (2) the specific isotopics of WG Pu, and (3) the use of hydride-derived PuO_2 in lieu of aqueous-derived PuO_2. These three issues are addressed in the planned irradiation test activities.

Gallium is an alloying agent present in WG Pu at concentrations up to approximately one weight percent. The technical issue is whether the small quantities of gallium present in the feed plutonium metal and the finished MOX fuel will adversely affect either MOX fuel fabrication or irradiation performance. *Residual gallium concentration is the primary variable of interest in the MOX fuel types to be produced by LANL.* One batch of fuel was fabricated from Pu feed that contains approximately one weight percent gallium and without special treatment for removal of impurities. The second fuel batch was made with a nominal one weight percent gallium feed processed with a PuO_2 powder thermal-conditioning step to remove the gallium. The gallium concentration was measured as necessary to map its evolution through the various processes.

The second generic issue to be addressed in this demonstration project is the specific isotopics of WG Pu. Early MOX fuel was made from plutonium recovered from low burnup UO_2 fuel, or from military stocks. However, only a very limited quantity of MOX was made from this high grade plutonium (low Pu^{240} content). Almost all of the commercial MOX fuel experience is with RG Pu, which is recovered from high burnup UO_2 fuel and contains an appreciable quantity of the higher isotopes (primarily Pu^{240} and Pu^{241}). Differences in nuclear characteristics are apparent between fuels made with the different Pu feeds. The fabrication, handling, performance prediction, and actual irradiation performance of WG MOX fuel will be demonstrated by this Project.

The final generic issue to be addressed is the determination of the effects of variations in the metal-to-oxide conversion process. The RG PuO_2 used as feed in commercial MOX is produced almost exclusively through precipitation of plutonium oxalate from aqueous nitric acid solution. The resulting powder has a uniform and well-characterized morphology, which assists in the achievement of a uniform finished MOX fuel product. Several dry pyroprocesses have also been investigated for possible application to the FMDP mission. The baseline pyroprocess, identified by the ARIES project, was used to convert the weapons components into the feed oxide powder for the two MOX test fuels.

5.0 Organizational Roles and Responsibilities

This test project is sponsored by the Department of Energy Office of Fissile Materials Disposition (DOE-MD), which is responsible for oversight to ensure that the goals of the project are consistent with the FMDP program objectives. DOE-MD arranges funding authority for the accomplishment of the test. Oak Ridge National Laboratory (ORNL), as lead laboratory for reactor alternatives for fissile materials disposition, manages the program for DOE-MD. As lead laboratory, ORNL coordinates and oversees the activities of the other parties to ensure success of the project and report on progress, schedule, and cost for the entire project to DOE.

Acting as the program manager, ORNL has the principal responsibility to ensure that the irradiation test program meets the approved goals, requirements, and technical issues outlined in Sections 3 and 4. ORNL has developed the pellet and fuel pin specifications, designed and fabricated the irradiation basket and capsules, and predicted the fuel behavior and ultimate burnup. ORNL has the continuing responsibility to perform the postirradiation examination, package and dispose of the waste materials, and report the test results.

As lead laboratory for MOX fuel fabrication, Los Alamos National Laboratory (LANL) is responsible for developing the process parameters and producing the test MOX fuels in accordance with the pellet specifications and drawings. LANL obtained a source of weapons-derived PuO_2 feed stock including the available technical data showing its processing history and characteristics. In this effort, Lawrence Livermore National Laboratory (LLNL) has assisted LANL as a support laboratory, reporting to ORNL and DOE through LANL.

LANL loaded the MOX fuel pellets into the fuel cladding supplied by ORNL and performed the seal welding of the fuel pins. LANL provided the required data on the characteristics of the finished fuel pellets as specified in the Fabrication, Inspection, and Test Plan. LANL was also responsible for the packaging, transportation, safeguards and security, emergency response, and appropriate notifications of the finished fuel transfer to Idaho National Engineering and Environmental Laboratory (INEEL).

INEEL is the operator of the Advanced Test Reactor (ATR) where the test is conducted, and as such, has the responsibility for ensuring that the test is designed and operated in compliance with all of the applicable safety and regulatory requirements. INEEL loaded the fuel pins obtained from LANL into the stainless steel capsules and performed the seal welding of these capsules. Specifications, drawings, reactor data, and other guidance provided by INEEL was used by LANL and ORNL as a basis for ensuring that the test design meets the requirements of the ATR. INEEL performs the necessary tests and calculations and provides the documentation to permit the test insertion, conduct the test irradiation, and remove test rods at prescribed burnups. INEEL is responsible for the packaging, safeguards and security, emergency response, appropriate notifications, and transportation to ORNL of the irradiated test fuels for disassembly and PIE. Funding authorization for the INEEL activities is executed through ORNL.

To facilitate decision-making and communications, the three laboratories involved in the planning and implementation of the LWR demonstration test have designated representatives and alternates to participate in teleconferences normally conducted weekly. These teleconferences are led by ORNL, which, as part of its overall project management role, is responsible for obtaining consensus on issues emerging during implementation of the test. Any issues that cannot be resolved among the project participants will be brought to DOE-MD for resolution.

6.0 Detailed Description of the Demonstration

The LWR demonstration test matrix, Table 1, describes the two test-fuel types that address the generic issues described above. The compositions of these test fuels have been established to focus primarily on the behavior and acceptability of gallium impurities in the fuel. These tests will be used to confirm and extend the results of the out-of-pile Ga-clad corrosion tests conducted by researchers at ORNL and at the Amarillo National Resource Center for Plutonium and will complement the gallium removal and fuel fabrication research activities conducted at LANL and LLNL.

Test fuel 1 is fabricated from weapons components containing about 1 weight percent gallium and converted to oxide through the hydride process identified by the ARIES project. Test fuel 2 is identical to test fuel 1 with the addition of a gallium-removal thermal-processing step for the plutonia powder.

Both fuels are fabricated to the generic LWR MOX fuel pellet specification developed specifically for these tests. Generic zirconium alloy (Zircaloy) is utilized for cladding. The pellet size and shape are generic, representative of LWR pellet geometry but identical to none of the commercial fuels. The pellet diameter is determined by the available sizes of off-the-shelf zirconium alloy cladding tubes. The uranium diluent for the test fuels was derived from a single lot of depleted uranium powder converted via the ammonium diuranate (ADU) process.

Both of the WG MOX test fuels contain a nominal 5 percent total plutonium (measured as mass of plutonium metal in mass of total metal), which is equivalent to 4.7 percent fissile Pu. The nominal linear heat generation rate for the tests is 8 kW/ft; however, the test objectives can be satisfied for heat rates within the range 2--10 kW/ft as described in the Design, Functional, and Operational Requirements Documents.

One test fuel pin of each type was removed from the reactor after reaching about 8 GWd/MT, to provide an opportunity for early indication of the effects of residual gallium at low burnup. One additional fuel pin of each type was removed after reaching about 20 GWd/MT, to provide intermediate indication of any developing trends. The remaining seven fuel pins will be irradiated to approximately 30, 40, or 50 GWd/MT in accordance with Table 1.

Table 1. Test Matrix

Fuel Type	Description[a]	Initial Feed[b]	Pu Purification	Pu to PuO_2 Conversion	BU[c] [GWd/MT]
Test 1A	5% WG Pu MOX	1% Ga WG Pu	none	hydride	8
Test 1B	5% WG Pu MOX	1% Ga WG Pu	none	hydride	20
Test 1C	5% WG Pu MOX	1% Ga WG Pu	none	hydride	30
Test 1D	5% WG Pu MOX	1% Ga WG Pu	none	hydride	40
Test 1E	5% WG Pu MOX	1% Ga WG Pu	none	hydride	50
Test 1F	5% WG Pu MOX	1% Ga WG Pu	none	hydride	50
Test 2A	5% WG Pu MOX	1% Ga WG Pu	thermal	hydride	8
Test 2B	5% WG Pu MOX	1% Ga WG Pu	thermal	hydride	20
Test 2C	5% WG Pu MOX	1% Ga WG Pu	thermal	hydride	30
Test 2D	5% WG Pu MOX	1% Ga WG Pu	thermal	hydride	40
Test 2E	5% WG Pu MOX	1% Ga WG Pu	thermal	hydride	50

[a] The plutonium concentration values are ± 1% relative (0.0500±0.0005).

[b] The 1% Ga feed specification is a nominal value.

[c] These are the target burnups. Irradiation began in February 1998, and cumulative calendar time requirements to reach actual burnups achieved by end FY 2000 are: 8.6 GWd/MT – 7 months, 20.9 GWd/MT – 19 months, and 29.6 GWd/MT – 29 months. Estimates for succeeding burnups are: 40 GWd/MT – 50 months, and 50 GWd/MT – 69 months.

With respect to NEPA requirements, these tests are subject to a categorical exclusion according to 10CFR, Part 1021, Subpart D, Appendix B, Section B.3.10, to wit: "Small-scale research and development projects and small-scale pilot projects conducted (for generally less than two years) to verify a concept before demonstration actions, performed in an existing structure without major modification."

7.0 Project Documentation Hierarchy and Control

The document hierarchy for this project comprises three levels as necessary to provide for the appropriate degrees of oversight while maintaining, at the working level, the flexibility essential to timely completion of the project milestones.

Level 1: Project Plan

This is the top-level, controlled document that completely identifies and defines the Mixed Oxide Fuel Irradiation Test Project. For maximum effectiveness, length is restricted to no more than ten pages. The level of detail includes:

- top level purpose for and description of project
- test matrix in table format
- identification of participating organizations and their respective roles
- major milestones
- cost estimates

Approval:	DOE-MD
Concurrence:	Lab leads and/or project leads at ORNL, LANL, and INEEL
Other review:	MPR Associates

Level 2: Controlled Working Documents

These are the controlled detailed working documents that specifically guide the performance of the various steps of the test project. The Level-2 documents address all features of fuel fabrication, irradiation, and PIE and include

- INEEL Project Management Plan
- Design, Functional, and Operational Requirements
- Thermal/hydraulic Calculations
- Design Calculations (Stress Analyses)
- Technical Specification: Mixed Oxide Pellets for the Light-Water Reactor Irradiation Demonstration Test
- Capsule Loading and Operation Schedule
- Fabrication, Inspection, and Test Plans
- Purchase Orders for Pellets, Pins, and Capsules
- Transportation Plan
- Post Irradiation Examination (PIE) Plan
- Quality Assurance Plan per DOE Order 414.1
- Technical Evaluation Report(s)

Approval:	Line management at originating organization
Concurrence:	Lab leads and/or project leads at ORNL, LANL, or INEEL, as appropriate
Information Copies:	DOE-MD, MPR Associates.

Level 3: Non-controlled Working Documents

These are the working-level documents most susceptible to requirements for rapid generation, implementation, and change. They include communications (e-mail, fax, letter) between participating organizations as well as working documents subject to purely internal controls within a particular organization. For the latter category, which comprises documents such as internal project plans, monthly reports, and meeting minutes, internal organizational approval practices will be followed. Some of these Level-3 documents may be transmitted to DOE-MD for information purposes, but for these, neither approval nor concurrence will be sought.

This three-level approach is consistent with the preferred approach described in the Operations Manual (OM) under which DOE-MD approval items are separated from lower-level information into a document hierarchy. This Level-1 document satisfies the deliverable for a project plan for the LWR Demonstration as described in the FY 1997 and subsequent Annual Operating Plans.

8.0 Cost and Schedule Estimates

All expenditures for this Project during any year are in accordance with the FMDP Annual Operating Plan (AOP) for that year, which is a controlled document and is periodically revised. The actual costs for FYs 1997–1999 and the current cost *estimates* for the remaining period of the LWR Demonstration Project are summarized in Table 2.

Table 2. Cost Estimates ($M)

	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001
ORNL					
Direct LWR Demonstration	1.23	1.39	1.25	0.80	0.70
PIE Preparation and Performance	0.09	0.55	0.98	1.00	1.10
Fuel/Reactor Vendor Subcontracts	0.21	0.23	0.13	0.10	0.10
LANL					
Direct LWR Demonstration	1.50	1.26	0.47	—	—
INEEL	0.71*	1.18*	0.91	0.80	0.75
Total	3.74	4.61	3.74	2.70	2.65

* Includes $0.23M (FY 1997) and $0.02M (FY 1998) direct funding from DOE-MD.

	FY 2002	FY 2003	FY 2004	FY 2005
ORNL				
Direct R&D Demonstration	0.60	0.60	0.50	0.40
PIE Preparation and Performance	1.20	1.30	1.30	0.80
Fuel/Reactor Vendor Subcontracts	0.10	0.10	0.10	0.10
LANL				
Direct LWR Demonstration	—	—	—	—
INEEL	0.75	0.75	0.60	0.10
Total	2.65	2.75	2.50	1.40

The estimated costs for FYs 2000–2001 include allowances for the planning of additional irradiation of existing fuel capsules in the ATR. (There is no allowance, however, for costs for design, fabrication, and irradiation of additional test fuel.) The bases for the INEEL cost estimates are explained in the INEEL Project Management Plan (PMP), which is a Level-2 document. Allowances for contingencies are not included in Table 2. Details of any future test irradiations not covered by this Test Project Plan will be described by a dedicated Plan to be prepared for that purpose.

As with the cost estimates, schedule estimates are taken from the AOP. Each year's AOP will contain an updated set of milestones and due dates that will serve as the official means of tracking progress. The milestones are summarized in Table 3.

Table 3. LWR Demonstration Project Milestones

Activity	Start Date	Completion Date
Hold organization meeting	Oct. 8, 1996	Oct. 9, 1996
Prepare requirements document	Oct. 8, 1996	Jun. 6, 1997
Issue approved test plan	Mar. 1, 1997	Jul. 23, 1997
Initial fuel fabrication	May 1, 1997	Nov. 13, 1997
Design review meeting	May 28, 1997	May 28, 1997
Fresh fuel shipping plan (ORNL)	Jun. 1, 1997	Sep. 17, 1997
Prepare PIE plan	Jun. 15, 1997	Sep. 26, 1997
Basket and capsule fabrication	Jun. 20, 1997	Dec. 15, 1997
Capsule loading and seal welding	Jan.5, 1998	Jan. 21, 1998
Irradiation	Feb. 5, 1998	Jan. 2004
Irradiated fuel transportation plan (ORNL)	Feb. 16, 1998	Oct. 16, 1998
Initial fuel removal	Sep. 1998	Sep. 15, 1998
PIE activities	Nov. 1998	Mar. 2005
Quick Look report (8 GWd/MT)	Dec. 1998	Jan. 22, 1999
PIE report on early withdrawals	Feb. 1999	Nov. 18, 1999
Intermediate fuel removal	Sep. 1999	Sep. 27, 1999
Quick Look report (21 GWd/MT)	Jan. 2000	Mar. 2000
PIE report on intermediate withdrawals	Mar. 2000	Dec. 2000
Design review for burnup extension	Jun. 2000	Jun. 2000
Fuel removal at 30 GWd/MT	Jul. 2000	Jul. 2000
Quick Look report (30 GWd/MT)	Nov. 2000	Feb. 2001
PIE report on 30 GWd/MT withdrawals	Feb. 2001	Sep. 2001
Fuel removal at 40 GWd/MT	Apr. 2002	Apr. 2002
Quick Look report (40 GWd/MT)	Aug. 2002	Nov. 2002
PIE report on 40 GWd/MT withdrawals	Nov. 2002	Jun. 2003
Achieve burnup of 45 GWd/MT	Mar. 2003	Mar. 2003

Table 3. (continued)

Final fuel removal at 50 GWd/MT	Nov. 2003	Nov. 2003
Quick Look report (50 GWd/MT)	Mar. 2004	Jun. 2004
PIE report on 50 GWd/MT withdrawals	Jun. 2004	Jan. 2005
Prepare final test summary report	Jun. 2004	Apr. 2005

The planned date (November 2003) for final fuel removal is subject to revision depending on the date for the next ATR Core Internal Changeout, which will require a reactor shutdown of about four months. Any significant change to the current schedule will be promulgated by means of a future revision to this document.

9.0 Summary

The plan described in this paper defines the FMDP Light Water Reactor MOX Fuel Irradiation Demonstration tests conducted in the Advanced Test Reactor (ATR). This activity demonstrates the resolve of the DOE to move forward with WG plutonium disposition. Furthermore, these tests, in conjunction with the ongoing gallium evolution and corrosion studies, investigate several of the outstanding technical issues facing the reactor disposition option including the effects of residual gallium impurities, and the performance under irradiation of weapons-derived plutonium.

ORNL provides overall program management for DOE-MD, coordinates the various aspects of the project, and provides comprehensive reporting. ORNL designed the test vehicle to be utilized in the ATR. LANL fabricated all of the fuel. INEEL supplies irradiation services, provides capsule-design assistance as requested, and performs independent safety reviews.

The test fuels reaching 50 GWd/MT will be irradiated for approximately four effective full-power years in the ATR. All of the irradiated fuel will be shipped to ORNL for PIE. Examination will focus on the behavior of gallium and its interaction with the cladding. Measurements will also be taken to verify the predicted performance of the WG MOX fuel. All waste streams will be incorporated into the existing waste collection/disposal systems at ORNL.