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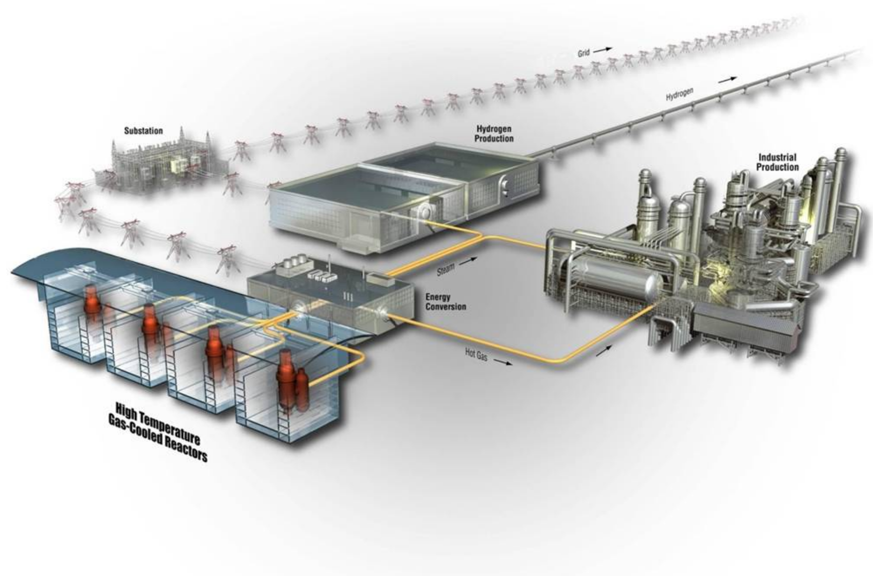
Statement of Work

Project No(s): 23841, 29412

AGR-2 PIE at Oak Ridge National Laboratory



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SIGNATURES			
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P For Preparer of the document.

A For Approval: This is for non-owner approvals that may be required as directed by a given program or project.

C For documented review and concurrence.

Note Quality Level 3 (QL3)

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	08/25/2014	All	New document
1	10/12/2015	All	Updated to include FY2016 work scope
2	04/26/2016	All	Revised to updated FY2016 work scope
3	10/24/2016	5, 10, 11, 13	Purpose/Objectives and scope
4	11/06/2017	All	Revised to updated FY2018 work scope
5	10/04/2018	All	Revised to updated FY2019 work scope

CONTENTS

1. INTRODUCTION

1.1 Background

Idaho National Laboratory (INL) Advanced Reactor Technologies (ART) is currently supporting a fuel development and qualification program, which includes fuel fabrication, test irradiations, and post-irradiation examination (PIE) and safety testing to assess fuel performance during normal irradiation and under potential accident conditions. PIE work on fuel from the second test irradiation, Advanced Gas Reactor-2 (AGR-2), began at INL in July 2014. This work scope includes Oak Ridge National Laboratory (ORNL) providing technical input, performing PIE testing and analysis, and contributing expertise to this effort.

1.2 Purpose/Objectives

The AGR-2 PIE work at ORNL includes:

a) Providing management support and oversight to planned activities
b) Performing safety testing using the Core Conduction Cooldown Test Facility (CCCTF)
c) Performing irradiated fuel compact deconsolidation and leach-burn-leach (DLBL) analysis
d) Performing visual inspection and irradiated microsphere gamma analysis (IMGA) of individual irradiated particles
e) Performing microanalysis of particles using various techniques, including optical and electron microscopy, elemental analysis, and x-ray microtomography
f) Developing equipment and performing individual particle heating tests
g) Performing moisture testing of surrogate materials and analyzing results
h) Preparing and shipping particles to INL for microscopy and re-irradiation
i) Performing burnup analysis on particles from designated compacts
j) Performing waste handling and disposition.

Experiments performed on irradiated AGR-2 fuel compacts will be performed as described in individual Compact Examination Plans. These will include specific data requirements and testing necessary for each compact and will be prepared in coordination with INL and ORNL staff prior to the start of PIE on the fuel specimens.

1.3 Anticipated Benefits

The primary objective of these activities is to better understand low enriched uranium carbide/oxide (LEUCO) and low enriched uranium dioxide ($LEUO_2$) fuel performance—in particular, fission product release behavior during irradiation and during high temperature accident simulations—and the effects of neutron irradiation and temperature on properties of the tristructural isotropic (TRISO) fuel such as particle coating layer microstructures.

2. APPLICABLE CODES AND REFERENCES

ASME NQA-1-2008/1a-2009, Part I is applicable to the work scope performed.

PLN-2690, Revision 18, August 2018, “INL ART Quality Assurance Program Plan”.

PLN-3636, Revision 7, June 2018, "Technical Program Plan for INL ART Advanced Gas Reactor Fuel Development and Qualification Program".

PLN-4616, Revision 0, December 2013, "AGR-2 Post-Irradiation Examination Plan".

3. SCOPE

3.1 Work to Be Performed

3.1.1 Provide Oversight and Technical Support

ORNL will support the INL ART AGR-2 PIE effort by providing technical input, analysis, and expertise; evaluating new PIE methods and preparing evaluation reports as needed; performing PIE work scope as identified below; and participating in PIE activities as requested. This work scope includes the general oversight of the ORNL PIE activities identified below, reporting on a bi-weekly and monthly basis as requested, and attending technical program meetings to present and discuss PIE data. Level 2 milestones related to completion of work on certain high priority activities have been established between INL and ORNL with deliverables prepared to provide the objective evidence of having completed the activities.

3.1.2 Training and Qualification

ORNL will perform training and qualification of operators and staff as necessary; develop or revise PIE procedures as required; maintain and upgrade the ORNL Quality Assurance Plan to include any new PIE activities; and maintain and update as necessary the ORNL Software Quality Assurance Plan.

3.1.3 Deconsolidation and Leach-Burn-Leach

Designated irradiated compacts will undergo deconsolidation and leach-burn-leach (DLBL) analysis using equipment installed in the shielded hot cells at the Irradiated Fuel Examination Laboratory. This activity is used to deconsolidate the compact matrix to liberate individual particles and then quantify the isotopic inventory outside of intact SiC coatings and determine if any particles with a defective SiC layer are present in the compact by performing analysis (gamma-ray and mass spectrometry) of the leaching solutions.

3.1.4 Particle Analysis and Irradiated Microsphere Gamma Analyzer

Individual irradiated particles (generated from compact deconsolidation as described above) will be visually inspected using the Particle Micro-Manipulator, with specific particles selected for subsequent analyses as needed. Particles will then be gamma counted using the advanced Irradiated Microsphere Gamma Analyzer (IMGA) device to quantify the inventory of gamma-ray-emitting radioisotopes. This activity will help to identify particles that may have damaged coating layers causing abnormally high fission product release and provide information on the extent of diffusive release of selected fission metals.

Maintenance, repairs, modifications, upgrades, installations of repaired/modified/replaced/upgraded IMGA equipment, etc. is also included.

3.1.5 Sample Preparation and Microanalysis

This activity will include non-destructive x-ray tomography of particles and materialographic sample preparation of whole compacts and/or individual particles using methods established previously at ORNL, with particular emphasis on defective particles identified by IMGA. Materialographic specimens will be characterized using a number of techniques, as appropriate, including: optical microscopy, scanning electron microscopy with elemental analysis (energy dispersive x-ray spectroscopy [EDS], and wavelength dispersive x-ray spectroscopy [WDS]). Other advanced techniques, such as transmission electron microscopy (TEM) and optical ellipsometry, may also be used to characterize coating fragments. Based on specific results and discussions with the INL ART PIE Technical Lead, some of these mounted particles may be sent to INL for additional microanalysis.

The goals of this activity are to investigate the detailed microstructures of particle kernels and coating layers and identify the location of fission products or actinides within the coating layers. This will provide a better understanding of the effect of irradiation on particle microstructures, the mechanisms of fission product transport through the coating layers, and possible particle failure mechanisms. This activity will also include the maintenance and repair of the associated analytical instruments as needed.

3.1.6 CCCTF Operations

This activity includes performing safety testing on as-irradiated AGR-2 compacts and/or particles. A safety test includes heating the fuel compact(s) or particle(s) in the CCCTF furnace to the specified target temperature (typically 1600 to 1800°C) for the specified time (typically 300 hours), while monitoring the time-dependent release of fission gas Kr-85 and condensable fission products collected on hot-swapped deposition cups. The work will involve maintenance and repair of the CCCTF furnace, operation of the furnace during safety testing, monitoring of the CCCTF fission gas collection system for Kr-85, and change out and initial gamma analysis of the deposition cups.

This activity may also include upgrading and modifying hardware and procedures as necessary, based on lessons learned during testing of irradiated compacts or in response to programmatic needs (e.g. addition of capability for simultaneous safety testing of three compacts in the CCCTF). This may include improvement in system calibration, metallic fission product collection efficiency, and analysis in coordination with similar development on the INL Fuel Accident Condition Simulator (FACS) furnace system.

3.1.7 CCCTF Deposition Cup and Component Analysis to Support Planned AGR-2 Safety Tests

Following safety testing, the internal components (in particular the graphite fuel holder, tantalum liner, and gas inlet tube) of the CCCTF furnace will be removed for radiochemical analysis for selected fission products. Deposition cups will also be subjected to supplemental gamma monitoring, if needed, followed by leaching for additional radiochemical analysis of the deposition cups to measure non-gamma emitting isotopes.

Post-safety test PIE of the fuel compacts will be performed as detailed above, including DLBL, IMGA, and microanalysis as required based on discussion with the INL ART TDO PIE technical lead.

3.1.8 Individual Particle Heating Tests

Safety testing of loose particles (deconsolidated from compacts) in the Furnace for Irradiated TRISO Testing (FITT) will enable the determination of fission product releases from the particles themselves without the effects of sorption/desorption of fission products from the compact matrix. Particles may be chosen in order to compare UO_2 and UCO performance. The testing will also allow releases over extended times (thousands of hours, if necessary) to be evaluated without monopolizing the CCCTF furnace. Particles having the same construction and similar burnups but different temperature histories (such as Capsule 2 versus Capsule 5) can be compared. Suitable particle holder materials and geometries will be chosen. Pre-test IMGA may also be used to select particles of interest. Pre-test gamma counting will determine the fission product inventory of the loose particles. Additionally, post-test gamma counting will determine the fraction of fission products retained in the particles. Both particles and FITT furnace components may be gamma counted. The difference between the pre- and post-test gamma counts provides a measurement of the fission product inventory that escaped the particle.

3.1.9 Moisture Testing of Surrogate Materials

In gas-cooled reactors, Probabilistic Risk Assessments (PRAs) have indicated that moisture-ingress events (due to steam generator tube leaks/ruptures) are more likely to occur than air-ingress events. Thus, data on the moisture oxidation of TRISO fuel layers (particularly the SiC layer) and fuel compact graphitic matrix material are desired in order to support accident modeling. The ORNL test matrix will be focused on graphitic matrix materials.

Some graphitic matrix samples have been fabricated from matrix precursor powder, and basic pre-test characterizations (e.g. density and microstructure) have been performed. While significant graphitic matrix sample production and characterization has been carried out, additional characterization of the as-fabricated graphitic matrix samples and comparisons to AGR-2 compacts will be performed. Furthermore, destructive and/or non-destructive exams will be done on graphitic matrix samples after oxidation testing.

Measurements of graphitic matrix moisture oxidation kinetic parameters was performed at ORNL in a thermogravimetric analyzer (TGA). The completion of data analysis and the reporting of these results is part of the work for FY19.

Some interest has been expressed by Nuclear Energy University Program (NEUP) participants in the graphitic matrix samples and other surrogate samples. ORNL work to organize/catalog available samples and send them (as-appropriate) to NEUP participants is included.

3.1.10 Prepare and Ship Particles for Re-irradiation Heating Testing or for Microscopy

This activity includes preparation, packaging, and shipping particles from ORNL to the Hot Fuel Examination Facility (HFEF) at INL. Particles for re-irradiation at INL will be selected from ORNL IMGA archives, impact fractured, and x-ray imaged to verify that the kernel has been exposed. Particles will be packaged in DOT Type A transportation packages and sent to INL. If warranted, additional particles could be sent to INL after discussing with the INL ART PIE technical lead. If requested by INL, additional particles would be riffled or specifically selected from existing AGR-2 particle archives available after planned compact deconsolidation and particle recovery for IMGA.

3.1.11 Burnup Analysis

The burnup and actinide isotopic inventories of representative particle samples from selected compacts will be analyzed based on chemical separations and high-resolution mass spectrometric measurements in order to compare to the predicted values from as-run physics simulations, as well as the measured values based on compact gamma spectrometry data. Chemical analysis and burnup calculation methods will be determined based on discussion with subject matter experts at INL and ORNL and will incorporate lessons learned from the AGR-1 burnup analysis. Methods will be approved by the INL ART PIE Technical Lead.

Selection of specific compacts to be used for this analysis will be based on several factors, including the as-run physics predictions for compact burnup (it may be desirable to select compacts that span the range of burnups), fast fluence, and irradiation temperature.

3.1.12 Waste Handling

This task includes the non-radiological and radiological waste handling and disposition from AGR-2 PIE activities to be performed at ORNL.

3.2 Work Excluded

Only AGR-2 related work scope is included. All other work scope is specifically excluded.

3.3 Requirements

3.3.1 Environmental

Work will be performed in accordance with applicable ORNL requirements.

3.3.2 Safety and Health

Work will be performed in accordance with applicable ORNL requirements.

3.3.3 Quality Assurance

ORNL will perform this work in accordance with its approved quality assurance program in compliance with ASME NQA-1-2008/1a-2009 criteria. INL ART Quality Assurance may elect to perform work inspections of selected processes. The INL and ORNL technical leads will identify the selected processes for inspection. INL will supply the inspection checklist to ORNL approximately three weeks prior to the inspection.

3.4 Place of Performance

The work scope identified in this SOW will be performed at various facilities at ORNL.

3.5 Interfaces

Interfaces will be between INL and ORNL technical representatives.

3.6 Miscellaneous

Preparations of presentations and reports, and travel will be included within this work scope in order to share the results found. This is expected and will be charged to the appropriate activity being supported.

4. DELIVERABLES

Activity Description	Completion Date	Deliverable	Associated INL Milestone	Milestone Level
ORNL to provide summary report(s) of two (2) AGR-2 destructive examinations	06/01/2019	Report(s) submitted to INL	ORNL to complete destructive examination on two (2) AGR-2 compacts	2
ORNL to provide summary report of Transient Safety Testing of three (3) AGR-2 compacts	09/06/2019	Report submitted to INL	ORNL to complete Transient Safety Testing of three AGR-2 compacts	2
ORNL to provide summary report(s) of the burnup analysis of two (2) AGR-2 compacts	9/12/2019	Report(s) submitted to INL	Complete burnup analysis of two (2) AGR-2 compacts	3

In addition to these specific deliverables, ORNL will provide input to INL ART monthly and quarterly progress reports as needed, and participate in bi-monthly AGR program teleconferences to discuss the latest progress and report any issues.

5. SCHEDULE AND MILESTONES

See “Deliverable” table in Section 4 above for schedule and proposed milestone.

6. COMPLETION CRITERIA AND FINAL ACCEPTANCE

Review and acceptance of documentation provided by ORNL will be performed by INL.

7. APPENDICES

None

8. ATTACHMENTS

None