ORNL/TM-2011/125

OAK RIDGE NATIONAL LABORATORY

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LOGOS Nuclear Systems

# Coated Particle Fuel and Deep Burn Program

# Monthly Highlights

## April 2011

**TRISO-Coated Particle with Mixed Pu, Th Oxide Kernel after High Pu Burnup**

UT-BATTELLE

ORNL-27 (4-00)

ORNL/TM-2011/125

# Coated Particle Fuel and Deep Burn Program

## Monthly Highlights
**for**
## April 2011

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Issued

May 2011

**Prepared for the**
**U.S. Department of Energy**
**Assistant Secretary for Nuclear Energy**
**Under DOE Idaho Operations Office**
**Contract DE-AC07-05ID14517**

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# 1. Project Management and Planning

The baseline change proposal BCP-FCRD-11026 submitted to change the due date for M21AF080202 "Demonstrate fabrication of Transuranic kernels of Plutonium-239/3.5at%Neptunium-237 using newly installed glove box facilities in ORNL 7930 hot cell complex" from 4/25/11 to 3/30/12 was approved this month.

## 1.1. Program reporting (*ORNL*)

During FY 2011 the CP & DB Program will report Highlights on a monthly basis, but will no longer produce Quarterly Progress Reports. Technical details that were previously included in the quarterly reports will be included in the appropriate Milestone Reports that are submitted to FCRD Program Management. These reports will also be uploaded to the Deep Burn website www.ms.ornl.gov/deep_burn/index.shtml

The Monthly Highlights report for March 2011, ORNL/TM-2011/96**,** was distributed to program participants on April 8, 2011. As reported previously, the final Quarterly for FY 2010, Deep Burn Program Quarterly Report for July – September 2010, ORNL/TM-2010/301, was announced to program participants and posted to the website on December 28, 2010.

## 1.2. Archiving program records (*ORNL*)

Program participants are requested to send reports, milestone documents and other pertinent documents to the webmaster, Shirley Shugart, shugartsa@ornl.gov, for uploading to the website.

# 2. Thermochemical Data and Model Development

## 2.1 Thermochemical Modeling

**Thermochemical behavior *(ORNL)***
A thermochemical Si-O-H database is now available for computing possible recession rates of the FCM SiC matrix under LOCA conditions. Preliminary calculations were performed assuming typical BWR fuel assembly configurations with pin surfaces consisting of SiC. LOCA conditions of 5 m/s steam velocities were used to compute recession rates of SiC assuming turbulent flow (ideal mixing). The results will be compared to experiment to understand any kinetic constraints.

## 2.2 Thermomechanical Behavior

**Thermomechanical behavior of TRISO in SiC matrix *(ORNL)***
The first principal stress state of a TRISO particle with and without SiC matrix was modeled via COMSOL based on the assumptions that no debonding will occur at the $UO_2$ kernel and porous graphite buffer layer, and also that CVD pyrocarbon properties are isotropic. The maximum first principal stress calculated at the interface of the $UO_2$ kernel and porous graphite buffer layer is 306 MPa and 238 MPa with and without SiC matrix, respectively. The first principal stress state with the cases of debonding and anisotropic properties of pyrocarbon will be modeled next. Also, mechanical properties (including Young's modulus and hardness) of coating layers will be measured via nano indentation.

## 2.3 Actinide and Fission Product Transport

*Nothing to report this month.*

## 2.4 Radiation Damage and Properties

**Thermal Transport *(ORNL)***
Thermal conductivity modeling of SiC continued during this period, on implementing a modified Tersoff interatomic potential. In addition, calculations were performed to determine the accuracy of the Green Kubo method for calculating thermal conductivity. Calculations with a large number of atoms have started.

# 3. TRU TRISO Development

## 3.1 TRU Kernel Development

**Glovebox installation at the REDC *(ORNL)***
Work to qualify the new glove boxes that will be used to fabricate the TRU gel spheres at the Radiochemical Engineering Development Center (REDC) has resumed. Remaining work to secure operational approval includes connecting the glove boxes to the ventilation system, final testing, and issue of the change and dedication packages. While operational approval is expected by the end of June, plutonium will not be introduced into the glove box until DOE approves plutonium operations.

**Fabrication of urania kernels containing SiC *(ORNL)***
The new internal gelation system continues to be used to fabricate uranium microspheres with 4 mol % silicon carbide, where the SiC will serve as an oxygen getter to enable good TRISO particle fission product retention at high burn up. Even though the amount of silicon carbide is relatively small, its presence has made it difficult to maintain a constant flow of feed to the gelation column. Modifications to the gelation system and test conditions have reduced the variability in the flow rate.

Initial calcination testing of $UO_2$/SiC microspheres up to 1265°C in argon and in argon-4% hydrogen was completed. The platinum tube furnace used in these tests was not designed to sinter fuel kernels because tramp oxygen can easily enter the furnace. Both hydrogen and oxygen will react with the SiC at the higher temperatures. The concentration of hydrogen needed to minimize the weight change due to these reactions was identified. Microspheres that were heated to 1265°C in 0.5% hydrogen had average diameter 769 ± 54 µm. When fully sintered these spheres are expected to have an average diameter in the range of 550 µm.

## 3.2 Coating Development

**TRISO coating system *(ORNL)***
Progress with TRISO coating work includes fabrication, procurement, and now assembly of the new coating furnace. The components for the new furnace were delivered from the fabrication vendor in March and the assembly of the furnace has begun. Several off the shelf items such as fasteners, gaskets, and o-rings are being procured, if they were not already available in local stocks, and assembled along with the custom machined components supplied by the vendor. Furnace assembly is expected to be complete on schedule with the existing milestone M2N1AF080203 "Complete fabrication and assembly of new coating furnace and issue letter report summarizing the status of planned glove box coating facility," due 6/30/2011.

# 4. Advanced TRISO Applications

## 4.1 Metal Matrix Fuels for LWR *(ORNL)*

Metal Matrix Microencapsulated fuel preparation is underway with fabrication of more Hot Isostatic Press and Extrusion cans.

# 5. LWR Fully Ceramic Fuel

## 5.1 FCM Fabrication Development

**FCM fabrication process optimization *(ORNL)***
Small amounts of sintering additives such as Y2O3 and Al2O3 are required for SiC matrix densification in producing SiC-matrix FCM fuel. Any retained sintering additives are potential weak links in mechanical properties and differential swelling compared to SiC produced by other methods. SiC plates fabricated by several conditions showed that SiC hot-pressed at 1900ºC reached strength above 1 GPa even with 3% retained sintering additives.

**FCM pellet fabrication *(ORNL)***
Twenty-four Fully Ceramic Microencapsulated pellets have been fabricated for HFIR irradiation. Different pellets were produced to provide unique particle loading and powder preparation conditions.

## 5.2 FCM Irradiation Testing *(ORNL)*

*Nothing to report this month.*

# 6. Fuel Performance and Analytical Analysis

## 6.1 Fuel Performance Modeling

**Fuel Performance Modeling *(INL)***
Benchmark calculations have been performed to verify lattice calculations in DRAGON. These will serve as confirmatory analyses for the extension of DRAGON models from single cell to assembly calculations.

Work continued on the planning of irradiation experiments for ATR with progress on modeling the Displacement Kerma cross section for carbon in SiC

Nuclear data preparation work for Pu and minor actinides has continued. In the reporting period, Penn State University in collaboration with INL completed the development of higher order terms for the treatment of resonant scattering by heavy nuclides, such as those present in Deep Burn fuel.

**Nuclear Systems support of Coated Particle fuel development *(Logos)***
The work by LOGOS is targeted at the analysis of performance and safety of the Fully Ceramic Micro-encapsulated (FCM) fuel when used in LWRs for utilization of Transuranics from LWR spent fuel. The main activities are:

- Neutronics performance studies, aimed at the optimization of TRU burnup using FCM within acceptable ranges of refueling cycles and enrichment
- Neutronics safety analysis, evaluating reactivity coefficients in the FCM TRU fueled LWR cores
- Thermohydraulics performance studies, aimed at minimizing the perturbation introduced by the use of FCM TRU fuel in LWR operations
- Thermohydraulics safety analysis, evaluating the safety of FCM TRU fuel with respect to DNB margins and Loss of Coolant events

Two LWR core configurations are being analyzed, at the fuel assembly and full core levels:

- CE System-80, using 16x16 fuel assemblies
- Westinghouse AP-1000, using 17x17 fuel assemblies

The work is proceeding on schedule and was 50% complete on April 30, 2011. In April we completed the analysis of reactivity feedbacks for the CE System-80 core and started the full core calculations for this configuration. We also completed the power peaking calculations for the Westinghouse AP-1000 core.

# 7. ZrC Properties and Handbook

## 7.1 Properties of ZrC

**Ag diffusion in ZrC (*UW-M*)**

Diffusion studies of Ag in ZrC will use $ZrC_{0.8}$ rods that were procured from Applied Physics Technologies. Pure zirconium and silver were also prepared for Ag/ZrC diffusion experiments.

# Appendix I

## Coated Particle and Deep Burn Fuels Program - ORNL FY2011

## Milestone Status April 30, 2011

| Item No. | Milestone number and description | Level | Due Date | % Complete |
|---|---|---|---|---|
| 1 | M31AF080104 - Report on Completed Design and Procurement of Simultaneous Thermal Analyzer. | M3 | 2/5/2011 | Completed |
| 2 | M31AF080105 - Model physical properties of TRISO fuel and fuel matrix to high dose. | M3 | 7/20/2011 | 50 |
| 3 | M31AF080106 - Issue report on thermochemistry and fission product transport and attack of high-burnup fuel including experimental verification path-forward. | M3 | 9/23/2011 | 35 |
| 4 | M31AF080102 - Simultaneous thermal analyzer is to be installed in a glove box to be used for identification and characterization of evolving fuel chemistry. | M2 | 9/23/2011 | 35 |
| 5 | M31AF080103 - Submit report summarizing progress and path forward on thermochemistry of high-burnup fuel including experimental path-forward. | M2 | 9/30/2011 | 35 |
| 6 | M31AF080204 - Report on Operational Approval to fabricate transuranic-bearing kernels in Bldg. 7920. | M3 | 6/30/2011 | 80 |
| 7 | M21AF080202 – Demonstrate fabrication of Transuranic kernels of Plutonium-239/3.5at% Neptunium-237 using newly installed glove box facilities in ORNL 7930 Hot Cell Complex. | M2 | 3/30/12 | 40 |
| 8 | M21AF080203 - Complete fabrication and assembly of new coating furnace and issue letter report summarizing status of planned glovebox coating facility. Document work to date on installation of in-cell TRU-coating facility. Develop plan for continuation of in-cell installation of coating equipment in 2012. | M2 | 6/30/2011 | 50 |
| 9 | M31AF080205 - Issue report documenting initial PIE of fuel compacts from the FTE-13 irradiation experiment focusing on Deep Burn relevant aspects of fuel. | M3 | 12/31/2011 | 30 |
| 10 | M41AF080302 - Incorporate SiC and graphite matrix physical properties models into FRAPCON and perform preliminary analysis. | M3 | 12/17/2010 | Completed |
| 11 | M31AF080303 - Issue report documenting the results of FRAPCON calculations comparing the fuel-clad physical interaction of SiC and graphite matrix options for fully ceramic matrix fuel form. | M3 | 2/25/2011 | Completed |
| 12 | M31AF080307 - Report on final design of rabbit irradiation vehicle for fueled and surrogate FCM fuel. | M3 | 3/17/2011 | Completed |
| 13 | M31AF080306 - Issue report on FCM optimization with surrogate TRISO. | M3 | 8/12/2011 | 50 |
| 14 | M31AF080305 - Issue report documenting work performed to expand parameters beyond initial point design economic analysis of the Deep Burn fuel system to understand critical drivers which may impact fuel design. | M3 | 11/25/2011 | |
| 15 | M2N11OR130202 – 7.2.7 Procure glove boxes for TRU-TRISO coating | M2 | 3/31/2011 | Completed |
| 16 | Temperature dependence of Ag diffusion in ZrC | | 9/30/11 | 5 |

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