NRC FORM 189 (3-81)

U.S. NUCLEAR REGULATORY COMMISSION

PROJECT AND BUDGET PROPOSAL FOR NRC WORK

DATE OF PROPOSAL: July 1983

☐ NEW ☒ REVISION NO.

PROJECT TITLE: SEVERE CORE DAMAGE MATERIALS PROPERTY TESTS

FIN NUMBER: B2455

NRC OFFICE: Nuclear Regulatory Research

NRC B&R NUMBER: 6019201

DOE CONTRACTOR: Pacific Northwest Laboratory - Battelle Memorial Institute

CONTRACTOR ACCOUNT NUMBER: TD 1687

SITE: Richland, Washington

DOE B&R NUMBER: 40-10-01-06

COGNIZANT PERSONNEL	ORGANIZATION	FTS PHONE NUMBER	PERIOD OF PERFORMANCE
NRC PROJECT MANAGER R. Van Houten	RES/DAE/FBBR	427-4463	STARTING DATE Ongoing
OTHER NRC TECHNICAL STAFF			COMPLETION DATE 09/30/85
DOE PROJECT MANAGER Maynard J. Planuta	RL/EPD	444-7034	
CONTRACTOR-PROJECT MANAGER E. L. Courtright	PNL	444-6926	
PRINCIPAL INVESTIGATOR(S) J.E. Garnier J.T. Prater C.W. Griffin G. Hunnel	PNL PNL PNL PNL	444-2483 444-6905 444-3436 444-2581	

STAFF YEARS OF EFFORT (Round to nearest tenth of a year)	FY 83	FY 84	FY 85	FY	FY
Direct Scientific/Technical	1.0	.9	1.2		
Other Direct (Grades)	.5	.6	.6		
TOTAL DIRECT STAFF YEARS	1.5	1.5	1.8		
COST PROPOSAL					
Direct Salaries	64	82	111		
Materials and Services (Excluding ADP)	25	20	20		
ADP Support	0	0	0		
Subcontracts	0	0	0		
Travel Expenses — Foreign	0	5	10		
Travel Expenses — Domestic	0	10	10		
Indirect Labor Costs	19	25	33		
Other (Specify)	37	28	38		
General and Administrative (%)	45	58	78		
TOTAL OPERATING COST	190	228	300		
CAPITAL EQUIPMENT FIN CHARGED: B2390 (TD 1359(	0	30	0		
TOTAL PROJECT COST	190	258	300		

FY 84

MONTHLY FORECAST EXPENSE

OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
38	25	20	20	20	20
APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
15	15	15	15	15	10

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FIN NUMBER: B2455

DATE: July 1983

PROJECT TITLE: SEVERE CORE DAMAGE MATERIALS PROPERTY TESTS

DOE PROPOSING ORGANIZATION: Richland Operations Office - Energy Programs Division

FORECAST MILESTONE CHART Scheduled to Start – △——▲ – Completed (Shown in Quarter Year)
PROVIDE ESTIMATED DOLLAR COST FOR EACH TASK FOR EACH FISCAL YEAR

TASK		FY 82 1st	FY 82 2nd	FY 82 3rd	FY 82 4th	FY 83 1st	FY 83 2nd	FY 83 3rd	FY 83 4th	FY 84 1st	FY 84 2nd	FY 84 3rd	FY 84 4th	FY 85 1st	FY 85 2nd	FY 85 3rd	FY 85 4th	FY 1st	FY 2nd	FY 3rd	FY 4th
I. Analysis & Reporting	SCHEDULE	△															▲				
	COST	2.5				47				50				110							
II. Zr-H_2O Oxidation	SCHEDULE		△												▲						
	COST		138				98				70				70						
III. Zr(O)-UO_2H_2O Reaction Kinetics	SCHEDULE			△													▲				
	COST			10			1				60				120						
IV. Viscosity of Liquified Fuel	SCHEDULE			△							▲										
	COST			66			44				40										
	SCHEDULE																				
	COST																				
TOTAL ESTIMATED PROJECT COST			216.5*				190				228				300						

PROJECT DESCRIPTION: *(Provide narrative descriptions of the following topics in the order listed. Attach an plain paper to this NRC Form 189. If an item is not applicable, so state.)*

1. OBJECTIVE OF PROPOSED WORK
2. SUMMARY OF PRIOR EFFORTS
3. WORK TO BE PERFORMED AND EXPECTED RESULTS
4. DESCRIPTION OF ANY FOLLOW-ON EFFORTS
5. RELATIONSHIP TO OTHER PROJECTS
6. REPORTING SCHEDULE
7. SUBCONTRACTOR INFORMATION
8. LIST NEW CAPITAL EQUIPMENT REQUIRED
9. DESCRIBE SPECIAL FACILITIES REQUIRED
10. CONFLICT OF INTEREST INFORMATION

SEE NRC MANUAL CHAPTER 1102 FOR ADDITIONAL INFORMATION

APPROVAL AUTHORITY–SIGNATURE: John D. Hughes — DATE: JUL 28 1983

*FY82 funded through FIN #82372 (TD1345)

1.0 Objectives

The purpose of this work is to provide high temperature materials property data in support of planned NRC Severe Core Damage programs. Primary focus is directed at high temperature ex-reactor physical property and reaction kinetic tests to develop data on cladding-fuel-structure reaction products. The program is divided into four tasks as follows:

Task I: Analysis and Reporting Results

Task II: $Zr-H_2O$ oxidation kinetics above 1500°C

Task III: $Zr(O)-UO_2-H_2O$ thermodynamic and reaction kinetic studies

Task IV: Viscosity of liquified fuel

2.0 Summary of Prior Efforts

Initial efforts were started in FY-82 under FIN B2372 and were directed at building and assembling the required experimental apparatus needed to obtain useful data. Key accomplishments to date are as follows:

- The experimental equipment needed to obtain high temperature transient oxidation data has been assembled and made operational.
- An oscillating cup viscosimeter was reconstructed and the capabilities developed to measure kinematic or shear viscosity in molten $Zr(O)/UO_2$ mixtures.
- The ability to detect ZrO_2 formation by laser-raman spectroscopy was demonstrated. However, preliminary tests indicated that a Ar^+ ion laser was not powerful enough to excite measureable H_2O and H_2 signals. A more powerful excitation source must be employed.
- Isothermal oxidation kinetics data was obtained at 1400°C for calibration purposes. The data is in good agreement with that reported previously by other investigators using different experimental techniques.

- The capability to perform fast-high temperature transient oxidation experiments and monitor thermal response in real time was demonstrated. Preliminary experiments have indicated that the sudden temperature rise commonly observed in Zr-H_2O reactions at high temperatures may be a result of poor heat dissipation in the developing oxide film as opposed to rapid total consumption of the underlying metal substrate. These results could have important implications in modeling fuel bundle damage during the course of a postulated accident.

- Viscosity measurements for Zr and Zr - 10 mole % UO_2 were made at temperatures up to 2000°C. The solids remaining in the initial two phase liquid-solid mixture significantly affect fluid behavior until complete melting has occurred.

3.0 Work to be Performed and Expected Results (FY-84)

Task I:

The purpose of Task I is to coordinate the program and to integrate data output with user needs. A close working relationship with SFD test programs in NRU and PBF will be established and an interface maintained with the studies being performed at KfK in Germany. Expected output for FY-84 are as follows:

- Quarterly reports

- A data report for Zr-U-O viscosity on mixtures containing up to 10 mole % UO_2 will be compiled. 10/15/83

- Issue a preliminary report of Zr-H_2O isothermal oxidation rates for temperatures between 1600°C-1800°C. 11/15/83

- Issue report identifying rate constants and activation energies for Zr-H_2O reaction kinetics between 1600°C-2000°C. 4/1/84

- Presentation of results and data at meetings identified by NRC. As required

- Hold coordination meetings with EG&G personnel to discuss SCDAP developments. As required

Task II:

An important part of analyzing and controlling high temperature SFD experiments requires a thorough understanding of Zircaloy - Steam Oxidation Kinetics at temperatures where the reaction is thought to be autocatalytic. The purpose of this task is to provide a data base suitable for analytically predicting the heat output, temperature rise, and amount of cladding wall thickness consumed during the course of a postulated SFD transient. Data defining rate constants are needed from 1500°C up to and exceeding the melting point of liquid Zirconium. Analysis techniques capable of real time measurement during a thermal excursion are required. Laser-raman spectroscopy will be used to measure the influence of H_2, H_2O, and H_2/H_2O on reaction kinetics if suitable signal responses can be obtained. Expected results for FY-84 are as follows:

- Complete isothermal Zr-H_2O oxidation tests between 1600°C - 1800°C. 9/15/83
- Determine if Nd:YAG laser excitation will induce a strong enough raman signal to measure H_2 and H_2O species during the course of an oxidation event. 10/1/83
- Establish preliminary effects of H_2 and H_2O on reaction kinetics (assuming Nd:YAG laser provides suitable analytical results). 12/1/83
- Complete transient Zr-H_2O oxidation tests to temperatures of 2000°C or above. 1/1/84

Task III:

Reaction kinetic studies are needed to develop heat of reaction data for the UO_2-Zr-Steam System between 1500°C and 2000°C. The nature of these reactions, i.e. whether they are endothermic or exothermic, must be understood to properly analyze energy balance during the course of a postulated SFD event. The purpose of this task is to provide baseline thermodynamic data and kinetics information to support analytical modeling of fuel rods exposed to SFD conditions. The work will focus on the reactions associated with Zircaloy-Steam Oxidation and with the dissolution of UO_2 into oxygen saturated Zirconium. Post test gravimetric evaluation of total oxygen uptake, measurements of reaction depths, and details of oxygen concentration profiles in the reaction zones will be used. Expected results for FY-84 are as follows:

- Perform reaction rate measurements between Zr and UO_2 at temperatures up to 1700°C. 2/1/84

- Develop capability for extending reaction kinetic measurements to temperatures up to and including the melting point of oxygen saturated Zirconium, and if possible to 2000°C. 6/1/84

Task IV:

The viscosity of liquified fuel as a function of temperature is important in the modeling of fuel rod behavior during severe high temperature accident conditions to properly account for melting and refreezing of the cladding. The purpose of this task is to obtain the viscosity data needed to model the redistribution of liquified fuel during conditions which support rapid heating of fuel rods. The viscosity of U-Zr-O mixtures will be measured with an oscillating cup viscosimeter. The composition to be measured is contained in a ceramic lined refractory metal capsule. The capsule is suspended from a tungsten torsion wire inside a tungsten-mesh resistant heated vacuum furnace. Expected results in FY-84 are as follows:

- Complete viscosity measurements for compositions less than 10 mole % UO_2. 9/1/83

- Determine the influence of ThO_2 crucible reactions on viscosity and make appropriate corrections to viscosity data. 10/1/83

- Perform viscosity measurements on mixtures containing 12, 15, and 16 mole % UO_2. The following data is needed based on new information that the $Zr(O)$-UO_2 eutectic is at 15 mole % as opposed to the 5 mole % previously believed. In addition, the maximum solubility of UO_2 and Zircaloy at 2000°C is thought to be 16 mole %. Thus, the viscosity of this mixture needs to be determined. 2/1/84

5.0 Relationships to Other Projects

This program is supportive of other NRC efforts in PBF and NRU which are evaluating the behavior of LWR fuel during "small break" loss of coolant accident conditions. The program should provide information of interest to jointly sponsored industry-EPRI-EDCOR efforts on degraded core conditions related to Class 9 accidents and to the international community interested in obtaining information on fuel rod behavior under SFD conditions. Physical property measurements and separate effects tests are also being performed at KfK in Germany.

6.0 Reporting Schedule

- FY-83: No reports issued other than Quarterlies
- FY-84: The data reports identified in Task I will be prepared and issued per NRC directives to insure proper dissemination and that only the appropriate international organizations receive distribution.

7.0 Subcontractor Information

No subcontracts are anticipated in support of Battelle Pacific Northwest Laboratories efforts.

8.0 New Capital Equipment Requirements

Most of the sophisticated laboratory equipment needed to perform the high temperature transient oxidation studies, the viscosity measurements, and the heats of reaction determination are in place. The Nd:YAG laser needed to obtain sufficient signal response at high temperatures from reactive H_2 and H_2O species has been acquired on a complementary DOE sponsored program. Installation and operation of this equipment is expected by August 1983.

A high temperature furnace needed to perform heats of reaction and phase equilibria studies on Zr-UO_2 above 1700°C will be required if all Task III objectives are to be achieved. The estimated cost of this furnace is $30K.

9.0 Facilities

Laboratory equipment and space in Battelle's Physical Sciences Laboratory (PSL) will be used to perform the high temperature oxidation studies, and facilities in the Engineering Development Laboratory (EDL) will be used for the viscosity measurements. The differential thermal analysis equipment is located in the Fuels Laboratory in Building 306-W. All of the equipment described above has been used concurrently on DOE programs and no conflict with either equipment or facilities are anticipated in FY-84.

10.0 Conflict of Interest

This project has been reviewed by Battelle's Corporate Scope Coordinator, who indicates that it does not duplicate work being performed for others.