NRC FORM 189 (3-81)

U.S. NUCLEAR REGULATORY COMMISSION

PROJECT AND BUDGET PROPOSAL FOR NRC WORK

DATE OF PROPOSAL: 8/1/83

☐ NEW
☐ REVISION NO.

PROJECT TITLE: LWR Core Debris Coolability

FIN NUMBER: A-1340

NRC OFFICE: Research

NRC B&R NUMBER: 60190201

DOE CONTRACTOR: Sandia National Laboratories

CONTRACTOR ACCOUNT NUMBER: DE-AC04-76DP00789

SITE: Albuquerque, NM 87185

DOE B&R NUMBER: 401001060

COGNIZANT PERSONNEL	ORGANIZATION	FTS PHONE NUMBER
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OTHER NRC TECHNICAL STAFF		
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K. R. Boldt, P. A. Kuenstler,	SNL/6421	844-6286
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PERIOD OF PERFORMANCE

STARTING DATE: 10/1/83

COMPLETION DATE: 9/30/84

[redacted]

STAFF YEARS OF EFFORT (Round to nearest tenth of a year)	FY 83	FY 84	FY 85	FY 86	FY 87
Direct Scientific/Technical	8.2	4.4	8.5		
Other Direct (Graded)					
TOTAL DIRECT STAFF YEARS	8.2	4.4	8.5		

COST PROPOSAL	FY 83	FY 84	FY 85	FY 86	FY 87
Direct Salaries	889	450	935		
Material and Services (Excluding ADP)	639	146	433		
ADP Support	10	10	5		
Subcontracts	28	39	129		
Travel Expenses — Foreign	2	0	1		
Travel Expenses — Domestic	6	5	6		
Indirect Labor Costs	0	0	0		
Other (Specify)	0	0	0		
General and Administrative (%)	--	--	--		
TOTAL OPERATING COST	1574	650	1509		
CAPITAL EQUIPMENT FIN CHARGED: ______	0	0	0		
TOTAL PROJECT COST	1574	650	1509		

FY 84 MONTHLY FORECAST EXPENSE

OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
75	75	75	75	125	50

APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
50	25	25	25	25	25

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LWR CORE DEBRIS COOLABILITY -- A1340

1. Objective of Proposed Work

This program is an experimental study of core debris coolability for postulated LWR accidents. The experimental data obtained will be used to confirm for LWR application phenomenological models which predict cooling of degraded core materials. The program seeks to provide a continuum of understanding with the knowledge gained in the Debris Formation and Relocation Program (A1335), the Molten-Core Coolant Interaction Program (A1030), and the Core Melt Retention Program (A1247), as well as other pertinent severe fuel damage programs, such as the PBF Severe Fuel Damage Test Series. The program will emphasize inpile experiments in the Annular Core Research Reactor (ACRR) utilizing fission heating of UO_2 to simulate intrinsic decay heat generation. It will make maximum use of the experience, experimental techniques, and analysis methods developed in the Core Debris Behavior Program (A1181) for debris cooling analysis in LMFBRs. New approaches and techniques will be developed as required by the uniqueness of LWR conditions and materials.

A review of LWR accident scenarios, past research results, and current programs has revealed five phenomenological uncertainties which govern LWR debris coolability and need further analysis.

a) Debris Type: Coarse debris results from the quench of core materials that have not attained a fully molten state or from a nonenergetic molten fuel/coolant interaction. Fine debris results from the energetic dispersal and resolidification of molten fuel. The two types of debris exhibit different cooling behavior which will be separately investigated along with mixtures of prototypic core structural materials (i.e., ZrO, Zr and stainless steel).

b) Debris Depth: The large core of an LWR and limited volumes of the reactor pressure vessel (RPV) and reactor cavity suggest the possibility of formation of deep (1 to 2 meter) beds. Because these beds are far deeper than those treated in the present data base, investigation of significant variations from the currently understood behavior of "deep" debris is required.

c) Bottom Boundary Condition: Debris formed on concrete can experience gas flow from the eroding concrete which could decrease the coolability of the overlying bed.

Also, if a particle bed settles on a porous surface (such as the lower core plate or core support casting), cooling water can be supplied to the bottom of the bed either from natural convection or forced convection. The convection "loop" formed by this manner can significantly change the coolability of the bed.

d) Pressure Effects: Because debris coolability questions are pertinent throughout a spectrum of terminated and unterminated accident sequences, coolant pressures and saturation temperature can vary significantly (from 1 to 3 atmospheres in the reactor cavity to 170 atmospheres in the RPV). Current models of debris behavior predict a strong dependence of coolability on pressure; verification of this dependence is necessary.

e) Stratified Debris: Energetic dispersal of molten fuel (e.g. from a steam explosion) will result in a water/fuel mixture. Large particles will initially settle out of the mixture onto horizontal surfaces with smaller particles settling out later. The resultant stratified particle bed exhibits significantly different coolability behavior than homogeneous mixed beds as demonstrated by LMFBR-related experiments in the Core Debris Behavior Program (A1181).

A tentative experiment matrix has been formulated which investigates each phenomenon's impact on debris coolability.

2. Summary of Prior Efforts

FY83 was devoted to continued design and procurement of equipment and hardware for DCC-1 and DCC-2. Testing of materials was completed for the experiments. The Program Plan was completed and published. The safety analysis was performed and documented and sent to the Reactor Safety Committees and DOE. Safety approval was obtained from all concerned parties. The particle size distribution for the first experiment was reduced to a small size distribution (log normal with an effective diameter of 0.4 mm) typical of "late" debris which has sustained some melt. This required the addition of a high pressure 4 kW heater to the experiment, redesign of the closure lids, and a new order for fuel.

All the hardware was prooftested and a prototype containment was destructively tested. DCC-1 was assembled and run late in the year. DCC-1 was composed of a small particulate distribution, 50 cm high by 10 cm diameter. Dryout powers were

measured as a function of bed power, temperature, and pressure up to 170 atmospheres. Analysis was performed to support the experiments and to refine the existing coolability models, particularly the time-dependent coolability model. A quick look report was issued on the results of DCC-1. The helium trailer for cooling of the experiments was upgraded to increase the flow rate by installing a higher capacity motor and drive system. The 5000 gallon liquid nitrogen dewar with new internal heat exchanger for the precooling of the helium has been installed and proofed. A new data acquisition system was added to the PAHR Data Acquisition system to monitor and control the helium loop cooling system. A development test was performed on several neutronic poisons added to the fuel to mitigate the effects of water loss on dryout.

Testing was also performed on the integrity of the thermocouple and for leak rates with open sheaths. A number of other development tests were performed to satisfy the technical and safety needs of the experiment. Initial steps were taken to increase the steady-state power of the ACRR reactor from 2 MW(t) to 5 MW(t). The analysis was performed and approval was obtained from DOE to perform the experiment to determine the potential for increase in power.

Studies on porosities of uniform spheres and the FITS debris were conducted. The FITS debris formed beds with higher porosity than similar beds with grit or spheres.

A debris coolability model was modified such that it would be available for the system codes such as CONTAIN. The results of time-dependent model were compared with quench experiments looking at velocity of quench fronts. An important result is that the quench front velocity is limited by the ability of the liquid to fill in behind the quench front.

3. Work to be Performed and Expected Results

The DCC-2 experiment will be conducted examining the coolability of a large size particulate distribution typical of early quench of reactor fuel. The bed will be fission heated in the ACRR with a height of 50 cm by 10 cm diameter. The sides and bottom of the bed are insulated to produce one-dimensional heat flow in the vertical direction. The dryout power will be measured as a function of bed power, temperature, and pressures up to 170 atmospheres. A data report will be issued soon after the experiment and a topical report will be issued covering both DCC-1 and DCC-2 and the applicability of the LMFBR coolability models to the LWR accident.

The SNL DCC-1 and DCC-2 experiments will provide the only existing coolability data for deep (large and small particle) water beds at high pressure, parameter regimes of large importance to LWR safety analyses. They should thus provide a crucial test of the adequacy of existing LMFBR models to predict the coolability limits in LWRs, in addition to supplying important information needed for the further development of time-dependent and other phenomenological post dryout models. A summary report of the status of knowledge of LWR debris coolability taking into account the results of DCC-1, DCC-2, SNL out-of-pile experiments and any other experiments which may have been conducted in FY 84 (i.e. at KfK) shall be completed in September.

Sandia program personnel will continue in a coordinated exchange and development of coolability models with Culham Laboratory. This includes continued development of analytic time-dependent quench and dryout models(SNL) and two-dimensional, time-dependent numerical models(Culham). Experimental information will be exchanged with KfK as it becomes available.

Following completion of planned FY 84 PBF SFD experiments, SNL DFR experiments and the TMI examination, the current follow-on test matrix shall be reformulated. Redesign of the DCC test capsule may be necessary to allow for liquid inflow to the bottom of the debris. Succeeding DCC experiments will use simulated degraded core material with characteristics dictated by examination of the debris from the above mentioned debris formation experiments. It is currently envisioned that they will include bottom flow experiments, in beds that can be semi-stratified during the experiment by fluidization and settling. Degraded pin bundles, alone or in combination with debris, are also planned. Supplementary out-of-pile experiments will be performed when advantageous. These may include transient debris-on-concrete experiments that are needed to verify the small-scale experiments of this type that have already been conducted at SNL.

Sandia personnel will provide NRC with fast-response technical consultation on LWR core-debris-coolability phenomenology and provide NRC/DAE with a continuous assessment of research (national and international) in this area.

Note: With the funding level projected last year for FY84 of $1250K, the follow-on experiments could be moved up approximately a year from what is projected in this document. This would permit design and procurement of the hardware and possibly operation for DCC-3 in FY84 which is now scheduled for FY85. Additional funds in FY84 would eliminate this unfortunate delay.

4. <u>Description of Any Follow-On Efforts</u>

During FY85 and FY86 a total of three additional experiments are tentatively planned. The purpose of these experiments will be to investigate the effects of coolability for a stratified bed, for a combined distorted pin and debris geometry, and with coolant and/or gas bottom feed. Additional or different experiments may be required if other important phenomena are identified in the previous PBF/SFD, DFR, or DCC experiments.

5. <u>Relationship to Other Projects</u>

Debris coolability is an important risk significant branch point in current probabilistic analyses of operating LWRs. If the debris is coolable the accident is effectively terminated. If not, considerable enhancement of H_2 generation, aerosol production, heat and pressure generation in the containment is likely. This could have considerable impact on both containment effectiveness and the radiological source term. This program contributes to the bases for assessing this critical branch point.

Inpile LWR core degradation studies will be performed at SNL (Debris Formation and Relocation Program) and at INEL (PBF Severe Fuel Damage Tests) to determine core and debris characteristics at various stages of a meltdown accident. A close c-- espondence between the results of these experiments and the DCC test matrix will be maintained. The DCC matrix will be revised to reflect new results on a timely basis.

SNL out-of-pile phenomenological experiments (Technology for Core Melt Retention Concept Assessment) designed to investigate the behavior of debris lying atop concrete and to investigate debris formation from melt subjected to a slow quench can produce important information to the DCC program. Additional debris types of interest may be identified, which will be included in the DCC matrix. The perturbation of debris bed dryout behavior by gas flow from below has been predicted by models developed under the LWR program. This model can be verified by comparison with results from these experiments.

6. <u>Reporting Schedule</u>

Brief monthly letters will be written summarizing recent accomplishments in the program. These will be published in the Technical Highlights/Administrative Reports for NRC Advanced Reactor Safety Research Program. Secti ns will also be written and published in the Sandia Advanced Reactor Safety Quarterly Reports indicating progress, achievements and results for the

calendar quarter. Topical reports will be prepared and issued covering each individual in-core experiment.

Publications for FY83

1. E. D. Bergeron, et al, "LWR Severe Core Damage Phenomenology Program Plan, Volume 2, LWR Degraded Core Coolability Program," SAND82-1115 (2 of 2), Sandia National Laboratories, June 1983.

2. E. D. Bergeron, "Remaining Uncertainties in Predicting the Coolability Limits of a Degraded Reactor Core," SAND Report, to be published.

3. M. S. El-Genk and R. Coen, "Characterization of Vapor Explosion Fragments: Permeability Measurements in Mixed and Stratified Beds," UNM report no. NE-95(83) SNL-162-1, June 1983.

4. M. S. El-Genk and D. Louie, "Porosity and Capillary Head Measurements in Particle Beds," UNM report no. NE-94(82) SURP-080-6, November 1982.

Publications for FY84

1. K. R. Boldt, et al, "Results of DCC-1 Experiment," Data Report, October 1983.

2. P. A. Kuenstler, et al, "Results of DCC-2 Experiment," Data Report, May 1984.

3. E. D. Bergeron, et al, "Analysis of the Coolability of LWR Severely Damaged Fuel Debris and Comparison with Experiments DCC-1 and DCC-2," Topical Report, September 1984.

7. Subcontractor Information

It is not anticipated that any significant subcontracts will be required as part of this task. Expenditures for fuel and experiment packages will amount to approximately 30 percent of the overall program. Expenditures will be performed using standard Sandia National Laboratories purchasing procedures.

8. New Capital Equipment Required (in order of priority)

Shield storage casks required for each experiment -- $25K each

Positive displacement pump and control system for incorporation into follow-on experiments for bottom feed -- $15K