



# MASTER

29 September 1978

DOE/SF/80016 -- T2

Quarterly Progress Report No. 14  
1 April - 30 June 1978

EXPERIMENTAL STUDIES IN ATTENUATION OF  
RADIOLOGICAL CONSEQUENCES OF CDA ENERGETICS\*

By: D. J. Cagliostro, Project Leader  
C. M. Romander  
R. J. Tobin

Contributors: A. L. Florence, Project Supervisor  
D. W. Ploeger

Prepared for:

DEPARTMENT OF ENERGY  
Nuclear Division  
Chief, Safety Analysis Branch  
Reactor Development and Demonstration  
Washington, D.C. 20545

Attention: Mr. G. Cunningham

Contract No. EY-76-C-03-0115  
189 No. SX 032  
SRI International Project PYU-3929

Approved:

*A. L. Florence*

A. L. Florence, Project Supervisor  
Engineering Mechanics Group

G. R. Abrahamson, Director  
Poulter Laboratory

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

\*Previously "Experimental Studies in Reactor System  
Response to Core Disassembly Accidents"

333 Ravenswood Ave. • Menlo Park, California 94025  
(415) 326-6200 • Cable: STANRES, Menlo Park • TWX: 910-373-1246

M&R File 0115 / 18-2

## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

## I INTRODUCTION

Four concerns in the safety analysis of liquid metal fast breeder reactors are the release of radioactive core materials to the environment following a hypothetical core disruptive accident (HCDA), the structural response of the reactor vessel to HCDA loads, the protection of the secondary containment from HCDA-generated missiles, and the work potential, or energetics, of an HCDA.

The objectives of this program are to:

- (1) Develop a basic understanding of the dynamics and thermodynamics of expanding bubbles similar to the core disassembly accident (CDA) bubble in liquid metal fast breeder reactors (LMFBR). This information will aid in developing analytical models for core material transport through the upper plenum and sodium pool.
- (2) Determine experimentally the structural response of an LMFBR to simulated CDA loads resulting from a postulated fuel vapor expansion. This information will be used to determine the sensitivity of head response to accident energetics and to verify REXCO predictions.
- (3) Investigate potential hazards of CDA-generated missiles to the secondary reactor containment system.
- (4) Investigate phenomena that may limit the work potential of HCDA bubble expansions.

The current status of the subtasks on this program is:

Subtask A: Experimental Studies in In-vessel Core Material Transport-Completed 9/77\*

Subtask B: Experimental Studies in Reactor Structural Response to CDA Pressures - In progress

\* Results are presented in Technical Report 1, "Experimental Study of Heat Transfer from a Simulated Hypothetical Core Disruptive Accident" (Nov. 1975), and Technical Report 2, "Development and Characterization of a Liquid-Vapor Bubble Source for Modeling HCDA Bubbles" (March 1977).

#### DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Subtask C: Missile Damage to Reactor Containment Systems:  
A preliminary study - In progress

Subtask D: LOA 4, Protect Secondary Containment - Began in FY 78

Subtask E: LOA 4, Limit Energetics - Began in FY 78

The main goals of the program during FY 78 are to investigate the potential damage to the secondary containment from CDA-generated missiles (Subtask D) and to investigate the potential mechanisms that may limit CDA energetics (Subtask E).

## II PROGRESS

### Subtask B: Experimental Studies in Reactor Structural Response to Core Disassembly Accident Pressures

The purpose of this subtask was to determine the structural response of the Clinch River Breeder Reactor (CRBR) to a 661 MW-sec CDA. Our approach was to simulate the CDA using a low-density explosive in the core of four 1/20-scale models of the CRBR, each of increasing structural and instrumental complexity. The experiments were completed in FY 77.

During this quarter, preparation of a draft final report on these experiments and analysis of the results continued. The final draft will be completed by the Fall of 1978.

### Subtask C: Missile Damage to Reactor Containment Systems

The purpose of this subtask was to evaluate the potential hazard to reactor containment systems of CDA-generated missiles from the CRBR. Work on this subtask was completed in December 1977, and preliminary results were presented at a review meeting held at DOE, Germantown, Md., on December 5, 1977. A discussion of results appeared in Quarterly Progress Report No. 12.

### Subtask D: LOA 4, Protect Secondary Containment

#### Subtask D.2: Missile Hazard to Secondary Containment of 1000-MW<sub>e</sub> Reactor

The purpose of this subtask is to determine the CDA energetics required to generate missiles that could reach the secondary containment of a 1000-MW<sub>e</sub> LMFBR. The design used in the analysis is one of three conceptual designs developed for DOE and the Electric Power Research Institute (EPRI). The 1000-MW<sub>e</sub> reactor is similar to the CRBR in that the cover consists of three rotating plugs separated by shear rings.

The head is penetrated by control rods in a manner similar to that of the CRBR. Dimensions and masses of key components of the head and control rods of the 1000-MW<sub>e</sub> reactor were obtained from Westinghouse ARD.

During the last reporting period (second quarter of FY 78) a conservative analysis of the hazards of two potential missiles to the secondary containment was completed. The two missiles considered were the head and a control rod. The head was assumed to be unrestrained (no shear rings to prevent upward motion upon slug impact). The control rod was free to be pushed up through the head without friction. Results of this analysis were presented in Quarterly Progress Report No. 13.

During the current reporting period, the analysis was expanded to include simple restraints on these two missiles. Accounting for the restraints provides more realistic (less conservative) estimates of the energy required for these missiles to reach the secondary containment. The simple restraint model analyses and the unrestrained model analysis provide bounds on the potential hazards of missiles to the secondary containment of the 1000-MW<sub>e</sub> reactor.

For determining the height reached by potential missiles as a function of core release energy, loads in the reactor were calculated by Argonne National Laboratory using REXCO. Core release energies ranging from 1500 to 5800 MW-sec were used in REXCO to calculate the resulting core pressures, wall pressures, and slug impact pressures.

Restraint of the head under slug impact loading is by the shear rings. In the analysis we calculate the CDA energy level and the resulting head loads required to break, or fail, the shear rings. Loads above the failure loads drive the head upward in unrestrained flight.

Restraint of the Control Rods is provided by threaded connectors on the head that hold the columns in place. Analyses show that with a minimal restraint force, the control rods buckle under very low CDA loads. Once a control rod buckles, it cannot be forced out the narrow control-rod opening in the head and become a missile.

Results of this less conservative analysis will be complete by mid-July.

## Subtask E: LOA 4, Limit Energetics

### Subtask E.1: Axisymmetric Transparent Vessel Experiments

The purpose of this subtask is to determine experimentally the effect of the upper core structure (UCS) and upper internal structures (UIS) on the expansion of simulated CDA bubbles. The experiments are performed in a simple, transparent, 1/30-scale reactor vessel. The upper core structure is simulated by a cylindrical aluminum plug having an array of axial holes that approximately simulate empty subassembly ducts in the upper core region. Fuel pins are not simulated. The upper internal structure is simulated by an aluminum structure having the same cross section as that in a typical reactor and is supported by four rigid columns connected to the vessel cover. The structural response of the UIS and its columns to the simulated CDA are not studied in this subtask. (See Subtask E.4.).

The CDA bubbles are simulated by a nitrogen bubble source and by a liquid-vapor water bubble source. The expansions are observed with high-speed photography, and the core pressures and coolant impact pressures are measured. From these measurements, we can calculate the entrainment characteristics and the work potential of the bubbles.

Analysis of the experiments, completed last quarter, on the effects of internal vessel structures on simulated HCDA bubble expansions has been completed during this quarter. The major results can be summarized as follows:

- (1) The expansion of the nitrogen gas bubble with no internal structures present is unsteady rather than quasi-steady. The expansion work, therefore, is less than the ideal work based on a quasi-steady constant energy and constant entropy expansion.
- (2) The expansion work produced by the flashing water bubble with no internal structures present was 33% lower than the ideal work potential, based on a constant energy isentropic expansion of the bubble.

- (3) Internal vessel structures reduce the coolant slug velocity (and increase the expansion time scale), the peak cover pressure, and the slug impact impulse, as shown in Table 1 by a combination of throttling and a diversion of some of the expansion work from producing axial motion to producing rotational and turbulent motion.
- (4) For the flashing water bubble source with both an upper core and upper internal structure, only approximately 5% of the ideal work potential is realized as axial kinetic energy of the coolant slug.
- (5) Because of the different natures of a high pressure gas source and a flashing liquid source, different types of pressure histories were recorded in the lower core, upper core, and bubble.
- (6) Entrainments of liquid within the expanding bubbles ranged from 80% soon after door opening (indicating significant mixing in the upper core) to 25% at coolant slug impact.
- (7) The bubble interface velocity increases as the upper core empties and then decreases to a constant value as the bubble enters the pool.
- (8) The nitrogen source experiments scale.

A rough draft of an interim report on these experiments was completed during this quarter.

#### Subtask E.2: Scaling and Prototypicality Analysis and Experiments

The purpose of this subtask is to define the important dynamic and thermodynamic phenomena associated with CDA bubbles and to derive the scaling laws governing these phenomena in scale-model experiments. These scaling laws will show how the results from scale-model experiments can be related to full-scale reactors and how the use of nonprototypic materials affect such phenomena as heat transfer, condensation and vaporization, and entrainment in the transport of materials from the core to the cover gas region. Moreover, the results of the analysis will indicate the appropriate simulant materials to use in scale models to obtain quantitative results for predicting the actual behavior of CDA bubbles in full-scale reactors.

Table 1

SUMMARY OF THE EFFECTS OF INTERNAL VESSEL STRUCTURES

<u>Internal Structure(s)</u>	<u>Reduction Compared to No Internal Structures</u>		
	<u>Peak Surface Velocity</u>	<u>Peak Cover Pressure</u>	<u>Slug Impact Impulse<sup>a</sup></u>
Nitrogen Gas Bubble Source			
UCS <sup>b</sup> Only	7%	17%	11%
UIS <sup>c</sup> Only	44	49	35 22 <sup>d</sup>
Both UCS + UIS	52	51	40 27 <sup>d</sup>
Flashing Water Bubble Source			
UCS Only	7	54	22
UIS Only	37	55	42 11 <sup>d</sup>
Both UCS + UIS	51	75	56 25 <sup>d</sup>

<sup>a</sup>Based on the time that the slug is in contact with the cover during the first slug impact.

<sup>b</sup>Upper Core Structure.

<sup>c</sup>Upper Internal Structure.

<sup>d</sup>With structure load added.

By experiments performed in a simple one-dimensional chamber, we will study the important dynamic and thermodynamic phenomena of two-phase expansions. These phenomena will be used to verify the scaling laws defined in the scale-model experiments described above and to verify modeling of these expansions in the LASL SIMMER code.

No work was performed on this subtask during this quarter. However, results of the previously completed scaling analysis of the nitrogen bubble source experiments are presented and discussed in the draft report prepared during this quarter under Subtask E.1.

### Subtask E.3: One-Dimensional Planar Vessel Experiments

The purpose of this subtask is to study the fluid dynamics and thermodynamics of flashing liquid expansions and to provide simple, well-defined experiments for verifying modeling techniques used in the LASL SIMMER-II code. The experiments are related to the flashing molten fuel expansions that may occur in an LMFBR during a hypothetical core disruptive accident.

This fiscal year we began the design of a one-dimensional transparent planar vessel consisting of a lower heated section for the flashing liquid and an upper section for the coolant simulant. The two sections will be separated by a fast opening valve (sliding doors as used in the three-dimensional transparent vessel experiments in Subtask E.1).

We will investigate the flashing of liquid water or liquid freon or both with high-speed photography, pressure transducers, and fast-response-time thermocouples.

During this quarter, D. J. Cagliostro and R. J. Tobin attended the SIMMER-II tutorial workshop at LASL. This user-oriented workshop described the models contained in SIMMER and enhanced our ability to design meaningful experiments in support of SIMMER verification. While at the workshop, SRI personnel attended several meetings with LASL personnel to discuss potential instrumentation techniques that may be used in the SRI experiments designed to help verify SIMMER.

#### Subtask E.4: Response of the Upper Internal Structures to Highly Energetic CDAs

The purpose of this subtask is to determine the CDA energy level at which the UIS is displaced one core diameter above the core barrel in the CRBR. This information is required to establish the energy level below which one of the basic assumptions in the LASL SIMMER II code is valid. This assumption is that the UIS is not displaced upwards during the CDA and that it restricts the release of hot molten fuel from the core, allowing the fuel to mix and cool with surrounding cooler fuel.

Our approach is to perform experiments in a rigid 1/20-scale model of the CRBR vessel. In the experiments, a low-density explosive is used to simulate, on a 1/20-scale, a range of CDA energy releases from 661 MW-sec to 1980 MW-sec. Pressure transducers are used to measure core and UIS loading pressures, strain gages to measure UIS column loads, water surface gages to measure slug motion, and displacement gages to measure UIS motion. Figure 1 shows a schematic of the test apparatus.

The model of the UIS consists of an aluminum model of the UIS and the four columns that suspend the UIS over the core. The columns are made of 8-inch-long, 0.700-inch-diameter, 0.050-inch-wall Ni 200 tubes that simulate the strength of the CRBR UIS columns. Short solid steel sections are welded to each end of the Ni 200 sections to provide secure attachment to the UIS and the head. The UIS model is identical in design to the UIS model used in the 1/20-scale CRBR tests performed in FY 77 except that the flow passages have been plugged to simulate conditions in which upper core materials have plugged these passages.

The test apparatus was designed during the current reporting period. Twenty-four columns, enough to perform six experiments, are being fabricated. The head is now being fabricated and the vessel is being modified.

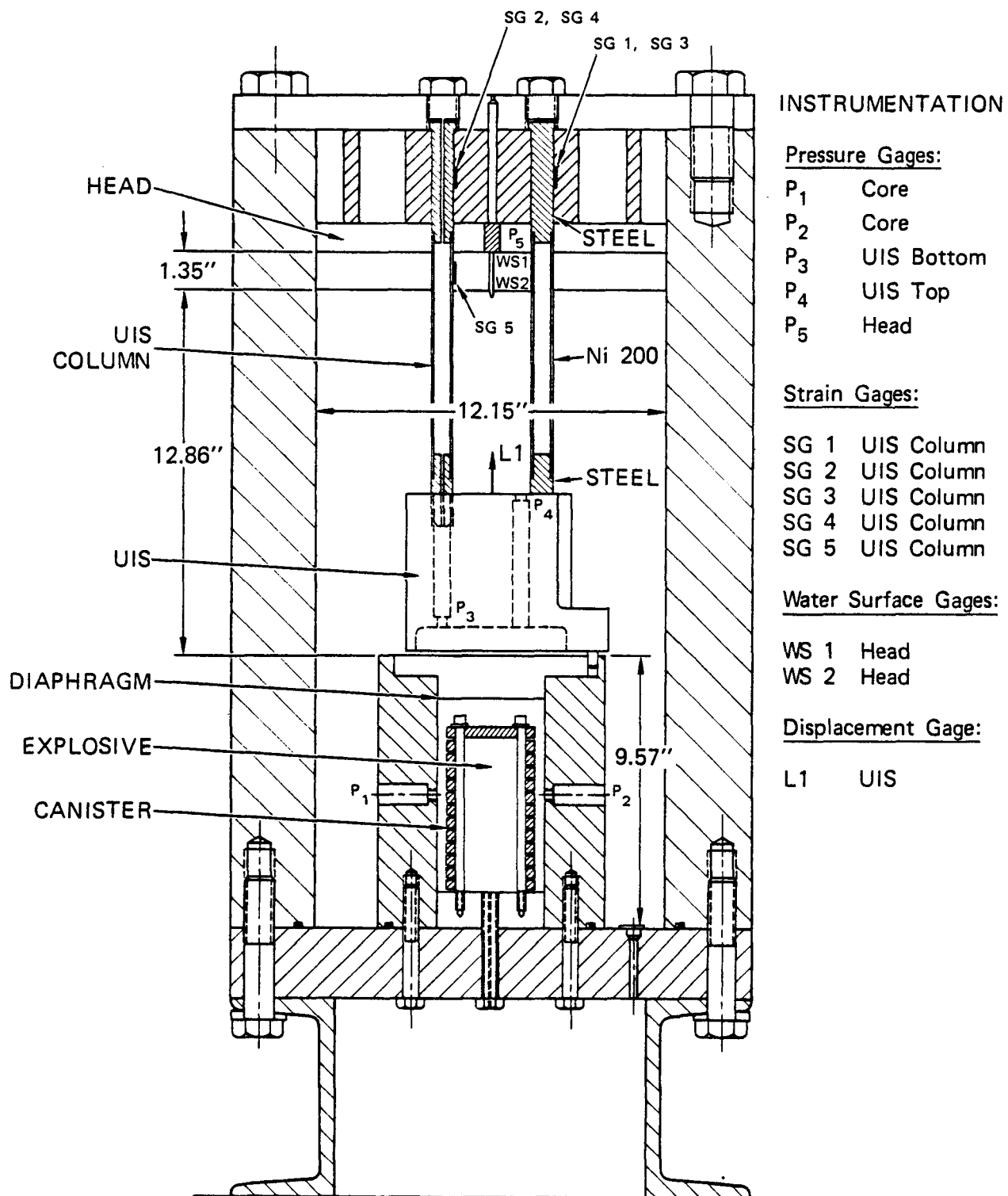


FIGURE 1 EXPERIMENTAL APPARATUS FOR UIS COLUMN TESTS

## FUTURE WORK

### Subtask D: LOA 4, Protect Secondary Containment

Under Subtask D.2, analyses that focus on the potential hazards of missiles to the secondary containment structure of the 1000-MW<sub>e</sub> reactor will be completed. The analyses will consider simple restraint models for the potential missiles already identified (head and control rod).

### Subtask E: LOA 4, Limit Energetics

Under Subtask E.1, the draft report entitled "Effects of Internal Vessel Structures on Simulated HCDA Bubble Expansions" will be reviewed and prepared for publication in the Fall of 1978. A composite film containing the high-speed movies of the experiments will be prepared. Planning of the simple one-dimensional experiments in support of SIMMER II verification and studies to increase understanding of flashing and mixing will continue.

Under Subtask E.4, experiments will be started to measure UIS displacement as a function of CDA release energy.