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Aerosol Release and Transport Program Quarterly Progress Report for July–September 1983

R. E. Adams M. L. Tobias

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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AEROSOL RELEASE AND TRANSPORT PROGRAM QUARTERLY PROGRESS REPORT FOR JULY–SEPTEMBER 1983

R. E. Adams M. L. Tobias

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FOREWORD

This report summarizes progress under the Aerosol Release and Transport Program [sponsored by the Division of Accident Evaluation of the Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research] for the period July–September 1983.

Work on this program was initially reported as Volume III of a four-volume series entitled *Quarterly Progress Report on Reactor Safety Programs Sponsored by the NRC Division of Reactor Safety Research*. Prior reports of this series are

Report No.	Period covered
ORNL/TM-4655	April–June 1974
ORNL/TM-4729	July–September 1974
ORNL/TM-4805	October–December 1974
ORNL/TM-4914	January–March 1975
ORNL/TM-5021	April–June 1975

Beginning with the report covering the period July–September 1975 through the report for the period July–September 1981, work under this program was reported as *LMFBR Aerosol Release and Transport Program Quarterly Progress Report*. Prior reports under this title are

Report No.	Period covered
ORNL/NUREG/TM-8	July–September 1975
ORNL/NUREG/TM-9	October–December 1975
ORNL/NUREG/TM-35	January–March 1976
ORNL/NUREG/TM-59	April–June 1976
ORNL/NUREG/TM-75	July–September 1976
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ORNL/NUREG/TM-142	April–June 1977
ORNL/NUREG/TM-173	July–September 1977
ORNL/NUREG/TM-193	October–December 1977
ORNL/NUREG/TM-213	January–March 1978
ORNL/NUREG/TM-244	April–June 1978
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ORNL/TM-8149	July–September 1981

Beginning with the report covering the period October—December 1981, work under the program is being reported as *Aerosol Release and Transport Program Quarterly Progress Report*. Prior reports under this title are

Report No.	Period covered
ORNL/TM-8307	October—December 1981
ORNL/TM-8397/V1	January—March 1982
ORNL/TM-8397/V2	April—June 1982
ORNL/TM-8397/V3	July—September 1982
ORNL/TM-8397/V4	October—December 1982
ORNL/TM-8849/V1	January—March 1983
ORNL/TM-8849/V2	April—June 1983

Copies of all these reports are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

SUMMARY

M. L. Tobias

The Aerosol Release and Transport Program at Oak Ridge National Laboratory (ORNL) is designed to investigate the release, transport, and behavior of aerosols that may carry radionuclides originating from a severe accident resulting in core melting. Aspects of the program apply to both light-water reactors (LWRs) and liquid-metal fast breeder reactors. The experimental programs are being conducted in the Fuel Aerosol Simulant Test (FAST) Facility (which also includes the CRI-III vessel), the NSPP Facility, and the CRI-II Facility. The analytical efforts are designed to support the experiments and to provide an independent assessment of the safety margins that exist for the estimation of the radiological consequences of a core meltdown accident.

In the FAST/CRI-III program, three undersodium experiments (FAST-105, FAST-106, and FAST-107) were performed. These tests were at sodium heights above the fuel specimen centerline of 107, 20, and 10 cm, respectively. The (absolute) cover gas pressure was 120 kPa, and the fuel sample xenon pressure was 340 kPa. Bubble behavior in FAST-105 is compared with that in FAST-104, which was at a lower sample xenon pressure of 135 kPa (abs). Differences in bubble (aerosol) behavior were noted, but more experiments will be needed to determine whether the cause was in fact associated with the xenon pressure. In the other tests, bubble oscillation period decreased with decreasing height. Bubble radii of up to ~10 cm have been estimated. There is no evidence that the primary bubble broke the surface.

Aerosol samples taken during the undersodium FAST-104 test were analyzed and the results compared with CDV-109 (an argon atmosphere test) and CDV-110 and CDV-111 (underwater tests). Liquid height appears to have a strong effect with $<10^{-4}$ of the fuel vapor being found in the undersodium test FAST-104 (depth = 107 cm), while that in the underwater test CDV-110 (depth = 21 cm) was about 0.01.

In the NSPP program, results from experiments 611 and 612, which involved mixed Fe_2O_3 and U_3O_8 aerosols in a steam-air environment, are reported. These tests, which both ran for somewhat more than 24 h, were intended to simulate aerosols that could emanate from molten fuel and molten core support and structural materials. In experiment 611, steam was fed into the vessel until the pressure and temperature were raised to 0.183 MPa (abs) and 382 K. The two aerosols were then generated using separate plasma torches (PTs). The iron oxide torch ran from t = 0 min to t = 11.5 min, while the U_3O_8 torch ran from t = 2 min to t = 10 min. Steam injection was continued for about 6 h, during which time the temperature rose to 383 K and the pressure to 0.203 MPa. The vessel was then allowed to cool for 18 h. Mass concentration measurements at 4 min after cessation of Fe_2O_3 aerosol generation indicated that the concentration of Fe_2O_3 was 3.1 $\mu g/cm^3$ and that of the U_3O_8 was 1.9 $\mu g/cm^3$. Extrapolation back to t = 11.5 min gave corresponding concentrations of 5.5 and 4.0 $\mu g/cm^3$ for a Fe_2O_3/U_3O_8 ratio of 1.4. Sampler data from four different locations indicate that a fairly homogenous mixture of aerosols and steam was achieved. Certain results suggest coagglomeration of the

Fe_2O_3 and U_3O_8 aerosols. The internal surface plateout of aerosol at the end of the experiment was 17%, while the remaining 83% settled on the vessel floor.

In the other NSPP experiment, No. 612, the vessel pressure and temperature were brought to 0.218 MPa and 385 K, respectively. The Fe_2O_3 torch ran for 25.5 min; the U_3O_8 aerosol generator was started 20 min after the Fe_2O_3 generator and ran for 5 min. As in test 611, steam flow was maintained for 6 h to balance wall condensation, with pressure and temperature rising to 0.234 MPa and 388 K, following which the vessel was allowed to cool for 18 h. Aerosol suspended concentrations, estimated at the time of generator cutoff, were 0.5 $\mu g/cm^3$ for Fe_2O_3 and 1.8 $\mu g/cm^3$ for U_3O_8, so that the ratio of Fe_2O_3 to U_3O_8 was about 0.3 to 1.0. The rate of removal of the two components from the vessel atmosphere was about the same, suggesting that coagglomeration was occurring. At the end of the test, 76% of the aerosol was found to have settled on the floor while the remaining 24% was on the internal surfaces.

Technical support work for the ATT (Marviken, Sweden) and DEMONA (Battelle-Frankfurt, Federal Republic of Germany) programs continues. The CRI-II Facility is being readied for a trial test of the ORNL-developed PT generator under the steam conditions expected in the European experiments. On site consultations by ORNL staff are reported on various material balance measurement questions. Tests of a centrifugal clarifier were successfully carried out in CRI-II, a technique which could be useful in Marviken decontamination procedures. Testing of a small-scale LASL-Stöber aerosol centrifuge is discussed. A special chemical exchange experiment is being prepared in cooperation with the DEMONA project to observe the interaction between aerosols of silver and cesium iodide.

In the core-melt experimental program, experiment CM-35 was performed in which both Te and TeO_2 were used as additives. The major portion of the TeO_2 was released in the first heating cycle. A black smoke formed, which is believed to be metallic Te created by reduction of the oxide by hydrogen. In experiment CM-36, a possible back-reaction of TeO_2 vapor with hot zirconium is believed to have been produced. In that test, the vapor was forced to contact both the hydrogen and the zirconium before escape as an aerosol. A high degree of tellurium retention was observed. In experiment CM-37, a boiling-water reactor control rod/fuel interaction was simulated, yielding significant quantities of white aerosol believed to be B_2O_3.

The 250-kW generator for the 10-kg core-melt system is being installed. Hookup of power and water services is under way, and delivery of coaxial transmission lines is expected.

In analytical work connected with the FAST program, a finite-difference program was used to model the various stages of the capacitor discharge vaporization process to compare energy densities with those that might exist in a reactor transient. Results were computed in excess of 2.8 kJ/g of sample, which is near the 3-kJ/g level estimated for an HCDA.

In other analysis related work, steam-only experiment 99 was performed in the NSPP Facility. Catch pans were installed near the upper flange to obtain data on condensation. Wall run-off sampler measurements were made, and data were recorded from a number of heat meters and thermocouples that were installed at various points on the vessel surface. Visual observations of the vessel interior showed a foggy atmosphere throughout the experiment.

Among code implementation activities, adaptation of the QUICKM code (BMI-Columbus) to local facilities was successfully completed and sample calculations were run. A study of the definition of certain statistical output from the QUICK code was carried out, comparing the results of the code with parallel calculations of variously determined radius averages.

Attempts made to run the MAEROS (Sandia) code with a condensation option were unsuccessful because of numerical instability problems.

A study of the status of validation of the NAUA computer code used for the Accident Source-Term Reassessment Study was carried out and reported on during this period.

GLOSSARY OF ACRONYMS

ABCOVE	Aerosol Behavior Code Validation and Evaluation
AMMD	aerodynamic mass median diameter
ART	aerosol release and transport
ATT	Aerosol Transport Test
BCL	Battelle-Columbus Laboratories
CDA	core-disruptive accident
CDV	capacitor discharge vaporization
CRBR	Clinch River Breeder Reactor
CRI-II	name of a facility for conducting basic aerosol experiments (originally, Containment Research Installation)
CRI-III	name of an experimental facility in which aerosols are generated by capacitor discharge vaporization
CSTF	Containment Systems Test Facility
DEMONA	name of an aerosol experimental facility at Battelle-Frankfurt (Demonstration Nuklearen Aerosolverhaltens)
FAST	Fuel Aerosol Simulant Test
GSD	geometric standard deviation
HCDA	hypothetical core-disruptive accident
ICP	inductively coupled plasma (spectrometric method)
ITRI	Inhalation Toxicology Research Institute
KfK	Kernforschungszentrum Karlsruhe
LANL	Los Alamos National Laboratory
LMFBR	liquid-metal fast breeder reactor
LWR	light-water reactor
NRC	Nuclear Regulatory Commission
NSPP	name of a facility in which secondary containment aerosol experiments are conducted (originally, Nuclear Safety Pilot Plant)
ORNL	Oak Ridge National Laboratory
PSL	polystyrene latex
PT	plasma torch
PWR	pressurized-water reactor
rf	radio frequency
SASCHA	name of a core-melt experiment facility at KfK (Schmelzanlage für Proben mit Schwacher Aktivität)
WROS	wall run-off sampler

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R. E. Adams M. L. Tobias

ABSTRACT

This report summarizes progress for the Aerosol Release and Transport Program sponsored by the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, Division of Accident Evaluation, for July–September 1983. Topics discussed include (1) several capacitor discharge vaporization (CDV) experiments in the Fuel Aerosol Simulant Test Facility; (2) descriptions of mixed-aerosol experiments 611 and 612, which involved iron oxide and uranium oxide in steam; (3) technical support work for the aerosol test program at Marviken, Sweden; (4) core-melt experiment CM-35, in which tellurium and its oxide were used as additives; (5) progress in construction of a 10-kg core-melt induction furnace; (6) finite-difference calculations of energy deposition in CDV specimens; (7) a steam-only experiment in the NSPP; (8) code implementation activities; and (9) NAUA code validation studies.

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1. INTRODUCTION

The Aerosol Release and Transport (ART) Program at Oak Ridge National Laboratory (ORNL), sponsored by the Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research, Division of Accident Evaluation, is a safety program concerned with aerosol release and transport. The program's scope includes aerosol release from fuel, transport to and release from primary containment boundaries, and behavior within containments. The overall goal of the program is to provide the analytical methods and experimental data necessary to assess the quantity and transient behavior of radioactive aerosols released from reactor cores as a result of postulated events of varying severity up to and including accidents resulting in core melting.

The program is divided into several related experimental and analytical activities:

1. development of apparatus to investigate the characteristics and transport behavior of materials vaporized from molten fuel;
2. study of the characteristics and behavior of fuel-simulant aerosols in several small vessels; and
3. production and study of aerosols in the NSPP for the validation of models, with particular emphasis on the behavior of mixtures of

nuclear aerosol species relevant to both light-water reactor (LWR) and liquid-metal fast breeder reactor (LMFBR) systems.

Additionally, the program has included studies related to hypothetical LMFBR core-disruptive accidents (CDAs) that involve fuel interactions, expansion, and thermal behavior within the sodium pool as the resultant fuel-vapor bubble is produced and transported through the sodium to the cover-gas region. These studies, which had been suspended, have been reactivated with resumption of program funding.

Varying levels of effort are anticipated within these categories, with analytical models accompanying the experimental work. The analytical requirements are mainly concerned with dynamic aerosol behavior at high concentrations in the bubble and containment atmospheres.

An attempt will be made to consolidate and present the analyses and data in a manner that will facilitate direct assessment of the radiological hazard associated with arbitrary hypothetical accident scenarios.

2. EXPERIMENTAL PROGRAM

2.1 Source-Term Experiments in FAST/CRI-III

A. W. Longest J. M. Rochelle*
W. A. Bird† C. V. Hardin

2.1.1 Introduction

The Fuel Aerosol Simulant Tests (FAST) and the Containment Research Installation-III (CRI-III) tests are performed by using the capacitor discharge vaporization (CDV) technique to place UO_2 fuel samples into the high-energy states that could be produced in LMFBR hypothetical CDAs (HCDAs). The primary goal of the FAST/CRI-III test program is to use the experimental results as a data base for developing analytical models that could be used to predict fuel transport through the coolant in severe accidents.

During this quarter, the second through the fourth (FAST-105 through FAST-107) of a planned series of ten undersodium UO_2 fuel vaporization experiments were performed in accordance with the test schedule and test plan shown in Fig. 1 and Table 1, respectively. These experiments are designed to study fuel bubble behavior and fuel aerosol transport to the cover gas as a function of sodium height above the fuel sample assembly, cover-gas pressure, and xenon gas pressure in the fuel sample assembly (to simulate fission gas in reactor fuel). FAST-105 through FAST-107 were the first three of a subset of four experiments in which the sodium height above the fuel assembly was varied while holding the argon cover gas and xenon pressures constant (Table 1). Pressure measurements were made in the sodium at a distance of 23 cm from the test sample and in the cover gas above the sodium. Aerosol samples were obtained from the cover-gas region in each test. A schematic of the FAST test vessel showing the locations of the two pressure transducers, the eight-stage mass sampler used in obtaining the aerosol samples, and other equipment is given in Fig. 2. Details of the test sample assembly (vaporizer unit in Fig. 2) are shown in Fig. 3.

Test specimen and electrical input data for all the tests shown on the schedule in Fig. 1 and performed through this quarter are presented in Tables 2 and 3 for convenient reference. Also included for comparison are data from FAST-103, the last test conducted prior to a 1-year shutdown of the facilities.[1] Only one other undersodium fuel vaporization test (FAST-101 at a much lower high-preheat level of 1100 W) and one undersodium preheat-only test (FAST-102) were performed previously.[2] The preheat stage of the two-stage electrical process for fuel vaporization is designed to partially melt the fuel pellets and reduce the resistance of the fuel sample to a level where the energy stored in the capacitor banks can be discharged in a few milliseconds at ~10 MW power to raise

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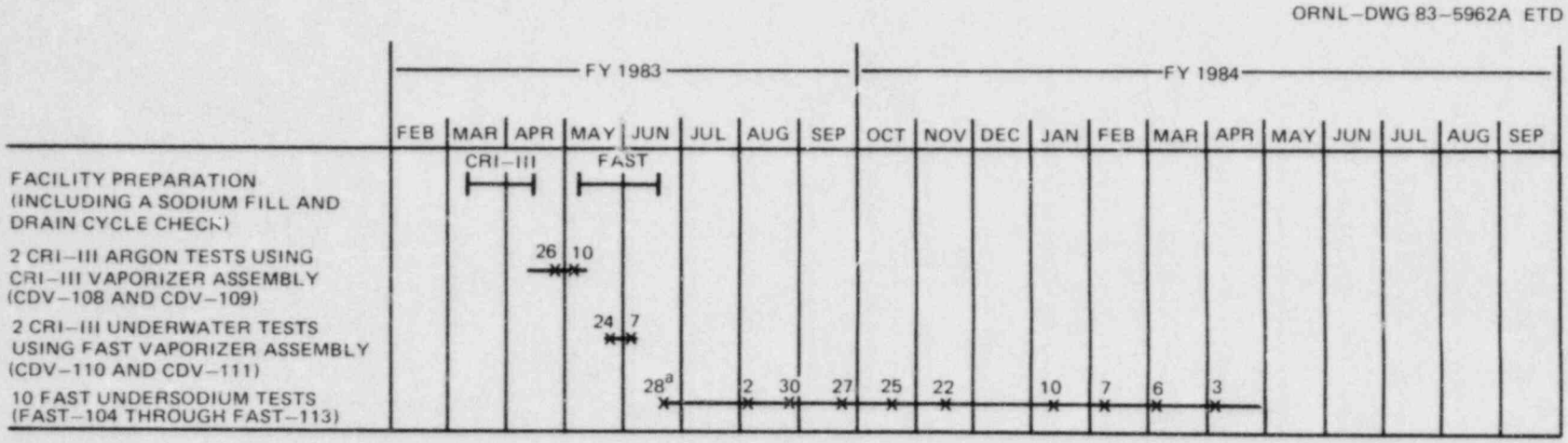
*Consultant from The University of Tennessee.

†Instrumentation and Controls Division, Oak Ridge National Laboratory.



[a]REPEAT OF FAST–103 TEST.

Fig. 1. Schedule for FAST/CRI-III tests.

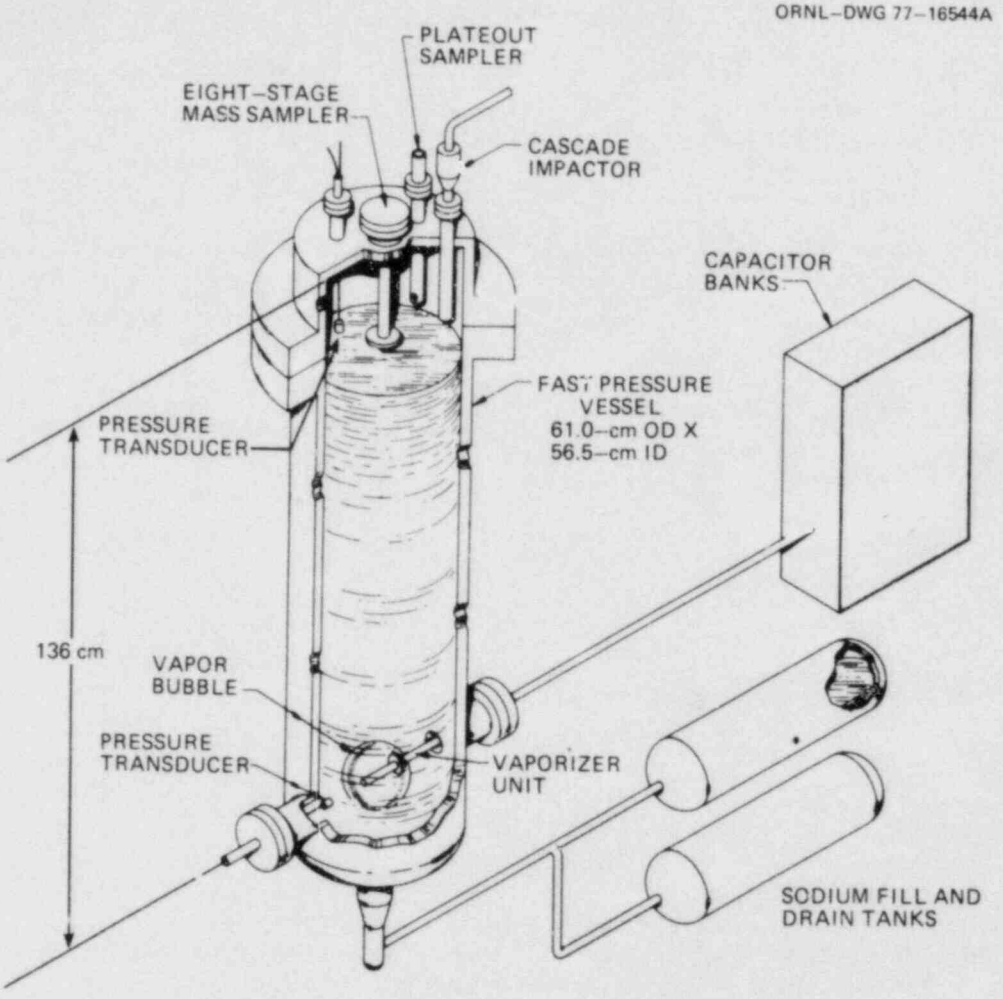


Fig. 2. Schematic of FAST test vessel.

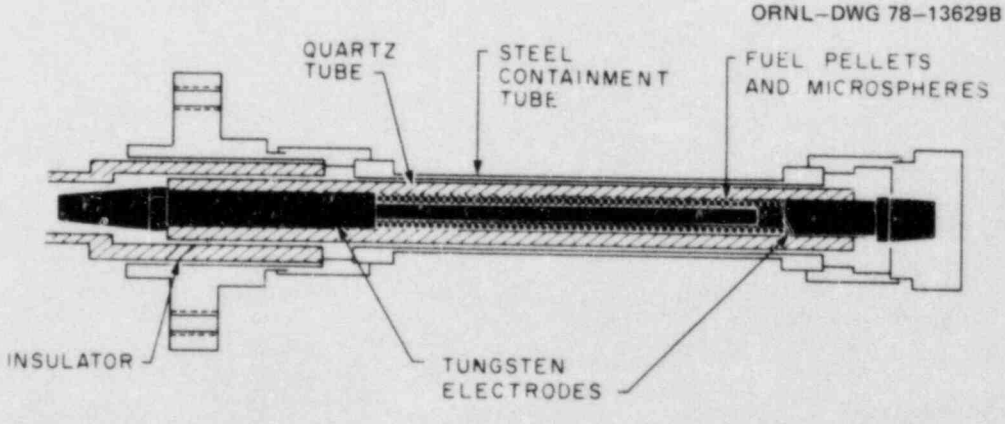


Fig. 3. Schematic of test sample used in underwater and undersodium tests. (Steel tube that surrounds quartz tube has a 19.6-mm OD and wall thickness of 0.13 mm. Quartz containment tube is 17.1-mm OD by 9.71-mm ID, and fuel pellet column is 4.86-mm diam by ~90 mm long.)

Table 1. Fast single-pin undersodium test plan[a]

FAST test	Pressure [kPa (abs)]		Sodium height above fuel specimen centerline (cm)	Objectives
	Argon cover gas	Xenon fuel sample		
104	120	135	107	Repeat of FAST test 103; compare with previous results
105	120	340	107	Determine effect of changing xenon pressure
106	120	340	20	Determine effect of changing sodium height
107	120	340	10	Same as 106
108	120	340	5	Same as 106
109	300	340	5	Determine effect of changing sodium height at a second cover-gas pressure level
110	300	340	10	Same as 109
111	300	340	20	Same as 109
112	300	340	107	Same as 109
113	300	750	107	Determine effect of changing xenon pressure

[a]In all tests, the pressure vessel and sodium temperature will be 540°C.

Table 2. Test specimen data

Test	UO_2 Pellet stack		UO_2 Microsphere mass (g)	Quartz tube dimension (mm)	
	Mass (g)	Length (mm)		ID	OD
CDV-108	17.35	90.2	32.05	9.72	17.15
CDV-109	17.35	90.2	32.77	9.70	17.15
CDV-110	17.27	89.7	30.66	9.70	17.15
CDV-111	17.41	90.4	32.69	9.72	17.15
FAST-103[a]	17.36	90.4	32.93	9.70	17.15
FAST-104	17.58	91.7	32.39	9.70	17.15
FAST-105	17.49	91.2	32.06	9.70	17.15
FAST-106	17.59	91.4	31.97	9.70	17.15
FAST-107	17.50	91.1	31.48	9.70	17.15

[a]Included for comparison. FAST-103 was performed on December 15, 1981, prior to a 1-year shutdown of the facilities.

Table 3. Electrical energy input data

Test	Preheat power (W)		Resistance at end of high preheat (Ω)	Time delay between high preheat and CDV (s)	Energy stored in capacitor banks (kJ)	CDV time to arcing (ms)	CDV energy input to arcing (kJ)
	Low	High					
CDV-108	500	1700	0.45	2.0	77.3	4.96	50.5
CDV-109	500	1700	0.52	2.0	76.9	3.26	33.0
CDV-110	500	1700	0.44	2.0	76.9	2.60	30.9
CDV-111	500	1700	0.45	2.0	76.5	3.26	35.6
FAST-103[a]	600	1600	0.43	2.0	76.5	3.15	37.9
FAST-104	600	1600	0.44	2.0	76.5	3.14	37.4
FAST-105	600	1600	0.41	2.0	76.9	2.61	32.2
FAST-106	600	1600	0.41	2.0	76.9	2.98	37.6
FAST-107	600	1600	0.46	2.0	76.5	2.30	28.8

[a]Included for comparison. FAST-103 was performed on December 15, 1981, prior to a 1-year shutdown of the facilities.

the energy level of the fuel to ~3 kJ/g by the time fuel sample disassembly occurs.

Test results obtained this quarter are presented in the following section.

2.1.2 Discussion of FAST undersodium test results

The experimental results obtained this quarter related to fuel bubble behavior and aerosol transport to the cover-gas region in the FAST undersodium tests are presented in Sects. 2.1.2.1 and 2.1.2.2.

2.1.2.1 Fuel bubble behavior. Pressures are measured in the sodium and the cover gas to monitor the fuel bubble pressure and size vs time and the period of oscillation of the bubble (time between repetitive bubble expansions and contractions in the closed system). Preliminary modeling calculations have indicated that the pressure at the measurement point in the sodium (23 cm from the test sample centerline) is close to the fuel bubble pressure (within about 25% during the first bubble oscillation) in tests conducted at the sodium height of 107 cm, but follows the bubble pressure less closely at the lower sodium heights of 20 and 10 cm.

Pressure measurements made in the FAST-105 test are compared with those previously reported for the FAST-104 test[3] in Fig. 4. The times between the peaks in the sodium pressure trace indicate the bubble oscillation periods. Although the peaks in the cover-gas pressure traces are much weaker than the peaks measured in the sodium, they correspond fairly well to bubble expansion to maximum size. The cover-gas pressure record can be used (knowing the cover-gas volume) to estimate fuel bubble size vs time; this estimate becomes inaccurate and of little value at the lower sodium heights because of the loss of measurement sensitivity with increased cover-gas volume. An expansion of the sodium and cover-gas pressure traces obtained in FAST-105 is shown in Fig. 5. Pressure peak results for FAST-105 are summarized and compared with results for FAST-104 in Table 4.

As evident in the comparisons in Fig. 4 and Table 4, there was a significant difference in fuel bubble behavior in the FAST-104 and FAST-105 tests. Although the bubble oscillation periods were essentially the same in the two tests, the sodium pressure peaks were much lower and broader in FAST-105 than in FAST-104, and the first cover-gas pressure peak in FAST-105 was less than one-half the magnitude of the same peak in FAST-104, indicating a smaller fuel bubble volume. The only planned difference in the test conditions for the two tests was the increased xenon pressure in the fuel sample assembly in FAST-105 (Table 1); however, the capacitor discharge energy input to the time of sample disassembly was 14% lower in FAST-105, and the cover-gas volume was ~6% higher because of a slightly lower sodium height in FAST-105. The lower energy input would tend to decrease the bubble size and presumably the magnitude of the pressure peaks. Also, the difference in fuel bubble behavior might possibly be a result of differences in the way that disassembly occurred rather than a result of the increased xenon pressure. When the results of all the planned tests are available, the effect of changing xenon pressure may become clearer.

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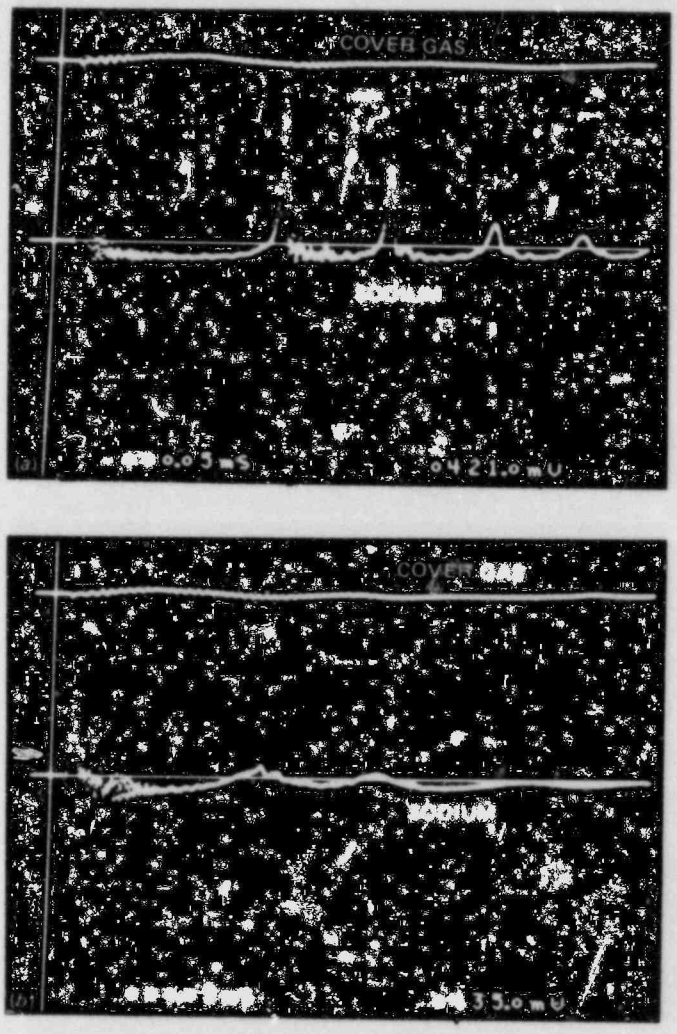

Fig. 4. Comparison of oscilloscope pressure-traces in (*a*) FAST-104 with those in (*b*) FAST-105.

Oscilloscope traces of the pressure records obtained in FAST-105 through FAST-107 are shown in Figs. 6 and 7; the sodium pressure data are summarized in Table 5. These results show a decreasing initial bubble-oscillation period (τ_1) from 32 to 17 ms with decreasing sodium height above the fuel sample from 107 to 10 cm for the test conditions of 120 kPa (abs) argon cover-gas pressure, 340 kPa (abs) xenon pressure in the fuel sample, and 540°C sodium and test vessel temperature. There was no evidence that the primary fuel bubble broke the sodium surface in these tests, as might be expected in the next planned test (FAST-108) at a sodium height of 5 cm. In the present series of FAST sodium tests, sodium pressure increases up to 1.2 MPa have been measured, and bubble radii up to ~10 cm have been indicated by the cover-gas pressure increases.

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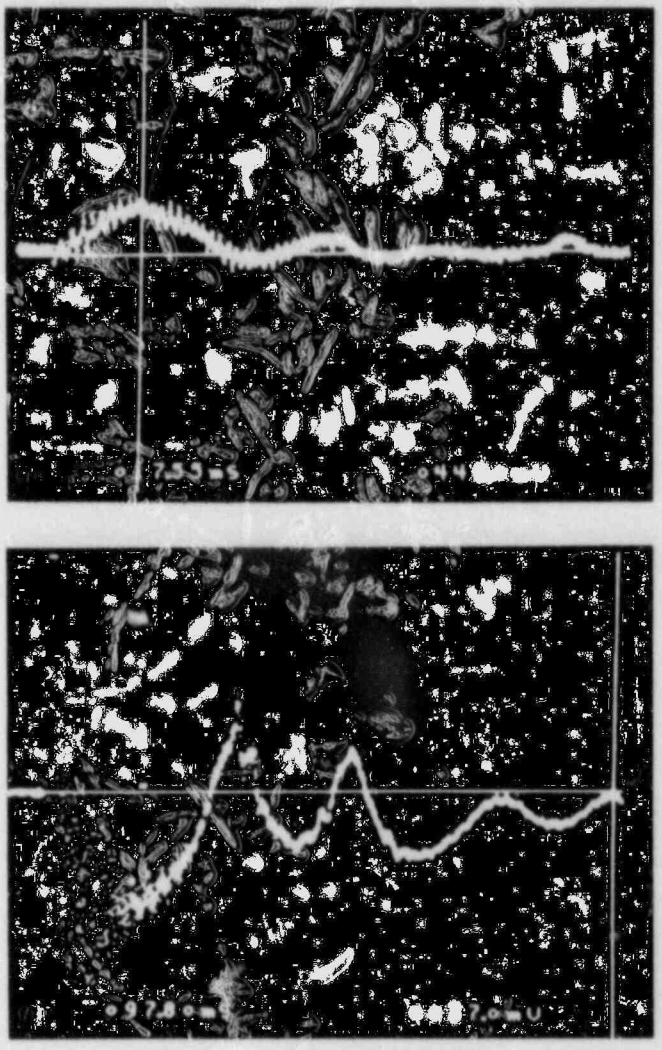

Fig. 5. Expanded views of oscilloscope pressure-traces in FAST-105.

2.1.2.2 Aerosol transport. A series of up to eight aerosol samples of the cover gas were obtained in each test starting soon after capacitor discharge (time = 0). The aerosol sampling procedure consists of drawing a measured amount of cover gas through a collection filter (located inside the vessel at the lower end of the eight-stage mass sampler at ~540°C) and, after the test, having the filters analyzed for uranium content (and other chemical species) by the ORNL Analytical Chemistry Division. The filter used in the sodium tests is a 28.5-mm-diam by 1.6-mm-thick, 2-μm pore-size, sintered stainless steel (Type 316) disk.

Results from the chemical analysis of the aerosol samples of the cover gas taken during the FAST-105 test were received recently, but data reduction to concentration vs time is incomplete. These results and those for FAST-106 and FAST-107 (not yet received) will be given in the next progress report.

Table 4. Pressure peak data from FAST-104 and FAST-105 indicating significant differences in fuel bubble pressure and size in the two tests[a]

Pressure peak	Time from sample disassembly (ms)		Pressure indication above baseline value (kPa)	
	FAST-104	FAST-105	FAST-104	FAST-105
	Sodium pressure [Baseline value = 128 kPa (abs)]			
1	1.06	0.99	1237	807
2	34.71	32.49	1100	90
3	52.86	51.84	593	42
4	70.31	77.09	177	−7.4
5	84.71	95.19	94	0.0
	Cover-gas pressure[b] [Baseline value = 120 kPa (abs)]			
1	18.21	14.94	10.9	4.7
2[c]	57.86	46.94	2.2	0.85

[a]Capacitor discharge energy input to arcing was 37.4 kJ in FAST-104 and 32.2 kJ in FAST-105.

[b]Cover-gas volume was ~0.090 m^3 in FAST-104 and 0.095 in FAST-105.

[c]Data for the second cover-gas peak in each test contain large uncertainties, because the signal is relatively weak compared with the noise in the signal.

Data reduction and evaluation of the aerosol samples taken during the FAST-104 test have been completed. These results are summarized in Fig. 8, where the results from a typical CRI-III fuel vaporization experiment in argon (CDV-109) and two CRI-III underwater experiments (CDV-110 and CDV-111), reported previously,[3] are included for comparison. The airborne aerosol mass plotted in Fig. 8 is the value obtained after correction was made for depletion, that is, correction for the loss from the cover gas of material collected on the filters. Thus, the airborne uranium mass is presumably equivalent to the amount that would have been present had no samples been taken. When the cover-gas inventory is relatively large compared with the sample losses, this correction is insignificant.

By comparing the cover-gas aerosol sampling results with those from an equivalent fuel vaporization test in an inert gas atmosphere (CDV-109 in Fig. 8), which represents an upper bound for the release that could be expected, an estimate of the fraction of the fuel vapor transported

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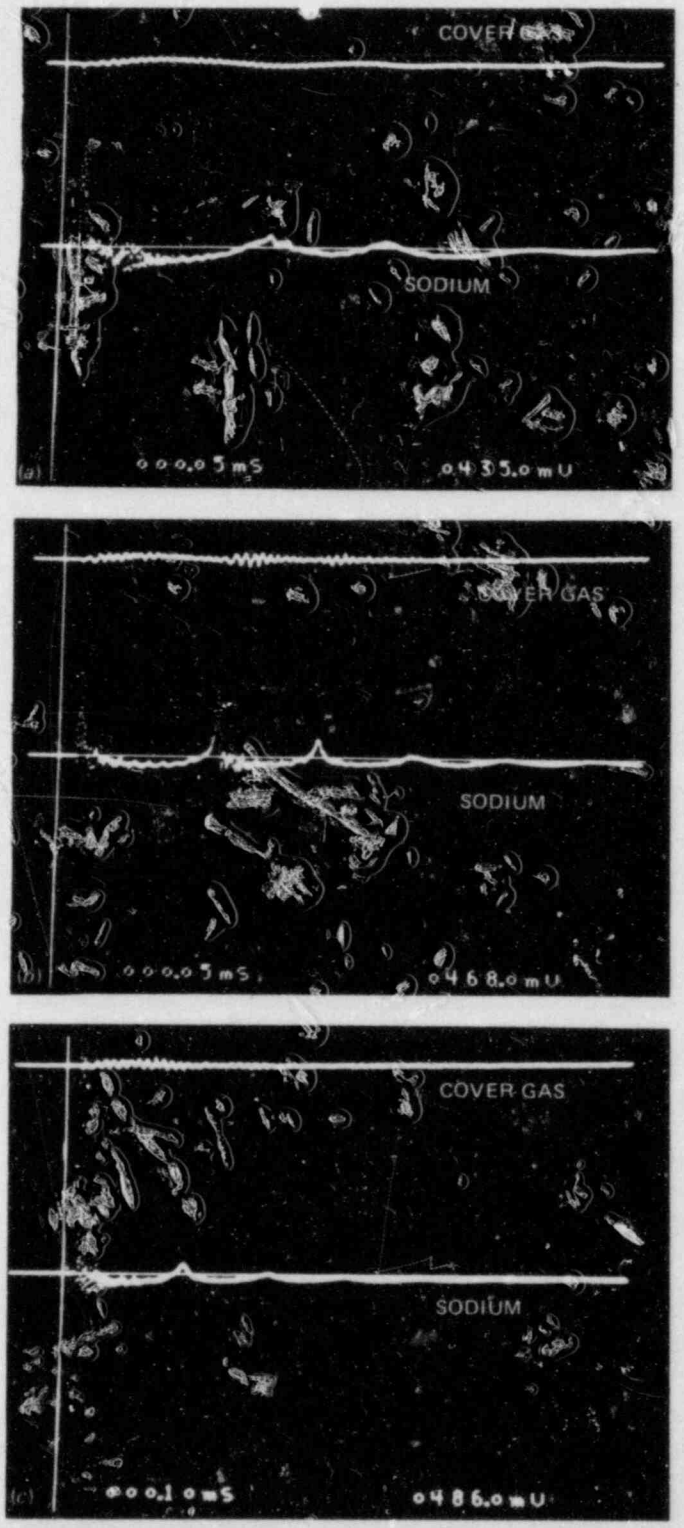

Fig. 6. Comparison of oscilloscope pressure traces in (*a*) FAST-105, (*b*) FAST-106, and (*c*) FAST-107.

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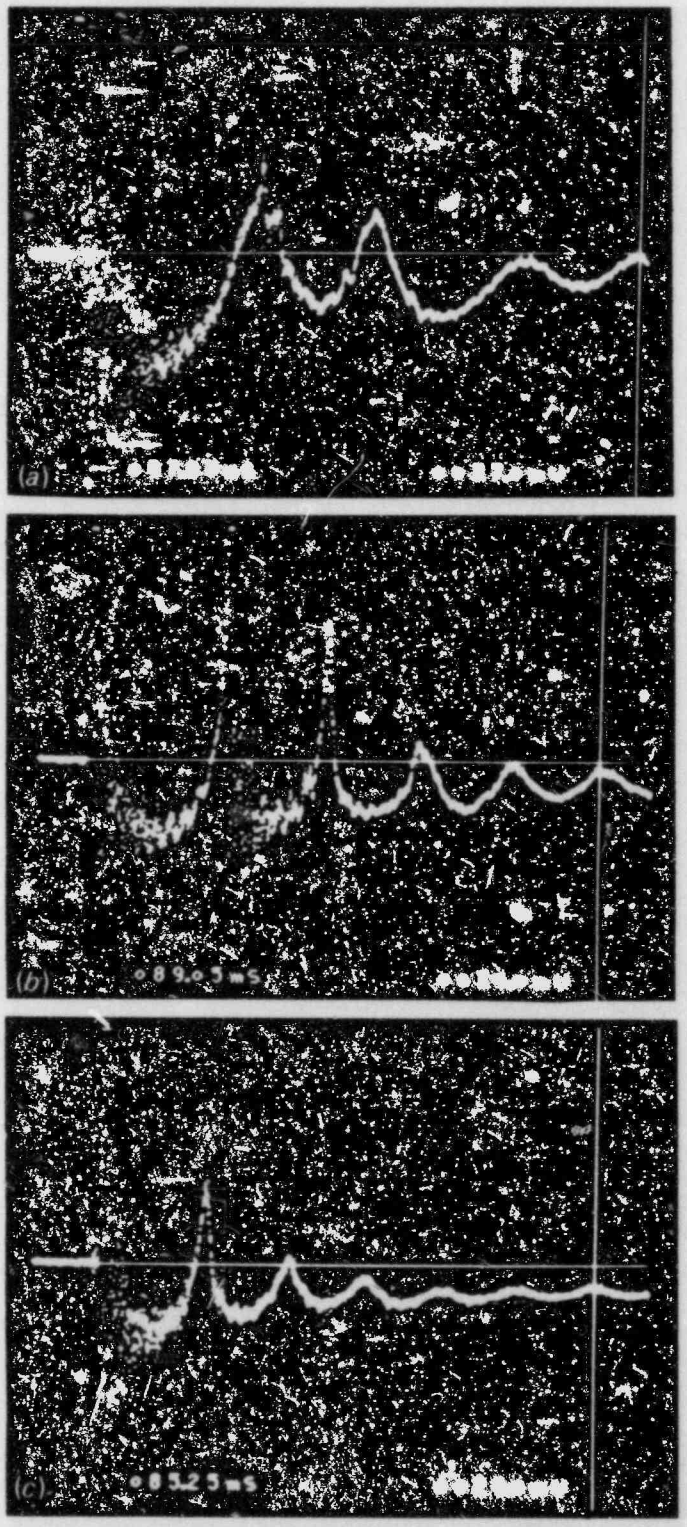

Fig. 7. Expanded views of oscilloscope sodium-pressure traces in (*a*) FAST-105, (*b*) FAST-106, and (*c*) FAST-107.

Table 5. Sodium-pressure maximum and minimum points from FAST-105 through FAST-107

[Effects of energy input level[a] and decreasing sodium height (H) are shown]

Pressure point	Time from sample disassembly (ms)			Pressure indication above baseline value[b] (kPa)		
	FAST-105 (H = 107 cm)	FAST-106 (H = 20 cm)	FAST-107 (H = 10 cm)	FAST-105 (H = 107 cm)	FAST-106 (H = 20 cm)	FAST-107 (H = 10 cm)
Maximum						
1	0.99	0.62	0.80	807	388	277
2	32.49	23.57	17.80	90	551	81
3	51.84	40.62	32.10	42	138	7.5
4	77.09	56.42	45.05	−7.4	20	−15
5	95.19	72.42	58.05	0.0	0.0	−26
6		86.07	70.90		−5.4	−26
7			82.95			−23
Minimum						
1	16.39	12.27	8.95	−120	−68	−72
2	42.84	32.12	24.10	−57	−56	−57
3	63.39	48.47	38.30	−65	−49	−41
4	86.34	64.37	51.35	−35	−49	−43
5		79.52	63.90		−34	−36
6			76.45			−34
7			89.25			−32

[a]Capacitor discharge energy input to arcing was 32.2 kJ in FAST-105, 37.6 kJ in FAST-106, and 28.8 kJ in FAST-107.

[b]Baseline sodium pressure was 128 kPa (abs) in FAST-105 and 121 kPa (abs) in FAST-106 and FAST-107.

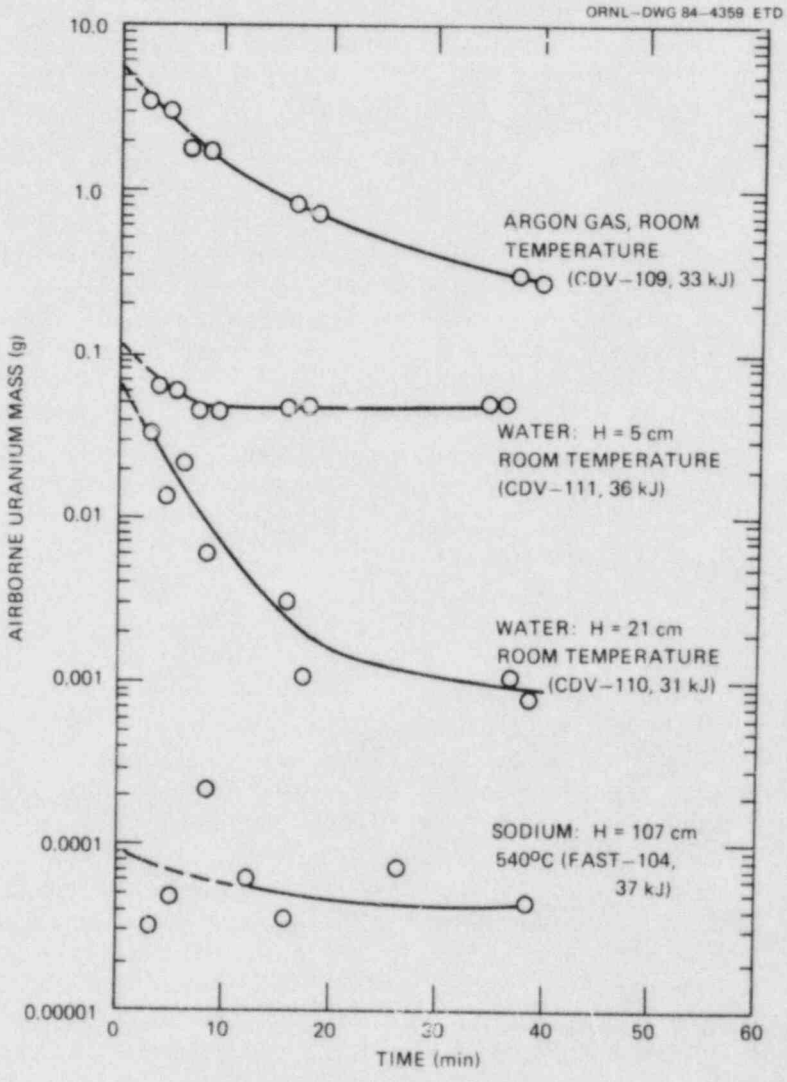

Fig. 8. Aerosol sampling results for FAST/CRI-III tests.

through the sodium to the cover gas may be obtained. On this basis, the aerosol sampling results given in Fig. 8 show a large reduction of the fuel release by increasing liquid height above the sample, with $<10^{-4}$ of the fuel vapor found in the cover gas in FAST-104 at the sodium height of 107 cm. This result should be considered as specific to the FAST test vessel and the FAST-104 experimental conditions.

2.2 Secondary Containment Aerosol Studies in the NSPP

R. E. Adams M. T. Hurst
A. L. Johnson

2.2.1 Introduction

Studies continued on the behavior of aerosols assumed to be released into containment environments during LWR accident sequences. Previous progress reports contain results from experiments involving U_3O_8 aerosol, Fe_2O_3 aerosol, and concrete aerosol in both dry air and steam-air environments. Results from two tests involving a mixed Fe_2O_3-U_3O_8 aerosol in a steam-air environment are contained in this report. These tests are the second and third tests involving a two-component aerosol; the first two-component aerosol test involved Fe_2O_3 and concrete aerosol.[4]

2.2.2 LWR aerosol experiment 611

Experiment 611 was the first test involving a mixed aerosol of Fe_2O_3 and U_3O_8. This mixture is a simulant for aerosols emanating from molten fuel and molten core support and structural materials. To prepare the test atmosphere, steam was introduced into the vessel, which was initially at 0.036 MPa (abs), to bring the vessel atmosphere (air) to an average temperature of 382 K and a pressure of 0.183 MPa (abs). This step required about 1.3 h; at this point, the rate of steam injection was reduced, and the accumulated steam condensate was removed to a holding vessel. The two aerosols were produced with separate PT generators and mixed within the vessel. The Fe_2O_3 aerosol was generated for a period of 11.5 min starting at time 0; the U_3O_8 aerosol generator was operated for a period of 8 min starting at an elapsed time of 2 min, and ending at 10 min, but it appears that all of the uranium metal powder was probably injected into the generator over the first 4 min of operation. Steam injection at the low rate was maintained for ~6 h to balance steam losses caused by wall condensation. Over this period, the temperature and pressure slowly increased until, at 6 h, the average temperature was 383 K and the pressure was 0.203 MPa (abs). The vessel was allowed to cool for 18 h after termination of the steam injection.

2.2.2.1 Aerosol mass concentration. The two aerosols are injected into the vessel in the upper quadrant at two different locations, and the steam is introduced near the bottom of the vessel. To facilitate mixing, a small fan-mixer is installed in the center of the vessel near the bottom. Operation of this fan-mixer produced a fairly homogenous mixture of aerosol and steam as illustrated in Fig. 9, which contains the results for Fe_2O_3 aerosol from the four in-vessel filter samplers installed at four different locations within the vessel.

The first set of aerosol mass concentration samples was taken at 4 min after termination of Fe_2O_3 aerosol generation. At this time the average mass concentrations of Fe_2O_3 and U_3O_8 aerosol were 3.1 and 1.9 $\mu g/cm^3$, respectively. Extrapolation of these data to the time of Fe_2O_3 aerosol generation cutoff (11.5 min) yields values of 5.5 and 4.0 $\mu g/cm^3$ for Fe_2O_3 and U_3O_8 aerosol, respectively. These ratios of

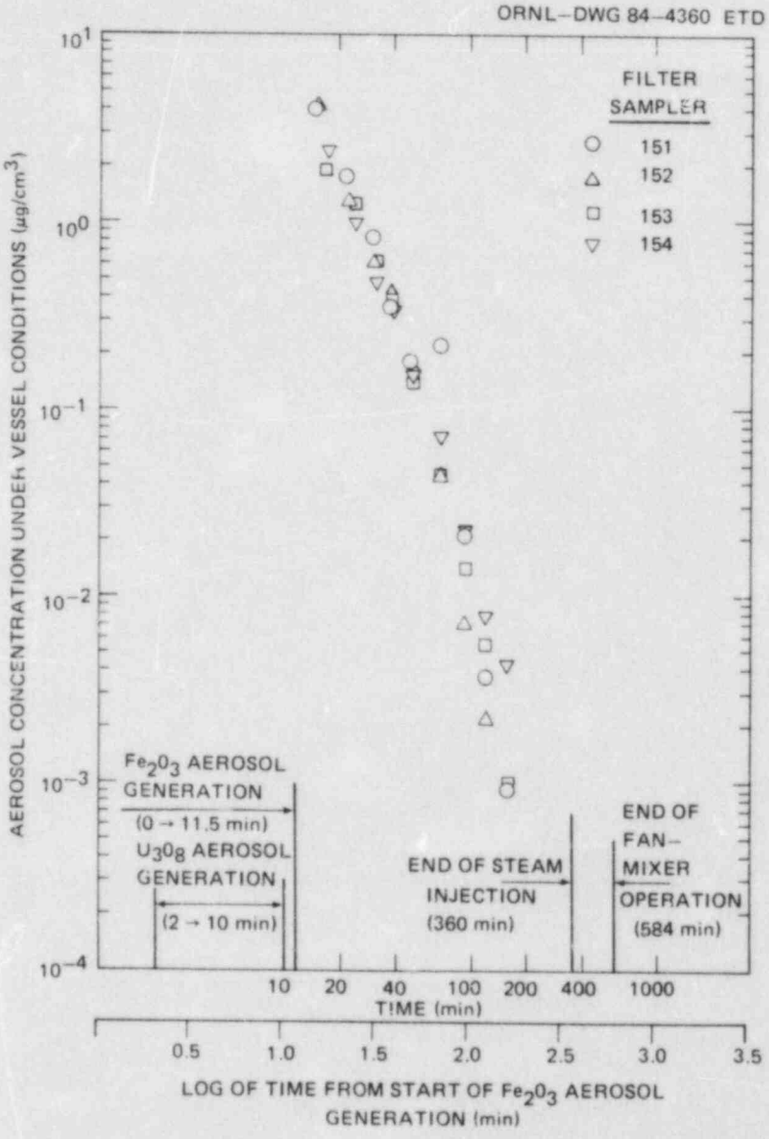

Fig. 9. Aerosol mass concentration as function of time for Fe_2O_3 component of mixed Fe_2O_3–U_3O_8 aerosol in steam environment (Run 611).

Fe_2O_3 to U_3O_8 are 1.6 to 1 and 1.4 to 1, which are reasonably close to the desired 1 to 1 ratio. The rate of disappearance of the two aerosols from the vessel environment is approximately the same as illustrated in Fig. 10; this behavior suggests that the two aerosols were coagglomerated.

2.2.2.2 Aerosol particle size. The aerodynamic mass median diameter (AMMD) of the aerosol was measured by both the spiral centrifuge sampler and the cascade impactor (Andersen Mark III). The "wet" aerosol was dried by dilution with clean air before introduction into the samplers. At 18 min after termination of the Fe_2O_3 aerosol generation, an AMMD of

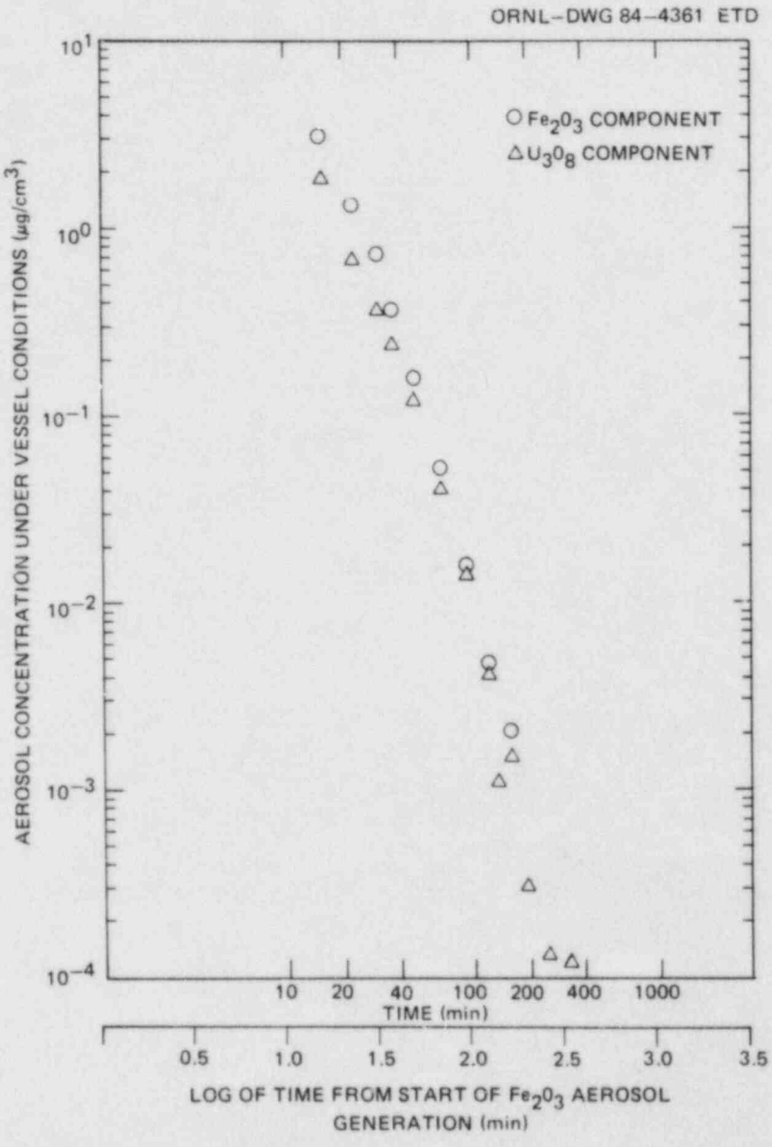

Fig. 10. Comparison of behavior of each component of mixed Fe_2O_3–U_3O_8 aerosol in steam environment (Run 611).

about 1 μm (σ_g = 1.5) for the mixed aerosol was determined by the centrifuge sampler; at 38.7 min, an impactor sample indicated an AMMD of 1.7 μm (σ_g = 1.9) for the aerosol mixture. Determination of the AMMD by using only the Fe_2O_3 mass fraction or the U_3O_8 mass fraction yielded equivalent values to those determined using the total mass of aerosol; this behavior also suggests that the two aerosols may be coagglomerating.

2.2.2.3 Aerosol distribution. At the termination of the test (24 h), the approximate distribution of the mixed aerosol (Fe_2O_3 + U_3O_8), as determined by the total fallout samplers, the total plateout samplers,

and the final filter samples, was as follows: aerosol settled onto the floor of vessel, 83%; aerosol plated onto internal surfaces, 17%; and aerosol still suspended in the vessel atmosphere, nil.

2.2.3 LWR aerosol experiment 612

Experiment 612 was the second test involving a mixed aerosol of Fe_2O_3 and U_3O_8. To prepare the test atmosphere, steam was introduced into the vessel, which was initially at 0.036 MPa (abs), to bring the vessel atmosphere (air) to an average temperature of 385 K and a pressure of 0.218 MPa (abs). This step required about 1.3 h; at this point the rate of steam injection was reduced, and the accumulated steam condensate was removed to a holding vessel. As before, the two aerosols were produced with separate PT aerosol generators and mixed within the vessel. The Fe_2O_3 aerosol was generated for a period of 25.5 min starting at time 0; the U_3O_8 aerosol generator was started at an elapsed time of 20 min and operated for 5 min, ending at an elapsed time of 25 min. Steam injection at the low level was maintained for 6 h to balance steam losses to vessel walls. Over this period, the temperature and pressure increased until, at 6 h, the average temperature was 388 K and the absolute pressure was 0.234 MPa. The vessel was allowed to cool for 18 h after termination of steam injection.

2.2.3.1 Aerosol mass concentration. The two aerosols and the steam were fairly well mixed by the fan-mixer as illustrated in Fig. 11, which contains the results for U_3O_8 aerosol from the four in-vessel filter samplers installed at four different locations within the vessel.

The first set of aerosol mass concentration samples was taken at 2.8 min after termination of Fe_2O_3 aerosol generation. At this time the average mass concentrations of Fe_2O_3 and U_3O_8 were 0.4 and 1.5 $\mu g/cm^3$, respectively. Extrapolation of these data to the time of Fe_2O_3 aerosol generator cutoff (25.5 min) yields values of 0.5 and 1.8 $\mu g/cm^3$ for Fe_2O_3 and U_3O_8 aerosol, respectively. These ratios of Fe_2O_3 to U_3O_8 are about 0.3 to 1; similar ratios for Run 611 were 1.6 to 1 and 1.4 to 1. The rate of disappearance of the two aerosol components from the vessel environment is approximately the same (Fig. 12); this behavior suggests that the two aerosol components were coagglomerated.

2.2.3.2 Aerosol particle size. The AMMD of the aerosol was measured by a cascade impactor (Andersen Mark III). Other samples of the aerosol were taken with the spiral centrifuge sampler, but insufficient material was obtained for chemical analysis. The wet aerosol was dried by dilution with clean air before introduction to the cascade impactor. At 4.5 min after termination of the Fe_2O_3 aerosol generator, an AMMD of about 1.5 μm (σ_g = 2.1) was determined for the mixed aerosol. Determination of the AMMD by using only the Fe_2O_3 mass fraction produced a value of 1.2 μm (σ_g = 2.3); by using the U_3O_8 mass fraction, an AMMD of 1.8 μm (σ_g = 1.9) was obtained. This incidence provides some support for the observation that the two aerosols are possibly coagglomerated.

2.2.3.3 Aerosol distribution. At the termination of the test (24 h), the approximate distribution of the mixed aerosol (Fe_2O_3 + U_3O_8),

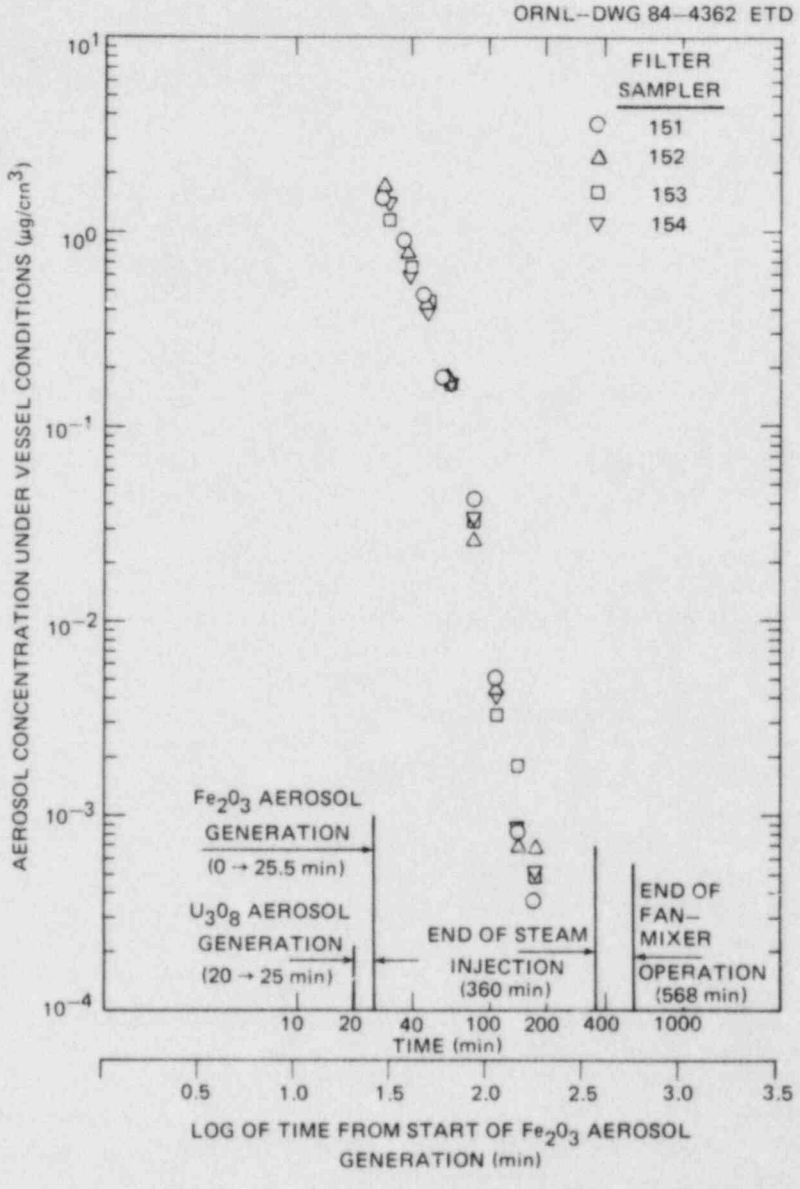

Fig. 11. Aerosol mass concentration as function of time for U_3O_8 component of mixed Fe_2O_3–U_3O_8 aerosol in steam environment (Run 612).

as determined by the total fallout samplers and the total plateout samplers, was as follows: aerosol settled onto the floor of vessel, 76%; aerosol plated onto internal surfaces, 24%; and aerosol still suspended in the vessel atmosphere, nil.

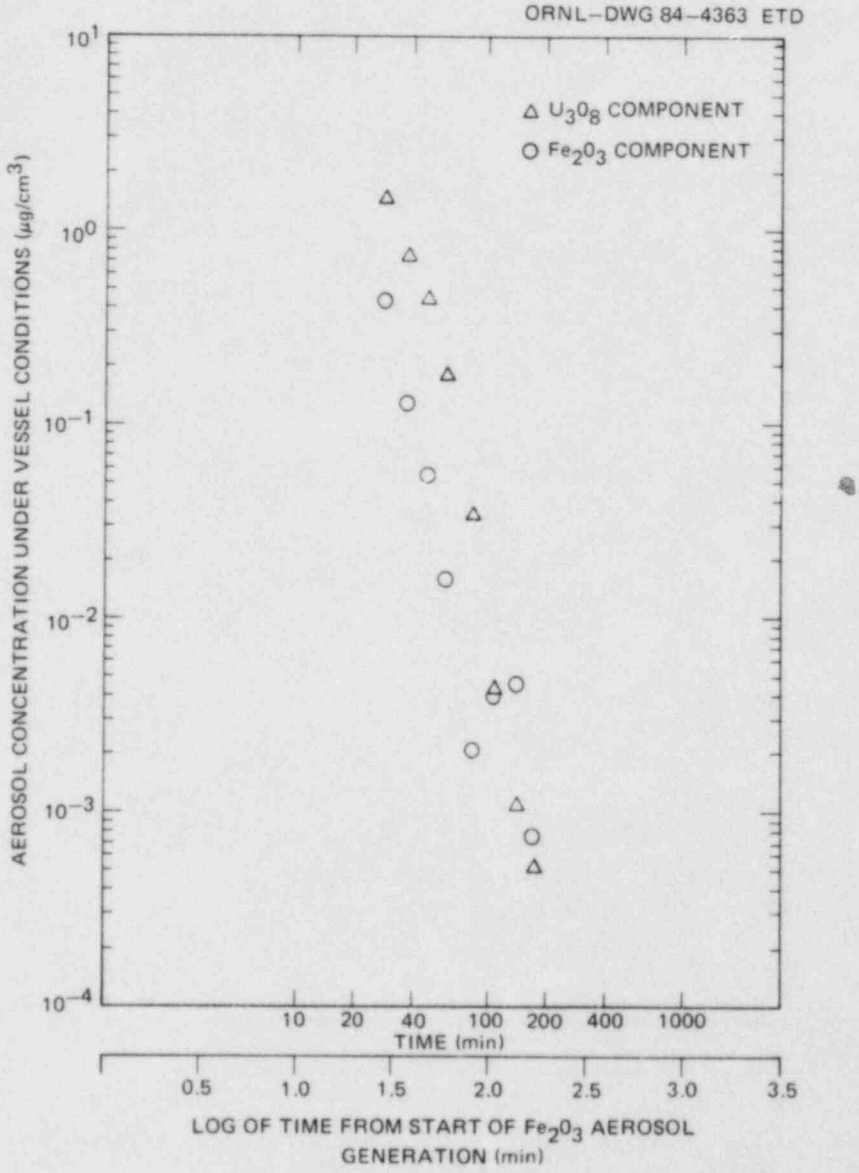

Fig. 12. Comparison of behavior of each component of mixed Fe_2O_3–U_3O_8 aerosol in steam environment (Run 612).

2.2.4 Comments on behavior of mixed aerosols

Observations have now been made on the behavior of single-component aerosols (U_3O_8, Fe_2O_3, and concrete) and multicomponent aerosols (Fe_2O_3 + U_3O_8 in a steam-air environment. It is therefore possible to make general comparisons of their behavior at this time; these comparisons are based, in some cases, on very limited data and are subject to change as more data are obtained.

The aerodynamic behavior of the mixed aerosol, (U_3O_8 + Fe_2O_3) in Runs 611 and 612 is very similar. The rate of disappearance from the vessel environment is comparable even though the mass ratios of the two aerosol components are different; this is illustrated in Fig. 13 where the normalized aerosol mass concentration is presented as a function of time from termination of aerosol generation.

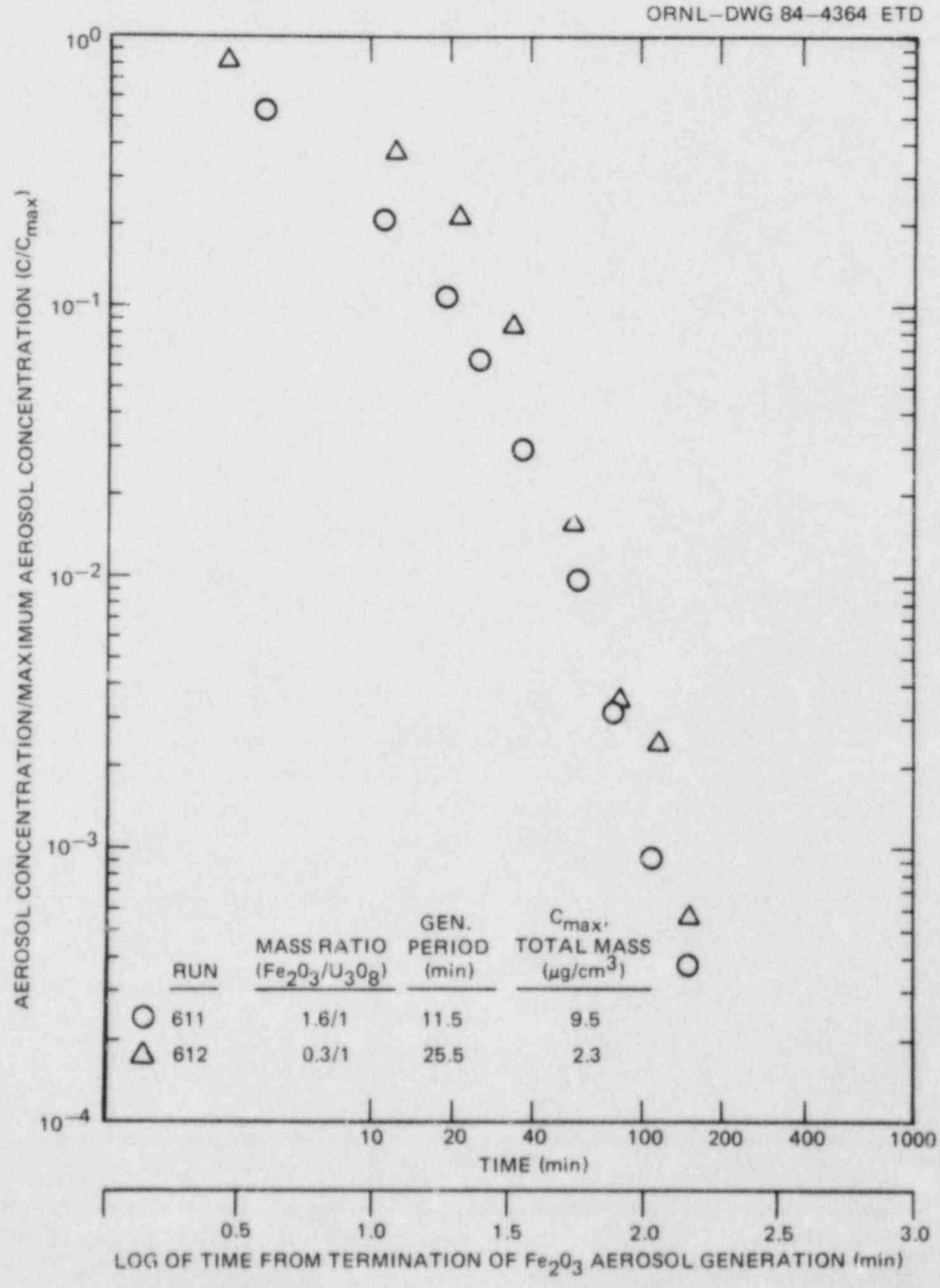

Fig. 13. Comparison of behavior of mixed Fe_2O_3–U_3O_8 aerosols at different mass ratios in steam environment.

Figure 14 compares the aerodynamic behavior of single-component and multicomponent aerosols in a steam-air environment within the NSPP vessel. It may be observed that the mixed aerosol (U_3O_8 + Fe_2O_3) in Run 611 behaves in a fashion more similar to that of an Fe_2O_3 aerosol (Run 505) than that of a U_3O_8 aerosol (Run 402). When Fe_2O_3 is mixed with a concrete aerosol (Run 601), it remains airborne longer in the manner of a concrete aerosol.[5] The significance of these observations will be better defined as additional data are obtained.

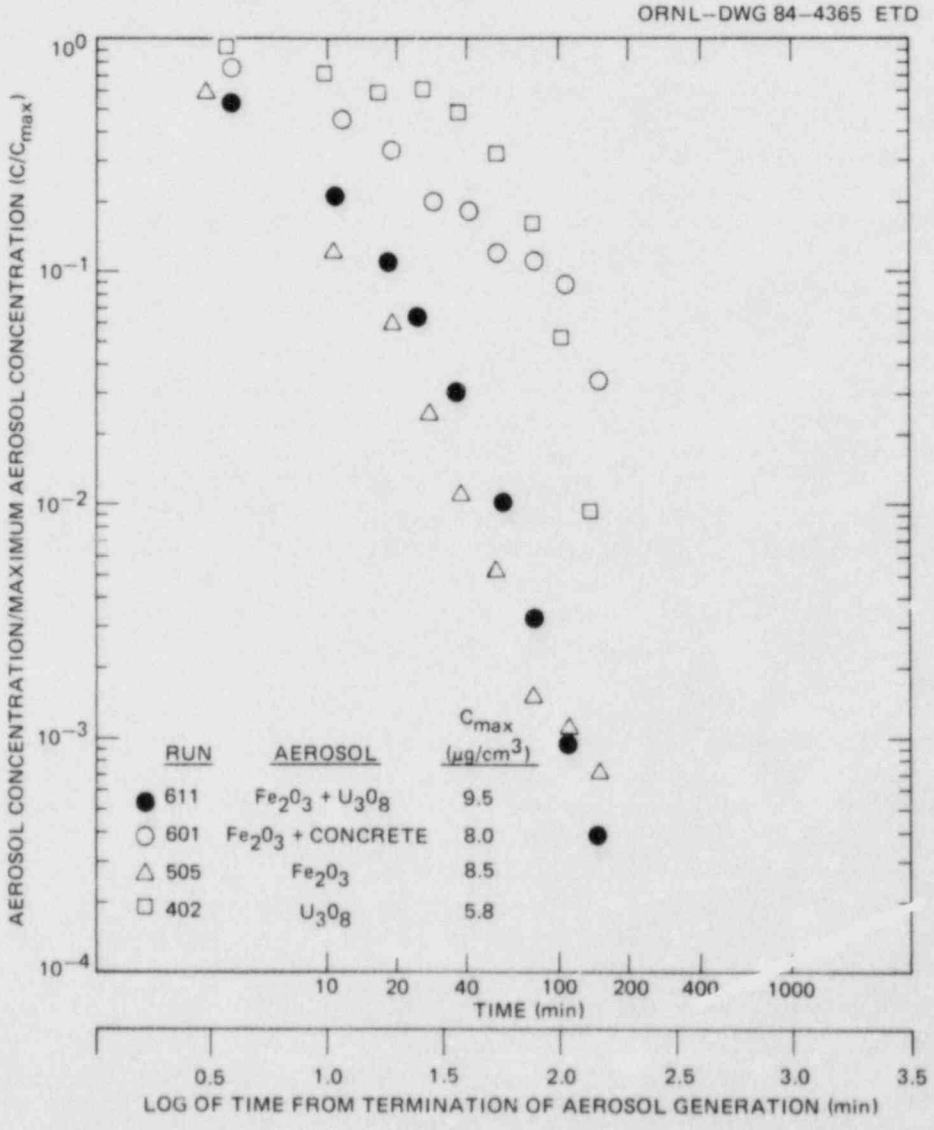

Fig. 14. Comparisons of behavior of mixed aerosols (Runs 611 and 601) with that of single-component aerosols (Runs 505 and 402) in steam environments.

2.3 Basic Aerosol Experiments in CRI-II

G. W. Parker A. L. Sutton, Jr.
G. E. Creek (Consultant)

2.3.1 Introduction

The basic aerosol experimental program has been temporarily redirected to provide technical support in various aspects of aerosol generation to the proposed LWR primary-system aerosol transport test (ATT) program at the Marviken facility in Sweden and the proposed large-scale test program on LWR aerosol behavior in containment (DEMONA) at the Battelle (Frankfurt, West Germany) facility.

One possible area of assistance concerns the power requirements, the development of designs, and the operation methods of PT generators of the sizes and types needed for these facilities. For the Marviken facility, the generation of aerosols of a "fissium" mixture (CsOH, RuO_2, SrI_2, and metallic Te) is of interest, while the Battelle-Frankfurt program is concerned with methods of generating iron oxide or tin oxide aerosols or an alternate candidate oxide at the maximum rate.

The versatility of the ORNL-developed metal-oxygen dc PT aerosol generator has resulted in a recent request for design details and drawings from KfK and from Kraftwerk Union, West Germany, as well as from the Marviken project.

At Battelle-Columbus Laboratories (BCL), the aerosol generator is being used in an Electric Power Research Institute (EPRI)-sponsored suppression pool aerosol washout test program. In West Germany at the Battelle-Frankfurt Laboratory, a large-scale multiple-unit torch installation is being considered to supply a test aerosol for a 600-m^3 pressure vessel. Some of the development work in progress at these locations should also be of value in the decision-making process for the Marviken ATT project.

The CRI-II facility, which has external heating and temperature control, is being readied for a trial test of the aerosol generator under the steam atmosphere conditions expected in both the Frankfurt and the Marviken primary vessel environment. Initially, only low-pressure steam of 15 to 30 psi will be applied to determine the extent of impairment of the aerosol generation efficiency. The design limit of the CRI facility is ~75 psi, but this amount of pressure cannot presently be accommodated by the existing powder feeders without placing them in added pressurized containment.

Any aerosol characterization or size measurements made under such pressurized conditions will require a partial dilution in a back-pressure expansion vessel from which samples will be removed under normal ambient pressure and temperature.

2.3.2 Marviken technical support

In response to a request from NRC, a recent visit to the Marviken site was arranged to discuss both the progress and remaining problem areas indicated by two shakedown "fissium" test runs conducted in the

Marviken pressurizer vessel. Three Metco Model 10, 80-kW PTs were used to vaporize up to 63 kg of cesium, 7.3 kg of iodine, and 3.5 kg of tellurium.

After the tests, a commercial contract cleaning specialist was engaged to decontaminate the vessels and piping to obtain material balance data that accounted for up to 75% of the calculated feed materials. Continued repeat analyses seemed to improve the final values except for iodine, which may have been swept out after encountering nitric oxide inadvertently produced by the PTs.

Problems encountered were mainly with the difficulty of removal of the fissium elements from metal surfaces. High-pressure jet washing and brush surface abrasion were used, and the resulting wash solutions were often slurries that complicated quantitative sampling.

ORNL was requested to provide guidance on solving the problems with material balance, with the aerosol instrumentation, and with the chemical identification of species of the fissium element. In addition to suggestions made on the site, we plan to provide a demonstration in the CRI-II Facility of both the use of an ultra high-pressure jet decontamination process and the use of a centrifugal liquid-solids clarifier to obtain a homogenous liquid phase and a concentrated solids phase. We think this should provide a more reproducible method of analysis. ORNL also proposed calibrating a small spiral aerosol centrifuge (Lovelace type) with an appropriate pressure letdown system that could be made adaptable to the Marviken conditions.

In an effort to substantiate our suggestion that the Marviken project might use a high-speed centrifugal clarifier to separate the two-phase chemical washes generated during the postrelease vessel cleanup for material balance, we have successfully applied the technique to a CRI-II high-pressure jet wash in which metallic zinc, copper, and iron oxide were all separated completely from a liquid phase. This centrifuge and a clarified solution are shown in Fig. 15.

The centrifuge, a Sharples Model AS-12NF Super Centrifuge, which has sufficient liquid capacity and solids collection space for the scale of the Marviken project, could be loaned if the need arises.

Calibration of the small-scale version of the LASL-Stöber aerosol centrifuge, known as the Lovelace or ITRI (Inhalation Toxicology Research Institute) centrifuge (Fig. 16), with monodisperse PSL microspheres yielded a satisfactory comparison with the larger centrifuge, which we regard as the best reference aerosol size measurement instrument. We have also ordered a speed-control device and an alternate motor that will permit operation of the centrifuge at a slower speed, thereby increasing its sensitivity to larger aerosol sizes. At the same time, the new motor and speed-control would permit operation at the Marviken site, which has 50-cycle 230-V power for instrumentation. A further demonstration of the application of the small centrifuge to the measurement of "corium" aerosols from a high-pressure CRI test after transfer to a letdown expansion tank will be conducted and size-distribution data compared with that from the six-stage cascade cyclone separator that we are also evaluating in support of the Marviken project.

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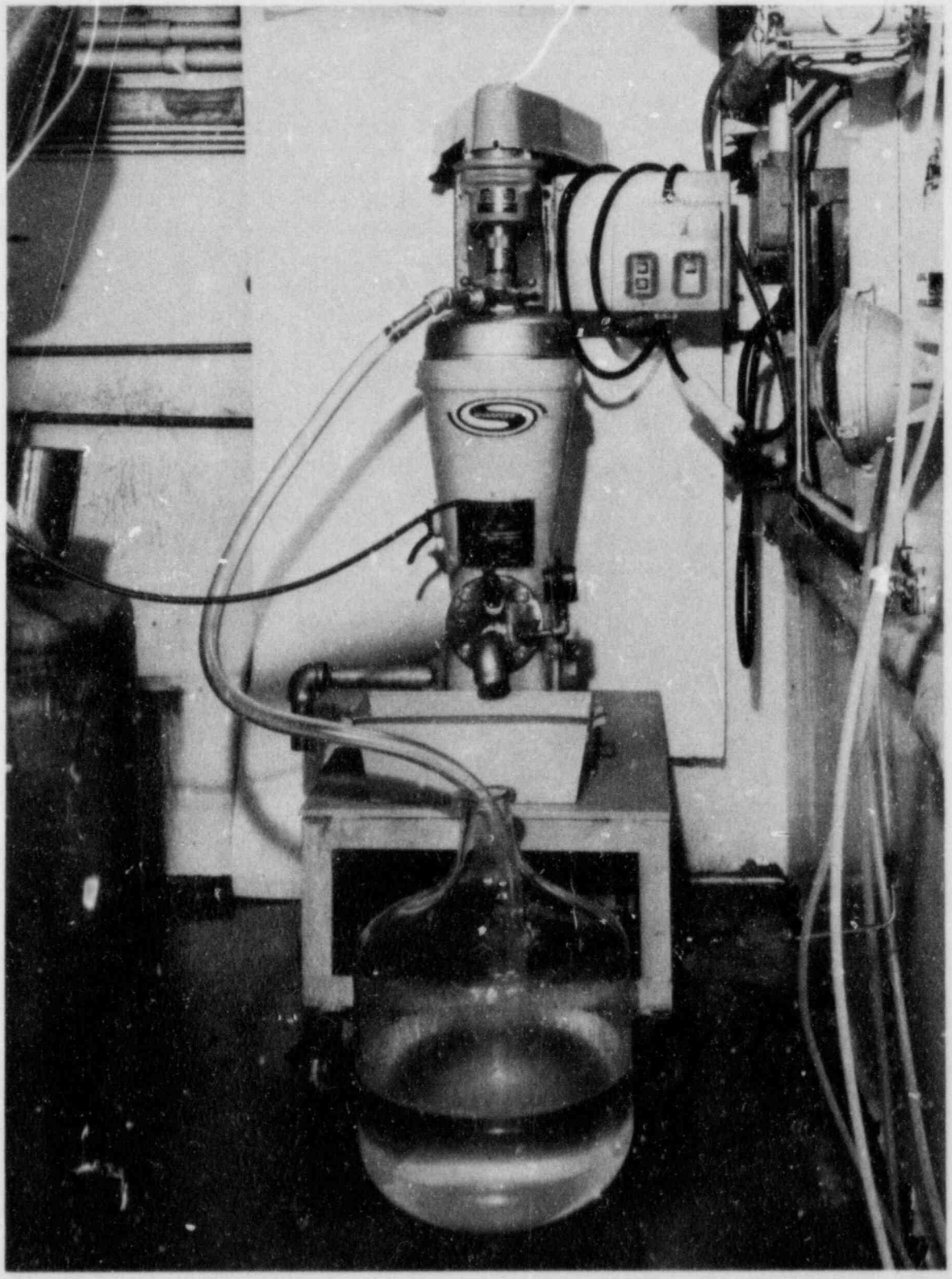

Fig. 15. High-speed Sharples Centrifugal Clarifier used to separate undissolved solids in wash solutions.

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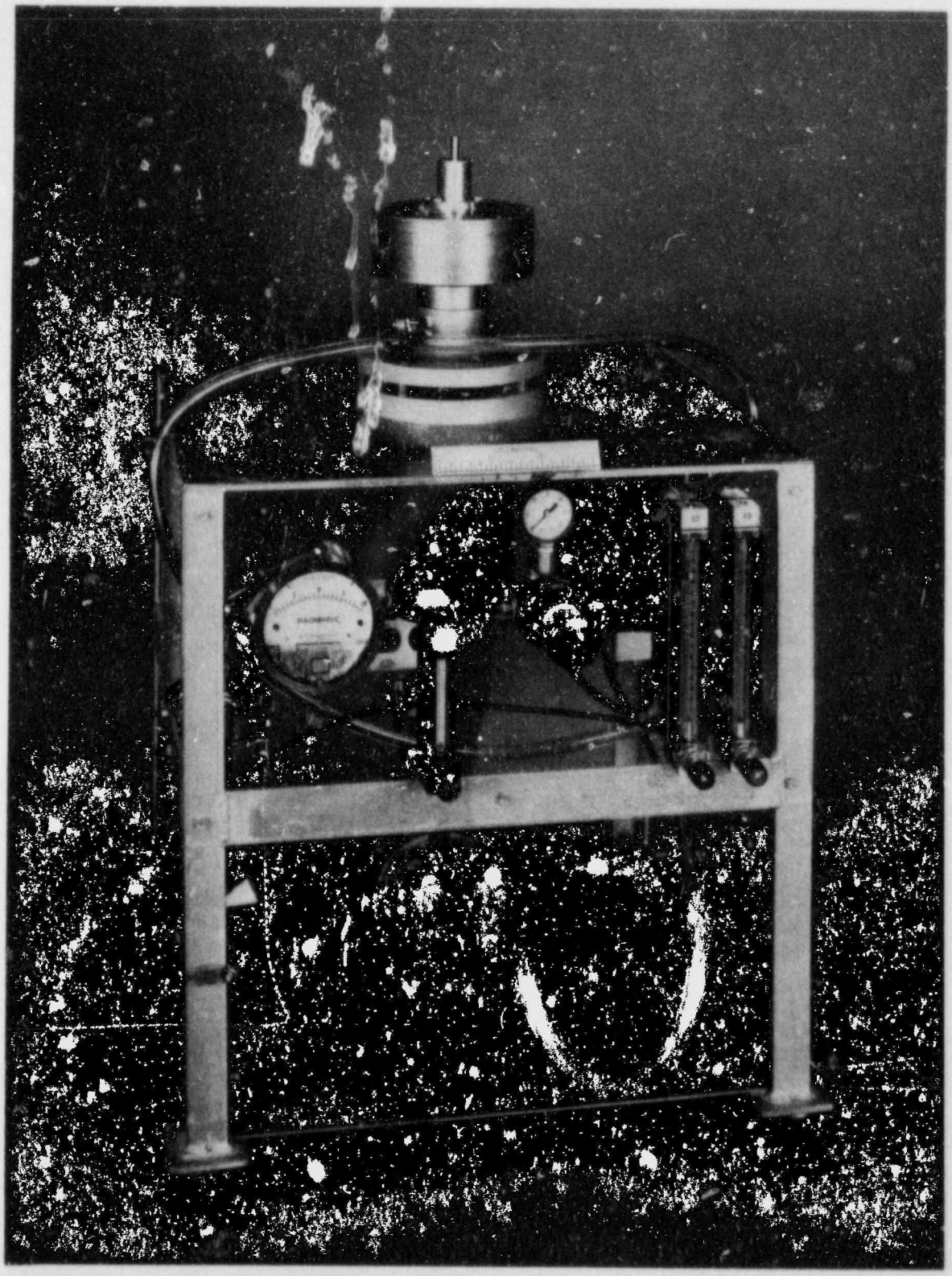

Fig. 16.. Single-turn Lovelace Aerosol Particle Separator.

2.3.3 DEMONA Project support

In cooperation with the DEMONA Project, a special chemical exchange experiment is being prepared for the CRI in which silver aerosol will be vaporized simultaneously with cesium iodide and the extent of the iodine-silver interaction will be measured. The methodology for making these measurements should also be applicable to the Marviken project in the same type test.

For chemical species identification, a combination May-pack filter and charcoal absorber system was proposed and will be demonstrated in the CRI-II.

2.4 Core-Melt Aerosol Release and Transport

G. W. Parker A. L. Sutton, Jr.
G. E. Creek (Consultant)

2.4.1 Introduction

The core-melt ART experiments are intended to address phenomena associated with LWR Class IX accidents, particularly the postulated large-scale vaporization and aerosol formation by fission products, core components, and structural materials. To attain the desired high temperature and melting rates, the radio frequency (rf) induction melting of Zircaloy-clad fuel pins in presintered, powdered oxide crucibles of ThO_2 (the skull-melting technique) has been chosen as the basis of the experimental system.

Previous work has dealt with the pressurized-water reactor (PWR) silver alloy control rod interaction with Zircaloy cladding and extensive vaporization of cadmium and silver at temperatures as low as 1400°C, the temperature at which the stainless steel sleeve containing the alloy appears to rupture. The cladding is found to be extensively wetted by the silver through formation of low-melting silver-zirconium alloy. Upon further temperature increase, the cladding is melted off the UO_2. The pellets are left in a free-standing mode presenting the appearance of being wetted by a UO_2-Zr solid solution or pseudoeutectic. Further heating in steam to ~2400°C produces a liquid phase containing both Zr and ZrO_2, in addition to UO_2. The silver-zirconium phase is not distinguishable in eutectic mixtures. Free metallic uranium has been reported by others to be formed at the Zr-UO_2 interface, and evidence for this formation has been obtained through our identification of a U-Zr phase in the metallic stainless steel residue.

More recently, the direction of the project has been toward a critical examination of fission-product release fractions and an evaluation of differences in release rates observed on a smaller scale at KfK compared with the larger (1-kg) ORNL experiments. Several contributing factors inherent in the different experimental approaches toward demonstrating core-melt release seem to account for the variances. However, there is no obvious means of resolving the differences, because they appear to be determined by the unique approach of each of the experimental routines.

2.4.2 Noble metal fission-product element volatility suppression by molten stainless steel and zirconium

In continuing our investigation of the release of tellurium, we have completed a test melt (CM-35) in which equivalent amounts of both tellurium (Te) as the element and tellurium oxide (TeO_2) were used as additives.

It was therefore not unexpected that some tellurium was observed to be released as a black smoke very early in the first heating cycle (1600°C maximum Te temperature). We estimate now that 80% of the TeO_2 (none of the Te metal) was vaporized through the vent in the end cap plug and that this was almost instantly reduced by the hydrogen to form the black smoke (Te metal).

In the subsequent heating cycles to 2000°C and 2400°C, significant amounts of manganese, iron, chromium, and some uranium were released but no additional tellurium.

Two other core-melt experiments, both of which gave rather significant results with respect to source-term definition, were conducted this quarter. In the first experiment (CM-36), we demonstrated a high back-reaction rate of TeO_2 vapor with hot zirconium. This was done by loading TeO_2 additive into a mixture containing Te, Ru, and Mo metal powder blended into dry UO_2 powder. In the fuel assembly, four center fuel tubes were filled with the mixture, the same as in experiment CM-35 above, except that the assembly was inverted so that the vent plugs through which the TeO_2 had been released in experiment CM-35 were pointed downward. This was done to force the TeO_2 vapor back in contact with both hydrogen gas and hot zirconium before it could escape as an aerosol. By visual observation, no significant amount of tellurium could have been released. Detailed analytical results show only about 1% of the tellurium included in the analyses (Table 6). From this initial demonstration it appears that the large inventory of hot zirconium in a power reactor could conceivably retain all the tellurium that could be vaporized in an oxidized state near the melt formation zone.

In the second experiment, CM-37, the first BWR type control rod interaction and vaporization test was conducted using an array of three B_4C powder-filled stainless steel tubes with the amount of B_4C in the ratio of 1:100 to the amount of UO_2. After only two steps in the three heating cycles to about 1750°C, significant amounts of white aerosol have been collected (B_2O_3 is the expected form) on the filter paper. Further heating to complete melting is yet to be completed, and material balance will be performed to determine total conversion of B_4C.

2.4.3 Status of the 10-kg core-melt induction furnace

Installation of the 10-kg core-melt induction melting systems has passed a significant milestone with the delivery and placement of the 250-kW generator in the 4501 Building crane-bay (Fig. 17). Hookup of power and water services is under way, and delivery of the coaxial transmission lines is expected in the next few weeks.

Table 6. CM-36: Tellurium oxide release from bottom-vented pins

Element	Weight (g)	Heat A[a]			Heats B and C[b]			Heat D[c]			Total all heats	
		Filter (mg)	Wash (mg)	Total (mg)	Filter (mg)	Wash (mg)	Total (mg)	Filter (mg)	Wash (mg)	Total (mg)	mg	%
Manganese	0.221	0.011	<0.039	0.05	0.44	0.017	0.46	2.29	<0.051	2.34	2.85	1.3
Tellurium	0.061	0.0115	0.117	0.129	0.36	0.051	0.41	0.14	0.017	0.16	0.70	1.1
Uranium	523.87	0.019	0.013	0.032	0.059	0.017	0.076	1.1	0.017	1.12	1.23	2.3×10^{-4}

[a]Heating time — 6 min, maximum temperature 1650°C.

[b]Heating time — 10 min, maximum temperature 1900°C.

[c]Heating time — 3 min, maximum temperature 2400°C.

ORNL–PHOTO 5895–83

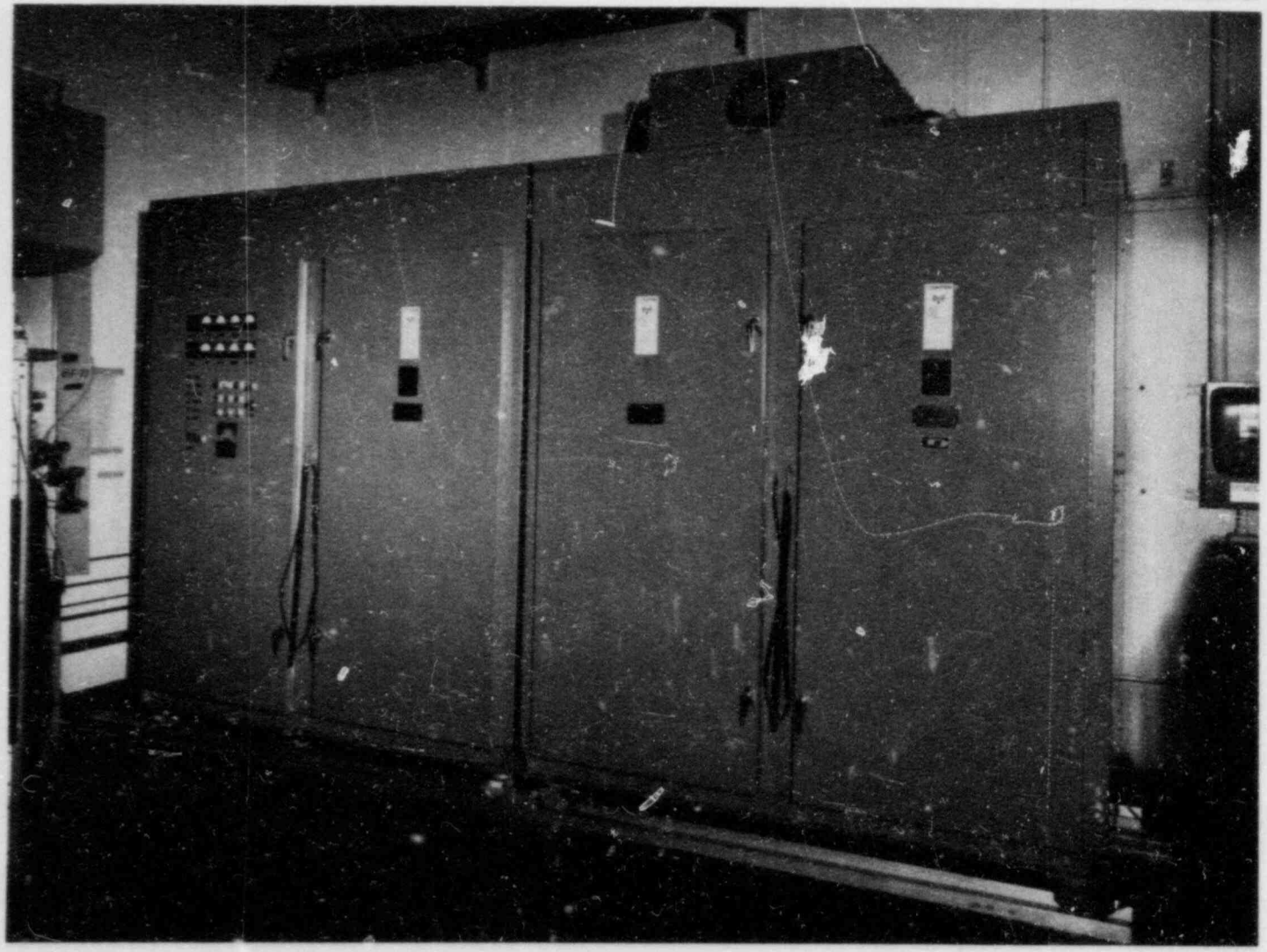

Fig. 17. 250-kW rf induction generator at ORNL.

3. ANALYTICAL PROGRAM

R. E. Adams
J. C. Petrykowski
T. S. Kress
M. L. Tobias

3.1 Introduction

The analytical efforts in the ART Program consist mainly of mathematical computational activities designed to process and interpret the data obtained in various experiments. Typical activities in the past have been the development of theories of bubble behavior in the FAST experiment, processing of data from NSPP runs, comparison of predicted aerosol behavior with experiments using such codes as HAARM3, implementation of advanced aerosol and bubble behavior codes from various institutions, and the development of models to describe steam behavior in the NSPP.

3.2 LMFBR Fuel Vaporization Simulations in the FAST Facility*

J. C. Petrykowski
A. L. Wright
T. S. Kress

Out-of-reactor experiments are being conducted in the LMFBR ART project to investigate the vaporization and release of fuel postulated to occur during hypothetical core-disruptive accidents (HCDAs). Uranium-dioxide pellets are vaporized under sodium in the FAST Facility to simulate the transport of fuel-vapor bubbles during HCDAs and to estimate the potential radiological release to the cover gas. As part of the reactivation of the FAST Facility, a study was undertaken to identify the phenomenological sequence that could occur during HCDAs and to determine the similarities that exist between the initial thermodynamic states of FAST-type and HCDA-type bubbles.

Two types of energetic HCDAs have been postulated to release fuel, fission products, and sodium vapor from LMFBR cores: transient undercooling (TUC) with failure to scram and transient overpower (TOP). A typical TUC could be initiated by a flow coastdown followed by heatup and local boiling of core coolant. In a TOP, a reactivity insertion caused by rapid withdrawal of the control rods leads to fuel pin failure and mixing of molten fuel and coolant. Positive reactivity feedback in both accidents caused by sodium voiding produces a rapid power excursion and vaporization of portions of the core. The excursions terminate when the internal core pressures are sufficient to produce mechanical disassembly. Although the fuel energy density is determined by complicated reactivity feedback mechanisms, the power excursions can be characterized by a "slow" deposition ramp (predisassembly) followed by a much faster

*A summary of this work was presented at the 1983 American Nuclear Society Winter meeting, San Francisco, Calif., October 30—November 3, 1983.

one (disassembly).[6,7] The energy density of the fuel during these transients may reach 3 kJ/g.

To simulate these energetic fuel states, uranium dioxide samples are energized by two-stage direct electric heating. The energy input during the first stage (predisassembly) is supplied by an electrical heater operated in a constant power mode. At the end of this stage, the sample is partially molten with an energy density of ~1 kJ/g. The second-stage heating is provided by capacitor banks that are discharged in a few milliseconds to vaporize and disassemble the fuel sample.[8]

The energy density of a typical sample was estimated using a finite-difference unsteady heat conduction code and direct electrical measurements of the discharge current and voltage. These calculations (Table 7) suggest that melting begins during the first stage and that vaporization occurs during capacitor discharge. In addition, the average energy density of the sample exceeds 2.7 kJ/g, suggesting that HCDA-type energy states can be achieved in the FAST Facility.

Table 7. Uranium dioxide sample characteristics[a]

Sample mass (g)	End of first stage		End of second stage		Total energy density (kJ/g)
	Enthalpy (kJ)	Average temperature (K)	Enthalpy (kJ)	Average temperature (K)	
17.6	19.9	3050	>48	>5500	>2.7

[a]Data obtained from FAST-104 test.

3.3 Steam-Only Experiments in the NSPP

M. L. Tobias

To achieve a better understanding of the behavior of steam in the NSPP vessel, source exploratory experiments are being performed. In this period, experiment 99 was run, in which two catch pans were placed near the top of the vessel and measurements were made of the accumulation rate of water in the pans. One of the pans was directly under the top flange, while the other was placed off to one side. The results of these measurements have not yet been analyzed, but it is clear that the uninsulated area of the top flange is a significant contributor to the total condensation rate. In addition to these measurements, wall run-off sampler (WROS) measurements were made as well as moisture sample measurements. Thermocouples and heat meters were placed at various points on the outer vessel surface, particularly on the reinforcing flanges that are suspected of acting as radiating fins and thus distorting the measurements of the WROS. A total of 264 kg (70 gal) of water was collected

during ~4 h of steady state operation of the experiment. After the vessel was allowed to cool, 53 kg (14 gal) was collected.

During the course of the run, the atmosphere of the vessel appeared cloudy. A definite Tyndall effect was observed. This contrasts with other runs in which the atmosphere became clear when a steady state, like that in this experiment, had been established. (This clear atmosphere was noted before the start of aerosol generation in NSPP experiment 611, for example.)

3.4 Aerosol Code Implementation Activities

M. L. Tobias

A study of the exact meaning of output from the QUICK[9] code of various statistical measures of particle radius was carried out and compared with special computations of the following quantities:

1. number geometric mean mass equivalent radius,
2. mass mean aerodynamic radius,
3. mass geometric mean aerodynamic radius,
4. mass median aerodynamic radius, and
5. logarithmic standard deviation.

The QUICKM[10] (former name MSPEC) was succesfully implemented on the Computer Science Division facilities at ORNL.

Attempts to use the MAEROS code[11] steam-aerosol calculations with the built-in (Fuchs-Sutugin) model failed because of numerical instabilities.

3.5 NAUA Validation Study

M. L. Tobias R. E. Adams

At the request of the NRC Accident Source-Term Program Office,[12] work continued on a contribution, concerning the NAUA code, to a study of the status of validation of the various codes used in the accident source-term reassessment study. This required study of the original German documentation of experiments, discussions with BMI-Columbus staff, and correspondence with the KfK authors of the code. A description of the code operation, modeling basis, shortcomings, advantages, and existing and required experimental support was prepared and a summary presented to NRC staff on Sept. 28, 1983, at Silver Spring, Maryland.

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This report summarizes progress for the Aerosol Release and Transport Program sponsored by the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, Division of Accident Evaluation, for July–September 1983. Topics discussed include (1) several capacitor discharge vaporization (CDV) experiments in the Fuel Aerosol Simulant Test Facility; (2) descriptions of mixed-aerosol experiments 611 and 612, which involved iron oxide and uranium oxide in steam; (3) technical support work for the aerosol test program at Marviken, Sweden; (4) core-melt experiment CM-35, in which tellurium and its oxide were used as additives; (5) progress in construction of a 10-kg core-melt induction furnace; (6) finite-difference calculations of energy deposition in CDV specimens; (7) a steam-only experiment in the NSPP; (8) code implementation activities; and (9) NAUA code validation studies.

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