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NUREG/CR-3830
Volume 2
ORNL/TM-9217/V2

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Aerosol Release and Transport Program Semiannual Progress Report for April 1984–September 1984

R. E. Adams M. L. Tobias

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements DOE 40-551-75 and 40-552-75

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NUREG/CR-3830
Volume 2
ORNL/TM-9217/V2
Dist. Category R7

Engineering Technology Division

AEROSOL RELEASE AND TRANSPORT PROGRAM SEMIANNUAL PROGRESS REPORT FOR APRIL 1984–SEPTEMBER 1984

R. E. Adams M. L. Tobias

Manuscript Completed – November 28, 1984
Date Published – December 1984

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements DOE 40-551-75 and 40-552-75

NRC FIN No. B0121
NRC FIN No. B0476

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-840R21400

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FOREWORD

This report summarizes progress under the Aerosol Release and Transport Program [sponsored by the Division of Accident Evaluation, Office of Nuclear Regulatory Research, Nuclear Regulatory Commission (NRC)] for the period April 1984–September 1984.

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
ORNL/NUREG/TM-90	October–December 1976
ORNL/NUREG/TM-113	January–March 1977
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
ORNL/NUREG/TM-276	July–September 1978
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ORNL/NUREG/TM-416	January–March 1980
ORNL/NUREG/TM-417	April–June 1980
ORNL/TM-5806	July–September 1980
ORNL/TM-7884	October–December 1980
ORNL/TM-7946	January–March 1981
ORNL/TM-7974	April–June 1981
ORNL/TM-8149	July–September 1981

Beginning with the report covering the period October–December 1981, work under the program was 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
ORNL/TM-8849/V3	July–September 1983

Beginning with the report covering the period October 1983–March 1984, work under the program is now being reported as *Aerosol Release and Transport Program Semiannual Progress Report*. The previous report under this title is

Report No.	Period covered
ORNL/TM-9217/V1	October 1983–March 1984

SUMMARY

M. L. Tobias

The Aerosol Release and Transport (ART) 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 (LMFBRs). The experimental programs are being conducted in the Fuel Aerosol Simulant Test (FAST) Facility, the NSPP Facility, and the new Aerosol-Moisture Interaction Test (AMIT) Facility. The analytical efforts are designed to support the experiments and to provide comparisons between the experimental observations and the results of computer codes intended to simulate aerosol behavior.

During this period the final experiment (FAST-113) of a planned series of ten UO_2 fuel vaporization experiments was performed under sodium. This test was done at a shallow sodium level, 3 cm above the test sample centerline. Pressure responses indicated markedly different fluid motions from previous undersodium tests. Only a single bubble oscillation was noted, while the cover-gas pressure traces and liquid-level probe data showed active behavior. Thick deposits of material were found on the aerosol sampling equipment, including significant amounts of sodium. While much more uranium was found on the filters, it is not clear whether it was released to the cover gas as an aerosol or as a contaminant in mechanically dispersed sodium. Following this last undersodium test, work was begun to prepare the FAST Facility for proposed LWR experiments.

In the NSPP program, a limestone-aggregate concrete aerosol test, No. 522, was conducted in a steam-air atmosphere. Aerosol was generated by plasma torch; back extrapolation of sampling data indicate that the aerosol concentration at the time of generator cutoff was 1.5 g/m^3. Size measurements with the cascade impactors were unsuccessful because insufficient aerosol was collected. At the end of 24 h, the suspended concentration was still 11% of the total generated; an estimated 55% had settled on the floor, and 34% was plated on internal surfaces. As in the previous concrete-steam experiment (No. 521), the condensing steam had only a small effect on the rate of change of the suspended concentration, even though the aerosol particle shape was changed from chain-agglomerate to partially spherical.

Several changes were made to enhance evaluation of thermohydraulic conditions in the NSPP. A steam heater has been added, and the vessel insulation has been renovated. Two steam-only tests (NSP runs 54 and 55) were made before and after the improvement was made to the thermal insulation on the vessel to evaluate its effect.

A planned series of experiments is described for testing heating effects due to the plasma torch. A small (0.35-m^3) vessel will be used. The progress of work on the AMIT Facility is discussed, and the test plan is briefly outlined.

In the analytical program, work connected with the acquisition and implementation of the computer codes AEROMECH, MAEROS, and QUICKM is discussed. Improvements have been made in the computer programs that are used to process NSPP experimental data. The modifications have been in the treatment of sampling data, temperature measurements, and in plotting capability. Participation in the ABCOVE program and work related to Nuclear Regulatory Commission/Industry Degraded Core Rulemaking Program technical exchange meetings are briefly described. Finally, a study was conducted to compare and evaluate in-vessel and ex-vessel cascade impactor size distribution measurements made in those NSPP experiments performed in a steam-air atmosphere. It was found that particle sizes measured in-vessel were consistently larger than ex-vessel measurements. Both distributions were approximately log normal, and standard deviations were about the same.

GLOSSARY OF ACRONYMS

ABCOVE	Aerosol Behavior Code Validation and Evaluation
AMIT	Aerosol Moisture Interaction Tests
AMMD	aerodynamic mass median diameter
ART	aerosol release and transport
BCL	Battelle-Columbus Laboratories
CDA	core-disruptive accident
CDV	capacitor discharge vaporization
CRBR	Clinch River Breeder Reactor
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
HEDL	Hanford Engineering Development Laboratory
ICP	inductively coupled plasma (spectrometric method)
IDCOR	Industry Degraded Core Rulemaking Program
IMSL	International Mathematical and Statistical Libraries
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
PWR	pressurized-water reactor
WROS	wall run-off sampler

AEROSOL RELEASE AND TRANSPORT PROGRAM SEMIANNUAL PROGRESS REPORT FOR APRIL 1984–SEPTEMBER 1984

R. E. Adams M. L. Tobias

ABSTRACT

This report summarizes progress for the Aerosol Release and Transport Program sponsored by the Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Accident Evaluation, for the period April 1984–September 1984. Topics discussed include (1) the experimental program in the Fuel Aerosol Simulant Test Facility, (2) NSPP experiments involving an aerosol of limestone-aggregate concrete in a steam-air atmosphere, (3) revisions in the NSPP experimental program, (4) experiments relating to NSPP thermohydraulic conditions, (5) aerosol-moisture interaction test plans, (6) aerosol code implementation activities, (7) improvements in data processing procedures for NSPP experiments, and (8) a study comparing in-vessel and ex-vessel cascade impactor aerosol size measurements in the NSPP.

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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, Office of Nuclear Regulatory Research, Division of Accident Evaluation, is a safety program concerned with aerosol release and transport. The program 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;
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 light-water reactor (LWR) systems;

4. studies related to liquid-metal fast breeder reactor (LMFBR) hypothetical core-disruptive accidents (HCDAs) 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; and
5. comparison of the results of experiments with calculations using existing aerosol computer codes or with specifically developed analytical procedures.

2. EXPERIMENTAL PROGRAM

2.1 Source-Term Experiments in FAST/CRI-III

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C. V. Hardin

2.1.1 Introduction

The Fuel Aerosol Simulant Tests (FAST) and the Containment Research Installation-III (CRI-III) tests are performed using the capacitor discharge vaporization (CDV) technique to place UO_2 samples into the high-energy states that could be produced in LMFBR 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 aerosol transport through the coolant in severe accidents.

During this report period, the final experiment (FAST-113) of a planned series of ten UO_2 fuel vaporization experiments was performed in accordance with the test schedule and test plan shown in Fig. 1 and Table 1, respectively. These experiments were designed to study bubble behavior and aerosol transport to the cover gas as a function of sodium height above the sample assembly, cover-gas pressure, and xenon gas pressure in the sample assembly (to simulate fission gas in reactor fuel). For FAST-113, these values were h_{NA} = 0.03 m, P_{CG} = 119 kPa, and P_{Xe} = 338 kPa, respectively. Pressure measurements were made in the sodium pool 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. 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 data, test conditions, and electrical input data for all the experiments conducted to date are presented in Tables 2–4 for convenient reference.

2.1.2 Description of FAST-113

The principal objective of FAST-113 was to further identify the relationship between the depth of sodium covering the sample and the aerosol transport to the cover-gas region. Airborne aerosol concentrations in previous FAST undersodium tests were very low. This observation suggested that most of the UO_2 aerosol was retained in the sodium pool. To further examine this observation, the experiment was conducted with a shallow depth of sodium covering the test sample in an attempt to force the vapor bubble through the sodium and into the cover gas. The level of

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*Instrumentation and Controls Division.

†Consultant from University of Tennessee.

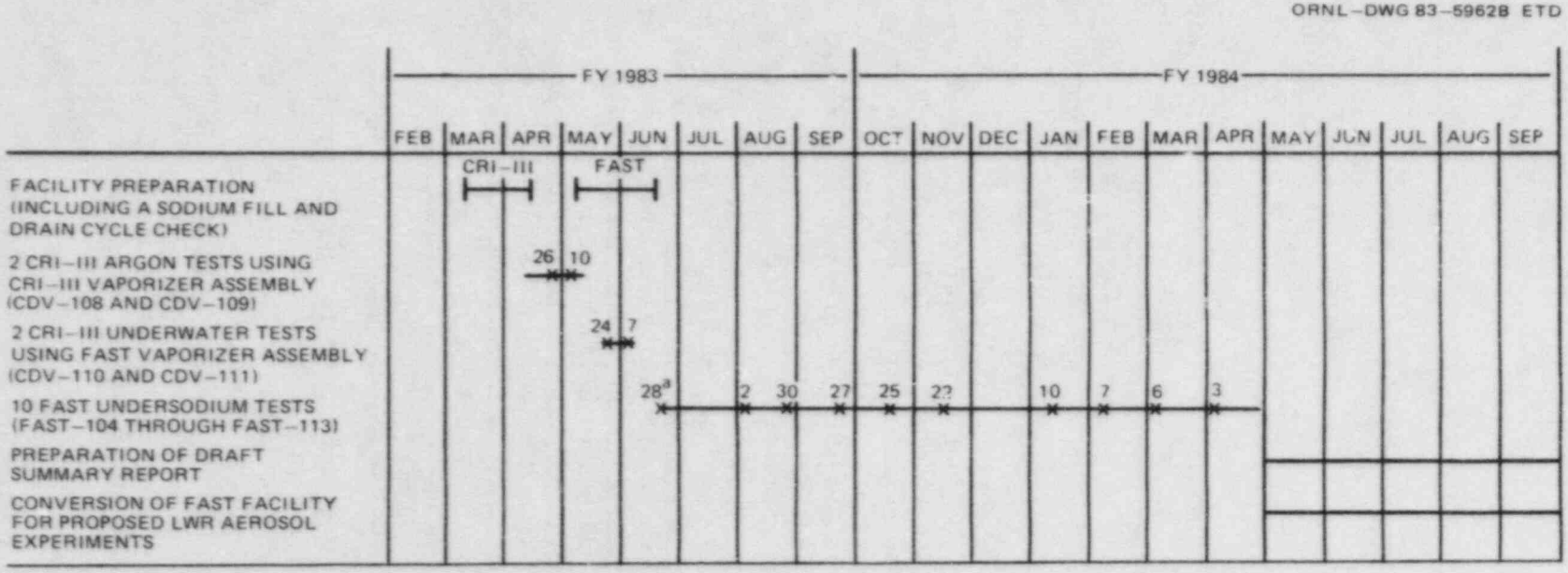

Fig. 1. Schedule for FAST/CRI-III tests.

Table 1. FAST experimental test plan[a]

FAST experiment No.	Pressure [kPa (abs)]		Nominal[b] sodium pool level above vaporizer centerline (mm)	Objective
	Argon cover gas	Xenon sample		
104	120	135	1070	Repeat of FAST 103 Compare with previous results
105	120	340	1070	Determine effect of changing xenon pressure
106	120	340	200	Determine effect of changing pool level
107	120	340	100	Same as 106
108	120	340	50	Same as 106
109	300	340	50	Determine effect of changing pool level at a second cover-gas pressure level
110	300	340	100	Same as 109
111	120	340	−300	Determine aerosol behavior over sodium at 810 K Verify aerosol sampling technique
112	300	340	200	Same as 109
113	120	340	30	Same as 109

[a]In all tests, the nominal temperatures of the vessel and the sodium were 810 K.

[b]See Table 3 for actual pool levels.

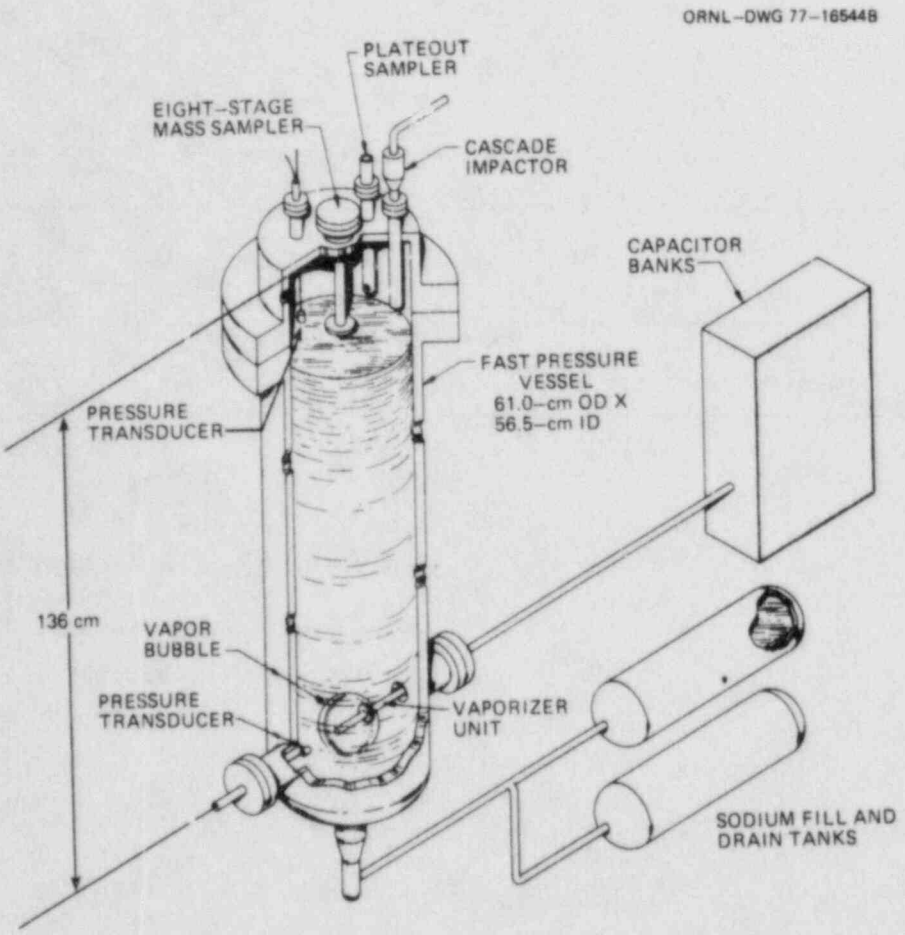

Fig. 2. Schematic of FAST test vessel.

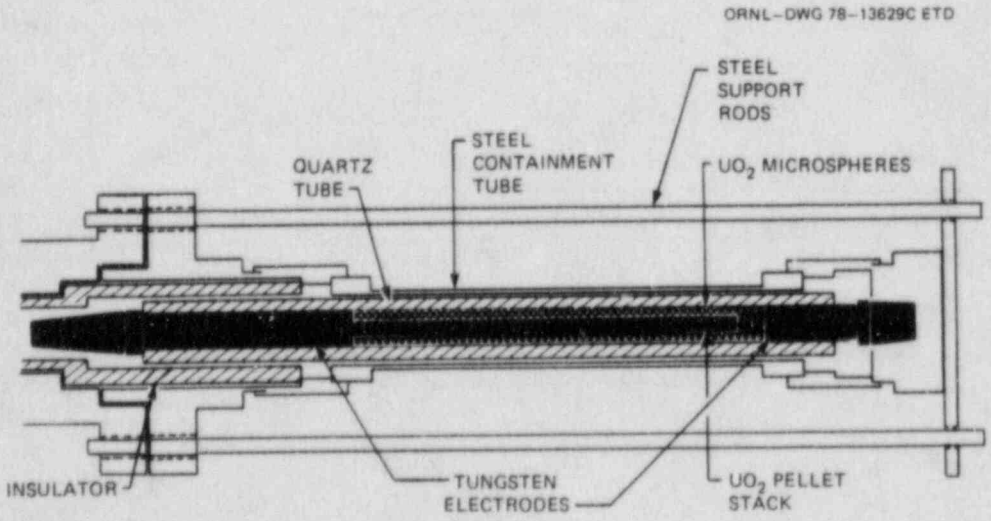

Fig. 3. Schematic of test sample in undersodium tests.

Table 2. Principal conditions in FAST experiments

Experiment No.	Type	Temperature (K)	Argon cover gas		Sample pressure at start of low preheat [kPa (abs)]	Sodium pool	
			Volume (m^3)	Pressure [kPa (abs)]		Volume (m^3)	Level above vaporizer centerline (mm)
FAST-103[a]	Undersodium	810	0.092	120	134	0.37	1050
FAST-104	Undersodium	810	0.090	120	133	0.37	1060
FAST-105	Undersodium	810	0.095	120	341	0.37	1040
FAST-106	Undersodium	810	0.30	120	340	0.16	240[b]
FAST-107	Undersodium	810	0.32	121	341	0.14	140[b]
FAST-108	Undersodium	810	0.34	120	340	0.12	80
FAST-109	Undersodium	810	0.33	300	341	0.13	100
FAST-110	Undersodium	810	0.32	300	340	0.14	140
FAST-111	Undersodium	810	0.45	122	341	0.014	−300
FAST-112	Undersodium	810	0.30	300	338	0.16	250
FAST-113	Undersodium	810	0.35	119	338	0.11	30

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

[b]Level previously reported was revised based on the results of a comparison of the "Twin-I" indications with recent independent (and presumably more accurate) continuity-probe measurements in the range of pool levels between 30 and 150 mm.

Table 3. Data for FAST specimens

Experiment	UO_2			Quartz tube dimension (mm)	
	Pellet stack		Microsphere mass (g)		
	Mass (g)	Length (mm)		ID	OD
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
FAST-108	17.36	90.3	31.68	9.70	17.15
FAST-109	17.66	91.9	31.86	9.70	17.15
FAST-110	17.63	91.5	32.08	9.70	17.15
FAST-111	17.57	91.5	31.99	9.73	17.15
FAST-112	17.44	90.7	31.84	9.73	17.15
FAST-113	17.36	91.1	31.70	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.

sodium was 3 cm above the centerline of the test sample or 2 cm above the top of the sleeve surrounding the test sample. A special liquid-level probe was fabricated and installed to accurately make this measurement.

The test sample consisted of 13 UO_2 pellets stacked end-to-end having a total mass of 17.4 g. Direct electric heating of the sample occurred in two stages: a power-controlled preheat followed by a very rapid capacitor discharge. The discharge delivered 37 kJ of energy in 2.95 ms from four capacitor banks charged to 1950 V each. Joule heating during this stage was sufficient to produce vaporization and disassembly of the test sample.

A preliminary analysis of the measured pressure responses in the sodium and the cover gas showed significant deviations from those measured in previous undersodium experiments, suggesting markedly different fluid motions. The confined vapor bubble underwent a single oscillation instead of several, and the cover-gas pressure trace was more active than usual (see Fig. 4). Measurement of the level of the interface between the sodium and the cover gas by the special liquid-level probe showed repeated displacements (of this level) of 1 cm or more for a period of seconds following disassembly of the test sample. Posttest visual inspection of the surfaces of the aerosol sampling equipment revealed unusually thick deposits of material. These observations suggest that a rather vigorous exchange of energy between the test sample, the sodium pool, and the cover gas occurred with a resulting transfer of material.

Table 4. Electrical energy input data for FAST experiments

	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 shorting (ms)	CDV energy input (kJ)
	Low	High					
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
FAST-108	600	1600	0.39	2.0	76.9	1.55	19.6
FAST-109	600	1600	0.40	2.0	76.5	1.65	20.3
FAST-110[b]	540	1600	0.40	2.0	76.5	2.35	28.2
FAST-111	500	1550	0.41	2.0	77.3	1.93	22.8
FAST-112	540	1600	0.40	2.0	76.5	2.16	26.5
FAST-113	500	1600	0.41	2.0	76.5	2.95	37.0

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

[b]Preheat power levels modified for FAST-110 through FAST-113 to improve vaporizer performance.

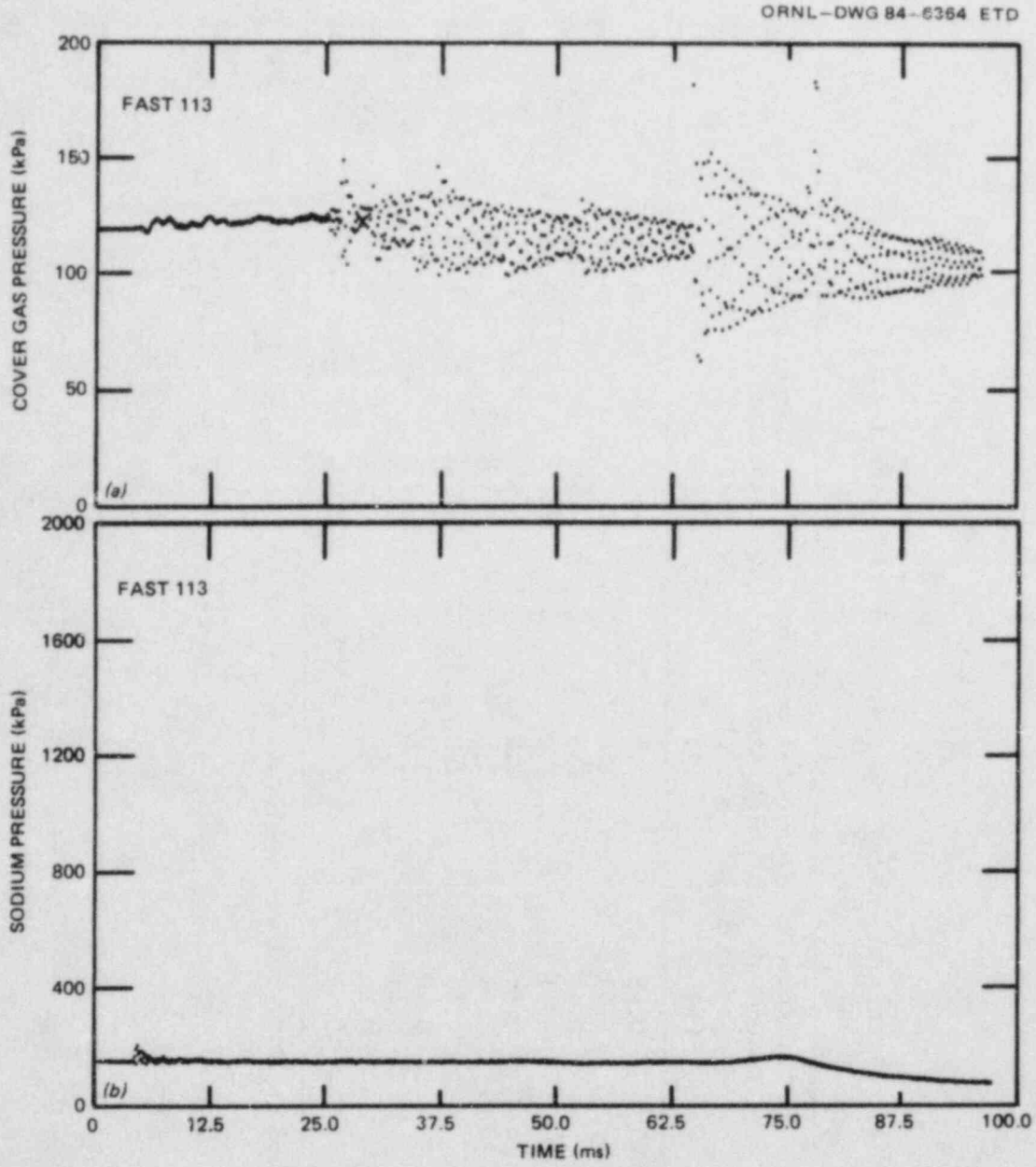

Fig. 4. Pressure traces in (*a*) cover gas and (*b*) sodium in FAST-113.

Chemical analysis of aerosol samples revealed the presence of large quantities of sodium (up to 100 mg in some cases). This information, together with visual observation of the sodium deposits on the outer surfaces of the filter sampler mechanism, strongly suggests that sodium was mechanically dispersed from the pool upon rupture of the vaporizer. The mass of uranium found on the filters was much larger than in any of the previous undersodium experiments (Table 5). However, further analysis indicated that the ratio of uranium-to-sodium mass on the filters was similar to that of the background contamination of uranium in the sodium pool ($\sim 10^{-3}$). This contamination was caused by a suspension of very fine

Table 5. Composition of FAST aerosol samples by chemical analysis

FAST	Average sodium content (μg)	Average uranium concentration (wt U/wt Na)
108	4,000	0.56×10^{-3}
109	5,950	0.20×10^{-3}
111	5,107	1.59
113	198,000	1.9×10^{-3}

UO_2 particles resulting from the previous undersodium experiments. Consequently, it was not immediately clear whether UO_2 was released to the cover gas as an aerosol, a contaminant in the dispersed sodium, or as a combination of these forms.

Close examination of pressure records suggested that significant release probably occurred during FAST-113. This conclusion was inferred by comparing cover-gas pressure records from FAST-113 and FAST-111, the oversodium experiment in which significant release was confirmed. High-level "noise" in both cover-gas pressure records was associated with turbulent mixing of the cover gas contents (which included UO_2 aerosols). Although the noise levels were similar, onset was delayed ~25 ms in FAST-113 (see Figs. 4 and 5). Delay was attributed to bubble retention

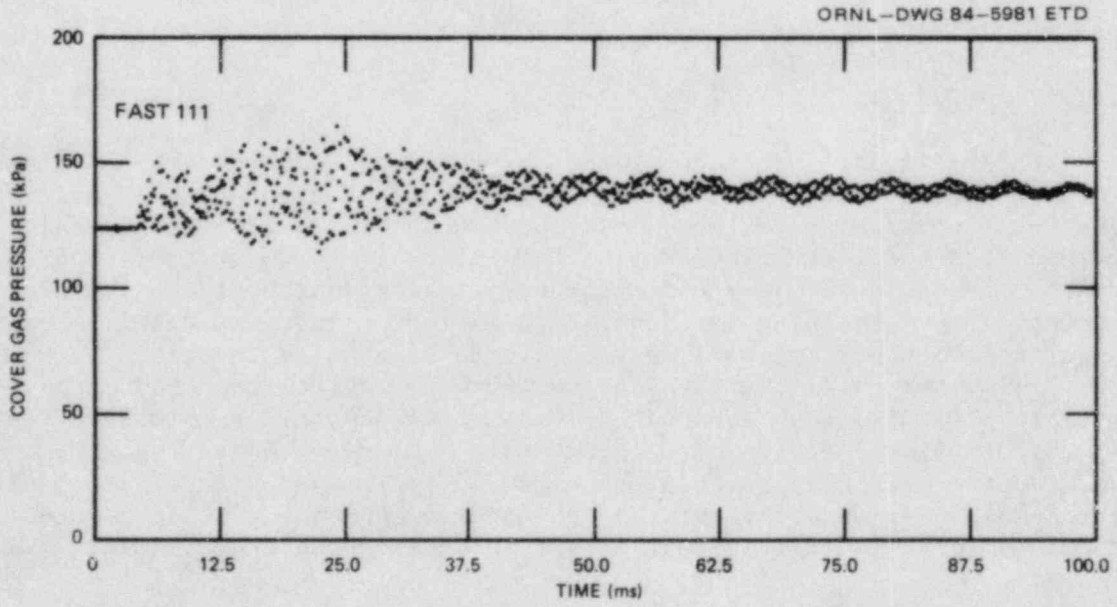

Fig. 5. Cover-gas pressure trace in FAST-111.

in the pool during the initial growth phase. Onset at 25 ms was attributed to venting of bubble contents into the cover gas; venting may have occurred near the first maxima. In addition, an unusually flat pool pressure trace (see Fig. 4) in conjunction with delayed cover-gas noise indicated less coupling between pool and cover gas than in other undersodium experiments, consistent with a less confined bubble pulsation.

It appears, therefore, that significant aerosol release did occur but perhaps not at the levels implied by the data in Fig. 6 because of probable contamination of the filters by UO_2 debris.

2.1.3 Additional activities

Following the final undersodium experiment, work was begun to prepare the FAST Facility for proposed LWR aerosol experiments. This work included disposing of the sodium and decontaminating the FAST vessel. Sodium sump tanks were sealed and removed from the facility. Thermal insulation, electric heaters, and thermocouples were removed from the vessel. The bottom thimble, containing the debris from undersodium experiments, was cut from the vessel; a specimen was cut and removed from the thimble for future metallographic examination. Cleaning operations on the interior of the vessel to remove sodium contamination were completed. A dye penetrant inspection of all the welds was also performed.

During this period, a draft summary report on the undersodium experiments was completed.

2.2 Secondary Containment Aerosol Studies in the NSPP

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M. T. Hurst K. J. Van Stelle*
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 quarterly and semiannual progress reports contain results from single-component aerosol experiments with U_3O_8 aerosol, Fe_2O_3 aerosol, and concrete aerosol in both dry air and steam-air environments. More recently, attention is also being given to the behavior of multicomponent aerosols. Results from the first pair of aerosols to be studied in detail, U_3O_8 and Fe_2O_3, were given in the last semiannual progress report.[1] One other pair of aerosols, Fe_2O_3 and concrete, was studied in a preliminary test in 1982 (Run 601) and reported previously.[2] During the current report period, the NSPP test plan was enlarged to include additional two- and three-component aerosol tests in dry air and condensing steam-air environments; details of this revised test plan are presented in Sect. 2.2.2.

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*ORNL summer research participant.

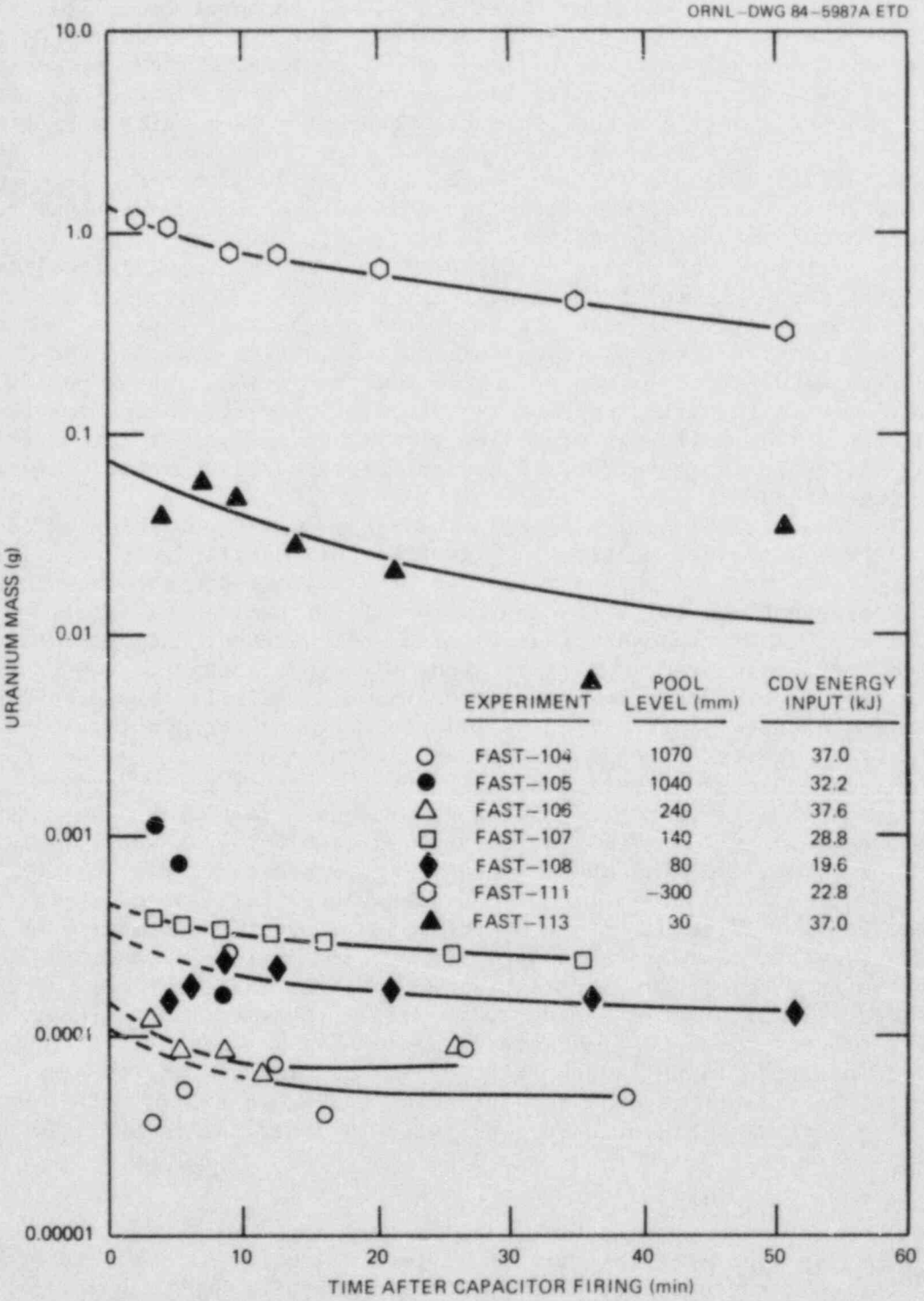

Fig. 6. Measured UO_2 mass in cover gas (low argon pressure: ~120 kPa) in FAST sodium experiments.

The second limestone-aggregate concrete aerosol test (No. 522) in a condensing steam-air environment was conducted on April 5–6, 1984. This test was intended to provide additional data for use in determining the behavior of concrete aerosol in dry air and condensing steam-air atmospheres. A secondary objective was to evaluate our present capability for producing concrete aerosols in high concentrations using a single plasma torch generator. Detailed results from this experiment are given in Sect. 2.2.3; the results are compared with those from the first concrete aerosol test in steam (No. 521) and the one concrete aerosol test conducted in dry air (No. 531) in Sect. 2.2.4.

Preparations for a test in May were delayed due to mechanical problems with the air compressor supplying the building compressed air system. Although difficulty in obtaining the needed repair parts caused a few weeks delay before the next test, the extra time provided the opportunity to make needed modifications to the facilities. These modifications included installation of a backup air compressor to improve the reliability of the building compressed air system and installation of a steam heater to provide improved control of the steam temperature during test operations.

Several significant changes in the scope of LWR aerosol studies resulted from a project meeting in Silver Spring, Maryland, on June 12–13, 1984. It was decided that the planned NSPP multicomponent aerosol tests should be postponed for a few months (and for a period thereafter conducted at a lower frequency than before) so that other data more urgently needed for development and verification of aerosol-behavior computer codes may be obtained. New studies designed to fulfill this need involve obtaining detailed information on (1) thermohydraulic conditions during NSPP aerosol tests in condensing steam-air environments, (2) thermal output and aerosol mass generation rates for the plasma torch aerosol generator, and (3) influence of humidity on aerosol particle shape factors. Before resuming the NSPP multicomponent aerosol tests, several tests are being performed and evaluated to obtain thermohydraulic data for NSPP test conditions and operating data on the plasma torch aerosol generator. A new facility is being set up at the NSPP to obtain information on humidity effects; tests in this facility will be performed concurrently with the NSPP multicomponent tests. Progress in each of these new areas of study is described in Sects. 2.2.5–2.2.7. A test plan to study humidity effects on aerosol behavior is presented in Sect. 2.2.8.

In addition to this work, a study was carried out to compare particle size distributions measured in-vessel and ex-vessel in NSPP experiments by cascade impactor. This activity is described in Sect. 3.

2.2.2 NSPP test plan

The expanded NSPP test plan was prepared during this report period with the assistance of the ORNL Engineering Physics and Mathematics Division.* This experimental plan is designed to systematically determine the behavior of multicomponent aerosols comprised of U_3O_8, Fe_2O_3, and concrete at a target aerosol mass concentration of 10 g/m^3 in both dry

*M. D. Morris.

air and condensing steam-air environments. Included in the statistical plan are all one-component aerosol tests, all possible two-component aerosols with relative mass ratios of 1:1 and 3:1, and all possible three-component aerosols with relative mass ratios of 1:1:1 and 2:1:1. Of the total of 32 tests, 11 have already been completed; the remaining 21 tests are time-ordered in 5 subsets intended to maximize the information available at intermediate times.

The first subset of remaining tests consists of four multicomponent (three two-component and one three-component) aerosol tests in a condensing steam-air environment. From this subset, we have selected the two-component Fe_2O_3-concrete aerosol in a mass ratio of 3:1 for the next test (No. 602).

2.2.3 LWR aerosol experiment 522

Experiment 522 was the second limestone-aggregate concrete aerosol test in a quasi-steady-state steam-air environment. To prepare the test atmosphere, steam was introduced into the vessel, which was initially at 0.029 MPa (abs) and ambient temperature of 296 K, to bring the vessel atmosphere (air and steam) to an absolute pressure of 0.158 MPa and an average temperature of 378 K. This heating step required about 1.2 h; at this point the rate of steam injection was reduced to the level required to offset heat losses through the walls of the insulated test vessel and maintain wall temperature nearly constant. Also at this time, the small fan-mixer inside the vessel was turned on. Approximately 1 h later, the accumulated steam condensate in the NSPP vessel was removed to a holding tank, and concrete aerosol generation was started. The concrete aerosol was produced with the plasma torch aerosol generator with 524 g of concrete powder passed through the torch over a period of 31.4 min. The test environment was a mixture of air and steam at an absolute pressure of 0.181 MPa and a temperature of 380 K at the time of termination of aerosol generation. At the end of 6 h of low-level steam injection, the absolute pressure and temperature had increased to 0.185 MPa and 381 K, respectively. At this point, steam injection was terminated and the vessel was allowed to cool undisturbed for 18 h.

Aerosol mass concentration. The first set of aerosol mass concentration samples was taken 3.8 min after termination of aerosol generation. Subsequent samples were obtained over a period of 24 h in accordance with the normal sampling procedures.

Analytical procedures previously developed[2,3] for the chemical analysis of aerosols produced by vaporization of powdered concrete involve treatment of the aerosol mass by lithium metaborate ($LiBO_3$) fusion followed by dissolution in dilute nitric acid. Elemental analysis for Fe, Si, Ca, Mg, and Al can then be obtained on these solutions by inductively coupled plasma (ICP) spectrometry. X-ray diffraction analysis of earlier samples revealed that the concrete aerosol is composed of oxides of these metals, in varying quantities, plus some complex silicates involving Ca, Al, Fe, and Mg. For calculational purposes, the concrete aerosol is considered to be composed of a simple mixture of Fe_2O_3, SiO_2, Al_2O_3, CaO, and MgO; this assumption should not introduce any large error

in calculating the mass quantities of aerosol present in the various samples.

The mass concentration of concrete aerosol as a function of time as measured by the seven individual aerosol mass samplers is given in Fig. 7. The offset in aerosol mass concentration values as determined by the in-vessel filter samplers (151—154) and the wall filter samplers (155—157) is immediately obvious. This behavior has not been encountered in previous concrete aerosol tests; the values obtained by the two types of samplers have been in accord.[3] Inspection of the raw data revealed that the calcium values (Fig. 8) were largely responsible for this misalignment. Of the five constituents of the concrete aerosol, the aerosol mass concentration values for three were in alignment (Fe_2O_3, SiO_2, and MgO) and for two were misaligned (CaO and Al_2O_3). Rechecks on the analysis for calcium were requested on the samples taken by both the in-vessel samplers and the wall filter samplers. For the in-vessel samples the new calcium values were within 15% of the original values. Unfortunately, the samples from the wall filter samplers could not be rechecked because the solutions had been inadvertently discarded.

For comparison of these data with other results from concrete aerosol tests, it was assumed that the data for calcium were correct from the in-vessel samplers and incorrect (too large) from the wall samplers. The calcium data from the wall filter samples were reduced by a constant factor so that the offset between the data from the two filter samplers disappeared. This modified mass concentration decay curve is shown in Fig. 9.

Extrapolation of the data of Fig. 9 back to the time of aerosol generator cutoff (31.4 min) yields a value of 1.5 g/m^3. This value compares with maximum concentrations of 1.1 g/m^3 in test 521, the first concrete aerosol test in a condensing steam-air environment, and 1.5 g/m^3 in test 531, the one concrete aerosol test conducted in a dry air environment. Because 1.5 g/m^3 appears to be about the maximum concentration we can currently obtain, we plan to conduct additional small-scale tests in an attempt to further optimize the plasma torch method of producing concrete aerosol.

Aerosol particle size. Aerosol size measurements were attempted with the cascade impactors but were not successful; an insufficient mass of aerosol was collected.

Aerosol distribution. At the termination of the test (24 h), the approximate aerosol distribution, as determined by the total fallout and total plateout samples and the final aerosol filter samples, were as follows: aerosol settled onto the floor of the vessel, 55%; aerosol plated onto internal surfaces, 34%; and aerosol still suspended in the vessel atmosphere, 11%.

2.2.4 Influence of condensing-steam environment on behavior of limestone concrete aerosol

Three limestone-aggregate concrete aerosol experiments have been completed; two were conducted in a condensing steam-air environment and one in a dry air [relative humidity (RH) about 20% or less] environment. A summary of experimental details and results is given in Table 6.

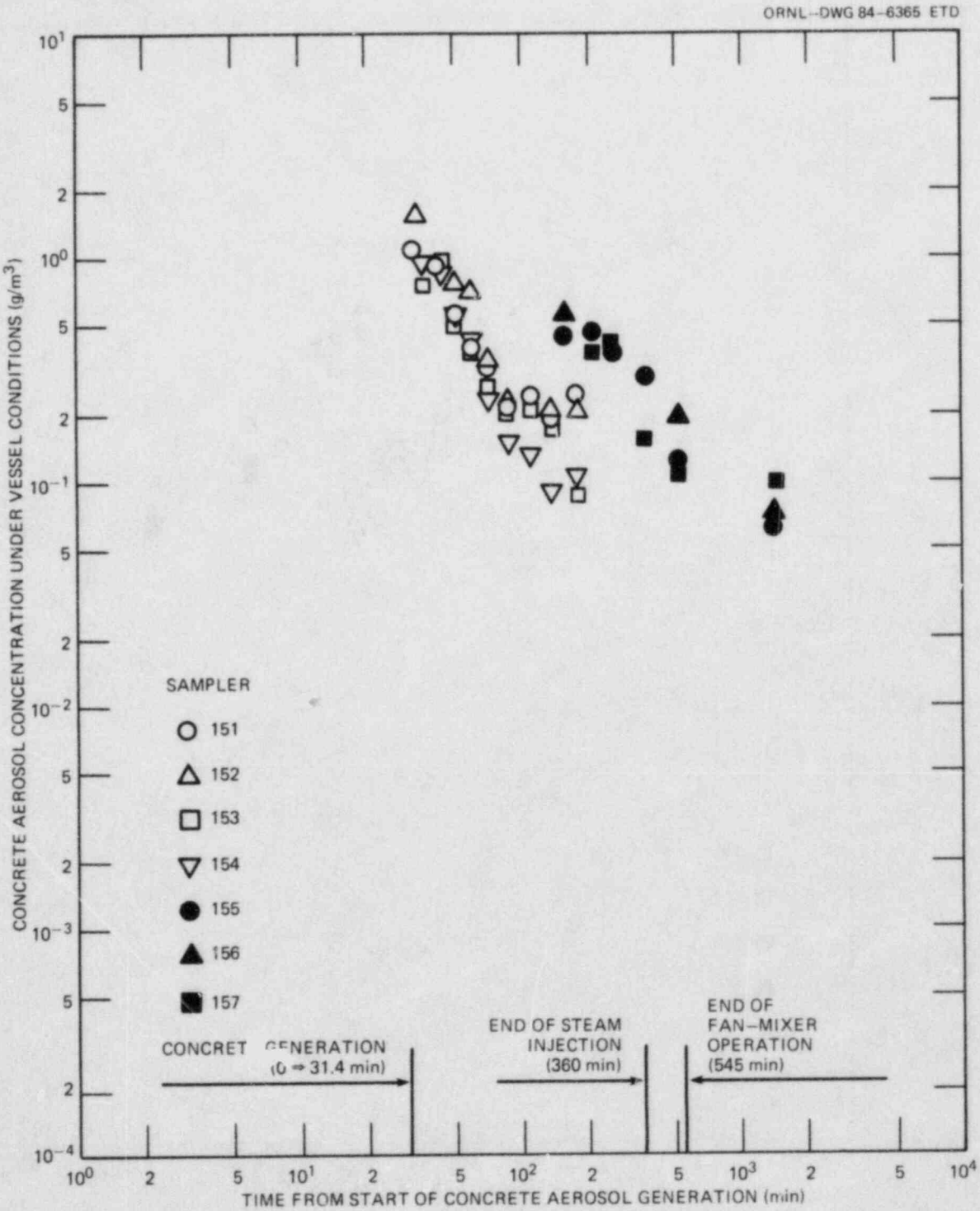

Fig. 7. Aerosol mass concentration (concrete) as function of time in steam-air environment (NSPP run 522).

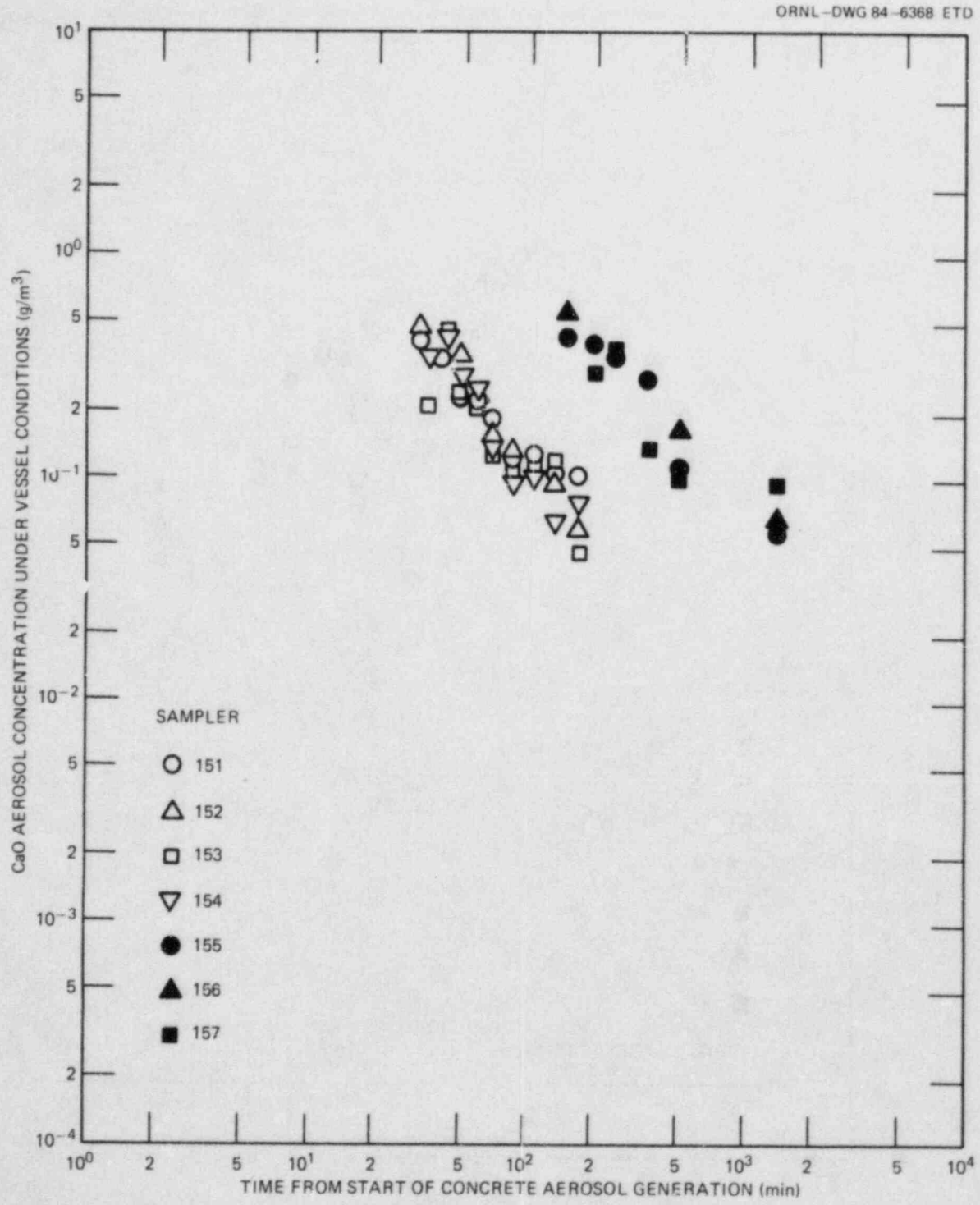

Fig. 8. Aerosol mass concentration as a function of time for CaO component of concrete aerosol in steam-air environment.

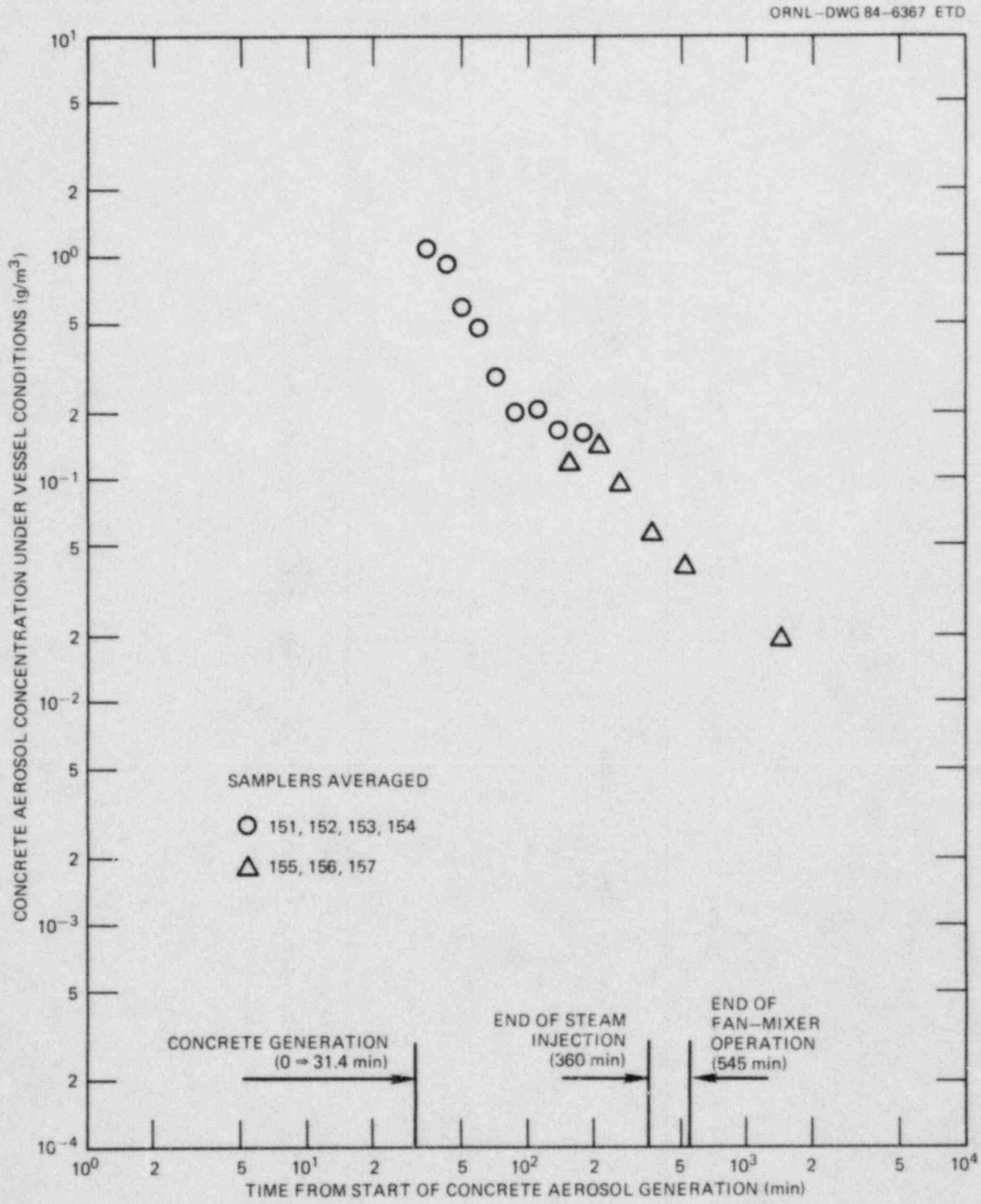

Fig. 9. Average aerosol mass concentration (concrete) as function of time in steam-air environment (NSPP run 522). (Data from 155, 156, 157 modified; see text.)

Table 6. Summary of experimental details and results of NSPP concrete aerosol tests

Experiment No.	Vessel atmosphere	Total aerosol generation period (min)	Maximum concentration[a] (g/m^3)	Aerosol distribution at test termination (%)			AMMD[b] range (μm)
				Total fallout	Total plateout	Suspended in vessel atmosphere	
521	Condensing steam-air	20	1.1	29	69	2.4	[c]
522	Condensing steam-air	31.4	1.5	55	34	11	[c]
531	Dry air	33.5	1.5	32	57	11	<0.5–0.8

[a]Value obtained by extrapolating data to time of generator cutoff.

[b]Aerodynamic mass median diameter; range of values measured during experiment.

[c]Measurements were not successful.

To illustrate the effect of steam on the behavior of the limestone concrete aerosol, the aerosol mass concentrations in all three tests are plotted as a function of time *after* termination of aerosol generation in Fig. 10. As evident, the rate of aerosol removal was the same in the two experiments conducted in a condensing steam-air environment and only slightly lower in experiment 531 conducted in dry air.

Results from these three tests indicate that condensing steam had only a small effect on the mass concentration reduction rate of concrete aerosol in the NSPP vessel for the first 24 h after termination of aerosol generation even though, as reported previously,[3] it changed the shape of the aerosol from chain agglomerate to partially spherical. This is in contrast to the behavior noted for single-component U_3O_8 and Fe_2O_3 aerosols where condensing steam enhanced the mass concentration reduction rate.

2.2.5 NSPP thermohydraulic conditions

During this report period, several improvements were made to the facilities and several steam tests were performed in an effort to better define NSPP thermohydraulic conditions. A steam heater was installed to provide improved control of the inlet steam temperature during test operations, and improvements were made to the thermal insulation on the 38.3-m^3 test vessel to improve its temperature uniformity. Improvements to the thermal insulation included the insulation of two large flanges and two circumferential support ribs that were previously uninsulated, repair of the insulation where it may have been of different quality (such as where the insulation had been disturbed previously to install heat flux meters), and sealing of the entire outside surface of the insulation to discourage formation of convective currents between the insulation and the vessel wall.

In late June, a successful test was conducted to determine the operating characteristics of the steam heater that was installed to improve control of steam quality during aerosol tests conducted in condensing steam-air environments. In this test (NSPP steam test 053), it was demonstrated that the supply steam at saturation conditions of temperature and pressure could be superheated a controlled amount while the system was operated under the normal operating conditions. With this new capability, it was decided that the steam heater should be used in future tests to control the supply steam at a superheat level of about 3 to 8 K above saturation to ensure that the steam will be dry in the supply pipe down to the point where it discharges into the test vessel. The steam discharges through a 0.64-cm-diam orifice at the end of the 2.57-cm-ID supply pipe.

Two steam tests were performed specifically to obtain thermohydraulic data, one before (NSPP Run 054 on July 18) and one after (NSPP Run 055 on August 14) the improvements were made to the thermal insulation on the NSPP vessel. Analysis of these test results is in progress.

A detailed in-situ calibration was performed on the vortex flowmeter and orifice meter on the steam supply line; improved steam flow rate determinations will be possible in future tests using these two independent measurement devices.

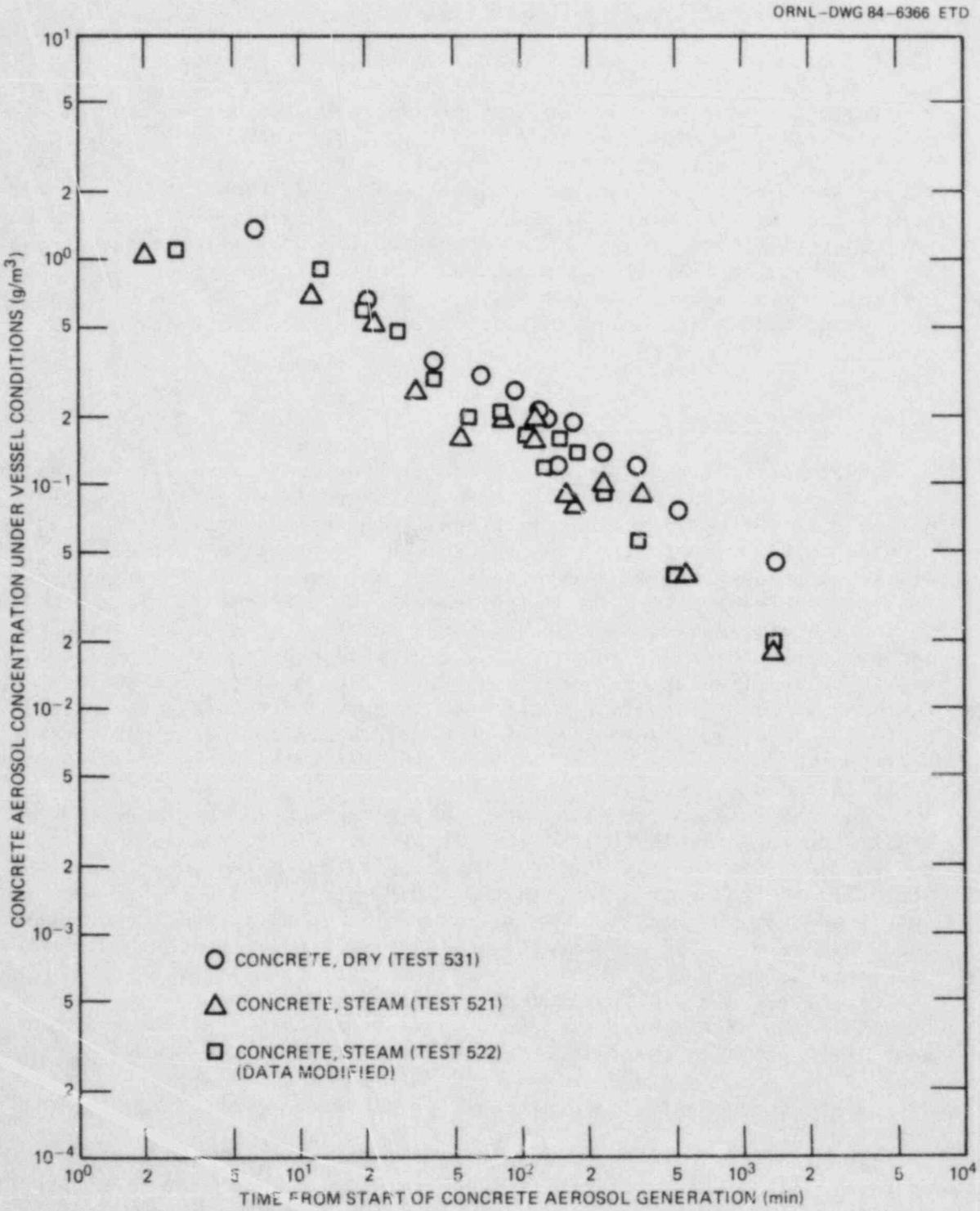

Fig. 10. Comparison of behavior of limestone concrete aerosol in condensing steam-air and dry air environments.

2.2.6 Plasma torch aerosol generator characteristics

Preparations are being made for a series of experiments in a small (0.35-m^3) test vessel to obtain detailed information on the operating characteristics of the plasma torch aerosol generator (e.g., thermal output and aerosol mass generation rates). A rack containing 24 thermocouples (6 at each of 4 axial locations) has been assembled for measurement of gas temperatures inside the test vessel. These thermocouples along with outside-wall thermocouples and heat flux meters will be used to monitor the thermal input to the vessel by the aerosol generator, which will be installed at one end of the cylindrical vessel. Also, generator power and cooling water heat losses will be measured. Information on aerosol mass generation rates will be obtained by (1) filter sample measurements of aerosol mass concentration vs time and (2) posttest collection and sieve analysis of deposited material to determine the amount of the feed material that was converted to an aerosol.

Installation of a cable tray to route the instrument leads from the small test vessel (and from the AMIT test vessel described in the next section) to the NSPP control room is in progress. When this work is completed, the setup will be ready for the first experiment (probably in October 1984).

2.2.7 Aerosol-moisture interaction tests

A facility is being prepared to allow the study of the effect of various levels of humidity on the physical characteristics (shape factors) of aerosols of interest in LWR accident sequences. The test vessel (0.56 m^3), formerly the CRI-III aerosol test vessel of the FAST/CRI-III Facility, is in place, and installation of a work platform has been completed. Connection of electrical, instrument, air, vacuum, and offgas lines is in progress. This vessel plus support equipment is now the Aerosol-Moisture Interaction Test (AMIT) Facility.

An instrument to measure moisture levels in the AMIT vessel atmosphere has arrived. A condensation nuclei counter to measure aerosol number concentration and a retrofit kit for the existing plasma torch aerosol generator to improve its operation at low operating power levels are on order. Other instruments and equipment used in NSPP tests are available for use in this facility.

Preliminary experiments in the AMIT facility may be performed as early as December 1984.

2.2.8 AMIT test plan

An AMIT test plan involving single and multicomponent aerosol tests under relative humidity conditions ranging from dry to 100% RH was prepared with the assistance of the ORNL Engineering Physics and Mathematics Division.* This proposed experimental plan is designed to systematically study the effect of moisture on the shape of agglomerated aerosols comprised of U_3O_8, Fe_2O_3, and either concrete or Ag_2O/CdO in single-component

*M. D. Morris.

and multicomponent tests (with equal masses of each component) at two aerosol mass concentration levels. Included in the statistical plan are four one-component, five two-component, and two three-component tests at each of two concentration levels, with tests at the low concentration at four RH levels and tests at the high concentration at dry and 100% RH only.

Earlier work indicates that agglomerates are chainlike under relatively dry conditions, and approximately spherical under relatively humid conditions. Furthermore, it appears that the change from chainlike to spherical occurs over a narrow range of humidity values. Hence, for a particular aerosol, agglomerates might be chainlike and relatively similar in shape factors for humidity levels below 60% and spherical at humidity levels from 70 to 100%.

This indicates that use of a fixed set of humidity values would be a rather inefficient approach to finding the breakpoint in relative humidity for each aerosol. Instead, a binary search will be followed in conducting the low concentration tests at four humidity values. Each aerosol will be tested at 50% RH; then, if the 50% RH run displays chainlike agglomerates, the next run would be made at 80% RH etc. In this way, four runs are sufficient to determine the breakpoint to within 10%.

The above plan of a maximum of 66 tests will allow the joint effects of aerosol composition and relative humidity to be examined at the low concentration, and the joint effects of aerosol composition and concentration at the dry and saturated humidities.

3. ANALYTICAL PROGRAM

M. L. Tobias

3.1 Analysis of Steam-Only Experiments in the NSSP

Work has resumed on the analysis of the steam-only experiments that have been performed in the NSPP. These were done to gain a better understanding of heat transfer and condensation processes in the test vessel. This work will also include calibration of the vortex flowmeter used to measure steam flow into the vessel.

Major emphasis has been in development of improved data processing capability. The main computer code has been revised to tabulate data from the vortex flowmeter, the heat flux meter on the wall run-off sampler, and the steam-line temperature and pressure. The code has been revised to provide graphical representations as well. As a result of this activity, it will be relatively easy to create a similar code for treating data to be generated in AMIT Facility tests.

3.2 Aerosol Code Implementation Activities

3.2.1 Implementation of the AEROMECH Code

Aerosol code implementation is given considerable attention in our work. Not only do we wish to apply the codes to analyze our own experiments but also those at other installations, such as the Hanford Engineering Development Laboratory (HEDL) ABCOVE tests.

Discussions were held on May 18 with S. K. Loyalka, University of Missouri, concerning the work on the AEROMECH code that he and his students are developing. The code is intended to solve numerically a set of nonlinear integro-differential equations that model aerosol behavior. The "J-Space" method is used, which in essence divides up the size range into discrete increments. Features such as diffusiophoresis and steam condensation, of interest in LWR accident analysis, are to be included.

A tape of the code together with a large number of sample problems have been received. The program was compiled successfully, but attempts to run the code on the sample cases failed until recently. The difficulty appears to lie in unidentified differences between versions of the differential-equation-solving software package DGEAR in the IMSL library, which both installations were using. Success in running the first sample case was finally obtained by use of an initial time step of 10^{-20} s instead of the value of 10^{-6}, which was recommended by the University of Missouri. This sample case was also run with an alternative software package DVERK. In addition, the code was modified to permit use of the LSODE solver, as advocated by an ORNL mathematical software advisor.

Identical results to those of the sample case were obtained, but the running time varied considerably.

Package	Running time (s)
DVERK	359
DGEAR	122
LSODE	30

The LSODE package seems clearly superior at this point, and the use of this alternative approach will be further studied.

3.2.2 Implementation of the MAEROS code

A substantial effort was made to implement the latest version of the MAEROS code in collaboration with Technology for Energy Corporation.* Despite all attempts to reconcile differences between results obtained on TEC's VAX machine and our IBM 3033s, the code performance remained unsatisfactory. We communicated with the code originator, who was unable to explain the differing results. We have been recently advised by Sandia Laboratory staff that use of MAEROS through the CONTAIN code (which includes the MAEROS code) will probably enable us to use it successfully.

3.2.3 The QUICKM code

The QUICKM code was also received during this period from BCL, but no attempt has yet been made to run the code.

3.3 Improvements in Computer Processing Programs for NSPP Experimental Data

3.3.1 Reporting of exact time of in-vessel sampling

The main program for processing NSPP data has been modified to report the exact time of day during which samples of the vessel atmosphere are taken. This change, which enables true sampling periods to be distinguished from possible spurious or defective readings, has been put to use in the case of data from experiment 522 to check on some apparently anomalous results.

3.3.2 Improvement in recording of temperature data

The readings of the thermocouples that are used to measure in-vessel temperatures are now being recorded in millivolts rather than in degrees

*H. Mitchell.

Fahrenheit with the use of a cold junction immersed in an ice-water mixture. The precision of these readings is 1 μV. To take advantage of this increased sensitivity, the data processing code has been modified to convert the emf readings on the data tape to temperature by interpolating from built-in tables of emf-temperature data taken from the "ASTM Reference Tables for Thermocouples."[4] This change has increased the precision of the recorded temperature data to the 0.1°F level. The result of this change is a considerable reduction in fluctuations in the plots of temperature data, particularly those for temperature gradients.

3.3.3 Improvement in plotting capability

The main data processing code has in the past saved data for plotting over preset time ranges starting from the base time. (This is usually the time at which aerosol begins to be introduced into the vessel.) If this preset range did not contain the data of interest then a rerun of the entire program had to be performed to examine a different time domain. Now, the data can be recorded once for the entire experimental period, and plots can be made for any desired time interval by making simple ad hoc changes in the plotting programs. The procedures were tested and used successfully in the course of processing data from NSPP experiment 522.

3.4 Participation in the ABCOVE Program

The ABCOVE program for aerosol behavior code validation and evaluation is a cooperative effort between the USDOE and the USNRC, involving their contractor organizations currently engaged in aerosol code development or application. We had participated in making pretest and blind posttest predictions for the first large-scale test (AB5) in the Containment Systems Test Facility (CSTF) vessel at HEDL, but other commitments made it impossible to participate in the analysis of the second such test (AB6). However, we attended the information exchange meeting of May 15, 1984, in which the results of participants' calculations for AB6 were compared with experimental observations to renew contact with this program. We expect to participate in the work connected with experiment AB7. While this program deals with sodium fire situations relevant mainly to LMFBRs, it affords a unique opportunity to compare techniques of aerosol code application.

3.5 Work Related to NRC/IDCOR Technical Exchange Meetings

In response to a request from NRC staff, some NAUA calculations have been performed to assist TEC staff participating in the NRC/IDCOR exchanges. The calculations were related to postulated accident situations in a boiling-water reactor (BWR) and a pressurized-water reactor (PWR). The BWR case is an attempt to model behavior in the secondary containment of a BWR (Peach Bottom with MARK-I containment) with continuous release

of volatile material from the dry well and a continuous source of concrete aerosol. The PWR case is based on the Zion reactor; the containment is assumed to be filled with 120 kg of "corium" aerosol into which a concrete aerosol source is continuously injected. So far, only dry aerosol calculations have been done, but it is expected that calculations with steam will also be performed. TEC is also interested in NAUA calculations for those NSPP experiments that relate to these accident conditions.

3.6 Evaluation of the Aerosol Particle Size Distribution in NSPP Experiments as Measured by the Cascade Impactor

K. J. Van Stelle*

3.6.1 Introduction

Cascade impactors are not intended for use at the high pressure and humidity encountered in the NSPP vessel during steam tests. Calibration curves supplied by the manufacturer are given for dry aerosols at one atmosphere pressure. This study was an attempt to correct impactor calibration for the effects of steam conditions. All NSPP experiments involving steam were analyzed.

Two aerosol sampling methods were used. The in-vessel method involved taking a sample at actual vessel conditions; in the ex-vessel method, the sample was taken after the aerosol was diluted with dry instrument air, cooled, and brought to atmospheric pressure (Fig. 11).

*ORAU student research participant presently at Georgia Institute of Technology. This section was prepared by the editors from project notes.

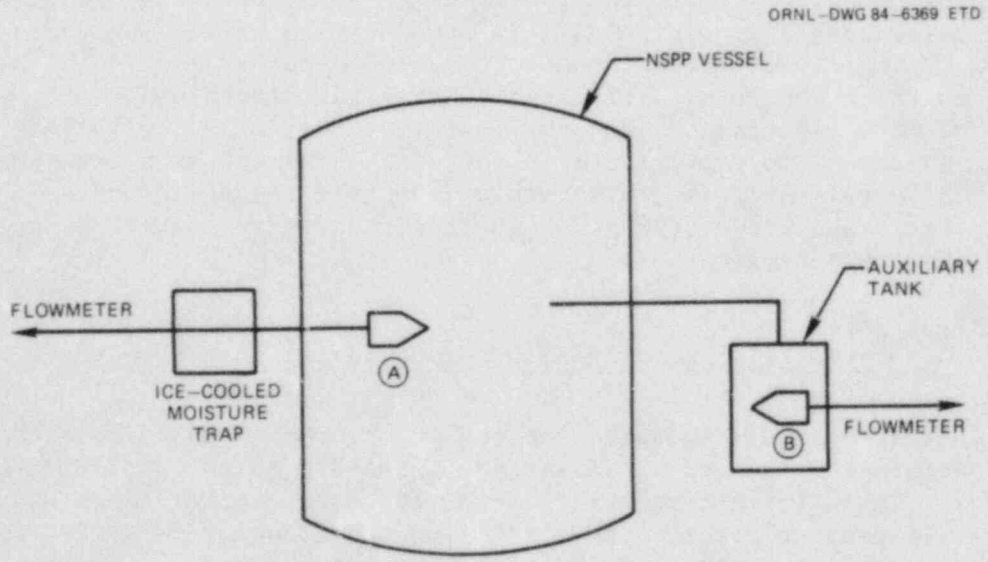

Fig. 11. Schematic depiction of in-vessel (A) and ex-vessel (B) aerosol sampling in NSPP experiments.

3.6.2 Theory

Effective cut diameters or stage constants for each impactor stage were calculated by the following equation

$$D_{50} = (18\pi\psi_{50}\mu D_j^3 X_j P_j / 4C\rho_p Q_s P_s)^{1/2} , \quad (1)$$

where

ψ_{50} = inertial impaction parameter,
μ = viscosity,
D_j = jet diameter,
X_j = number of jets on stage j,
P_j = pressure incident on stage j,
P_s = NSPP vessel pressure,
C = slip correction factor,
ρ_p = particle density,
Q_s = volumetric flow rate through impactor.

The parameters most affected by the presence of steam are the viscosity, the slip factor, and the flow rate. The viscosity was taken as a weighted average of the steam and air viscosities and assumed constant during the course of an experiment. The slip correction factor was calculated from the formula

$$C = 1 + (2\lambda/D_{50})[1.23 + 0.41 \exp(-0.44\ D_{50}/\lambda)] , \quad (2)$$

where λ is the mean free path of gas molecules; the value for air was assumed. The flow rate through the impactor as indicated by rotameter measurements must be corrected for the effects of temperature, pressure, and humidity. The following equation was used:

$$Q_s = Q_{rot}\ (P_{rot}\ T_{ves}/P_{ves}\ T_{rot})[1/(1 - F_{H_2O})] , \quad (3)$$

where

Q_{rot} = measured flow rate through the rotameter,
P_{rot} = pressure in rotameter,
P_{ves} = pressure in vessel,
T_{rot} = temperature in rotameter,
T_{ves} = temperature in vessel,
F_{H_2O} = volumetric fraction of water removed from air by an ice-cooled moisture trap located between the impactor and the rotameter.

The flow rate through the in-vessel impactors was found to be about twice the measured flow rate at the rotameter.

3.6.3 Results of the analysis

Table 7 compares the stage constants calculated from Eq. (1) with those supplied by the manufacturer. The steam-air values are only slightly larger in most cases. The in-vessel values represent averages over several tests at slightly different conditions.

Table 7. D_{50} values for dry air and steam-air environments

Impactor stage	Ex-vessel[a] D_{50} (μm)	In-vessel[b] D_{50} (μm)
0	13.7	14.2
1	8.5	8.9
2	5.8	6.0
3	4.0	4.1
4	2.5	2.6
5	1.3	1.3
6	0.78	0.82
7	0.53	0.61

[a]Manufacturer's values: dry air, 37.8°C.

[b]Steam-air calibration, 106.7°C.

Figure 12, a log-probability plot, shows the difference in size distributions between in-vessel and ex-vessel particle size measurements determined for 63 min and 56.5 min respectively in Run 404 (uranium oxide in steam). The in-vessel AMMD is about twice the ex-vessel value. Note that both distributions are generally linear, indicating log-normal distributions. The standard deviations were about the same. This seems to have held true for all the experiments.

Figure 13 represents the same Run 404 data displayed as a mass distribution plot. The ordinate is the logarithm of $dM/d(\log D_{50})$ (i.e., the change in mass collected with change in the logarithm of D_{50}), and the abcissa is the geometric mean diameter (i.e., the geometric mean of successive stage constants). On the ordinate, the derivative was approximated by dividing the mass collected on each stage by the difference in the logarithm of successive stage constants. The maximum points are the AMMD values corresponding to the 50% points of Fig. 12. The in-vessel value is again seen to be larger by about a factor of 2; this relationship seems to hold for most of the runs.

Figure 14 shows AMMD values estimated as a function of time during the run using data from all of the 400 series experiments (uranium oxide in steam) conducted to date. Figure 15 is a similar plot for the 500 series (iron oxide in steam), and Fig. 16 displays data for the 600

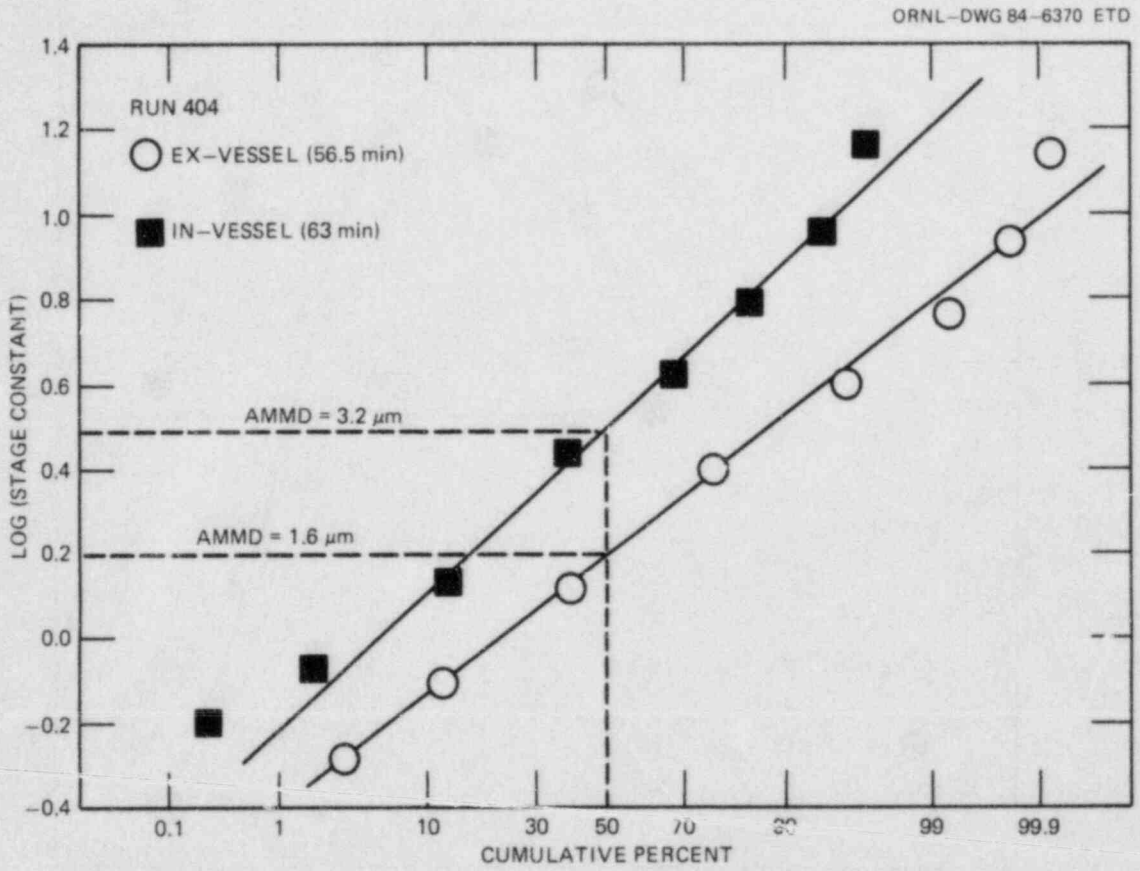

Fig. 12. Logarithmic-probability plot of size distributions from in-vessel and ex-vessel measurements in NSPP experiment 404.

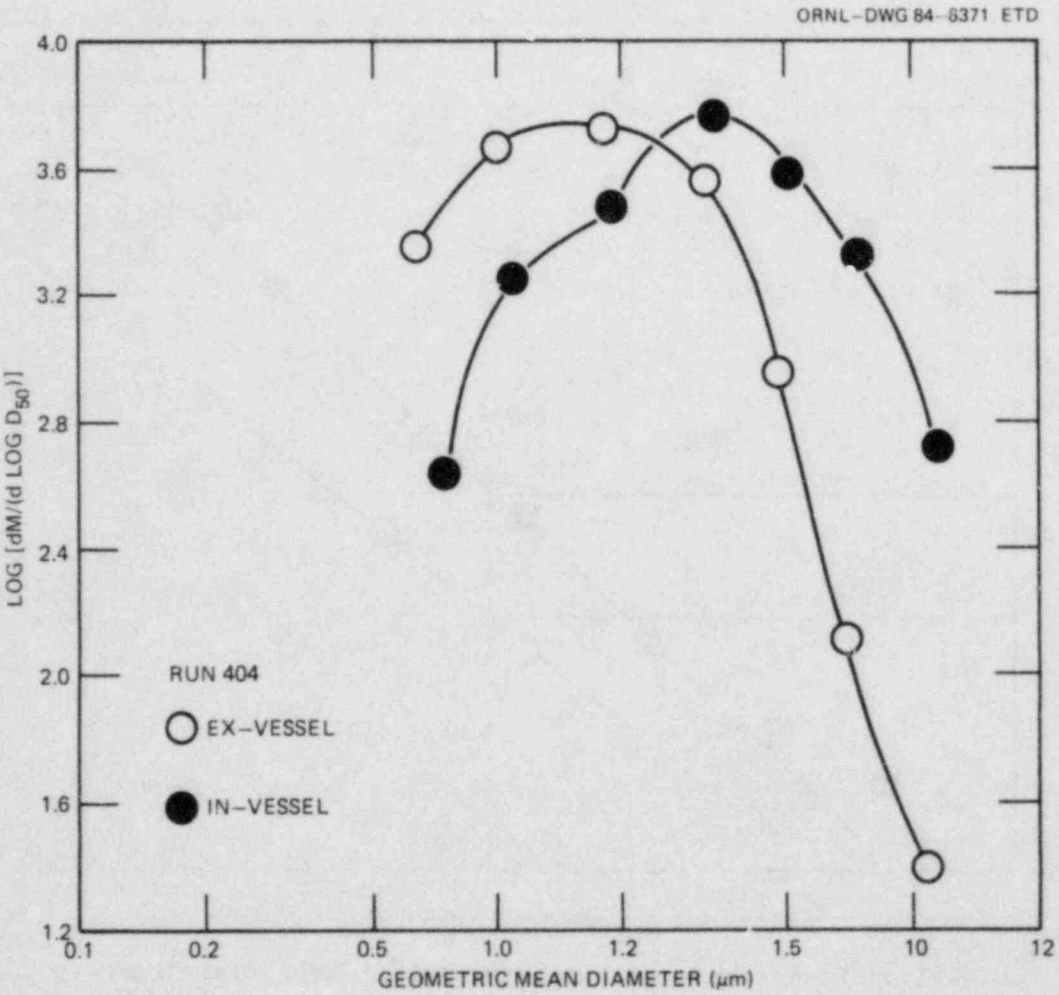

Fig. 13. Mass distribution plot of in-vessel and ex-vessel aerosol size measurements for NSPP experiment 404.

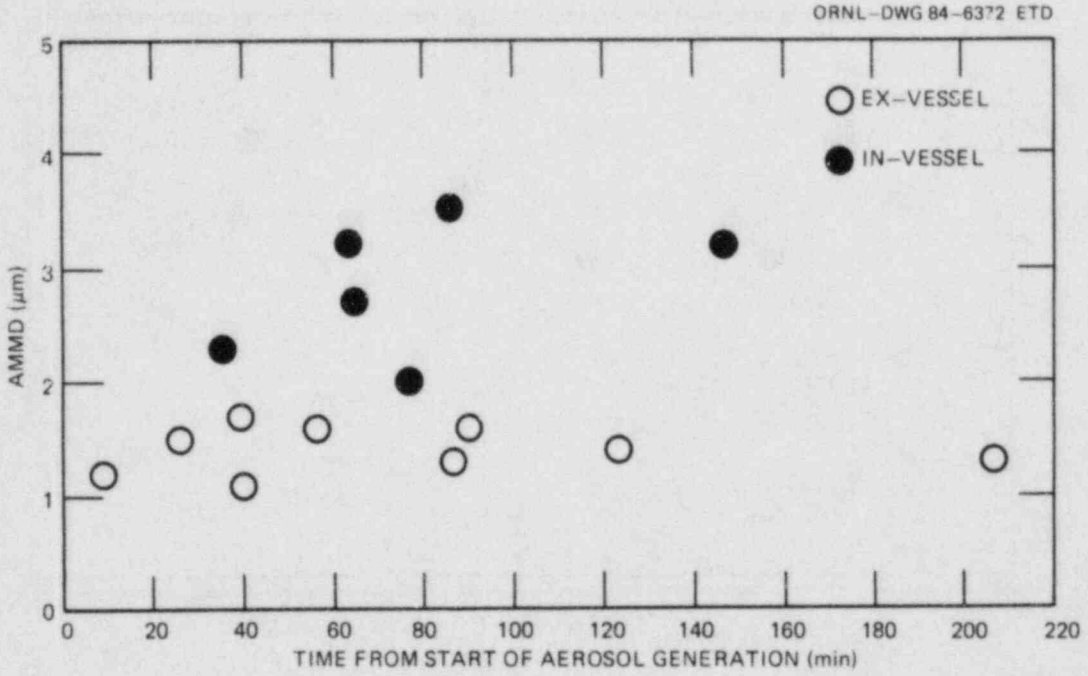

Fig. 14. In-vessel and ex-vessel AMMD values vs time, NSPP experiments 403, 404, 406, 407 (uranium oxide in steam).

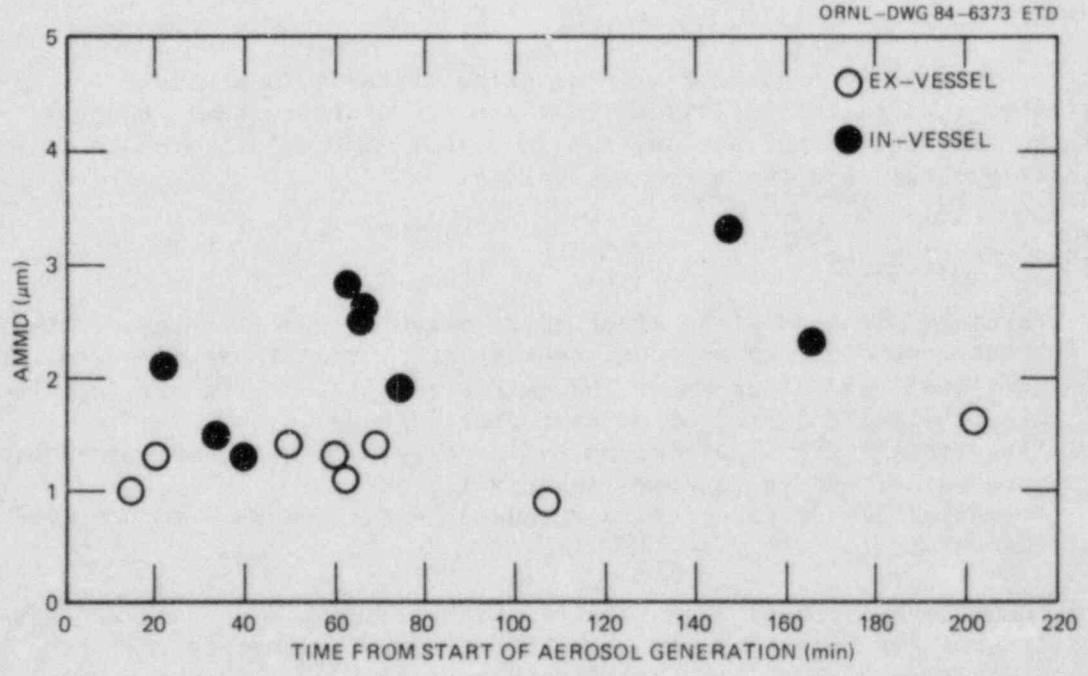

Fig. 15. In-vessel and ex-vessel AMMD values vs time for NSPP experiments 501–505 (iron oxide in steam).

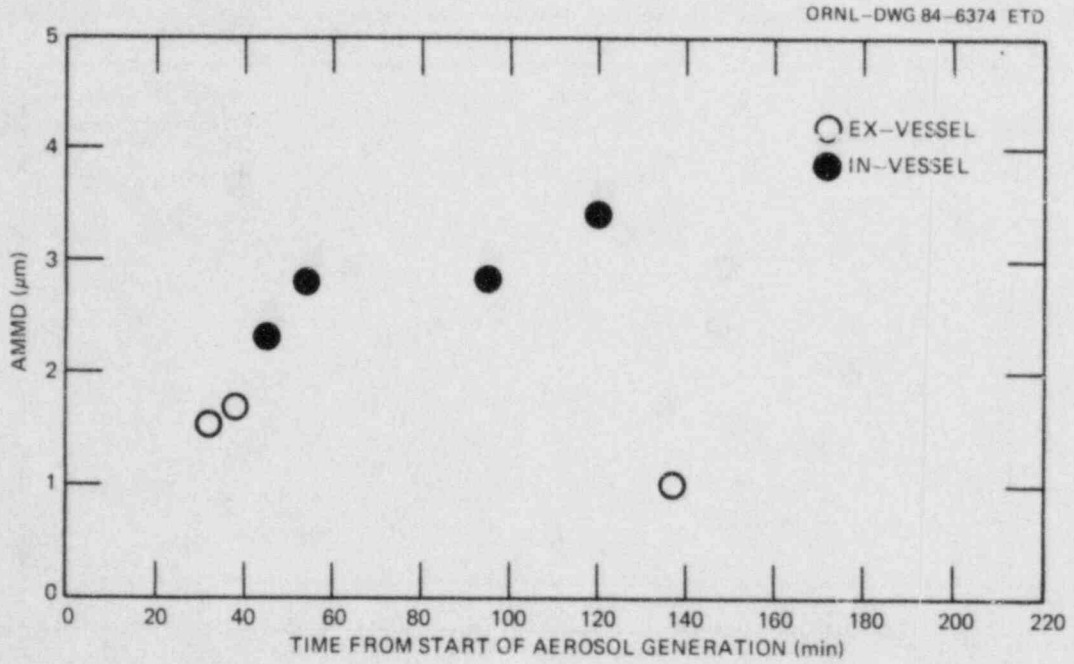

Fig. 16. In-vessel and ex-vessel AMMD values vs time for NSPP experiments 611, 612, and 613 (mixed oxides of uranium and iron in steam).

series runs (iron oxide and uranium oxide mixtures in steam). For simplicity, results for individual runs are not distinguished on these plots. As these figures show, the in-vessel AMMD values are significantly greater than the ex-vessel values.

3.6.4 Conclusions

1. Particle sizes in steam experiments measured under in-vessel conditions were found to be consistently larger than those measured under ex-vessel conditions where the sample is diluted with dry instrument air, cooled, and brought to atmospheric pressure.
2. Size distributions determined by in-vessel and ex-vessel procedures were both found to be approximately log normal.
3. No noticeable differences in standard deviations were found between the results.

Additional work is necessary to establish mean free path and viscosity data for conditions in each NSPP test. The results that have been found might be used to help estimate the aerosol water content due to condensation on the particles.

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1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-3830/V2
ORNL/TM-9217/V2

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Aerosol Release and Transport Semi-Annual Progress Report for April 1984–September 1984

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
R. E. Adams, M. L. Tobias

5. DATE REPORT COMPLETED
MONTH: November | YEAR: 1984

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37831

DATE REPORT ISSUED
MONTH: December | YEAR: 1984

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Accident Evaluation
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
B0121, B0476

13. TYPE OF REPORT
Semi-annual

PERIOD COVERED (Inclusive dates)
April 1984–September 1984

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

This report summarizes progress for the Aerosol Release and Transport Program sponsored by the Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Accident Evaluation, for the period April 1984–September 1984. Topics discussed include (1) the experimental program in the Fuel Aerosol Simulant Test Facility, (2) NSPP experiments involving an aerosol of limestone-aggregate concrete in a steam-air atmosphere, (3) revisions in the NSPP experimental program, (4) experiments relating to NSPP thermohydraulic conditions, (5) aerosol-moisture interaction test plans, (6) aerosol code implementation activities, (7) improvements in data processing procedures for NSPP experiments, and (8) a study comparing in-vessel and ex-vessel cascade impactor aerosol size measurements in the NSPP.

17 KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT

19. SECURITY CLASS (This report)
UNCLASSIFIED

21. NO. OF PAGES

20. SECURITY CLASS (This page)
UNCLASSIFIED

22. PRICE
$

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