MASTER

RECENT AEROSOL TESTS IN THE CONTAINMENT SYSTEMS TEST FACILITY

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I. INTRODUCTION

The Containment Systems Test Facility (CSTF) is a 20-meter high, 850³ model containment vessel in which various sodium fire aerosol air cleaning tests are studied for purposes of developing and proof testing air cleaning techniques. The first series of tests was designed to study the properties of sodium fire aerosols without any air cleaning and to provide a data base for model verification using large-scale experiments. To date, three such tests (two pool fire and one spray fire) have been completed and are being analyzed. These tests will be discussed, as will plans for the air cleaning tests to follow.

II. AEROSOL BEHAVIOR TESTS

A. Pool Fire Tests

The first pool fire test, designated AB1, used a normal air atmosphere, as was discussed in the previous report to this group⁽¹⁾. The second test, AB2, was similar except that steam was injected into the containment atmosphere to simulate the release of water vapor from heated concrete. Either type of atmosphere can be postulated for accident conditions, depending on the type of accident, geometry and quantity of sodium released. The test conditions used in tests AB1 and AB2 are listed in Table 1, and Figure 1 is a schematic of the test vessel. A detailed report of the test results was given at the 15th DOE Air Cleaning Conference⁽²⁾.

In both tests, sodium was spilled rapidly into a pan located at the bottom of the CSTF containment vessel. The sodium burned vigorously in the air atmosphere, releasing approximately 26% of the oxidized sodium as aerosol particles. Convection currents induced by the chemical heat of combustion caused rapid mixing in both tests, as evidenced by the uniformity of the aerosol mass and oxygen concentration in the gas phase at various elevations. After the sodium had burned for one hour, the reaction was terminated by closing the lid on the burn pan. This also stopped the release of aerosol particles, providing a precisely known value (zero) for the aerosol source term input to computer codes. In test AB2, steam was injected near the center of the containment vessel at a ratio of 1.0 kg H₂O per kg of aerosol.

The chemical form of the aerosol particles in test AB1 was determined to be a mixture of Na₂O₂, NaOH, and Na₂CO₃, with high hydroxide content initially and high peroxide concentration near the end of the burning period. This is consistent with reaction of sodium to form Na₂O₂ particles which then react to form NaOH as soon as they contact water vapor present in the containment vessel atmosphere. The 10°C dew point atmosphere contained sufficient moisture to convert approximately half of the aerosol to hydroxide. The steam added to the containment atmosphere in test AB2 converted nearly

Table 1. Test conditions for CSTF tests AB1 and AB2.

	<u>AB1</u>	<u>AB2</u>
<u>Containment Vessel</u>		
Diameter, m	7.62	
Overall height, m	20.3	
Volume, m ³	850	
Total horizontal surface, m ²	88	
Shell surface, m ²	520	
Total internal surface, m ²	1000	
Vessel steel mass, kg	103,000	
Leakage rate, %/d at 10 psig	2.0	
<u>Sodium Spill</u>		
Mass sodium spilled, kg	410	472
Sodium burn pan surface, m ²	4.4	4.4
Initial sodium temperature, °C	600	600
Sodium fire duration, sec	3600	3600
Total sodium oxidized, kg	154	146
<u>Steam Addition</u>		
Flow started, sec after time zero	-	960
Flow stopped, sec after time zero	-	4560
Flow rate, kg/sec	0	0.019
<u>Initial Containment Atmosphere</u>		
Oxygen, vol %	19.8	20.9
Dew point, °C	10.0	7.6
Temperature, °C	26.5	20.5
Pressure, MPa (absolute)	0.125	0.128
<u>Containment Atmosphere During Test</u>		
Maximum temperature, °C	91	96
Maximum pressure, MPa (absolute)	0.142	0.153
Final oxygen, vol %	14.7	16.7
Final dew point, °C	-40	-1.5
<u>Aerosol Source</u>		
Type	Na pool fire	Na pool fire
Source duration, sec	3600	3600
Average source rate (as sodium), g/s	11.1	10.8
Total aerosol release (as sodium), kg	40.0	38.8
Fraction of oxidized sodium released	0.261	0.266

CONTAINMENT SYSTEMS TEST FACILITY

Figure 1. Schematic of test facility.

all the aerosol to NaOH with excess water of hydration and solution. Approximately 5% of the sodium was converted to Na_2CO_3 by the naturally occurring CO_2 in the air. No hydrogen was detected in either test. The reactions appear to have occurred in the following sequence:

Other reactions undoubtedly occur, including adding water of hydration and solution. The extent of each reaction depends on the quantities of reactants available. In both tests, there was a large excess of oxygen and a very limited quantity of carbon dioxide. The quantity of available water varied between the two tests, as discussed above.

The suspended mass concentration in the CSTF containment atmosphere is shown in Figure 2 for tests AB1 and AB2. The concentration here is expressed as total mass. The equivalent sodium concentration can be calculated by multiplying the total mass by the factor shown in Figure 3. Figure 2 shows that aerosol in the dry atmosphere (AB1) attained slightly higher concentrations during the initial period when the aerosol was being released, and that after the aerosol source stopped, the rate of depletion of the dry aerosol was greater. At longer times the concentration in the dry test was significantly lower than in the wet test. The quantity of sodium released as aerosol was essentially equal (68 kg as Na_2O_2) in each of the tests, but an additional 68 kg of water vapor was added in test AB2. Also plotted in Figure 2 is the pretest prediction made with the computer code HAA-3B⁽³⁾. The figure shows that the computer prediction was quite good during the aerosol release period, but falls below the observed concentrations at longer times.

The behavior of aerosol particles (agglomeration, gravitational settling, plate-out) is affected by the density, size and shape of particles. For this reason, aerosol computer models deal with the actual particle mass. However, for radiological safety assessment purposes, the equivalent sodium content may be more appropriate because the ratio of sodium to fuel or fission product mass remains relatively constant regardless of the chemical changes occurring in the aerosol. Figure 3 displays the mass fraction of sodium in the suspended aerosols plotted over the entire five-day period. This factor was determined by weighing the aerosol collected on filter papers and then analyzing for sodium content by either acid titration or emission spectrometric techniques.

HEDL 7811-089.5
 Neg no 7814047-11

Figure 2. Suspended mass concentration in the CSTF atmosphere.

Figure 3. Mass fraction of sodium in suspended aerosol.

HEDL 7806-14.6
 Neg no 7807153-6

After the tests, additional computer calculations were made to investigate various input parameters. Improved fits to the experimental data were obtained. Figure 4 compares the AB1 experimental results with two HAA-3B cases using a time dependent and constant source terms. Figure 5 presented the effects of variations in α , the density modification factor, on the test AB2 HAA-3B predictions.

For these time dependent calculations in Figures 4 and 5, the sodium oxide aerosol generation rate was taken to be proportional to the oxygen concentration of the containment atmosphere, and thus it decreased with time. The code calculation, however, deals with total aerosol mass and the sodium oxide aerosol generated was assumed to react with water vapor initially present in the containment atmosphere. This rapid reaction with the limited amount of water leads to an aerosol source rate which is appreciable higher, at early times, than the average rate.

Calculations using the time dependent source rate show improved fits to the data at early times, as can be seen from Figure 4. This is an important time to predict accurately because the high aerosol concentrations can lead to high leakage potentials. The use of a time dependent source rate has only minor effects on the predicted airborne mass at longer times. Variations in α , the density modification factor, have an effect over the longer time span as shown in Figure 5.

A computer prediction of the suspended mass for test AB2 was also made at Battelle Columbus using the HAARM-3 aerosol code⁽⁴⁾. The results of these calculations are shown in Figure 6. When the average observed source rate is used (30 g/sec), the code overestimates the early concentrations, and underestimates at longer times.

The particle size was measured during the tests using cascade impactors. The aerodynamic mass median diameter (AMMD) was essentially the same in both tests as shown by the data in Figure 7. Also given is the HAA-3B particulate size prediction.

Previously observed differences in particle sizes determined by cascade impactors having rectangular and round jet orifices have been reduced by using recent calibration data obtained for the Environmental Protection Agency⁽⁵⁾. The sizes now obtained by the two types of impactors show good agreement.

B. Spray Fire Test

In the third test, AB3, sodium was released as a spray near the top of the CSTF containment vessel into a normal air atmosphere. Commercial spray nozzles were used to create the spray. The test conditions are listed in Table 2.

HEDL 7811-089.1
Neg no 7814047-9

Figure 4. Aerosol mass concentration during test AB1 compared with HAA-3B predictions using two source terms.

HEDL 7811-089.2
 Neg no 7814047-8

Figure 5. Aerosol mass concentration during test AB2 compared with HAA-3B predictions.

HEDL 7811-089.4
Neg no 7814047-10

Figure 6. Aerosol mass concentration during test AB2 compared with HAARM-3 predictions.

HEDL 7811-089.3
Neg no 7814047-7

Figure 7. Aerosol particle size measured by cascade impactor and predicted by HAA-3B.

TABLE 2
TEST CONDITIONS FOR SPRAY FIRE--TEST AB3

<u>Containment Vessel (CV)</u>	CSTF
CV free gas space [ft ³ (m ³)]	30,000 (850)
Horizontal cross section [ft ² (m ²)]	490 (45.6)
Total horizontal surface for settling [ft ² (m ²)]	950 (88.2)
Total internal surface [ft ² (m ²)]	10,700 (1,000)
CV steel mass [lb (kg)]	226,000 (103,000)
Thermal insulation	Exterior fiberglass, 1 in., k = 0.027 Btu/hr-ft ⁰ F at 200 ⁰ F
CV leakage rate (%/day at 10 psig)	1.1

Aerosol Source

Type	Sodium spray fire
Means of creating sodium spray	Commercial spray nozzles
Quantity of nozzles	2
Nozzle manufacturer	Spraying Systems Co.
Catalogue number	3/8BA15
Nozzle orientation	Downward
Pressure drop across nozzle (psid)	40
Total Na flow rate (kg/s)	0.34
Na temperature [⁰ F (⁰ C)]	1110 (600)
Spray drop size (μm, MMD)	670
Drop size standard deviation (σ _g)	1.5
Spray duration (seconds)	140
Total Na aerosol release (kg)	48

Initial CV Atmospheric Conditions

Composition	Normal air
Temperature [⁰ F (⁰ C)]	66.0 (19)
Pressure [psia (MPa)]	18.1 (0.125)
Dew point [⁰ F (⁰ C)]	42 (5.6)

Motion pictures and thermocouple data showed that the sodium spray drops burned to completion before falling very far below the downward-directed spray nozzles. It is believed that the heated air near the nozzles caused upward convection currents in the vicinity of the nozzles, which caused all of the heat and aerosol release to occur in the top 20% of the containment volume. The containment atmosphere temperature and pressure are plotted in Figure 8. To illustrate the poor mixing during the spray, the containment volume is divided into five zones of equal volume. The figures show clearly that large temperature gradients existed in the containment atmosphere in the vertical direction. The SPRAY code⁽⁶⁾ predicted slightly higher pressures and uniform temperatures, based on the assumption that sodium burns during the entire drop fall distance. Figure 8 shows this to be a poor assumption, but the prediction of mean temperature was good.

The aerosol mass concentration is shown as a semi-log plot in Figure 9 for early times after the spray. The experimental points are the mean values of four filter samples taken at various locations from high to low in the vessel. The concentration is plotted as elemental sodium. The pretest prediction made by the HAA-3B code is also shown in Figure 9. The code gave very conservative (high concentration) predictions for the first few minutes, but was non-conservative at longer times. The concentration is plotted on log-log paper in Figure 10 for the entire three-day test period. Post-run variations of the computer input to obtain improved fits have not yet been made.

The aerosol particle size was determined by cascade impactors. The particles attained a larger aerodynamic size than the pool fire tests, which is consistent with the higher local concentrations attained during the spray fire.

C. Nozzle Performance Test

An "in-house" test, NT-1, to check spray nozzle performance as a long duration aerosol source was made. The test conditions are given in Table 3.

As in the previous spray test, AB3, stable temperature gradients within the vessel were produced. The test demonstrated that sprays can form the basis of a long-term aerosol source. One interesting observation from NT-1 was that the deposited aerosol had a very low (0.05g/cm^3) bulk density, significantly lower than the values of 0.24 measured for the test AB3 aerosol.

HEDL 7804-338.12
Neg no 7814047-2

Figure 8. CSTF containment temperature and pressure--test AB3.

HEDL 7804-338.3
 Neq no 7814047-6

Figure 9. Suspended concentration at early times during sodium spray--test AB3.

HEDL 7804-338.13
Neg no 7814047-3

Figure 10. Aerosol concentration for 3-day period--test AB3.

Table 3
NT-1 SODIUM SPRAY CONDITIONS

Vessel	CSTF
Cell volume, m ³	850
Initial oxygen concentration, vol%	20.9
Initial dew point, °C	10.1
Initial pressure, MPa	0.124
Number of spray nozzles	1
Type of nozzle	Spraying Systems Co., Model 1/4 B1
Nozzle distance above floor, m	17
Nozzle pressure drop, MPa	0.068/0.276
Spray direction	Downward
Spray drop size, μm MMD	320/380
Drop geometric std. deviation, σ_g	1.5
Total sodium released, kg	82
Sodium spray rate, g/s	3.41 for 1.05×10^4 s 6.84 for 6.72×10^3 s
Spray duration, s	1.72×10^4
Temperature of sodium, °C	545

D. Conclusions, Aerosol Behavior Tests

On the basis of the tests previously discussed, some conclusions can be made:

- The CSTF tests provide a data base for comparison of computer models.
- Computer predictions by the HAA-3B code are good for pool fires.
- Spray fires are less well understood and computer models are not as well developed as for pool fires.
- Spray fires can form the basis for long-term aerosol sources for air cleaning tests.

III. BREEDER REACTOR EMERGENCY AIR CLEANING SYSTEM TESTS

Presently under construction at the CSTF and nearing completion is the Air Cleaning Test loop. This test loop will be used to develop and perform proof-of-principle tests of various systems for controlling effluents from postulated, but highly improbable, breeder reactor accidents.

The tests will be performed in the Containment Systems Test Facility (CSTF). A flow diagram of the test loop is shown in Figure 11. The loop is sized for $0.47 \text{ m}^3/\text{s}$ ($1000 \text{ ft}^3/\text{min}$) nominal gas flow. This is approximately 0.1 scale of a large plant system and permits full-scale testing of modules of the fibrous scrubber and HEPA filters. The quench scrubber and venturi scrubber are scale models of plant components.

The test system will consist of:

- 1) A spray nozzle near the mid-point of the CSTF capable of producing a constant sodium oxide aerosol source for up to 70 hours.
- 2) A quench tank containing internal water sprays to cool the inlet aerosol/gas stream. Some aerosol removal will be obtained here.
- 3) A jet venturi scrubber using water. Approximately 90% removal efficiency is expected.
- 4) A fiber bed scrubber to remove fine aerosol particles and entrained scrubber liquid droplets with high efficiency (>98%) will complete the test train.

Parameters which will be investigated during the testing are listed in Table 4. The overall design efficiency for removing particles is 0.999, but the effects of the parameters listed in the table are uncertain and must be determined using test aerosols having properties similar to those expected in postulated major accidents.

Although the tests will be performed using aerosols of various sodium compounds, the results will be applicable to removal of radioactive fuel and fission product materials also, since the aerosol properties are dominated by the much larger mass release of sodium during the postulated accidents.

Air cleaning systems testing is expected to start in December and occupy most of FY-1979. During this time, however, one aerosol behavior test, AB4, a sodium spray in an inert atmosphere, is planned.

Figure 11. Flow diagram of CSTF air cleaning scrubber system.

HEDL 7804-338.15
Neg no 7814047-5

Table 4
EACS TEST PARAMETERS

<u>Parameter</u>	<u>Range</u>
Gas flow rate	0.047 to 0.47 m ³ /s at STP
Liquid to gas ratio	Low to high
Sodium concentration in scrubber solution	0 to concentrated
Temperature of inlet gas	50 to 370°C
Aerosol inlet concentration	1 to 50 g/m ³
Aerosol inlet particle size	1 to 10 μ m aerodynamic mass median diameter
Aerosol chemical form	Na ₂ O ₂ , NaOH, Na ₂ CO ₃ and mixtures of these
Operating time	To 70 hr per test, 200 hr accumulated

V. REFERENCES

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