LARGE-SCALE SODIUM SPRAY FIRE CODE
VALIDATION (SOFCOV) TEST

D. W. Jeppson
L. D. Muhlestein

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ABSTRACT

A large-scale, sodium spray fire code validation test was performed in the HECL 650-\(\text{m}^3\) Containment System Test Facility (CSTF) as part of the Sodium Spray Fire Code Validation (SOFICOV) program. Six hundred fifty-eight kilograms of sodium was sprayed in an air atmosphere for a period of \(2400\) s. The sodium spray droplet sizes and spray pattern distribution were estimated. The containment atmosphere temperature and pressure response, containment wall temperature response and sodium reaction rate with oxygen were measured. These results are compared to post-test predictions using the NACOM\(^4\) computer code.

INTRODUCTION

The ability to calculate containment atmosphere temperature, gas composition, and pressure response following a postulated sodium spray fire is required for breeder reactor safety analysis. Several sodium spray codes have been developed to calculate the containment response to a sodium spray, but they have not been validated for large cells. Those codes presently available include SPRAY-3\(^2\), SPCA-2\(^2\), SOFICOV\(^4\), SOMIX-III\(^5\), NACOM\(^4\), and CONTAIN\(^6\).

In order to provide a data base to be used to validate sodium spray fire codes, a large-scale sodium spray code validation test was recently completed in the HECL 650-\(\text{m}^3\) Containment System Test Facility (CSTF). The sodium spray fire code validation (SOFICOV) program also included pre- and post-test computer code predictions of containment atmosphere response by several program participants.

TEST FACILITY AND EQUIPMENT

The spray test was performed in a 650-\(\text{m}^3\) containment vessel within the Containment Systems Test Facility (CSTF). This vessel, shown in Figure 1, was fabricated with carbon steel and was designed for a pressure of 0.517 MPa gauge and a leakage rate of \(0.1\) l/day. It is located within a ventilated concrete building. The inner vessel wall surfaces are coated with a modified phenolic paint and the outer shell is covered by 2.54 cm thick fiberglass insulation with an outer aluminum vapor barrier. Further details of the vessel are provided in Table 1. Additional support features within CSTF include a sodium supply system, instrumentation systems, control room and data acquisition system, data reduction and analysis systems, chemical laboratory rooms, utility services, a maintenance shop and offices.

The sodium supply tank has a capacity of 1700 liters and can be used to transfer sodium at temperatures up to 850\(\text{C}\) to the containment...
Figure 1: Containment Vessel Schematic

Dimensions

- Diameter (I.D.): 7.32 m
- Overall Height: 33.9 m
- Cylinder Height: 19.5 m
- Enclosed Volume: 882 m³

Weight, lb:
- Top Head: 2,067
- Bottom Head: 2,083
- Cylinder: 69,300
- Penetrations and Doubler Plates: 1,197
- Catch Pan: 504
- Internal Components: 12,753
- Total Weight: 102,290

Surface Areas for Heat Transfer, m²:
- Top Head: 85.0
- Bottom Head: 85.0
- Cylinder: 220.
- Total Area for Heat Transfer to Environments Internal Components: 220

Surface Areas for Aerosol settling, m²:
- Bottom Head: 36.7
- Catch Pan: 11.1
- Personnel Deck: 1.2
- Internal Components: 16.3
- Total: 70.2

Surface Areas for Aerosol Plating, m²:
- Vessel Shell: 550
- Internal Components: 225
- Total: 775

Thickness for Heat Transfer, mm:
- Average lumped values:
  - Top Head: 8.1
  - Bottom Head: 18.1
  - Cylinder: 22.6
  - Internal Components: 3.4

*Average thickness = weight (area) (density of steel)

Table 1: Containment Vessel Properties

The inerted catch pan and collar assembly, on to which the unreacted spray drops fell, is shown in Figure 3. It was located at the vessel centerline and an argon purge of 0.9 l/s was supplied to the catch pan portion to inert any sodium collected in it throughout the test period.

Forty-four thermocouples were located throughout the containment vessel atmosphere to measure the atmosphere temperatures at strategic locations through the test period. Thirty-four thermocouples were located on the containment vessel walls and structure to measure the change of steel temperature during the test. Seven oxygen analyzers were used to monitor the oxygen concentration at various locations in the containment vessel both in and out of the spray.

* Spraying Systems Company, Model LHH30100 ss, Wheaton, IL 60187
ZONE DURING THE TEST. AEROSOL SAMPLERS WERE LOCATED AT FOUR POSITIONS IN THE CONTAINMENT VESSEL TO PROVIDE MEASURING CAPABILITY OF AEROSOL CONCENTRATION, PARTICLE SIZE AND CHEMICAL COMPOSITION OF AEROSOL SUSPENDED IN THE VESSEL ATMOSPHERE THROUGHOUT THE TEST.

SPRAY TEST CONDITIONS

INITIAL CONDITIONS

The large-scale sodium spray fire test was performed by spraying sodium at an average rate of 273 g/s for a spray period of 2400 s. The initial atmosphere pressure was 108 kPa absolute, the initial gas temperature was 33°C, and the average containment vessel wall temperature was 320°C. The initial oxygen concentration in the test enclosure was 20.9 percent. No oxygen was added to the containment atmosphere, hence, the oxygen concentration decreased during the test. The sodium spray inlet temperature was 540 ± 30°C throughout the spray period. The pressure drop across the spray nozzle was maintained between 41 and 90 kPa. This range in pressure drop across the spray nozzle produced a full circular sodium spray with an estimated range in sodium drop size from 5.4 to 3.6 mm mass median diameter (MMD) with a geometric standard deviation of 1.6. Some of the sodium reacted at the surface of a shallow pool on the catch pan collar after falling the entire spray height. Some of the sodium drained from the collar to the inerted catch pan where it cooled without reacting. The diameter of the sodium spray pattern on the surface of the catch pan after a fall of 13 m was about 4 m. The amount of sodium which reacted as a pool was estimated based on temperatures recorded by thermocouples located in the catch pan collar, mass of sodium recovered from the catch pan and collar, and hydrogen produced during cleanup. This quantity was in agreement with the amount of oxygen reacted during the test.

SODIUM SPRAY RATE

The sodium spray rate was 253 g/s during the first 1200 s, 258 g/s during the next 400 s and 304 g/s during the remaining 800 s.

SPRAY DROPLET SIZE

Spray droplet size is an important parameter in determining the sodium spray burning rate. Tests were conducted as part of this program to determine if sodium droplets (near 5 mm in diameter, at temperatures near 540°C, and at near terminal velocities) could be collected for sizing by capturing in liquid nitrogen or an organic liquid. The results indicated that significant droplet breakup occurred for all fluids tested. It appears that the most appropriate method of spray drop measurement would be by photography of the actual spray from the nozzle to be used in the spray test. This photographic method of measuring spray drops could be conducted in an inert atmosphere to minimize the formation of interfering aerosol. The spray droplet size determined for use in the computer code comparison studies was determined from data obtained for water spray through the nozzle used in this test. Equation (1) was used to determine the sodium droplet size based on water.

\[
\frac{x_{Na540}}{x_{H2O}} = \left( \frac{d_{Na540}}{d_{H2O}} \right)^{1.05} \left( \frac{T_{Na540}}{T_{H2O}} \right)^{0.35} \left( \frac{\rho_{H2O}}{\rho_{Na540}} \right)^{0.44} \left( \frac{\mu_{H2O}}{\mu_{Na540}} \right)^{-1.16}
\]

where:

- \( x_{Na540} \) = sodium drop Mass Median Diameter (MMD) at 540°C,
- \( x_{H2O} \) = water drop MMD at 25°C,
- \( d_{Na540} \) = diameter of orifice at 540°C,
- \( d_{H2O} \) = diameter of orifice at 25°C,
- \( W_{Na} \) = mass flow rate of sodium,
- \( W_{H2O} \) = mass flow rate of water,
- \( \sigma_{Na} \) = surface tension of sodium at 540°C,
- \( \sigma_{H2O} \) = surface tension of water at 25°C,
- \( \mu_{Na} \) = viscosity of sodium at 540°C, and
- \( \mu_{H2O} \) = viscosity of water at 25°C

Droplet size reported by the spray nozzle manufacturer. The flow rates for sodium and water were those measured at the same pressure.
drop across the spray nozzle for their respective temperatures. Equation (1) is for swirl-type nozzles and compensates for increased orifice diameter due to temperature difference, mass flow rate, surface tension and viscosity effects on droplet size. From Eq. (1), the sodium spray drop size (MMD) for test SA-1 conditions was calculated to be 1.28 times greater than that reported for water at the same test average pressure drop across the nozzle (80 kPag).

TEST RESULTS COMPARISON WITH CODE PREDICTIONS

Photographs of the initial spray sequence, taken through a viewing window in the containment vessel wall, are shown in Figure 4. The photographs show that the sodium burned immediately as it was discharged from the nozzle and that it burned during the total fall distance. The velocity of the initial sodium spray drops was determined from these photographs. Aerosol was generated immediately and soon blocked the visibility in the vessel.

The actual test results are compared with post-test, NACOM computer code predictions. The NACOM code accounts for spray reactions only and does not include heat generation and gas consumption from pool reactions. Comparison of NACOM code predictions for pressure with test SA-1 results are shown in Figure 5, for average atmosphere temperature in Figure 6, for average containment vessel wall temperature in Figure 7.
and for oxygen consumption in Figure 8. Included in these Figures are code predictions for spray drop MMD of 4.0 mm to compare the effect of varying the drop size.

0 Drop size measurements should be made for test SA-1 spray nozzle with sodium at the test temperature and with the same pressure drop across the spray nozzle.

0 A spray test is recommended be conducted for the same drop size but with no pool fire to separate spray fire effects from pool fire effects.

0 Efforts to compare test results with predictions from codes which include both spray and pool fire effects are continuing.

REFERENCES


