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AI-AEC-13144

QUARTERLY TECHNICAL PROGRESS REPORT
NUCLEAR SAFETY
CHARACTERIZATION OF SODIUM FIRES
AND
FAST REACTOR FISSION PRODUCTS
OCTOBER - DECEMBER 1974

AEC Research and Development Report

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Division of Reactor Research and Development,
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Program: Characterization of Sodium Fires and Fission Products

AEC Task: Task 10 - Characterization of Sodium Fires and Fission Products

Program Manager: R. W. Keaten

Project Manager: H. A. Morewitz

Reporting Period: October-December 1974 Category: HN-70-01-00.0

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C. T. Nelson, E. R. Specht, C. Guderjahn

I. PROJECT OBJECTIVES

- 1) Develop a computer program for calculating two-dimensional, transient natural convection phenomena arising from various postulated pipe breaks and pool fires in LMFBR heat transfer equipment vaults
- 2) Develop experimental programs and conduct tests that will characterize the behavior of sodium, sodium oxide, fuel, fission product and other aerosols as they might be generated by various postulated LMFBR accidents
- 3) Determine by analysis and experiment the generation and transport of these aerosols with respect to source (location, type and configuration), release, dispersal, agglomeration, attenuation, and removal for the entire course of events associated with real and hypothetical accident conditions.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1975

The fluid mechanics portion of SOMIX-1 was developed. Computer runs showed that the code was computationally stable over the entire range of Grashof numbers tested, which covered all flow ranges up to the onset of turbulent flow. The conversion of SOMIX-2 to cylindrical geometry was completed and excellent agreement was achieved with SOMIX-1 for low Grashof number cases.

A series of HCDA source term bubble scoping tests were initiated in a water filled test column using air and air-steam mixtures to simulate the HCDA bubble. Observations were made of the bubble during (1) formation, (2) rise period, and (3) surface break-through.

The Laboratory Spray Modeling (LSM) test apparatus was designed and fabricated.

Five-year program plans and work plans for the Characterization of Sodium Fires and Fission Products were prepared and issued.

III. PROGRESS DURING REPORT PERIOD

A. SUBTASK A - SODIUM SPLASH DISPERSAL

Fabrication of the Laboratory Spray Modeling (LSM) test apparatus was completed. Calibration and scoping jet tests using fluids of density and viscosity similar to sodium and a wide range of surface tensions will be conducted in this test apparatus.

The liquid jet tests conducted in the LSM will determine the behavior of a liquid jet as it impacts on a perpendicular surface, the instabilities of a liquid sheet that forms after impaction, and the resulting size and distribution of droplets formed when the liquid sheet falls away from the plate. These effects will be determined using liquids of various physical properties, e.g., surface tension, viscosity and density; to form liquid jets and sheets in a range of jet velocities and sheet thicknesses which may be typically formed in hypothetical pipe ruptures. The tests conducted will provide scaling and correlation factors required to extrapolate experimental data derived from the LSM, and later jet tests conducted in the LTV and large hydraulic laboratory at Rocketdyne, to full scale configurations.

B. SUBTASK B - PROGRAM PLAN

Program Plan A for the characterization of Sodium Fires and Fission Products was completed and issued as PP-707-130-001. This plan includes a detailed program description, engineering development and test plans for the source, release, dispersal, agglomeration and attenuation of aerosols.

C. SUBTASK C - SOMIX CODE DEVELOPMENT

Upon satisfactory checkout of the hydrodynamic portion of SOMIX-1, code development activities were directed toward completing the sodium spray breakup and droplet combustion routines.

Two types of pipe rupture conditions were considered: a horizontally directed fan spray from a longitudinal or circumferential through-crack and a vertically directed cylindrical jet or flat sheet which impinges on the ceiling, spreads and disintegrates into a rain of falling drops (Figure 1).

A literature search indicated that, in general, the breakup of sheets into drops is due to the formation of perturbations on the surface of the sheet (Figure 2) under the action of turbulent eddies, pipe vibrations, and the like. These wave-like protuberances are subject to aerodynamic forces as they move down the sheet, as shown in Figures 3 and 4. Under the action of these aerodynamic forces, the amplitude of the wave grows as the wave moves down the sheet, resulting in disintegration of the leading edge into ligaments, theoretically of half wavelength widths which coalesce into circular rods. According to Rayleigh's analysis, the rods are unstable and disintegrate into drops whose diameter is 1.88 times the diameter of the rods.

A combination of dimensional and theoretical analysis of sheet breakup suggests that the factors which affect drop diameter for both horizontal sheets and vertical impinging jets can be collected together into a single relationship of the following form:

$$\frac{d}{D} (\gamma / \eta_L U)^{\alpha} (\rho_L / \rho_g)^{1/6} (\eta_L / \eta_r)^{1/6} f(1/Re_{\text{pipe}})$$

where

γ = liquid surface tension

η_L = liquid viscosity

U = liquid discharge velocity

ρ_L = liquid density

ρ_g = gas density

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Figure 1. Two Types of Pipe Rupture Conditions

WAVING
SHEET

DILATING
SHEET

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Figure 2. Basic Wave Forms

Figure 3. Aerodynamic Forces
Acting at Interface

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9005-4533

Figure 4. Aerodynamic Forces
Acting on a Thin Liquid Sheet

η = reference viscosity, e. g., of the test fluid

Re_{pipe} = Reynolds number based on the pipe diameter and discharge velocity

The function $f(1/Re_{\text{pipe}})$ correlates with the viscous drag exerted by the fluid on the ceiling. It disappears from the equation when the equation is applied to the determination of drop sizes from horizontal sprays. D is a suitable characteristic dimension of the opening.

For fan spray, theory and test show that $\alpha = 1/3$; for two jets impinging on each other at an angle of 180 degrees, $\alpha = 1/4$. For the pipe rupture studies, the constant of proportionality and the exponent, α , will be determined experimentally during the jet splash tests using jets of varying velocity and diameter and liquids with surface tension equal to or less than that of water. The results of the sodium spray breakup studies were issued as TI-707-130-034.

A literature review of droplet combustion indicated that because of the complex nature of spray breakup and multiple-drop combustion, workers have concentrated their efforts on experimental and theoretical studies of the combustion of single droplets. Virtually all of the drop combustion theories which have been developed are based on a spherically symmetric combustion zone. The theories show that the combustion rate of a droplet is controlled by its vaporization rate which, in turn, is controlled by the rate of heat transfer to the drop. A linear relationship between drop radius and mass burning rate is predicted by the theories.

Equations for predicting the burning rate of single sodium droplets are usually expressed in terms of Frossling's equation

$$\dot{M}_M = \dot{M}_S (1 + A Re^{1/2} Pr^{1/3})$$

where

Re = Reynolds number based on drop diameter and gas properties

Pr = Prandtl number based on gas properties

Frossling's equation shows that the burning rate of a moving drop, $\dot{M}_M$, is expressible in terms of the burning rate of a stationary drop, $\dot{M}_S$, augmented by a function which takes into account the increased burning due to forced

convection flow. The burning rate, $\dot{M}_S$, of a stationary drop can be calculated from fundamental mass transfer principles. The augmentation factor is a function of drop diameter and velocity.

An interesting sidelight of the literature review was the result, as shown by Turkdogan, Gieveson and Danken* and confirmed by Rossner,[†] that when a metal at a temperature well below the boiling point is vaporizing into an oxidizing atmosphere, as may be the case with free-falling sodium drops, there can be an abrupt and a many-decade reduction in vaporization rate as the oxygen atmosphere is reduced. This is attributable to the formation of a passivating oxide layer on the vaporizing surface. This phenomenon has often been exhibited in sodium pool burning in air. Figure 5, taken from Reference 2, shows that one millimeter diameter stationary sodium drops can be expected to passivate in air atmospheres if the surface temperature drops below 770°F.

One centimeter diameter drops will passivate if the surface temperatures drop below 700°F. The passivation temperature decreases with decreasing oxygen concentration. The effect of droplet motion on passivating temperatures was not considered in the above analyses. During the sodium burning experiments, the behavior of the drops will be observed for indications of passivation effects.

The mass transfer equations required to calculate the burning rate of stationary drops were developed. The equations required to determine the physico-thermal and the physico-chemical properties of sodium, sodium vapor, oxygen and nitrogen were also developed. The heat and mass transfer equations, the physio-thermal property equations, and the equations required to integrate the burning drop model into SOMIX were assembled into a report which was issued as TI-707-130-034.

D. SUBTASK D - HCDA SOURCE TERM SCOPING TESTS

A series of scoping tests were conducted in the small HCDA source term test apparatus to determine the characteristics of rising condensible and

*E. T. Turkdogan, P. Gieveson, and L. S. Danken, J. Phys. Chem., Vol 67, 1963, pp 1647-1654.

[†]D. E. Rossner, Oxidation of Metals, Vol 4, No. 1, 1972, pp 1-25.

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Figure 5. Surface Passivation as a Function of Critical Oxygen Partial Pressure, $P_{O_2,e}^*$

noncondensable bubbles in a column of water under atmospheric conditions. These tests were conducted using the test procedure DTP-707-130-002.

Photographs of these preliminary bubble scoping tests were made to provide initial information on bubble formation, the degree of bubble instabilities occurring during initiation and period of bubble rise, and surface breakthrough phenomena. Figure 6 illustrates these phenomena for a noncondensable bubble rise. Figure 6a shows the bubble turbulence upon initiation. During the rise period, the bubble surface stabilizes and forms a hemispherical shape with the underside exhibiting turbulence and breakup as shown in Figure 6b. At the moment of surface breakthrough, Figure 6c shows a film of water lifting from the column surface as the bubble rises above the water column surface. As the bubble disintegrates in the cover gas space, ejected water droplets are observed to strike the test apparatus cover, Figure 6d. These photos were taken with a Fast-X camera.

During the initial scoping test series, two condensable tests were conducted using an air-stream mixture to form the bubble. During the initial bubble formation, approximately the same degree of bubble turbulence was observed in these tests as in the noncondensable bubble tests. During the rise period, bubble disintegration and condensation were observed. The shape of the condensable bubbles as they approached the column surface was ellipsoidal, as shown in Figure 6e.

E. SUBTASK E - AEROSOL LEAKAGE

A test plan, TP-707-130-012, was prepared for the aerosol leakage tests to be conducted in the LSV. Design and procurement of test apparatus materials has been initiated. In addition, a Technical Information Report, TI-707-130-033, was issued which discusses the theoretical and experimental causes of cracking in concrete, the effect of the cracks in leak rate, reduction of aerosol leakage by passage through concrete, and measured attenuation efficiencies of particulates through concrete cracks from preliminary tests.

Figure 6a. Initiation of 850-cc
Noncondensable Bubble

Figure 6b. Noncondensable
Bubble During Rise Period

Figure 6c. Noncondensable Bubble
Lifting Column Surface During
Breakthrough

Figure 6d. Bubble Disintegration
and Surface Turbulence

Figure 6e. Condensable Bubble (850 cc
at Initiation) During Rise Period

Figure 6. Results of Scoping Tests on Bubble Formation

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IV. NEXT REPORT PERIOD ACTIVITIES

The spray breakup and drop combustion equations will be converted to finite difference form and integrated into SOMIX-1. Oxygen diffusion and convection equations will be developed to describe oxygen depletion due to burning and subsequent oxygendilution due to gas circulation in the enclosure. Upgrading of SOMIX-2 will continue and attempts will be made to push the code into the high Grashof number range. Gas circulation tests will be defined for the experimental verification studies of the SOMIX codes.

The techniques of developing noncondensable bubbles will be refined and Fast-X movie coverage will be provided. The degree of aerosol attenuation in both condensable and noncondensable bubbles will be determined.

Based on the results of the LSM experimental test data, a series of sodium jet tests will be conducted in the LTV to provide confidence in the developed scaling and correlation factors for liquid jets.

A test procedure will be prepared to conduct the initial aerosol leakage tests. Fabrication of the test article holding fixture will be completed and installed in the LSV.

V. DOCUMENTATION RELEASED DURING REPORT PERIOD

J. Otter, et al., "Parametric Radiological Evaluation of the FFTF HCDA," TI-707-240-021, November 11, 1974

C. T. Nelson, "Test Plan for Subtask 10-E, Aerosol Leakage, TP-707-130-012, December 3, 1974

R. P. Johnson, "Test Procedure for the HCDA Source Term Scoping Tests," DTP-707-130-002, October 18, 1974

M. P. Heisler, "Combustion of Falling Drops in Heat Transfer Equipment Vaults," TI-707-130-034, November 8, 1974

R. P. Johnson and C. T. Nelson, "Review of Liquid Sheet and Droplet Formation and its Application to the Sodium Splash Dispersal Test Series," TI-707-130-032, October 24, 1974

R. P. Johnson, "Test Plan for Subtask 10A - Sodium Jet Dispersal Tests," TP-707-130-011, December 3, 1974

R. P. Johnson and C. T. Nelson, "Test Plan for Subtask 10 - HCDA Aerosol Source Term," TP-707-130-010, October 18, 1974

M. P. Heisler, "Drops Formed by Impingement Jets and Fan Spray Sheets," TI-707-130-035, December 12, 1974

C. T. Nelson, "Gas and Particulate Leakage," TI-707-130-033, November 13, 1974

H. A. Morewitz and Staff, "Program Plan A - Characterization of Sodium Fires and Fission Products," PP-707-130-001, December 19, 1974

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