MASTER

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

AEC Research and Development Report

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Atomics International Division
Rockwell International

8900 De Soto Ave.
Canoga Park, California 91304

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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

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Principal Investigators: M. P. Heisler, R. P. Johnson, J. M. Otter,
C. T. Nelson, E. R. Specht

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

In support of various safety studies being performed by HEDL in connection with the FFTF, a series of parametric studies was conducted. These studies concerned the release of sodium, fission products, and plutonium following a hypothetical core disruptive accident. The potential consequences of such releases were calculated using HEDL versions of the AI developed computer codes - SOFIRE-II, HAA-3B, and COMRADEX. The results indicated that

acceptably low site-boundary doses result in all cases, even with conservative assumptions.

III. PROGRESS DURING REPORT PERIOD

A. SUBTASK A - SODIUM SPLASH DISPERSAL

Efforts were completed to re-establish the basic test configuration of the Large Test Vessel (LTV), in order to conduct sodium and water jet tests. This task required dismantling the LTV, and removing the doughnut section and the two-cell apparatus. The vessel was completely cleaned and re-assembled, and its associated test instrumentation was serviced and calibrated.

Procurement of the instrumentation and materials that are required to perform the sodium and water jet tests and the SOMIX droplet verification tests was completed. The material for a heated impingement plate was obtained, and the plate was fabricated.

A conceptual design of an auxiliary apparatus that will permit studies to be made of the characteristics of liquid sheet dispersal at the outer edge of the sheet on the horizontal impingement plate was prepared. The concept includes the capability of using various types of plate material in the apparatus, including Lucite. The latter material will be used with water jets, and will permit photographic records of the dispersal phenomenon.

Studies were carried out, and concepts were identified, for determining the burning characteristics of both stationary and falling drops of sodium. A unique method for determining the temperature and mass of a single drop of sodium after it has fallen through a column of air was devised, and consisted of allowing the drop to fall into a calorimeter where the temperature rise of the system and the mass increase can be monitored.

A review and an evaluation of previous analytical, as well as experimental, efforts (both at AI and elsewhere) to characterize the size and mass distribution of drops formed by liquid jets was initiated. An interim technical information document, summarizing previous analyses at AI and some very current work by foreign investigators, was prepared in draft form.

B. SUBTASK B - PROGRAM PLAN

Efforts were initiated to prepare a program plan for a 5-year period. A somewhat detailed scope of work for eight subtasks was prepared for GFY 1975 and GFY 1976, as part of the Schedule 189a preparation, and outlines of scope of work for an additional 3 years were formulated in a PERT-type drawing. A careful review of the LMFBR Program Plan - Element 10 (WASH-1110) - was carried out, in order to make this plan meet the general organizational philosophy of WASH-1110. The preparation of accident progression diagrams relative to the release of aerosols was initiated.

C. SUBTASK C - SOMIX CODE DEVELOPMENT

During this reporting period, computer comparisons between SOMIX-1 and Torrance's cylindrical geometry code were completed for the high Grashof number case ($N_{Gr} = 4 \times 10^8$, corresponding to hot plate temperatures of 635°C). Good agreement between calculated results from the two codes was achieved, meeting the current milestone in the development of SOMIX-1.

Subsequent code development work concentrated on improving SOMIX-2, which is based on Fromm's high-order accuracy methods. Fromm's original version, which was developed for plane geometry, was modified for application to the cylindrical geometry applications required of SOMIX-2. In its current form, SOMIX-2 now accepts both plane and cylindrical geometry. Both versions are functional for low Grashof numbers. Excellent agreement with Torrance's results was achieved for Grashof numbers of $\sim 1 \times 10^5$.

Optimization studies of code running times proceeded along two directions, using SOMIX-1 as the development vehicle. In the first, a second-order extrapolation procedure was applied to the elliptic stream function equation. This provided a better initial guess of the field values for the method of Successive-Over-Relaxation. A substantial reduction in the number of iterations required for convergence to a final solution was obtained - typically, one-half to one-third as many iterations as were required without optimization. In addition, a 30% reduction in running time was achieved.

The second method adapted recently developed Fast-Fourier-Transform techniques to the solution of the elliptic stream function equation. Prior to incorporating this method into SOMIX-1, the correctness of the program was

verified by a test case in which the vorticity field was replaced by a simple algorithm which generated 1024 random numbers, corresponding to a 32 by 32 finite difference mesh. The total computing time for generating the random numbers and performing a Fourier analysis and synthesis on the 1024 mesh points was <0.5 sec. The maximum difference between numbers put in and the numbers generated by the Fast-Fourier-Transform was $<10^{-6}$, indicating a high-order accuracy was obtained by this technique.

Upon successful completion of the test case, the Gauss Successive Elimination Method required to round out the Fast Fourier Transform technique was developed, and the two were programmed into SOMIX-1. A number of computer runs were made for low Grashof numbers, $\sim 1 \times 10^5$. Good agreement with Torrance's results was achieved, as indicated in the following listing.

	Dimensionless Time	
	0.01	0.03
Fast Fourier Transform	0.12	0.63
Torrance	0.13	0.61

With the Fast Transform method, an additional 40% decrease in computer running time was achieved, as compared to that obtained with the extrapolation procedure used in the method of Successive-Over-Relaxation.

During this quarter, work was initiated on developing droplet size and droplet combustion models. The breakup of the leading edge of fan sprays has features common to the breakup of ceiling jets in pipe rupture situations. Small fan sprays have been studied intensively in laboratory and industrial applications, and a number of drop formation models have been developed. The most useful correlations of drop size parameters for SOMIX application appear to be those of Ford and Furnidge (Brit. J. Appl. Physics, 18, p 335, 1967). These correlations show a somewhat weak dependence of drop size on surface tension and density, and a strong dependence on jet velocity. The available analytical correlations for small sprays were studied, for possible extension to predictions of drop sizes from large ceiling jets. The analytical studies will give support to, and be supported by, experimental model studies conducted under Subtask A.

A review of the available literature on droplet combustion has been initiated. The results of the literature survey will be incorporated into drop combustion models suitable for predicting the vaporization rate of fume-forming condensed phases in low-oxygen and oxygen-rich gases. The development of a quasi-empirical film theory for combustion of individual droplets was initiated. Interference effects encountered with droplet sprays will be accommodated by empirically determined modification factors.

D. SUBTASK D - HCDA AEROSOL SOURCE TERM

Design and fabrication efforts were completed on the small-bubble test apparatus. A 1-ft diameter by 6-ft long Lucite pipe was mounted on a flange containing four inlet ports, through which a noncondensable gas bubble can be injected into a column of water. The shape and size of the bubbles, and their rise times and breakout at the surface, can be observed photographically with this test setup.

E. SUBTASK E - AEROSOL LEAKAGE

The preparation of a technical information document dealing with information on the phenomenon of gas and aerosol leakage through building construction barriers, with the formation of cracks in concrete, and with filtration efficiencies of aerosols through cracked and uncracked concrete, was started.

F. SUBTASK F - FUEL AND FISSION PRODUCT RELEASE FROM BURNING SODIUM

No effort to be expended during GFY 1975.

G. SUBTASK G - IMPROVE AEROSOL MODELS AND TESTS

No effort is to be expended during GFY 1975.

H. SUBTASK H - FFTF FSAR SUPPORT

A parametric study was made to determine the potential radiological consequences of an FFTF hypothetical core disassembly accident as a result of sodium, fission product, and plutonium releases. The consequences were calculated, using the HEDL versions of the following computer codes:

- 1) SOFIRE-II, to determine the containment pressure and leak rate following the accident
- 2) HAA-3B, to determine the fuel and sodium oxide aerosol concentration inside the containment building as a function of time
- 3) COMRADEX, to determine potential radiological doses as functions of distance from the reactor and time of exposure.

The consequences were calculated for releases to the head compartment of from 0 to 10,000 lb of sodium, of from 1 to 50% of the core fuel and solid fission products, and 100% of the noble gas fission products.

The results indicate that acceptably low site boundary doses result in all cases, even with conservative assumptions.

About 36 cases were run at AI initially. Comparison of the results with those of earlier studies performed by HEDL showed differences due primarily to the use of somewhat different assumptions and models. Some of the cases were repeated, using modified HEDL assumptions and the HEDL CDC computer system. Several inaccuracies in data transfer between the SOFIRE II, HAA-3B, and COMRADEX codes (HEDL versions) were discovered, and corrected in the latter runs.

Compilation and documentation of the analyses at HEDL were performed and reviewed by HEDL personnel. Those results were presented to the Directorate of Licensing by HEDL. In the AI study at HEDL, additional parameters were varied. The containment leak rate was varied from 0.1 to 1.0% per day, the release of halogens in elemental form was varied from 0 to 1%, and the aerosol settling velocity correction factor was varied by 50%. The effect of enclosing the head compartment (1000% per day leak rate) was also evaluated. Typical results are shown in Figures 1 through 4. A document, entitled "Parametric Radiological Evaluation of FFTF HCDA," by J. P. Hale, R. S. Hart, R. P. Johnson, H. C. Martin, J. M. Otter, P. R. Shire, and E. R. Specht, is to be published.

Work performed at AI on the IBM computer system was prepared in draft form in TI-707-240-021, "Parametric Radiological Evaluation of the FFTF HCDA," by J. M. Otter, E. R. Specht, R. S. Hart, and R. P. Johnson

Figure 1. FFTF HCDA Radiological Evaluation -
30-day Dose vs Distance (10,000 lb sodium,
10% of Core)

9005-4526

Figure 2. FFTF Radiological Parametric Survey – Open Head Containment Pressure History

Figure 3. FFTF Radiological Parametric Survey - Variation of Stokes Settling Velocity Correction Factor (α) (10,000 lb sodium, 10% of core)

9005-4528

Figure 4. FFTF Radiological Parametric Survey - Closed Head Compartment Containment Pressure History

(October 1974). This document discusses in depth five key cases from the matrix of cases that were studied at HEDL. Typical results are shown in Figure 5 and Table 1.

TABLE 1
POTENTIAL DOSES
(rem)

Sodium Release (%)	Core Release (%)	Time and Location	Organ			
			Bone	Thyroid	Lung	Whole Body
10,000	10	2 hr, er*	1.77	1.15	1.69	0.053
		30 days, lpz†	0.41	0.26	0.40	0.017
10,000	1	2 hr, er	0.56	0.36	0.54	0.022
		30 days, lpz	0.15	0.09	0.14	0.010
1,000	1	2 hr, er	0.24	0.16	0.23	0.011
		30 days, lpz	0.06	0.04	0.06	0.006
100	10	2 hr, er	0.51	0.33	0.49	0.016
		30 days, lpz	0.12	0.08	0.12	0.006
100	1	2 hr, er	0.08	0.05	0.08	0.004
		30 days, lpz	0.03	0.02	0.03	0.003

*er = exclusion radius

†lpz = low-population zone

IV. NEXT REPORT PERIOD ACTIVITIES

A. SUBTASK A - SODIUM SPLASH DISPERSAL

The fabrication of the Laboratory Spray Modeling (LSM) test apparatus and initial checkout of liquid jets and sprays will be completed. The fabrication of an apparatus to study the burning characteristics of single stationary and single falling drops of sodium will be initiated.

B. SUBTASK B - PROGRAM PLAN

Program Plan A will be issued during the next quarterly period.

Figure 5. 30-day Low-Population Zone (7200 m) Bone Dose as Functions of Sodium Release and Fuel Release

C. SUBTASK C - SOMIX CODE DEVELOPMENT

Work will continue on extending SOMIX-2 to high Grashof numbers (i.e., to high gas temperatures and large enclosure size). Dimensional analysis studies of the drop formation parameters associated with large spreading sheets will be initiated. Algorithms will be developed for programming the single-drop combustion models into SOMIX-1. Work on defining combustion models for sodium pool burning in heat transfer equipment vaults will be started.

D. SUBTASK D - HCDA AEROSOL SOURCE TERM

Several tests to determine the characteristics of a noncondensable and a condensable gas rising in a column of water will be conducted, and used to draw conclusions on the attenuation of fuel and fission product aerosols rising in a bubble in a pool of sodium that is characteristic of that in an LMFBR.

E. SUBTASK E - AEROSOL LEAKAGE

Efforts on this task will be directed toward the completion of the Test Plan, initiation of test vessel modifications, and preparation of the concrete test specimens. A technical information document will be published, describing the theoretical and experimental causes of cracking in concrete, the effects of the cracks on the leakage rate, and the mechanisms which reduce the passage of particulates through concrete cracks.

F. SUBTASK H - FFTF PSAR SUPPORT

A technical information document, summarizing the results of several hypothetical accident cases that were analyzed by AI in support of HEDL studies, will be issued.

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