QUARTERLY TECHNICAL PROGRESS REPORT
LMFBR SAFETY PROGRAMS
JANUARY-MARCH 1972

The preceding Progress Report was AI-AEC-13020

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Atoms International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

CONTRACT: AT(04-3)-824
ISSUED: MAY 31, 1972

This document is
PUBLICLY RELEASABLE
Larry E. Williams
Authorizing Official
Date: *08/07/2007*

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

1

CONTENTS

<u>Program</u>	<u>AEC Task No.</u>	<u>Project Title</u>	<u>Page</u>
Reactor Development	10	Nuclear Safety, Characterization of Sodium Fires and Fission Products	5

TABLES

1. Large Test Vessel Sodium Jet Test Summary	9
2. Normalized Vessel Pressure Due to Oxidation of Sodium	11
3. Experimental Sodium Droplet Distribution for Test No. 4	17
4. Geometrical Parameters	24
5. Computed Mass and Thermal Parameters for FFTF Cases and LTV Simulants	25

FIGURES

1. Sodium Jet Velocity vs Time	6
2. Sodium Released vs Time	8
3. Sodium Splash Test in LTV - Sodium Sheet and Droplet Formation	10
4. Pressure Rise History	11
5. Distribution of Fallout with Selected Size Distributions, Jet Test No. 6	12
6. Distribution of Fallout with Selected Size Distributions, Jet Test Nos. 7 and 8	14
7. Cumulative Mass Distribution of Fallout Material at Stated Oxygen Atmospheres	15
8. Vessel Pressure vs Time	16
9. Peak Pressure vs Volume Fraction	18
10. Peak Pressure vs Drop Diameter	18
11. Impinging Jet Problem	22
12. Aerosol Concentration Test UAM 72-1	24
13. Correlation of Model Results for Nusselt No., Grashof No., and H/L	26

Program: Reactor Development		
AEC Task: 10 - Nuclear Safety, Characterization of Sodium Fires and Fission Products		
Project Manager: H. A. Morewitz		
Reporting Period: January-March 1972	189A: 13481	
General Order: 09005	Subaccount: 31111	Category: 04-60-40-04.1

Principal Investigators: M. Silberberg, R. L. Koontz, R. P. Johnson,
C. T. Nelson, L. Baurmash, E. U. Vaughan,
J. Beoletto

I. PROJECT OBJECTIVES

The general objective of this project is to develop experimentally verified analytical models for postulated LMFBR accidents involving release and transport of energy and aerosols (sodium, PuO_2 , and fission products) in support of: (1) FFTF safety development needs, and (2) LMFBR Demonstration Plant safety analysis, engineered safeguards design, and siting. Postulated LMFBR accidents under consideration by this project include sodium spills, hypothetical core disruptive accidents, and fuel handling incidents. The objectives of this project are related to those of Tasks 10-2.6 and 2.7 of the "LMFBR Program Plan, Section 10, Safety," (WASH-1110).

II. MAJOR ACCOMPLISHMENTS FY 1972

A series of water jet impingement tests was completed to obtain information on the characteristics of jet breakup and droplet formation required for the development of models of sodium jet discharge hydrodynamics for hypothetical LMFBR pipe-rupture accident analysis.

Five sodium jet discharge simulation tests were completed in the Large Test Vessel (LTV) with a 1-in. sodium jet impinging at 10 fps and a horizontal plate in both inert and low percent oxygen environments (0.8 to 5.0%). Data were obtained for pressure rise history, oxidation product, aerosol concentration, sodium drop size distribution, distribution of drop rainout, and temperature of sodium at the impingement plate and after it fell on the floor. The average drop size was 0.18 in. $\pm$ 0.03 in. for the five simulation tests

Figure 1. Sodium Jet Velocity vs Time

The pressure rise rate was also normalized to the pounds of sodium consumed per second per pound of sodium injected, and compared to the oxidation model for sodium droplets. The agreement was good but the model predicted higher oxidation rates than was observed experimentally.

Empirical relations between the number of aggregates in an agglomerated particle and its "shape factor" correction for settling and further agglomeration have been found.⁽¹⁾ These relations can be programmed into the HAA-3 aerosol agglomeration code and will eliminate the use of a reduced agglomerate settling velocity independent of its size.

A. SIMULATIONS OF SODIUM JET DISCHARGE

1. Sodium Jet Tests in LTV

Experimental studies were continued using the sodium jet installation in LTV described in AI-AEC-13020. These tests were performed to characterize sodium drop interaction with 5 and 1% oxygen atmospheres. In these tests, observations were made of the gas temperature at various positions, the plate temperature, the fallout pattern, and the droplet size distributions. The jet velocity and drive pressure were also monitored. An improvement in the technique for measuring sodium droplet temperature at the floor position was made by monitoring the temperature of an oil bath with known thermal properties as sodium entered the oil.

The initial conditions and some of the results are shown in Table 1. In addition the test data for Tests 3 and 4 are repeated. Visual test coverage was made with a high speed movie camera located on the top of the LTV and a video-taped closed circuit television (CCTV) located at the LTV bottom. The movie camera provided an oblique horizontal view of the jet nozzle and impingement plate to illustrate the pattern of sodium sheet formation and pattern of droplets at the point of separation from the plate. The CCTV viewed the impingement plate and nozzle assembly vertically showing the entire fallout pattern.

Figure 1 shows the resulting sodium velocity for Tests 6, 7, and 8. The velocity of Test 6 remained fairly constant for the 5-sec injection period. Velocities observed on Tests 7 and 8 were of the same magnitude but involve transfer of approximately one-half of the mass in Test 6. The higher velocity

4-28-72

9005-4502

Figure 2. Sodium Released vs Time

TABLE 1
LARGE TEST VESSEL SODIUM JET TEST SUMMARY

Parameter	Test Number					
	3	4	5	6	7	8
Ambient Pressure (psia)	14.3	14.3	14.3	14.3	14.3	14.3
Initial Vessel Pressure (psig)		1.45	5.2	1.45	1.45	1.45
Initial Vessel Gas Temperature (°F)	75	75	75	75	75	75
Initial Sodium Temperature (°F)	990	990	1000	985	1000	1000
Initial Oxygen Concentration (%)	0	0	4.9	4.8	0.8	0.8
Jet Velocity (ft/sec)	19.3	10.1	5.2	10.6	8.8	9.9
Mass Sodium Introduced (lb)	9.0	12.4	6.6	12.3	5.2	6.0
Resulting Pressure Rise (psig)	0.7	0.6	0.7	4.2	0.7	0.4
Resulting Oxygen Depletion (%)	0	0	0.4	0.7	0	0
Drop Temperature at Floor (°F)				980 and 240	600 and 180	
Fallout Mean Size (μ m)	0.18	0.21		0.16	0.145	0.145

peak observed on each of these tests is due to gas expansion of the stored nitrogen entering the 1000°F charge reservoir volume, momentarily increasing the drive pressure.

The integrated jet velocity is plotted as injected mass on Figure 2 for Tests 6, 7, and 8. The profile of sodium sheet and droplet formation which occurs upon impingement on the strike plate, typical for Tests 6, 7, and 8, is shown in Figures 3a and b. Figure 3a was taken 0.02 sec after impact in Test 6 and Figure 3b was taken 0.2 sec after impact, and shows the falling sodium droplets after sheet breakup.

The pressure histories for Tests 6 and 8 are shown in Figure 4. The data for Test 7 were not recorded but the peak pressure was read on a Heise gage connected to the vessel. A summary analysis of the data is shown in Table 2, where the observed peak pressures are normalized to a fixed mass of injected sodium.

0.02 sec

9006-4006

a.

0.2 sec

9000-4007

b.

Figure 3. Sodium Splash Tests in LTV — Sodium Sheet and Droplet Formation

TABLE 2
NORMALIZED VESSEL PRESSURE DUE TO OXIDATION OF SODIUM

Parameter	Test			
	4	6	7	8
Initial Oxygen Concentration (%)	0.0	4.8	0.8	0.8
Mass Sodium Introduced (lb)	12.4	12.3	5.2	6.0
Pressure Rise (psig)	0.6	4.2	0.7	0.5
Normalized Pressure	0.6	4.2	1.6	1.0
Pressure Due to Oxidation	0.0	3.6	1.0	0.4
Pressure/% O ₂ (psig/% O ₂)	-	0.75	1.25	0.50

4-28-72

9005-4503

Figure 4. Pressure Rise History

4-28-72

9005-4504

Figure 5. Distribution of Fallout with Selected Size Distributions, Jet Test No. 6

The results indicate that for an average injection velocity about 10 fps, 12.4 lb of sodium will generate additional pressure, above that from the latent heat, which is a linear function of the oxygen content. This relationship is $0.75 \text{ psig}/\% \text{ O}_2 \pm 0.25 \text{ psig}/\% \text{ O}_2$, or $0.06 \pm 0.02 \text{ psig}/\% \text{ O}_2$ -lb sodium. Data from Test 6 were used to compute burning rates which could be compared to model computed results for low oxygen sodium burning rates. The peak pressure in Test 6 was 4.2 psig. This is equivalent to 1.28 lb of sodium burned if monoxide is formed, or 1.11 lb if peroxide is formed. 12.3 lb of sodium was injected into the vessel in 5.5 sec and the pressure peak occurred at 9.5 sec. The fractional burning rate is $3.1 \times 10^{-3} \text{ lb burned/lb sodium-sec-}\% \text{ O}_2$ if monoxide is formed and 2.7×10^{-3} for peroxide. Analyses of the aerosol phase from Tests 6, 7, and 8 show that in a 5% oxygen atmosphere about 40 to 60% of the aerosol is sodium peroxide while in 1% oxygen, the aerosol is predominantly condensed sodium and/or all monoxide.

Figures 5 and 6 show the area integrated mass distribution of the fallout, with particle size distributions at the positions shown. Most of the fallout in Test 6 was between 1-1/2 and 2-1/2 feet from the center compared to 1 to 2 feet for Tests 7 and 8 and the earlier Test 4. The particle size distributions show a decrease in mean particle size with increasing distance from the center which was noted in Test 4. Figure 7 shows the comparison of cumulative particle size distribution for all the collected fallout samples. The drop size for Tests 6, 7, and 8 was somewhat smaller than that in Test 4. The mean size for Tests 6, 7, and 8 was 0.15 in.

2. Comparison of Sodium Droplet Model with Sodium Jet Tests in LTV

The results of one of the sodium jet tests, Test 4, have been compared with the results obtained from the sodium droplet heat transfer model, NALTV. This model now permits the incorporation of a distribution of droplet diameters in the heat transfer calculations. In this analysis, the droplet size distribution obtained experimentally in Test 4 was used. The distribution is given in Table 3.

Test 4 had effectively 0% oxygen concentration in the test vessel. The analytical results are presented along with the experimental data for the vessel pressure rise as a function of time in Figure 8. The analytically predicted

4-28-72

9005-4505

Figure 6. Distribution of Fallout with Selected Size Distributions, Jet Test Nos. 7 and 8

Figure 7. Cumulative Mass Distribution of Fallout Material at Stated Oxygen Atmospheres

4-28-72

9005-4507

Figure 8. Vessel Pressure vs Time

TABLE 3
EXPERIMENTAL SODIUM DROPLET DISTRIBUTION
FOR TEST No. 4

Mean Droplet Diameter (in.)	% of Mass
0.045	9.0
0.085	2.0
0.105	3.0
0.12	3.0
0.145	5.0
0.175	6.0
0.593	72.0

pressure rise of 0.81 to 0.94 psi compares reasonably with the experimental value as noted in the following discussion. Analytical calculations were performed for initial sodium temperatures of 1000 and 880°F because, although initially the sodium temperature as determined by the thermocouples in the test vessel piping was fixed between 985 and 1000°F, the response of a thermocouple attached to the impact plate indicates a temperature of only 880°F. There is, therefore, some uncertainty in this initial sodium temperature, and the analytical results are intended to bracket the real temperature. The delay in the rise rate of the experimental curve can be explained by consideration of energy transfer from the sodium to the steel impact plate. The energy in the plate is significant even though a 0.005-in. plate was used to limit the energy loss. In fact, if the amount of energy to raise the impact plate temperature to 880°F is determined, this corresponds to all the energy of the sodium jet that was calculated to be transferred to gas for the initial 1.4 sec of spray. This then accounts for the apparent delay in the experimental pressure rise curve. Also the energy transferred to the plate was not effectively available to the LTV if all of the plate were heated to 880°F. This loss amounts to about 0.13 psi.

The analytical results were based upon a spray volume fraction of 0.5. This value was calculated assuming that the sodium jet breaks up and leaves the impact plate in a parabolic trajectory, and it was further assumed that the sodium droplets dispersed throughout the parabolic envelope. Visual observations made

Figure 9. Peak Pressure vs Volume Fraction

Figure 10. Peak Pressure vs Drop Diameter

during the experiment seem to indicate that a conical region in the center of the vessel receives very little spray actually and, as is seen in Figure 9, where spray volume fraction is plotted vs peak pressure rise, a decrease in spray volume fraction results in smaller pressure rise. It can be noted from Figure 9 that the effect is small for the low sodium-to-gas ratio of the test. That is, if the volume fraction is reduced from 0.5 to 0.1, the peak pressure rise will be reduced by only approximately 12% to 0.83 psig.

In the droplet distribution used in this analysis, 72% of the mass is comprised of droplets with diameters from 0.186 to 1.0 in. and is represented by a mean diameter of 0.593 in. To determine whether this gross grouping of mass has any significant effect, this fraction of mass was broken into three equal divisions of mass of 24% each with mean diameters of 0.32, 0.60, and 0.88 in., respectively. The results obtained analytically showed less than a 5% increase in peak pressure, illustrating that the mass associated with the smaller droplet sizes is dominant.

Analytical results were also obtained assuming that the sodium mass was characterized by a mean droplet diameter. The results of this analysis are presented in Figure 10. It is seen that an effective mean diameter of 0.24 in. results in the same pressure rise as the droplet distribution. Also Figure 10 shows the large sensitivity the vault pressure has to drop size.

The discrepancy between analytical results and experimental results may be due to several considerations. First, the volume fraction used in the calculations is likely too large. A more detailed investigation of the sodium dispersal shape would be required to adjust this value. Finally, the model assumes a infinite thermal conductivity for the droplets which results in higher than actual heat transfer to the gas. Later developments of the model will account for internal energy distributions within the droplets. This work has commenced and a calculational routine has been developed to perform this function. It remains to incorporate this work into the model.

2. Models of Jet Hydrodynamics

The numerical hydrodynamics code ZUNI, previously acquired, was converted from operation on the CDC computer at Los Alamos to that at LRL, Berkeley, and successfully checked out. Since the code did not admit inflow of

liquid from below, the study of the impact of a jet on a ceiling was attempted with a liquid column of finite length substituted for the jet, but it soon appeared impossible to provide a column long enough to permit an approach to anything like a steady state. The code was therefore modified to admit inflow from below, and the modified version was checked out on a problem that could be done by either version.

The problem selected for the first round of calculations with ZUNI was that of a water jet leaving a nozzle 1 in. in diameter at 10 ft/sec and rising a few inches before striking a ceiling. This choice was made because its Reynolds number, which was 7.75×10^4 for the water viscosity of one centipoise, was the smallest that was encountered among the cases for which extensive experiments had been made, and it was hoped that this property would minimize numerical instabilities in the calculations. Moreover, the experiments seemed to show that the jet forms a simple sheet on the ceiling in that case, whereas with larger or faster jets, part of the liquid is lost from the sheet by splashing. While the splashing process is perhaps the most interesting subject for numerical investigation because of its analytical intractability, it was considered best to simplify the initial calculations by avoiding it.

The calculations were carried out in cylindrical coordinates within a radial section bounded on the left by the center line of the jet and on the top by the ceiling. The lower boundary was at the level of the nozzle, and the right boundary was a limiting radius equal to twice the jet diameter, or 2 in. The cell dimensions of the spatial grid used for digitalization, and the length of the time step between calculated flow states, were varied from case to case. All times are specified in terms of a standard unit of 0.00417 sec.

The output of ZUNI, produced for pre-selected times, includes a printed table showing for each cell of the grid whether it contains liquid, and, if so, giving its velocity. More interesting is the graphic output, consisting of two graphs, one showing the distribution of the liquid, and the other the velocities in the cells that contain liquid. The second graph thus contains the same information as the printed output, but the first has additional information, as it defines the free surface of the liquid more accurately than the cells do.

Figure 11 presents the graphs for a calculation of the problem as described above in which gravity was omitted: the height was 3.2 in., the cell was 0.1 in. on a side, and the time step was 0.005 units. The first pair of graphs is for the initial state, with the jet about to hit the ceiling. Later pairs, for 1.5 and 5.0 time units, show the sheet spreading out on the ceiling until it fills the computing region, and also show the appearance and subsequent spreading and amplification of notable irregularities of surface configuration and velocity distribution. The graphs at 5.0 time units show quite violent irregularities, and this growth continued thereafter and terminated the calculation before it could reach 6.5 time units.

The irregularities correspond to an instability that is not very surprising, since the Reynolds number 7.75×10^4 corresponds to a turbulent flow. This instability can be avoided by using a sufficiently large viscosity, thus reducing the Reynolds number. Current work is directed toward extracting significant results from calculations with unrealistic viscosity values. Hopes for achieving this are based in part on the idea that there may be a viscosity value for which the calculation is stable, yet for which viscous losses are small for liquid that has not spread too far from the jet; and, in part, on the fact that a steady irrotational flow satisfies the equations of motion for all viscosity values.

B. UO_2 AEROSOL TESTS

1. UO_2 Arc Vaporization Generator Tests

An improved generator system was designed to obtain better arc time-release rates whereby the new arc vaporization technique would enable UO_2 aerosol tests to be successfully performed in the LTV. The tests performed during this report period were to assess the current-voltage-time ratios for maximum UO_2 release. The problem involved was to determine the current-voltage-time settings which would enable the UO_2 to be heated and made conductive before the tungsten strike pin in the UO_2 was vaporized away. Successful tests were conducted starting with a current of 50 amp for initial heating, and increasing the current in steps of 50 amp until the desired current was obtained. The current setting and arc time are dependent on the allowable temperature of the electrode holder, steel pot, and electrode consumption.

LIQUID
DISTRIBUTION

LIQUID
VELOCITY

$t = 0$

$t = 1.5$

$t = 5.0$

4-28-72

9005-4510

Figure 11. Impinging Jet Problem

The tests demonstrated that a 20-min vaporization period was possible with current settings of greater than 200 amp.

2. Arc-Vaporized UO₂ Aerosol Tests in LTV

A UO₂ aerosol test was performed in the LTV using three arc generators and three welder power supplies. A 6-ft² heated pan was used to induce a stirred environment. Analysis of the suspended concentration and observation of the contents of the steel pot after the test indicated that only one of the power supplies performed as commanded, resulting in a maximum concentration of 4 µgm/cc or 1/3 the expected aerosol concentration. The two power supplies which failed are being replaced by the type (or equivalent) used during the LTC tests which has an improved current start control.

The peak concentration as shown in Figure 12 occurred in approximately 8 min and dropped by a factor of 10 in 120 min and a factor of 100 in 540 min.

The deposition rate was approximately 20% less near the top of the vessel as compared to that for the floor.

C. LARGE SCALE SODIUM POOL BURNING TESTS

1. Two-Cell Test Planning

A two-cell test assembly was designed for installation in LTV to model the FFTF Vault-Containment 2-Cell Geometry. The design was based on an approximate 1/10 linear scale, as shown in Table 4. These parameters were used in SOFIRE II - 2-cell model calculations for 1.5×10^5 and 3.5×10^4 lb sodium spill in the FFTF vaults and 160- and 40-lb sodium spill in the LTV experiment. Table 5 lists some of the computed values for mass and thermal conditions. The computed sodium burning rates are lower for the LTV cases. This is due to the higher gas temperatures which develop in the cell gas volume immediately after the sodium spill, since the burning rate is dependent on the temperature difference between sodium and gas.

The ventilation and pressure conditions are lower for LTV. Additionally, the volumes in the secondary and cell of LTV are such that the oxidation process is oxygen limited and both 160- and 40-lb sodium fires consume all the oxygen before the sodium is completely burned. The rapid reduction in oxygen content keeps the system pressure low, and actually the pressure can go below

TABLE 4
GEOMETRICAL PARAMETERS

Parameter	FFTF	LTV
Secondary Volume (ft ³)	1.31×10^6	1.46×10^3
Cell Volume (ft ³)	2.96×10^4	34.3
Sodium Burn Area (ft ²)	825	9.16
Vent Diameter (ft)	10.0	1.5 or 0.75
Vent Thickness (ft)	7.5	1.0 or 0.33
Secondary Wall Thickness (in.)	1.0	0.25
Secondary Wall Insulation (in.)	2.5	2.0
Cell Liner Thickness (in.)	0.25	0.125
Cell Wall Insulation (in.)	60	2.0

4-28-72

9005-4511

Figure 12. Aerosol Concentration Test UAM 72-1

AI-AEC-13026

TABLE 5

COMPUTED MASS AND THERMAL PARAMETERS FOR FFTF CASES AND LTV SIMULANTS

Sodium Spill (lb)	FFTF		LTV							
	1.5×10^5	3.5×10^4	160	160	160	160	40	40	40	40
Vent Diameter (ft)	10.0	10.0	1.5	1.5	0.75	0.75	1.5	1.5	0.75	0.75
Vent Thickness (ft)	7.5	7.5	1.0	0.33	1.0	0.33	1.0	0.33	1.0	0.33
Peak Sodium Burn Rate (lb/hr-ft ²)	3.05	2.95	2.35	2.38	2.2	2.17	2.0	2.0	1.6	1.4
Peak Velocity in Vent (ft/sec)	5.54	5.49	1.83	1.32	1.57	1.12	1.86	1.36	1.72	1.24
Time, Peak Exchanger Rate (hr)	7.0	3.0	1.5	1.5	2.0	2.5	2.0	1.0	1.75	2.5
Peak Gas Temperature in Cell (°F)	520	476	710	730	810	815	690	760	940	990
Time of Peak Cell Temperature (hr)	14.0	7.0	2.0	2.0	3.5	3.5	1.25	1.50	2.5	3.5
Peak Gas Temperature in Secondary (°F)	250	206	168	155	115	110	170	160	125	115
Peak Pressure in Secondary (psig)	2.0	1.55	0.55	0.37	0.096	0.087	0.89	0.74	0.25	0.17
Time of Peak Secondary Temperature (hr)	30.0	23.0	5.0	6.0	8.0	11.0	3.5	5.0	7.5	10.0
Time of Peak Pressure (hr)	17.0	6.0	1.5	1.5	<0.10	<0.10	1.5	1.5	1.0	0.5
Cell Exchange Time Concentration (sec ⁻¹)	9.4×10^{-3}	9.4×10^{-3}	4.5×10^{-2}	3.4×10^{-2}	1.0×10^{-2}	7.2×10^{-3}	4.8×10^{-2}	3.5×10^{-2}	1.1×10^{-2}	8.0×10^{-3}

Figure 13. Correlation of Model Results for Nusselt No., Grashof No., and H/L

atmospheric. This problem area will be further evaluated before tests are initiated. However, in order to confirm the scaling effect, a correlation between the Nusselt and Prandtl numbers, normalized for the vent thickness-to-vent diameter ratio and the Grashof number was made according to the method of Brown.⁽¹⁾

$$\text{Nusselt Number} = \text{Nu}_H = \frac{1/2 \bar{\rho} C_p H V}{K}$$

$$\text{Prandtl Number} = \text{Pr} = \frac{C_p \mu}{K}$$

$$\text{Grashof Number} = \text{Gr}_H = \frac{\Delta \rho g H^3}{\bar{\rho} \nu^2}$$

where:

$\bar{\rho}$ = mean density between two compartments (lb/ft³)

C_p = average heat capacity (Btu/lb-°F)

H = thickness of vent (ft)

V = gas velocity in vent (ft/hr)

K = thermal conductivity (Btu/hr-ft-°F)

μ = viscosity (lb/ft-hr)

$\Delta \rho$ = density difference (lb/ft³)

g = acceleration due to gravity (ft/sec²)

ν = kinematic viscosity (ft²/sec)

L = diameter of vent (ft).

Figure 13 compares the normalization parameters from the SOFIRE II - 2-cell calculations to the theory. The agreement is good. It can be seen that the correlation is insensitive to four-fold variations in the quantity of sodium or to two-fold variations in the vent diameter but is very sensitive to variations in the vent thickness. This effect can also be seen by comparing the peak gas exchange rates in Table 5. The data show that varying the vent diameter for a

given sodium spill or varying the size of the sodium spill for a given vent diameter does not change the rate as much as varying the vent thickness.

The test configurations needed to simulate the FFTF geometry have been designed based on these calculations (see Table 4).

IV. EVALUATION OF EFFORT TO DATE

Significant progress has been made in understanding the pressurization of a vault in which a large sodium pipe ruptures. The behavior of jets impinging on the ceiling is being investigated both experimentally and analytically. From these early experiments and analyses, estimates have been made of the fallout behavior and drop sizes for use in an analytical model of sodium droplet heat transfer. This model has allowed preliminary conservative estimates of the pressure rise expected in the LMFBR vaults following a hypothetical pipe rupture accident. Additional sodium splash-dispersal tests resulted in further improvements in the model by showing the need to represent several drop sizes simultaneously. This will permit better evaluations of the LMFBR hypothetical pipe rupture accident including sensitivity evaluations. The results from the particle in cell hydrodynamics code (ZUNI) are encouraging in that necessary modifications to simulate a continuously flowing jet have been successful and the initial impact flow behavior is as would be expected. More work is necessary to obtain valid stable long time flow behavior however. When this is accomplished, along with supporting analytical and experimental work, it should be possible to predict the volume of a given vault that will be swept out by the sodium spray. Or conversely, how design features, such as ceiling webs, might be added to limit the vault pressurization.

Some key requirements of the supporting experimental work have been identified. These include the need for full-scale jet impingement tests, since the analytical results to date indicate a significant difference in the hydrodynamics behavior between small jets and large jets, the need to make more detailed measurement of droplet size distribution as a function of space, and the determination of the volumes swept out by the various spray distributions.

Some of the main areas for analytical work have also been identified, and these include incorporation of the more detailed thermal droplet model, verification of the sodium oxidation rate, accounting for multiple spray gas volume as well as multiple droplet sizes, and free and forced gas convection. It is expected that this approach will provide verified analysis methods for predicting the pressure rise in LMFBR primary heat transfer system vaults following hypothetical pipe rupture accidents.

The comparison of two-cell sodium pool fire tests predicted behavior in LTV and FFTF accident cases to be simulated has provided a good basis for interpreting and correlating test results with predicted results for FFTF pool fire accidents, and SOFIRE II validation assessment.

V. NEXT REPORT PERIOD ACTIVITIES

Additional comparisons will be made between the LTV sodium jet test data and the current sodium droplet model.

One additional UO_2 aerosol test and one mixed UO_2 - sodium oxide aerosol test will be performed in the LTV.

Two-cell sodium pool fire test preparation will be completed and testing initiated.

Draft reports of test results and code descriptions will be prepared for sodium pool fires and aerosol studies.

REFERENCE

1. Brown, "Natural Convection Through Rectangular Openings in Partitions-2," Int. J. Heat Mass Trans 5, 869 (1962)