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QUARTERLY TECHNICAL PROGRESS REPORT
NUCLEAR SAFETY
CHARACTERIZATION OF SODIUM FIRES
AND
FAST REACTOR FISSION PRODUCTS
JULY — SEPTEMBER 1975

ERDA Research and Development Report

*Prepared for the United States
Energy Research and Development Administration,
Division of Reactor Research and Development,
under Contract Number AT(04-3)-824*

Rockwell International

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$4.00 Microfiche \$2.25

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The preceding Progress Report was AI-ERDA-13155.

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CONTRACT: AT(04-3)-824
ISSUED: NOVEMBER 15, 1975

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Program: Characterization of Sodium Fires and Fission Products			
ERDA Task: Task 10 — Characterization of Sodium Fires and Fission Products			
Program Manager: R. W. Keaten		Project Manager: H. A. Morewitz	
Reporting Period: July-September 1975		Category: HN-70-01-00.0	
General Order: 09005	Subaccount:	12200, 13100, 13200,	189a Number: SA-002
		14120, 15100, 15200,	
		18000	

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I. PROJECT OBJECTIVES

- 1) Develop a computer program for calculating two-dimensional, transient natural convection phenomena such as those arising from various sodium spill accidents in LMFBR heat transfer equipment vaults, head compartments, containment buildings, and secondary heat transfer systems.
- 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 REPORT PERIOD

A. SUBTASK A – SODIUM JET DISPERSAL TESTS

1. Stationary Sodium Drop Tests

The burning characteristics of a single drop of sodium were determined under various test conditions in the Laboratory Drop Modeling test apparatus (LDM). The LDM consisted of an acrylic plastic pipe 30-cm diameter and 1.8

TABLE 1
STATIONARY DROP BURNING TEST SUMMARY

Test Number	LDM Humidity (ppm)	Initial Sodium Drop Weight (gm)	Initial Preheat Temperature (°C)	Sodium Drop Volume at 888°C (cc)	Theoretical Diameter at 888°C (cm)	Release Fraction (wt %)	Na ₂ O ₂ in Released Aerosol (%)	Burning Rate (gm/sec x 10 ⁻³)	Surface Temperature* (°C)	Observed Temperature Drop During Burning** (°C)
8	11,200	0.174	427	0.235	0.766	87.3	-	8.5	1358	893
9	12,000	0.113	427	0.153	0.664	87.8	-	7.2	-	899
11	12,000	0.129	427	0.176	0.695	87.6	-	8.3	1302	899
12	14,000	0.130	427	0.175	0.695	90.7	-	179.0†	-	-
13	14,000	0.146	427	0.197	0.723	88.4	-	36.5	-	898
14	13,800	0.128	427	0.174	0.692	89.6	-	313.0†	-	888
15	3,600	0.087	427	0.118	0.609	44.3	100	3.6	1140	854
16	2,100	0.128	427	0.174	0.692	79.9	-	0.05	1225	793
17	620	0.223	427	0.301	0.832	79.0	-	1.3	1181	882
18	620	0.186	427	0.251	0.783	79.6	-	0.95	1245	882
19	620	0.166	427	0.225	0.755	68.5	-	6.8	1245	882
20	620	0.124	427	0.169	0.686	74.3	-	6.1	1307	860
21	620	0.092	538	0.125	0.620	-	71.2	4.3	1100	893
22	620	0.125	538	0.169	0.686	75.6	85.2	7.9	1217	882
23	620	0.099	538	0.133	0.634	-	86.3	-	-	885
24-28§	10,000	-	-	-	-	-	-	8.4	-	-

*Surface temperature measured with optical pyrometer.

†Forced convection supplied by fan.

**Sodium drop temperature measured with imbedded thermocouple

§Burning rate obtained from high-intensity back-illuminated movie

meters long to accommodate the stationary drop preheat and holding fixture. A total of 24 stationary sodium drop burning tests were conducted. From these tests, it was observed that the burning rate was relatively consistent for both high and low humidity 21 vol % O_2 tests (0.008 gm/sec) with a slight dependency of combustion product release fraction as a function of humidity (88.5% at humidities $>10,000$ ppm, and 76.1% at humidities $<1,000$ ppm). As the air recirculation around the stationary drop was changed from natural to forced, it was observed that the burning rate increased by a factor of 40 (Table 1). Three drop burning tests conducted in $<1,000$ ppm humidity air atmosphere exhibited low burning rates which were attributed to inert gas buildup within the LDM column.

As the humidity within the LDM column was decreased to $<1,000$ ppm, it was observed that the release fraction (the quantity of sodium released as Na_2O or Na_2O_2 as an aerosol from the burning sodium drop) decreased from a nominal 88% to 76%. It was also observed during these low humidity tests that the ratio of the combustion product species was $\sim 85\%$ Na_2O_2 (which is comparable to previous sodium jet spray test results).⁽¹⁾

The characteristics of burning sodium drops in a 21 vol % O_2 atmosphere were determined using standard, infrared, Schlieren, and intense back-illumination photography. From these different types of photography: (1) the flame front was defined, (2) the thickness on the flame was determined, (3) the temperature of the sodium flame was optically measured, (4) the aerosol production region and vaporization region were defined, and (5) the burning rate, in terms of gm/sec, was determined.

A nichrome wire heating element was positioned in the field of view (inside the LDM test apparatus) of both an optical pyrometer and an infrared movie camera to provide a calibrated heat source for the infrared movies. Measurements obtained from these instruments confirmed the thermocouple data which indicated that the sodium drops were at boiling temperature ($883^\circ C$) during combustion.

2. Falling Sodium Drop Tests

The falling sodium drop tests were conducted in the LDM test apparatus with two height configurations, 3.9 and 5.5 meters, to determine the burning rate of sodium drops in a 21% air atmosphere containing $\geq 10,000$ ppm water vapor. Still

Figure 1. Streak Photograph of Burning Sodium Drop in 3.9 m LDM Test

9005-40104

Figure 2. Streak Photograph of Burning Sodium Drop in 5.5 m LDM Test

9005-40105

photographs were taken of the sodium drop to determine its initial size upon release from the preheat tube. Each drop was preheated to 430-480°C prior to release. The still photographs indicated that the average size of each drop was 0.76-cm diameter.

To determine the point or elevation that ignition of falling drops occurred, streak photography was employed. With both the 3.9- and 5.5-meter LDM tests, it was observed that ignition of the drop started after the drop had fallen 0.6 meters and became fully ignited after falling 2.5 meters. Figures 1 and 2 show typical streak photograph results of falling sodium drop tests conducted in the 3.9- and 5.5-meter LDM, respectively.

During each of the LDM tests, the falling sodium drop was captured in a dewar of LN₂. The size and mass of the unburned sodium were measured and, accounting for flight time, the burning rate was measured. From both the 3.9- and 5.5-m LDM tests, the burning rate of sodium in 21 vol % O₂ was determined to be 170 mg/sec. A test report was prepared summarizing the test series.⁽⁴⁾

3. Sodium Jet Support Tests for SOMIX

The Large Test Vessel (LTV) has been modified to a right circular cylinder, ~3 m high by 3 m diameter. The sodium preheat tank outlet nozzle was modified to produce a 5-cm diameter jet directed vertically at the ceiling centerline. Both a Test Plan and Test Procedure were prepared for the test series.^(2,3) Checkout of instrumentation lead wires and power control circuits has been completed.

B. SUBTASK C – SOMIX CODE DEVELOPMENT

SOMIX-1 was incorporated into the Lawrence Berkeley Computing Facility and its interactive time-share system. The necessary modifications required to make the code operational on the Berkeley CDC 6600-7600 computers were completed. A number of sample thermal convection and spray fire problems have been run and the code appears to be operational on the Berkeley computer.

SOMIX-1 was described in detail to GE personnel at the code information meeting held at GE, Sunnyvale, September 16. Background information on the finite difference approximations used in the code was presented and pertinent

publications relative to the makeup of the code were given to GE. The various control cards needed to activate the code were described for both spray fire and plate heating problems. A copy of SOMIX-1 and a sample spray fire problem have been transferred to the GE files at the Lawrence Berkeley Computer Facility.

SOMIX-1 was programmed for simulation studies of the LTV sodium jet tests in order to determine optimum thermocouple locations and establish instrumentation and gas pressurization requirements. Isothermal contours of the gas recirculation patterns obtained from these studies are shown in Figures 3 through 7. The LTV gas pressure history is shown in Figure 8.

Work on developing SOMIX-2 was continued. Finite difference approximations which are second order accurate in time and fourth order accurate in space have been incorporated into the program. Computational results of a case, Grashof number of 1×10^5 , compared very well with a previous SOMIX-1 run and with Torrance's work. Trial runs of SOMIX-2 are now being made for the previously calculated LTV sodium jet tests with the objective of extending the calculations to longer running times and more intensive spray fire situations, such as spray fires in air environments.

C. SUBTASK 10E - AEROSOL LEAKAGE

The top blind flange of the 61-cm ID by 148-cm high Aerosol Leakage Test Vessel was modified to accept five leak specimens and a sampling manifold for measuring vessel aerosol concentration and particulate size. A recording system was added such that each leak specimen could be monitored for gas flow rate and total volume. In addition, a pressure feedback system was installed to maintain a constant gas pressure across the leak specimens during the test.

The test specimens included smooth capillaries: 0.056 to 0.13 cm diameter by 3.8 cm, a split smooth capillary 0.1-cm diameter by 3.8 cm, and a split rough crack 1.27 cm by 3.8 cm. The split leak specimens were constructed so that the aerosol buildup in the leak path could be observed at the end of the test.

Visual observations indicate that smooth capillaries do not readily plug when exposed to a low humidity ($<4,000$ ppm). However, an agglomeration mechanism (presently undefined) produces agglomerates 50 to $1,000 \mu\text{m}$ in

TIME = 1.000000 SEC
 MIN = 299.999512 °K
 MAX = 392.885010 °K)

CONTOUR IDENTITY

1 306.520020	5 343.673340	9 380.826660
2 315.808350	6 352.961670	A 390.114990
3 325.096679	7 362.250000	B 399.403320
4 334.385010	8 371.538330	

9005-40106

Figure 3. Isotherm of LTV Test No.2-A

TIME = 2.016639 SEC
 MIN = 299.998291 °K
 MAX = 402.281484 °K

CONTOUR IDENTITY

1 306.848633	5 347.761719	9 388.674805
2 317.076904	6 357.989990	A 399.903076
3 327.305176	7 368.218262	B 409.131348
4 337.533447	8 378.446533	

9005-40107

Figure 4. Isotherm of LTV Test No.3-B

TIME = 3.003329 SEC

MIN = 299.997559 °K

MAX = 403.180420 °K

CONTOUR IDENTITY

1 309.545410	5 350.817871	9 392.090332
2 319.863525	6 361.135985	A 402.408447
3 330.181641	7 371.454102	B 412.726563
4 340.500000	8 381.772217	

9005-40108

Figure 5. Isotherm of LTV Test No. 4-C

TIME = 4.010099 SEC
 MIN = 300.000000 $^{\circ}\text{K}$
 MAX = 399.934082 $^{\circ}\text{K}$

CONTOUR IDENTITY

1 309.794678	5 349.767334	9 389.739990
2 319.787842	6 359.760498	A 399.733154
3 329.781006	7 369.753662	B 409.726318
4 339.774170	8 379.746826	

9005-40109

Figure 6. Isotherm of LTV Test No. 5-D

TIME = 4.986360 SEC

MIN = 300.000000 °K

MAX = 427.593750 °K

CONTOUR IDENTITY

1 306.222900	5 357.260010	9 408.297119
2 318.982178	6 370.019287	A 421.056396
3 331.741455	7 382.778565	B 433.815674
4 344.500732	8 395.537842	

9005-40110

Figure 7. Isotherm of LTV Test No.6-E

9005-40111

Figure 8. LTV Gas Pressure History

diameter at the capillary exit. As the humidity increases, the agglomerates become larger and plugging occurs in the leak path. When exposed to an environment of $\geq 8,000$ ppm, plugging tends to occur at the capillary entrance.

The data from two crack attenuation tests are shown in Table 2. These data indicate that for the type of cracks tested, the sodium oxide aerosol did not penetrate the leak paths. Photographs of the cracks show that the aerosol penetrated Crack A to a depth of ~ 1.5 cm and Crack B to ~ 0.5 cm.

D. SUBTASK F – FUEL AND FISSION PRODUCT RELEASE FROM BURNING SODIUM

Tests were conducted in a 25-liter chamber in which sodium containing 1 wt % U as sodium uranate was burned to completion. During these tests, 10 gm of the mixture was burned and the released aerosol collected on filters. After each test, the filters were exposed to CO_2 to form a sodium carbonate residue

TABLE 2
SODIUM OXIDE AEROSOL ATTENUATION BY PASSAGE
THROUGH ROUGH CRACKS

Crack* Type	Aerosol Concen- tration ($\mu\text{g/cc}$)	Humidity (ppm)	Gas [†] Volume (liter)	Aerosol Mass (mg)		
				Available [§]	Collected	
					Crack**	Filter ^{††}
A	0.95	4,000	7.65	7.27	1.6	0
B	10.0	14,000 to 7,400	1.02	10.0	1.9	0

*The crack characteristics are described in the gas flow equation:

$$Q = C_1 P + C_2 P^{1/2}$$

where

Q = flow rate (liters/min)

p = pressure differential (cm H₂O)

C₁, C₂ = leakage coefficients

Crack A: C₁ = 0.0058, C₂ = 0.09

Crack B: C₁ = 0.0083, C₂ = 0.115

[†]Volume of gas which passed through the crack before plugging

[§]Available mass (sodium oxide) is obtained by multiplying aerosol concentration by gas volume

**Mass of sodium (chemical analysis) found in the crack

^{††}Mass by weight

which prevented the formation of sodium hydroxide. Visual observations of the test apparatus indicated that some fraction of the released oxide plated out in the sampling manifold. No material was found on the floor and walls.

Two tests were conducted with the sodium and sodium uranate mixture and one test was conducted with sodium only as a control. During each test, 11 filter samples were taken in sequence in such a manner that approximately an equal amount of material was collected by each filter. Assuming 25% release fraction from a sodium fire, an average of 230 mg of sodium was collected by each filter.

Figure 9. Test Chamber for Burning Sodium Experiments

9005-40101

Each filter was analyzed for uranium by x-ray fluorescence. Samples from the sodium uranate tests were compared to the control samples (sodium oxide only) and in all cases this technique of analysis (within its limits of sensitivity) did not detect the presence of uranium. This leads to an estimate of the release fraction of uranate as $<10^{-3}$.

The apparatus used for these burning experiments is shown in Figure 9. The chamber consists of a base plate, top plate, and 25-cm diameter, 52-cm stainless steel cylinder. Inside the chamber is a heater, burn pan, aerosol collection funnel (mounted immediately above the burn pan) and gas diffusion nozzle. The diffusion nozzle is connected to the gas (dry air) inlet and the funnel outlet to the filters. A thermocouple is placed in the burn pan to monitor the sodium temperature.

A test plan was written for the PuO_2 release from burning sodium tests to be conducted at Rocky Flats.⁽⁵⁾ The test chamber shown in Figure 9 will be used for these tests.

E. SUBTASK I - AEROSOL SOURCE TERM FROM VAPORIZED FUEL

Previously, apparatus for exploding metallic wires in closed chambers had been constructed. The equipment consists of a capacitor bank, ignition switch, test chamber, and associated recording equipment.

Work has been proceeding in producing current discharges of controlled size, recording pressure data, and collecting the aerosols produced.

F. SUBTASK J - PROPERTIES OF HIGH TEMPERATURE FUEL MIXTURES

The purpose of this subtask is to study the interaction of molten UO_2 with sodium and stainless steel under conditions which would prevail during reactor overpower. UO_2 is used as a simulant for the mixed plutonium and uranium oxide fuel used in LMFBR's. Of particular interest is any expansion or foaming produced by molten fuel contacting stainless steel structural material in the reactor.

In previous tests, UO_2 has been melted in tungsten crucibles by induction heating. However, the vapor produced during the melting tended to escape the crucible and interfere with the induction melting process. To avoid this problem,

argon cover gas will be provided in the crucible while maintaining a vacuum outside the crucible. The argon suppresses evaporative losses; a vacuum is needed outside the crucible to reduce radiation losses.

Providing a cover gas inside a vacuum chamber is a considerable complication as the crucible must be sealed while allowing access for various manipulative instrumentation. A suitable design has been made, most of the needed apparatus acquired and assembly is in progress.

The tungsten crucible is now suspended from above by means of a thin-walled tube. The tube is attached at its upper end to an argon filled tank. Means are provided for forcing molten UO_2 out of the crucible into a secondary chamber where it may interact with stainless steel and/or sodium. Also, equipment for measuring viscosity, density, and surface tension is incorporated. Instrumentation includes an automatic pyrometer, temperature recorders, pressure indicators, and strain gage force measurement equipment. An on-line computer will also be provided to collect and record data during tests.

G. SUBTASK K - AEROSOL SOURCE FROM MFCI

Previously, a site at the Santa Susana test laboratory was selected for large scale UO_2 experiments. The site (Bldg 28, the former SNAP shield test reactor building) is being decontaminated at present. This work will be completed in January 1976, and the building made ready for occupancy. The building has adequate shielded space, radioactive exhaust system, and provisions for cooling water.

The means of melting UO_2 has been tentatively selected as arc melting in a water-cooled skull furnace. A large tilt pour arc melting furnace, previously used in UC melting at AI, has been acquired for this purpose. Other techniques for melting UO_2 are also being investigated. Direct resistance heating between tungsten electrodes is attractive, since it can be accomplished with transformer supplied alternating current, while arc-melting requires a controlled direct current supply.

III. NEXT REPORT PERIOD ACTIVITIES

Upon satisfactory completion of the SOMIX-2 revisions, the code will be put on the Berkeley computer and applied to long-time sodium fires in large heat transfer equipment vaults. Comparison studies of calculated spray fire data and the results of the LTV spray fire tests will be carried out. Full-scale LMFBR pipe rupture analysis will be initiated.

The 25-liter aerosol test chamber will be shipped to Rocky Flats and the Test Plan, "PuO₂ Release From Burning Sodium," N707-TP-130-018, will be implemented. A preliminary report will be written.

An investigation will be made of the release of I₂ from fuel rods following a loss of cladding integrity (LOCI). This test series is described in "Simulated Fuel Element Source Term Tests."⁽⁶⁾ These tests will assess the attenuation of carrier-iodine compounds when released with noble gases under a column of liquid sodium. These tests will determine if the carrier-iodine compound is carried into the cover gas region as the parent compound, and if decomposition and recombination into NaI occurs. The tests will be conducted in a 325-liter stainless steel vessel at 540°C.

The UO₂ aerosols produced by a condenser discharge apparatus will be characterized.

UO₂ will be melted under argon gas and contacted with stainless steel. Planning for large-scale UO₂ melting experiments will continue. Equipment will be acquired and tested.

IV. RECENT REPORTS

1. Staff, "Annual Technical Progress Report - LMFBR Safety Programs," GFY 1970, AI-AEC-12970 (August 15, 1970)
2. R. P. Johnson, C. T. Nelson, "Test Plan for Sodium Jet Dispersal Gas Recirculation Tests in the LTV," TP-707-130-016 (June 5, 1975)
3. R. P. Johnson, C. T. Nelson, "Test Procedure for LTV Gas Recirculation Tests for SOMIX," N707DTP130-007 (August 13, 1975)
4. R. P. Johnson, C. T. Nelson, "Test Report for the Sodium Splash Dispersal Stationary and Falling Drop Tests in LDM," N707TR130-010 (September 30, 1975)

IV. RECENT REPORTS (Continued)

5. R. P. Johnson, C. T. Nelson, H. A. Morewitz, "Test Plan to Subtask F, PuO₂ Release From Burning Sodium," N707TP130-018 (September 19, 1975)
6. R. P. Johnson, C. T. Nelson, "Test Plan for Simulated Fuel Element Source Term Tests," N707TP130-017 (September 18, 1975)