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REACTOR SAFETY
APRIL – JUNE 1979

DOE Research and Development Report

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Department of Energy,
Division of Reactor Research and Technology,
under Contract Number DE-AT-03-76SF74028*

MASTER

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CONTENTS

<u>Program</u>	<u>DOE Task No.</u>	<u>189a No.</u>	<u>Project Title</u>	<u>Page</u>
LMFBR Safety	28	SA048	AI LOA Integration Tasks, Subtask A	5
		SA048	AI LOA Integration Tasks, Subtask B	7
		SA046	AI LOA-3; WBS A3.1, Subtask A	9
		SA046	AI LOA-3; WBS A3.2, Subtask B	13
		SA047	AI LOA-4; WBS A4.1, Subtask A	15
		SA047	AI LOA-4; WBS A4.2, Subtask B	19

FIGURE

1. Optical Diameter vs Cumulative Mass Percent.

Program: LMFBR Safety			
DOE Task: Task 28, Reactor Safety — AI* LOA Integration Tasks, Subtask A			
Program Manager: R. J. Beeley		Project Manager: H. A. Morewitz	
Reporting Period: April - June 1979		Category:	
General Order: 09321	Budget Activity: AG-10-20-41-5	189a Number: SA048	

Principal Investigators: H. A. Morewitz, E. U. Vaughan, J. Mills

I. PROJECT OBJECTIVES

The project objectives are to provide the working group with licensing support, and to provide participation in SACRD as required.

II. ACTIVITY DURING REPORT PERIOD

Trips:

- April M. Heisler, J. Hartung, H. A. Morewitz attended the LOA-3 meeting at Sunnyvale. H. A. Morewitz, E. Specht, R. Paschal attended the LOA-2 meeting at Sunnyvale
- May H. A. Morewitz, J. Brittingham attended the NRC transition phase meeting at Silver Springs. H. A. Morewitz attended the SACRD meeting at Oak Ridge. J. Hartung joined the TMC office at ANL
- June J. Mills, J. Hartung, E. Vaughn participated in LOA 1, 2, 3 and 4 meetings with DOE and TMC. E. Vaughn presented a paper, coauthored with T. J. Hoffman ORNL, "An Evaluation of Stochastic Void Models for Bubble Worth Calculations," at the ANS annual meeting in Atlanta, GA.

*Atomics International (AI) Division of the Energy Systems Group (ESG) of Rockwell International.

Program:	LMFBR Safety		
DOE Task:	Task 28, Reactor Safety – AI LOA Integration Tasks, Subtask B		
Program Manager:	R. J. Beeley	Project Manager:	H. A. Morewitz
Reporting Period:	April - June 1979	Category:	
General Order:	09321	Budget Activity:	AG-10-20-41-5
		189a Number:	SA048

Principal Investigators: J. Hartung, C. J. Meisl

I. PROJECT OBJECTIVES

The project objectives are to conduct risk assessments and cost-benefit analyses as required.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1979

Program planning in the LOA-3 and LOA-4 areas has been established on a risk-based approach. Each task has been ranked according to its cost effectiveness in reducing risk.

III. PROGRESS DURING REPORT PERIOD

None. The task is essentially complete except for continuing surveillance of problems arising in the LMFBR Safety program.

IV. NEXT REPORT PERIOD ACTIVITIES

Risk assessment and cost benefit analyses will be updated as needed.

Program:	LMFBR Safety		
DOE Task:	Task 28, Reactor Safety — AI LOA-3; WBS A3.1, Subtask A		
Program Manager:	R. J. Beeley	Project Manager:	H. A. Morewitz
Reporting Period:	April - June 1979	Category:	
General Order:	09319	Budget Activity:	AG-10-20-41-3 189a Number: SA046
Task Title:	AI LOA-3 Tasks		
Subtask Title:	Energetics Effects of Sodium Spray Fires		

Principal Investigators: M. P. Heisler, K. Mori

I. SUBTASK A OBJECTIVES

Subtask A objectives are to provide a means of analysis of sodium spray fires in air atmospheres in confined spaces. A computer code, SOMIX-II, will be developed which will extend a previous code, SOMIX-I, to the air environment of the secondary heat transfer vault and the secondary containment envelope. Pressure rise is the principal variable to be calculated. The analysis is to be supported by experiments in sodium drop and spray burning.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1979

None.

III. PROGRESS DURING REPORT PERIOD

A sodium spray injection subroutine was developed to calculate the effect of sodium drop injection. This was done by adding a source term to the axial and radial sodium drop momentum, sodium mass, and number density equations.

The source term consists of the axial and radial convection for sodium injection in cylindrical coordinates. Input data for the sodium spray injection includes axial and radial drop velocities, axial and radial drop number densities, drop diameters, and temperatures.

All of the sodium drop equations for momentum, mass and number densities, temperature transport, drag force, injection, and combustion were combined into a 2-D transport program called TDDROP for check-out purposes. This program excluded the gas circulation routines to minimize the number of calculations. Preliminary check-out runs indicated that the cylindrical geometry of the test model was causing the computations to not conserve mass, particularly near the central axis. Also, the "upwind" finite differencing method used for the convection terms was introducing significant artificial diffusion (Eulerian mixing) and unwanted distortion of the spray configuration.

IV. NEXT REPORT PERIOD ACTIVITIES

SOMIX-II Code Development will be continued. Preparations for a drop burning experiment will be made. This test will be used to confirm the calculation.

REFERENCES

1. Amsden, A. A. and Harlow, F. H., "KACHINA: an Eulerian Computer Program for Multifield Fluid Flows," LA5680, December 1974

Program:	LMFBR Safety		
DOE Task:	Task 28, Reactor Safety — AI LOA-3; WBS A3.2, Subtask B		
Program Manager:	R. J. Beeley	Project Manager:	H. A. Morewitz
Reporting Period:	April - June 1979	Category:	
General Order:	09319	Budget Activity:	AG-10-20-41-3 189a Number: SA046
Task Title:	AI-LOA-3 Tasks		
Subtask Title:	Core Debris Accommodation — Ex-Vessel Retention in Reactor Cell		

Principal Investigators: C. A. Guderjahn

I. SUBTASK B OBJECTIVES

Subtask B objectives are to conduct tests that will determine the effect of molten core debris on underlying structural or sacrificial material. A large arc furnace is available for melting UO_2 and steel for this purpose.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1979

A recirculating cooling water system has been installed.

III. PROGRESS DURING REPORT PERIOD

The instrumentation and power control system has been improved.

IV. NEXT REPORT PERIOD ACTIVITIES

Methods of increasing pour size from 15 Kg to 35 Kg of UO_2 will be developed.

Program:	LMFBR Safety		
DOE Task:	Task 28, Reactor Safety — AI LOA-4; WBS A4.1, Subtask A		
Program Manager:	R. J. Beeley	Project Manager:	H. A. Morewitz
Reporting Period:	April - June 1979	Category:	
General Order:	09320	Budget Activity:	10-20-41-4
		189a Number:	SA047
Task Title:	AI-LOA-4 Tasks		
Subtask Title:	Attenuation in Faulted Containment: High Density Aerosol Depletion		

Principal Investigators: C. T. Nelson and E. U. Vaughan

I. SUBTASK A OBJECTIVES

The objectives for this subtask are to investigate mechanisms that will lead to rapid attenuation of aerosol within reactor containment, and to continue development of the HAA-3 Code in order to calculate the rate of depletion of high concentration aerosols.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1979

A technique for producing mixed UO_2 and sodium aerosols has been developed. Dense UO_2 aerosols are produced within the containment tank of a large arc furnace. The arc is turned off, and liquid sodium is sprayed into the crucible containing the molten UO_2 , where the sodium is vaporized. Sodium vapor then condenses on the previously produced UO_2 aerosol. A technique for analyzing aerosols using an elutriator has been developed.

III. PROGRESS DURING REPORT PERIOD

A. HIGH DENSITY AEROSOL INVESTIGATION

Two high density aerosol concentration tests were performed and analyzed for maximum aerosol concentration and particle size distribution as produced in the UO_2 arc melter. Results indicate that 93 to 97% of the mass of UO_2 aerosol particulates that entered the elutriator contained sizes ranging from 14 to 215 μm optical diameter. The remaining 3 to 7% which represents the percent

Figure 1. Optical Diameter vs Cumulative Mass Percent

respirable mass) comprise sizes ranging from 0.45 to 7.0 μm aerodynamic diameter. Aerosol concentrations obtained in the two tests range from 54 $\frac{\mu\text{g}}{\text{cc}}$ to 64 $\frac{\mu\text{g}}{\text{cc}}$. The mass of the samples was determined by X-ray fluorescence spectroscopy and the optical diameter by the use of a microscope.

The 50% mass of the aerosol as collected by the elutriator ranges from 60 to 64 μm optical diameter as shown by Figure 1.

B. HAA-3 DEVELOPMENT

Turbulence agglomeration and size-dependent collision efficiencies were added to the HAA-3B code. The models are those described in the October-December Quarterly Report. Work was initiated on addition of the size-dependent morphology correction described there also. Both CDC and IBM versions were produced. Checkout of added models is ~50% complete.

C. COMRADEX DEVELOPMENT

The improved model of plume depletion for a gravitating plume (described in Subtask B) was incorporated into the COMET code. Results are being examined.

IV. NEXT REPORT PERIOD ACTIVITIES

Mixed sodium and UO_2 aerosol tests will be conducted using the elutriator and turntable. HAA-3 development will continue.

Program:	LMFBR Safety		
DOE Task:	Task 28, Reactor Safety — AI LOA-4; WBS A4.2, Subtask B		
Program Manager:	R. J. Beeley	Project Manager:	H. A. Morewitz
Reporting Period:	April - June 1979	Category:	
General Order:	09320	Budget Activity:	AG-10-20-41-4
		189a Number:	SA047
Task Title:	AI-LOA-4 Tasks		
Subtask Title:	Attenuation in Environment - Aerosol Depletion During Atmospheric Transport		

Principal Investigators: R. P. Johnson, C. T. Nelson, J. Otter

I. SUBTASK B OBJECTIVES

Subtask B objectives are as follows:

- 1) Calculate the atmosphere release tests and compare analytical with experimental results. Make improvements in the computer codes as needed to better predict the behavior of any sodium combustion product aerosols released to the atmosphere following a hypothetical reactor accident.
- 2) Release sodium combustion product aerosols in the open atmosphere and determine rate and amount of fallout, change of chemical species, particle size, and behavior of plume.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1979

Further LOA-4 experiments, involving the release of sodium combustion product aerosols to the atmosphere, have been conducted at the Idaho National Engineering Laboratory (INEL). These tests* have investigated the behavior of the aerosols released by sodium spray fires under stable atmospheric conditions.

*These tests were conducted jointly with the Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration

III. PROGRESS DURING REPORT PERIOD

A. DEPLETION OF A TILTED GAUSSIAN PLUME BY GROUND DEPOSITION

Calculations made with the atmospheric dispersion code COMET* for comparison with atmospheric sodium release test results encountered difficulties with material conservation laws that suggested some inadequacy of the treatment⁽¹⁾ of ground deposition and plume depletion by the code. This treatment used a form of the "source-depletion" model⁽²⁾ of plume depletion, modified for application to plumes "tilted" to account for gravitational settling of the particles constituting the plume. While the source-depletion model is not exact, it is intended to satisfy conservation laws exactly, and its failure to do so was disconcerting. The resulting investigation has indicated that at least part of the difficulty is associated with mesh resolution and numerical methodology, but it has also confirmed that the application of the source-depletion model to tilted plumes in COMRADEX-IV⁽¹⁾ was not quite correct.

The tilted Gaussian plume, uncorrected for deposition, can be written

$$\psi(x,y,z) = \frac{Q}{2\pi\bar{u}\sigma_y\sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left[-\frac{(z-h+wx/\bar{u})^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h+wx/\bar{u})^2}{2\sigma_z^2}\right] \right\} \quad \dots(1)$$

where

$\psi(x,y,z)$ = concentration in plume at distances x downwind and y crosswind from the source and elevation z above the (horizontal) ground,

Q = strength of point source at elevation h ,

$\bar{u}$ = mean wind speed,

*COMET is the single (nonradioactive) isotope version of COMRADEX-IV tailored to evaluate the meteorological transport of sodium combustion aerosols.

w = settling speed of particles in plume,

$\sigma_y(x), \sigma_z(x)$ = empirical dispersion parameters of the plume, reflecting current local meteorological conditions.

The two terms of the curly bracket correspond to a "real" plume and an "image" plume, which together would produce a distribution symmetric about the ground in the absence of the tilt. This represents a reflection boundary condition at the ground, corresponding to the absence of ground deposition at this stage of the formulation.

However, the tilting of the plumes also tilts the plane of symmetry which thus no longer coincides with the ground. To avoid this by tilting the image plume upward is impossible since part of this plume is above ground and must settle downward like the real plume. The image plume in the presence of settling thus fails to represent a reflection boundary condition at the ground. Since, however, the settling speed, w , is commonly much smaller than the wind speed, $\bar{u}$, and the tilt angle is consequently small, this failure is relatively small, and the image plume worth retaining. It is practically inescapable anyway, since it is used in the semi-empirical analysis that provides the function $\sigma_y(x)$ and $\sigma_z(x)$.

Since the boundary condition at the ground can no longer be treated simply by symmetry, a more general approach is needed. The basis for such an approach is the recognition that the "real" and "image" plumes of Equation (1) are infinite-medium point-source solutions of the convective-diffusion equation

$$\bar{u} \frac{\partial \psi}{\partial x} - \bar{u} \sigma_y \sigma_y' \frac{\partial^2 \psi}{\partial y^2} - w \frac{\partial \psi}{\partial z} - \bar{u} \sigma_z \sigma_z' \frac{\partial^2 \psi}{\partial z^2} = 0, \quad \dots(2)$$

where the primes represent differentiation with respect to x . In fact, direct substitution of ψ from Equation (1), or either of its two terms, into Equation (2) will verify that it is a solution. It follows that the treatment of ground deposition and plume depletion can be formulated as a boundary-value problem for the partial differential equation (2).

To do this still requires a boundary condition at the ground surface. The vertical current at the ground implied by Equation (2) is

$$J_{z0}(x,y) = - \left[\bar{u} \sigma_z \sigma_z' \frac{\partial \psi}{\partial z} + w \psi \right]_{z=0} \quad \dots(3)$$

The effect of ground deposition is to produce a net current into the ground given by

$$J_{z0}(x,y) = - (v + w) \psi(x,y,0), \quad \dots(4)$$

where the new coefficient v is the so-called "deposition velocity" used to represent the "dry deposition" mechanisms to which the settling deposition must be added. Equating these two expressions gives the boundary condition as

$$\bar{u} \sigma_z \sigma_z' \frac{\partial \psi}{\partial z} = v \psi \text{ at } z = 0 \quad \dots(5)$$

Solution of Equation (2) with the boundary condition of Equation (5), though now a well-defined problem, is quite intractable. An approximate solution can be obtained, however, by the "source-depletion" method, in which the plume is represented in the form

$$\bar{\psi}(x,y,z) = Q'(x) \psi(x,y,z)/Q, \quad \dots(6)$$

where

$\bar{\psi}$ = concentration in depleted plume of Equation(2)

ψ = concentration given by Equation (1)

$Q'(x)$ = modified ("depleted") effective source strength.

Then Equation (5) can be satisfied exactly and Equation (2) approximately by taking $\bar{Q}(x)$ as

$$Q'(x) = Q'(0) \exp \left[- \frac{v}{u} H(x) + h \sigma_z \sigma_z' K_-(x) - \frac{w}{u} \sigma_z \sigma_z' K_+(x) \right], \quad \dots(7)$$

where

$$H(x) = \sqrt{\frac{2}{\pi}} \int_0^x \frac{ds}{\sigma_z^3(s)N(s)} \cosh \left(\frac{w}{\bar{u}} \frac{hs}{\sigma_z^2(s)} \right) \exp \left(- \frac{h^2 + w^2 s^2 / \bar{u}^2}{2\sigma_z^2(s)} \right), \quad \dots(8)$$

$$K_-(x) = \sqrt{\frac{2}{\pi}} \int_0^x \frac{ds}{\sigma_z^3(s)N(s)} \sinh \left(\frac{w}{\bar{u}} \frac{hs}{\sigma_z^2(s)} \right) \exp \left(- \frac{h^2 + w^2 s^2 / \bar{u}^2}{2\sigma_z^2(s)} \right), \quad \dots(9)$$

$$K_+(x) = \sqrt{\frac{2}{\pi}} \int_0^x \frac{sds}{\sigma_z^3(s)N(s)} \cosh \left(\frac{w}{\bar{u}} \frac{hs}{\sigma_z^2(s)} \right) \exp \left(- \frac{h^2 + w^2 s^2 / \bar{u}^2}{2\sigma_z^2(s)} \right), \quad \dots(10)$$

and

$$N(x) = 1 + \frac{1}{2} \left[\operatorname{erf} \left(\frac{h-wx/\bar{u}}{\sqrt{2}\sigma_z(x)} \right) - \operatorname{erf} \left(\frac{h+wx/\bar{u}}{\sqrt{2}\sigma_z(x)} \right) \right], \quad \dots(11)$$

with

$$\operatorname{erf}(q) = \frac{2}{\sqrt{\pi}} \int_0^q dp \exp(-p^2), \quad -\infty < q < \infty. \quad \dots(12)$$

Equations (6) - (12) constitute the corrected formulation of the source-depletion method for tilted Gaussian plumes. The integrals in Equations (8) - (10) must be evaluated numerically. The corrected formulation has been used in an improved version of COMET.

IV. NEXT REPORT PERIOD ACTIVITIES

The improved COMET Code will be run and compared with results of the sodium releases at INEL.

REFERENCES

1. J. M. Otter and D. K. Chung, "Description of the COMRADEX-IV Code," N707TI130047, September 1977
2. I. Van der Hoven, "Deposition of Particles and Gases," in Meteorology and Atomic Energy — 1968 (D. Slade, Editor), TID-24190, USAEC, July 1968