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METHODS FOR NUCLEAR AIR CLEANING SYSTEM ACCIDENT CONSEQUENCE ASSESSMENT

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Abstract

This paper describes a multilaboratory research program that is directed toward addressing many questions that analysts face when performing air cleaning accident consequence assessments. The program was initiated by the United States Nuclear Regulatory Commission and involves three laboratories, Oak Ridge National Laboratory, Pacific Northwest Laboratory, and Los Alamos National Laboratory. The program involves developing analytical tools and supportive experimental data that will be useful in making more realistic assessments of accident source terms within and up to the atmospheric boundaries of nuclear fuel cycle facilities. The types of accidents considered in this study include fires, explosions, spills, tornadoes, criticalities, and equipment failures.

The main focus of the program is developing an accident analysis handbook (AAH). We will describe the contents of the AAH, which include descriptions of selected nuclear fuel cycle facilities, process unit operations, source-term development, and accident consequence analyses. Three computer codes designed to predict gas and material propagation through facility air cleaning systems are described. These computer codes address accidents involving fires (FIRAC), explosions (EXPAC), and tornadoes (TORAC). The handbook relies on many illustrative examples to show the analyst how to approach accident consequence assessments. We will use the FIRAC code and a hypothetical fire scenario to illustrate the accident analysis capability.

I. Introduction

The Nuclear Regulatory Commission (NRC) is responsible for ensuring that nuclear fuel cycle facilities are designed and operated in a safe manner so that the release of radioactive material under both normal and accident conditions will not result in unacceptable radiological effects on the surrounding population and the environment. To meet its regulatory responsibility, the NRC's licensing staff evaluates safety analyses submitted in support of an application for a fuel cycle facility license or license amendment. To perform these evaluations and analyze the effects of proposed regulatory requirements, the NRC staff needs accident analysis methods that can provide realistic assessments of accident-induced facility source terms. The analysis methods currently being used in these evaluations are based on conservative assumptions, and there is a need to develop improved analysis techniques. In response to this need, the NRC's Office of Nuclear Regulatory Research has initiated a research program with certain Department of Energy Laboratories to develop improved techniques for analyzing the consequences of major accidents at light water reactor (LWR) fuel cycle facilities. These laboratories are Los Alamos National Laboratory, Battelle Pacific Northwest Laboratory, and Oak Ridge National Laboratory.

The scope of the research program includes most of the LWR fuel cycle facilities. It does not address accidents at nuclear reactors, uranium mining and milling facilities, or nuclear waste repositories. The types of accidents being investigated are fires, explosions, tornadoes, and spills to be followed by criticality accidents and equipment failures. The scope of the program is limited to providing methods for determining the facility accident source term. Atmospheric dispersion of released material and the resulting dose to the surrounding population are not within the scope of the program.

The accident analysis methods being developed in the research program are being documented in a Fuel Cycle Facility Accident Analysis Handbook (AAH),(1) which contains five chapters. Chapter 1 is an introduction to the handbook, includes a discussion of the purpose and scope of the AAH, and identifies potential users. Limitations of the analytical methods presented also are discussed. Chapters 2 and 3 identify features of fuel cycle facilities and associated processing. Included are typical ranges of values for important accident analysis parameters. Chapter 4 discusses the procedures for providing source terms to the accident analysis. It includes guidance on the development of accident scenarios and the methods for determining the accident-generated source term at the accident location. Chapter 5 provides the procedures for performing the general analysis; this includes transport of the accident-generated aerosol, which was determined in Chap. 4, throughout the facility and to the environment and the effect of the accident on the components of the facility's ventilation system. User manuals for the accident analysis computer codes, supporting experimental data, and technical explanations of the analytical models are appendixes to the AAH. Several examples to illustrate the accident analysis methods are included in the AAH . Thus, although one purpose of the AAH is to provide analysts with methods for performing accident analyses for nuclear fuel cycle facilities, a second purpose is to serve as an instruction manual complete with illustrative examples.

We anticipate publishing the first version of the AAH in January 1983. The AAH will be published in a three-ring binder format so that it can be updated easily as the research program continues, improvements on the analysis techniques are developed, and additional experimental data are obtained.

We will develop and analyze a fire accident scenario to illustrate how the AAH can be used. The scenario is a fuel pool fire that burns rubber gloves in the slug-press pit of a large process canyon in a MOX fuel fabrication facility. The details of our example will be discussed as we describe each part of the AAH in succession.

II. Facility Descriptions Pertinent to Accident Analysis

The essential information to derive using Chap. 2 of the AAH is the airflow pathways through the structure. The design or steady-state flows and pressure zones must be identified. The volume, dimensions, and location of inlets and exhaust openings in rooms are required. Probable leakage pathways should be identified. The size and length of the interconnecting ductwork should be specified. Other ventilation components (such as dampers, blowers, and filters) should be located along with their characteristic operating values. The location of other engineered safety systems (such as sprinklers or sprays) and their performances also must be determined. This information should give the analyst a start in constructing a coarse system network for the facility airflow pathways.

Drawings, specifications, material lists, safety analysis reports, and existing schematics are sources that can be used in deriving a system description. A physical inspection of the facility and consultations with the designer(s) before and after the schematic is drawn may be necessary to verify that it is correct. At this stage, the user frequently encounters a lack of data; although there is no substitute for accurate data, assumptions, averaging, or conservative estimates can be used to make the problem manageable.

Chapter 2 provides the analyst with general background information about several types of nuclear fuel cycle facilities. Fuel manufacturing, fuel separation, fuel recycling, spent fuel storage, and waste solidification plants are discussed. In Chap. 2, the discussions of airflow parameters and the facility ventilation, filtration, and cleanup systems are of particular importance. The analyst should review these sections of the AAH to obtain typical values and guidance for modeling his particular facility. General information about the configuration of the facility and the facility heating, ventilating, and air conditioning (HVAC) systems is given. We assume that the analyst is moderately well acquainted with the design and layout of nuclear fuel cycle facilities, and these sections of Chap. 2 are only intended to highlight the type of information required. The glovebox ventilation, filtration, and cleanup system also should be considered and incorporated into the airflow pathways.

Representative Facility

Illustrative examples to show the analyst how the handbook can be used are given throughout the AAH. We use a hypothetical representative facility to illustrate the examples in the handbook. This representative ventilation and air cleaning network system is shown in Fig. 1 with a set of room sizes and steady-state flows and pressures. We believe that this system contains many of the features that are found in fuel cycle facilities. Multiple fans, compartments, dampers, and filter systems are included. The ventilation network connections are in both parallel and series arrangements. Supply and exhaust fans are included, as is leakage around doors and other areas. In addition, several pressure zones are provided, with airflow progressing from the least contaminated zones to more contaminated zones.

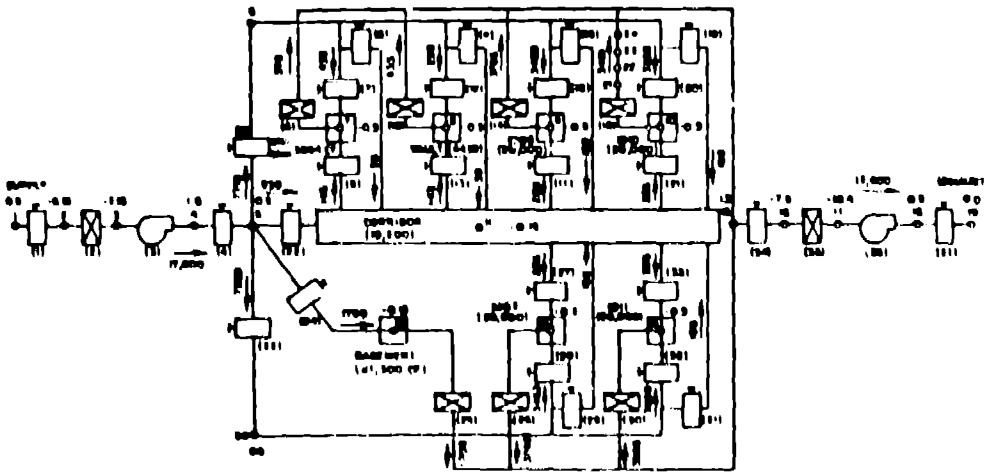

Figure 1. Representative facility.

This system was chosen so that a moderate yet realistic system would be available to illustrate the analysis procedures. We recognize that many features in the facility may not be included in certain fuel cycle facilities. However, using this facility as an instructional tool, we are able to modify the facility to accommodate accident scenarios that we wish to illustrate as example analyses.

The representative facility shown in Fig. 1 is made up of branches (labeled with numbers in parentheses) that are joined together at points called nodes. Chapter 5 describes how the analyst can use the information in Chap. 2 to construct this system. Figure 1 also shows the airflows in the branches and the pressures at the nodes.

As an example fire accident, we have selected a slug-press fire in a pit enclosure in a large, 2474.9-m^3 (87 400-ft^3) process canyon. For illustrative purposes we chose to model the MOX plant (or a part of it) using the representative facility. We located the process canyon at node 10 in Fig. 1 and, therefore, changed its volume from 566.3 to 2434.9 m^3 (20 000 ft^3 to 87 400 ft^3) in the computer simulation. The initial steady-state volumetric flow rate through the process canyon is 56.6 m^3/s (2000 ft^3/min). The ventilation system inlet and outlet, burned-out glove ports, and all other leak paths must be considered as potential flow paths for aerosol-laden air in the case of a fire because the fire could produce a positive room gauge pressure under certain conditions.

III. Processes and Unit Operations

Chapter 3 in the AAH describes the process parameters in the facility that are needed to analyze the accident. Each facility (MOX plant, reprocessing plant, and so on) has unique parameters for each accident type. For instance, in fires, this requires selecting the combination of combustible materials along with the radioactive materials at risk that could become airborne from the accident-generated stresses. Materials that are at risk generally include open containers of finely divided powders (for spills) and liquids (for spills and boiling) and contaminated noncombustible surfaces, contaminated combustible material (liquids and solids), liquid and powders in containers that could exceed design pressures and fail when heated in fires, and radioactive metals, such as plutonium or uranium, that are combustible in themselves.

We selected the slug-press enclosure for the example fire because it contains combustible hydraulic fluid and large numbers of combustible rubber gloves set in glove ports and surface contamination that can become airborne during the fire. The process canyon and slug-press fire enclosure are shown in Fig. 2.

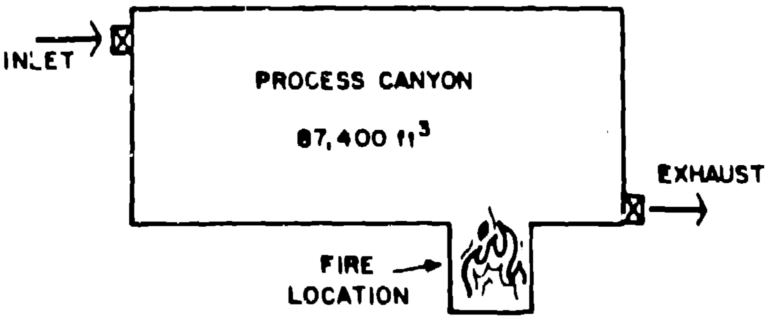

Figure 2. MOX plant sample fire geometry.

The following are considered as combustibles in the sample accident.

- 1 pt of acetone used in cleaning a hydraulic fluid spill
- 2 pt of hydraulic fluid
- 34.3 kg of other combustibles (rubber gloves, other elastomers, and plastics) calculated as 1,3 butadiene rubber

The radioactive source terms are a result of contamination on the rubber combustibles and on a MOX storage container that overpressurizes and spills at 230 s, resulting in 940 g of airborne material.

IV. Scenario and Source Term Definition

Chapter 4 helps the user put the accident scenario together and helps define the airborne source terms during the accident, which are analyzed up to the facility boundary with the external environment by methods discussed in Chap. 5. In defining an accident scenario, the user recognizes that accidents probably only occur if abnormal conditions exist in the room or process area of concern. These abnormalities could be spilled combustibles, inappropriately used solvents, failed and shorted electrical equipment, leaked explosive gases, degraded ion exchange resins, weakened process equipment, and accidentally arranged critical masses. Other accidents can occur as the result of violent acts of nature (tornadoes, earthquakes, or floods) or deliberate events such as sabotage, bombings, or arson.

The fire example was constructed from two abnormalities, a leaky slug-press and an accidental spill during cleanup with a flammable solvent. The solvent was spilled and ignited by hot equipment, which in turn caused the leaky slug press fluid to burn and melt the rubber gloves, adding to the burning material. The accident data shown in Table I results from this hypothetical scenario. The

Table I. Summary of source terms.

	Individual Combustibles			
Material	Acetone	Hydraulic Fluid as Dodecane	Other combustibles as 1,3 Butadiene Polymer	FIRAC Combined Source term
Amount (g)	374.0	710.0	34,300.0	
Burning Time (s)	37.4	71.0	230.0	230.0
q_t (kcal/s)	73.5	102.2	1225.0	
(kW)	308.0	428.0	5122.0	
q_c (kcal/s)	44.1	48.0	503.0	
(kW)	135.0	201.0	2098.0	2190.0
q_r (kcal/s)	29.4	54.2	722.0	
(kW)	123.0	227.0	3024.0	
Smoke				
Amount (g)	0.01	1.0	1300.0	1300.0
Size Distribution VMD (μm)		1.3	1.0	1.0
σg		2.0	1.5	1.5
Gas Volume Flowrate (L/s)	510.0	605.0	348.0	
Gas Temperature (°C)	1100.0	900.0	695.0	
Radioactive Particles Given Off (g MOX/s)	5×10^{-6}	5×10^{-6}	1.043	1.043
Equipment Failure at 230 s				940.0 g MOX
MOX Size Distribution	σg = 2.46 mean AED = 13 μm			

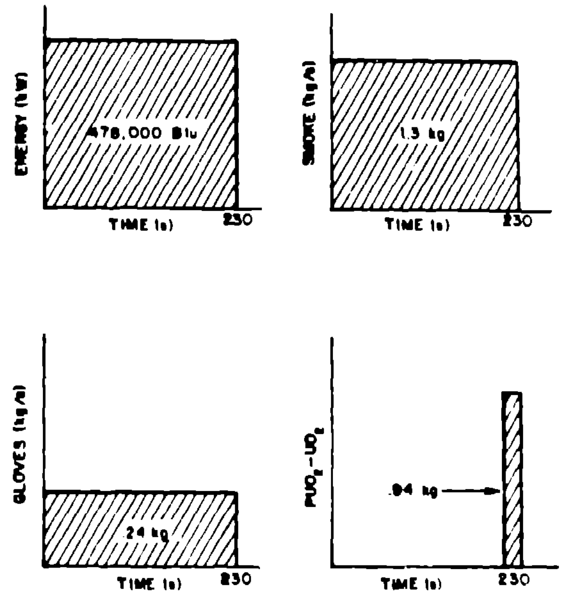

Figure 3. MOX plant accident source terms for slug-press scenario.

combustible materials were assumed to burn completely over the same time interval. The fire source terms are shown schematically in Fig. 3.

Pacific Northwest Laboratory is developing a fire source term code called FIRIN that will enable the user to provide input to the Los Alamos fire accident code FIRAC for more complex radioactive release mechanisms and more complex fires than the example used here. This code will use the fire mass burning rate to generate estimates of heat, mass, and induced room velocities that can entrain contamination on noncombustible surfaces, heat closed vessels containing radioactive powders and liquids to failure, evaporate and boil radioactive liquids, cause spills of radioactive materials, and give airborne releases of contamination from the burning combustibles. The code also will calculate compartment wall heat transfer and concrete wall thermal decomposition to produce added mass (H_2O and CO_2) to the compartment gases. This code is currently in the testing/verification stage and could not be used to generate example data for this paper.

V. Accident Consequence Assessment

Introduction

The methods that are included in the AAH are designed to allow the analyst to predict the effects of accidents on a nuclear facility's confinement system. The primary use of these methods is to determine the physical and chemical characteristics of any material release to the environment. (The analysis methods of the AAH do not extend beyond a plant's atmospheric boundary.) Using this information, the analyst then can perform an assessment of the consequences of a hypothetical accident. The analyses are oriented toward the consideration of any airflow pathways to the environment--principally, the ventilation system. Using these methods, an analyst can estimate the mitigating effects of the confinement system and evaluate the performance of the air cleaning system and any engineered safeguards.

The analysis methods require using computer codes that simulate accident-induced events within the airflow pathways of nuclear facilities. Initial emphasis in developing the AAH has been given to computer codes that will simulate the effects of fire, explosion, and tornado accidents; these computer codes are FIRAC, EXPAC, and TORAC, respectively. We will describe these codes in greater detail below.

The computer codes are being backed-up by an experimental program that will provide needed supportive data and verification as reported in Ref. (2). In addition, the codes are being developed in several stages, which allows increasingly greater levels of complexity and capability to be developed. This concept and the general analysis procedure are described below.

Description of Analysis Codes

A family of analysis codes designed to provide improved methods of accident analysis to the nuclear industry consists of the following.

- TORAC, a computer code to analyze tornado-induced flow and material transport within a structure(3)
- EXPAC, a computer code to analyze explosion-induced flow and material transport within a structure(4)
- FIRAC, a computer code to analyze fire-induced flow, thermal, and material transport(5)

These codes are directed primarily toward the analysis of nuclear facility ventilation systems. However, other airflow pathways within a structure also can be modeled with the current versions of the codes.

All of the accident analysis codes can analyze an arbitrary network of interconnected rooms, cells, canyons, or other airflow pathways. The airflow pathways that can be modeled include conventional ventilation system components (dampers, blowers, and ductwork) and air cleaning components such as filters. The accident simulation requirements are provided for in parametric form, that is, through energy and mass addition and pressure- or temperature-time histories of the accident event. Also associated with the accident event is the capability to entrain material into the airflow or to inject material at an arbitrary rate and time. The codes are capable of simulating both steady-state and transient flows through a ventilation network system. The capability for basic convective transport of material through the network system is provided. At this time, only material depletion because of gravitational settling and HEPA filter filtration are included. However, turbulent inertial deposition, depletion because of Brownian and turbulent diffusion, and aerosol interaction will be added in later versions of the codes as discussed in Ref. (6).

Although the accident analysis computer codes are an advancement in the capability to simulate accident events in air cleaning systems, major limitations remain in the codes. These limitations will be addressed and removed in later stages of code development. The major limitations are in two areas.

- The gas dynamics are based strictly on lumped-parameter formulations; that is, spatial simulation is obtained in an artificial way. This means that the analyst should view predicted values near the accident source with caution. This is particularly true for a fire or explosion accident.
- The material transport capability is very basic and relies on information found in the literature. In addition, only two mechanisms for material depletion are provided, but the codes are structured so that material interaction (coagulation and gas to particle conversion including condensation) and other material transport mechanisms can be added easily. See Ref. (6).

The computer codes are based on the following assumptions.

- Lumped-parameter formulation
- Gas dynamics decoupled from material transport

- Homogeneous mixture and dynamic equilibrium
- No material interaction, phase change, or chemical reaction allowed during transport
- Material entrainment based on the resuspension factor for rooms with semi-empirical rate equations and wind tunnel data for ducts.

Future versions of the codes will be directed toward providing increased spatial resolution by adding near-field analysis capability and multidimensional modeling. A number of compartment fire models currently are being assessed at Los Alamos.(7) Equally important will be a greater emphasis in the material transport area to expand the simulation process, including aerosol interaction, chemical reaction, agglomeration, and other mechanisms of deposition.

FIRAC Analysis

Using the representative facility described in Sec. II, we can calculate the effect of a fire in the process canyon as described in Sec. IV. We will use the FIRAC computer code to show what the analyst can determine from this example. As noted in Sec. II, the principal geometry shown in Fig. 1 is used. We modify node 10 to have a volume of 2474.9 m^3 (87 400 ft^3) and a normal steady-state exhaust flow rate of 56.6 m^3/min (2000 ft^3/min). In addition, we have added three nodes in the exhaust duct from node number 10 to better calculate the spatial temperature variation leaving the process canyon. The revised detail noding is shown in Fig. 4.

Representative Facility Results. The initial pressure in the process canyon is -0.3 in. w.g. During the transient, this pressure is expected to increase because of two factors.

1. Volumetric expansion of the gas in the fire compartment (and possibly reverse flow in the intake ducts) because of heating from the fire.
2. A general decrease in the fire compartment exhaust flow rate. This has two causes.

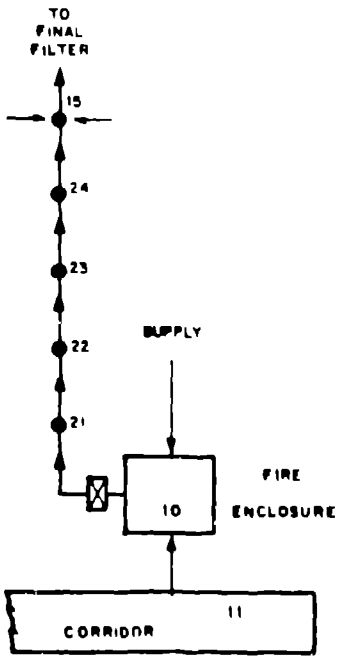

Figure 4. System schematic (near fire enclosure).

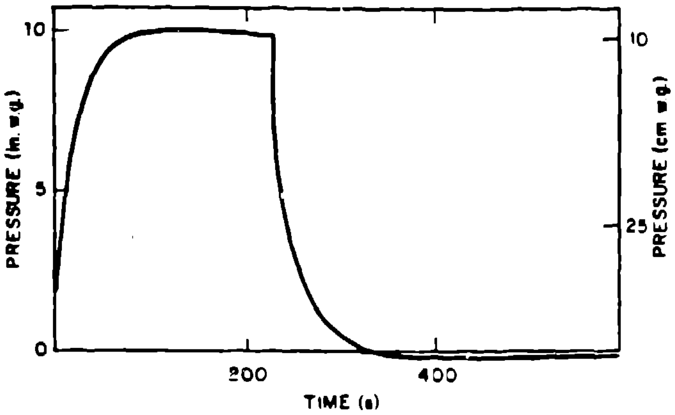

Figure 5. Process canyon average pressures.

- Degradation in the blower performance because of higher temperatures (lower densities) at the exhaust blower inlet.
- Higher resistance to flow in the exhaust duct because of filter plugging.

The FIRAC-predicted pressure transient experienced in the process canyon is shown in Fig. 5 and is a consequence of the above factors (as are other results). The process canyon generally experiences positive pressure for 325 s. During the time period of positive pressure, unfiltered leakage from the canyon as well as reverse flow in the intake ducts is a possibility.

The resulting reverse flow in the intake ducts is shown in Fig. 6. The supply duct experiences a flow reversal for approximately 4 min, whereas the corridor flow rate remains negative because of filter plugging by particulate material. These negative flows could contaminate the facility.

Two of the principal results of the calculation are the gas temperature and differential pressure achieved at various locations, especially the filters. The temperature at the process canyon exhaust filter is shown in Fig. 7. The maximum temperature reached is 461°F, and therefore, the filter is not in jeopardy because of high temperatures. The differential pressure across this filter is shown in Fig. 8. The peak differential pressure achieved is 10.7 cm w.g. (4.2 in. w.g.), which is well below its breaking point.

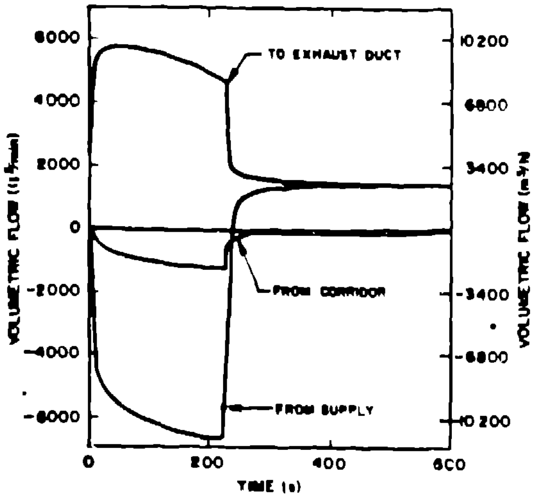

Figure 6. Flow rates into and out of the process canyon.

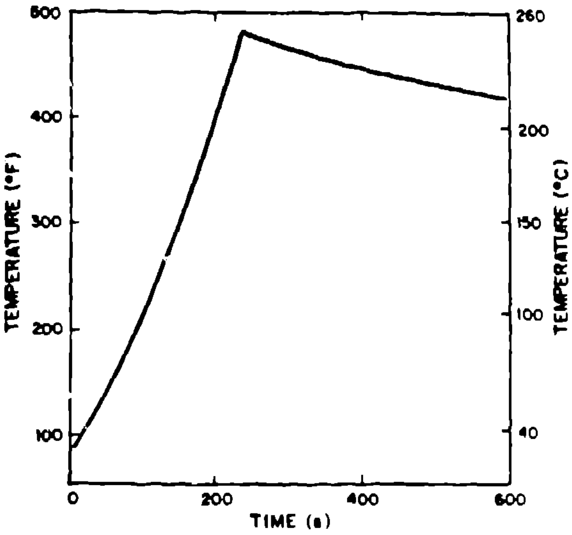

Figure 7. Process canyon exhaust filter temperature.

The particulate species are injected and mixed with the combustion gas in the process canyon and further diluted by the intake air and are swept constantly into the exhaust system. In the exhaust system, they are swept toward the filters and diluted by merging airstreams. Figure 9 and Table II show the distribution of each species at the end of the calculation (10 min). The largest fraction of each species remains airborne at this time, and almost none escapes through the exhaust filters because all exhaust from the system must pass through double filtration.

VI. Summary

We have described a multilaboratory NRC research program that is directed toward providing a more realistic assessment of accident consequences in nuclear fuel cycle facilities. The focal point for the analysis methods developed in this program is a fuel cycle facility accident analysis handbook. We have summarized the contents of the AAH, which includes facility and process descriptions, accident scenario and source-term definition, and accident consequence analysis. We have illustrated the use of the AAH by describing and analyzing the consequences of a hypothetical fire in a MOX plant. The first version of the AAH is scheduled for release in January 1983.

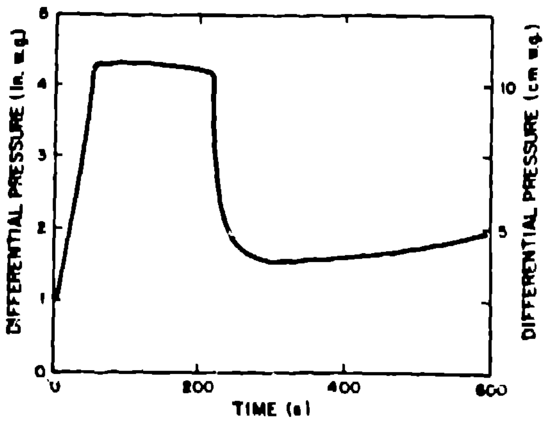

Figure 8. Process canyon exhaust filter differential pressure.

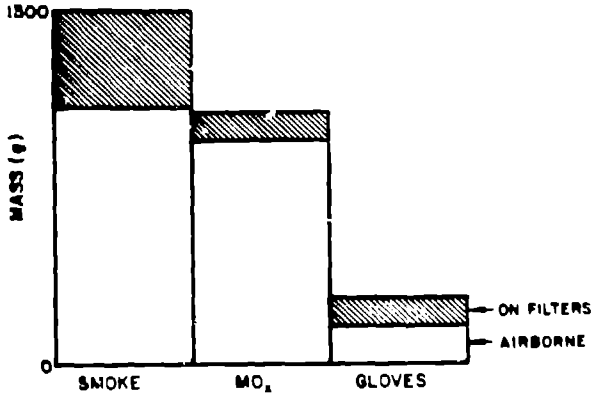

Figure 9. Material distribution 10 min after accident.

Table II. Material distribution after 10 min.

	Material		
	Smoke	Gloves	PU O_2 - UO_2
On filters (g)	351	62.0	97.0
Airborne (g)	951	168.0	841.0
Escaped through exhaust filter (mg)		.02	.03

References

1. Los Alamos National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratory, *Accident Analysis Handbook*, Los Alamos National Laboratory report LA-9180-M, PNL-4149, NUREG/CR-2508 in preparation.

2. W. S. Gregory, P. R. Smith, D. E. Fenton, and R. A. Martin, "Response of HEPA filters to simulated accident conditions," *Proc. of the 17th DOE Nuclear Air Cleaning Conference*, Denver, Colorado (August 1982).

3. R. W. Andrae, P. K. Tang, R. A. Martin, and W. S. Gregory, "TORAC users manual - a computer code for analysis of tornado-induced flow and material transport in nuclear facilities," Los Alamos National Laboratory report in preparation.

4. P. K. Tang, R. W. Andrae, J. W. Bolstad, R. A. Martin, and W. S. Gregory, "EXPAC users manual - a computer code for analysis of explosion-induced flow and material transport in nuclear facilities," Los Alamos National Laboratory report in preparation.

5. R. W. Andrae, J. W. Bolstad, W. S. Gregory, F. R. Krause, R. A. Martin, and P. K. Tang, "FIRAC users manual - a computer code for analysis of fire-induced flow and material transport in nuclear facilities," Los Alamos National Laboratory report LA-7397-M (July 1978).

6. P. K. Tang, R. A. Martin, A. P. Harper, J. D. Novat, and W. S. Gregory, "Material transport analysis for accident-induced flow in nuclear facilities," Los Alamos National Laboratory report in preparation.

7. F. R. Krause and W. S. Gregory, "Simulation of underventilated fires," *Proc. of the 17th DOE Nuclear Air Cleaning Conference*, Denver, Colorado (August 1982).