Session 9

AIR CLEANING EQUIPMENT RESPONSE TO ACCIDENT RELATED STRESS

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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.

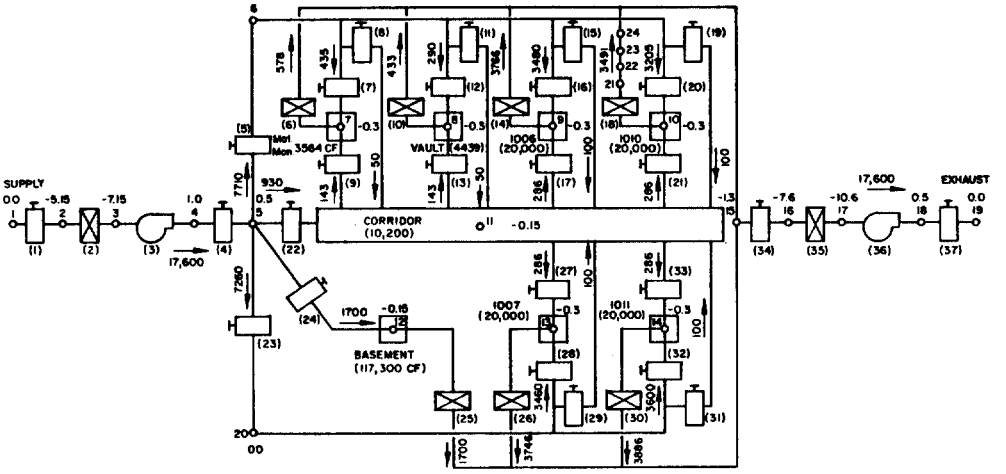

Figure 1. Representative facility.

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.

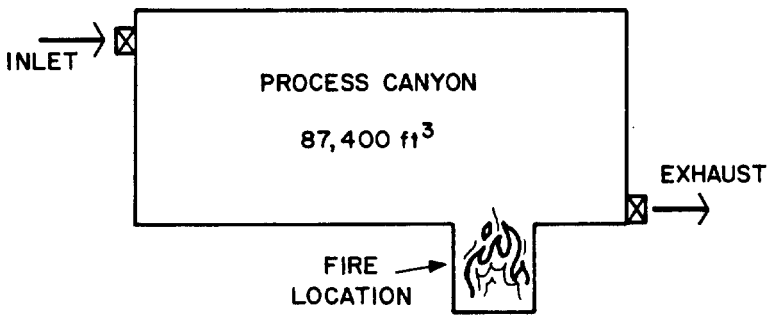

Figure 2. MOX plant sample fire geometry.

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)	185.0	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	g = 2.46 mean AED = 13 μm			

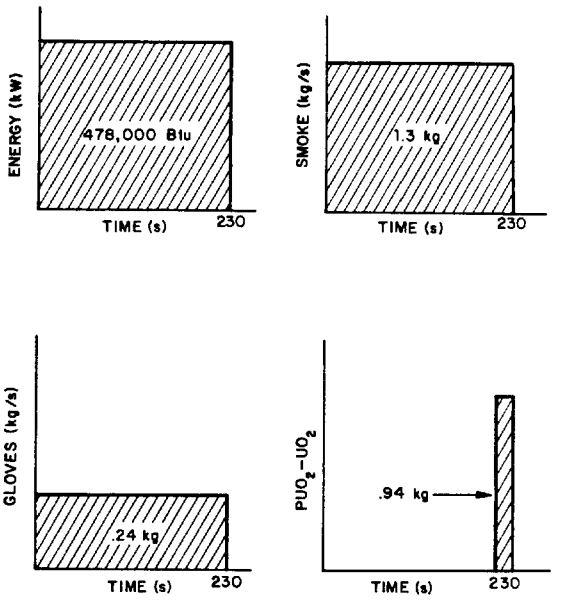

Figure 3. MOX plant accident source terms for slug-press scenario.

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.

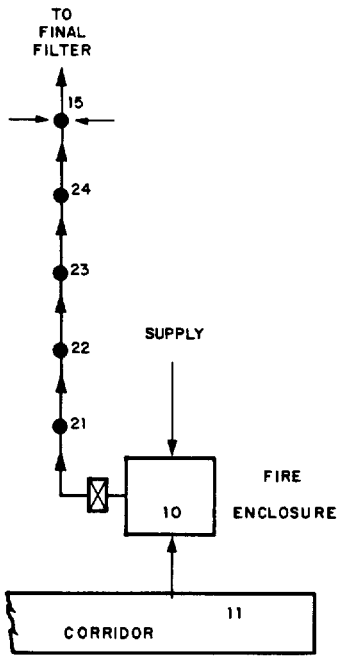

Figure 4. System schematic (near fire enclosure).

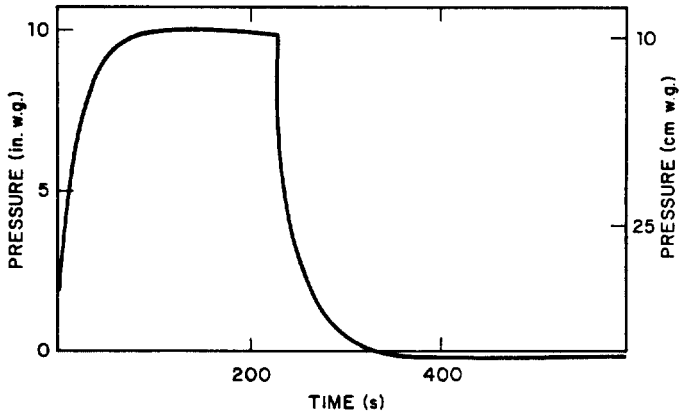

Figure 5. Process canyon average pressures.

- 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.

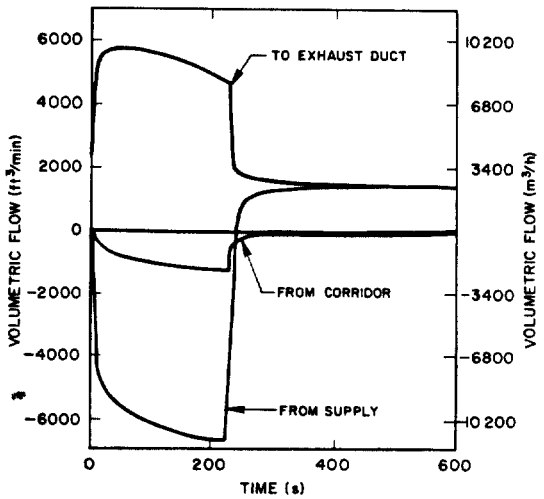

Figure 6. Flow rates into and out of the process canyon.

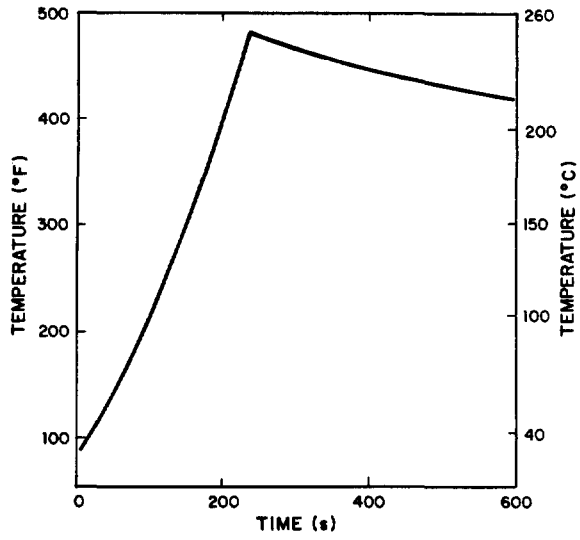

Figure 7. Process canyon exhaust filter temperature.

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.

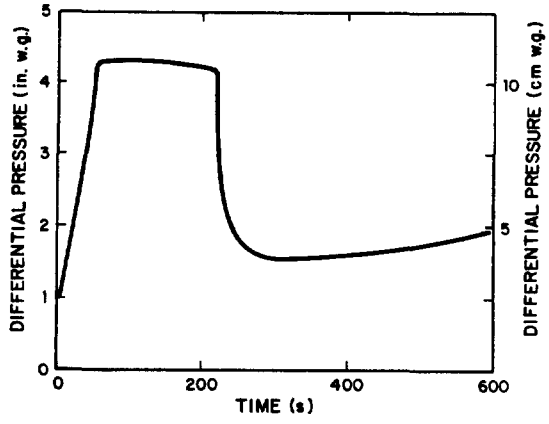

Figure 8. Process canyon exhaust filter differential pressure.

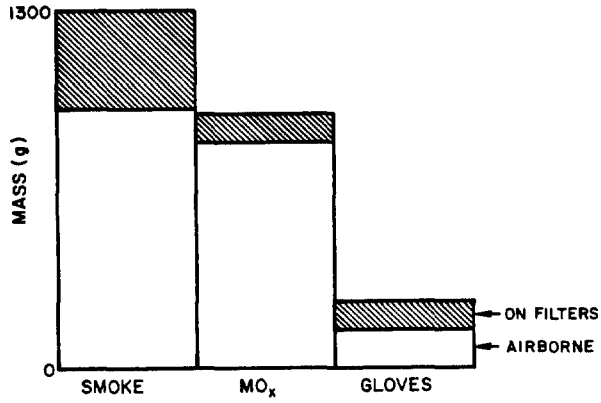

Figure 9. Material distribution 10 min after accident.

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

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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.

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DISCUSSION

ROUYER: What will be the utilization of the Handbook; a guide to the designer, or the operator so that he makes his safety analysis himself, or a guide to collect data so that a vaulable safety analysis can be made by another body?

GREGORY: We hope that the Handbook will be used by safety analysts to evaluate the responses of accident-induced transients on ventilation and air cleaning system design. However, the Handbook could be used, as well, as a guide to identify data that are needed to perform a detailed safety analysis. The safety analysis could then be performed by someone else.

BERGMAN: Can the computer code predict whether the fire ventilation problem will be one of a thermal or a particulate hazard, as far as the HEPA filters are concerned?

GREGORY: Both are time dependent phenomena. From the fire analysis point of view, the things that we are trying to predict that would be important from the air cleaning point of view, are the thermal effect and the plugging effect. Both of these processes are going to be going on simultaneoulsy and, as of yet, I don't think that we can distinguish one from the other, because they are going to interact and have combined effects. In other words, as the filter becomes plugged it is going to affect the fire. Possibly, the fire goes out, or it may start generating an even greater amount of unburned flammables and send more unburned flammables into another part of the air cleaning system where highly oxygen-rich dilution air may cause ignition. It is a very complex phenomenon and I think we have just cracked the surface of the problem.

LEYSE: Could you tell me what additional reviews this program has had so the user can have confidence in it?

GREGORY: I think that is a good question and something that the Nuclear Regulatory Commision would like to have a good feeling about. We have released a preliminary version to the NRC and they have their own employees using the code on several problems. They may range from hypothetical problems to license applications. They have found problems with our code in the areas of documentation and places where we need to make it a bit more clear. NRC wants to release a high quality product and will not release the codes or the Handbook until they are assured of a product that people can depend on.

ROUYER: I think the effects depend on the type of fire, also. We saw that, according to the type of fire, you may have a thermal problem or a plugging problem. There are many types of fires. Do you intend to utilize the Handbook to develop criteria for the designers and operators, or do you intend to give this Handbook to designers and operators so they can make better safety analyses for themselves?

GREGORY: To respond to that question I would have to look to the NRC as to how they want to distribute the book. Our responsibility is to try and help them develop the book. How they would like to see it implemented is, I believe, up to them. Coming back to the first thing that you had to say, Dr. Krause is going to talk a bit more about the modeling of fires in another presentation, and you are quite right, the types of fires amid the facilities are quite different from ordinary industrial fires. The subject is very complicated.

HEPA FILTER EXPERIENCE DURING THREE MILE ISLAND REACTOR BUILDING PURGES

by

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ABSTRACT

Recovery operations from the March, 1979, accident at Three Mile Island Unit 2 are continuing. The gaseous radioactive materials generated during the accident and contained in the Reactor Building were purged during June and July of 1980. This purge resulted in approximately 47,000 curies of Krypton 85 being released to the environment, along with very small quantities (microcuries) of particulates. All releases were routed through one train of the Reactor Building purge system, a 20,000 cfm filter train with a roll-type prefilter, redundant banks of HEPA filters and space for activated carbon trays (void of carbon for the purge).

The HEPA filters were replaced immediately before the purge and left in operation until at least early 1981. During the time period from July 1980, until 1982, purges of the Reactor Building to support manned Reactor Building entries occurred periodically, and the effluent was passed through the HEPA filters. Onsite radiation surveys in December 1981, showed area radiation levels in the 10-30 mrem/hr range outside the housing with contact readings on the face of the upstream HEPA's 60-80 mrem/hr gamma radiation and 150-350 mrad/hr beta radiation. The second bank of HEPA's showed minimal radiation levels.

This paper will present the available details on the radiation surveys, as a function of individual HEPA filters. Results of offsite analyses of representative samples of the HEPA filter and prefilter media will be discussed and analyzed in an effort to ascertain radioactive material loadings. Also included will be potential future changeout criteria based on radiation levels instead of pressure drop.

INTRODUCTION

The Reactor Building purge system at Three Mile Island Unit 2 has seen considerable service since the March 1979 accident. Since the Reactor Building was isolated very early in the accident, significant gaseous radioactive materials accumulated in the Reactor Building. Commencing in June 1980, and continuing to the present, the Reactor Building purge system has been periodically operated to remove these contaminants and release them to the environment. Manned entries into the building have been occurring since the summer of 1980, and these purges support the entry personnel in keeping their occupational doses as low as reasonably achievable.

Although not an engineered-safety-feature system in the context of USNRC Regulatory Guide 1.52[1], the licensee for Three Mile Island, GPU Nuclear, has instituted periodic surveillance on the Reactor Building Purge System. The basic guidance of ANSI N510-1975[2] is implemented but minimal followup actions by the licensee have led to a potential bypass problem of significant proportions. This problem has since been corrected. Further discussions of this area is contained below in Section IV.

HEPA filter use was evidenced by the fairly high radiation levels measured during surveys conducted in December 1981, by licensee personnel. Two of these filters have been identified for offsite laboratory analysis. Area radiation levels outside the filter housing were in the 10-30 mrem/hr range, while contact readings on the face of the first bank ranged from 60 to 80 mrem/hr gamma radiation and from 130 to 350 mrad/hr beta radiation. The second bank of HEPA filters showed minimal radiation levels.

II. HEPA FILTER DEGRADATION

The Reactor Building purge system at Three Mile Island Unit No. 2 consists of redundant 20,000 cfm filter trains. Each train includes a roll-type prefilter, a bank of HEPA filters, space for trays filled with activated carbon, and a second bank of HEPA filters. Since the radioiodine inside the reactor building decayed to negligible levels during the time period commencing with the accident in March 1979, and ending with the purge in June 1980, the carbon trays have been removed. In addition, due to differential pressure/fan interlock maintenance, only one train of the Reactor Building purge system was operable from June 1980 until March 1982, and all effluent therefore passed through one filter train. For this filter train, new HEPA filters were installed and tested in June 1980, prior to any Reactor Building purge. Although all tests proved satisfactory, observations of the filter test personnel may be interpreted as indicating the train was in actuality in a degraded state during purging. This aspect will be discussed further in Section IV, System Bypass.

Radiation surveys of the Reactor Building purge system filter train "B" were conducted on December 30, 1981. Twenty-three survey points were identified on the exterior of the filter housing by the upstream (inlet) bank of HEPA filters. The areas surveyed included both sides and the top. General area radiation readings ranged from a low of 9 mrem/hr to a high of 29 mrem/hr, all measured three feet from the housing surface. When a similar survey was performed by the downstream (outlet) bank of HEPA filters, no readings above background were noted.

Surveys performed inside the housing on the face of each HEPA filter give an indication of the distribution of activity. For the twenty upstream HEPA filters, contact gamma radiation readings ranged from a low of 60 mrem/hr to a high of 80 mrem/hr. Beta radiation contact readings ranged from a low of 152 mrad/hr to a high of 342 mrad/hr. The gamma radiation survey data support a uniform deposition of contamination across the face of the bank. The spread in readings is within ± 20%, which is the acceptance level for the air flow distribution test according to plant technical specifications. Although the beta readings show more spread, the results are not considered to indicate poor air flow distribution. Beta surveys tend to be more sensitive to minor changes, such as actual location on the HEPA filter face, and the instrument used (an RO2A with open window) adds more inaccuracy to beta measurements than to gamma measurements.

Smears for loose contamination were also taken inside the filter housing, at five different locations. These swipes showed loose gamma contamination ranging up to a maximum of 9900 disintegrations per second per 100 cm^2(dpm/100 cm^2), with loose beta contamination ranging up to a maximum of 63,000 dpm/100 cm^2. Figure 1 identifies all of the available measurements and survey data from inside of the filter housing near the upstream HEPA filter bank.

A similar survey was performed near the downstream HEPA filter bank. Results showed minimal radiation or contamination levels. On the face of the twenty HEPA filters, radiation levels were minimal. Gamma radiation levels ranged from 1 mrem/hr to 2 mrem/hr, and beta radiation levels ranged from below detectable (.1 mrad/hr) to 2 mrad/hr. These surveys are all contact readings. Smear surveys for loose contamination at eight locations showed no loose contamination (gamma or beta). All of these surveys were performed December 30, 1981. These data, as indicated in Figure 2, are not sufficiently different from background levels to draw any conclusions regarding uniformity of flow or deposition of particulate matter.

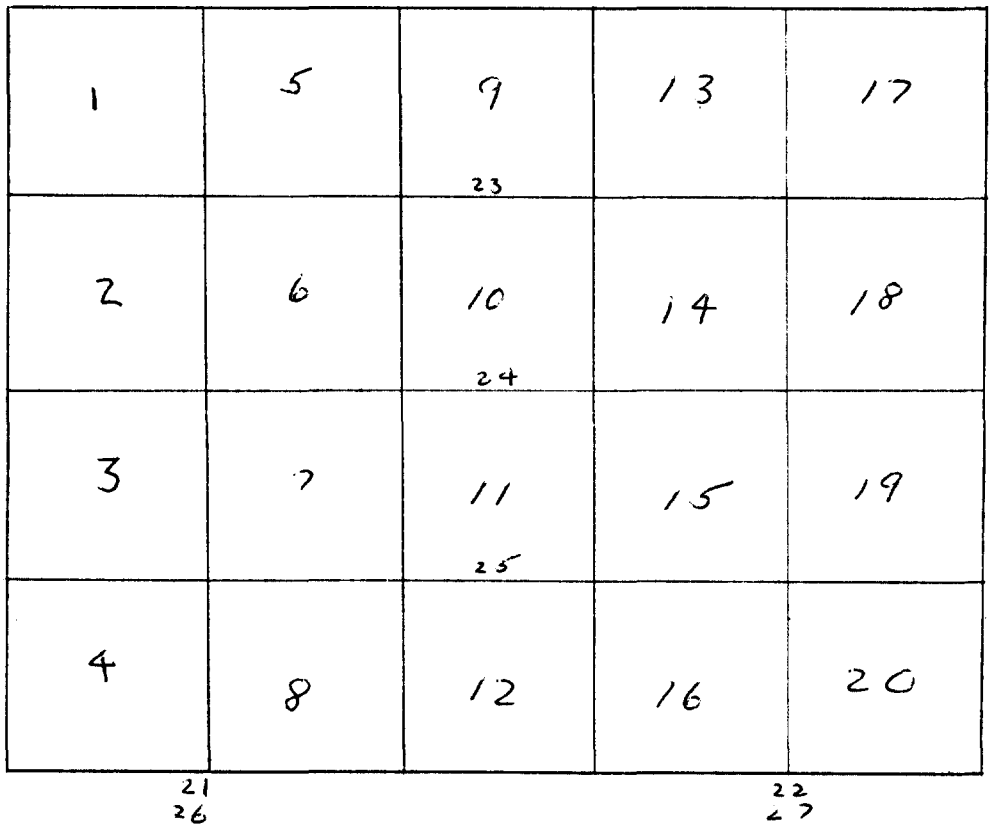
III. OFFSITE EVALUATION

The laboratory evaluation of two selected HEPA filters taken from the filter banks during the March 1982 changeout has been initiated. The Idaho National Engineering Laboratory (INEL), is analyzing the media for parameters such as weight loading, gross beta and gamma levels, and isotopic analysis. The results are expected to be beneficial in assisting in an evaluation of filter system performance and the source term being generated inside the TMI-2 Reactor Building. The two filters chosen include, one filter from the upstream bank and one filter from the downstream bank. The filters are identified by filter location 15 on Figure 1, and filter location 6 on Figure 2.

Unfortunately, offsite analysis of these two filters has not proceeded as expeditiously as planned. Although the filters were removed from service in March 1982, they were not readied for shipment or shipped until June 14, 1982. Higher priority decontamination work by the licensee took precedence, and the required health physics support was not readily available. INEL was prepared to accept the filters, yet a special shipping cask was required, and the project could not support a sole-use truck from Pennsylvania to Idaho. Transportation plans were thus devised considering additional materials being shipped. Finally, funding for the project was not readily available. Although total expenses were considerably less than $10,000, support for ventilation-type areas of research was difficult to obtain. Convincing interested parties of the potential usefulness of the offsite analysis proved difficult. The filters have now been received at INEL, and testing is underway. Results are expected to be available during the early fall of 1982.

IV. SYSTEM BYPASS

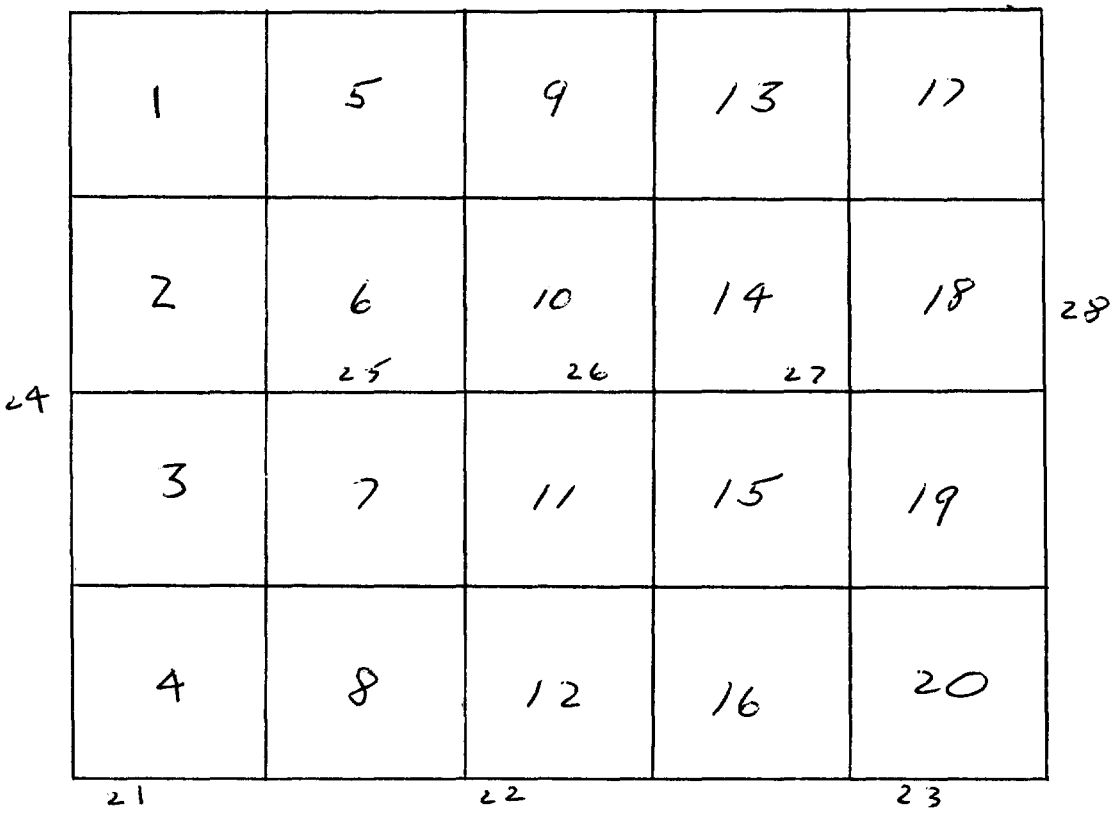
A significant problem of potential generic applicability, both at the TMI Station and other reactors, was uncovered in early 1982. In June of 1980, prior to any purge of the Reactor Building, filter replacement occurred. Maintenance records associated with this changeout identified filter bypassing in the Reactor Building purge filter trains due to the filter cabinet underdrain system. Figure 3 identifies the bypass path. Note from Figure 3 that each train contains five plenums, one upstream of the prefilter, three between filter



Location	Gamma mrem/hr	Beta mrad/hr	Location	Gamma mrem/hr	Beta mrad/hr
1	60	228	12	70	190
2	60	304	13	60	342
3	60	266	14	60	304
4	60	228	15	60	228
5	60	228	16	60	266
6	60	228	17	60	342
7	80	152	18	60	266
8	80	152	19	60	228
9	60	228	20	60	228
10	70	228	21	100	380
11	80	152	22	80	152

Smear Location	Gamma dpm/100cm^2	Beta dpm/100cm^2
23	5,938	39,000
24	7,226	48,000
25	5,382	36,000
26	9,440	63,000
27	1,632	11,000

Figure 1 Upstream HEPA Filter Radiological Surveys



Location	Gamma mrem/hr	Beta mrem/hr	Location	Gamma mrem/hr	Beta mrem/hr
1	2	ND	11	1.5	1.85
2	1.5	ND	12	1.5	1.85
3	1	2	13	2	.75
4	1.5	ND	14	1.6	.75
5	2	ND	15	1.6	1.5
6	1.4	2.22	16	1	ND
7	1.5	2	17	1.8	.75
8	1.5	ND	18	1	1.85
9	1.8	.75	19	1.5	ND
10	1.5	1.11	20	1	ND

ND - Not Detectable (<.1)

Smear Location	Gamma dpm/100cm^2	Beta dpm/100cm^2
21	36	<500
22	50	<500
23	46	<500
24	28	<500
25	24	<500
26	18	<500
27	14	<500
28	22	<500

Figure 2 Downstream HEPA Filter Radiological Survey

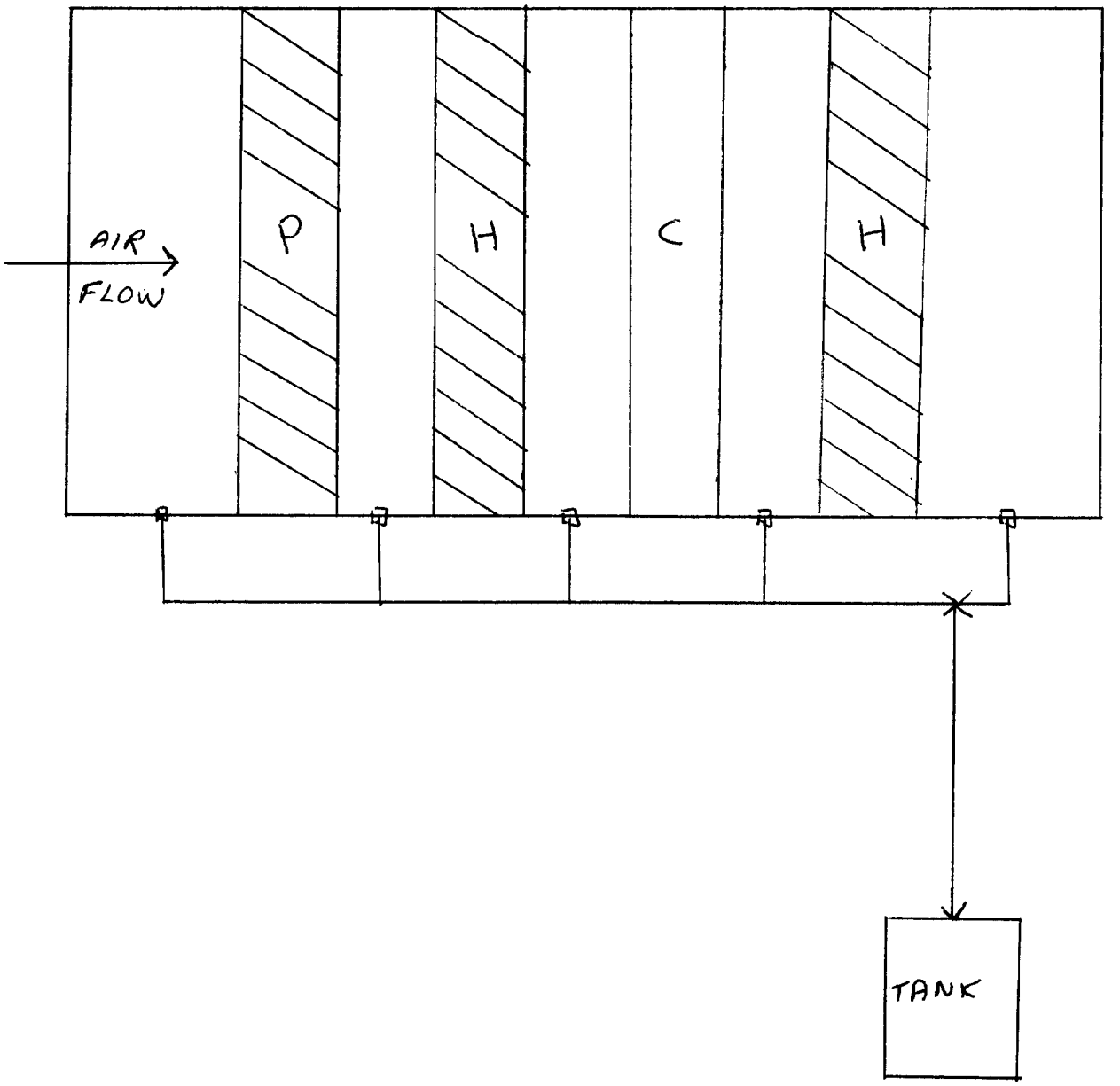


FIGURE 3 FILTER HOUSING UNDERDRAIN SYSTEM

banks, and one downstream of the final filter bank. Each plenum has a drain, and all five drains connect in a common drain header for each train. The two drain headers, one from each filter train, form a system drain. The problem is considered generic since at TMI-2 there are three drain system (the Auxiliary Building filtration system and the Fuel Handling Building filtration system in addition to the reactor building purge system) that discharge separately under water in a seal water tank. Four of the drains (clean-outs) should have been plugged with carbon steel plugs, with the center drain open for water drainage after water spray activation. Corrective action taken in June 1980 to prevent bypassing had consisted of using "tuck tape" and cardboard to seal the drains. This corrective action, although successful at the time, was in direct conflict with plant drawings showing the use of carbon steel plugs. Although maintenance and changeout procedures indicated an ANSI N510-1975 visual checklist, followup action was lacking. Better coordination between filter system maintenance personnel and plant personnel is needed to prevent similar occurrences in the future. The use of "tuck tape" is not acceptable to plug drains or cleanouts and has been observed in followup inspections to become loose and flap in the ventilation flow, re-creating the bypass path. Inadequate filter system performance was noted in an unusual event at TMI-2 on January 8, 1982. With high airborne activity in the buildings, system bypass became apparent.

A number of significant inadequacies are apparent. First, although the drawings called for carbon steel plugs in the drains, "tuck tape" and cardboard was employed. Second, identification of bypass by filter testing personnel in June of 1980 was not followed-up to verify appropriate corrective action (note that ANSI N510-1975 visual checklist was used). Third, and most important, the potential for bypass around filter system components via the underdrain system will completely negate the purpose of the air cleaning system. All licensees should verify that this situation is not occurring at any of their filter systems.

V. CONCLUSIONS

The reactor building purge filters are shown to be effective in removing significant amounts of particulate radioactive material, based on the contact gamma and beta radiation readings. Although the area levels are not high enough to prevent routine filter changeout, the levels are significant. A general area radiation level of 100 mrem/hr for workers is suggested as an upper level for routine changeout. This value, however, has not been implemented. Further consideration of filter system downtime, man-rem exposure, personnel availability, filter cost, and waste cost from the changeout and subsequent handling, packaging, and shipping is necessary.

The radiation levels for the individual filters in the Reactor Building purge system support a uniform air flow distribution. Further offsite evaluation of specific filters is planned to substantiate this conclusion. To date, attempts to initiate the offsite evaluation have met unusual stumbling blocks, including proper priority, understanding of the goal, and funding.

Filter system bypass via the underdrain system, is identified as a significant technical deficiency that defeats the purpose of the air cleaning system. Bypass can be eliminated by the installation of proper components (carbon steel plugs instead of "tuck tape"), adequate testing and maintenance with appropriate followup and communication, and constant surveillance of filter systems.

REFERENCES

1. U.S. Nuclear Regulatory Commission Regulatory Guide 1.52, "Design, Testing and Maintenance Criteria for Post-Accident Engineering-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units Used in Light-Water-Cooled Nuclear Power Plants", Revision 2, March 1978.

2. ANSI N510-1975, "Testing of Nuclear Air-Cleaning Systems."

DISCUSSION

SGALAMBRO: Did you perform an analysis of what type of aerosol had been collected on HEPA filters?

BELLAMY: The work is presently in progress and should be available for the 18th Air Cleaning Conference.

PRATT: Based on Figure 1 and Figure 2 data, I inferred a decontamination factor of 30 - 50 for gamma levels. Please comment on that.

BELLAMY: I would hesitate to use general area radiation readings for calculation of decontamination factors (DF). However, a DF of 30 - 50 sounds reasonable. It should be confirmed with upstream and downstream measurements.

KOVACH, J.L.: It is the responsibility of the testing company to supply a test report on the status of a filter system. The repair or enforcement of actions to be taken is supposed to be the realm of the utility and the NRC.

BELLAMY: All of us have a responsibility for the public health and safety.

BURCHSTED: As an aside to the topic of the paper, I note a bank design of 4 filters high, and I noted the same bank design in another paper this morning. From a maintenance standpoint, we do not have many 8-foot people capable of reaching the top tier of filters to replace or inspect them. We should standardize on a maximum bank height of 3 filters or, if a work platform is provided between the 3rd and 4th tiers, a bank height of 6 filters. This is a matter of access for testing and maintenance, which should take precedence over the practice of optimizing space utilization in the building.

BELLAMY: You comment is noted.

SIMULATION OF FORCED VENTILATION FIRES

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Abstract

Fire hazard descriptions and compartment fire models are assessed as input to airflow network analysis methods that simulate the exposure of ventilation system components to fire products. The assessment considered the availability of hazard descriptions and models for predicting simultaneous heat and mass release at special compartment openings that are characterized by a one-dimensional and controllable volumetric flux.

I. Introduction

The airflow network analysis codes developed by the Los Alamos National Laboratory simulate the effects of tornadoes and explosions with source terms that describe heat and mass release to ventilation systems.[1],[2] Extending the codes to fire accident simulation analysis requires prescribing heat and mass release from fires.[3] Fire models are needed in this accident simulation to predict heat and mass exhaust from compartment openings. Therefore, available fire hazard classifications and models were assessed for their capability to simulate heat and mass exhaust from fire zones.

Industrial facilities usually have doors and windows that allow the smoke to escape before it descends to the fire. Thus, industrial fire protection and the associated fire models are concerned with efficient combustion in the presence of uncontaminated air and the bi-directional flow of both air and fire products through the same openings. Nuclear facilities use radioactivity barriers to protect employees and the public against the hazards of ionizing radiation. Filtered venting systems and associated forced ventilation are often installed to confine radioactive dust, and the same confinement is inadvertently imposed on smoke. Therefore, nuclear plant fire models are concerned with inefficient combustion in the presence of smoke (soot and low vapor pressure liquids) and with one-dimensional and controllable flow through compartment openings. They differ from industrial and building fires in the following ways (Fig. 1).

(1) Bi-directional flow of fire products and air through one large opening is replaced by unidirectional flow in intake and exhaust openings.
(2) Fire products descend to the seat of the fire. Therefore, fire plumes contain more reaction products and less fresh air.

There is a reasonable doubt that existing compartment fire data bases and compartment fire models will simulate adequately heat, toxic/corrosive gas, and particulate injection to the ventilation system adjacent to a fire zone. We evaluated available fire protection design standards and compartment fire models for their capability to simulate heat and mass release from forced ventilation fires. The assessment considered

(1) coverage of fire hazards that are commonly used for the design of active fire protection systems and
(2) the potential for existing fire models to be extended to forced ventilation situations.

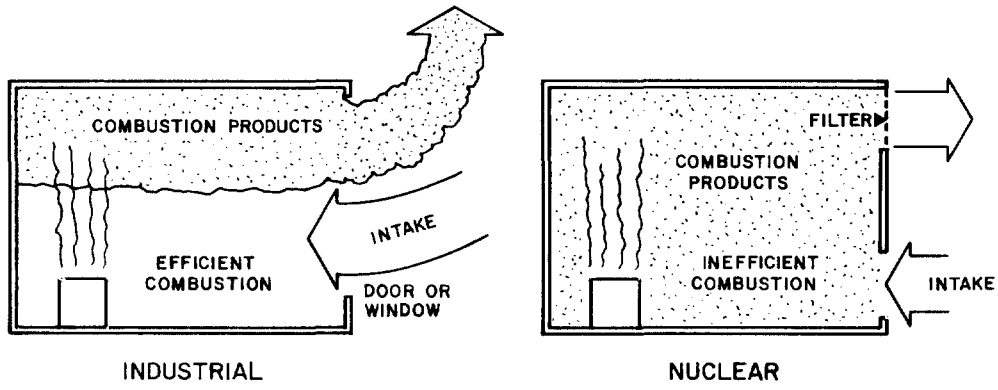

Figure 1. Difference between industrial and nuclear facility fires.

II. Requirements For Fire Accident Analysis

Volumetric exhaust flow rates usually are imposed by the ventilation system. Exhaust rates then are determined by the temperature and composition time history of the burn room atmosphere drawn into the ventilation system.

Analytical Requirements

In our opinion, a quantitative description of fire accidents requires the following tasks.

(1) Quantify fire hazards in terms of heat and mass release at the seat of the fire.
(2) Simulate temperature, oxygen, and fire product concentration transients in the burn room atmosphere as a function of volumetric exhaust and fire hazard.

The first task has to be addressed in the design of any fire ventilation and fire suppression system and denotes user requirements. The second task describes analytical requirements for the accident analysis use of compartment fire models. Both analysis requirements set the final performance criteria for any experimental or analytical simulation of forced ventilation fires.

User Requirements

The National Fire Protection Association (NFPA) uses a description of fire hazards when specifying the design, installation, and maintenance of fire-ventilation and fire-suppression systems.[4]-[7] Standards for installation of smoke and heat venting systems classify fire hazards in terms of low, moderate, and high heat release.[4] A quantitative description of associated heat release rates is implied by the minimum water discharge requirements for fire zones, which are given in Table I.[7]

Discharge requirements for gaseous fire suppression systems recognize that heat release per fuel decomposition are largely controlled by the type of combustible material.[5],[6] The following four different fire types are specifically mentioned in NFPA fire suppression standards.

Pool Fires. Fire accident scenarios describe the spill of flammable working fluids, cleaning fluids, process chemicals, and so on.[5]-[7] Halon fire-suppression standards call for analyzing the temperature dependence of flammable

Table I. Fire hazard classification of NFPA 13-76.

Heat Release Classification	Minimum Water Supply,[a] gal/min/ft^2	Equivalent heat[b] absorption, kW/m^2
Light	.050 (0.034 L/s·m^2)	86
Moderate	.095 (0.064 L/s·m^2)	164
High	.137 (0.093 L/s·m^2)	237
Very high	.162 (0.110 L/s·m^2)	280

[a]Assumes 4000 ft^2 (372 m^2) sprinkler protection.
[b]Evaporation of 1 gal H_2O absorbs 9.546 kW/s.

vapor concentrations.(7) Fuel weight loss or mass burning rates are controlled by heat feedback from laminar and turbulent diffusion flames. Pool size can be used to differentiate between laminar and turbulent combustion.(8)

Surface Fires of Noncharring Solids. Porous plastic fuels such as foam or cable trays have emerged as the most significant fire accident hazards. Both gas and water are used for fire suppression. Active fire protection is needed because noncharring plastic may melt and sporadically achieve the high mass-burning rates that characterize liquid pool fires. Excess pyrolyzate from rapid volatilization can produce excessively long flames that promote rapid fire spread into adjoining fire zones.(9) Mass burning rate is controlled by heat irradiation of the fuel and is strongly dependent on burn room gas temperature and composition.

Surface Fires of Charring Solids. Surface fires of charring solids are fire scenarios that describe the combustion of cellulosic materials such as wood, paper records, and clothes racks.(10) The preferred fire-suppressing agent is water. Mass burning rates are controlled by char oxidation, which proceeds independently of temperature and composition of the burn room gas. This independence has been confirmed through analysis of over 250 full-scale and reduced-scale compartment burn tests.(11)

Deep-Seated Fires. Deep-seated fires are isolated inside porous solid fuels such as plastic foams, record files, mattresses, and cable trays. The isolation makes deep-seated fires very difficult to detect. It also makes delivering fire-suppression agents to the seat of the fire very difficult. Although the rate of heat and mass release from deep-seated fires is low, it may still present a significant threat to ventilation systems because fuel vapor release may persist undetected for long periods of time and be mixed with ambient fresh air. Deep-seated fires also have been identified as one key to fire spread through reignition of surface fire during readmission of fresh air.(12)

Spray Fires. The above broad classification of fire hazards summarizes building and industrial plant fires. Also, nuclear facilities have combustible working fluids under pressure that would produce a fuel spray during an inadvertant break of a pressurized system. The most frequent fire accident that has required shutting down a reactor involves reactor coolant pumps, and the most common fuels involved are lubricating oils and electrical insulation materials.(13) The

international Committee for the Safety of Nuclear Installations has placed spray fires as a fifth class of important fire hazards.[14]

Based on the above survey of fire protection design hazards, preliminary user requirements for fire accident analysis are formulated as follows.

(1) Provide compartment fire model inputs of heat and fire product release rates for the following classes of fire hazards.
   - Spray fires
   - Pool fires
   - Surface fires of noncharring solids
   - Surface fires of charring solids
   - Deep-seated fires

(2) Simulate fire growth and recession, which are caused by the dependance of fire heat and mass release rates on the temperature and composition of the burn room atmosphere outside the fire plume.

III. Preliminary Assessment of Compartment Fire Models.

The development of analytical fire models is an active and progressive field. A comprehensive review of models in use and model updates was beyond the initial scope of our fire model assessment program. Instead, we selected seven multilayer models according to personal knowledge and informal professional contacts. The following models were reviewed.

- University of California Berkeley (UCB) model[15]
- Harvard model[16]
- Canada model[17]
- National Bureau of Standards (NBS) model[18]
- Illinois Institute of Technology Research Institute (IITRI) model[19]
- Japan model[20]
- California Institute of Technology (Caltech) model[21]

The associated references may not reflect the most recent developments in these models, and we hope that the reader will call our attention to both models and updates that should be included in the continuing assessment of analytical fire models.

Screening Criteria

Models were screened for simulation of forced ventilation, number and type of predicted burn room transients, and compatibility with user analysis requirements. The results of this review are summarized in Table II and are explained as follows.

Simulation of Forced Ventilation

All seven of the reviewed models describe bi-directional flows of air and fire products through a large uncontrolled opening (window or door). They are not designed to simulate forced ventilation. However, Creighton showed that a unidirectional exhaust flow can be simulated by using a fictitious second room, as shown in Fig. 2.[22] Thus, capabilities for simulating forced ventilation are available indirectly in any building fire model that has a multiroom capability. As shown in Table II, such a capability exists only for the most simple fire models, which ignore radiation. Available fire models may have a capability to simulate forced ventilation spray fires, surface fires of charring materials, and deep-seated fires. However, simulation capabilities for forced ventilation of pool

Table II. Overview of available models.

Originator(s) Institution	Forced Ventilation	Number of Simultaneous Transients	Radiation Exchange	Systematic Verification by Test	Advantages/ Disadvantages
Brabauskas UCB	Yes	1 of 3	No	No	2, 3, A, B, D
Emmons Harvard	No	3 of 3	Yes	Yes	3, A, C
Harmathy Canada	No	1 of 3	No	Yes	1, 2, 3, 4, A, B, D
Krause Los Alamos	Yes	3 of 3	No	New Model	2, 3, 4, D
Quintieri NBS	No	1 of 3	Yes	Yes	1, 3, C
Waterman, Page IITRI	No	2 of 3	Yes	Yes	1, 2, 3, A, C
Tanaka Japan	Yes[a]	1 of 3	No	New Model	2, 3, 4, C
Zukoski/Alvares/ Creighton Caltech	Yes[a]	2 of 4	No	New Model	2, 3, 4, A

ADVANTAGES	DISADVANTAGES
1. Model parameters summarize many tests	A. Lacks distinction of fire hazards
2. Simplicity	B. Limited to ventilation-controlled fires
3. Research basis for fire control	C. Lacks ventilation system interface
4. Multiple burn mode potential	D. Uncertain for bi-directional flow

[a]Requires "fictitious" room to represent unidirectional exhaust.

fires and surface fires of noncharring materials will most likely need additional research and development because both radiation exchange and forced ventilation must be simulated.

Spray fires are most easy to model without additional research and development because the spray release rate may be independant from the state of the burn room atmosphere. Thus, spray fires may be investigated without complex instrumentation and radiation exchange models. The spray fire results also may be applicable to surface fires or charring materials and deep-seated fires, which are equally independent from the state of the burn room atmosphere.

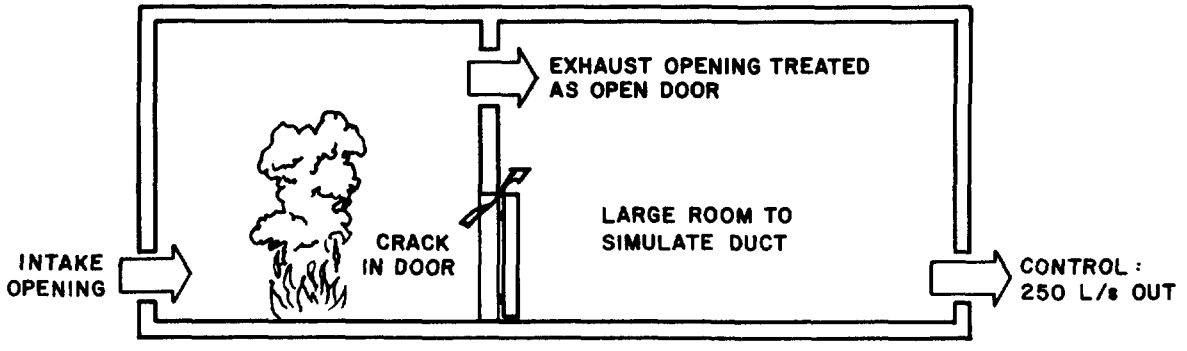

Figure 2. Caltech model simulation of ventilation-controlled exhaust opening.

We restricted the following preliminary assessment of fire models to spray fires because this choice reduces the complexity and maximizes the utility of results for other fire hazards. The restriction to spray fires also allows us to directly compare simple fire models that do not simulate radiation with higher-level fire models that do. In addition, the number of available fire models is enlarged.

Simulation of Burn Room Transients

As discussed above, existing methods of ventilation systems analysis require simultaneous time histories of temperature, oxygen concentration, and fire product concentration in the upper or hot layer of the burn room. Models were screened for their ability to predict these fire zone transients. Bulk "fire product" was defined as total mass density minus gaseous oxygen and gaseous nitrogen. This idealized fire product includes both combustion products (such as CO_2, CO, H_2O, and soot) and unburned components of the volatilized fuel (such as inert components and excess pyrolyzate). A model was credited with simulating fire product transients if it addressed the bulk fire product, CO_2, or soot.

Table II shows that simple layer fire models are restricted to gas temperature predictions (one out of three), whereas models with radiation exchange capabilities sometimes track soot and CO_2 concentrations (two out of three). We did not find a simple two-layer model that ignores radiation but still simulates both oxygen and fire product generation. Because such a model is essential for the simulation of forced ventilation spray fires, we developed such a model. This new forced ventilation fire model is included in Table II.

Compatibility with User Requirements

A single-compartment fire model alone cannot simulate the fire hazards described above. To illustrate, the new Los Alamos fire model has no capability to simulate bi-directional flows, flames, and heat loss to the fuel. Building fire models do not simulate ventilation control, oxygen, and burn product concentrations. All of these parameters are simulated by the Los Alamos fire model. Thus, a second and more detailed evaluation of compartment fire models was initiated to find out whether models could be modified and integrated to simulate all fire hazard classes. Preliminary screening criteria are given in Table II. The ratings represent our current subjective judgment and will be confirmed or amended by comparing test predictions with forced ventilation fire tests.

IV. Simulation of Forced Ventilation Spray Fires.

Los Alamos and the Lawrence Livermore National Laboratory (LLNL) coordinated their independently sponsored fire research programs to share existing capabilities for simulating forced ventilation spray fires. Model selection was based on the readiness of models to predict forced ventilation spray fires ahead of the test. Selected models then were assessed by comparing predictions with those from other models and with the tests.

Experimental Simulation

All fire tests were conducted in the LLNL fire test facility shown in Fig. 3. The tests used nonsmoking fuels, that is, methane, methanol, and isopropanol, and the test method was borrowed from previous filter plugging tests.[23] The main drawback of this approach is that volumetric exhaust and composition gases are

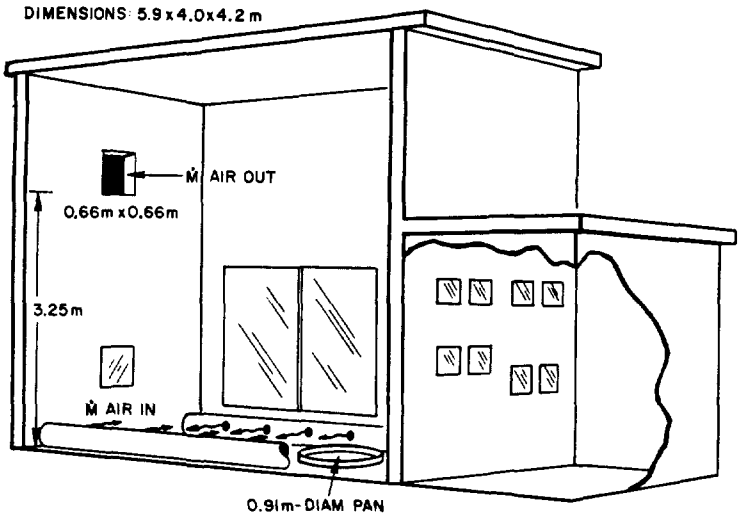

Figure 3. Lawrence Livermore National Laboratory burn room.

measured at the downstream high-efficiency particulate air (HEPA) filter end of a 9.75-m-long duct where exhaust temperatures have cooled to approximately 100°C. Information on composition in the hot layer and exhaust duct inlet was not available.

Individual fires were characterized by nominal fire strength (expected heat release in kilowatts) and nominal ventilation strength (expected volumetric exhaust flow rate at the HEPA filter in liters per second). A summary of the fires that are being used in our current assessment is given in Table III.

Table III. Preliminary verification of maximum temperature[a] predictions by Caltech and Los Alamos fire models.

Fire Strength (kW)	25	50	50	200	200	400	400	800	800
Forced ventilation (L/s)	250	250	500	250	500	250	500	250	500
Fuel Composition	← Methane →			← Propyl Alcohol →					
CALTECH/ Bolstad	---	175	110	157	103	305	575	---	---
CALTECH/ Creighton	60	183	111	627	357	1270	681	---	---
CALTECH/ Zukoski	--- to 168	144 to 97	86 to 584	486 to 263	311 to 1156	977 to 586	496 to	---	---
Los Alamos/ Krause	173	219	184	229	185	280	229	285	280
Experiment/ Alvares[c]	80	125	120	138	128	190	175	270	210

[a] Table temperatures are in °C.

[b] Using heat deposition input from Los Alamos model.

[c] Vertical temperature profile averaged over hot layer.

Analytical Simulation

Fire modeling groups at several institutions were asked to predict the planned tests. The modeling groups were asked to predict eight fire tests that were characterized by combustion heat release (50 kW, 100 kW, 200 kW, and 400 kW) and two controlled exhaust flow rates (250 L/s and 500 L/s). Model predictions were made ahead of the test by J. Bolstad (Los Alamos, Caltech model), J. Creighton (LLNL, Caltech model), F. Krause (Los Alamos, Los Alamos model), and E. E. Zukoski (Caltech, Caltech model). The Caltech and Los Alamos models were selected for the initial assessment. The results of the pretest predictions are summarized in Table III for the hot-layer temperature.

The major differences in these predictions are the assumed amount of heat deposition in the burn room gas. Heat deposition refers to the difference between enthalpy flux out (exhaust) and enthalpy flux in (air intake + spray). Creighton assumed that the total heat of combustion goes into the gas. This assumption overestimated the hot-layer temperature by the largest margin. Zukoski allowed for some heat loss to the wall, which was based on professional judgment and open-door fire tests. Resulting hot-layer temperatures are lower than Creighton's estimates but are still much too large for the recirculation time period. Bolstad and Krause estimated heat depositions by back-calculating previous fire tests. These predictions are much more reasonable but circumvent the unresolved problem of input selection. Comparing the pretest predictions illustrates the importance of input assumptions on heat deposition during fire product recirculation and also illustrates the large uncertainty of these inputs.

Krause estimated heat deposition in the gas by back-calculating previous crib fire tests. These predictions showed that 50-kW and 100-kW fires would be too weak to generate any burn product descent and that the burn product from the 200-kW fire would descend only 23% of the ceiling-to-fuel-top distance. Bolstad used these same heat deposition estimates.

In the case of weak fires, heat deposition was not available and convective heating rates were assumed to vary between 10% to 20% of the combustion heat release. With these inputs, the Caltech model predicted that the burn products would always descend close to the floor no matter how weak the fire is.

The very first tests at LLNL used methane spray with fire strengths of 25 kW and 50 kW. Visual observation of temperature-profile displays showed that transparent burn products did descend partially although they did not descend close to the floor. Thus, we concluded that crib fires simulate spray fires poorly. A new set of heat deposition inputs was chosen by back-calculating the 25-kW methane fires. We could make the burn product descend very slightly (2.5%), but we could not match the observed ceiling temperature (178°C that was calculated vs the 80°C determined experimentally).

The above comparison of the pretest predictions clearly shows that neither the Caltech model nor the Los Alamos model is ready for spray fire predictions. Usable fire models would need a reliable method for predicting the final heat deposition in the gas either from laboratory tests or from thermodynamic principles. Given reliable inputs, available models still must be updated to more correctly describe the partial descent of fire products during weak or overventilated fires. Back-calculation of heat deposition from previous fire tests in the same facility is not acceptable for a ventilation systems analysis where variation of burn room architecture and ventilation strength is one of the major user requirements.

Comparison of Predicted and Measured Burn Room Transients

Comparison of predicted and measured burn room transients is based on model predictions that use the back-calculated heat deposition values. This means that all Caltech model predictions were repeated after the tests by using heat deposition time history inputs that were produced by pretest predictions with the Los Alamos model. In this way, the comparison of the two models reflects the difference in fire physics assumptions and not individual opinions on model inputs.

The following subsection discusses the comparison of modeled and predicted fires for only one test that is typical for stronger fires (200 kW and more). Similar disussions of the other fire tests were omitted for brevity because both models and test methods are far from being finalized. Analytical simulations must be updated with better heat deposition estimates and experimental simulation must include sampling stations in the hot layer and/or the exhaust duct inlet. However, the conclusions do reflect information from all tests and not just from the one test used for illustration.

Heat Deposition in the Gas. Heat deposition in the burn room gas is an output from the Los Alamos model pretest prediction and an input to the Caltech model. The time history of the pretest prediction is shown in Fig. 4. However, there is no known experimental way to measure heat deposition directly. Comparison with experiments is indirect and is based on a convergence of evidence. Experimental evidence for heat deposition is available from heat release oven tests and from air intake measurements.

E. Smith and A. Tewarson have developed heat release ovens to measure the apparent heating value and generation rates of combustible vapors, smoke, toxic products, and corrosive products.[24],[25] Scalability of generation rates is tested by repeating the small-scale (10-cm by 10-cm by 10-cm test sample) combustion test at intermediate scale (.3-m by .3-m by 4.3-m high samples) and large scale (3-m x 3-m x 3-m).[25]

The majority of generation rates proved to be both reproducible and scalable. Data obtained so far indicate that simulation and testing of site-specific noncharring materials may not be necessary because materials could be classified in

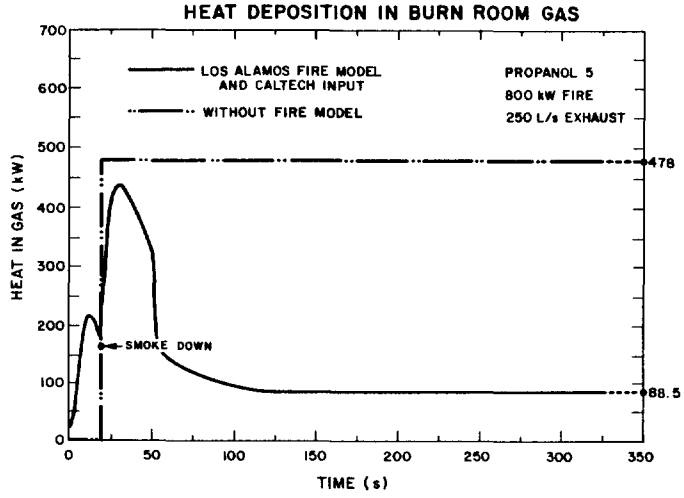

Figure 4. The prediction of the heat deposition in the burn room gas.

four groups based on chemical structure (nonaromatic, nonaromatic/aromatic, aromatic, and highly halogenated fuels). Thus, Tewarson's test method provides an important first step for simulating heat and mass release for noncharring materials. Smith oven tests have accumulated similar information on a large variety of materials and also might be used as soon as the scalability of release rates has been confirmed.[24]

A preliminary method for converting Tewarson's test results into heat disposition has been outlined by P. C. Owczarski.[26] The key assumption is that fires will rapidly grow to a stationary stage, which reflects the release rates per fire area that are measured in release rate oven tests. The release rates at fire zone openings then are step functions.

Using the step-function approximation, heat convection ($\dot{Q}_c$) through fire zone openings can be calculated from Tewarson's empirical data for convective heat release efficiencies.

$$\chi_c = \frac{\dot{Q}_c}{\dot{m} H_f} \quad , \tag{1}$$

where H_f (kilojoules per gram of fuel) denotes the apparent heating value of the fuel and $\dot{m}$ denotes the spray injection rate (g/s). This estimate of convective heat release describes the difference between ingoing and outgoing enthalpy fluxes.

$$\dot{Q}_c = \underbrace{\rho_h C_{ph} T_h \dot{V}_{ex}}_{\text{(hot exhaust)}} - \underbrace{\rho_a C_{pa} T_a \dot{V}_{in}}_{\text{(air intake)}} - \underbrace{C_{pf} T_f \dot{m}}_{\text{(fuel intake)}} \quad , \tag{2}$$

where ρ denotes density, C_p denotes heat capacity, and $\dot{V}$ denotes volumetric flux. The subscripts (h, a, f, ex, and in) are explained by the labels.

The step function of Fig. 4 illustrates the pretest prediction of the heat deposition in the gas that was made by extrapolating Tewarson's data. Proponal is also a nonaromatic fuel, and its convective heat-release efficiency should closely match that of other nonaromatic fuels. We use the value $X_c = .6$, which was selected by Mishima for nonaromatic fuels.[27] The mass burning rate $\dot{m}$ is given in terms of the nominal fire strength (Q_n),

$$\dot{Q}_n = H_f \dot{m} \quad .$$

Extrapolation of heat release oven tests is given by

$$\dot{Q}_c = .6\, \dot{Q}_n \quad . \tag{3}$$

This value represents the step function of Fig. 4. The step was placed at the time the fire products are within the vicinity of the floor. At this "smoke down" time, the burn room has filled with heat-absorbing substances, and heat deposition in the gas should be a maximum because the hot layer gas temperature is still cool that is, wall heat losses are still small.

The main difference between the direct extrapolation of heat release rate oven tests and the Los Alamos fire model is the duration of the peak. The fire model predicts that heat deposition in the gas will recede quickly from its peak value while the burn room gas gets hot, although the oven tests do not simulate such an increase of heating loss.

Additional experimental evidence of heat deposition may be obtained by converting the predicted heat deposition Q_c, which cannot be measured directly, to air intake predictions that are measured directly. Mathematically, this means that we have to solve Eq. (2) for the intake flux V_{in}. The temperatures in the hot layer (T_h), the ambient air (T_a), and the volatized fuel (T_f) are coupled by the isobaric condition of the fire zone. Neglecting the weak dependence of the molecular degrees of freedom on combustion product chemistry, we can approximate this coupling by using the following equation of state.

$$C_{ph}T_h\rho_h = C_{pa}T_a\rho_a = C_{pf}T_f\rho_f = 3.5\ p \quad , \tag{4}$$

where p denotes the hydrostatic pressure.

Substituting Eq. 4 into Eq. 2 and solving for $\dot{V}_{in}$ gives

$$\dot{V}_{in} = \dot{V}_{ex} - \frac{\dot{Q}_c}{3.5p} - \frac{\dot{Q}_n}{H_f\ \rho_f} \quad . \tag{5}$$

Thus, the intake flux is linearly proportional to the heat deposition in the gas in forced ventilation fires with the volumetric exhaust $\dot{V}_{ex}$ is held constant. Figure 5 shows the time history of the intake flux that was calculated using heat deposition shown in Fig. 4 according to Eq. (5) with the handbook value H_f = 33.2 kJ/g. This curve is labeled "Los Alamos Fire Model" and reflects the physical assumptions of Eq. (4). The assumptions of the Caltech model, although considerably more complex, lead to a similar result. Both models appear to be roughly equivalent and bracket the final intake flux. Based on this evidence, the predicted heat deposition time history of Fig. 4 appears to be a reasonable approximation of the real heat deposition. The sharply peaked and transient nature of this heat deposition is surprising because both the mass burning rate and the volumetric exhaust $\dot{V}_{ex}$ are held constant throughout the test.

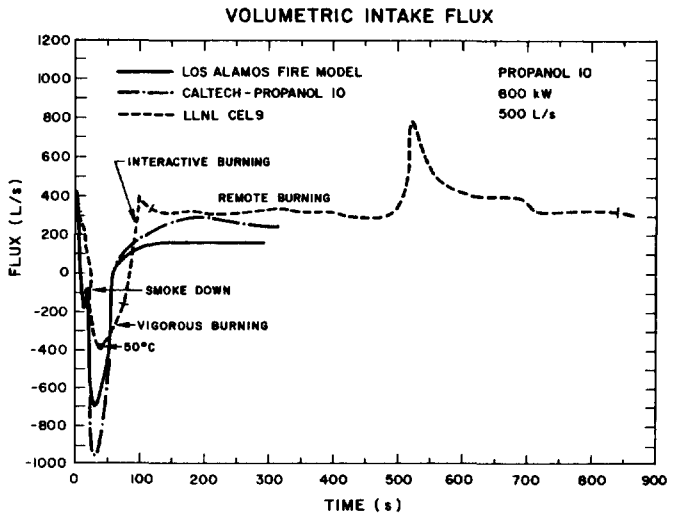

Figure 5. Comparison of intake fluxes.

The negative intake flux in Fig. 5 indicates that gases are blowing out of the intake opening; that is, the estimated amount of convective heat release can be accomodated only by flow reversal in the intake duct. A negative intake cannot exist for an extended time period because the fire will terminate through oxygen starvation. Thus, heat release oven tests are useful to estimate the transient peak heat deposition in the initial stages of the fire that will end with the descent of the fire products. However, heat release ovens do not adequately simulate the final stage of heat deposition.

Burn room temperatures. Burn room temperature profiles show the extent of the hot layer as indicated in Fig. 6. The time history of the near-ceiling temperature shown in Fig. 7 is also an important indicator of fire growth and fire recession.

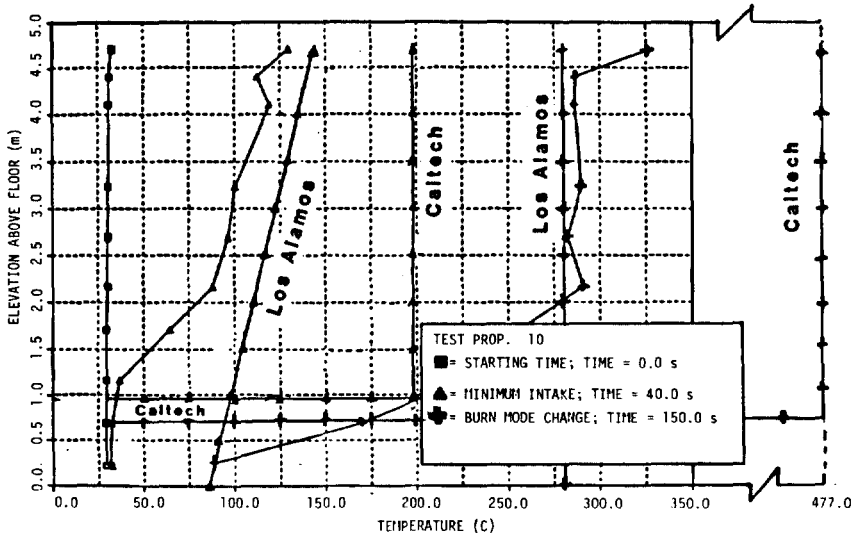

Figure 6. Temperature stratification, empirical events.

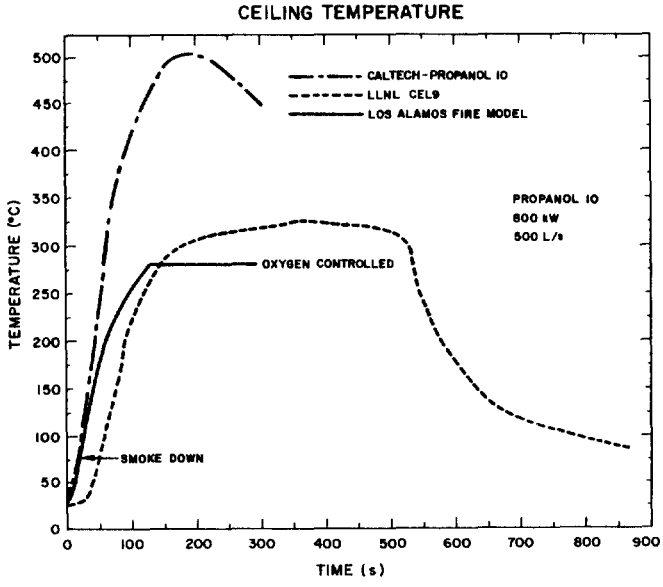

Figure 7. Comparison of ceiling temperatures.

The measured temperature profiles of Fig. 6 are plotted for special event times that represent miminum air intake and burn mode transition (strongest curvature of the near-ceiling temperature-time history). See Fig. 7. A comparison of measured and predicted temperature profiles shows that the fire products do not descend all the way to the floor, as assumed by the Los Alamos model, but leave a cool layer, as assumed by the Caltech model. However, this layer is almost twice as thick as predicted by the Caltech model. Hot-layer temperatures are overpredicted by the Caltech model, whereas the Los Alamos model gives a reasonable approximation.

The temperature-time history in Fig. 7 shows rapid fire growth for about 110 s after the fire product descent has stopped. The stationary fire exists from 140 s to 540 s and then is followed by fire recession.

Using the Los Alamos model, we speculated that the stationary fire stage would be characterized by oxygen starvation, which is initiated by a time-limited period of intake flow reversal. This speculation is based on a residual oxygen concentration of 13% that characterized the self-termination of flammable liquid fires in water-sealed compartments.[28] This speculation is not born out by the test as shown by the measured oxygen concentration time history in Fig. 8. Apparently, heat deposition in the gas is limited entirely by wall heat losses and not by an oxygen-controlled decrease of combustion efficiency.

NFPA, after reviewing many compartment fire tests with an open door or window, postulated building fire growth stages that are based on ceiling temperature and combustion heat release as shown in Table IV.[29]

Comparing the qualitative fire growth classification with the heat deposition of Fig. 4 and ceiling temperature of Fig. 7, we concluded that minimum intake coincides with vigorous burning and fire growth is associated with interactive burning. The stationary fire might be associated with remote burning provided the temperature threshold of remote burning is lowered from 400°C to 300°C. There are no remote pieces of furniture in the LLNL burn room, and remote burning (if it exists) would describe the ignition of remote fuel vapor accumulations in the hot layer. The instability of the intake flux after 450 s (Fig. 5) may support such speculation. Intake flux instability is more pronounced in weaker fires where the hot layer containes more oxygen.

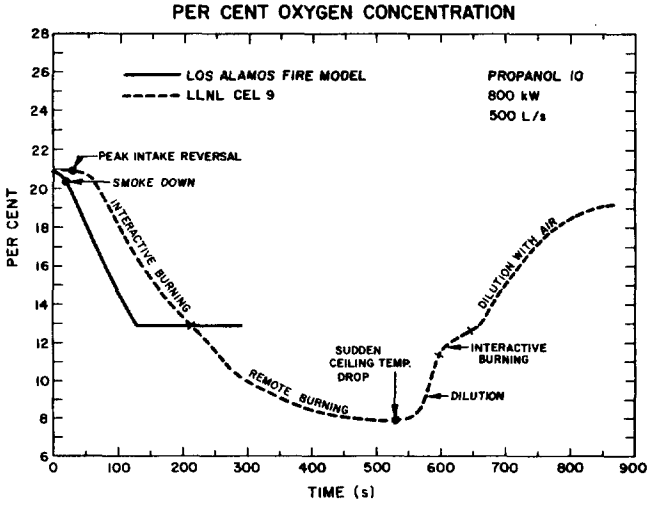

Figure 8. Comparison of oxygen concentration.

Table IV. NFPA classification of fire growth phenomena.

State	Phenomenon	Thermodynamic Definition
1	Preburning	No flames.
2	Sustained burning	Ignition (including smoldering) has occurred in the room of origin, but heat release rate does not exceed 2 kW.
3	Vigorous burining	Heat release rate inside the room of origin is between 2 and 50 kW, but the upper peak room temprature is less than 150°C.
4	Interactive burning	Average upper room temperature is between 150°C and 400° C, causing secondary ignitions beyond the room of origin but with heat release less than 2 kW.
5	Remote burning	Average temperature in room of origin is greater than 400°C, causing secondary ignitions beyond the room of origin with heat release of less than 2 kW.
6	Full room involvement	Burning beyond the room of origin releasing 2 to 50 kW; secondary fires have reached state 3 conditions.

Hot layer oxygen concentrations. Oxygen concentrations measured at the HEPA filter would be representative of the oxygen concentration in the hot layer, provided the composition of the exhaust gas does not change in the duct and the duct does not entrain outside air through leaks.

Figure 8 shows the comparison of measured and predicted oxygen concentrations. The measured curve is labeled with the NFPA burn mode classification assuming ceiling temperature thresholds of 150°C and 300°C. The label "dilution with air" refers to any time period during which oxygen concentration increases and temperatures decrease. The comparison shows that predictions of oxygen concentration time histories are reasonable above the assumed threshold of 13%.

The experimental curve goes to concentrations below the 13% threshold, and the transition threshold is marked by a transition from interactive to remote burning. Similar coincidences of residual (sealed self-termination) oxygen thresholds and fire growth stages are found in the other tests. Unfortunately, the data base is insufficient to confirm that NFPA criteria for fire growth may be extended to forced ventilation fires.

Fire product concentration. Fire product concentrations are important in nuclear facilities analysis because product release outside the fire zone may clog filters, produce health hazards, corrode sensitive electrical contacts or detectors, and produce acid waste water. Fire product concentrations are also the cornerstone for verifying the Los Alamos fire model because the model is based on a solution of the fire product balance equation.

Fire product concentration is defined as total hot-layer mass concentration (100%) minus concentrations of residual oxygen and nitrogen gas. Thus, "fire product" denotes all foreign mass other than air and is made up of unburned fuel (excess pyrolyzate) as well as all products of combustion. In the LLNL tests, fire product components are CH_x, smoke particles, CO_2, H_2O, and CO.

The LLNL tests directly measured Ch_x equivalent CH_4, CO_2, and CO concentrations. Time histories of H_2O concentrations were assumed to be directly proportional to CO_2 concentrations. The factors of proportionality for methane (.82) and propanol (.72) fuel were estimated assuming stoichiometric combustion that produces only CO_2 and H_2O. Smoke concentration was ignored because methane and propanol usually burn lean (without generating any visible smoke). Our neglect of smoke is uncertain during periods of remote burning where visual observation indicated the formation of a black but still transparent smoke.

Figure 9 shows a comparison of predicted and measured fire product concentrations. The experimental curves were calculated by adding measured CO_2, CO, and CH_4 concentrations to estimated H_2O concentrations. All curves are labeled according to the burn-mode transitions that were discussed in preceeding sections.

The comparison of experimental and predicted fire product concentrations also shows a reasonable agreement for interactive burning. One intriguing new fact is that experimental oxygen and fire product concentrations are mirror images of each other. This may indicate that nitrogen mass concentration is constant because depleted oxygen is replaced by fire products.

V. Summary and Conclusions

1. A method for simulating fire product exposure of ventilation system components should meet the following performance requirements.
   - Provide model inputs on heat and fire product release rates for spray fires, pool fires, surface fires of noncharring materials, surface fires of charring materials, and deep-seated fires.
   - Simulate temperature and composition transients of the burn room atmosphere for each of the above hazards as well as for fire growth and recession, which is caused by heat and mass release dependance on atmospheric transients.

2. A review of seven building fire models showed that multiroom models may be manipulated to simulate forced ventilation by replacing unidirectional exhaust flow with a fictitious second room. However, all multiroom models lack the capability to simulate burn room transients of oxygen concentration and fire

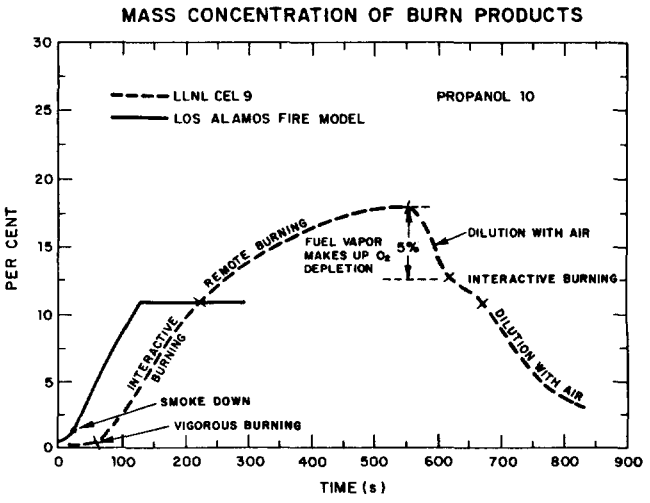

Figure 9. Comparison of burn product concentrations.

product concentration. Burn room composition transients are partially simulated by higher-level building fire models that simulate radiation exchange. However, at present none of the high-level models can simulate forced ventilation. Existing building fire models are not designed to simulate spray fires, surface fires of charring materials, and deep-seated fires.

3. Pretest predictions of forced ventilation spray fires were made with the Caltech and Los Alamos fire models. The comparison of the pretest predictions showed that
   - forced ventilation fires are characterized by a highly time-varying heat deposition in the burn room gas that peaks at the time when the descent of the fire products is stopped and
   - the final stationary rate of heat deposition is smaller by a factor of 3 to 5 than estimates based on the extrapolation of heat release tests.

4. A comparison of predicted and measured burn room transients showed the following.
   - Two-layer building fire models and the Los Alamos fire model show promise to predict both temperature and composition transients of the burn room atmosphere for spray fires, surface fires of charring materials and deep-seated fires.
   - The Caltech and Los Alamos models are not ready to simulate forced ventilation fires. The following simulation capabilities must still be developed and demonstrated.
     (1) Partial fire product descent for moderately strong fires
     (2) Spray fire of smoky fuels
     (3) Burn room transients caused by oxygen starvation
     (4) Heat and mass release input selection for fire hazards other than fuel spray

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DISCUSSION

LEYSE, R.: I realize you did not give the paper on the Accident Analysis Handbook, but do you think it would be premature to release the Accident Analysis Handbook as early as January 1983, based on your progress.

KRAUSE: Although this work is part of the Accident Analysis Handbook, I am not sure I can answer the question. I think the lack of knowledge on cross-ventilation fires is such that it will take a major research program to fill the gaps. We would very much like to see a coordination of effort for programs in this area. On the other hand, we cannot wait, so we make simple estimates. I have given you some of the insights from this research that can be used as a substitute for better data, keeping in mind that you have a "garbage in - garbage out" problem. I believe we now know something about spray fires and we will find out whether they are true for other kinds of fires. There may be some simple rules, such as: the maximum mass you can produce is proportional to the oxygen that has been consumed.

LEYSE: You referred to reactor fires and a Factory Mutual report called, The Evaluation of Fire Hazards. Is there any merit to trying to reconstruct that experience?

KRAUSE: The Factory Mutual report was most interested in light water reactors and our work is aimed at nuclear facilities other than light water reactors; the main difference being cable fires.

ROUYER: Did you calculate overpressurization?

KRAUSE: No. Most compartment fire tests show pressure transients are so small that they do not affect balance equations. This shortcut to modeling may be in error in airtight fire zones that can take significant overpressures. An estimate of overpressures could be derived from the air intake flow as long as the flow resistance of the intake opening is known.

ROUYER: What is your experimental experience concerning stratification related to the position of inlet and outlet ventilation ducts?

KRAUSE: A stable two-layer stratification was assured by using a near-ceiling exhaust and near-floor intake opening. We would anticipate an unstable temperature stratification if exhaust and intake were switched. The burn room atmosphere should then resemble a single-layer, well stirred reactor. However, in forced ventilation fires, the hot layer extends close to the floor. There may not be much difference between one or two layer models with regard to the final stage of the fire.

Fire Testing of HEPA Filters installed in Filter Housings

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Abstract

The objective of the test programme was to (a) establish that in adopting a realistic high temp test of HEPA filters this could lead to a more flexible approach in their design and (b) to establish the max air inlet temp for filters in standard housings.

The filter units tested were constructed using established production techniques with wood, plastic and steel cases, also various gasket and paper edge seal materials.

The tests were in two parts (a) to tests at 500°C for periods of 10 minutes and 45 minutes to ascertain whether continuous operation was feasible without impairing the filtration efficiency too greatly and (b) to establish the max inlet face temp before break through of the flame and the destruction of the filter.

The testing demonstrated that wooden cased HEPA filters could withstand inlet air temp of 500°C for in excess of 45 minutes without impairing the containment or resulting in unacceptable filtration efficiency. The time temp relationships based on BS 476 part 8, 1972, showed that the wooden case filters remained unbreached for 25 minutes and the max air temp associated with this period of time was approx 825°C.

The tests demonstrated that the geometry effect, the insulating properties of materials, the methods of construction, and the heat loss by radiation are all factors in establishing the temp criteria.

The figs illustrate the temp/time curve, the rig set up, the tests in progress and the subsequent fire damage.

1. Introduction

The designated test of filter packs in the UK to establish their acceptance as a so-called high temp resistant unit is to insert the pack in an oven at 500°C for a period of ten minutes without it contributing to combustion It is considered that this is a rather severe test and is very much removed from reality. These high temp resistant filters are usually fitted as primary filters and as such contain the long lived fission product nuclides which present problems in their disposal as radioactive waste. An ideal material for this aspect of the filter design would be wooden cases, so a preliminary series of fire tests on wood samples was carried out before the design of filter packs was undertaken.

The tests described in this report are an introduction to considering further hot testing at the designed flow of HEPA filters and also to investigate the use of materials more compatible with methods of disposal. It was considered that evaluation using a simple test facility with no forced circulation of the hot air or analysis of the dust burden should be the starting point. This to be followed by a custom built rig for more detailed analysis at some time in the future.

The filter packs used were developed and supplied by Vokes Air Filters Ltd, Burnley, UK, with exception of test no 16 in which a "high flow" unit was used. The test facility used was the standard fire testing equipment of the Warrington Research Centre, Warrington UK who supply a fire research, testing and consultancy service to the UK industries.

2. Wooden cases for Filter Packs

As a starting point prior to fire testing the filter packs in their housings, it was decided that it would be worthwhile to carry out an investigation into the treating of wood to improve its flame retardant properties.

Purpose of Investigation

To assess the ignition characteristics of chipboard and a plywood material when they are subjected to elevated temperatures in the absence of any pilot ignition.

Materials tested

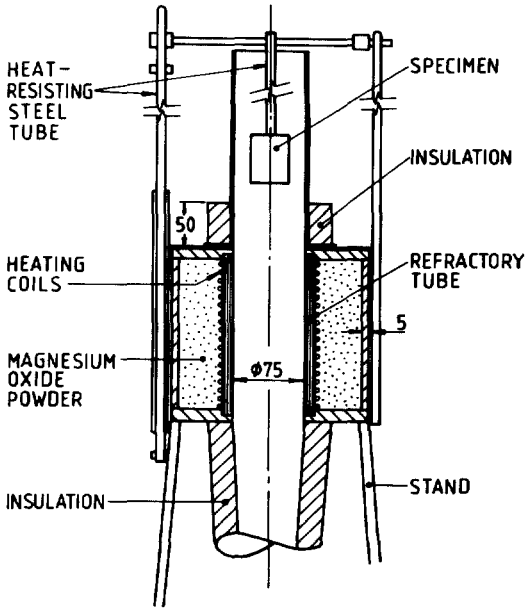
A chipboard material, nominally 12.7mm in thickness, and a plywood material, nominally 12.7mm in thickness, were the subject of the investigation. They were in the form of boards measuring approximately 600mm by 300mm and two boards of each material were supplied.

One board of each material was submitted to The Timber Fireproofing Co Ltd, Market Bosworth, Leicestershire, where it was impregnated with flame retardant salts by the 'Oxylene' vacuum pressure impregnation process to an average dry net salt retention of 50.5 kg/m^3.

Prior to test the materials were conditioned to equilibrium moisture contact with air at a relative humidity of 55-65% and a temperature of 20-22°C.

Method of Test

Two methods of test were utilised to examine the ignition behaviour of the materials:



DIAGRAMMATIC ARRANGEMENT OF THE APPARATUS USED TO SUBJECT THE TEST SPECIMENS TO ELEVATED GAS TEMPERATURES

Fig 1

Method A

Small specimens of the material were inserted into the stream of hot gases rising from an electrically heated vertical cylindrical furnace. The furnace was adjusted to produce the test temperature at the centre of a 75mm diameter vertical tube prior to insertion of the test specimens. The test specimens measured 50mm by 45mm by 12.7mm thickness and they were inserted into the vertically rising gas stream with their 50mm dimension vertical. A diagrammatical arrangement of the test equipment is shown in Figure 1.

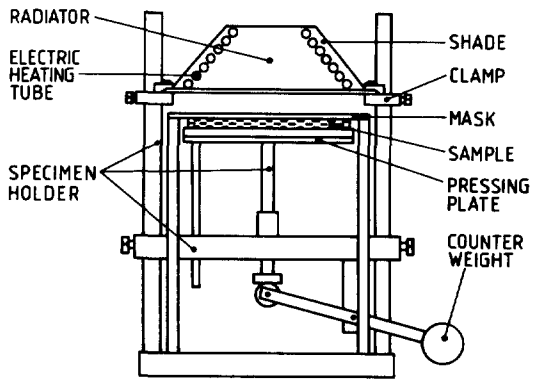
The apparatus was set at an initial temperature of approximately 480-500°C. The time of any ignition, defined as sustained flaming of greater than 10 seconds duration, was noted, and the temperature rise within the vertical tube was monitored.

Test Results

Table 1 gives for Test Method A the ignition times for each material together with the initial gas stream temperature and the temperature of the gas stream at the time of ignition.

Table 1 - Results of Test - Test Method A

Material	Initial Gas Stream Temp. °C	Ignition Time. min	Gas Temp °C at Ignition or at 20 minutes
Plywood	479	7	564
Oxylene treated Plywood			
Specimen 1	482	No ignition	576
Specimen 2	500	at 20 mins	565
Chipboard	475	6	570
Oxylene treated Chipboard			
Specimen 1	484	No ignition	592
Specimen 2	488	at 20 mins	549



DIAGRAMMATIC ARRANGEMENT OF THE APPARATUS USED TO SUBJECT THE UPPER SURFACE OF THE TEST SPECIMENS TO RADIANT HEAT

Fig 2

Method B

An area of the upper surface of a horizontally orientated specimen was exposed to radiant heat from a conical radiator using the apparatus shown diagrammatically in Figure 2. Each specimen measured 165mm by 165mm by 12.7mm thickness and the central 150mm diameter area was subjected to an irradiance of 3 watts/square centimetre. A thermocouple was fixed into a small groove cut into the top surface of each specimen to monitor the surface temperature at the centre of the exposed area. For each material the time of any ignition of the surface was noted, together with the temperature rise of the upper surface.

Discussion of Results

When small specimens of untreated plywood and untreated chipboard were inserted into a gas stream, which was at a temperature of approximately 480°C-500°C, such that both faces of the material were subjected to heat, ignition occurred after periods of approximately 7 minutes and 6 minutes respectively for the plywood and the chipboard. When similar specimens of 'Oxylene' treated plywood and chipboard were subjected to the same heating environment, no ignition of either material occurred within a period of exposure of 20 minutes.

When one surface only of specimens of untreated plywood and untreated chipboard was subjected to a thermal irradiance of 3 watts/cm^2, ignition of the chipboard occurred after approximately 2½ minutes, at which time the surface temperature had risen to approximately 450°C, whereas ignition of the plywood did not occur within the 20 minute test period at which time its surface temperature exceeded 600°C. When similar specimens of 'Oxylene' treated plywood and chipboard were subjected to the same irradiance, no ignition of either material occurred within the 20 minute test period, although the temperature of their surfaces had reached in excess of 550°C.

3. Filter Packs Tested

The filter packs were the standard size 1000cfm, the materials used were:

i Wooden plywood cases impregnated with a flame retardant salt using the Oxylene process with the standard high temp filter edge seal material ie glass-fibre wool and silicone rubber gaskets.

ii As above, using untreated wood.

iii As above, wood painted with "Trimonox" fire retardant paint with silicone rubber edge seal of filter paper.

iv Standard steel case filters.

v As above with silicone rubber gasket.

vi Standard low temp high flow unit.

4. Filter Housings

The filter housings used were standard units in use in the industry in the UK with no special preparations for fire testing, these were:

i A new design of housing in use at the UKAEA Dounreay site.

ii Standard mild steel painted "Unipak" single housing manufactured by Vokes Air Filters Ltd, UK.

iii Standard stainless steel "Ozonair Safechange" unit manufactured by Ozonair Engineering Co Ltd, Maidstone, UK.

5. Test Facility

The gas oven was box shaped approx a four foot cube with the air inlet and observation holes on one side, the natural gas flame being emitted from the adjacent side. The filter housing was placed on top with an aperture the same size as the housing. This arrangement allowed the hot air to flow vertically through the units giving a measure of flow due to natural convection.

A total of 25 thermocouples were fitted, these were coupled through a print out unit taking readings at 1 minute intervals.

6. Test Procedure

The natural gas was ignited and the air inlet temp to the filter units was brought up rapidly to the test temp and held there by manual adjustment. The air flow through the filter was not controlled, the hot air and fumes emitted was extracted from the building using the building extract system. The print out was monitored to give adequate warning of any materials reaching ignition temperature.

7. Test Programme

In the first phase of testing each housing was installed in turn and an initial test was carried out at 500°C for 10 minutes. This was followed by 500°C for 45 minutes. The filter packs were removed and despatched back to Vokes Air Filters Ltd, for filtration efficiency tests. A replacement unit was then inserted and a test to destruction carried out.

The second phase of testing was 500°C max temp tests for 10 and 45 minutes duration using the "Unipak" housing only. Again the filter packs were returned to Vokes for filtration efficiency tests. These tests were designed to test various combinations of materials used for encasing and sealing the filter pack.

8. Test Results

Table II gives a complete summary of the important tests that were carried out. A preliminary test of 500°C for 10 mins was carried out prior to the extended and destruction tests as reported in this report. In no case was there fire damage severe enough to cancel the test apart from test No 16 which had a low temp high flow filter pack installed.

TABLE II FIRE TESTING OF FILTERS IN HOUSINGS

TEST NO	TEST DETAILS	FILTER MATERIALS			FILTER CASE TEMPERATURE		HOUSING TEMPERATURE		TEST RESULTS		
		CASE	GASKET	EDGE SEAL	CENTRE	BOTTOM	TOP	BOTTOM	CASE	GASKET	FILTER PAPER
1	A	Impregnated wood	Silicone Rubber	Glass-fibre	42		30		Not affected (NA)	Slightly discoloured (SD)	SD
2	B	"	"	"	86		73		Wood bead charred (WBC)	Cracked where exposed (CWE)	Discoloured (D)
3	C	"	"	"	105		109		Flame broke-through after 28½ minutes maximum air inlet temperature = 820°C (See Figures 5, 6 & 7)		
4	B	Untreated wood	Glass-fibre	"	108		80	300		Stuck to housing	SD
5	C	"	EPDM RA25	"	125/28 MIN 300/30 MIN		150	700	Flame broke-through after 31 minutes maximum air inlet temperature = 850°C (See Figures 10, 11 & 12)		
6	B	Treated wood (painted)	Silicone Rubber	"	108		70	158	WBC	Softened but OK	D
7	C	Untreated wood	"	"	100	230	74	310	Flame broke-through after 24 minutes maximum air inlet temperature = 790°C (See Figure 14)		
8	B	"	"	Silicone Rubber		232	114	375	Case charred (See Figure 15)	D	D
9	B	Steel	Glass-fibre	Glass-fibre		229	95	372	NA	Maximum gasket temperature = 274°C	D
10	B	"	PVC	"		238	105	365	NA	Melted MGT = 248°C	D
11	B	Untreated wood	Silicone Rubber	Silicone Rubber		221	104	321	WBC (See Figure 17)	D & CWE MGT = 283°C	D
12	B	Steel	"	"		243	108	363	NA	D MGT = 268°C	D
13	B	Untreated wood	"	"		218	108	370	WBC & D	Bond to wood failed in places MGT = 300°C	D
14	B	Steel	Glass-fibre	Glass-fibre		279	64	335	NA	D Delaminated at all edges MGT = 204°C	D
15	B	Steel	Silicone Rubber	"		286	55	322	NA	NA -	D
16	A	Plastic	"	ABS		58	103	294	Distorted	NA	Badly damaged
									White smoke at 1½ minutes (See Figure 18) Flames appeared at 4½ minutes Seal between filter paper and case almost completely consumed (see Figure 19)		

Notes:

1) Test Details: A = 500°C for 10 mins. B = 500°C for 45 mins. C = BS476 (pt 8) 1972.

2) Tests 1, 2 & 3 in purged filter housing, 6 & 7 in "Ozonair" housing. Remainder of tests in a "Unipak" housing.

The following is a more detailed analysis of specific tests from the test programme.

Test No 1 500°C for 10 minutes

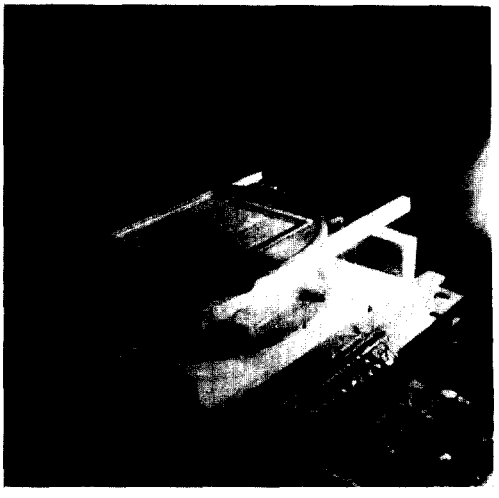


Fig 3

Filter housing installed in test facility.

Summary of Observations during Test

Light white smoke was given off from the upper surface of the filter during the test. The smoke production reached a maximum at approximately 8 minutes and then reduced to a negligible amount at approximately 11 minutes.

Summary of Inspection of Filter Unit after Test

The paper of the filter unit was slightly discoloured on the exposed face but the aluminium foil was unaffected. The unexposed face of the filter unit appeared to be unaffected. The timber beading on the exposed face of the filter unit was charred and cracked but otherwise intact. The treated plywood casing appeared to be completely unaffected. The silicone seal on the exposed face was slightly discoloured but was otherwise unaffected.

There were no holes through any part of the filter unit.

Test No 2 500°C for 45 minutes

Summary of Observations during Test

Light white smoke was given off from the upper surface of the filter during the test. The smoke production reached a maximum at approximately 10 minutes and then reduced to a negligible amount at approximately 22 minutes. The exposed timber beading of the filter unit started to glow at approximately 28 minutes and started to pull away from the unit at approximately 32 minutes.

Summary of Inspection of Filter Unit after Test

The paper of the filter unit was discoloured on both the exposed and unexposed faces but the aluminium foil on both faces appeared to be unaffected. The timber beading on the exposed face of the filter unit was badly charred and approximately 25% had fallen away. The timber beading on the unexposed face was unaffected. The treated plywood casing was charred in the area of the beading (ie the exposed edge of the casing) but was still in-tact and otherwise unaffected. The silicone seal on the exposed face was discoloured and cracked around the exposed edges but was otherwise unaffected.

There were no holes through any part of the filter unit.

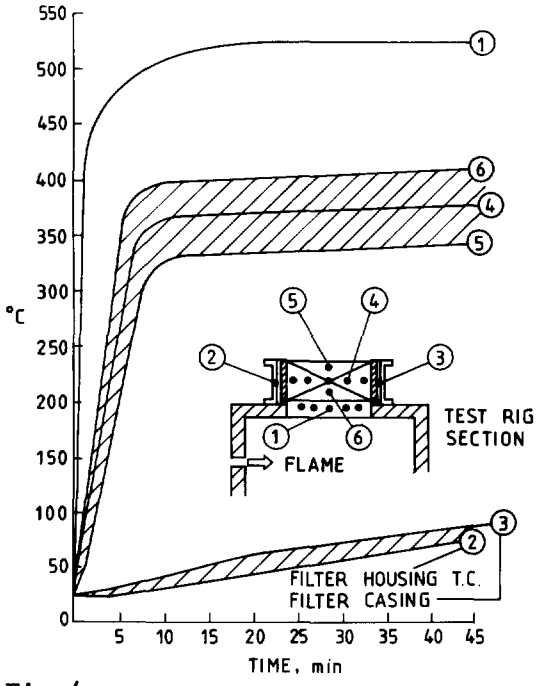


Fig 4

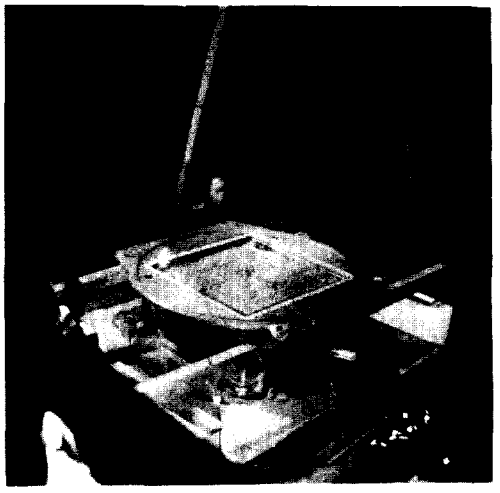


Fig 5

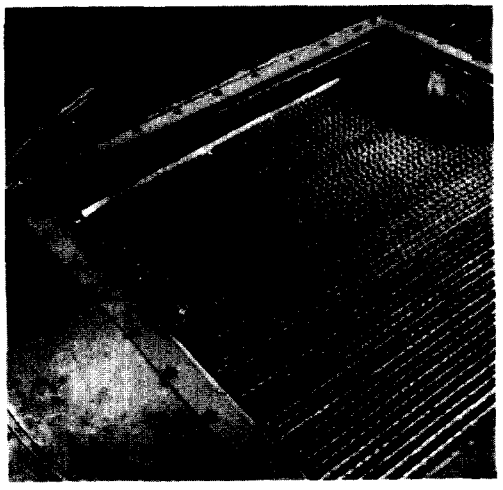


Fig 6

Temperature Log during Test

Fig 4 shows temp details during the test run.

Temp 1 is the inlet temp reaching test temp in approx 3 minutes.

Temp 3, filter casing and temp 2 housing are remarkably low. This was repeated in other tests. In these tests the whole of the inner surface of the filter casing was insulated with glass-wool which is the standard method of filter paper edge sealing in steel-cased high temp filters.

Test No 3 to BS 476 (pt 8) 1972

In this test the temp is increased progressively with time (as shown in fig 7) and the time for the flame to break-through signifies the end of the test.

Summary of Observations during Test

Light white smoke was given off from the upper surface of the filter during the test. The exposed timber beading of the filter unit started to glow at approximately 9 minutes and started to fall away at approximately 13 minutes. Intermittent flaming of the timber beading started at approximately 17 minutes and developed into steady flaming from approximately 20 minutes. At 25 minutes, the upper surface of the filter unit was still intact. At 28½ minutes flames broke through the filter unit at one corner and one minute later broke through at another corner. (See fig 5).

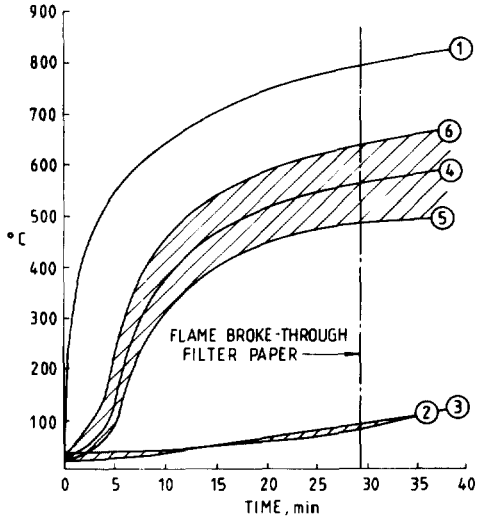
Summary of Inspection of Filter Unit after Test

Most of the filter media was intact but was badly distorted and was friable. A hole measuring approximately 250mm by 75mm had formed in one corner and another hole measuring approximately 300mm by 125mm had formed in another corner. The timber beading on the exposed face of the filter unit had been completely consumed. The plywood casing had been completely consumed in the areas of the holes in the filter media and the plywood had been damaged in adjacent areas. All of the silicone rubber seal on the exposed face had discoloured and some of the exposed edge had been consumed. Fig 6 is a view after

test showing damage to the downstream side of the filter unit. The filter case continued to burn gently after the test had been discontinued causing the damage shown to be rather worse than at the end of the test.

Temperature Log during Test

Fig 7 shows the temp during the test run. Temp 1 indicates the time-temp relationship of the BS 476 test procedure. The max temp before the flame broke-through was 830° after approx 28 min. Temps 2 and 3 are low as in previous tests. Ignition must have occurred lower down in the region of the lower gasket.



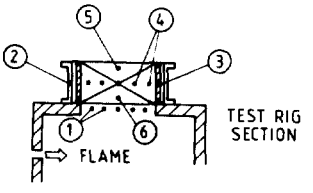


Fig 7

Test No 4 "Unipak" housing 500°C for 45 minutes

Summary of Observations during Test

Light white smoke was given off from the upper surface of the filter during the test. The smoke production reached a maximum at approximately 7 minutes and then reduced to a negligible amount at approximately 25 minutes. The paint on the filter housing began to discolour, at the bottom of the housing, at approximately 2 minutes and continued to discolour in this area throughout the test until light brown in colour. The paint on the filter housing in the area of the filter unit did not discolour at any time during the test. Fig 8 shows a view of the unipak on the test rig.

Fig 8

Summary of Inspection of Filter Unit after Test

The paper of the filter unit was slightly discoloured on both the exposed and unexposed faces Fig 6 but the aluminium foil protruding through both faces appeared to be completely unaffected. The timber beading on the exposed face of the filter unit was charred but intact. The timber beading on the unexposed face was unaffected. The plywood casing was slightly charred in the area of the

beading (ie the exposed edge of the casing) but the damage was negligible. The glass fibre seal was stuck to the filter housing and had to be forcibly freed before the filter unit could be removed from the filter casing. The seal was damaged on removal of the filter unit from the housing but the seal appeared to be maintained whilst the unit was clamped into the housing. There were no holes through any part of the filter unit.

The PVC sheet material, which had been positioned between the filter unit and the removable cover of the housing, had softened slightly during the test but remained completely intact.

The neoprene gasket which was used to seal the larger removable cover of the housing appeared to be completely unaffected but the neoprene gasket which was used to seal the smaller removable cover of the housing had melted along the top and bottom areas of the aperture, the neoprene at the sides of the aperture remaining unaffected.

Temperature Log during Test

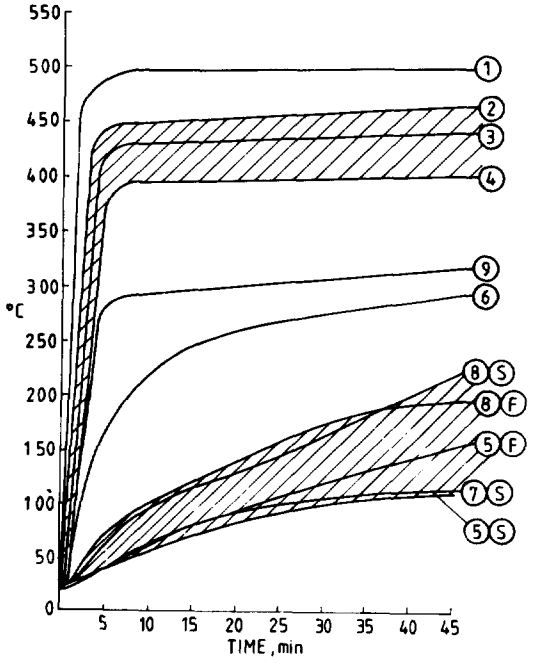


Fig 9 shows the temperature details during the test run. Temp 1 (inlet) and temp 4 (near outlet) shows the large proportion of the heat that escapes through the filter. Temp 6 shows the max gasket temp of 280°C but still rising slightly. Casing temp 8 front and side are reasonably the same the max being approx 220°C. The casing temp 5 front is higher than the 5 side, this can only be attributed to the 5 side being insulated with the filter paper on the inside and 5 front being the edge seal of silicone rubber.

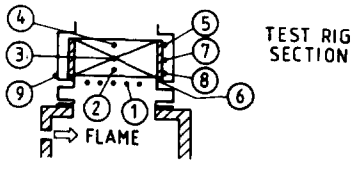


Fig 9

Test No 5 Unipak housing to BS 476 (pt 8) 1972

Summary of Observations during Test

Light white smoke was given off from the upper surface of the filter throughout the test. White smoke was also given off from the paint of the filter housing throughout the test. Large quantities of white smoke were given off from the PVC sheet material and/or the neoprene sealants used in the filter housing from approximately 15 minutes until the end of the test.