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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 18 1982

MEMORANDUM FOR: Those on Attached List

FROM: Steven Bernstein
Transportation and Material Risk Branch
Division of Risk Analysis
Office of Nuclear Regulatory Research

SUBJECT: MINUTES OF THE EIGHTH RESEARCH REVIEW GROUP (RRG) MEETING FOR THE FUEL CYCLE FACILITY SAFETY RESEARCH PROGRAM (FCFSRP)

Enclosed are the minutes of the subject meeting held on July 21-22, 1982 at the Factory Mutual Research Corporation Conference Center in Norwood, Massachusetts. At this meeting the experimental and analytical investigations involving the fire-related aspects of the research program were reviewed. Several fire experts, not previously involved in the FCFSRP, attended the meeting and provided their comments on the direction of the research program. See especially the review of selected fire models, item 7 of the enclosed minutes.

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Enclosure: As stated

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FUEL CYCLE FACILITY SAFETY RESEARCH PROGRAM
RESEARCH REVIEW GROUP (RRG) MEETING #8

1. INTRODUCTION

On July 21-22, 1982 the eighth RRG meeting on the Fuel Cycle Facility Safety Research Program (FCFSRP) was held at the Factory Mutual Research Corporation Conference Center in Norwood, Massachusetts. A list of attendees is included as Enclosure A. An agenda of the meeting is included as Enclosure B.

The purpose of this meeting was to receive presentations on the:

- Battelle Pacific Northwest Laboratories (PNL) source term model for fires, FIRIN1
- available results of the Factory Mutual Research Corporation (FMRC) fire experiments
- problems encountered by NRC is using the Los Alamos National Laboratory (Los Alamos) fire analysis code (FIRAC)
- objectives and plans for the Lawrence Livermore National Laboratory (LLNL) fire tests
- review of selected fire models
- addition of forced ventilation to the Harvard fire code
- FIRAC assessment program
- New Mexico State University Experimental Program
- Material Interaction Studies

S. Bernstein, NRC Program Manager, presented a brief overview of the FCFSRP. He outlined the purpose and scope of the program, discussed the structure and identified the users of the Fuel Cycle Facility Accident Analysis Handbook (AAH), and provided some examples of on-going research. Copies of the viewgraphs used are included as Enclosure C.

2. STATUS AND SCHEDULE OF DELIVERABLES

2.1 PNL Deliverables

PC Owczarski, PNL, presented the status and schedule for each deliverable in their program. This is given in Enclosure D. Item C2.1, the Combustion Product Literature Review, should be finalized by Fall 82. Items C2.5 and C2.6 should be completed in September 82. Item D.4, the experimental plan for the glove box fire experiments, may be revised to accomodate the capabilities of FIRIN1.

2.2 Los Alamos Deliverables

WS Gregory, Los Alamos, presented the status and schedule for each deliverable in their program. This is given in Enclosure E. The report on the filter plugging experimental apparatus will be delayed from July 82 to September 82. The literature review report and the reports on material transport modeling and the material depletion/modification experiments will be delayed from September 82 to November 82.

3. FIRIN1

3.1 Overview of FIRIN1

PC Owczarski, PNL, presented an overview of PNL's source term fire code, FIRIN1. FIRIN1 is the level one fire source term code to be used in chapter four of the AAH. It will provide the inputs needed for the Los Alamos' fire analysis code, FIRAC, as shown on page F-1. Level one FIRIN1 uses an idealized reference burning model. The assumptions used in this model are shown on page F-2. Dr. Owczarski outlined the uncertainties in the source term method as shown on page F-3. PNL hopes to reduce these uncertainties in higher levels of analysis through the use of a deterministic burning model and eventually a probabilistic burning model. A flow chart outlining the calculational steps in FIRIN1 is shown on page F-4. The code consists of three main subroutines, the fire source term calculation, heat and mass transfer considerations, and the computation of radioactive source terms. Detailed flow charts for each of these subroutines is shown on pages F-5 through F-7.

3.2 Burning Model of FIRIN1

M.K.W. Chan, PNL, began the presentation by identifying the typical combustible materials found in fuel cycle facilities. These are shown on page F-8. The physico-chemical properties of some of these materials are available from the experimental investigations of A. Tewarson, FMRC. The remaining properties are being obtained by PNL through a sub-contract to FMRC. The FIRIN1 burning model performs a mass balance inside the fire compartment. The components used in this balance for both the hot and cold layers are shown on page F-9. The continuity equations for these components in both the hot and cold layers are shown on pages F-10 and F-11, respectively. Flows into or from the ventilation system are determined by taking into account filter plugging using the current Los Alamos filter plugging model shown on page F-12.

The heat transfer aspects of FIRIN1 were presented by PC Owczarski, PNL. FIRIN1 uses the fire plume model developed by E.E. Zukoski as outlined on page F-13. The following heat transfer mechanisms and effects are included in FIRIN1:

- conduction in solids - includes heat transfer within ceilings, walls, floor, and equipment walls.

- concrete decomposition - includes release of water and carbon dioxide from concrete surfaces due to the heat flux from the fire.

- direct radiation - includes heat transfer from the fire to the hot layer and to the walls and equipment surfaces from the hot layer to the floor, and from/to the hot layer to/from surfaces.

- natural convection - includes convection between walls and equipment surfaces and the gas layers and convection within equipment.

- equipment heat transfer - includes direct radiation from fire, convective losses to cold layer, and convective and radiative interaction with hot layer; effects include equipment as heat sink, pressurized release of powders and liquids, and releases from open liquid containers.

Some of the fire modeling experts attending the meeting commented that some of the heat transfer models and calculational methods used by PNL have been used in the past and that more sophisticated models are available. The question remains as to whether these more sophisticated methods are necessary to adequately determine the radioactive release from a fire in light of the uncertainties in the radioactive material source term.

3.3 Radioactive Source Terms in FIRIN1

PC Owczarski, PNL, presented a description of the radioactive source terms included in FIRIN1. The major mechanisms involved in typical fuel cycle facility fires were identified and are shown on page F-14. For each mechanism simple models were developed based on the limited experimental work that has been done in the past. Most of the models are based on the assumption that a certain fraction of the radioactive material will be made airborne as a result of the fire and that this fraction remains constant throughout the accident event. Some models address entrainment of radioactive material by the fire plume. The models for each mechanism are shown on pages F-15 through F-27. Included is information concerning particle size distribution, a listing of other potential event defining parameters, and an identification of the reports from which the models were developed. Some of the limitations of these models were discussed. The most significant limitation concerns the fact that the models are based on only a limited number of experiments that were designed to examine a specific accident scenario. Questions remain on the applicability of these models for typical fuel cycle facility fire scenarios. It was noted that there is a high degree of uncertainty in some of the release fractions used in the models, but they are probably the best available information.

3.4 Sample Problem Using FIRIN1

PC Owczarski, PNL, presented the result of using FIRIN1 to analyze a typical fuel cycle facility fire scenario. The scenario consists of the burning of two cardboard boxes containing PVC bagged cellulosic rags contaminated with radioactive material. The fire takes place in a compartment of dimensions 3 meters x 3 meters x 3 meters. The details of this example fire problem are given on pages F-28 through F-30. FIRIN1 provides the time history of several variables in the burn room. These time histories are shown on pages F-31 through F-39. The oscillations in the fire compartment pressure shown on page F-34 will be examined and changes made in the modeling to rectify this. It was noted that similar oscillations resulted in earlier attempts by other investigators using the same modeling approach as PNL. The linear decrease in the mass loss rate shown on page F-38 is due to the assumption that the mass rate is a linear function of the availability of oxygen to the base of the fire. This linear dependence assumption is supported by limited Factory Mutual test data.

The question arose on why the release rate for the uranium dioxide, shown on page F-39, does not reflect the smoke and soot generation rates shown on page F-37. The two rates should have a similar shape since the radioactive material is made airborne as contaminated smoke. The explanation is that the release rate for the uranium dioxide has the same shape as the mass loss rate, since the model used in FIRIN1 relates the radioactive source term to the mass burning rate. The model was developed in this way because the bulk of the experimental data were taken as release fractions of the total mass of contamination involved in the fire.

4. FACTORY MUTUAL RESEARCH CORPORATION

4.1 Fuel Cycle Combustibles Experimentation

J. Steciak, FMRC, presented some preliminary results of the experiments being conducted under sub-contract to PNL. The experimental conditions are shown on page G-1 and the apparatus on page G-2. The combustibles being used in the experiments and their characteristics are given on page G-3. The "mixture" refers to a typical mixture of combustible materials found in fuel cycle facilities. The composition of the "mixture" used in the FMRC tests was identified by PNL and is given on page G-4.

The preliminary results for the mass loss rate, the heat generation rate, the generation rates and fractional yields of the combustion products, and the combustion efficiencies were presented for experiments conducted with ambient air and an external heat flux of 50 kW/m^2. These results are shown on pages G-5 and G-6. The results of tests performed on the typical "mixture" for three different external heat fluxes are given on pages G-7 and G-8. It was noted that there are some errors in these tables. Radioactive parameters (subscript, R) when added to convective parameters (subscript, C) should equal the actual value of the parameter (subscript, A). There are several places in the tables where this is not the case.

Time histories for some of the parameters were also presented on viewgraphs that were overlaid so that a comparison could be made between the results for each material and the results for the typical "mixture." A conclusion that can be made from this comparison is that the results for the typical "mixture" are significantly different than the results obtained for the individual materials. Knowing the combustion properties of materials provides little information on their collective behavior in a fire. It was noted, however, that the typical "mixture" was prepared by grinding the separate materials into powders and thoroughly mixing the powders together. This is clearly not representative of actual fire scenarios so that the applicability of the above conclusion to real fire problems is questionable. This issue will be examined further as additional data is obtained by FMRC.

4.2 Factory Mutual Data Applications

Questions have been raised on the applicability of data obtained in the small-scale FMRC combustion apparatus to analyzing full-scale fire scenarios. In response to these questions A. Tewarson, FMRC, gave a presentation on FMRC Data Applications. FMRC has performed a number of experiments in small-, intermediate-, and large-scale fire apparatus. These apparatus are shown on page G-9. Combustion properties of several materials were determined using these apparatus. Some of these results are given on pages G-10 through G-14. The data show that for many properties the results obtained from experimentation in the small-scale apparatus agree with the results obtained in the larger apparatus. The conclusion reached by FMRC is that the data obtained from small-scale experiments can be applied, with proper scaling, to analyzing full-scale, real fires.

5. LOS ALAMOS

5.1 Introduction

WS Gregory, Los Alamos, provided an introduction to the Los Alamos presentations. He outlined the overall objective of the fuel cycle research program and identified the Los Alamos role in the program. He identified the organizations and individuals involved in the fire-related portions of the Los Alamos effort as shown on page H-1. He also outlined the Los Alamos fire experimentation program being performed at New Mexico State University and Lawrence Livermore National Laboratory as shown on page H-2. Additional details on this program can be found in items seven and eleven.

5.2 Overview of FIRAC

Because some attendees at the meeting were unfamiliar with FIRAC, JW Bolstad, Los Alamos, presented an overview of FIRAC. This was essentially the same presentation given at the March 82 RRG meeting when a one day seminar on FIRAC was conducted by Los Alamos. The details of this seminar are provided in the minutes of that RRG meeting and will not be repeated here. The minutes of the March 82 RRG meeting are contained in a memorandum from S. Bernstein, NRC, dated June 22, 1982.

6. NRC PROBLEMS WITH FIRAC

S. Bernstein, NRC, outlined some problems the NRC had encountered in using FIRAC. These problems had been discovered primarily by R. Kratzke, an NRC fuel cycle licensing engineer, and C. Fasano, a summer intern working in the NRC research office. They had used the code on some typical problems and had identified problems in three areas as shown on page I-1. These areas are: (a) excessive temperature in burn room, (b) conservation of mass, and (c) incorrect volumetric addition.

6.1 Excessive Temperature in Burn Room

A typical fuel cycle facility licensing problem was analyzed using FIRAC. The schematic of the facility and the fire scenario are given on page I-2. The energy input, mass burning rate, and particulate generation rate used in the problem are shown on pages I-3 through I-5. These were determined using the procedures in the FIRAC user manual and the Accident Analysis Handbook.

The time history of the temperature in the burn room as determined by FIRAC is shown on page I-6. As can be seen by examining the graph, the temperatures predicted by FIRAC are far in excess of what can be considered reasonable. These excessive temperatures may have been produced by using unrealistic energy source terms in the problem. To explore this question, some additional FIRAC runs were made as shown on page I-7. In these additional runs the total energy input to the burn room was held constant while the burn time and energy input rate were varied. The energy input rates were held at or below 200 KW to ensure realistic energy input rates. The results are shown in the table on page I-7. When particulates were present the system did not achieve a steady state even after several hours. The temperature in the burn room appears to be unrealistically high and still increasing at the end of the run. Further examination revealed that the particulates plugged the HEPA filters causing the gas flow rate to drop to essentially zero. Since the only way for heat to be removed from the burn room is by being carried out in the gas flow, the high temperatures were produced by the continuous addition of heat. To verify this idea some runs were made without particulates. As shown in the table, steady state was achieved in these runs with reasonable final temperatures.

Los Alamos had examined the problem of the excessive temperatures in the typical licensing problem. They indicated that this problem was caused by an unrealistic source term. With the heat input given in the source term the gases in the burn room will be continuous drawn out to the point where there is no gases left. The given source term does not take into account the fact that the fire will adjust itself to the changing flow rates. Los Alamos has correctly analyzed the problem and showed that the temperature in the burn room reaches a maximum of about 600°F. Since the NRC used the source term guidelines contained in the FIRAC user manual in analyzing the problem, it was agreed that these guidelines need to be revised to clarify the procedures for developing a realistic source term description. Los Alamos will make the necessary revision in the next few weeks.

6.2 Conservation of Mass Problem

The output produced by FIRAC includes a listing of the mass accumulated on the HEPA filters and the mass still airborne in the facility. A variety of FIRAC runs were made, where the mass, particulate, and heat injection rates were varied as shown in the tables on page I-8 and I-9. It was noted that the sum of the mass on the filters and the mass airborne in the facility was greater than the total mass generated in the fire. Clearly, this violates the principle of conservation of mass. This problem may be caused by a numerical error in the computational method used in the computer code. Los Alamos indicated that they would examine this problem but noted that the percent difference was large only for very long duration fires. For fires of a realistic length the percent difference may be small enough to be neglected in the analysis.

6.3 Incorrect Volumetric Addition Problem

One of the assumptions used to develop FIRAC is that the burn products injected into the burn room are air. The volume of this air is equivalent to the mass of air injected which is equal to the mass of fuel burned. As shown on page I-10, the actual volume of burn products injected depends upon the chemistry of the fire. It is difficult to determine the significance of this problem. J. Quintiere, National Bureau of Standards, indicated that it is typical to assume that burn products are air in these gas dynamics/fire transport codes.

6. Remaining Issues

S. Bernstein, NRC, identified some issues, as shown on page I-11, that remain to be resolved. Some of the problems identified in using FIRAC may also occur in TORAC and EXPAC since some of the same assumptions were used in developing all three codes.

The question remains whether FIRAC is a workable fire analysis method without inclusion of a fire compartment model. The addition of a compartment model would avoid the problem of trying to use FIRAC with unrealistic source terms. Los Alamos plans to eventually include a compartment model in FIRAC, however, their revised source term guidelines should provide the user with an acceptable method for specifying realistic source terms.

The fire source term model, FIRIN1, being developed by PNL is intended to provide valid inputs for FIRAC. It remains to be determined whether these two codes are compatible. This determination will be made when the NRC receives FIRIN1 from PNL and has an opportunity to run the codes on some typical problems.

7. REVIEW OF SELECTED FIRE MODELS

PJ Pagni, University of California at Berkeley, presented a review of selected fire models and some recommendations concerning the NRC fuel cycle fire analysis program. An outline of his presentation is given on page J-1.

Dr. Pagni outlined the basic fire compartment problem. He described the geometry of the problem as shown schematically on page J-2. Most compartment models were developed to address the situation of free ventilation where there is a large opening, such as a doorway, into the compartment. On page J-3 is the same diagram modified to show how the geometry changes for the fuel cycle facility problem. Here the doorway is replaced by an inlet and outlet to the ventilation system and there is forced, rather than free, ventilation.

As shown on page J-4, Dr. Pagni identified the information that is known by the analyst at the start of the problem. This includes the basic geometry of the compartment, the properties of the fuel, and information on the ignition event. On page J-5 is a listing of possible unknowns for a fire problem. On page J-6 is a list of categories of information that are important in analyzing fires. Dr. Pagni stressed the importance of fuel chemistry and geometry especially its relationship to the yield of combustion products found in the fire compartment. He stated that PNL should be complimented for deciding to use the FMRC data since, in his opinion, this is best source of this information. Dr. Pagni continued by pointing out the information that can be neglected as shown on pages J-7 and J-8. One of the unique aspects of the fuel cycle facility fire problem is that the inlet from the ventilation system is usually located near the top of the room and the outlet is located near the bottom. This means that during a fire cold air entering at the top is injected into the hot layer. Dr. Pagni recommended that experimentation is needed to determine if a stable two layer model is still applicable in analyzing this problem. Dr. Pagni pointed out that the fuel cycle facility fire problem is easier to address than the general compartment fire problem because a) ventilation system flows are usually unidirectional and the complex problem of modeling bidirection flows is eliminated, and b) the types of fuel formed in these facilities are known and generally controllable.

Dr. Pagni outlined, as shown on page J-9, the information that can not be neglected in analyzing fuel cycle facility fires. For heat and mass transfer this includes heat feedback to the fuel, the heat flux on combustible materials, and the heat absorbed by the walls. Plume dynamics is also important since it affects the location of the hot layer which in turn affects the hot layer temperature and the yield of combustion products entering the ventilation system.

Dr. Pagni reviewed the experimental and analytical investigations that have been conducted in the area of fire analysis. On page J-10 is a listing of the experimental work that has been performed. The only experiments that have addressed forced ventilation are those being conducted at LLNL. On page J-11 is a listing of fire models and computer codes developed by various investigators. Characteristics of some of these models are shown in the table on page J-12. Dr. Pagni provided a more detailed review of the four models being evaluated in the NRC's Fuel Cycle Facility Safety Research Program.

Some of the characteristics of the Cal Tech model are shown on page J-13. The highlight of the Cal Tech model is the plume model. One of the difficulties of the Cal Tech model is that it does not calculate the heat loss to walls. The amount of heat loss must be supplied by the user. On page J-14 is a block diagram of the Harvard Computer Fire Code showing its modularized form. On page J-15 is a simplified flowchart showing how this code operates. Some of the basic features of the Los Alamos fire compartment model are outlined on page J-16. A potential difficulty with this model is that it does not directly address feedback of heat from the compartment to the fuel, but instead relies on the novel approach of maximizing the system's entropy. The details of the PNL fire model, FIRIN1, are given in section 3. On page J-16 are shown some of Dr. Pagni's criticisms of this model. In his opinion, the radioactive and convective heat transfer models used are "primitive" and duplicate existing work. He questioned the importance of outgassing of water and carbon dioxide as a result of heat fluxes on concrete walls. On page J-17 is Dr. Pagni schematic diagram of the fuel cycle facility fire problem. The diagram shows how the fire compartment model provides the link between the response of the fuel and the ventilation system. On page J-18 are Dr. Pagni's recommendations concerning the program. His recommendations are:

(1) The Harvard Computer Fire Code be used as the basis for a compartment fire model.

(2) PNL be responsible for the development of the fuel response model.

(3) Los Alamos be responsible for appropriately modifying the Harvard code and integrating this modified code with FIRAC.

Dr. Pagni noted that the US-Japan Joint Panel on Fire Research and Safety is planning to recommend the replacement of building fire codes with design criteria and computer modeling analysis. This is similar to the approach being taken in the Fuel Cycle Facility Safety Research Program with its Accident Analysis Handbook and ventilation system codes.

8. FIRAC ASSESSMENT

JW Bolstad, Los Alamos, presented some results of the on-going FIRAC assessment program. A large part of the assessment program consists of FIRAC simulations of the LLNL fire test facility. A diagram of this test facility is shown on page K-1. On page K-2 is schematic diagram of the computer simulation of the facility. Several comparisons were made between FIRAC predictions and the experimental results. The energy input used in these comparisons is shown on page K-3. On page K-4 through K-7 are shown some of the results of these comparisons. Except for the differential pressure across the HEPA filter, the comparison with the experimental data is good. The poor comparison for the differential pressure, shown on page K-7, led Los Alamos to develop an improved model for filter plugging and this improved model is included in the current version of FIRAC.

9. HARVARD COMPUTER FIRE CODE

H. Mitler, Harvard, provided a presentation on the Harvard Computer Fire Code (CFC), on modifications made to the code to make it applicable to fuel cycle facility fire scenarios, and on predictions of the LLNL fire tests using the modified CFC. Dr. Mitler presented some comparisons between CFC predictions and experimental data that showed good agreement between the code predictions and the test results.

The Harvard CFC was developed to address the general fire problem involving compartments with large openings such as doors and windows. Because compartments in fuel cycle facilities do not have these large openings, the CFC must be modified to be applicable to fire scenarios in these facilities. Dr. Mitler identified the two features of special interest in analyzing these fire scenarios. These are oxygen starvation and forced ventilation. His discussion of these features is included on page L-1.

Dr. Mitler described the forced ventilation algorithm he developed for modifying the CFC. This modified CFC was used by Dr. Mitler to predict the results of the LLNL fire tests. The derivation of the algorithm is described on page L-1 through L-7. Questions remain concerning the degree of turbulent mixing caused by injection of cold air from the ventilation inlet into the hot layer. The modification used by Dr. Mitler is based on the assumption that the injected air divides between the hot and cold layers according to the temperature ratio. Turbulent mixing is not included.

Dr. Mitler predictions of the LLNL fire tests are shown on pages L-8 through L-15. The CFC is one of the four models being evaluated by Los Alamos in its fire compartment model assessment program. These predictions will be compared with the actual data as part of this assessment program.

10. LAWRENCE LIVERMORE NATIONAL LABORATORY FIRE TESTS

10.1 LLNL Fire Test Facility

N. Alvares, LLNL, gave a presentation on the LLNL fire test facility. A schematic diagram of the overall facility is shown on page M-1. On page M-2 is a section view of the fire test cell and on page M-3 is a plan view of the test cell. A listing of the test parameters for the facility is given on page M-4. Dr. Alvares presented examples of the data obtained in previous tests. Some of these results are shown on pages M-5 through M-12.

Dr. Alvares has sent letters to several fire modeling groups requesting that they use their models to predict the results of the tests that will be conducted in 1982. On page M-13 is a table showing the tests to be performed. Identified in the table are the tests that will be used for the pretest predictions. S. Bernstein, NRC, asked if there were any measures being taken to safeguard the predictions and the test data so that there would be no question as to the independence and pre-test nature of the predictions. After some discussion it was agreed that Dr. Alvares would send a letter to the NRC identifying the modelers who provided pre-test predictions. The question was raised as to whether PNL would be making predictions using their FIRIN1 model. Dr. Owczarski, PNL, indicated that he would submit predictions to Dr. Alvares. Dr. Alvares closed his presentation by outlining the tests planned for FY83. This is given on page M-14.

10.2 FY82 Fire Experimental Plan

F. Krause, Los Alamos, provided a detailed presentation on the FY82 LLNL fire tests. The objectives of the tests are given on page N-1. Because of funding limitations and the fact that the tests are being performed in support of several programs, there are some programmatic restrictions as outlined on page N-2. In spite of these restrictions most of the needed data will be obtained. The anticipated results are outlined on page N-3. These items reflect the dual nature of the experimental program: to provide test data for development of a fire compartment model and for assessment of the FIRAC duct heat transfer module. The fuels to be used in the tests and their chemistry are shown on page N-4. They were chosen to provide a range from cleaning burning to smokey fires. Details of the test facility are given on pages N-5 and N-6. A summary of the parameters to be measured is given on pages N-7 and N-8. The experimental conditions to be used for each of the fuels are shown on pages N-9 and N-10. A subset of these conditions has been chosen for the pretest predictions as shown on page N-11. The specific parameters to be predicted are identified on page N-12. The logic to be used in selecting the order of the testing is shown in the flowchart on page N-13.

11. FY82 EXPERIMENTAL PROGRAM AT NMSU

RA Martin, Los Alamos, presented the status of the experimental program at NMSU. The purpose of the experimental program and the areas being addressed are shown on page O-1. The characteristics of the material transport modeling used in FIRAC are given on pages O-2 and O-3. Dr. Martin outlined some of the difficulties encountered in modeling the transport of material made airborne in a fire as shown on page 0-4. On page 0-5 are shown some of the modeling assumptions used in developing FIRAC. On page 0-6 is a chart showing the structure of the material transport module used in FIRAC.

11.1 Filter Plugging Experimental Program

Dr. Martin outlined the purpose of the filter plugging experimental program and identified the important parameters as shown on page 0-7. A series of idealized tests were performed with stearic acid and a water spray as the test aerosols as shown on page 0-8. The experimental data is given in the table on page 0-9. The results are shown graphically on page 0-10.

The current filter plugging model used in FIRAC and a more complicated model is shown on page 0-11. Dr. Martin showed a comparison of the dendrite model with some of the experimental data. This comparison is shown in the graph on page 0-12. The results of these idealized tests and some preliminary conclusions regarding the dendrite model are given on page 0-13.

Additional filter plugging tests will be performed during the summer of 1982 using more realistic aerosols. Some of the fuels to be used in these experiments, the modifications to be made to the experimental apparatus, and the experimental conditions are outlined on pages 0-14 through 0-16.

11.2 Aerosol Depletion/Modification Experimental Program

Dr. Martin outlined some of the mechanisms that can act to modify accident-generated aerosols as shown on page 0-17. The aerosol depletion model in FIRAC and the information supplied by the user are given on page 0-18. An outline of the experimental plan is included on page 0-19. The measurements to be taken are specified on page 0-20. The filter plugging test facility at NMSU will be modified for use in these experiments.

12. MATERIAL INTERACTION STUDIES

RA Martin, Los Alamos, presented some of the results of his studies on material interaction models. Some of the factors to be considered in studying material interaction are shown on page P-1. Dr. Martin has been examining the MAEROS code for use as an aerosol interaction module in FIRAC, EXPAC, and TORAC. Dr. Martin outlined some of the features of the MAEROS code as shown on page P-2. Dr. Martin has used MAEROS to study the dynamic behavior of certain aerosols. The characteristics of the aerosols and the room ventilation used in his studies are shown on pages P-3 and P-4. Some of the MAEROS results are shown on the graphs on pages P-5 through P-10. Some of Los Alamos' preliminary conclusions from these studies are given on page P-11. Dr. Martin also identified some additional MAEROS runs he plans to perform in his investigations. These are shown on page P-12.

13. ACTION ITEMS

The following action items resulted from this RRG meeting:

(1) Los Alamos will revise the fire source term guidelines contained in the FIRAC user manual.

(2) PNL will make predictions of the LLNL fire tests using the PNL fire code, FIRIN1. (On August 13, 1982 and August 20, 1982 PNL submitted these predictions to LLNL.)

(3) LLNL will submit, to the NRC, a list of the predictions th[illegible]e been received prior to the performance of the fire tests. (On August 27, 1982 and September 8, 1982, LLNL submitted to the NRC a copy of all pre-test predictions.)

A COMPARTMENT FIRE OVERVIEW

P.J. PAGNI (U.C. BERKELEY)

OUTLINE:

1.) PROBLEM DEFINITION

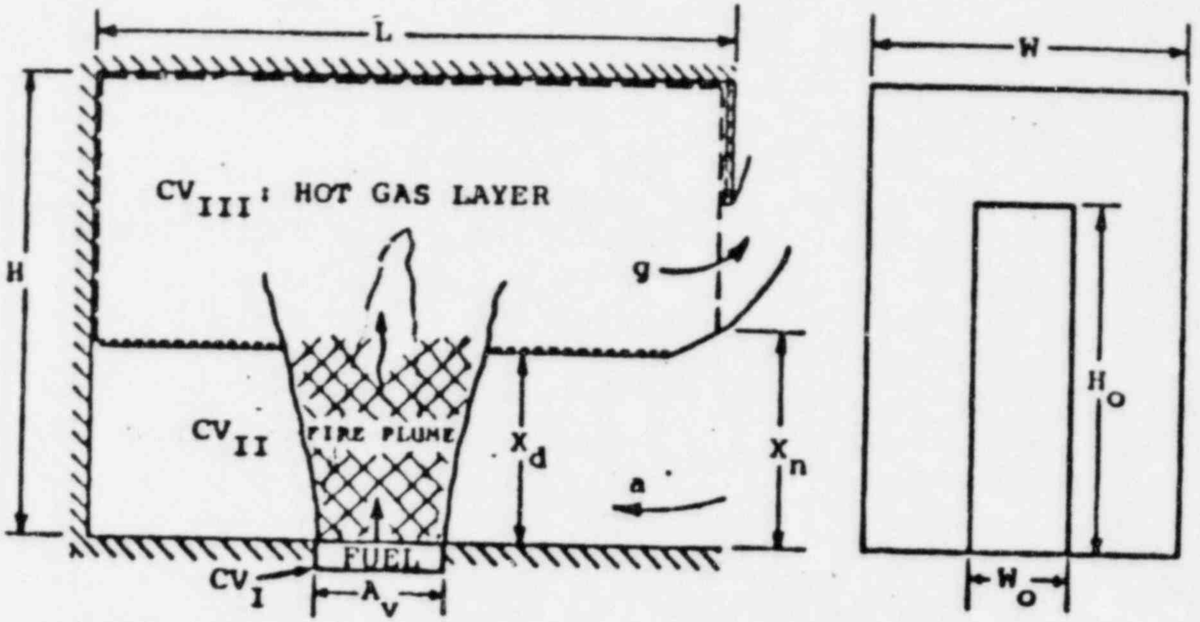
2.) WHAT CAN BE NEGLECTED?

3.) WHAT CAN NOT BE NEGLECTED?

4.) EXPERIMENTS

5.) ANALYSES & RECOMMENDATIONS

6.) FUTURE



CV_I - Fuel

CV_{II} - Lower layer, bounded by thermal discontinuity plane, walls and floor

CV_{III} - Upper layer, includes plume, bounded by walls, ceiling, thermal discontinuity plane and fuel surface.

a - Air entering compartment through doorway

g - Hot gases (combustion products) leaving compartment through doorway

X_d - Height of thermal discontinuity

X_n - Height of neutral plane

H - Height of compartment

L - Length of compartment

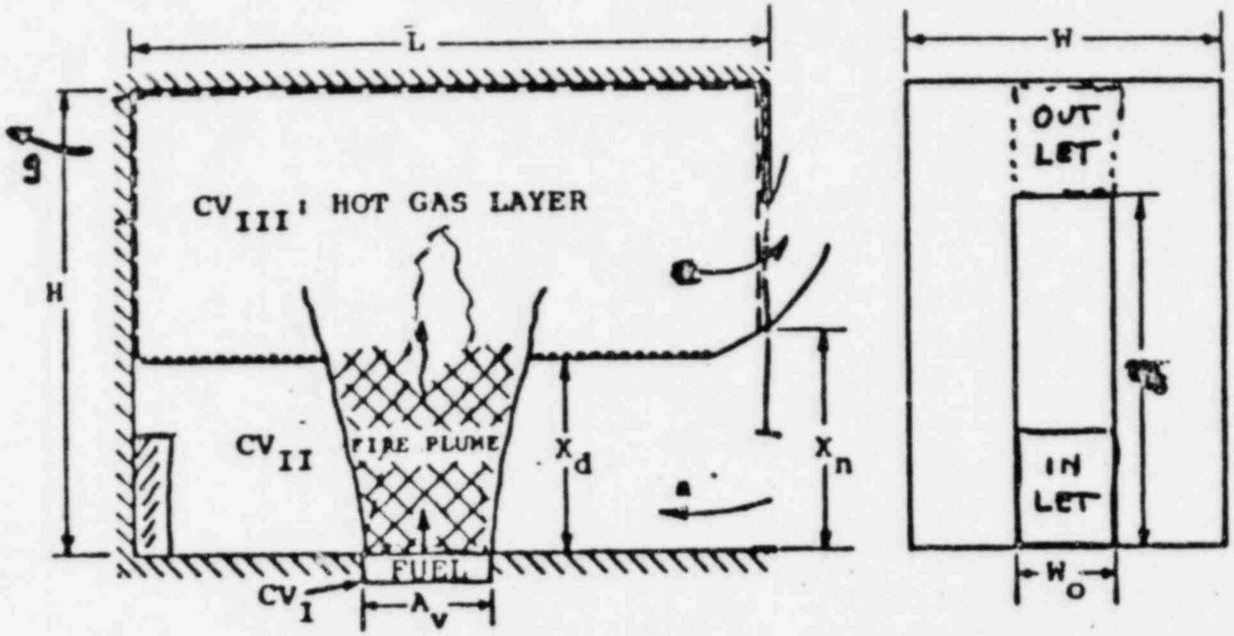
W - Width of compartment

H_o - Height of doorway

W_o - Width of doorway

FIGURE 4-8. NBS QUASI-STEADY MODEL CONTROL VOLUMES AND ROOM GEOMETRY

L3.



CV_I - Fuel

CV_{II} - Lower layer, bounded by thermal discontinuity plane, walls and floor

CV_{III} - Upper layer, includes plume, bounded by walls, ceiling, thermal discontinuity plane and fuel surface.

a - Air entering compartment through doorway

g - Hot gases (combustion products) leaving compartment through doorway

X_d - Height of thermal discontinuity

X_n - Height of neutral plane

H - Height of compartment

L - Length of compartment

W - Width of compartment

~~H_o - Height of doorway~~ INLET & OUTLET GEOM.

~~W_o - Width of doorway~~ & $\dot{M}(t)$ outlet

FIGURE 4-8. NBS QUASI-STEADY MODEL CONTROL VOLUMES AND ROOM GEOMETRY

GIVEN A PRIORI,:

— GEOMETRY
— OTHER
— OPTIONAL

1.) WALLS

SIZE
PROPERTIES

2.) OPENINGS

LOCATION
FORCED, + or −, $\dot{m}$
SIZE
SHAPE

3.) FUELS

SIZE
SHAPE
ORIENTATION
LOCATION
PROPERTIES (TEWARSON)

4.) IGNITION EVENT

LOCATION
INTENSITY

POSSIBLE UNKNOWNS:

$\dot{M}_{pyrolysis\ of\ fuel}(t)$

$\dot{Q}_{fire}(t)$

$\dot{Q}_{walls}(t)$

$\Delta\dot{Q}_{gas}(t)$

$\dot{M}_{inlet\ or\ exhaust}(t)$

$Y_{i\ exhaust\ gas}(t)$

$Y \equiv$ MASS FRACTION

$i \equiv CO_2, CO, H_2O, O_2, H_2O, C_xH_y$, solids

$T_{hot\ gas}(t)$

$T_{cold\ gas}(t)$

Radiative & Convective Feedback to Fuel (t)

Other Radiative & Convective Interchanges

$T(\underline{x}, t)$

$Y_i(\underline{x}, t)$

$P(t)$

Velocity Profiles in Openings

Existance of Flashover

THINGS THAT ARE IMPORTANT:

1.) FUEL CHEMISTRY

i.e. $C_x H_y$, L, Y_{INERT}

2.) FLUID MECHANICS

i.e. Re_x, Gr_x, Orientation, etc.

3.) FUEL GEOMETRY

4.) $Y_i(t)$ IN COMPARTMENT

WHAT CAN BE NEGLECTED ?

I.) $P(t)$

$P = P_0 =$ Constant is a reasonable approx. if one room vent is connected to ambient

Very Useful:

If $P = \text{const}$ & If Ideal Gas, $P = \rho R T$

Then $\rho R T = \text{const}$ or $\frac{M}{\mathcal{V}} R T = \text{const}$

But $\mathcal{V} = \text{const}$ so $MRT = \text{const}$

And $U = CMRT = \text{const.}$

i.e. $\dot{Q}_{\text{to gas in room}} \equiv 0$ for all t

& $\dot{Q}_{\text{fire}} = \Delta \dot{G}_{\text{gas flow}} + \dot{Q}_{\text{wall}}$ for all t.

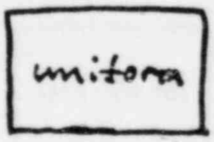
II.) $T(\underline{x}, t)$ & $Y_i(\underline{x}, t)$

Too Much Detailed Information

Experiments Suggest Two Options

Two Layer

Well-Stirred



Two Layer good if hot out at top & cold in at bottom

Well-stirred <u>probably</u> good if hot out at bottom or top
& cold in at top
" " " if both at bottom

Needs Experimentation

III.) BIDIRECTIONAL FLOW (t)

Enormous simplification to be able to say I know $\dot{v}^{e}(t)$ <u>a priori</u> AND that all vent flows are unidirectional.

Much effort is otherwise required to calculate iteratively the neutral plane height and the velocity profiles in all openings

IV.) MANY FUEL TYPES & GEOMETRIES

You are considering a much narrower set of fuels than the general fire problem must consider. And you have much more control over change.

WHAT CAN NOT BE NEGLECTED?

I.) Givens

II.) Basic Heat & Mass Transfer

a.) Heat Feedback to Fuel

$$\dot{m}_p = (\dot{Q}_e + \dot{Q}_{fl} - \dot{Q}_s)/L$$

$$\dot{Q}_{fire} = \dot{m}_p \cdot \chi \cdot \Delta H_c$$

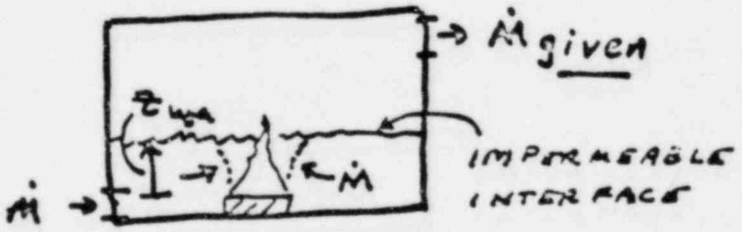
b.) $\dot{Q}_e$ to unignited or hazardous materials

c.) $\dot{Q}$ to walls

Then $\Delta\dot{Q}_{gas} = \dot{Q}_{fire} - \dot{Q}_{walls}$

III.) Plume Dynamics

a) Need to calculate existance & location of layer interface



Layer adjusts itself until

$$\dot{m} = \rho V_{entrainment} A$$

where $A = \pi D z_{layer}$

$V_{entrainment}$ is known experimentally

b) Get T_{hot} & $Y_{i\,out}$ once z_{layer} is known.

EXPERIMENTS

Free Ventilation

- Harvard / FMRC Test Series ~ '75
- FMRC
- NBS
- IITRI
- BRI - Borehamwood, England
- BRI - Tsukuba, Japan

Forced Ventilation

- LLNL

ANALYSES:

U.S.:

- HARVARD FIRE CODE
- NBS MODEL
- CAL TECH MODEL
- NOTRE DAME & JPL
- DAYTON & DOUGLAS
- IITRI CODE
- OHIO STATE
- LANL
- PNL
- Other

Foreign:

- Sweden – Wickstrom (NBS).
- France – Modified Harvard Code
- Japan – Modified Harvard Code

Figure 1

REVIEW OF ENCLOSURE FIRE MODELS — JAN 1979

	FIELD OR ZONE	CONSERVATION EQUATIONS					SURFACE IGNITION	COMBUSTION OF GASES	TURBULENCE	BOUNDARY CONDITIONS			RADIATION	PLUME MODEL	SPECIFIC DATA REQUIRED	PREDICTED QUANTITIES					
										VENTILATION		SURFACES									
		MASS	MOM	ENERGY	GAS SPECIE	SMOKE				NATURAL OR FORCED	NO. OPENINGS					P	T_g	T_s	$\vec{V}$	SMOKE	SPECIES
EFDIM J.P.L.	F (2-D)	✓	✓	✓	✓	LATER	LATER	P	EFFECTIVE TRANSPORT PROPERTIES	N/F	2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES; GASIFICATION OF FUEL	✓	N/A	THERMOPHYSICAL AND THERMOCHEMICAL PROPERTIES, STOICHIOMETRY	✓	✓	✓	✓	LATER	✓
NOTRE DAME	F (2-D)	✓	✓	✓					ALGEBRAIC MODEL (CORE AND WALL)	N	1, 2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES	1-D MODEL; SOOT, H_2O, CO_2 BANDS	N/A	VARIOUS FUNDAMENTAL PHYSICAL PROPERTIES; SPECIE AND SOOT CONCENTRATION	✓	✓	?	✓		
MC DONNELL DOUGLAS	Z (3)	✓		✓	UK		UK	SE		UK	UK	HEAT TRANSFER TO SURFACES	BLACK BODY?		UK		✓	✓			UK
DAYTON	Z (3)	✓$_E$	PLUME, CEILING JET ONLY	✓$_E$	✓$_E$	✓$_E$	✓$_E$	E		N/F	2	HEAT TRANSFER TO WALLS AND CEILING	ABSORBING AND EMITTING UPPER LAYER; FLAME RADIATION MODEL INCLUDING SOOT	FANG/ROCKET FLAME/PLUME MODEL; STEWARD MODEL IN BUOYANT PLUME	RATES AND TIMES GOVERNING TRANSITION STATES; HEAT RELEASE, SPECIE EVOLUTION, FLAME SPREAD		✓	✓		✓	O_2 CO HCN HCl SO_2 HF
IITRI	Z (2)	✓$_E$		✓$_E$			✓$_E$	E		N	1	HEAT TRANSFER TO WALLS AND CEILING	BLACK BODY?	FANG'S FLAME/PLUME MODEL	FUEL GASIFICATION RATES; COMBUSTION EFFICIENCY		✓	✓			
NBS	Z (4)	✓		✓				P		N	1	HEAT TRANSFER TO WALLS AND CEILING		STEWARD'S "TURBULENT DIFFUSION BUOYANT FLAME" MODEL	SOOT CONCENTRATION ΔH, GASIFICATION TEMPS, STOICHIOMETRY						
HARVARD	Z (2)	✓$_E$		✓$_E$				E		N	1	HEAT TRANSFER TO UPPER WALLS AND CEILING	?	MORTON'S "POINT-SOURCE" BUOYANT PLUME	BURNING RATES		✓	✓			

E - EMPIRICAL INPUT REQUIRED
SE - SEMI-EMPIRICAL

P - PREDICTED
NA - NOT APPLICABLE

UK - UNKNOWN

CAL TECH MODEL

1.) $\dot{Q}_{fire}(t)$ given a priori

NO HEAT FEEDBACK

2.) Vent Equation

Gives velocity profile for free flow.

EASY TO FOLLO w $\dot{m}(t)$

3.) Plume Model

Excellent Detail - Based on Zucoski's own data - highlight of model.

4.) $\dot{Q}_{wall}(t)$ given a priori

NO HEAT LOSS CALC.

5.) Vent Location & Number

Can have two rooms + ambience
Only 1 connection between them
Any no. of connections to outside

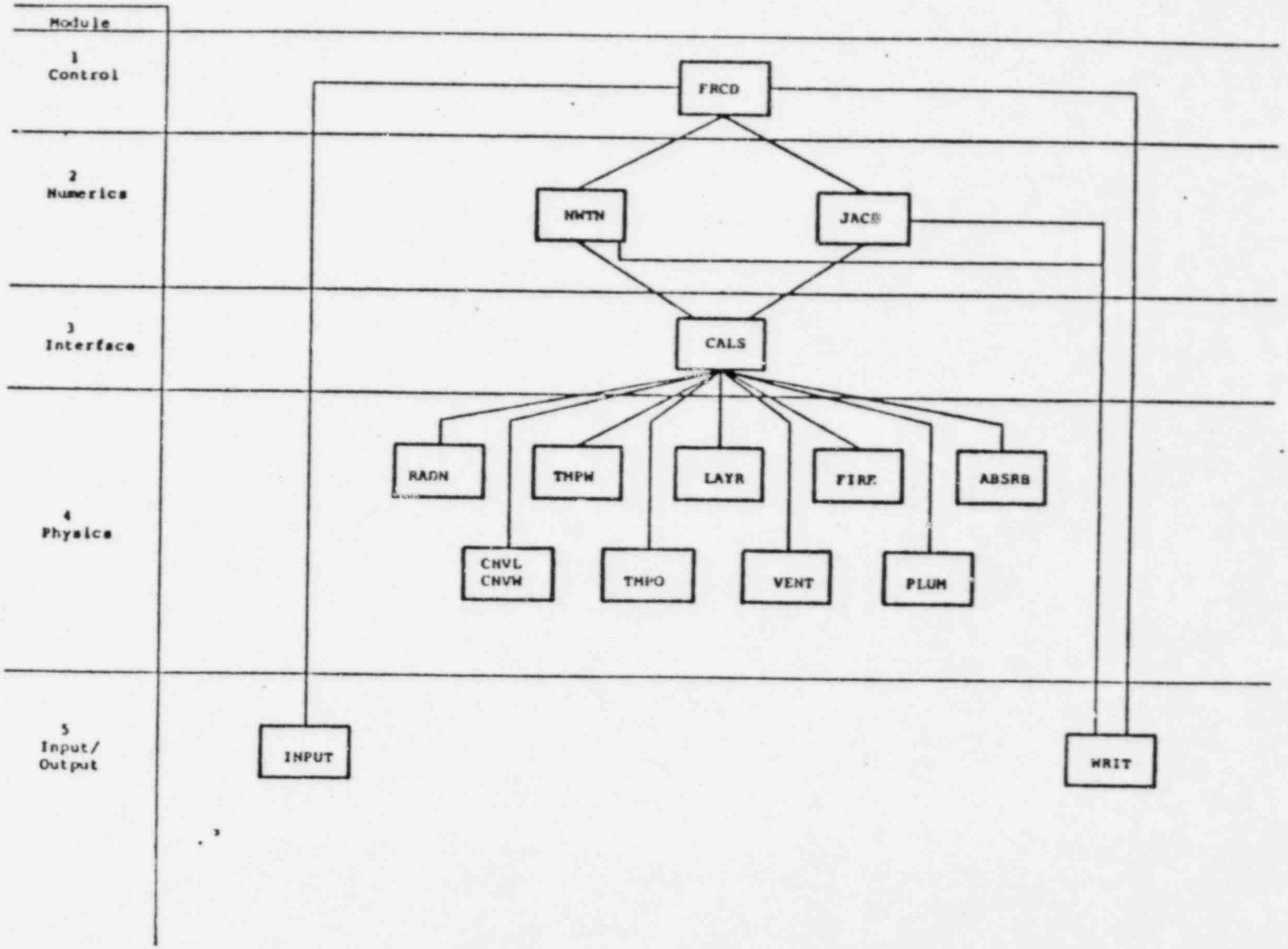


FIGURE 4-2. HARVARD COMPUTER FIRE CODE-ORGANIZATIONAL CHART[5]

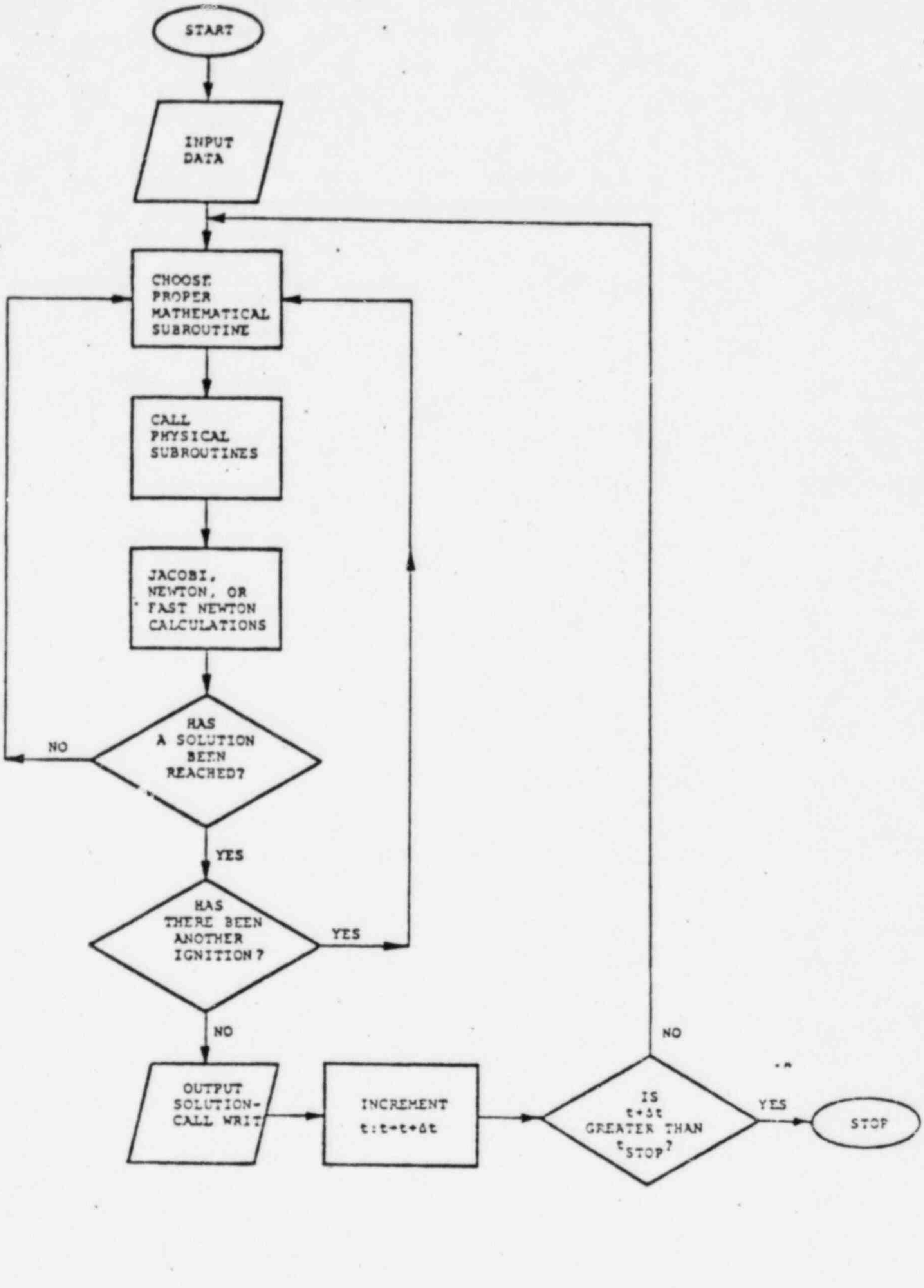


FIGURE 4-4. HARVARD COMPUTER FIRE CODE - SIMPLIFIED FLOWCHART

LANL

1.) $\dot{Q}\cancel{(t)}_{fire} = \text{const}$; $\dot{m}_p$ & $\dot{m}_{OUT}$ const : givens

2.) Species Balance

3.) Energy Balance

4.) Entropy Maximization

5.) Fits to ρ_{out} (z_{layer})

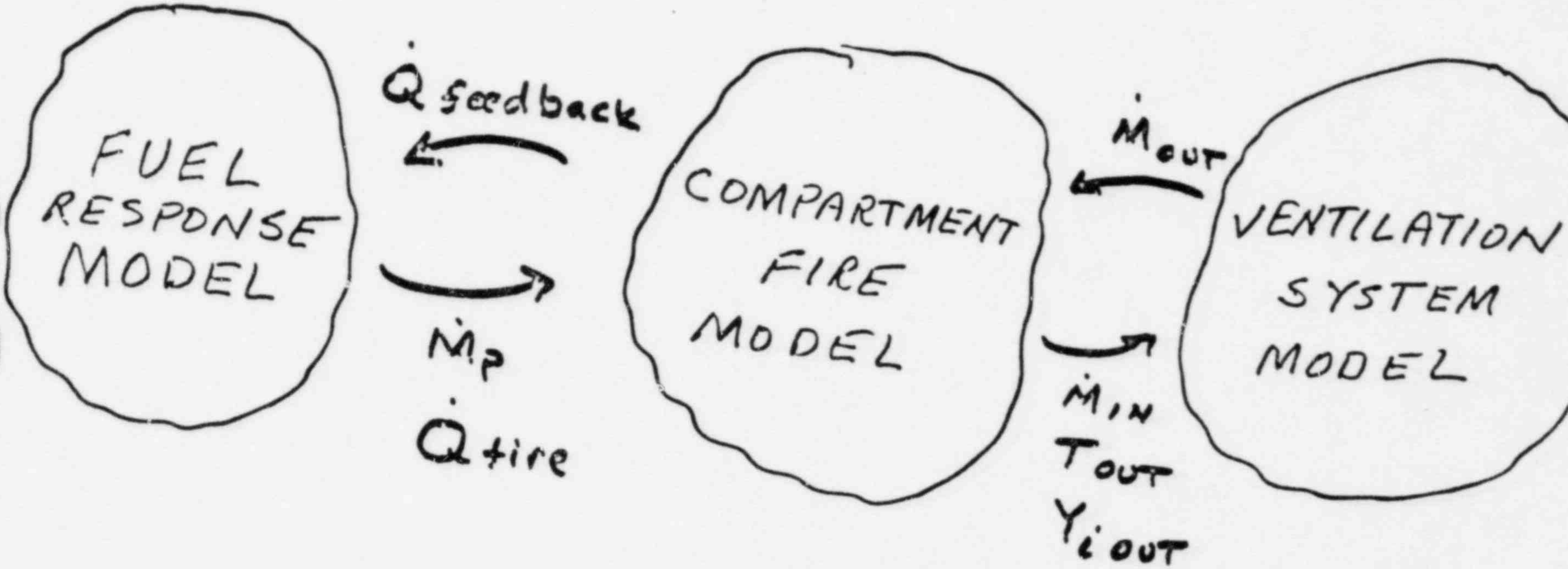
no feedback
Q, m const. -
difficult to generalize to f(t)
& feedback

PNL

saw details yesterday

primitive radiative &
convective heat transfer
duplicates existing work

SUMMARY:


FUEL RESPONSE MODEL
$\dot{Q}$ feedback
$\dot{M}_P$
$\dot{Q}$ fire
COMPARTMENT FIRE MODEL
$\dot{M}_{OUT}$
$\dot{M}_{IN}$
T_{OUT}
$Y_{i\,OUT}$
VENTILATION SYSTEM MODEL

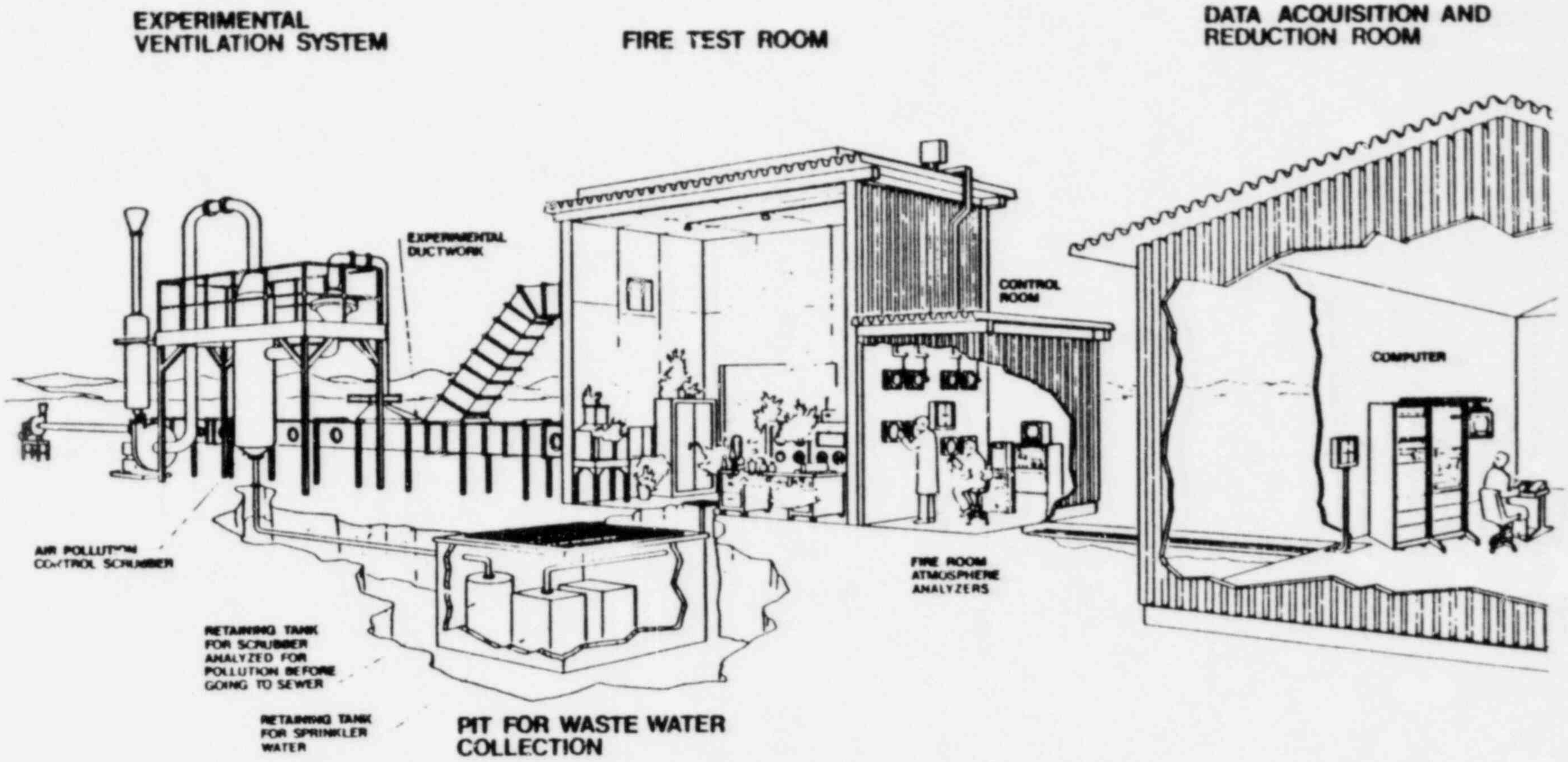
RECOMMENDATIONS:

The Concensus Among the Extended Fire Research Community is that the Harvard Fire Code is the best general compartment fire model available today.

In my opinion you should clearly adopt it fr. your problem.

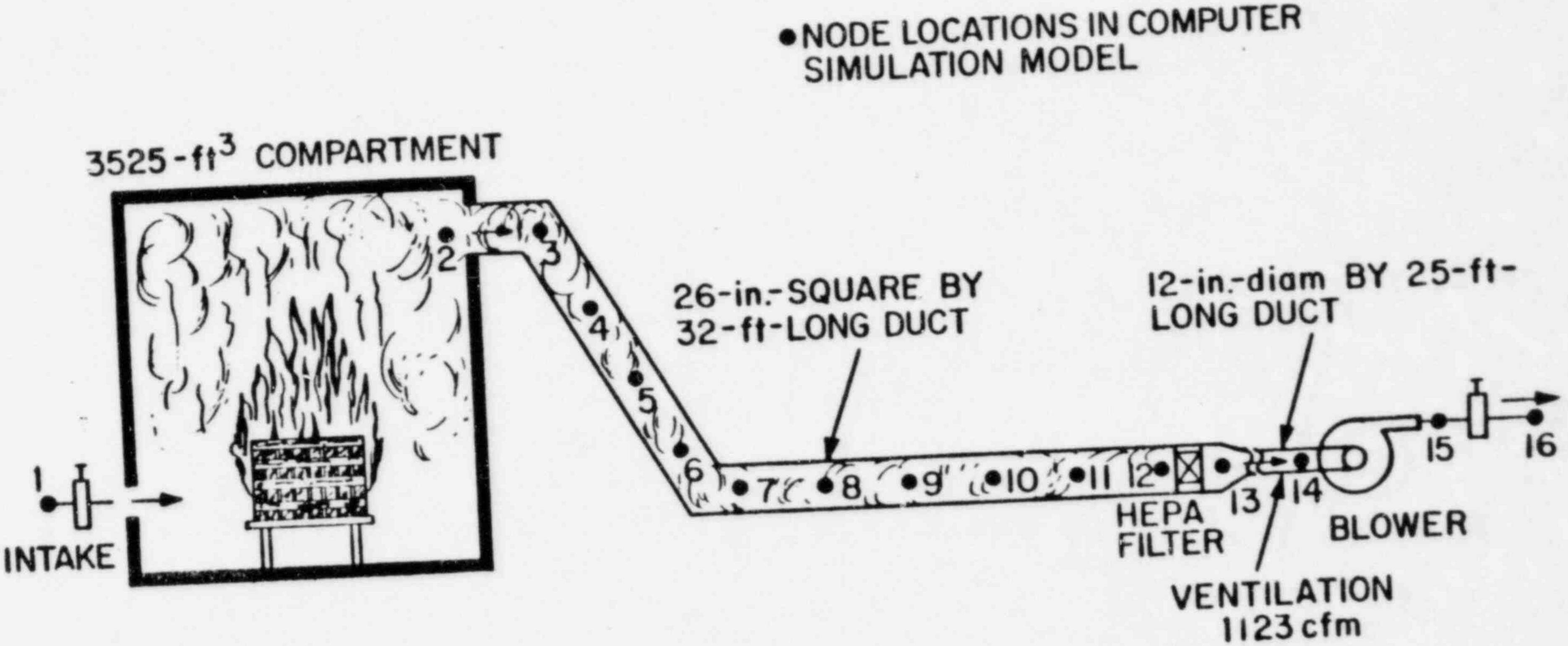
I will go further to recommend: 1) that PNL be responsible fr the definition & quantification of your particular fuel types using Tewarson's & other data – i.e. supply the givens to the Compartment Code. & 2) that LANL be responsible fr completing the FORCED ~~VENT~~ conversion and integration of the Compartment Code into FIRAC.

K-1



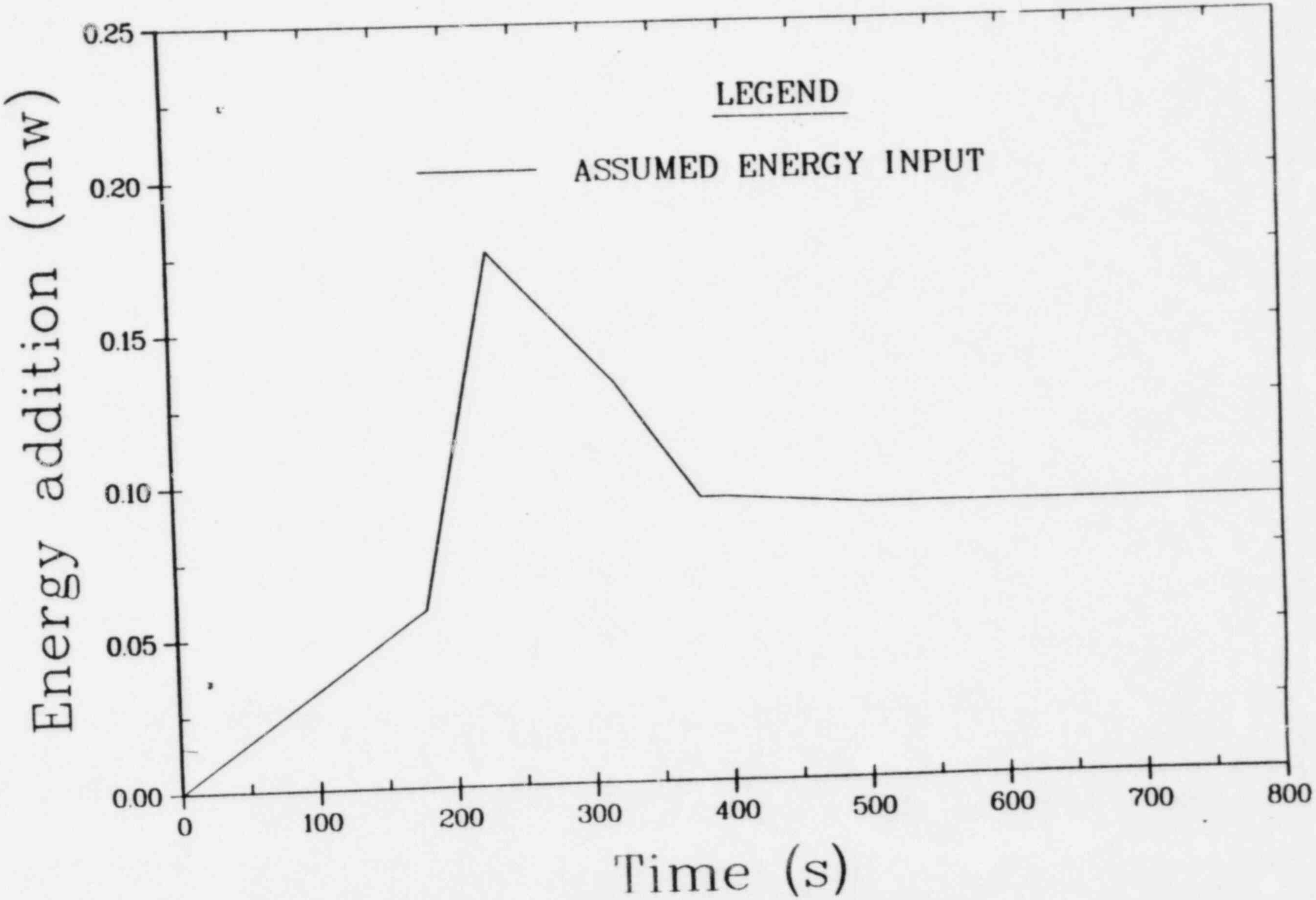
LLL Full-scale Fire Test Facility

K-2

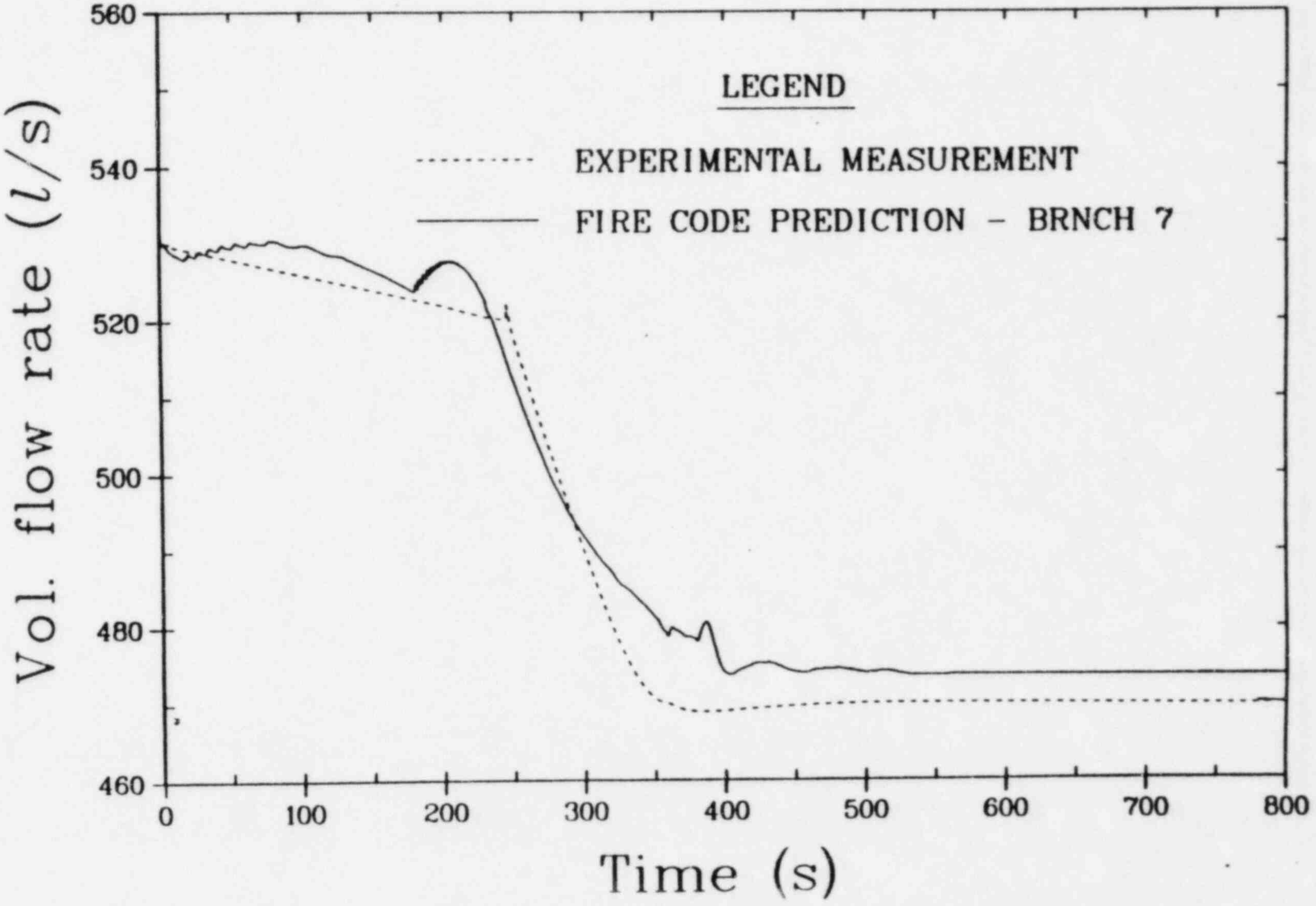


LLNL FULL-SCALE FIRE TEST FACILITY SYSTEM SCHEMATIC

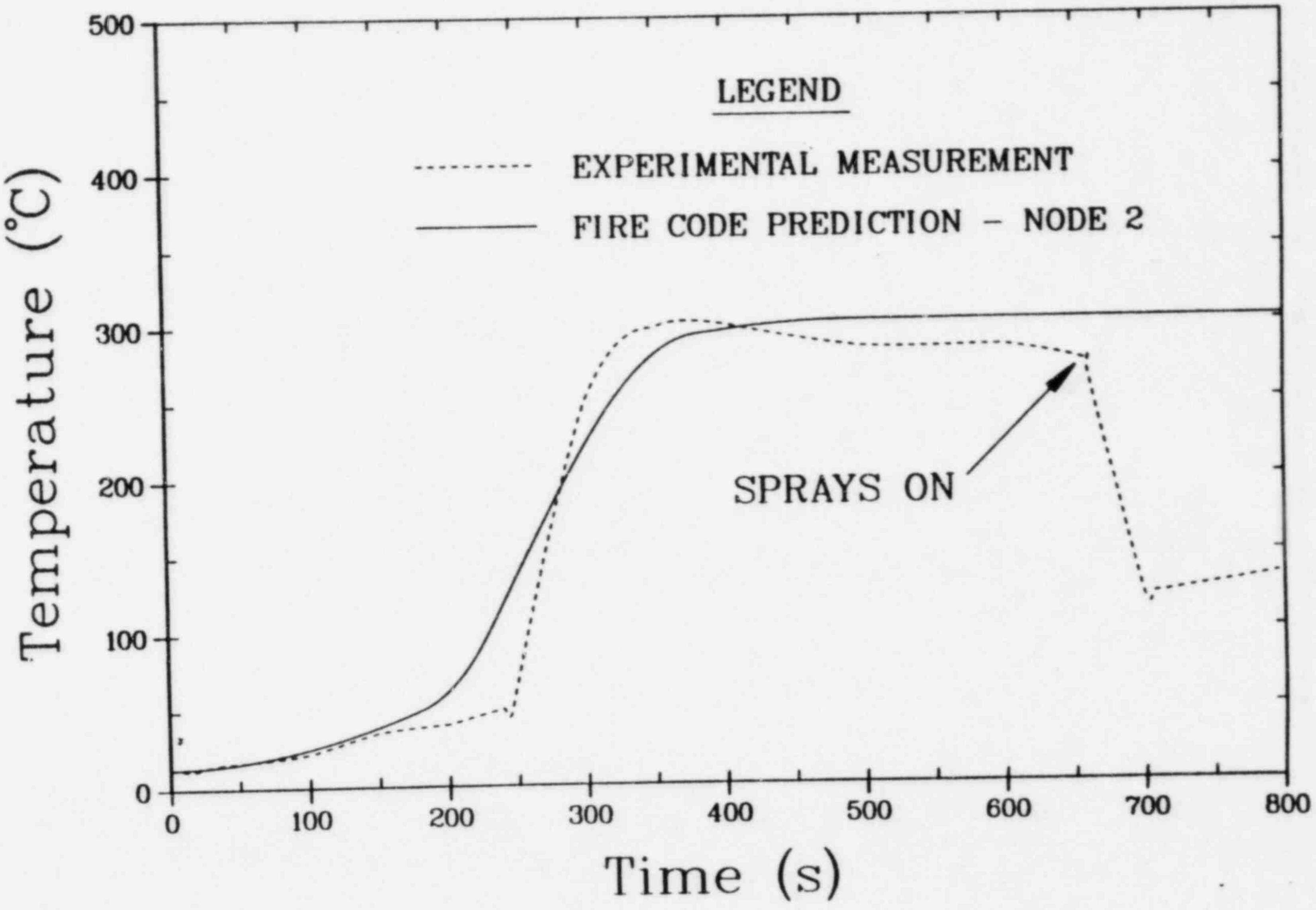
FIRE PARAMETERIZATION



COMPARISON OF FLOW RATE IN DUCT

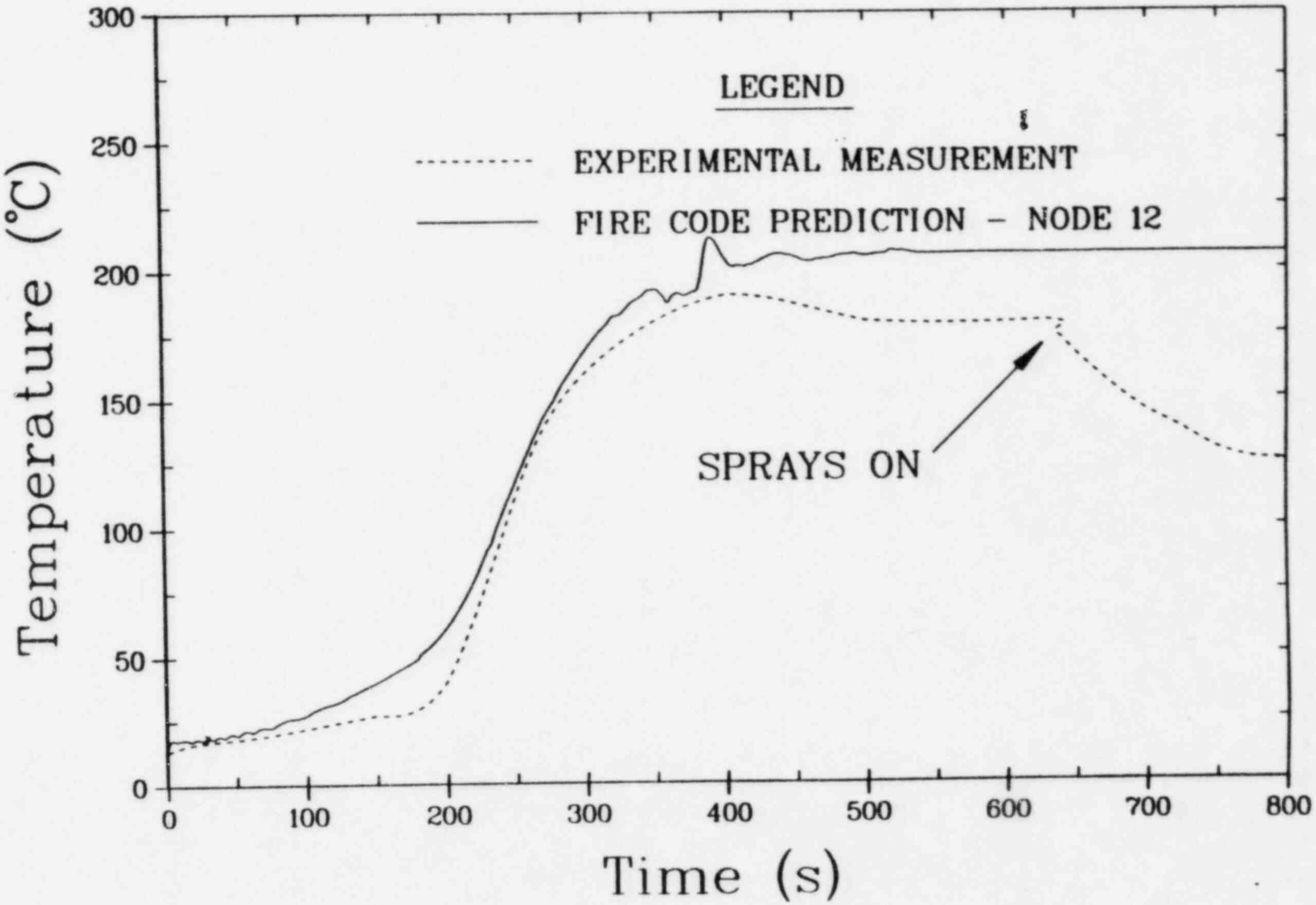


DUCT INLET TEMPERATURE COMPARISON

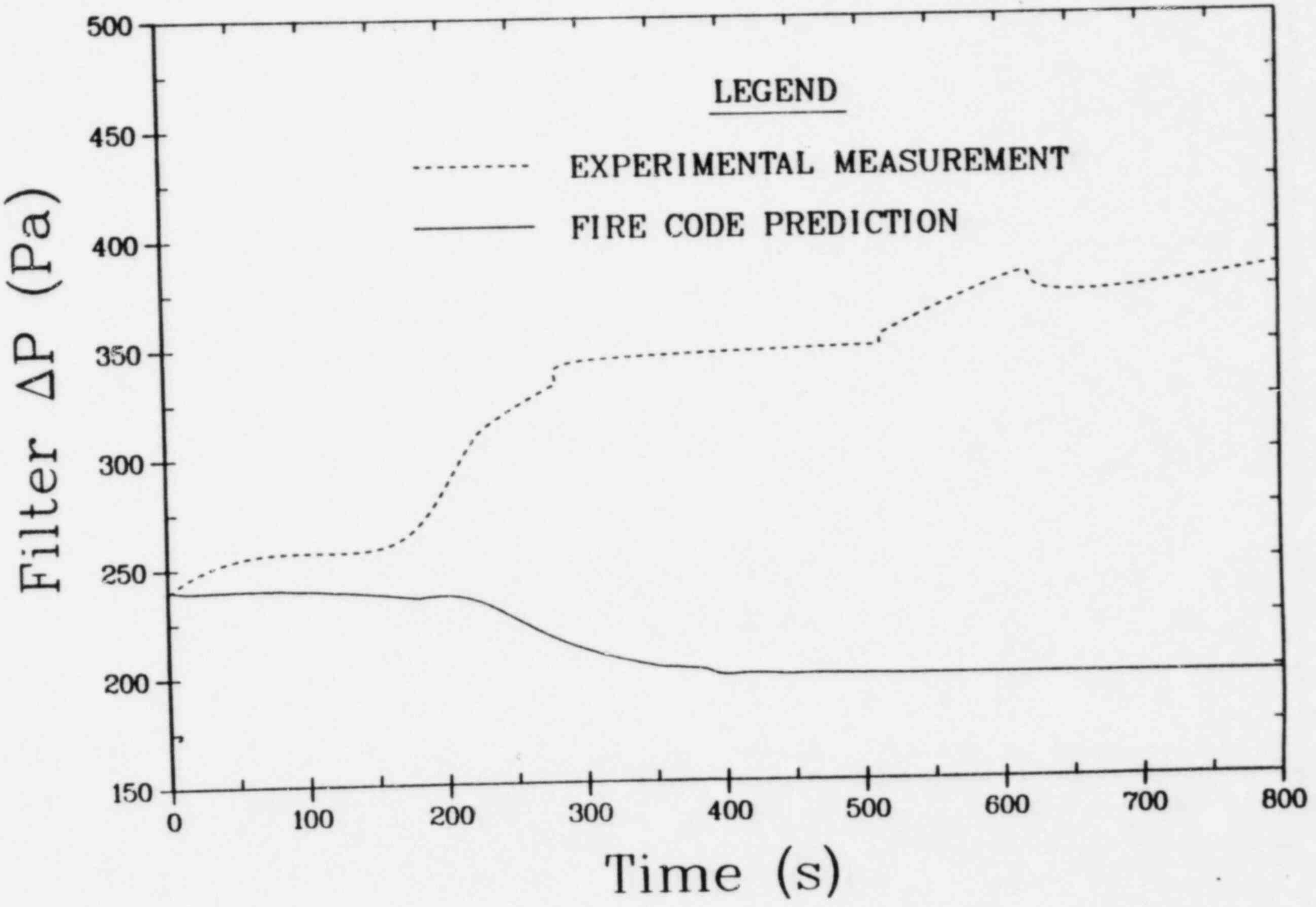


K-6

COMPARISON OF TEMPERATURE AT FILTER



COMPARISON OF FILTER ΔP



SIMULATION OF LARGE FIRES WITH FORCED VENTILATION

by Henri E. Mitler

Presented at FMRC, July 21, 1982

My presentation has two main parts: I will first discuss the model, and then I will show you the predicted results, and discuss them. If there's time, I will also show you the results of a sensitivity analysis.

First, then, the model: there really are only two features which are of special interest for us - oxygen starvation and forced venting.

When the out-venting for a fire is relatively low, the hot layer will descend as far as it can. In our model, the assumption has been made that air is entrained only in the lower part of the fire plume - that is, in that part below the interface between the upper and lower layers. This assumption is surely not correct, but it may be close enough to reality to be adequate. The consequence of this assumption is that when the layer descends to within a small distance of the fire base, insufficient air will be pulled in to permit combustion of all of the fuel which is being pyrolyzed; I call this situation "oxygen starvation". This limits the burning rate, of course, and stops the further descent of the layer.

Whether this will, in fact, happen, is an interesting question. Oxygen starvation is predicted for three of the eight cases I've run, and so these experiments will test our assumption of no entrainment in the upper part of the plume directly.

The second feature of the model which is important for these tests is my new forced-venting algorithm, and so I'll spend a few minutes describing it now: first, consider the fan pulling gas out the vent.

When the hot layer is above the opening - i.e., $H_L < H_t$

$$\dot{m} = \dot{m}_d = \rho_d \dot{V},$$

where ρ_d is the density in the lower part of the room, and $\dot{V}$ is the prescribed throughput.

When the hot layer is so deep that it covers the opening entirely,

$$\dot{m} = \dot{m}_u = \rho_u \dot{V} ,$$

where ρ_u is the density of the hot layer. These correspond to readily calculated pressure drops across the vent, Δp_d and Δp_u. I assume that when the hot/cold layer interface occurs <u>at</u> the vent, the pressure drop across the vent varies linearly with H_L, between Δp_d and Δp_u:

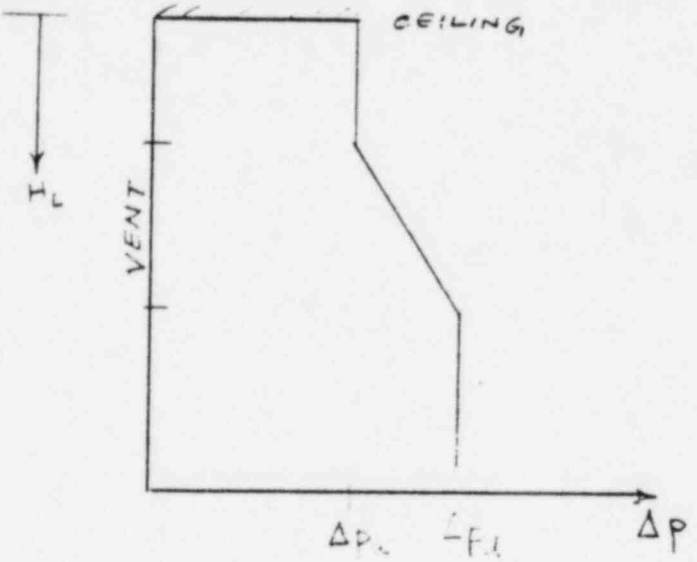


FIG 1

This leads directly to the expression I use in my algorithm:

$$H_L \leq H_t \implies \dot{m}_d = \rho_d \dot{V} , \qquad \dot{m}_u = 0 \tag{1}$$

$$H_t < H_L < H_v + H_t \implies \dot{m}_d = (1 - \xi)\dot{V}\sqrt{\rho_d \rho_\xi} , \qquad \dot{m}_u = \xi \dot{V}\sqrt{\rho_L \rho_\xi} , \tag{2}$$

$$\text{where } \xi \equiv (H_L - H_t)/H_v \quad \text{and} \quad \rho_\xi \equiv \xi \rho_L + (1 - \xi)\rho_d . \tag{3}$$

$$H_L \geq H_t + H_v \implies \dot{m}_d = 0 , \qquad \dot{m}_u = \rho_L \dot{V} . \tag{4}$$

If anyone would like to see a detailed derivation, please let me know at the end of the talk.

The emerging material is presumed to mix immediately upon exit; the resulting density (of outflowing gas) is

$$\bar{\rho} = \begin{cases} \rho_d & H_L \le H_t \\ [(1 - \xi)\sqrt{\rho_d} + \xi\sqrt{\rho_L}\,]\,\sqrt{\rho_\xi} & H_v + H_t > H_L > H_t \\ \rho_L & H_L \ge H_v + H_t \end{cases} \qquad (5)$$

Next, suppose flow is <u>into</u> the room: $\dot{V} < 0$. The incoming material is at density ρ_i (and temperature $T_i = \rho_o T_o / \rho_i$), and arrives at the rate

$$\dot{m} = \rho_i \dot{V} \qquad (6)$$

If $\rho_i < \rho_u$,
we might expect the material to rise (by buoyancy) in the hot layer, to form a third layer. Instead, we assume that the material mixes with that in the layer, for $\rho_i \le \rho_u$, as shown in Figure 2.
Similarly, if $\rho_i \ge \rho_d$, we assume that the mass plunges down into the lower layer and mixes with it there, as shown in Figure 3

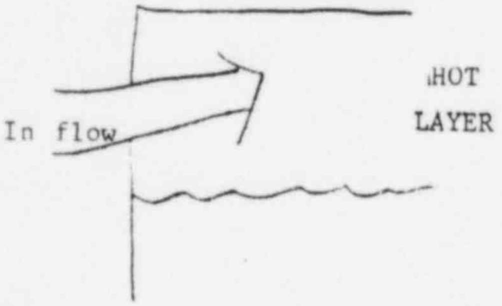


FIG 2

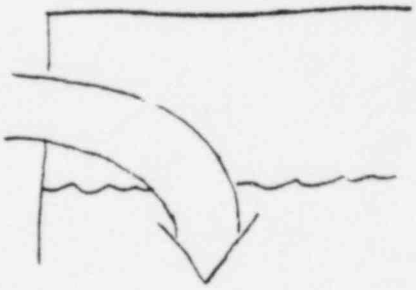


FIG 3

The choice is not so obvious for the case $\rho_d > \rho_i > \rho_u$, however: Again if it maintained its identity, we would expect it to form a third layer between the other two. If we insist on maintaining just two layers, however, we must have the material divide, some of it going into the upper layer and some into the lower, as shown in Figure 4.

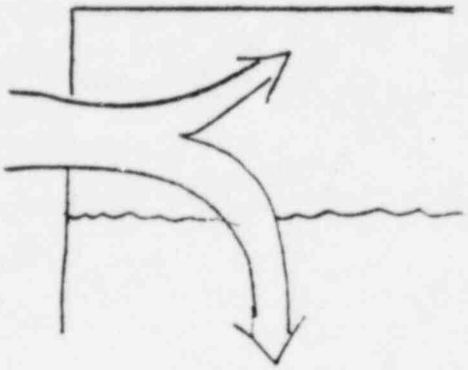


FIG 4

How should we make this division? Prof. Emmons has suggested that the fraction of the mass going into the upper layer is the same as the temperature ratio - that is,

$$\dot{m}_u = \dot{m}_i \left(\frac{T_i - T_d}{T_L - T_d}\right) \text{ and } \dot{m}_d = \dot{m}_i \left(\frac{T_L - T_i}{T_l - T_d}\right) \tag{7}$$

This is what I have used in the program.

Thus we have

Case I: $T_i > T_L \qquad (\rho_i < \rho_L)$

$$\dot{m}_d = \dot{E}_d = 0$$

$$\dot{m}_u = \rho_i \dot{V} , \quad \dot{E}_u = c_p \rho_o T_o \dot{V} \tag{8}$$

(This will heat the upper layer further; subscripts o refer to ambient.)

Case II: $T_L \geq T_i > T_d \qquad (\rho_d > \rho_i \geq \rho_L)$

$$\dot{m}_d = \left(\frac{T_L - T_i}{T_L - T_d}\right) \rho_i \dot{V} = \left(\frac{\rho_i - \rho_L}{\rho_d - \rho_L}\right) \rho_d \dot{V}, \quad \dot{E}_d = \dot{m}_d c_p T_i \tag{9a}$$

$$\dot{m}_u = \left(\frac{T_i - T_d}{T_L - T_d}\right) \rho_i \dot{V} = \left(\frac{\rho_d - \rho_i}{\rho_d - \rho_L}\right) \rho_L \dot{V} , \quad \dot{E}_u = \dot{m}_u c_p T_i . \tag{9b}$$

Case III: $T_i \le T_d$ $\qquad (\rho_d \le \rho_i)$

$$\dot{m}_u = \dot{E}_u = 0 \tag{10}$$

$$\dot{m}_d = \rho_i \dot{V} \ , \ \dot{E}_d = \dot{V} c_p \rho_o T_o \ .$$

(This will cool the lower layer.)

There is, however, no good <u>a priori</u> reason why we could not use the same reasoning with the <u>density</u> ratio; that is,

$$\dot{m}_d = \dot{m}_i \left(\frac{\rho_i - \rho_L}{\rho_d - \rho_L}\right) \ , \ \dot{m}_u = \dot{m}_i \left(\frac{\rho_d - \rho_i}{\rho_d - \rho_L}\right) \tag{11}$$

Indeed, this seems a little better motivated heuristically, because the buoyant forces are proportional to the density differences, rather than the temperature differences. Equation (11) will give rise to somewhat different results than eq (7), of course, and it should be up to experiment to choose between the two.

In neither case, however, do I include the possibility of mixing, which <u>should</u> be included in a good calculation: Thus, instead of Figures 3 and 4, the <u>correct</u> situation is as shown in Figures 5 and 6, respectively:

Fig 5

Fig 6

APPENDIX

Derivation of equations -

Suppose outflow is from lower layer only - $H_L < H_t$ - then

$$\dot{m} = \dot{m}_d = \rho_d \dot{V}$$

and $\dot{V} = v_d A$

where A is the vent area, v_d the velocity of outflow.

Thus $\dot{m}_d = \rho_d v_d A$;

The corresponding pressure drop is given by [see eq (3) 126 of TR 45]

$$\dot{m}_d = C_o B \sqrt{2g\rho_d\rho_a}\, H_v \sqrt{\Delta p_d}$$

where B is the vent width, C_o the vent coefficient (~0.68), ρ_a the ambient density, and H_v the vent height.

Next, consider what happens when the layer interface lies below the vent:

$$H_L > H_t + H_v$$

Then outflow is from the hot upper layer only, and

$$\dot{m} = \dot{m}_u = \rho_u \dot{V},$$

where $\rho_u < \rho_d$. The corresponding pressure drop <u>here</u> is given by

$$\dot{m}_u = B\, C_o \sqrt{2g\ \rho_u\rho_a}\, H_v \sqrt{\Delta p_u} \quad .$$

Hence $\Delta p_u = \frac{\rho_d \Delta p_d}{\rho_u} \left(\frac{\dot{m}_u}{\dot{m}_d}\right)^2 = \frac{\rho_u}{\rho_d} \Delta p_d$

Finally, consider the case where the interface occurs at the vent mouth:

$$H_t < H_L < H_t + H_v.$$

In order to find the mass outflow rates, we need the pressure drops across the vent; Δp will be fairly constant (except for a small buoyancy correction), and thus we need only to find Δp. If we assume that the pressure drop varies linearly in the layer height, as shown in figure 7,

$$\Delta p = \frac{1}{H_v} [(H_L - H_t)\ \Delta p_u + (H_v + H_t - H_L)\ \Delta p_d]$$

$$= \frac{\Delta p_d}{H_v} [(H_L - H_t) \frac{\rho_u}{\rho_d} + (H_v + H_t - H_L)]$$

$$= \Delta p_d\ [\xi \frac{\rho_u}{\rho_d} + (1 - \xi)]$$

Then for the hot gas, we have

$$\dot{m}_h = B\ C_o \sqrt{2g\ \rho_u\ \rho_o}\ (H_L - H_t) \sqrt{\Delta p}$$

Since $\dot{V} = \dot{m}_d/\rho_d = B\ C_o \sqrt{2g\rho_o}\ H_v \sqrt{\frac{\Delta p_d}{\rho_d}}$,

we can write $\dot{m}_h$ as

$$\dot{m}_h = \dot{V}\ \xi \sqrt{\rho_d\rho_u} \sqrt{\frac{\Delta p}{\Delta p_d}}$$

Similarly for the cold gas,

$$\dot{m}_c = B\ C_o \sqrt{2g\ \rho_d\rho_o}\ (H_t + H_v - H_L) \sqrt{\Delta p}$$

$$= \dot{V}\ \rho_d\ (1 - \xi) \sqrt{\frac{\Delta p}{\Delta p_d}}$$

with the definition

$$\rho_\xi \equiv \xi\ \rho_u + (1 - \xi)\ \rho_d \quad ,$$

we have $\Delta p = \dfrac{\Delta\rho_d}{\rho_d}\ \rho_\xi$,

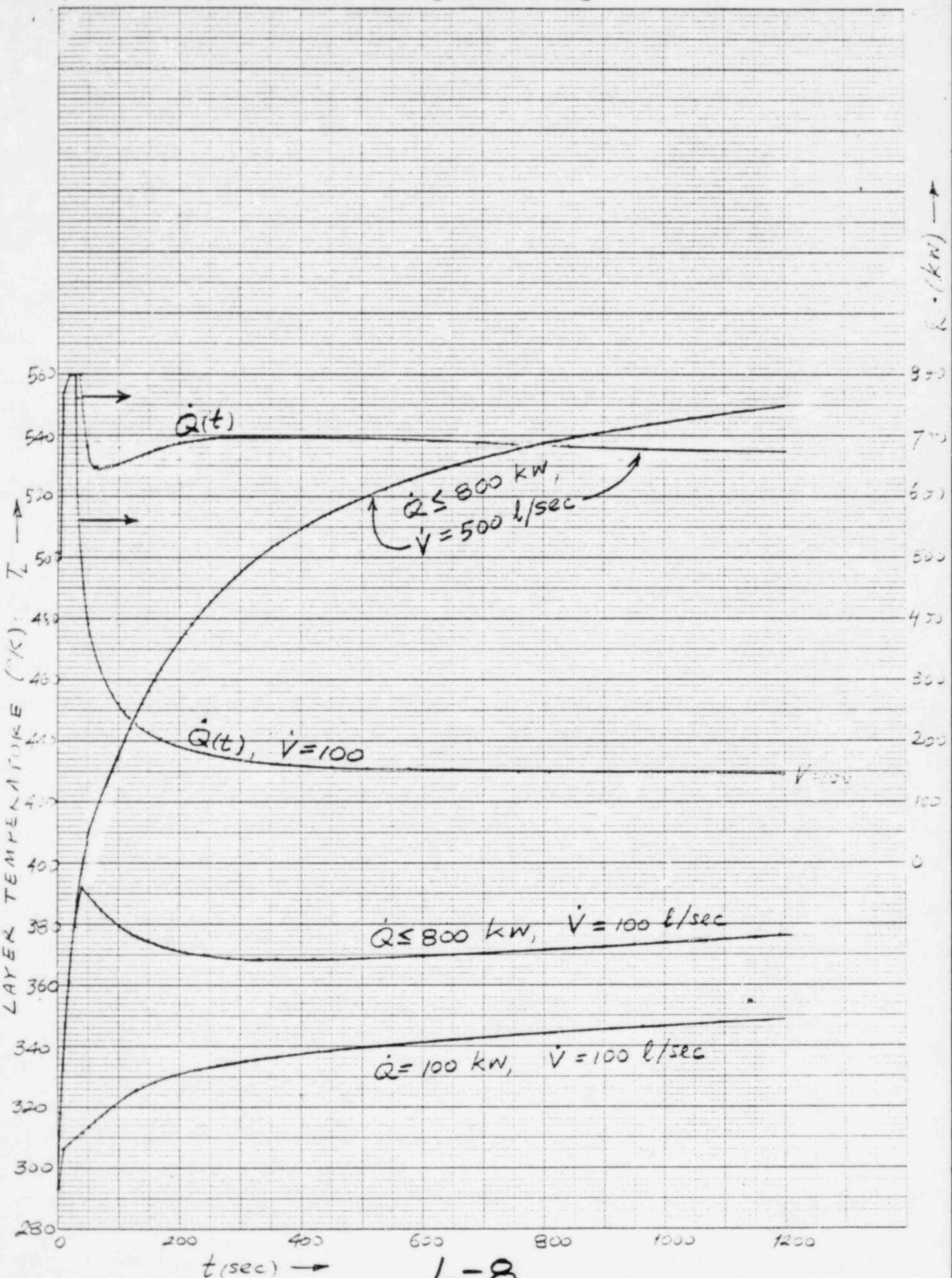
$$\dot{m}_h = \dot{V}\ \xi \sqrt{\rho_d\rho_u} \sqrt{\frac{\rho_\xi}{\rho_d}} = \dot{V}\ \xi \sqrt{\rho_u\rho_\xi} \quad ,$$

$$\dot{m}_c = \dot{V}\ (1 - \xi)\ \rho_d \sqrt{\frac{\rho_\xi}{\rho_d}} = \dot{V}\ (1 - \xi) \sqrt{\rho_d\rho_\xi}$$

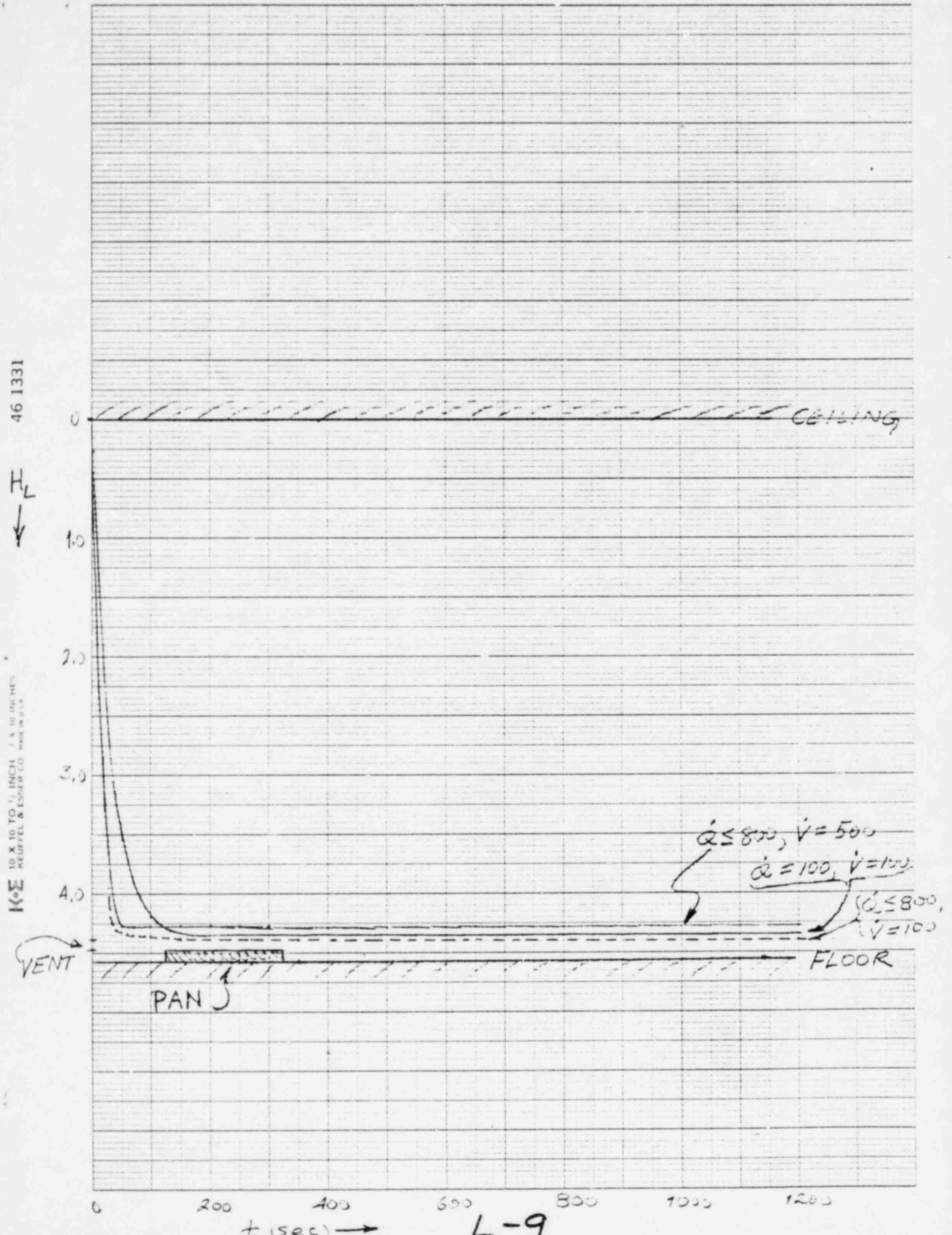
Q.E.D.

PLUS TOTAL HEAT RELEASE RATE

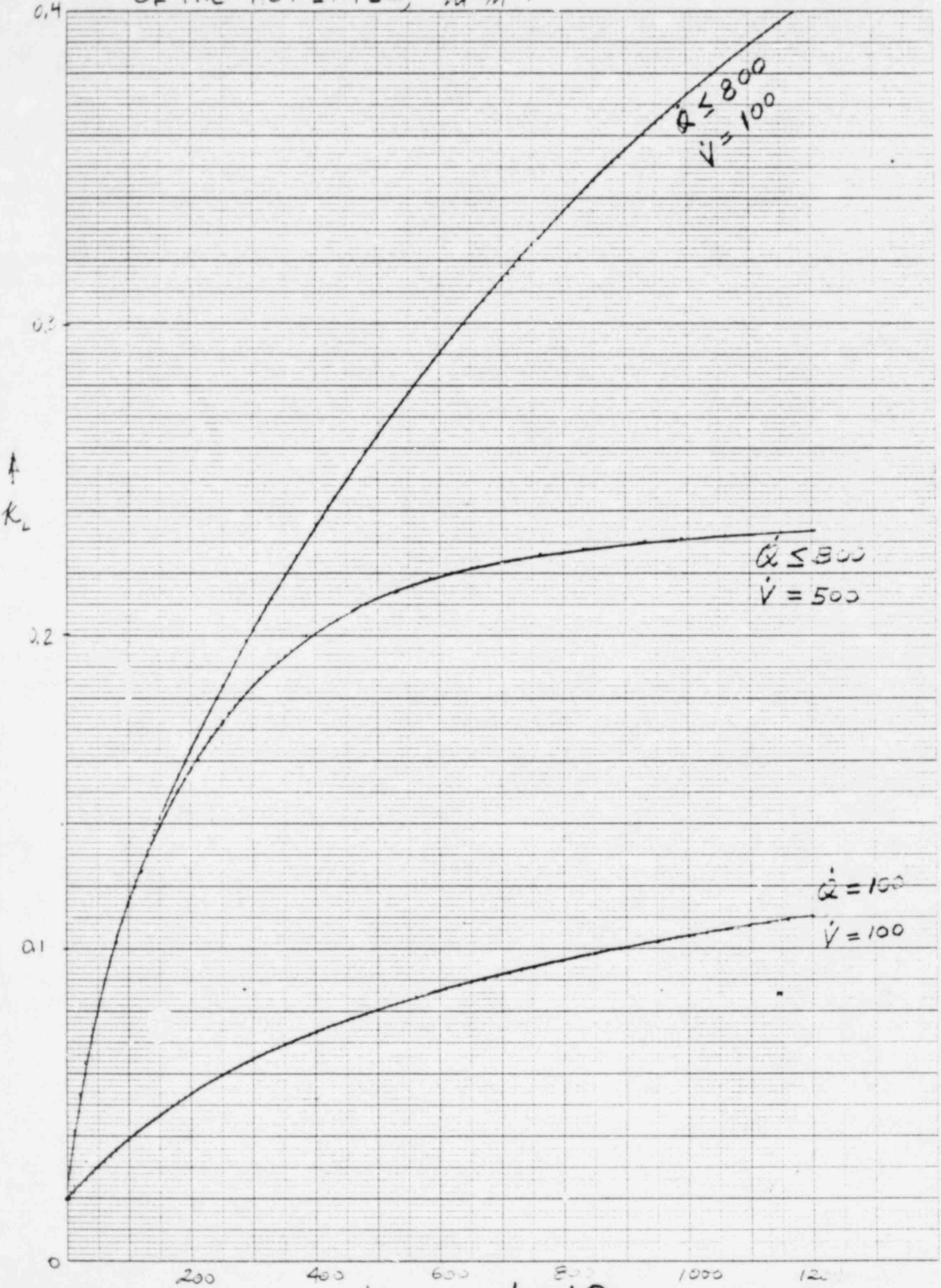
JULY 20, 1982. Using Mark 5.2



PREDICTED LAYER HEIGHTS (ISOPROPANOL FIRES)

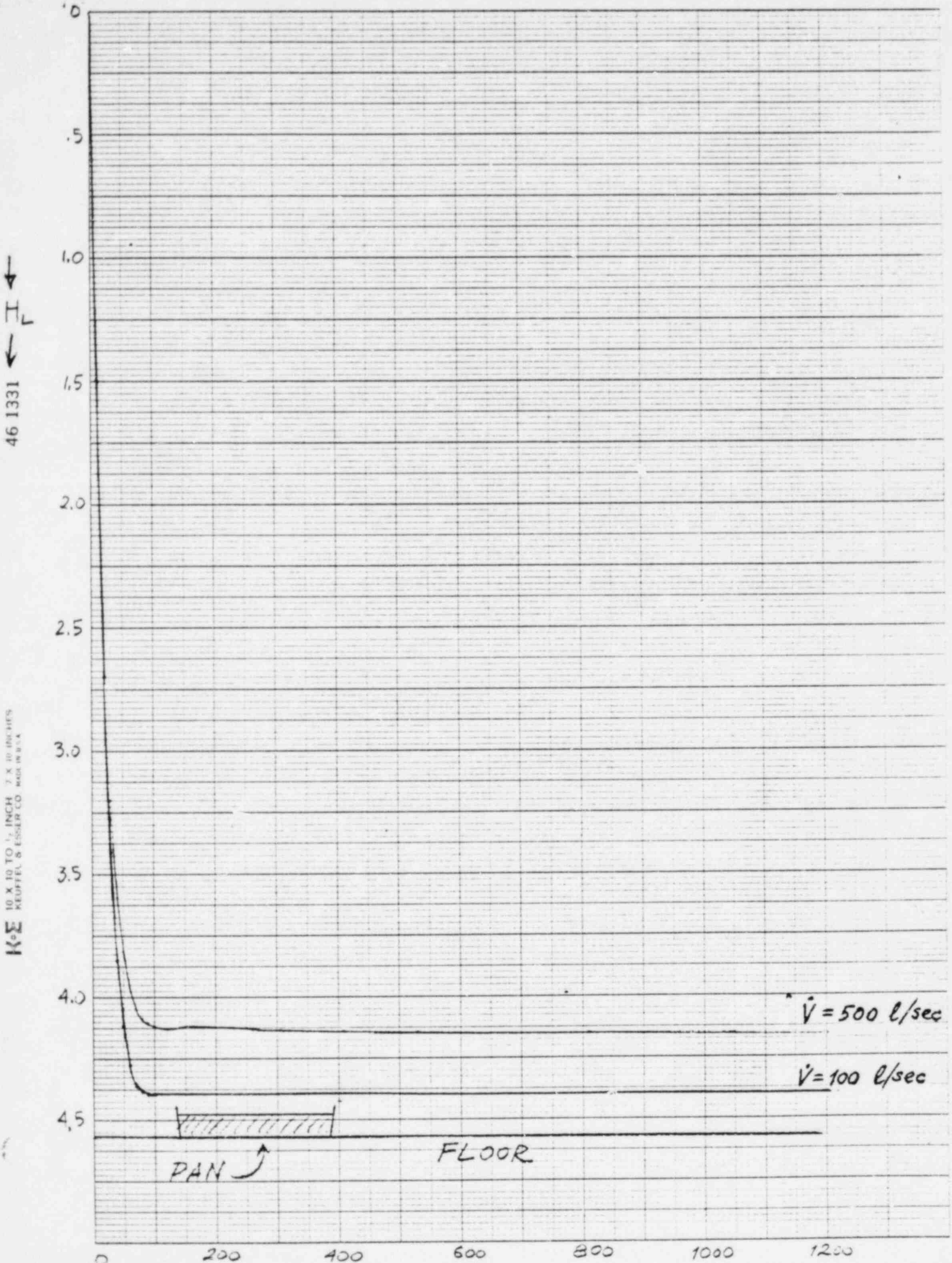


ABSORPTION COEFFICIENT OF THE HOT LAYER, in M-1 (ISOPROPANOL FIRES)

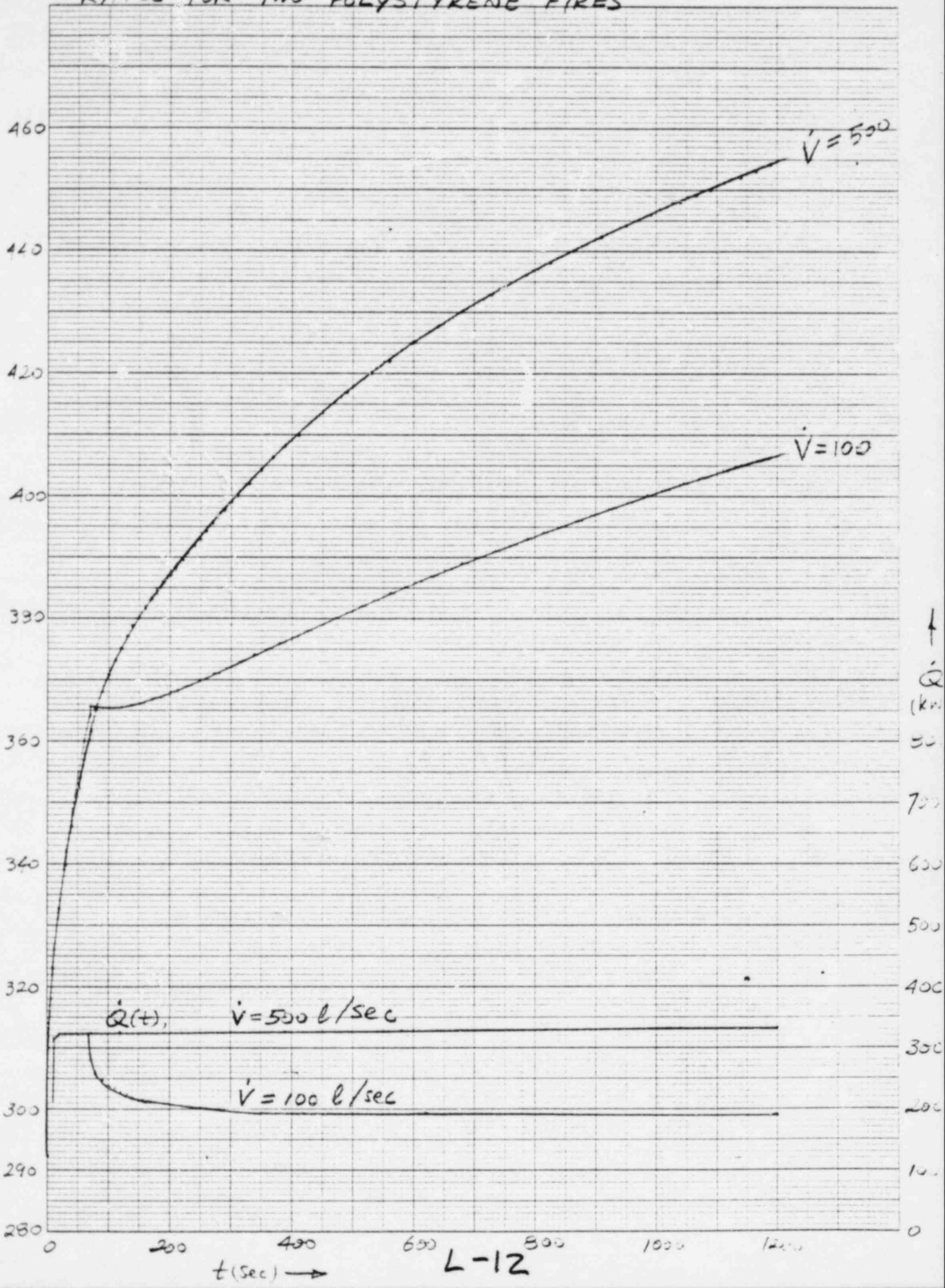


L-10

PREDICTED LAYER HEIGHTS (POLYSTYRENE FIRES)

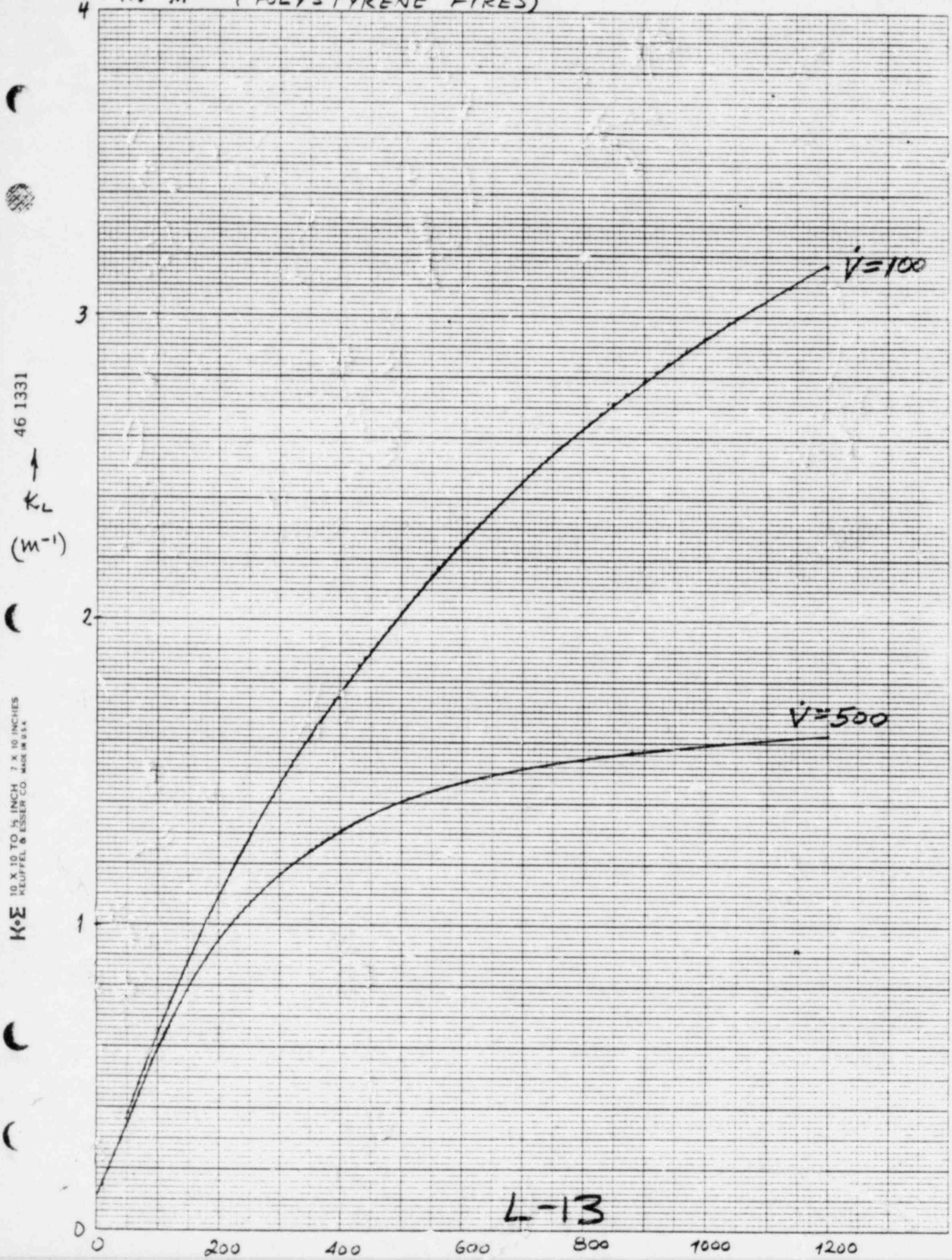


PREDICTED LAYER TEMPERATURES AND HEAT RELEASE RATES FOR TWO POLYSTYRENE FIRES



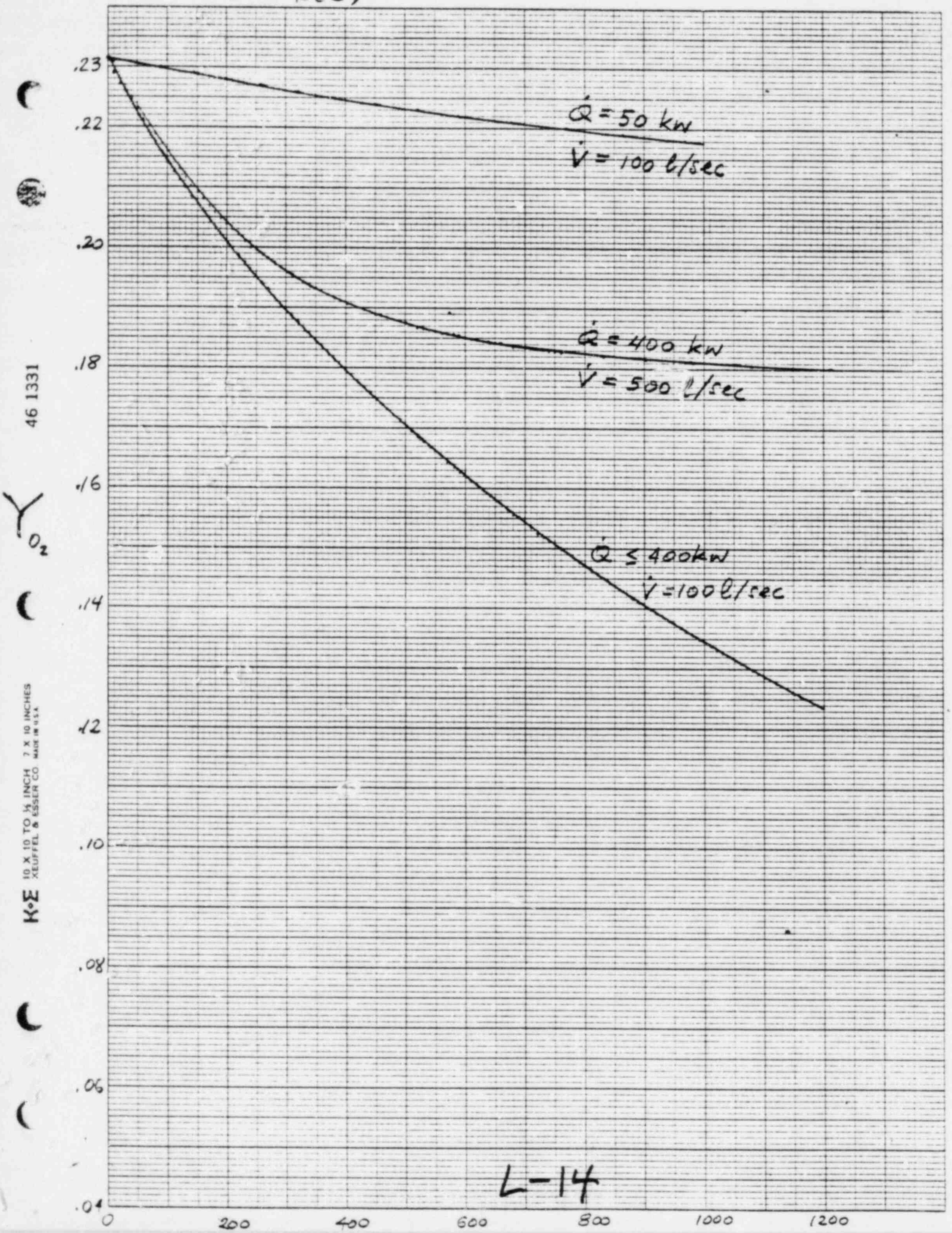
L-12

ABSORPTION COEFFICIENT OF THE HOT LAYER, IN M^-1 (POLYSTYRENE FIRES)



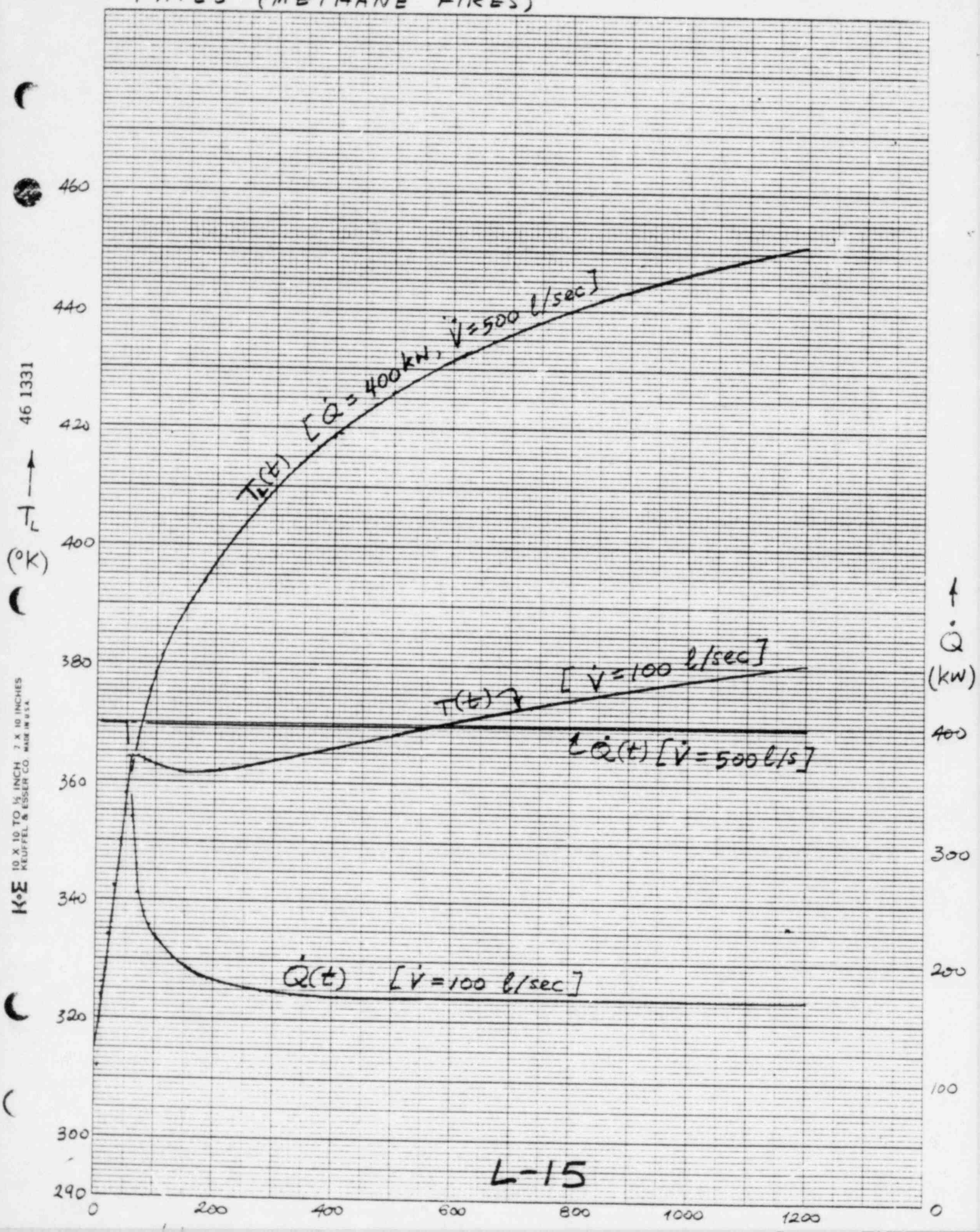
L-13

PREDICTED OXYGEN CONCENTRATION RATES, BY MASS
(METHANE FIRES)



L-14

TEMPERATURES AND HEAT RELEASE
RATES (METHANE FIRES)



LAWRENCE LIVERMORE LABORATORY

FULL SCALE FIRE TEST FACILITY

1-W

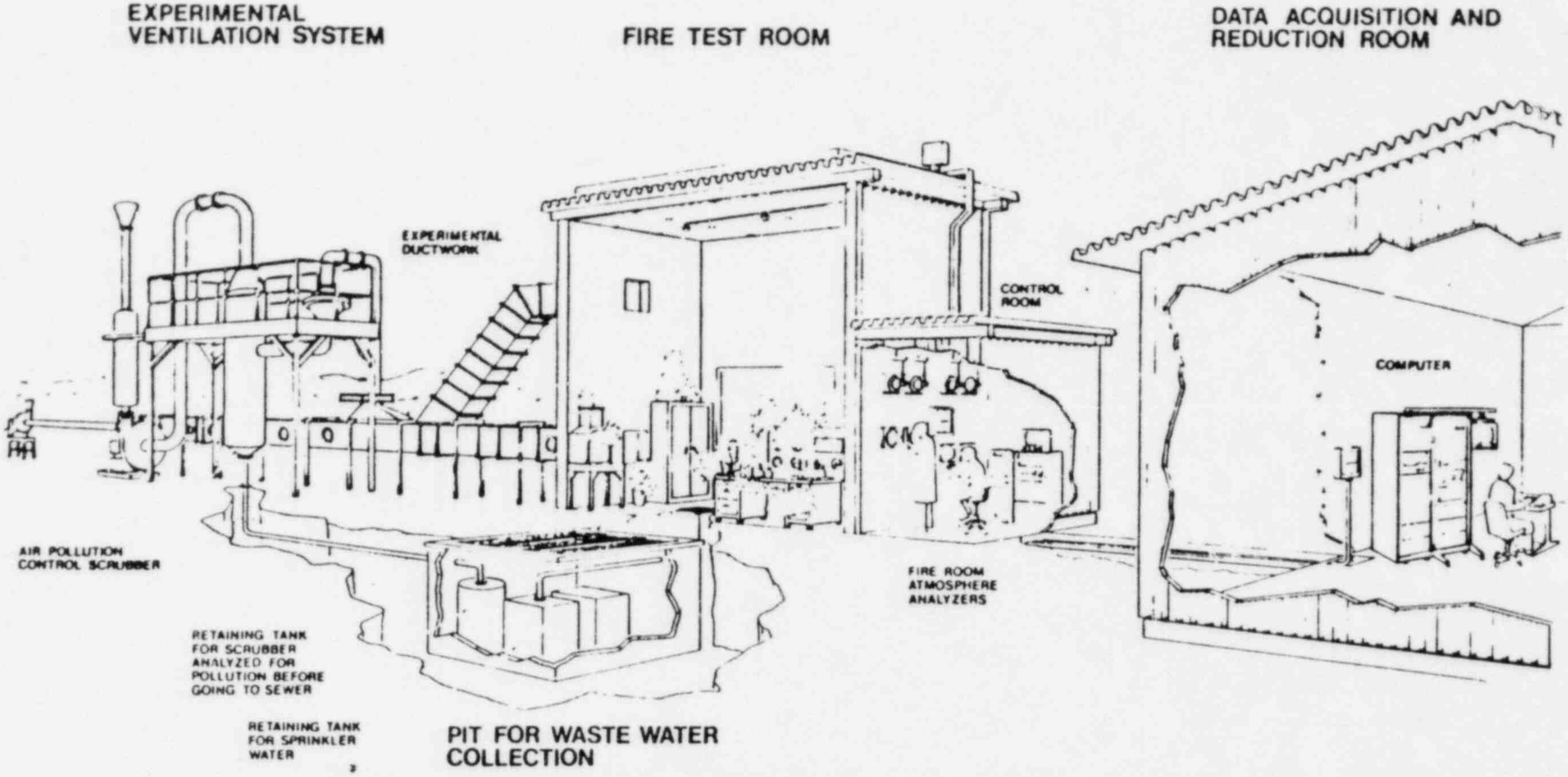
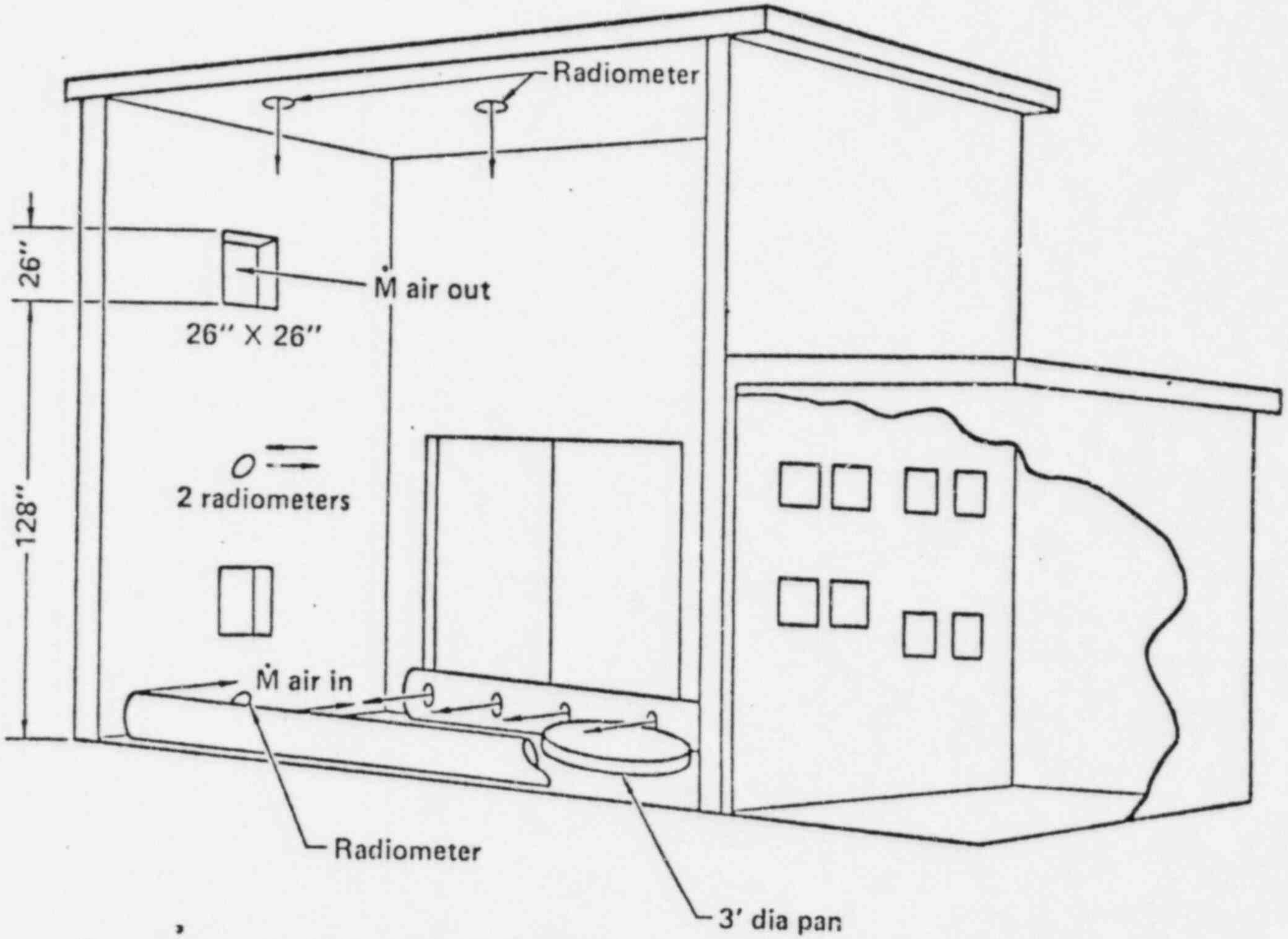


Fig. 1. Schematic layout of LLNL full-scale fire test cell with associated experimental ventilation system.

M-2

SECTION VIEW TEST CELL



Room dimension 20' L X 13'6" W X 15' H
Door dimension 7' W X 8' H

FIGURE 1B

PLAN VIEW TEST CELL

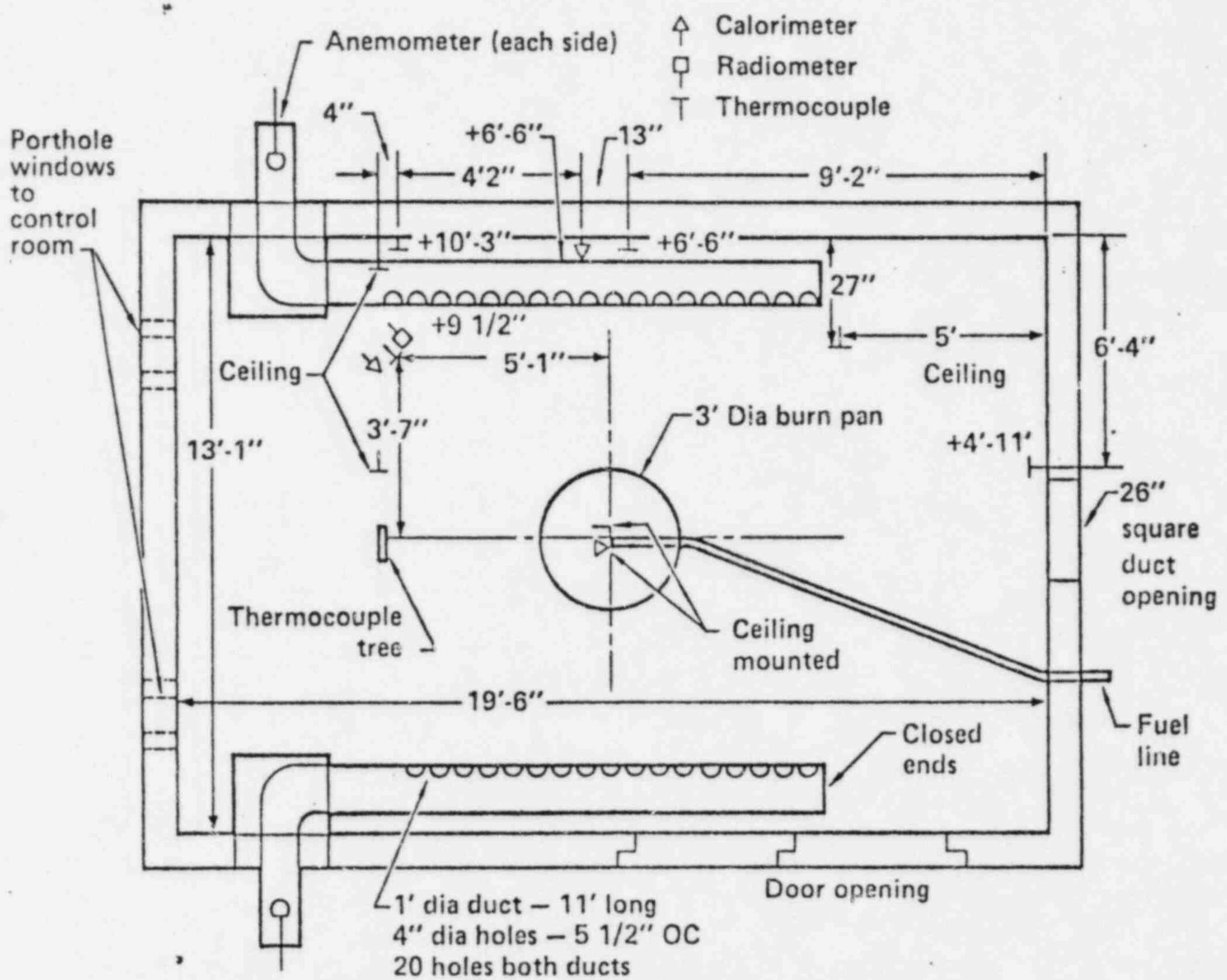


FIGURE-1A

TEST PARAMETERS

- 1.0 FUEL CHARACTERISTICS
  - 1.1 Fuel Type/Mode
    - 1.11 Gas/Burner
    - 1.12 Liquid/Spray
      - 1.121 Smoky
      - 1.122 Non-Smoky
    - 1.13 Liquid/Pool
      - 1.131 Smoky
      - 1.132 Non-Smoky
    - 1.14 Solid/2 dimensional
      - 1.141 Fuel composition
      - 1.142 Fuel Porosity
    - 1.15 Solid/3 dimensional
      - 1.151 Fuel composition
      - 1.152 Fuel porosity
  - 1.2 Fuel Distribution
    - 1.21 Contiguous Fuel (single)
      - 1.211 Corner/Center of room
      - 1.212 Floor Plane
      - 1.213 Mid room
      - 1.214 Ceiling Plane
    - 1.22 Discontiguous fuel (two)
      - 1.221 Corner/Center of room
      - 1.222 Floor plane
      - 1.223 Mid room
      - 1.224 Ceiling plane
      - 1.225 Mixed plane
    - 1.23 Complex Fuels (multiple)
  - 1.3 Fuel Heat Release Rate
    - 1.31 Fuel flow rate
    - 1.32 Fuel Size (area)
- 2.0 ENCLOSURE CHARACTERISTICS
  - 2.1 Ceiling/Walls/Floor
    - 2.11 Radiation Effect
    - 2.12 Heat Transfer
    - 2.13 Room Volume
  - 2.2 Room Objects
    - 2.21 Heat Transfer
    - 2.22 Size
    - 2.23 Number
- 3.0 VENTILATION CHARACTERISTICS
  - 3.1 Forced Ventilation
    - 3.11 Thru inlet
      - 3.111 Position
      - 3.112 Rate
    - 3.12 Thru Outlet
      - 3.121 Position
      - 3.122 Rate
  - 3.2 Natural Ventilation
    - 3.21 Position
    - 3.22 Area (Size)
    - 3.23 Number of openings
  - 3.3 Mixed Ventilation

M-5

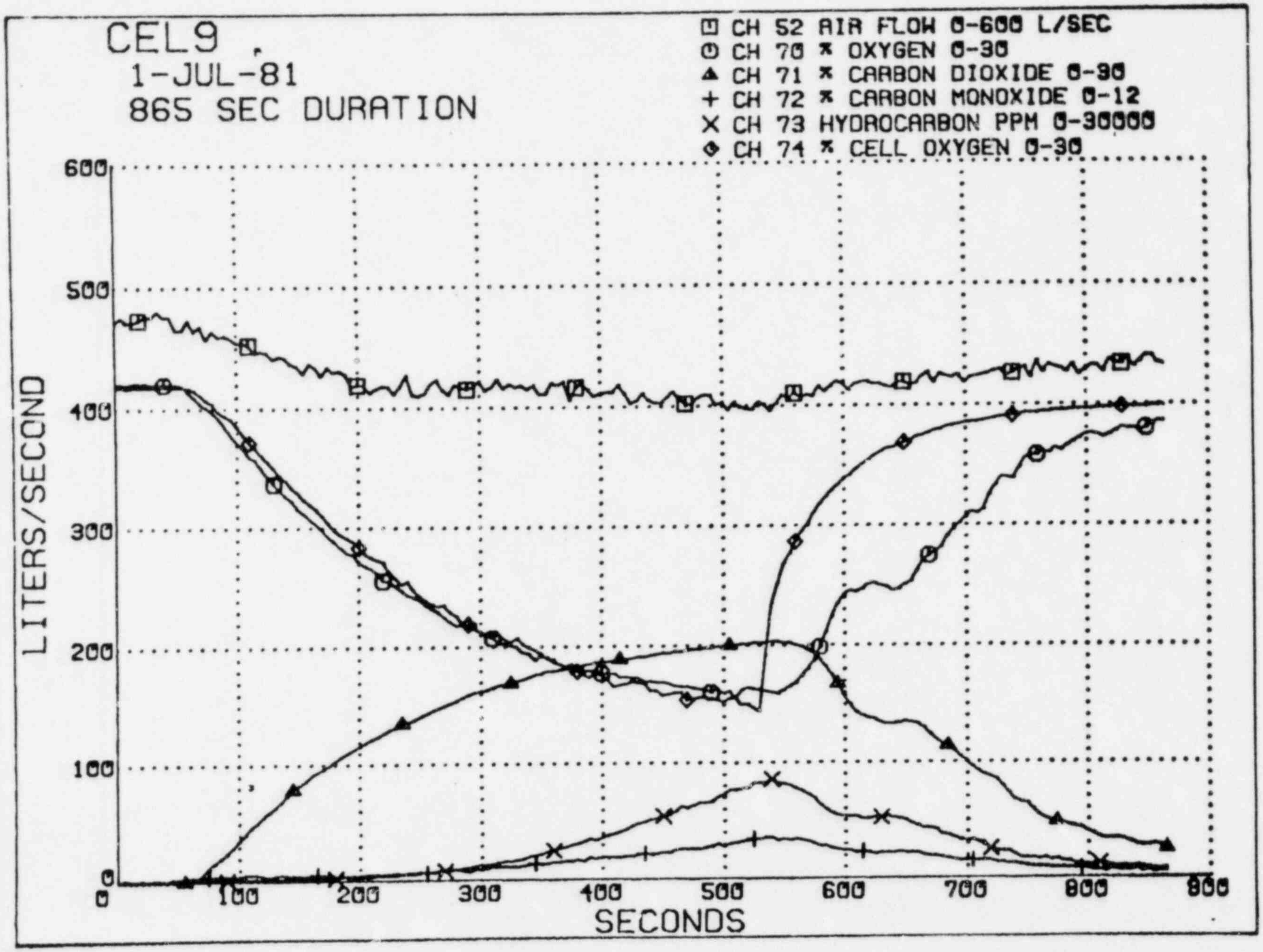

CEL9
1-JUL-81
865 SEC DURATION
□ CH 52 AIR FLOW 0-600 L/SEC
○ CH 70 % OXYGEN 0-30
▲ CH 71 % CARBON DIOXIDE 0-30
+ CH 72 % CARBON MONOXIDE 0-12
× CH 73 HYDROCARBON PPM 0-30000
◇ CH 74 % CELL OXYGEN 0-30
LITERS/SECOND
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
SECONDS

FIG. 47

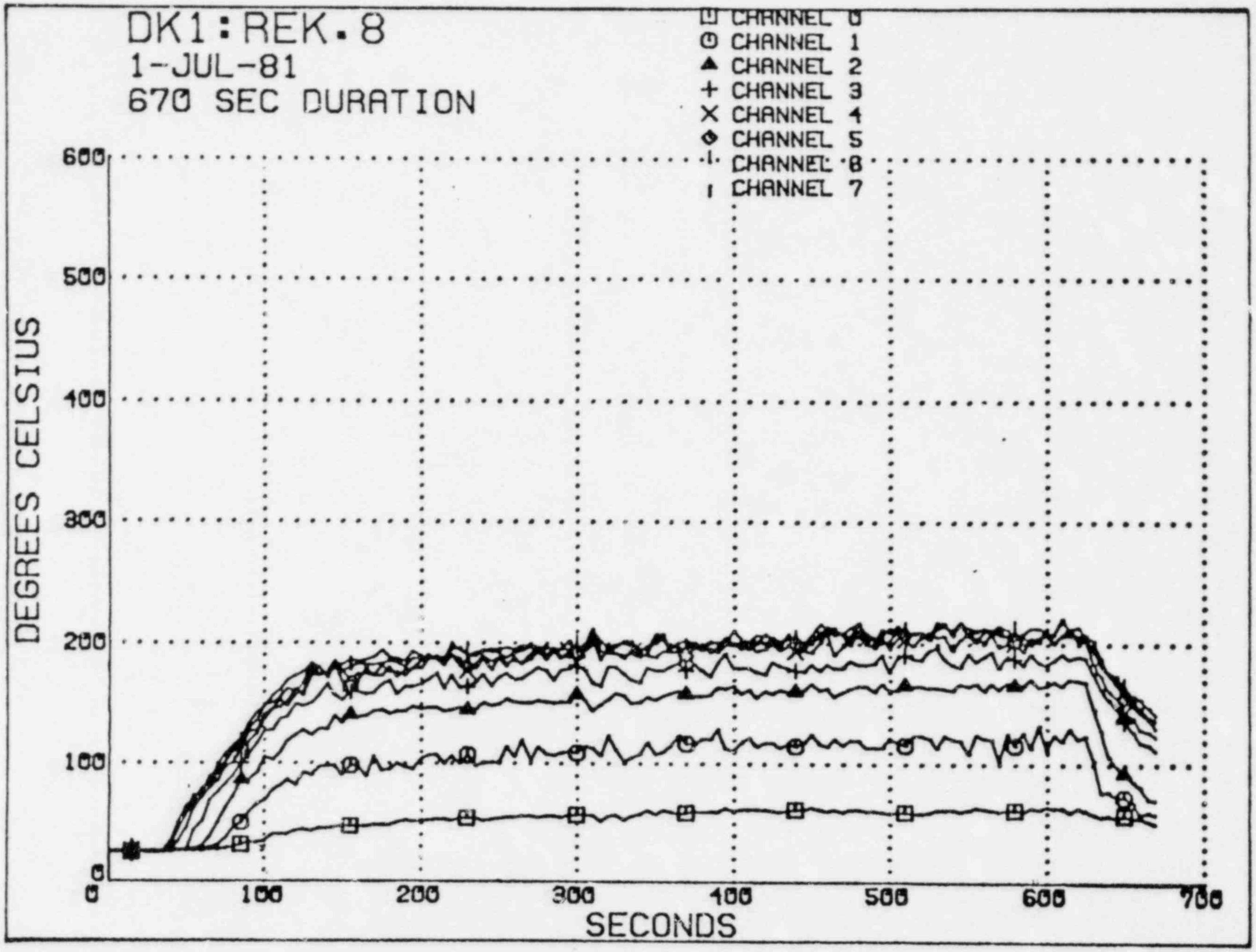

DK1:REK.8
1-JUL-81
670 SEC DURATION
□ CHANNEL 0
○ CHANNEL 1
▲ CHANNEL 2
+ CHANNEL 3
× CHANNEL 4
◆ CHANNEL 5
┼ CHANNEL 6
ı CHANNEL 7
DEGREES CELSIUS
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
SECONDS

FIG. 37

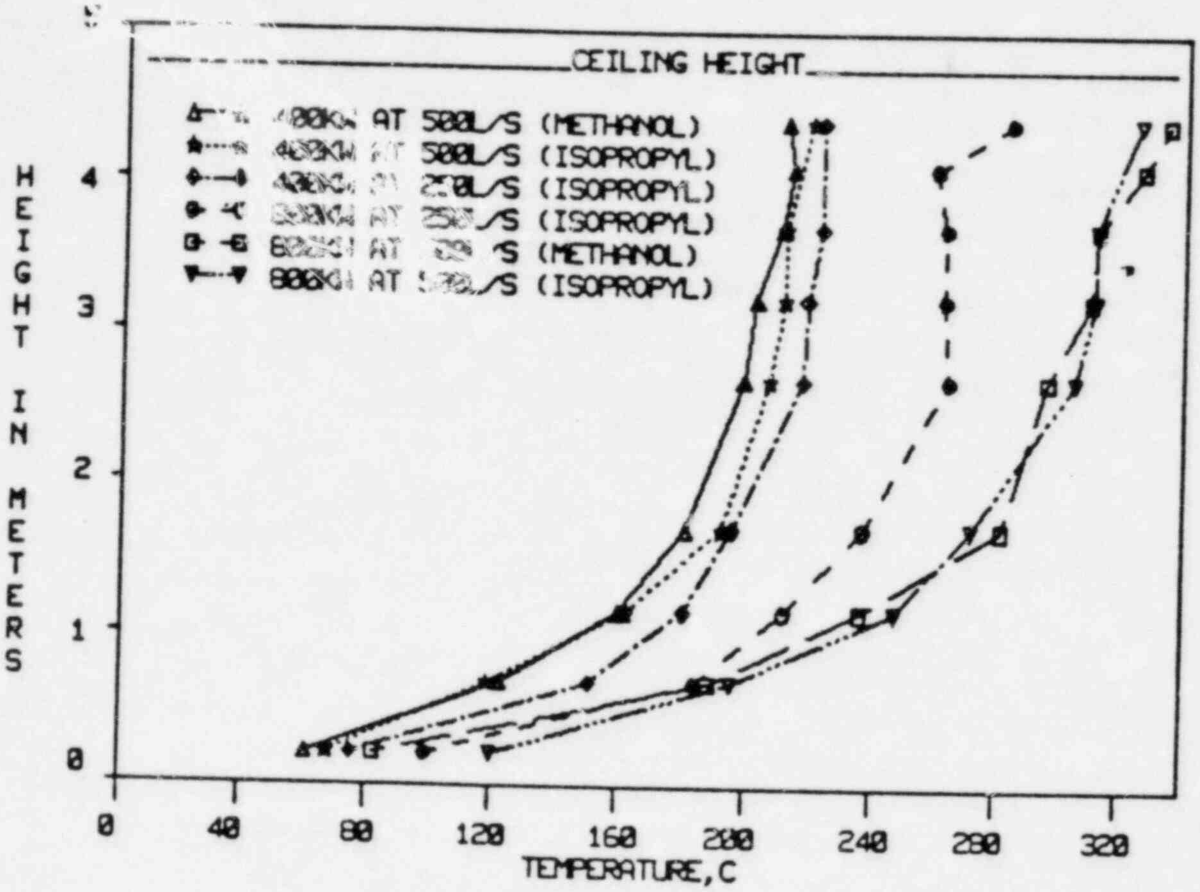
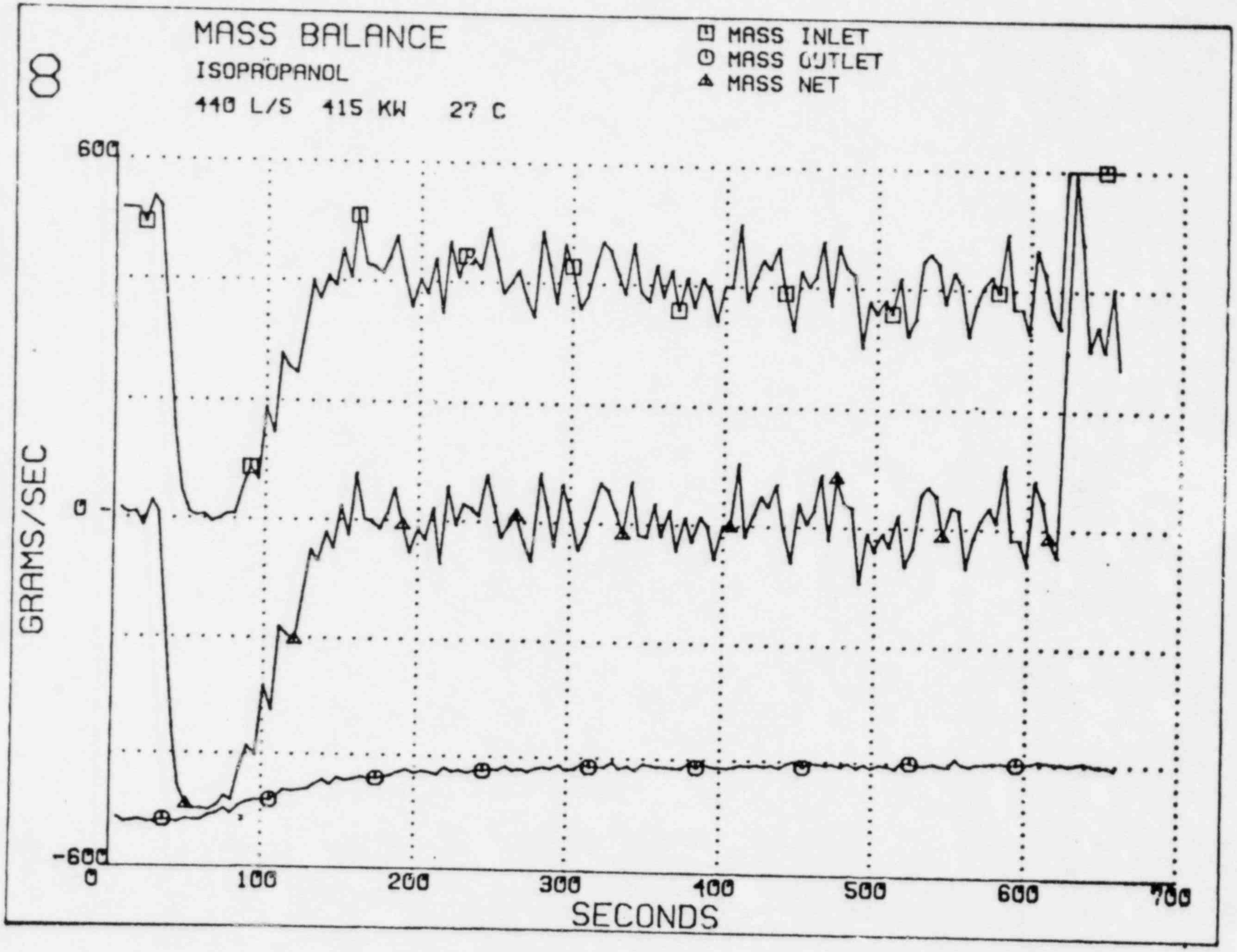
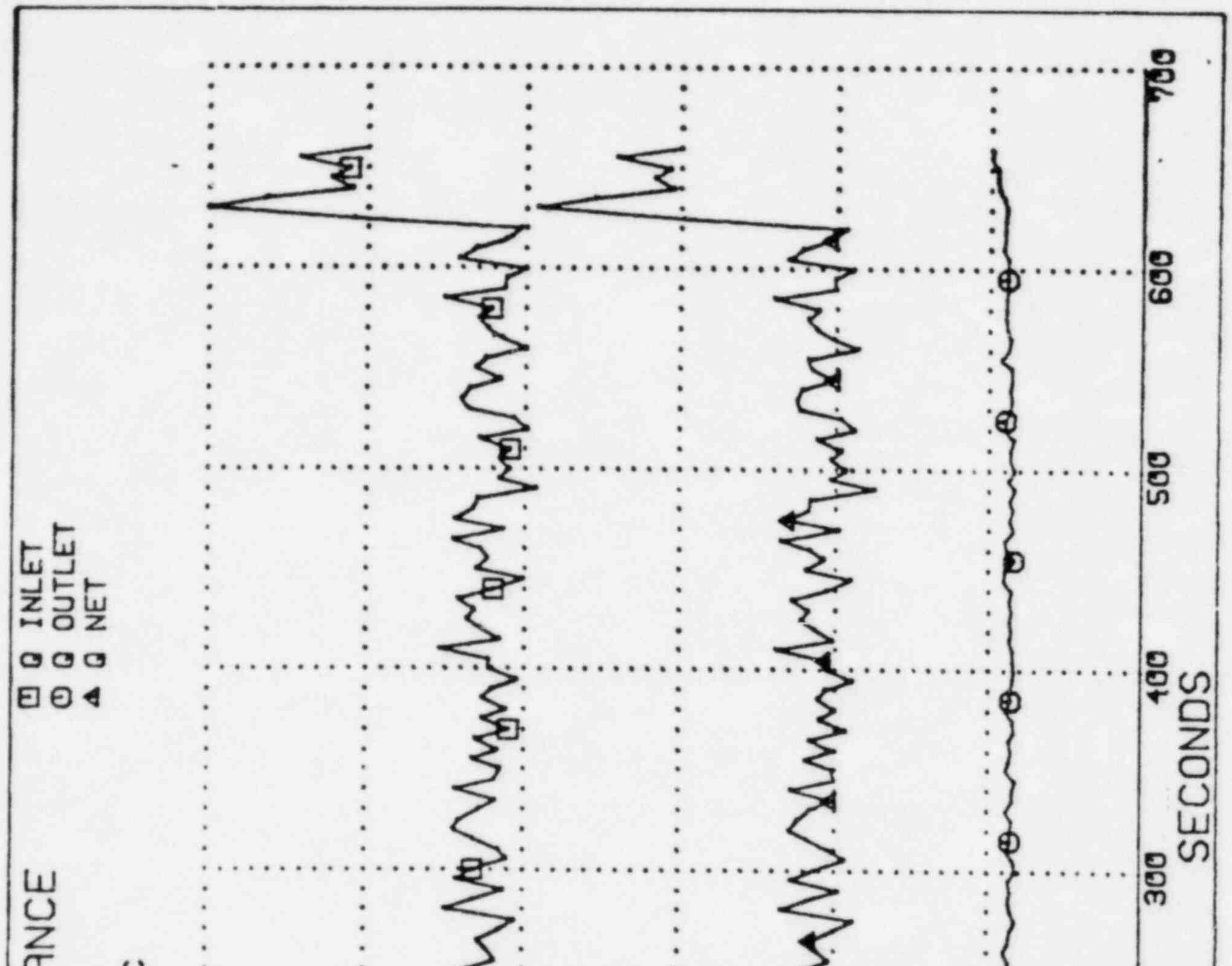
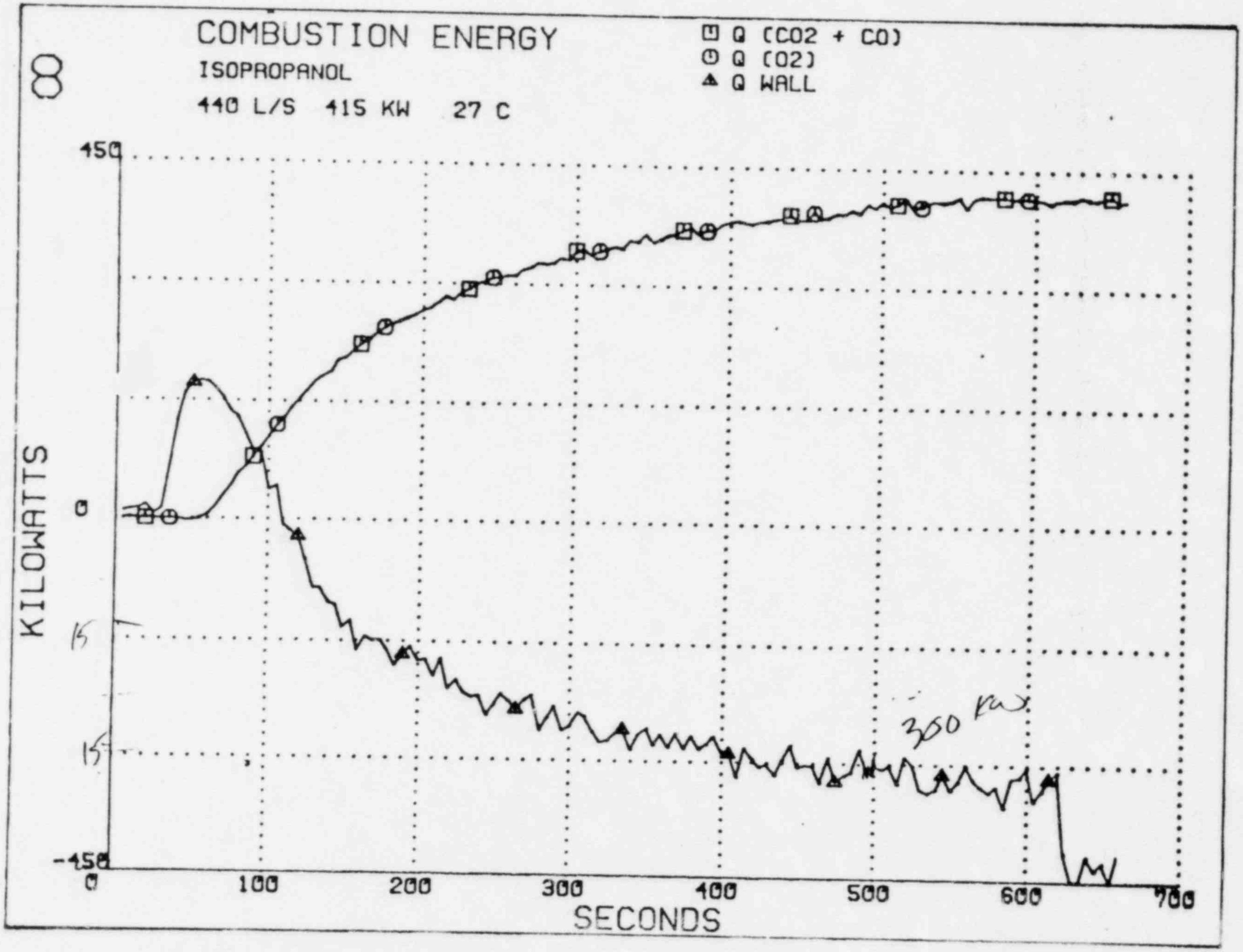
CEILING HEIGHT
400KW AT 500L/S (METHANOL)
400KW AT 500L/S (ISOPROPYL)
400KW AT 250L/S (ISOPROPYL)
800KW AT 250L/S (ISOPROPYL)
800KW AT 500L/S (METHANOL)
800KW AT 500L/S (ISOPROPYL)
HEIGHT IN METERS
0
1
2
3
4
0
40
80
120
160
200
240
280
320
TEMPERATURE, C

FIG. 44

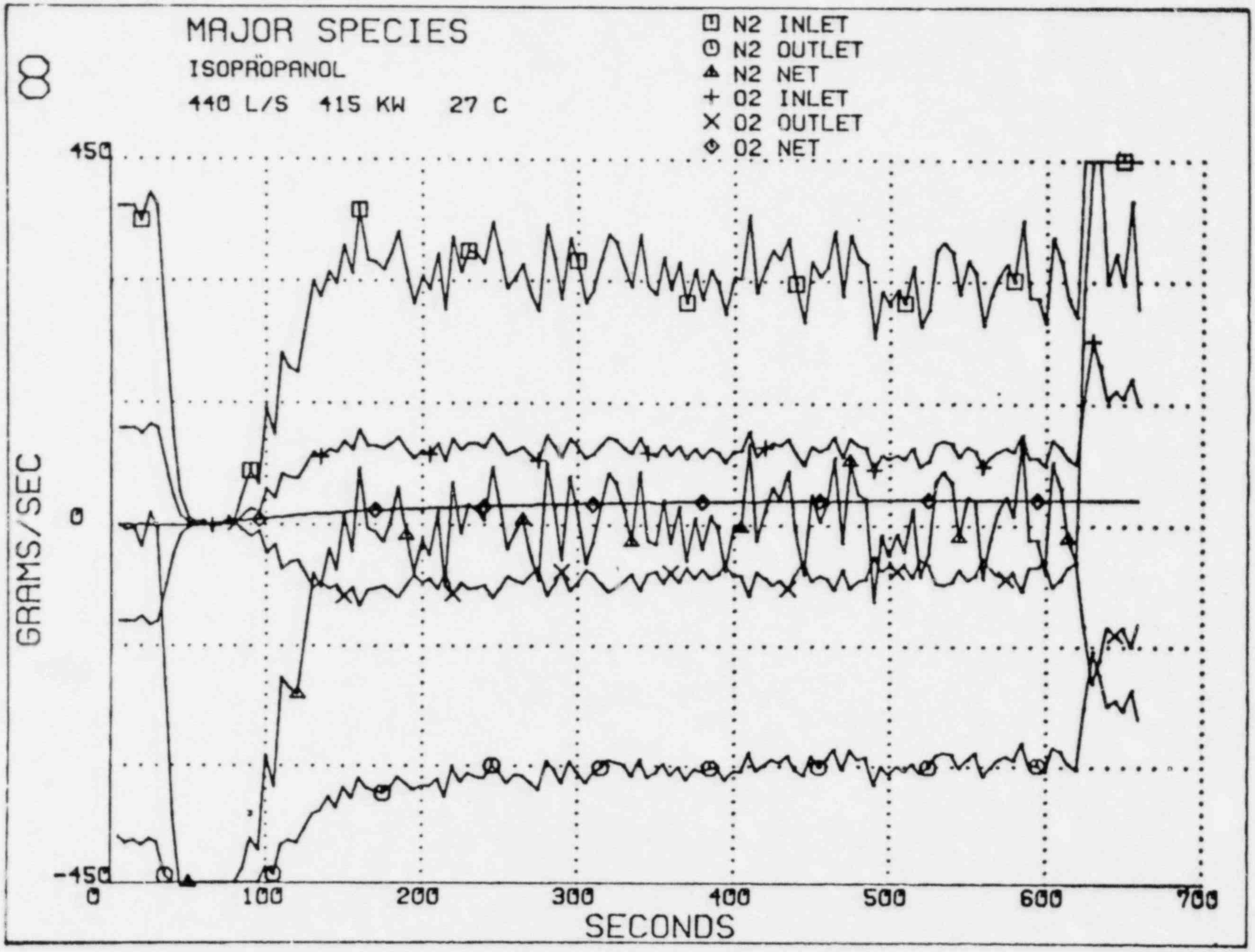

8
MASS BALANCE
ISOPRÖPANOL
440 L/S 415 KW 27 C
□ MASS INLET
○ MASS OUTLET
▲ MASS NET
GRAMS/SEC
600
0
-600
0
100
200
300
400
500
600
700
SECONDS


8
GAS ENERGY BALANCE
ISOPROPANOL
440 L/S 415 KW 27 C
Q INLET
Q OUTLET
Q NET
KILOWATTS
300
0
-300
SECONDS
0
100
200
300
400
500
600
700

M-9


8
COMBUSTION ENERGY
ISOPROPANOL
440 L/S 415 KW 27 C
□ Q (CO2 + CO)
○ Q (O2)
▲ Q WALL
KILOWATTS
450
0
15
15
-450
SECONDS
0
100
200
300
400
500
600
700
300 kw

M-10


8
MAJOR SPECIES
ISOPRÖPANOL
440 L/S 415 KW 27 C
□ N2 INLET
○ N2 OUTLET
▲ N2 NET
+ O2 INLET
× O2 OUTLET
◇ O2 NET
GRAMS/SEC
450
0
-450
0
100
200
300
400
500
600
700
SECONDS

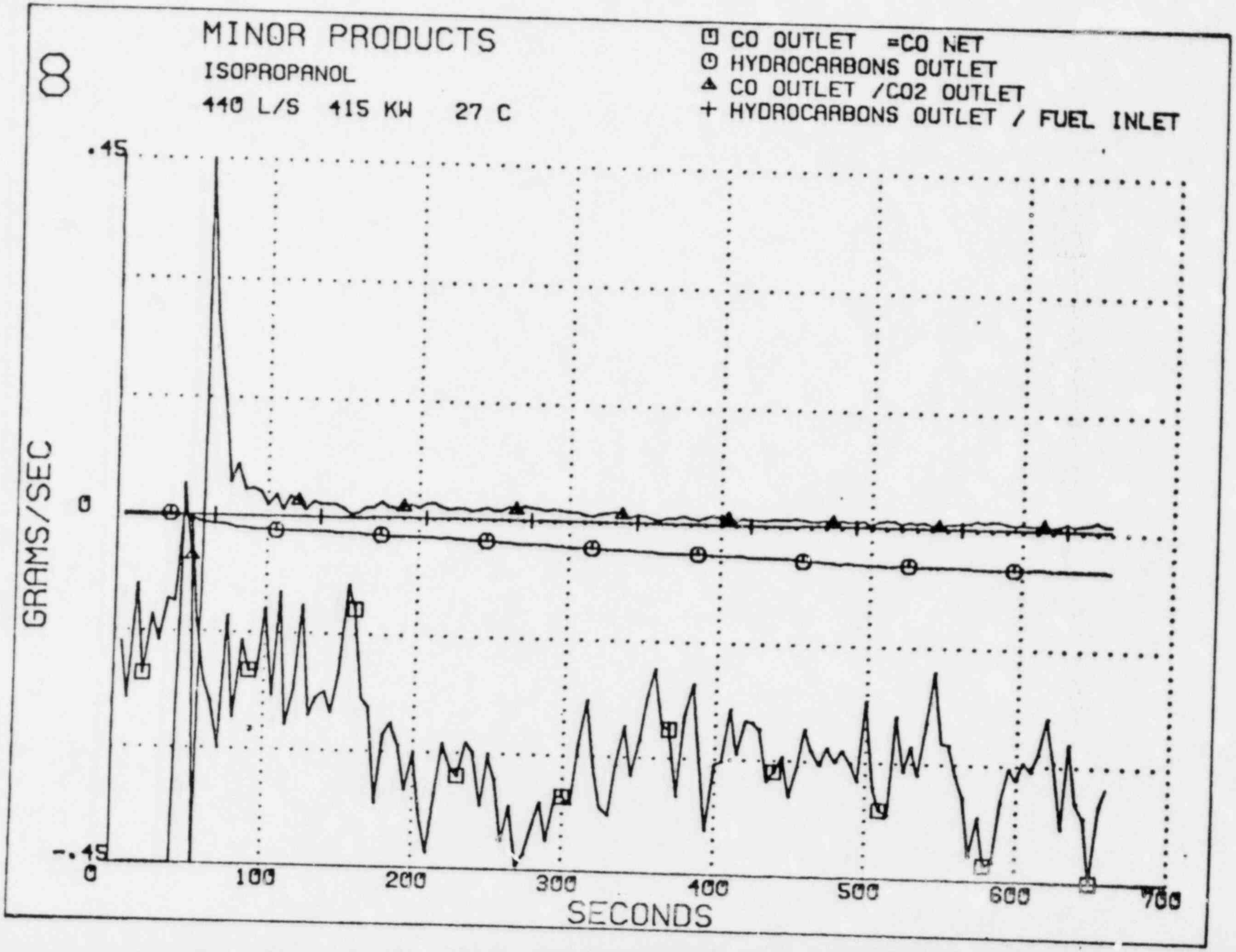

8
MINOR PRODUCTS
ISOPROPANOL
440 L/S 415 KW 27 C
□ CO OUTLET =CO NET
○ HYDROCARBONS OUTLET
▲ CO OUTLET /CO2 OUTLET
+ HYDROCARBONS OUTLET / FUEL INLET
GRAMS/SEC
.45
0
-.45
0
100
200
300
400
500
600
700
SECONDS

Table 1

1982 Fire Test Series

Test	Type	Fuel	Formula	Q (kW)	V (l/s)
1	Burner	Methane	CH_4	125	250 *
2	"	"	"	50	500
3	"	"	"	50	100 ▽
4	"	"	"	200	100
5	"	"	"	400	500 ▽
6	"	"	"	400	100 ▽
7	"	"	"	125	250 *
8	Spray	Isopropanol	C_3H_8O	400	500 *
9	"	"	"	800	500 ▽*
10	"	"	"	100	100 ▽
11	"	"	"	100	500
12	"	"	"	800	100 ▽
13	"	"	"	400	500 *
14	Spray	Isooctane	C_8H_{18}	400	500
15	"	"	"	800	500
16	"	"	"	800	100
17	Pool	Isopropanol	C_3H_8O	0.91m	500
18	"	"	"	"	100
19	Pool	Isooctane	C_8H_{18}	"	500
20	Pan	Polystyrene	$(C_8H_8)_n$	"	500 ▽
21	"	"	"	"	250
22	"	"	"	"	100 ▽

▽ Test for pretest predictions

* Repeats of 1981 tests

FY '83 TEST SERIES

- Combine LASL Source term & LLNL Model validation
- Change Heat Transfer character of walls (air gap insulation water cooled panels)
- Make different fire distribution (corner-halfway to ceiling)
- Add complicating elements to act as heat sinks
- Ventilation Changes
- Fire Growth

OBJECTIVES

- Assess the validity of extending available test methods and compartment fire models to spray fires in forced-ventilation burn rooms.
- Add exhaust duct heat-transfer measurements to last year's "clean fuel" test series for FIRAC sensitivity studies.
- Extend fire model assessment to oxygen poor fires, smoky fuels, and pool fires.

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PROGRAMMATIC RESTRICTIONS

- POSTPONE SOLID SURFACE FIRES OF CHARRING AND NONCHARRING MATERIALS AS WELL AS DEEP-SEATED FIRE INVESTIGATIONS
- NO PARTICLE SIZE AND WATER MEASUREMENTS
- NO INVESTIGATION OF CHANGE OF AIRFLOW PATTERNS IN THE BURN ROOM
- NO GAS SAMPLING IN THE HOT LAYER
- MEASUREMENT OF FILTER MASS DEPOSITION RESTRICTED TO A FEW REPLICATION TESTS

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ANTICIPATED RESULTS

- IDENTIFICATION OF FIRE MODELS AND ASSOCIATED MODULES THAT SHOULD BE INTEGRATED INTO A FORCED-VENTILATION COMPARTMENT FIRE MODEL
- PARTIAL ASSESSMENT OF THE FIRAC DUCT HEAT TRANSFER MODULE
- FIRST COMPREHENSIVE TEST DATA ON FORCED VENTILATION FIRES
- TECHNICAL FEASIBILITY OF SIMULATING OXYGEN POOR AND VERY SMOKY FIRES
- FIRE MODEL/FIRAC INTEGRATION REQUIREMENTS

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FUEL CHEMISTRY

Fuel	Bulk Chemistry	Heating Value, H_F
Methane	CH_4	50.0 kJ/g
Isopropanol	C_3H_8O	30.5 kJ/g
Iso-octane	C_8H_{18}	47.8 kJ/g
Styrene granules	C_8H_8	41.8 kJ/g

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LAWRENCE LIVERMORE

BURN ROOM CHARACTERISTICS

DIMENSIONS: 4.57 M HEIGHT; 4.15 M WIDTH; 6.17 M LENGTH

AIR INLET : 40 ORIFICES 98 MM IN DIAMETER NEAR BURN ROOM FLOOR

EXHAUST : .66-M X .66-M DUCT IN MIDDLE OF SIDE WALL AT 3.58 M CENTERLINE ELEVATION ABOVE FLOOR

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BURN ROOM CONSTRUCTION MATERIAL

Material Property	Ceiling & floor	Walls
Specific heat, J/kg K	250	250
Density, kg/m^3	1922	1440
Conductivity, W/m K	.63	.41
Thermal inertia or thickness	$2.3 - 10^5\ W^2s/m^2K^2$	10 cm

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FIRE TEST DATA COLLECTION

TEMPERATURES

- Temperature distribution (^{0}C)
  - Three 3 x 3 horizontal thermocouple arrays at .7-m, 2.1-m, and 3.7-m elevations above the floor. The center of this three-dimensional array is in the fire plume.
  - Vertical burn room temperatures stratification at 1-ft intervals.
  - Wall and centerline gas temperatures in the exhaust duct at duct inlet, duct center, and upstream of HEPA filter.
  - Wall and ceiling temperatures of the burn room.

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FIRE TEST DATA COLLECTION

CHEMISTRY AND FLUXES

- Fuel injection rate $\dot{m}$ (g/s)
- East and west air intake, $\dot{V}_{IN}$ (L/s)
- Volumetric exhaust flow control at HEPA filter end of exhaust duct, $\dot{V}_{EXH}$ (L/s)
- Exhaust flow volume concentration of O_2, CO_2, CO, CH_x
- Particulate mass deposition at HEPA filter for some replicated tests
- Cool-layer oxygen concentration
- Environmental conditions
    - Relative humidity in %
    - Ambient temperature in °C
    - Atmospheric pressure in atm.

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POTENTIAL FIRE SCENARIOS

SPRAY FIRES

METHANE SPRAY FIRES

$\dot{Q}_N$ (kW) = 50, 100, 200, 400

$\dot{V}_{EXH}$ (L/s) = 100, 250, 500

ISOPROPANOL SPRAY FIRES

$\dot{Q}_N$ (kW) = 100, 200, 400, 800

$\dot{V}_{EXH}$ (L/s) = 100, 250, 500

ISO-OCTANE SPRAY FIRES

$\dot{Q}_N$ (kW) = 100, 200, 400, 800

$\dot{V}_{EXH}$ (L/s) = 100, 250, 500

POTENTIAL FIRE SCENARIOS
POOL FIRES

POOL IS .91 M PAN, 10.16 CM DEEP

FUELS: ISOPROPANOL, ISO-OCTANE, STYRENE GRANULES

$\dot{V}_{EXH}$ (L/s) = 100, 250, 500

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DESIRED PRETEST PREDICTIONS

Fuel	Nominal Fire Strength	Ventilation Strength $\dot{V}_{EXH}$
Methane Gas	400 kW	500 L/s
	400 kW	500 L/s
	50 kW	100 L/s
Isopropanol & Iso-octane Spray	800 kW	500 L/s
	800 kW	500 L/s
	50 kW	100 L/s
Polystrene granule Pool	0.91-m-diam pan/10.16-cm-deep	500 L/s
		100 L/s

ADDITIONAL PREDICTIONS FOR IN-BETWEEN FIRE AND VENTILATION STRENGTH WOULD HELP IN DETERMING THE FIRES FOR WHICH THE PREDICTION MODEL IS VALID.

DESIRED PREDICTION FORMAT

I. Pretest prediction should provide, as far as practical, the following time histories.

- Temperature, oxygen, carbon monoxide, and carbon dioxide volume concentration in the hot layer in % and associated exhaust fluxes in grams per second.
- Descent of hot/cool layer interface in m.
- Rate of heat deposition in the gas (enthalyphy exhaust flux minus enthalphy influx of air and fuel) in kW.
- Heat loss to all internal surfaces.
- Total air intake in L/s.

II. Pretest predictions are to be sent to N. Alvares

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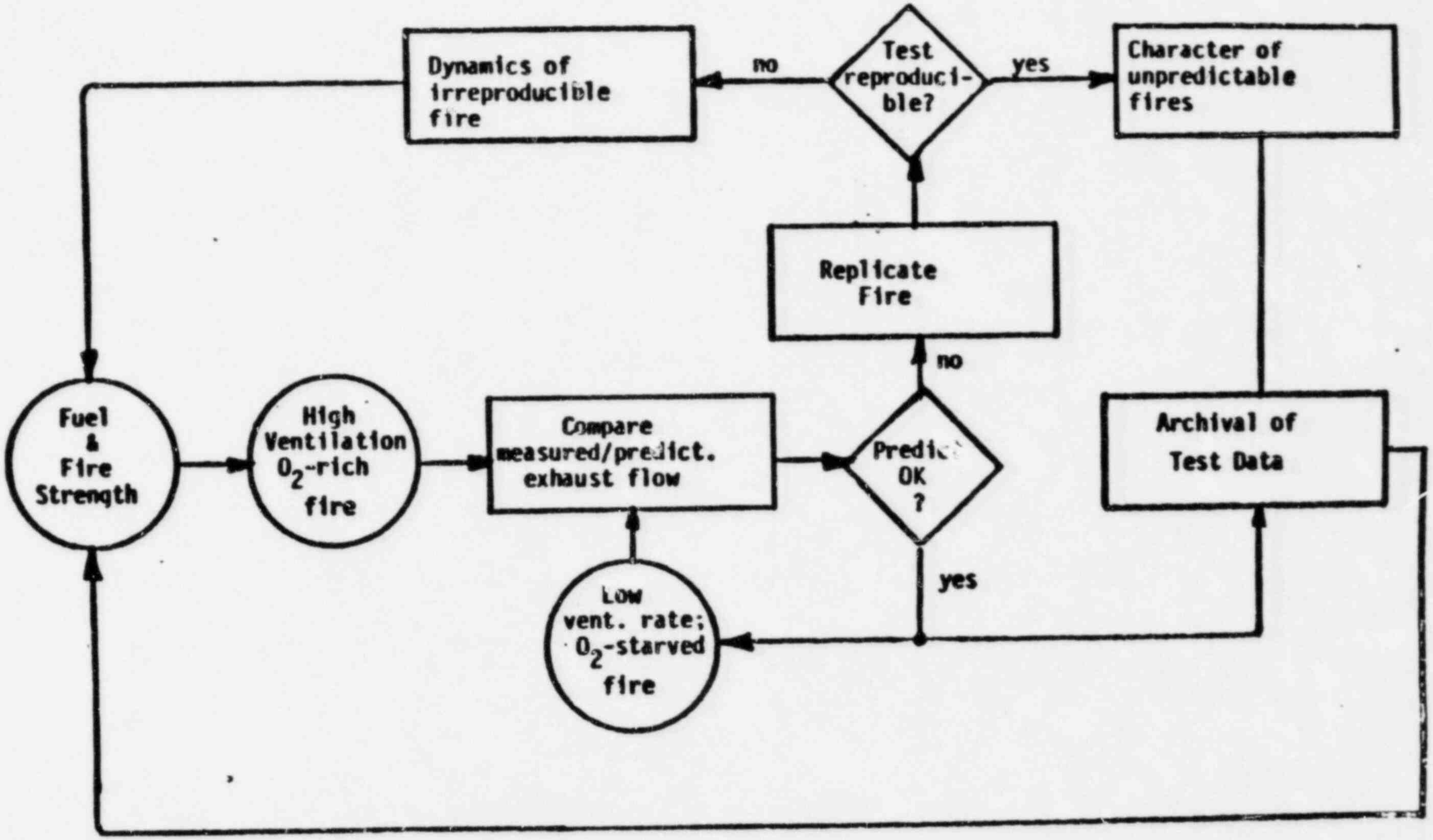

Logic for selection of test fires.

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FY 1982 EXPERIMENTAL PROGRAM

- The purpose of the Los Alamos FY 1982 Transport Experimental Program is to provide supportive data for assessment and improvement of the first generation FIRAC, EXPAC, and TORAC accident analysis codes

- We have identified a need for code module assessment in the areas of

  (1) Transport Initiation
  (2) Material Depletion
  (3) Filtration

- Fire accidents are being emphasized

FIRAC MATERIAL TRANSPORT MODELING

- FIRAC DESIGNED TO PREDICT FIRE-INDUCED FLOWS, TEMPERATURES, AND MATERIAL TRANSPORT.
- FIRAC DESIGNED TO ANALYZE SYSTEM OF INTERCONNECTED ROOMS, DUCTS, AND OTHER COMPONENTS.
- ANY MATERIAL TRANSPORT MODEL WILL NECESSARILY ADDRESS THE FOLLOWING ELEMENTS:
  1. MATERIAL CHARACTERISTICS
  2. TRANSPORT INITIATION
  3. CONVECTION
  4. INTERACTION
  5. DEPLETION
  6. FILTRATION

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THE PURPOSE OF A MATERIAL TRANSPORT CALCULATION IS TO ESTIMATE MATERIAL FLOW RATE AND CONCENTRATION AS A FUNCTION OF TIME AND LOCATION IN THE SYSTEM.

- IDEALLY, PREDICT QUANTITY AND PHYSICAL AND CHEMICAL CHARACTERISTICS OF MATERIAL (AEROSOL OR GAS).
- TRANSPORT OCCURS BECAUSE OF AIRFLOW THROUGH ROOMS, CELLS, CANYONS, CORRIDORS, GLOVEBOXES, AND DUCTWORK.

SOME OF THE DIFFICULTIES IN PREDICTING MATERIAL TRANSPORT RESULTING FROM A FIRE ACCIDENT ARE

- DIFFERENT MATERIALS,
- PHASE CHANGES,
- CHEMICAL REACTIONS,
- SIZE DISTRIBUTION,
- MATERIAL INTERACTION (COAGULATION),
- CONDENSATION,
- DIFFUSION, AND
- DEPOSITION

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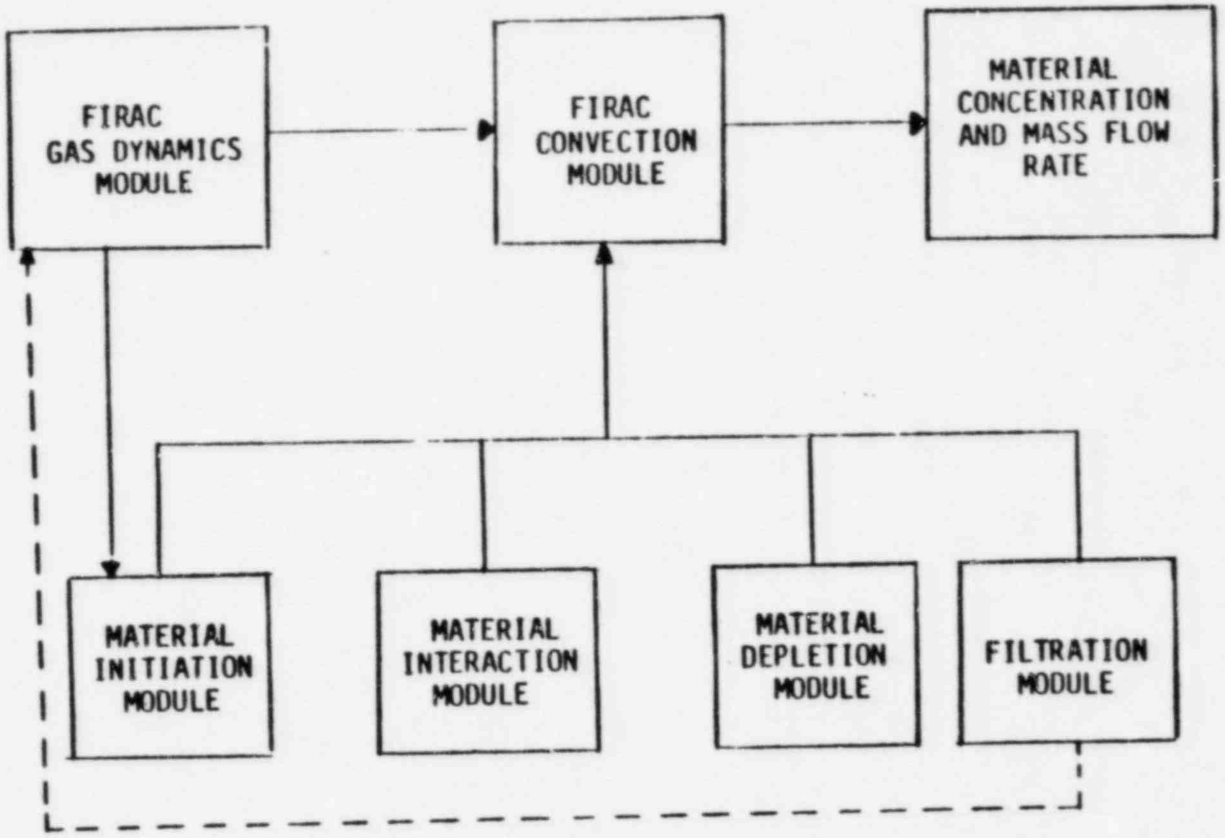
SIMPLIFY THE MATERIAL TRANSPORT MODELING PROBLEM WITH THESE LEVEL 1 ASSUMPTIONS.

- GAS DYNAMICS DECOUPLED FROM MATERIAL TRANSPORT
- HOMOGENEOUS MIXTURE AND DYNAMIC EQUILIBRIUM
- MULTIPLE SIZES OR SPECIES (FIRAC ONLY)
- NO INTERACTION
- DEPOSITION BASED ON SEDIMENTATION ONLY
- DIFFUSION AND PHORETIC EFFECTS NEGLECTED
- PHASE CHANGE, CHEMICAL REACTION, AND ELECTRICAL MIGRATION NOT ALLOWED
- ENTRAINMENT BY TABLES OR CALCULATION



Material transport modular structure.

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0-6

REVIEW FILTER PLUGGING PROGRAM

- THE PURPOSE OF OUR FILTER PLUGGING PROGRAM IS TO SUPPLY EXPERIMENTAL DATA TO SUPPORT THE PRESSURE DROP MODEL

$$\Delta p/\Delta p_o = F(M_A)(Q/Q_o)$$

- FOR HEPA FILTERS THE FORM OF THE POLYNOMIAL F AND SOME EMPIRICAL COEFFICIENTS WILL DEPEND ON

(1) AEROSOL TYPE,

(2) AEROSOL SIZE DISTRIBUTION,

(3) AEROSOL CONCENTRATION,

(4) WATER VAPOR,

(5) HEAT ADDITION, AND

(6) OTHER THINGS (ELECTROSTATICS, FLOW CONDITIONS, FILTER MEDIA PARAMETERS)

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IDEALIZED TESTS WITH STEARIC ACID AND WATER SPRAY

- A UNIQUE NULL-BALANCE FILTER WEIGHING SYSTEM AND FILTER LOADING FACILITY WAS CONSTRUCTED.
- BY 2/15/82, WE COMPLETED A TEST MATRIX OF 19 EXPERIMENTS TO EVALUATE THE EFFECT OF AEROSOL CONCENTRATION AND MOISTURE ON $\Delta p/Q$ VS M_A.
- THE SMOKE SIMULANT WAS STEARIC ACID SPHERES GENERATED BY A COMMERCIAL CONDENSATION-TYPE GENERATOR.
- AEROSOL CONCENTRATIONS VARIED BETWEEN 60 AND 120 MG/M^3 FOR THE HIGHEST GENERATION RATE (BECAUSE OF FILTER PLUGGING).

Summary of idealized filter plugging tests using stearic acid and water spray.

Test	Stearic Acid Volumetric Flow Rate (cm^3/min)	Water Mass Flow Rate (g/min)	Plugged Mass (kg)	Time to Plug (h)
17	0.0	100.0	3.447	27.0
18	0.0	200.0	7.729	9.52
19	0.0	400.0	6.996	5.27
4	0.105	0.0	0.415	32.2
7	0.105	100.0	6.481	32.9
6	0.105	200.0	8.060	5.787
5	0.105	400.0	6.583	4.93
1	0.241	0.0	0.401	20.7
10	0.241	100.0	6.179	31.5
9	0.241	200.0	6.941	4.53
8	0.241	400.0	6.336	4.13
2	0.941	0.0	0.550	13.4
13	0.941	100.0	3.796	6.22
12	0.941	200.0	5.429	6.23
11	0.941	400.0	5.450	3.90
3	2.05	0.0	0.454	4.87
16	2.05	100.0	4.251	5.97
15	2.05	200.0	5.345	6.05
14	2.05	400.0	6.449	3.00

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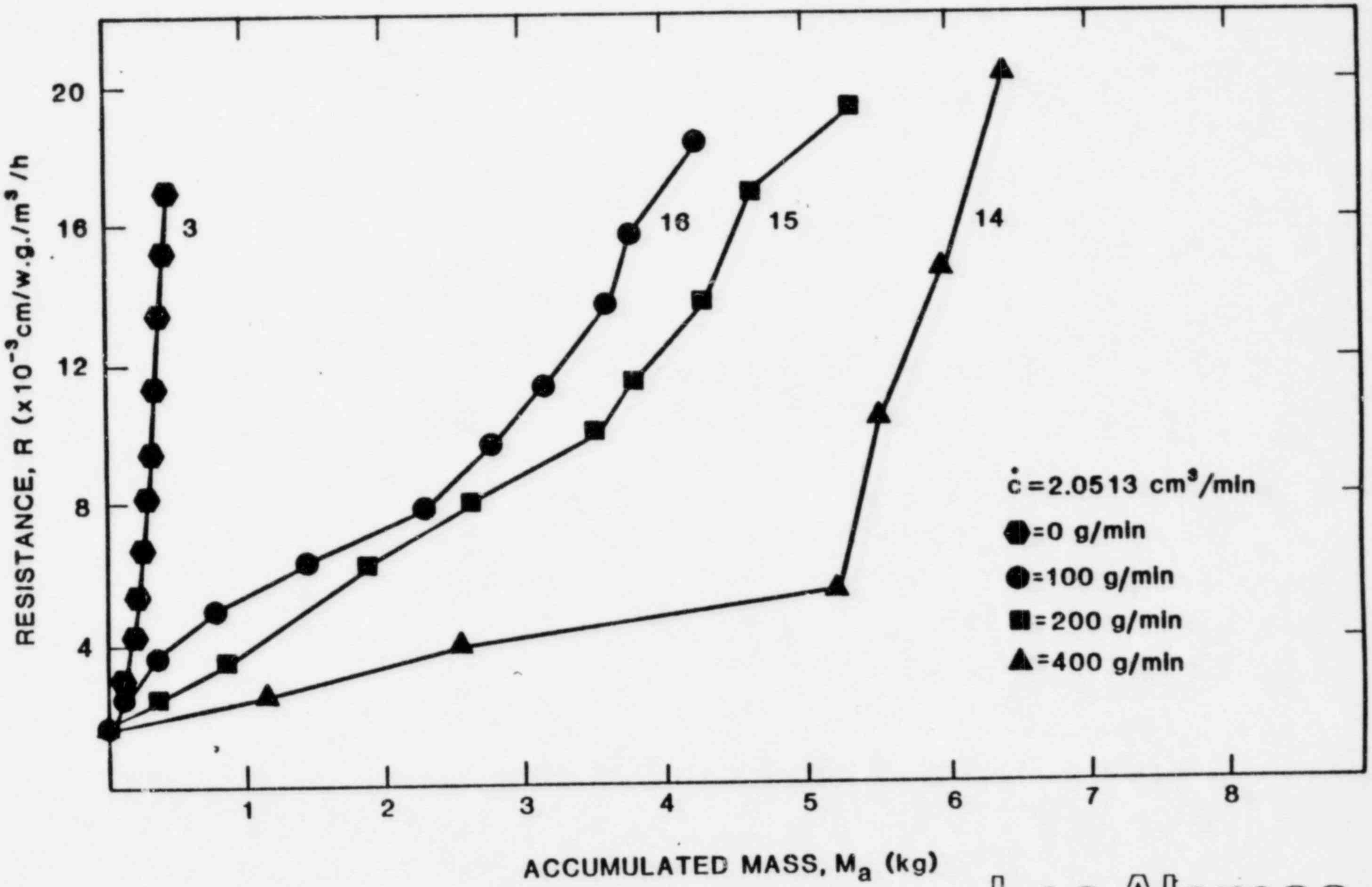

RESISTANCE, R (x10^{-3}cm/w.g./m^3/h
4
8
12
16
20
ACCUMULATED MASS, M_a (kg)
1
2
3
4
5
6
7
8
3
16
15
14
$\dot{c}$=2.0513 cm^3/min
⬢=0 g/min
●=100 g/min
■=200 g/min
▲=400 g/min

Los Alamos

FILTER PLUGGING MODELS

- ONE FORM OF THE SEMI-EMPIRICAL FILTER PLUGGING EQUATION IS

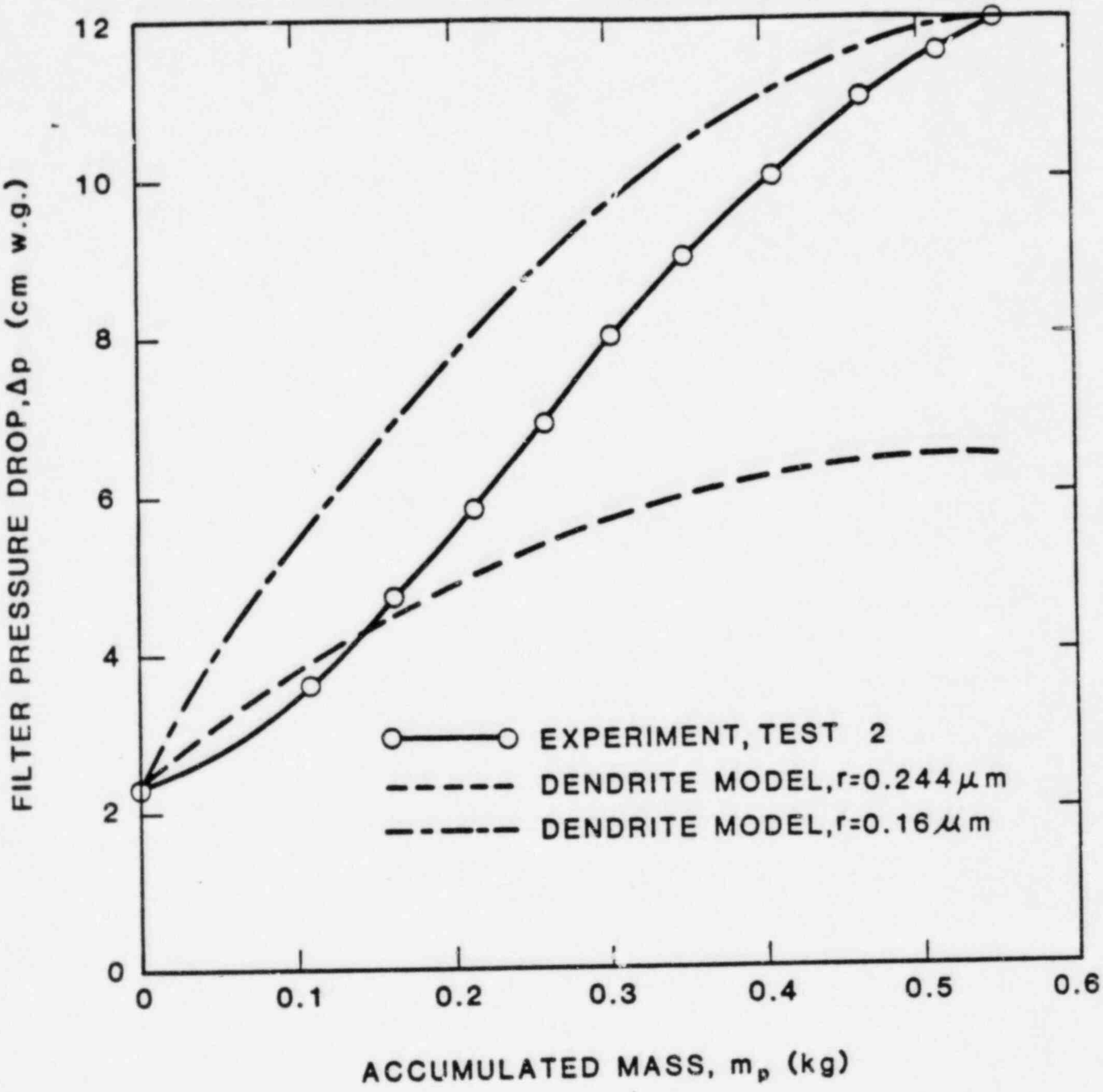
$$\Delta p/\Delta p_o = (1 + \alpha M_A)(Q/Q_o)$$

THIS LINEAR FORM IS PRESENTLY USED IN OUR CODES.

- ANOTHER MORE COMPLICATED FORM IS VERN BERGMAN'S DENDRITE MODEL (LLNL),

$$\Delta p/\Delta p_o = \left(1 + \frac{R\alpha_p}{r\alpha_F}\right)\left(1 + \frac{R^2\alpha_p}{r^2\alpha_F}\right)\left(Q/Q_o\right)$$

THIS FORM IS BASED ON THE ASSUMPTION OF THE FORMATION OF FIBER-LIKE DENDRITE CHAINS.



12
10
8
6
4
2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
FILTER PRESSURE DROP, Δp (cm w.g.)
ACCUMULATED MASS, m_p (kg)
EXPERIMENT, TEST 2
DENDRITE MODEL, r=0.244 μm
DENDRITE MODEL, r=0.16 μm

Los Alamos

FINAL RESULTS OF IDEALIZED TESTS

1. DRY STEARIC ACID WITHOUT MOISTURE PLUGGED THE HEPA FILTERS WITH SIGNIFICANTLY LESS MASS LOADINGS (0.40 TO 0.55 KG).
2. THE EFFECT OF STEARIC ACID PLUS MOISTURE ADDED BY A SPRAY NOZZLE AT 200 TO 400 G/MIN RESULTED IN FASTER FILTER PLUGGING (ABOUT 3 TO 6 H) WITH HIGHER MASS LOADINGS (ABOUT 5.5 TO 8 KG).
3. WATER MOISTURE ALONE PLUGGED THE FILTERS AFTER MASS LOADINGS OF 3.4 TO 7.7 KG.
4. WITH A PROPER CHOICE OF R, THE DENDRITE MODEL COULD BE USED TO APPROXIMATE OUR DRY LOADING TESTS; HOWEVER, A POLYNOMIAL CURVE-FIT WOULD BE MORE ACCURATE.

Los Alamos

FILTER PLUGGING EXPERIMENTS
USING MORE REALISTIC
SMOKE AEROSOLS

- A MORE COMPLICATED SERIES OF TESTS WILL BE CONDUCTED THIS SUMMER (AUGUST - SEPTEMBER 1982).

- A REPRESENTATIVE FUEL MIXTURE COMPOSITION IS (PNL)

COMPONENT	COMPOSITION (%)
1. POLYMETHYLMETHACRYLATE	45
2. CELLULOSIC	26
3. ELASTOMER	18
4. POLYVINYL CHLORIDE	8
5. HYDRAULIC FLUIDS	2
6. POLYSTYRENE	1

- TO BURN THESE MATERIALS, PNL DESIGNED A SPECIAL COMBUSTOR FOR INTEGRATION WITH THE LOS ALAMOS FILTER PLUGGING FACILITY.

Los Alamos

MODIFICATIONS TO FILTER PLUGGING FACILITY

1. COUPLING TO PNL COMBUSTOR
2. MODIFICATION OF COMBUSTOR FOR LIQUID FUEL FEED
3. DESIGN AND INSTALLATION OF A MIXING GRID
4. CONSTRUCTION OF METAL DUCT FOR HOT SECTION
5. ADDITION OF DUCTWORK TO BRING TEST SECTION TO 40 FT FOR AEROSOL DEPLETION/INTERACTION STUDIES

Los Alamos

FILTER PLUGGING TEST

PLANS (SUMMER 1982)

- BURN PMMA AND PS IN THE PNL COMBUSTOR BECAUSE THEY REPRESENT EXTREMES OF SMOKE-PRODUCING MATERIALS.
- USE TWO MASS-BURNING RATES BY CONTROLLING THE INLET AIR-SUPPLY RATE.
- REPLICATE THESE FOUR CONDITIONS THREE TIMES FOR REPRODUCIBILITY (12 TESTS).
- WE ARE PROPOSING FUTURE TESTS (FY 83) USING TYPICAL FUEL MIXTURES, ADDING HEAT AND MOISTURE TO FLOW, AND USING IMPROVED GAS ANALYSIS AND PARTICULATE-SIZE MEASURING INSTRUMENTATION.

Los Alamos

AEROSOL DEPLETION

- ENCLOSURES, DUCTS, AND VENTILATION SYSTEMS COMPONENTS CAN ACT AS AEROSOL FILTERS.

- THE FLOWS IN VENTILATION SYSTEMS WILL BE FULLY TURBULENT ($Re \gg 2100$).

- DEPLETION MECHANISMS (SINK TERMS) OF CONCERN ARE
  (1) TURBULENT (EDDY) AND MOLECULAR (BROWNIAN) DIFFUSION ($D_p < 1$ μM),
  (2) TURBULENT INERTIAL DEPOSITION ($D_p > 1$ μM), AND
  (3) GRAVITATIONAL SETTLING (SEDIMENTATION) AT ALL SIZES.

Los Alamos

AEROSOL DEPLETION

- IN GENERAL, $J = KN$, WHERE

  J = DEPOSITION FLUX, PARTICLES/ CM^2S,

  K = TRANSFER COEFFICIENT, CM/S, AND

  N = LOCAL AEROSOL CONCENTRATION, PARTICLES/CM^3.

- FOR SEDIMENTATION, K = TERMINAL SETTLING VELOCITY CORRECTED FOR SLIP.

- WE ASSUME STICKY SURFACES AND HOMOGENEOUS MIXTURES.

- USER SUPPLIES AEROSOL SIZE, DENSITY, AND DUCT FLOOR AREA.

Los Alamos

MATERIAL DEPLETION/MODIFICATION
EXPERIMENTAL PLANS
(SUMMER 1982)

- THE PURPOSE OF THESE TESTS IS TO MEASURE MASS DEPOSITION, AEROSOL SIZE DISTRIBUTION, AND AEROSOL CONCENTRATION FOR SIMULATED FIRE CONDITIONS.
- THESE DATA WILL BE USED TO ASSESS
  (1) THE IMPORTANCE OF DEPOSITION,
  (2) THE IMPORTANCE OF AEROSOL DYNAMICS, AND
  (3) VARIOUS KNOWN MODELS FOR THE TRANSFER COEFFICIENT, K.
- KNOWN EXPRESSIONS FOR K HAVE BEEN CONFIRMED ONLY IN SMALL-SIZED FLOW FACILITIES USING IDEAL AEROSOLS.

Los Alamos

MATERIAL DEPLETION/MODIFICATION
TESTS AND MEASUREMENTS

- USE SAME FACILITY AND TEST MATRIX AS FOR FILTER PLUGGING.
- PERFORM THE FOLLOWING MEASUREMENTS.
  (1) TOTAL MASS DEPOSITION AT ONE LOCATION ON THREE SURFACES
  (2) MASS CONCENTRATION ON THE DUCT CENTERLINE AT TWO LOCATIONS
  (3) AEROSOL SIZE DISTRIBUTION AT TWO LOCATIONS
  (4) GAS COMPOSITION SPOT CHECK

Los Alamos

AEROSOL INTERACTION

(RECOMMENDATIONS FOR FURTHER STUDY)

- UNFORTUNATELY, DURING A FIRE THE QUANTITY AND PHYSICAL AND CHEMICAL CHARACTERISTICS OF AIRBORNE MATERIAL CAN BE CHANGING.
- HEAVILY EMPHASIZED IN REACTOR SAFETY PROBLEMS.
- HOW MUCH RESPIRABLE MATERIAL REACHES PLANT BOUNDARY, OR LEAKS SOMEWHERE ELSE?
- AMOUNT AND CHARACTERISTICS OF MATERIAL CHALLENGING HEPA FILTERS?
- DEPOSITION MECHANISMS ARE SIZE-DEPENDENT.
- RELATIVELY HIGH CONCENTRATIONS OF AEROSOL (10^6 PARTICLES/CM^3 OR GREATER) COULD BE PRODUCED BY FIRES.
- USE GENERAL DYNAMIC EQUATION (MODELS FOR TERMS) TO SHUFFLE MATERIAL BETWEEN SIZE INCREMENTS AND SPECIES.
- SINGLE VS MULTIPLE SPECIES INTERACTIONS.

Los Alamos

MATERIAL INTERACTION STUDIES
USING MAEROS

- MAEROS IS A COMPUTER CODE WRITTEN BY FRED GELBARD THAT PREDICTS MULTICOMPONENT AEROSOL COMPOSITION AND MASS CONCENTRATION AS A FUNCTION OF PARTICLE SIZE AND TIME.

- MAEROS MODELS

  (1) COAGULATION BECAUSE OF BROWNIAN MOTION, TURBULENCE, AND GRAVITY;

  (2) PARTICLE DEPOSITION BECAUSE OF GRAVITATIONAL SETTLING, DIFFUSION, AND THERMOPHORESIS;

  (3) PARTICLE GROWTH BECAUSE OF CONDENSATION OF A GAS (WATER VAPOR); AND

  (4) TIME-VARYING SOURCES OF PARTICLES OF DIFFERENT SIZES AND CHEMICAL COMPOSITIONS.

Los Alamos

P-2

ASSESSMENT OF MAEROS AND PRELIMINARY RESULTS

- WE CURRENTLY ARE ASSESSING MAEROS FOR USE AS AN AEROSOL INTERACTION MODULE FOR THE LOS ALAMOS FAMILY OF ACCIDENT ANALYSIS COMPUTER CODES.

- WE HAVE BEEN STUDYING THE DYNAMICS OF A TWO-COMPONENT AEROSOL SYSTEM IN A 100 M^3 WELL-MIXED CHAMBER.

  (1) MONODISPERSE SMOKE (10 G/M^3)

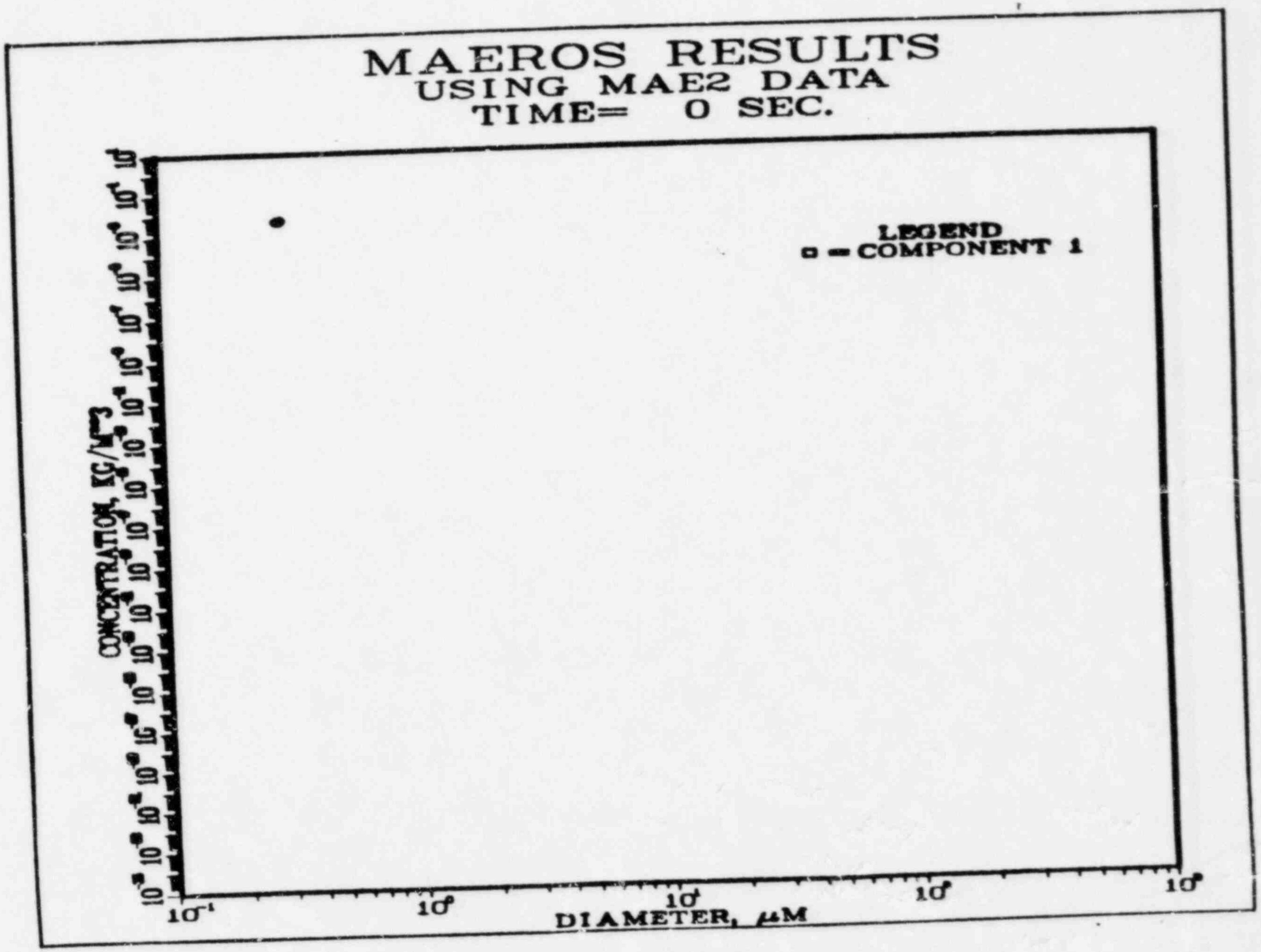
  (2) FUEL GRADE MOX POWDER SIZE DISTRIBUTION FROM AAH (0.1 G/M^3)

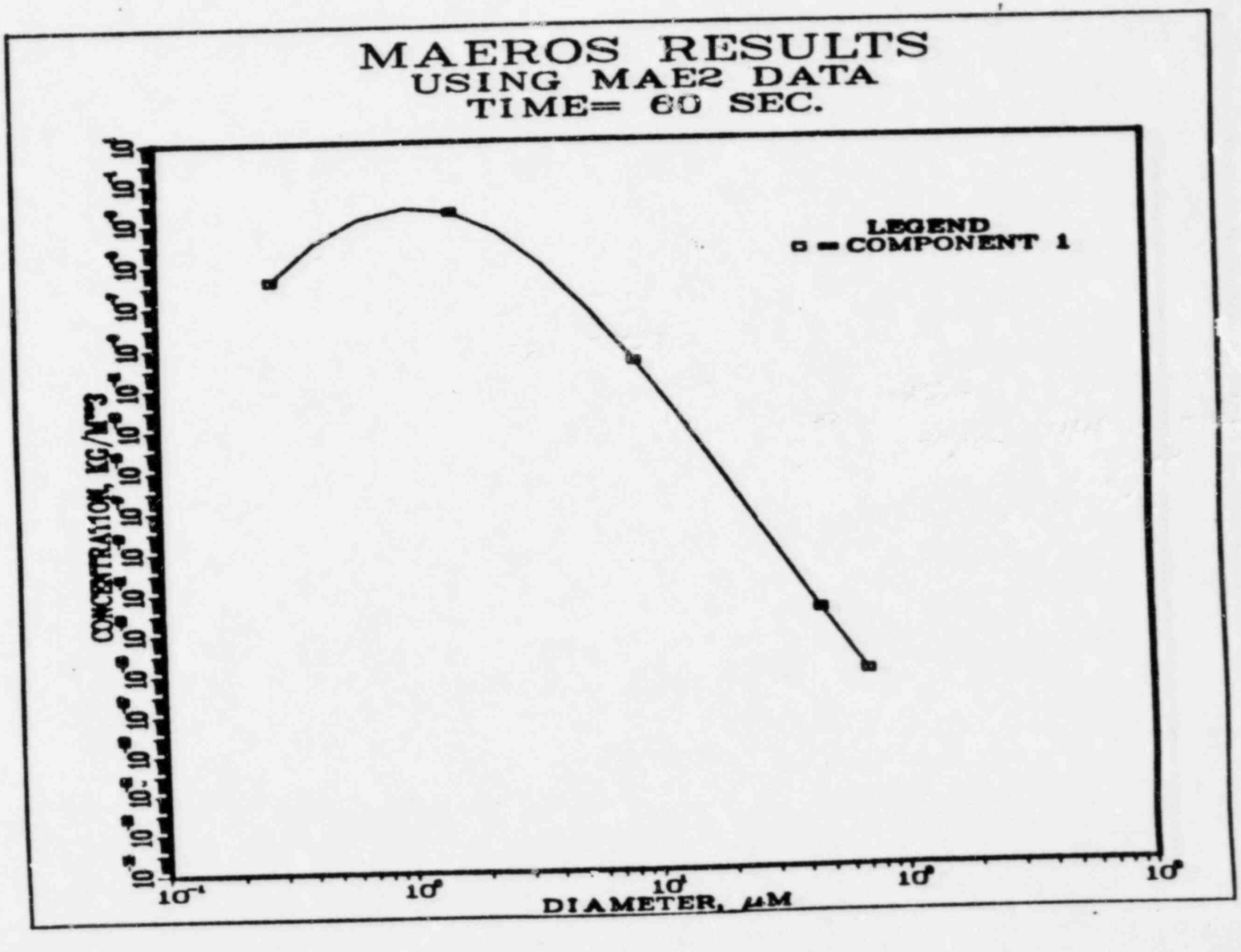
Los Alamos

Summary of MAEROS
Run Conditions

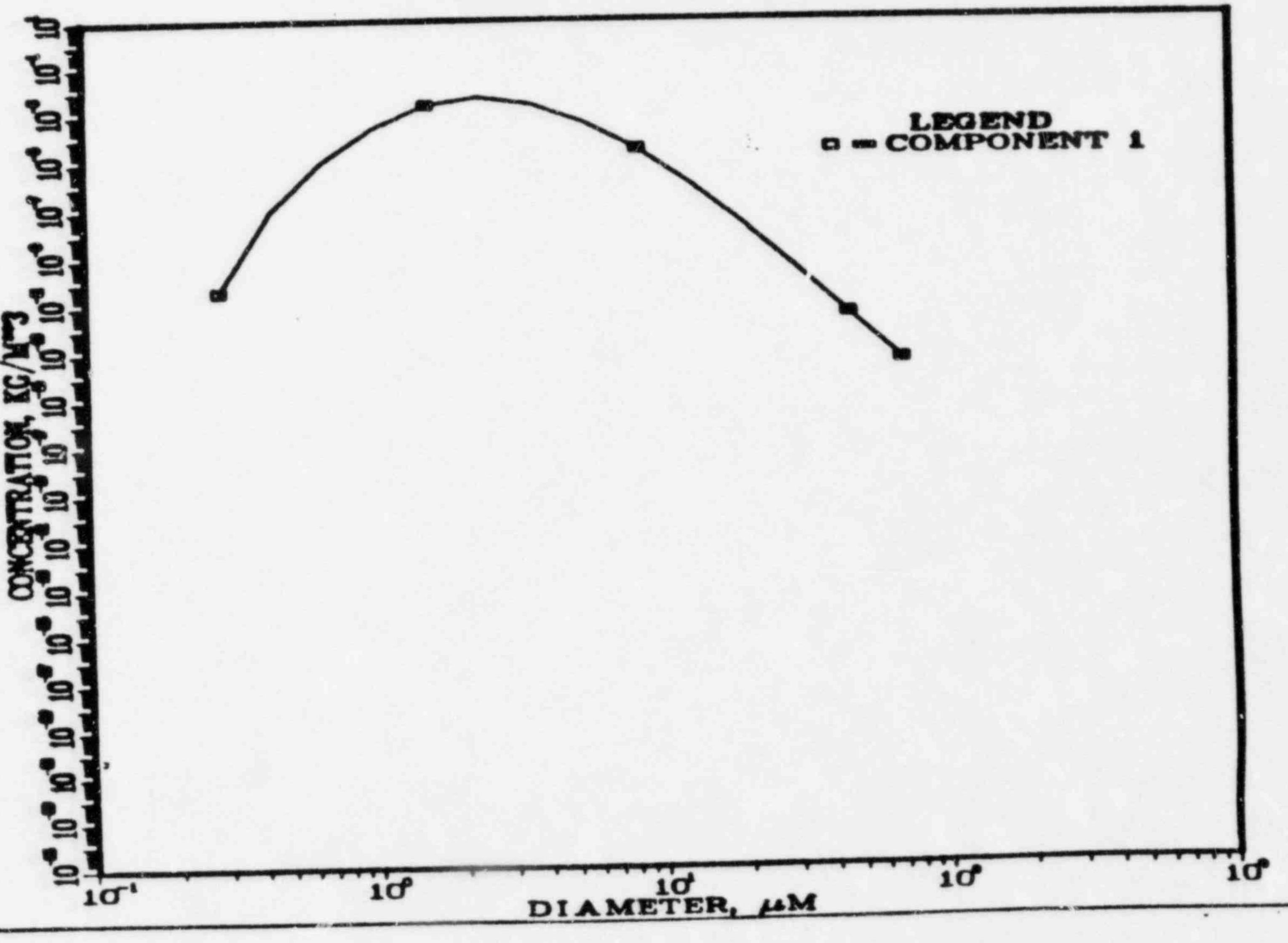
- MAE 2: Smoke (0.2 μm) alone without deposition
- MAE 7: Contaminant (1-70 μm, D_p = 13 μm MMAD, σg = 3.5) alone with deposition
- MAE 4: Smoke (0.2 μm) plus contaminant (1-70 μm) with deposition
- MAE 9: Smoke (25 μm) plus contaminant (1-70 μm) with deposition
- Room ventilation:
  For 9 room changes/h, (at LLNL, Q = 250 L/S) is equivalent to 6.67 min/room change

Los Alamos

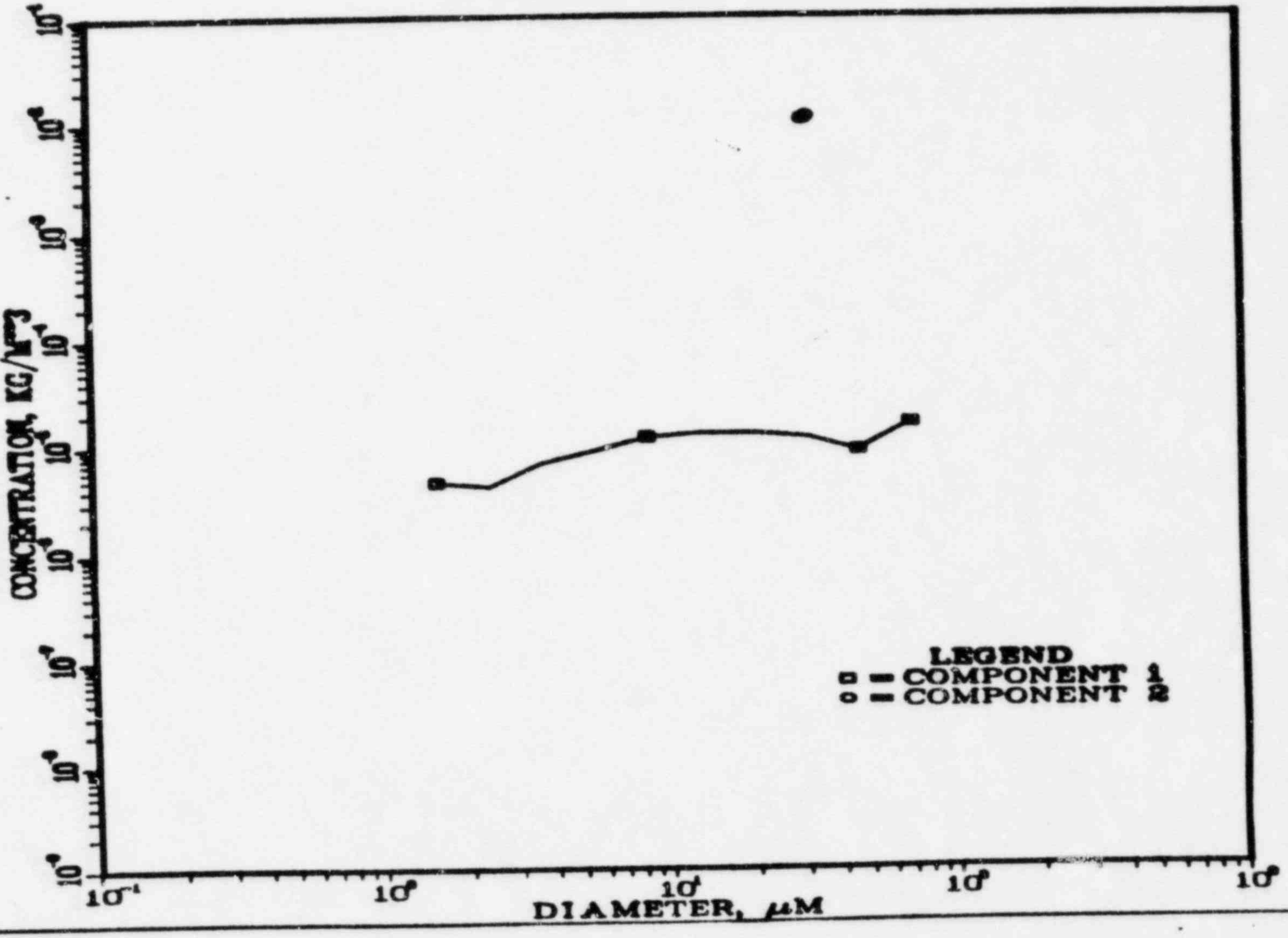

MAEROS RESULTS
USING MAE2 DATA
TIME= 0 SEC.
LEGEND
▫ = COMPONENT 1
CONCENTRATION, KG/M**3
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
DIAMETER, μM


MAEROS RESULTS
USING MAE2 DATA
TIME= 60 SEC.
LEGEND
□ = COMPONENT 1
CONCENTRATION, KG/M**3
10^0
DIAMETER, μM
10^-1
10^0
10^1
10^2
10^3

MAEROS RESULTS
USING MAE2 DATA
TIME=600 SEC.

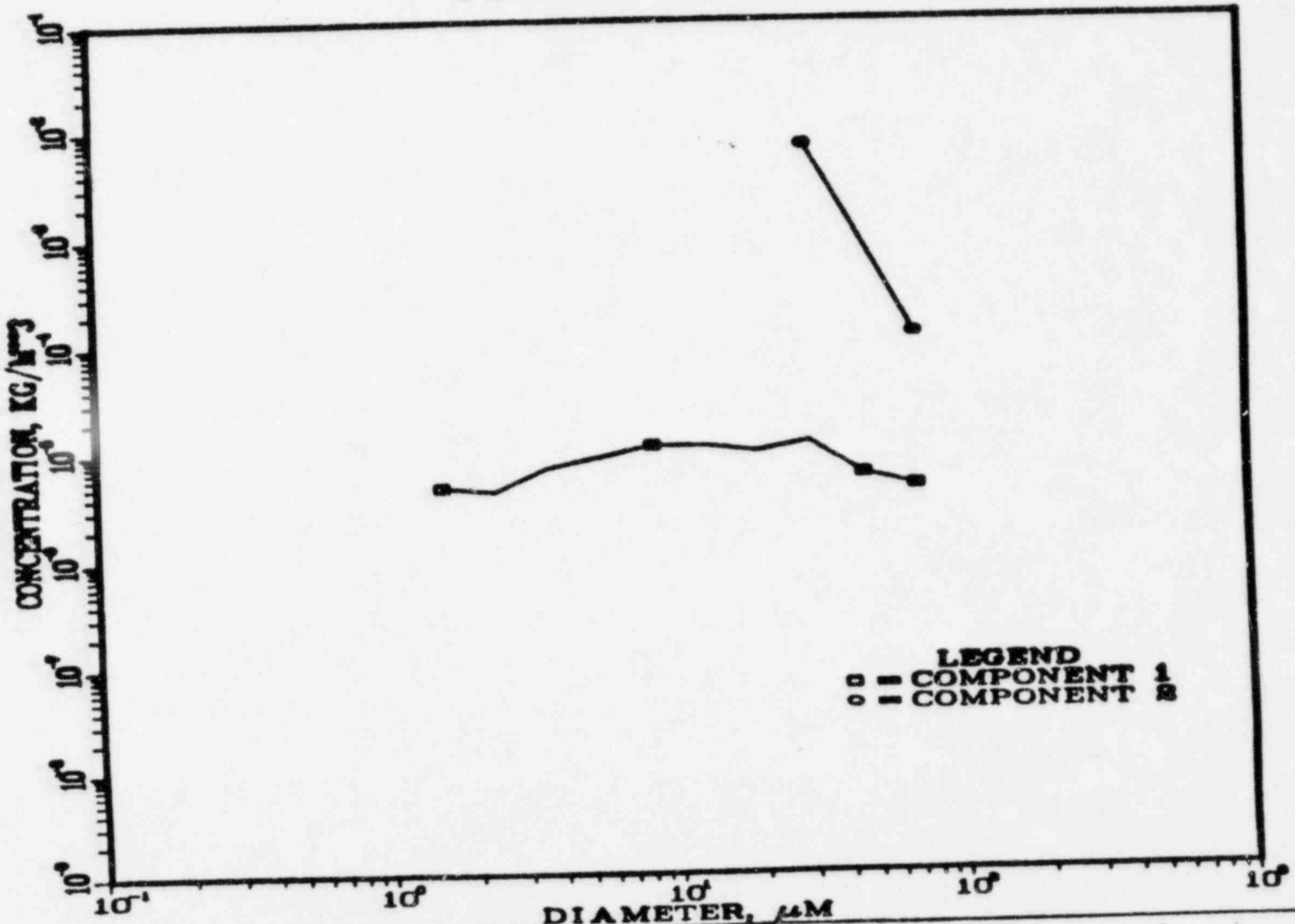


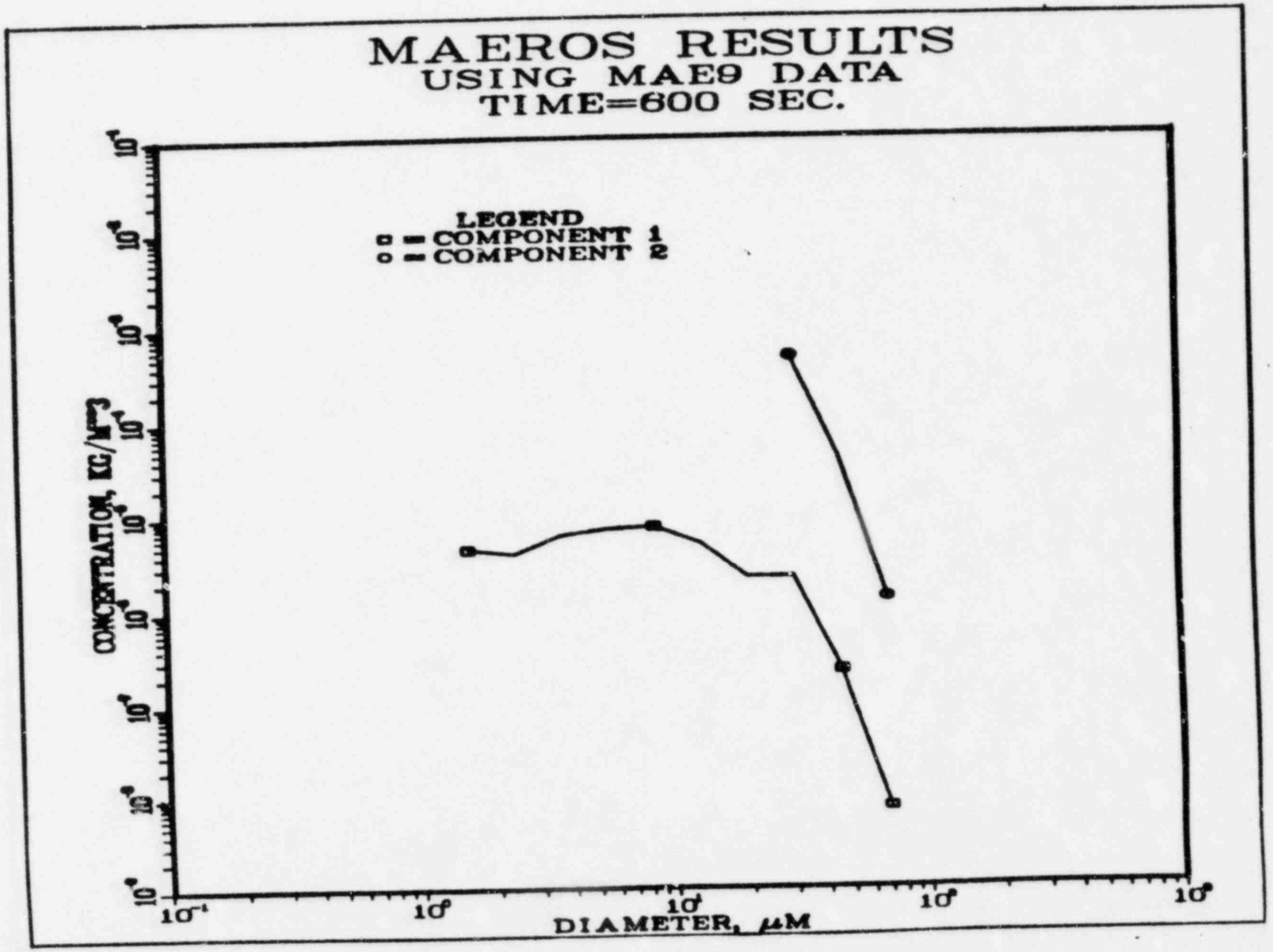
MAEROS RESULTS
USING MAE9 DATA
TIME= 0 SEC.



P-8

MAEROS RESULTS
USING MAE9 DATA
TIME= 60 SEC.




MAEROS RESULTS
USING MAE9 DATA
TIME=600 SEC.
LEGEND
□ = COMPONENT 1
○ = COMPONENT 2
CONCENTRATION, KG/M**3
DIAMETER, µM
10⁻¹
10⁰
10¹
10²
10³

SUMMARY OF MAEROS
PRELIMINARY RESULTS

- THE PEAK CONCENTRATION (OF 1 KG) OF SMOKE ALONE AFTER 10 MIN IS AT ABOUT 2 µm BECAUSE OF COAGULATION.
- THE MORE DILUTE CONTAMINANT AEROSOL ALONE IS DEPLETED BY 52% IN CONCENTRATION MOSTLY IN THE HIGHER SIZES BECAUSE OF DEPOSITION.
- THE PRESENCE OF A HIGH CONCENTRATION OF 0.2 µm SMOKE APPEARS TO HAVE LITTLE EFFECT ON THE DEPOSITION OF CONTAMINANT; HOWEVER, THE SIZE DISTRIBUTIONS OF BOTH AEROSOLS CHANGE SIGNIFICANTLY IN THE RESPIRABLE SIZE RANGE.
- THE PRESENCE OF A HIGH CONCENTRATION OF 25 µm SMOKE CAN AFFECT THE CONTAMINANT CONCENTRATION BY A FACTOR OF TWO LOWER IN THE SIZES BELOW 3 µm AND BY A FACTOR OF TWO HIGHER IN THE SIZES ABOVE 3 µm BY KEEPING MORE CONTAMINANT AIRBORNE.

Los Alamos

FUTURE MAERAOS RUNS

WE PROPOSE TO PERFORM ADDITIONAL MAEROS RUNS TO INVESTIGATE THE EFFECTS OF

- LARGER SMOKE PARTICLES,
- ELEVATED TEMPERATURE,
- CONDENSING WATER VAPOR, AND
- EXPERIMENTAL RESULTS FROM NMSU.

Los Alamos

Fuel Cycle Facility Safety Research Program

Research Review Group Meeting #8

NAME	ORGANIZATION	TELEPHONE
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Fritz Krause	Los Alamos	
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Archibald Tewarson	Factory Mutual	617-762-4300 x2950
Judi Steciak	FMRC	617-762-4300 x2952
Dick Martin	Los Alamos	FTS-843-6231

AGENDA

for

Fuel Cycle Facility Safety Research Program

Research Review Group Meeting #8

Date: July 21-22, 1982

Location: Factory Mutual Research Corporation Conference Center
1151 Boston-Providence Turnpike
Norwood, Massachusetts

TIME	ITEM	BY
July 21, 1982		
8:00 a.m.	Opening Remarks	S. Bernstein, NRC
8:15 a.m.	Review of Deliverables	P. C. Owczarski, PNL
8:30 a.m.	Overview of FIRIN 1	P. C. Owczarski, PNL
9:30 a.m.	Burning Model of FIRIN 1 (Part 1)	M. K. W. Chan, PNL
10:00 a.m.	Break	
10:15 a.m.	Burning Model of FIRIN 1 (Part 2 - Mass Balances)	M. K. W. Chan, PNL
11:00 a.m.	Heat Transfer in FIRIN 1	P. C. Owczarski, PNL
12:00 Noon	Tour of FMR Experimental Facilities	A. Tewarson, FMR
12:30 p.m.	Lunch	
1:30 p.m.	Radioactive Source Terms	P. C. Owczarski, PNL
2:30 p.m.	FMR Experiments for PNL	J. Steciak, FMR
3:15 p.m.	Break	
3:30 p.m.	Overview of FMR Data Applications	A. Tewarson, FMR
4:30 p.m.	Adjourn	

TIME	ITEM	BY
July 22, 1982		
8:00 a.m.	NRC Problems with FIRAC	S. Bernstein, NRC
9:00 a.m.	Los Alamos Introduction: • Status of Deliverables • FIRAC Input Needs • Fire Test Plans/Assessment	W. S. Gregory, Los Alamos
10:00 a.m.	Break	
10:15 a.m.	Lawrence Livermore National Laboratories (LLNL) Fire Tests • LLNL Facility • Experiments and Results • Future Objectives	N. Alvares, LLNL
11:15 a.m.	Review of Selected Fire Models (including FIRIN 1 approach)	P. Pagni, UCB
12:15 p.m.	Lunch	
1:15 p.m.	Forced Ventilation Addition to Harvard Fire Code	H. Mittler, Harvard
1:45 p.m.	LLNL Experimental Plans and Predictions	F. R. Krause, Los Alamos
2:45 p.m.	Break	
3:00 p.m.	FIRAC Assessment	J. W. Bolstad, Los Alamos
3:45 p.m.	New Mexico State University Experimental Program	R. A. Martin, Los Alamos
4:30 p.m.	Adjourn	

FUEL CYCLE FACILITY SAFETY RESEARCH PROGRAM

US NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REGULATORY RESEARCH

C-1

PURPOSE

TO DEVELOP IMPROVED METHODS FOR DETERMINING AND CHARACTERIZING THE RELEASE OF RADIOACTIVE MATERIALS CAUSED BY MAJOR ACCIDENTS AT FUEL CYCLE FACILITIES.

SCOPE

- FUEL CYCLE FACILITIES
    - MIXED OXIDE FUEL FABRICATION
    - AWAY FROM REACTOR SPENT FUEL STORAGE
    - FUEL REPROCESSING
    - HIGH LEVEL WASTE SOLIDIFICATION
    - URANIUM HEXAFLUORIDE CONVERSION
- MAJOR ACCIDENTS
    - FIRE
    - EXPLOSION
    - TORNADO
    - CRITICALITY
    - EQUIPMENT FAILURE
    - SPILL

End-Product

Accident Analysis Handbook (AAH)

- Purpose: Provide analytical techniques and required data for realistic accident assessment.
- Structure:
  - Chapter 1: Introduction
  - Chapter 2: Fuel Cycle Facility Descriptions
  - Chapter 3: Processes and Unit Operations
  - Chapter 4: Accident Scenarios and Source Term Definitions
  - Chapter 5: Accident Consequence Assessment
  - APPENDIX A: TORAC USER MANUAL
  - APPENDIX B: EXPAC USER MANUAL
  - APPENDIX C: FIRAC USER MANUAL
- Illustrative Examples - Representative Facility
- Draft AAH issued March 18, 1982

USERS OF ACCIDENT ANALYSIS HANDBOOK

- NRC LICENSING STAFF
- APPLICANTS FOR NRC FUEL CYCLE FACILITY LICENSE

DOE LABORATORIES

- BATTELLE PACIFIC NORTHWEST LABORATORIES
  - DESCRIPTION OF FACILITIES, PROCESSES, AND UNIT OPERATIONS
  - DEFINITION OF ACCIDENT SCENARIOS
  - DEVELOPMENT OF ACCIDENT SOURCE TERMS
  - MIXED OXIDE FUEL FABRICATION FACILITY
  - NEAR FIELD AEROSOL CHARACTERIZATION

- OAK RIDGE NATIONAL LABORATORY
  - DESCRIPTION OF FACILITIES, PROCESSES, AND UNIT OPERATIONS
  - DEFINITION OF ACCIDENT SCENARIOS
  - DEVELOPMENT OF ACCIDENT SOURCE TERMS
  - SPENT FUEL STORAGE, REPROCESSING, AND SOLIDIFICATION FACILITIES
- LOS ALAMOS NATIONAL LABORATORY
  - FAR FIELD ACCIDENT ANALYSIS
  - COMPUTER CODES: TORAC
    EXPAC
    FIRAC
  - GAS DYNAMICS
  - MATERIAL TRANSPORT
  - REPRESENTATIVE FACILITY

EXAMPLES OF CURRENT RESEARCH

- EXTENSIVE LITERATURE REVIEWS
    - ACCIDENT GENERATED AEROSOLS
    - COMBUSTION PRODUCT CHARACTERISTICS
    - ENGINEERED SAFETY SYSTEMS
- AEROSOL CHARACTERIZATION EXPERIMENTS
    - UNPRESSURIZED AND PRESSURIZED SPILLS
    - POWDERS AND LIQUIDS
- COMBUSTION PRODUCT CHARACTERIZATION EXPERIMENTS
- NEAR FIELD SOURCE TERM MODELS
    - SPILLS
    - FIRES
- FILTER PLUGGING EXPERIMENTS
- MATERIAL ENTRAINMENT EXPERIMENTS
- SIMPLE ILLUSTRATIVE EXAMPLE
    - FIRE IN MIXED OXIDE FUEL FABRICATION FACILITY
    - REPRESENTATIVE FACILITY
- ASSESSMENT OF FIRE COMPARTMENT MODELS
    - PREDICTION COMPARED TO LAWRENCE LIVERMORE NATIONAL LABORATORY FIPE TEST DATA
    - DEVELOPMENT OF IMPROVED MODEL

June 25, 1982

PNL SCHEDULE/PROGRESS OF DELIVERABLES - FY-82

TASK A. A.A.H. Deliverables

1. Revise Chapters 2 and 3 to Accomodate FIRIN1 (Sept 82)

   Percent Complete 50

2. Revise Chapter 4 to Accomodate FIRIN1 (Sept 82)

   Percent Complete 50

3. Write FIRIN1 User's Manual (Sept 82)

   Percent Complete 20

4. ORNL Material into New Format (Dec 82)

   Percent Complete 5

5. Identify Further Needs in ORNL Material (Dec 82)

   Percent Complete 0

6. First Explosion Problem (See Task C2.)

   Percent Complete --

7. Complete Planning Document with LANL (June 82)

   Percent Complete 70

TASK B. Aerosol Generation Experiment Deliverables

1. Revised Free Fall Spills Document (Nov 81)

   Percent Complete 100

2. Extended Spills (Dec 81)

   Percent Complete 100

3. Pressurized Powders and Liquids Document (1st Draft Aug 82)

   Percent Complete 30

4. FY-82 RART Plan (July 82)

   Percent Complete 97

5. Revised Source Term Literature Review (Early 82)

   Percent Complete 100

TASK C1. Fire Experiments Deliverables

(Factory Mutual Experiments Begin Jan. 82)

Factory Mutual Final Report (Sept 82)

Percent Experiments Complete 50

Percent Monthly Documentation Complete 30

Percent Final Documentation Complete 0

TASK C2. Fire and Explosion Studies

1. Combustion Products Literature Review (Jan 82)

   Percent Complete 100

2. LANL Smoke Generator (Feb/March 82)

   Percent Complete 100

3. Initiate Explosion Parameters Literature Review (Oct 81)

4. Draft Explosion Parameters Literature Review (3rd Qtr '83)

   Percent Complete 20 (first outline complete)

5. Develop Preliminary Level One Source Term Models for Explosions

   Percent Complete 60

6. Develop Radioactive Release Scenario for Each Model in 5. (Letter Report Sept 82)

   Percent Complete 20

7. For A.A.H., Provide Step-by-Step Procedures for Models in 5. (1st Qtr '83)

   Percent Complete 0

8. For A.A.H., Provide Sample Explosion Problem (2nd Qtr, FY-83)

   Percent Complete 0

TASK D. Failed Compartment Tests Deliverables

SUBTASK 1. Experiment Planning

1. Aerosol Behavior Code Literature Search (Jan. 82)
   Percent Complete 100
2. Summarize Historical Data on Glovebox Fires (Informal Report - April 82)
   Percent Complete 80
3. Experimental Plan to Characterize Glovebox (April 82)
   Percent Complete 35
4. Preliminary Plan for First Fire Release (Aug. 82)
   Percent Complete 10

SUBTASK 2. Experimentation

1. Complete Glovebox Characterization (June 82)
   Percent Complete 0
2. Analyze Data (July 82)
   Percent Complete 0
3. Prepare Equipment for Fire Experiments (Late 82)
   Percent Complete 0

TASK E. Models Deliverables

1. Free Fall Spills (Draft Aug 82)

   Percent Complete 40

2. Combustion Products Computer Code (Aug 82)

   Percent Complete 80

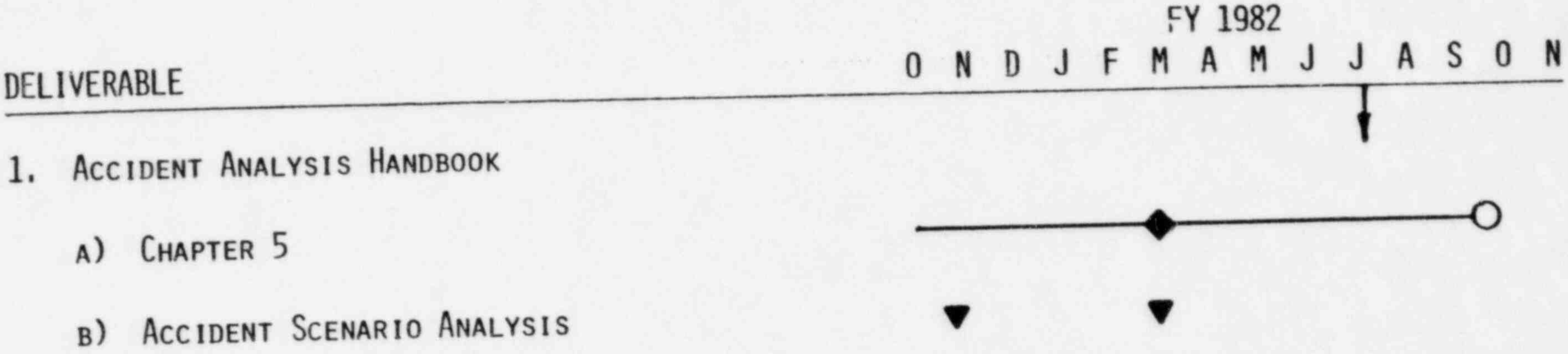
3. Pressurized Releases (Late 82)

   Percent Complete 0

4. Task D Support - Well Mixed Compartment (Late 82)

   Percent Complete 0

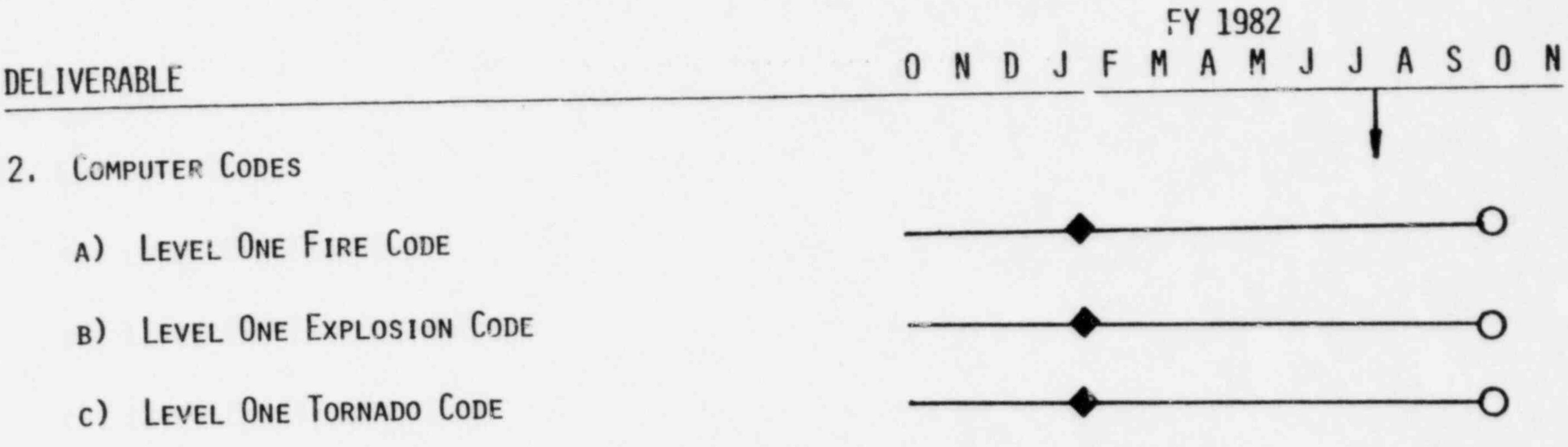
DELIVERABLE SCHEDULE AND STATUS



Darkened Symbols Indicate Completion
- - - - Scheduled Variation
_____ Activity Line
↓ Time Now

□ Informal Letter Report
◇ Draft Topical Report
○ Final Topical Report
△ Draft Interim Report

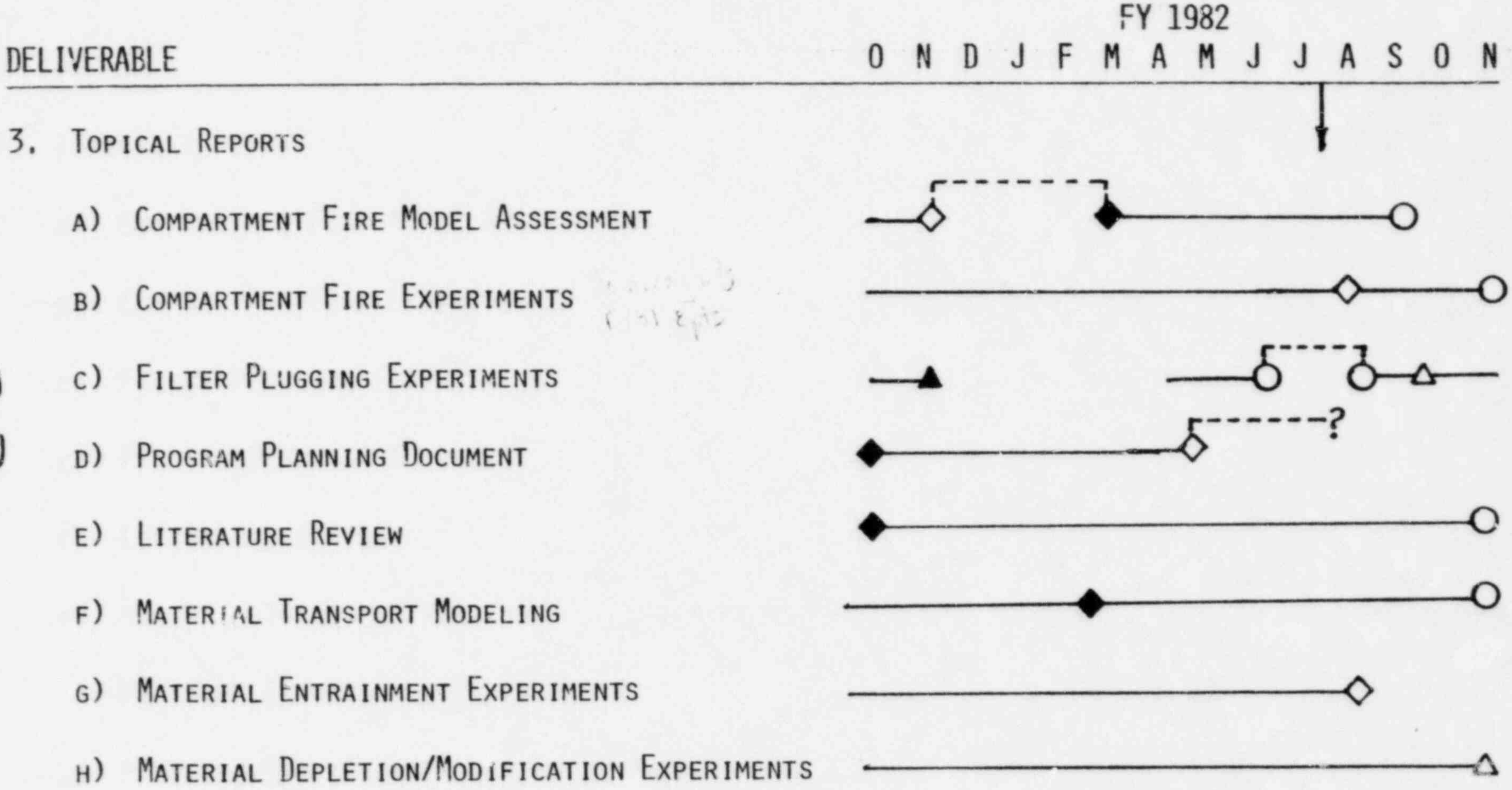
DELIVERABLE SCHEDULE AND STATUS



- DARKENED SYMBOLS INDICATE COMPLETION
- - - - - SCHEDULED VARIATION
- _____ ACTIVITY LINE
- ↓ TIME NOW

□ INFORMAL LETTER REPORT
◇ DRAFT TOPICAL REPORT
○ FINAL TOPICAL REPORT
△ DRAFT INTERIM REPORT

DELIVERABLE SCHEDULE AND STATUS



3. TOPICAL REPORTS

a) COMPARTMENT FIRE MODEL ASSESSMENT

b) COMPARTMENT FIRE EXPERIMENTS

c) FILTER PLUGGING EXPERIMENTS

d) PROGRAM PLANNING DOCUMENT

e) LITERATURE REVIEW

f) MATERIAL TRANSPORT MODELING

g) MATERIAL ENTRAINMENT EXPERIMENTS

h) MATERIAL DEPLETION/MODIFICATION EXPERIMENTS

- DARKENED SYMBOLS INDICATE COMPLETION
- - - - - SCHEDULED VARIATION
- _____ ACTIVITY LINE
- ↓ TIME NOW

□ INFORMAL LETTER REPORT
◇ DRAFT TOPICAL REPORT
○ FINAL TOPICAL REPORT
△ DRAFT INTERIM REPORT

DELIVERABLE SCHEDULE AND STATUS

DELIVERABLE	O	N	D	J	F	M	A	M	J	J	A	S	O	N
										FY 1982				
4. Experimental Plans										↓				
a) Compartment Fire Experiments								☐		■				
b) Filter Plugging									■					
c) Material Depletion/Modification									■					

- Darkened Symbols Indicate Completion
- - - - - Scheduled Variation
- _____ Activity Line
- ↓ Time Now

☐ Informal Letter Report
◇ Draft Topical Report
○ Final Topical Report
△ Draft Interim Report

FIRIN1

- LEVEL-ONE FIRE SOURCE TERM CODE
- PROVIDES 3-BASIC INPUTS FOR FIRAC
    1. Net Heat Rate to Fire Compartment Gases
    2. Airborne Mass Generation Rate of Combustion Products (and Particle Characteristics)
    3. Airborne Mass Generation Rate of Radioactive Particles (and Particle Characteristics)
- BASIC TOOL OF AAH, CHAPTER 4, SCENARIOS AND SOURCE TERM FOF FIRES

IRM FEATURES/ASSUMPTIONS - FIRIN1

1. Items will Burn Independently.

2. Total Item Surface Burning.

3. Flaming Combustion.

4. Order of Burning Established by Judgement or by Internal Logic (using critical heat flux)

5. Radioactive Source Terms by Calculational Models and by Judgement.

6. Correction for Underventilated Conditions.

7. Correction for Heat Losses to Structure and Equipment.

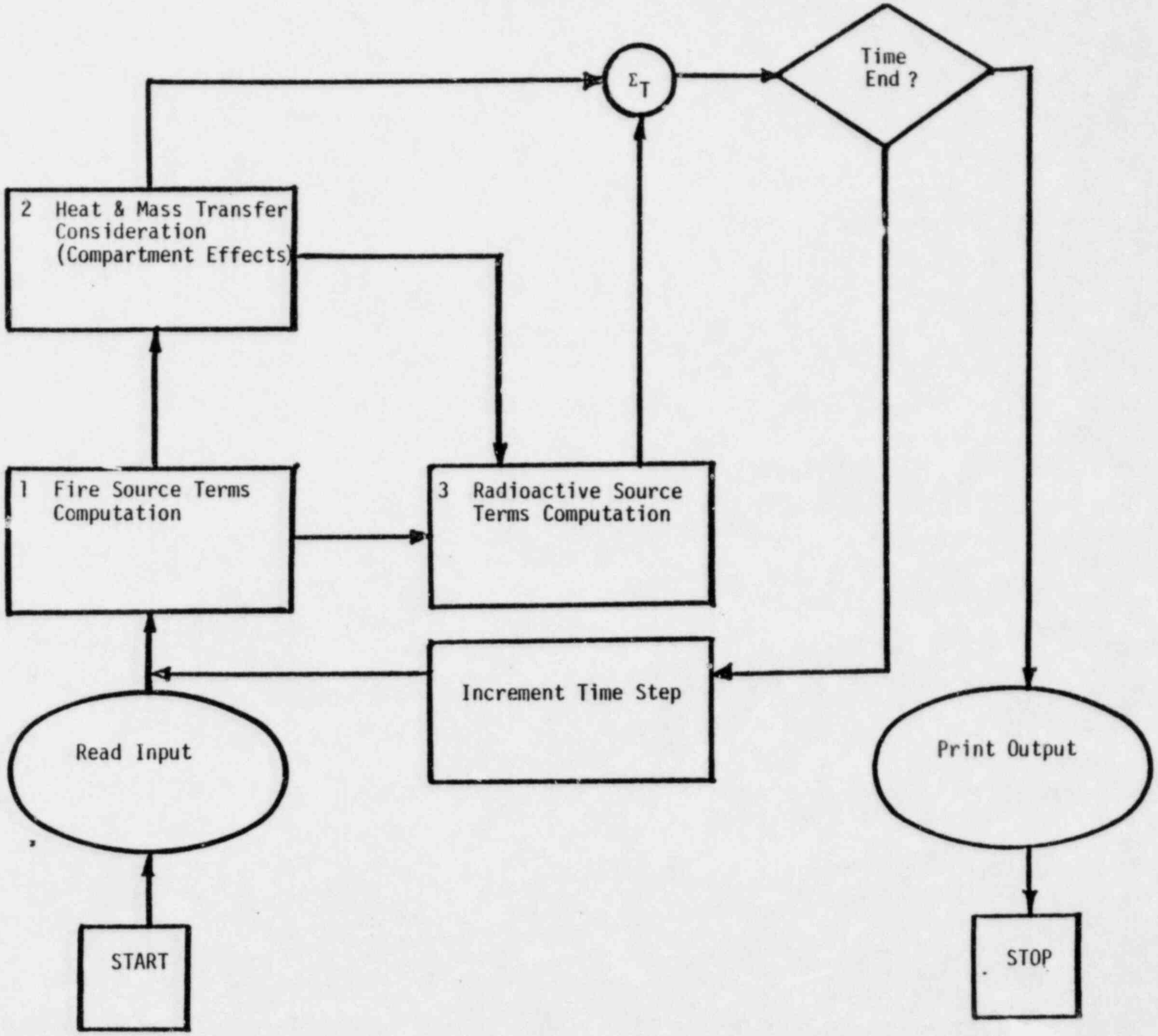
8. Correction for H_2O and CO_2 Produced from Heated Concrete.

9. Future Scale Modification.

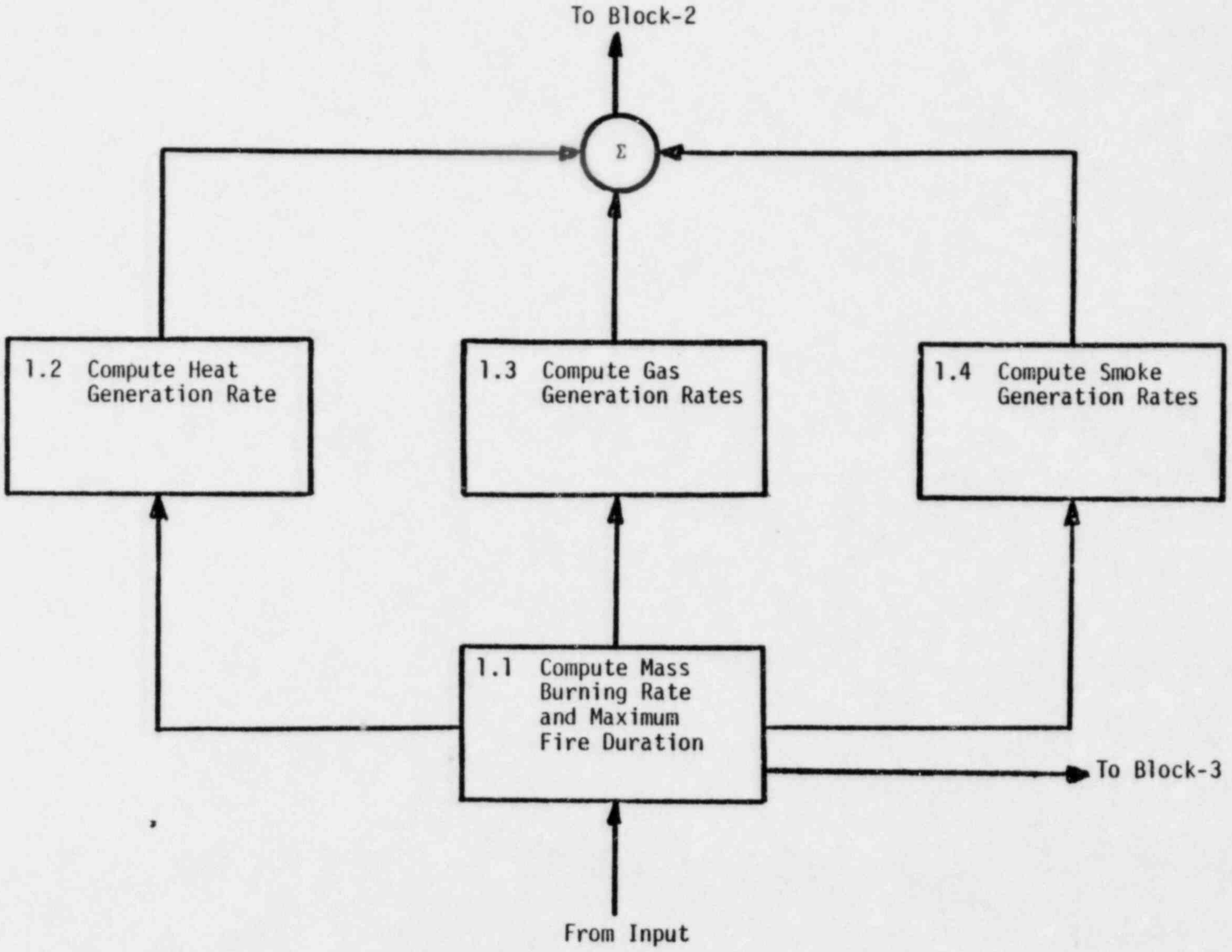
SOURCE TERM METHOD UNCERTAINTIES

1. Uncertainty of Ignition Point
2. Uncertainty of Path of Fire (Fire Growth)
3. Uncertainty in Completeness of Combustion and Burn Mode
4. Uncertainty in Equipment Failure Mode
5. Uncertainty in Quantities Involved (Exact Inventories at Time of Accident)
6. Uncertainty in Timing of All Events

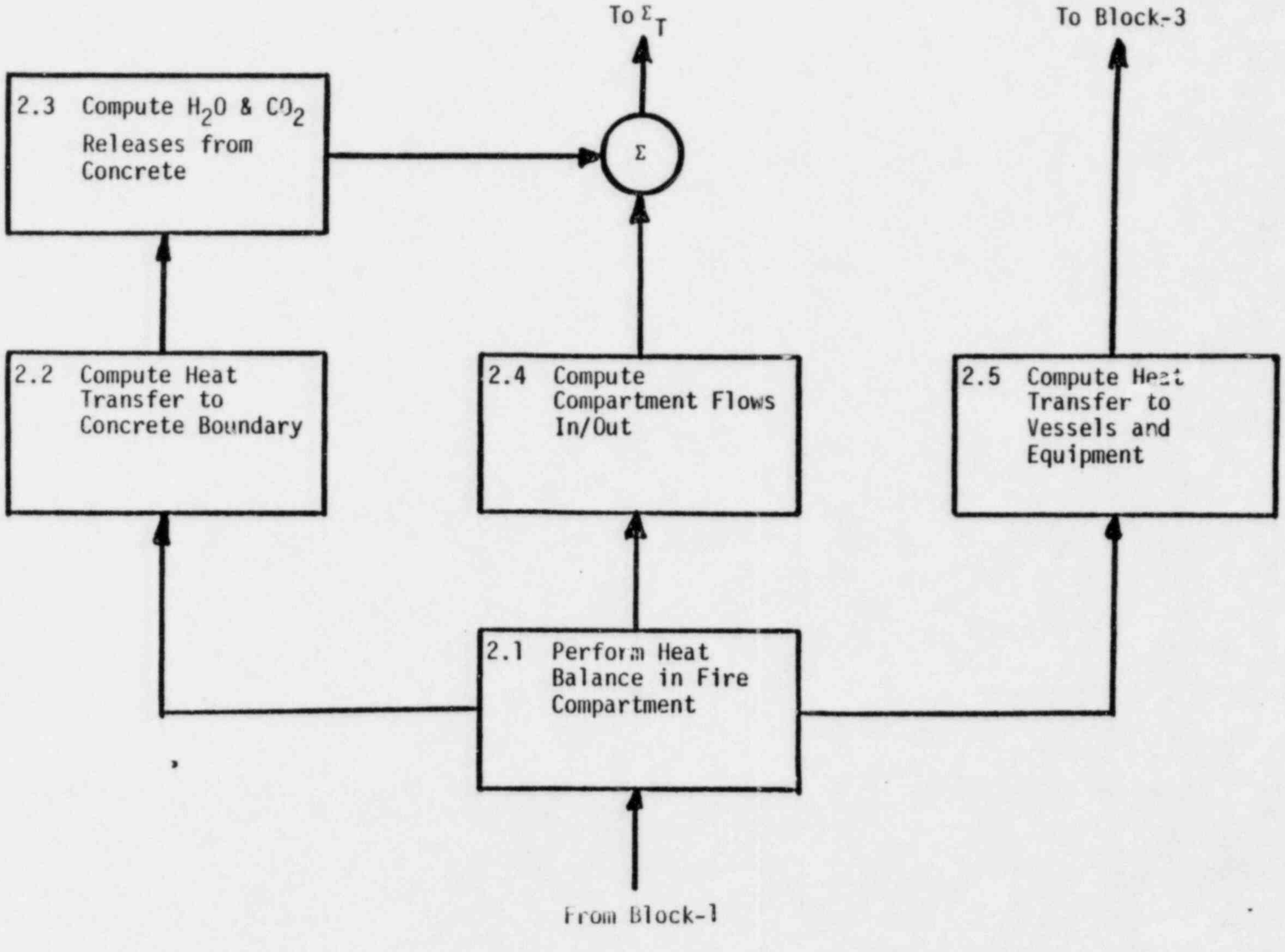
FIRIN1 OVERVIEW FLOW CHART



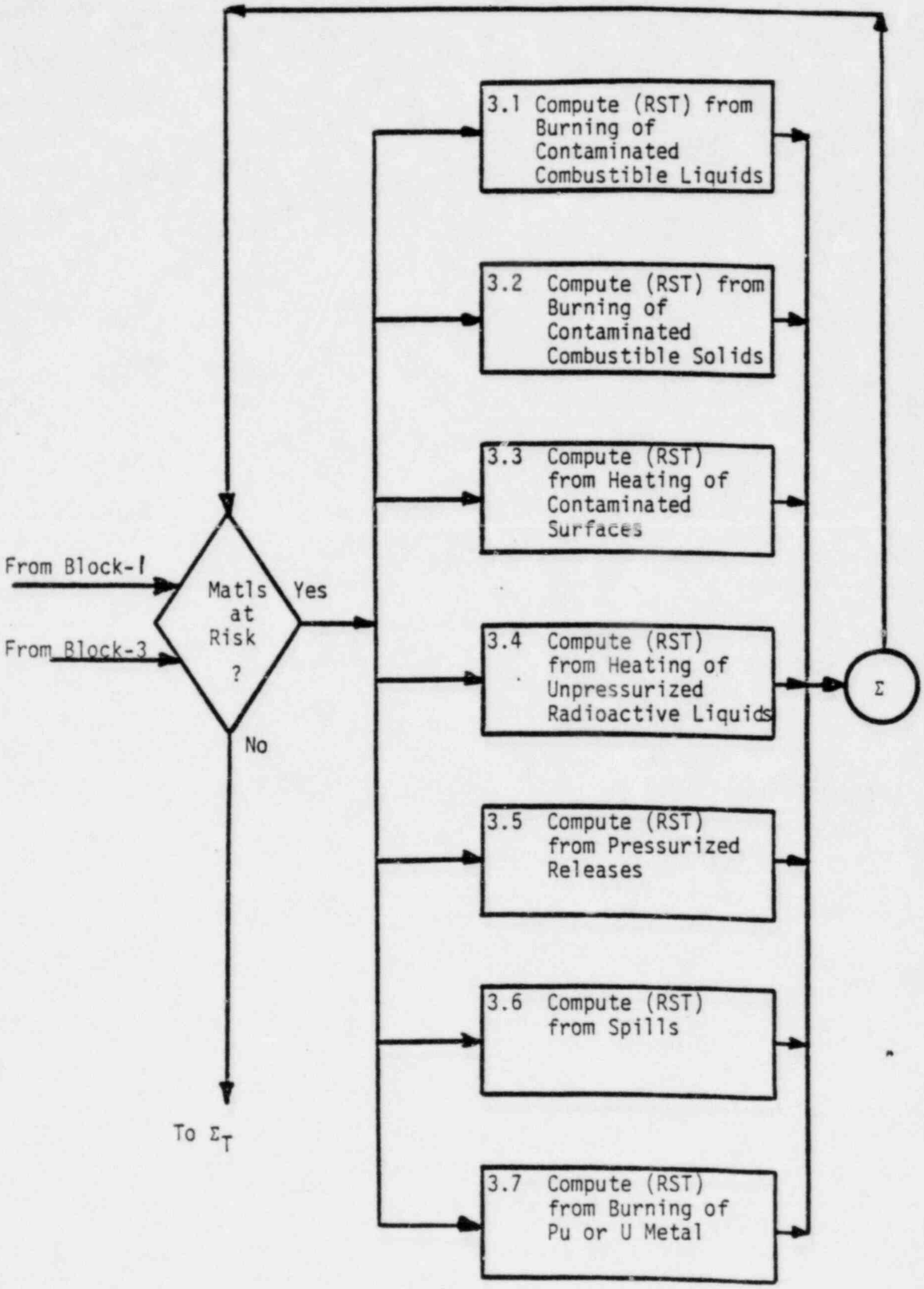
BLOCK-1 FIRE SOURCE TERMS COMPUTATION



BLOCK-2 HEAT & MASS TRANSFER CONSIDERATION OF COMPARTMENT EFFECTS



BLOCK-3 RADIOACTIVE SOURCE TERMS COMPUTATION (RST)



TYPICAL COMBUSTIBLE MATERIALS FOUND IN FUEL CYCLE FACILITY

- Polymethylmethacrylate (PMMA)
- Polystyrene (PS)
- Polyvinylchloride (PVC)
- Elastomer (i.e. Polychloroprene)
- Cellulose (i.e. wood)
- Cellulosic Material (i.e. paper and rags)
- Organic Fluids (i.e. kerosene, TBP, lubricating/hydraulic fluids)
- Polypropylene (PP)
- Polyethylene (PE)

COMPONENT BALANCES INSIDE THE FIRE COMPARTMENT

Component Balances in the layers

1. Hot Layer (smoke layer)
    - CO_2
    - CO
    - H_2O
    - HCl
    - N_2
    - O_2
    - Smoke and soot (mass bal.)
2. Cold Layer
    - N_2
    - O_2

COMPONENT CONTINUITY EQUATIONS (HOT LAYER)

Rate of Change of Moles of (Xth - component) inside hot layer =
Flow of (Xth) into/from hot layer from/out of inlet ventilation
+
Flow of (Xth) from hot layer out of outlet ventilation
+
Decomposition of (Xth) from concrete boundaries into hot layer
+
Generation/consumption of (Xth) in fire
+
Entrainment of (Xth) by fire plume into hot layer
+
Flow of (Xth) into/from hot layer from/out of new flow paths

COMPONENT CONTINUITY EQUATION (COLD LAYER) - O_2, N_2

Rate of Change of moles of (O_2, N_2) inside cold layer =

Flow of (O_2,N_2) into/from cold layer from/out of inlet ventilation

\+

Flow of (O_2,N_2) from cold layer out of outlet ventilation

\+

Consumption of (O_2) in fire

\+

Entrainment of (O_2, N_2) by fire plume away from cold layer

\+

Flow of (O_2, N_2) into/from cold layer from/out of new flow paths

FILTER PLUGGING MODEL*

$$Q = \frac{\Delta P}{\beta(1 + \alpha m_p)}$$

Q = Flow Rate

ΔP = Pressure Drop Across the Filter

m_p = Mass Accumulation on Filter

β, α = Filter Resistance Parameters

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* Los Alamos National Laboratory

PLUME PARAMETERS

1. VELOCITY OF CENTERLINE(a)

$$W_m = C_v \left[Q / \left(\rho_\infty C_p T_\infty \sqrt{gZ^5} \right) \right]$$

2. VERTICAL VELOCITY(a)

$$W = W_m \exp \left[- (r/\ell_v)^2 \right]$$

3. RADIAL VELOCITY(b)

$$U = \frac{b \ell_v{}^2}{r Z^{4/3}} \left\{ \left(\frac{r}{\ell_v} \right)^2 \exp \left[- \left(\frac{r}{\ell_v} \right)^2 \right] - \frac{5}{6} \left[1 - \exp \left[- \left(\frac{r}{\ell_v} \right)^2 \right] \right] \right\}$$

4. FLAME HEIGHT(c)

$$\text{FLAME HEIGHT} = \text{FLAME DIAM} \left(\frac{Q, \text{kw}}{200} \right)^{0.4}$$

References:

(a) E.E. Zukoski & T. Kubota, Fire & Materials <u>4</u> (1980).

(b) By solving continuity equation.

(c) E.E. Zukoski, et al., "Entrainment in Fire Plumes," CIT report, 1980.

Major Mechanisms of Release During a Fire

- Burning Contaminated Combustible Solids
- Burning Contaminated Combustible Liquids
- Heating Noncombustible Contaminated Surfaces
- Heating Unpressurized Radioactive Liquids
- Pressurized Releases of Radioactive Powders or Liquids
- Spills of Radioactive Powders or Liquids
- Burning Radioactive Pyrophoric Metals

Burning Contaminated Solids

<u>Powder Contaminant</u>

$$\dot{M}_r = 5.3 \times 10^{-4} \frac{W_r}{t} \qquad \text{(BNWL-1730)}$$

<u>Liquid Contaminant</u>

$$\dot{M}_r = 1.5 \times 10^{-4} \frac{W_r}{t} \qquad \text{(BNWL-1730)}$$

$\dot{M}_r$ = mass rate of radioactive material made airborne (g/sec)

W_r = weight of contaminant on combustible (g)

t = time over which combustible burns (sec)

Burning Contaminated Solids

User input W_r (weight of contaminant on combustible)

form of contaminant (powder, liquid)

FIRIN1 internally calculates t (time to burn combustible)

Other Potential Event Defining Parameters

Velocity of air

Type of combustible (tissue, wood, gloves)

Distribution of contaminant on combustible (uniform vs. lump)

Particle Size

80% less than 10μ AED (BNWL-1730)

Burning Contaminated Liquids (Stage 1: Burning)

U or Pu Powder (BNWL-1732)

$$\dot{M}_r = \frac{.0012\ W_r}{t} \qquad V < 180\ \text{cm/sec}$$

$$\dot{M}_r = (1.7 \times 10^{-5}V - 1.8 \times 10^{-3})\frac{W_r}{t} \qquad V > 180\ \text{cm/sec}$$

U or Pu Liquid

$$\dot{M}_r = \frac{2.7 \times 10^{-4} W_r}{t} \qquad V < 30\ \text{cm/sec (BNWL-B-274)}$$

$$\dot{M}_r = \frac{(7.15\times10^{-5}V - 1.88\times10^{-3})W_r}{t} \qquad 30 < V < 180\ \text{cm/sec (BNWL-1732)}$$

$$\dot{M}_r = \frac{(1.45\times10^{-4}V - .015)W_r}{t} \qquad V > 180\ \text{cm/sec (BNWL-1732)}$$

Other Radioactive Materials (BNWL-B-274)

$$\dot{M}_r = .0074\frac{W_r}{t} \qquad \text{nonvolatiles}$$

$$\dot{M}_r = .0025\frac{W_r}{t} \qquad \text{semivolatiles (Cs)}$$

$$\dot{M}_r = .66\frac{W_r}{t} \qquad \text{volatiles (I)}$$

$\dot{M}_r$ = mass rate of radioactive material airborne (g/sec)

W_r = weight of contaminant in liquid (g)

V = average velocity in the fire (cm/sec) (obtained from plume model)

t = time over which combustible burns (sec)

Burning Contaminated Liquids (Stage 1: Burning)

User input W_r (weight of contaminant in liquid)

form of contaminant - U or Pu powder
U or Pu liquid
Other nonvolatiles
Semivolatiles
Volatiles

FIRIN1 internally calculates t (time to burn combustibles) and V (average velocity in the fire)

Other Potential Event Defining Parameters

Type of Surface (smooth metal, sand, pavement)

Particle Size

66% less than 10μ AED (BNWL-1732)

Burning Contaminated Liquids (Stage 2: Entrainment of Residue)

$\dot{M}_r = 4.5 \times 10^{-6} W_r$	U or Pu (BNWL-1732)
$\dot{M}_r = 5.0 \times 10^{-7} W_r$	Other nonvolatiles (BNWL-1732)
$\dot{M}_r = 1.25 \times 10^{-5} W_r$	Semivolatiles (BNWL-1732)
$\dot{M}_r = 3.0 \times 10^{-4} W_r$	Volatiles (BNWL-1732)

$\dot{M}_r$ = mass rate of radioactive material airborne (g/sec)

W_r = weight of contaminant in liquid (g)

Release assumed over 10 minutes

Burning Contaminated Liquids (Stage 2: Entrainment of Residue)

User input W_r (weight of contaminant in liquid)

FIRIN1 internal calculations determine when fuel is consumed and entrainment begins

Other Potential Event Defining Parameters

Velocity of air

Temperature

Particle Size

83% less than 10μ AED (BNWL-1732)

Heating of Noncombustible Contaminated Surfaces

$$\dot{M}_r = (1.94 \times 10^{-8}V + 5.78 \times 10^{-7})W_r \quad \text{(BNWL-786)}$$

$\dot{M}_r$ = mass rate of radioactive material made airborne (g/sec)

W_r = weight of contaminant on surface (g)

V = average velocity in the fire

Heating of Noncombustible Contaminated Surfaces

User input — W_r (weight of contaminant on surface)

guidance given in AAH for surface contamination

FIRIN1 internally calculates V (average velocity in the fire) (will use v in vicinity of surface instead)

Other Potential Event Defining Parameters

- Powder Properties - bulk density
  - particle density
  - moisture content
  - agglomeration tendencies
- Temperature of Surface
- Thickness of Bed

Particle Size

- Distribution given in Figure 9 of BNWL-786

Heating of Unpressurized Radioactive Liquids

$\dot{M}_r = 1.1\text{x}10^{-10}\ W_r$ Preboiling (BNWL-931)

$\dot{M}_r = 5.0\text{x}10^{-10}\ W_r$ $R_B < .6$ mℓ/min* (BNWL-931)

$\dot{M}_r = (5.67\text{x}10^{-7}R_B - 3.5\text{x}10^{-7})W_r$ $R_B > .6$ mℓ/min* (BNWL-931)

$\dot{M}_r = 1.67\text{x}10^{-7}W_r$ Heating of Residue
(BNWL-931)
(Release over 2 hours)

$\dot{M}_r$ = mass rate of radioactive material airborne (g/sec)

R_B = boiling rate of liquid (mℓ/min)

W_r = weight of radioactive material in the liquid (g)

---

* per cm^2

Heating of Unpressurized Radioactive Liquids

User input W_r

FIRIN1 internally decides which stage is applicable and calculates R_B

Other Potential Event Defining Parameters

Temperature of Liquid (Preboiling)

Air Velocity (residue)

Temperature (residue)

Particle Size

20.5μ MMD with distribution as given in Figure 12 of BNWL-931

Pressurized Releases of Radioactive Powders or Liquids

Model Under Development

User input	weight of material at risk
	failure pressure of vessel
	powder or liquid characteristics as specified

FIRIN1 calculates when vessel fails from heat transfer equations

Size of Particles

Liquid - 1.5μ AMMD
Powder - 16μ AMMD
(most conservative RART releases)

Free Fall Spill of Radioactive Powders or Liquids

Model Under Development

User input	weight of material at risk
	height of spill
	time of spill
	powder or liquid characteristics as specified

Size of Particles

(Most conservative RART releases)

Burning Pyrophoric Radioactive Metals

$$\dot{M}_r = 4.9 \times 10^{-4} \frac{W_r}{t} \quad \text{(BNWL-357)}$$

$\dot{M}_r$ = mass rate of radioactive material made airborne (g/sec)

W_r = weight of radioactive metal (g)

t = time over which metal is burned (sec)

User Input W_r

FIRIN1 estimates t

Other Potential Event Defining Parameters

- Temperature
- Air Velocity
- Exposed Surface Area of Metal

Size of Particles

- 4.2μ MMD
- Size distribution given in BNWL-357

FIRIN1

Example Run: BURNING OF CONTAMINATED BOXES OF RAGS

Input Compartment Parameters -

1. Compartment Volume - 3m x 3m x 3m
2. Inlet Vent. Height - 3m
3. Outlet Vent. Height - 0.6m
4. Thickness of Walls, Ceilings and Floor - 0.15m
5. Materials of Construction - Firebrick

FIRIN1

Example Run: BURNING OF CONTAMINATED BOXES OF RAGS

Input Fuel Parameters -

1. Cellulosic Materials (cardboard box and rags)
   - Mass - 6250 g
   - Surface Area - 0.5 m^2
2. Polyvinylchloride (bags)
   - Mass 100 g
   - Surface Area - 0.001 m^2

Input Contamination Parameters -

1. Contaminated Rags
   - 100 g UO_2 - Powder
2. Contaminated Bags
   - 50 g UO_2 - Powder

FIRIN1

Example Run: BURNING OF CONTAMINATED BOXES OF RAGS

Initial Compartment Conditions -

1. Temperature - 298°K
2. Pressure - 0.995 ATM
3. Inlet and Outlet Vent. Flows - 0.075 m^3/sec (3 g-mole/sec) (10 air changes per hour)

Inlet Pressure - 1.0 ATM

Outlet Pressure - 0.990 ATM

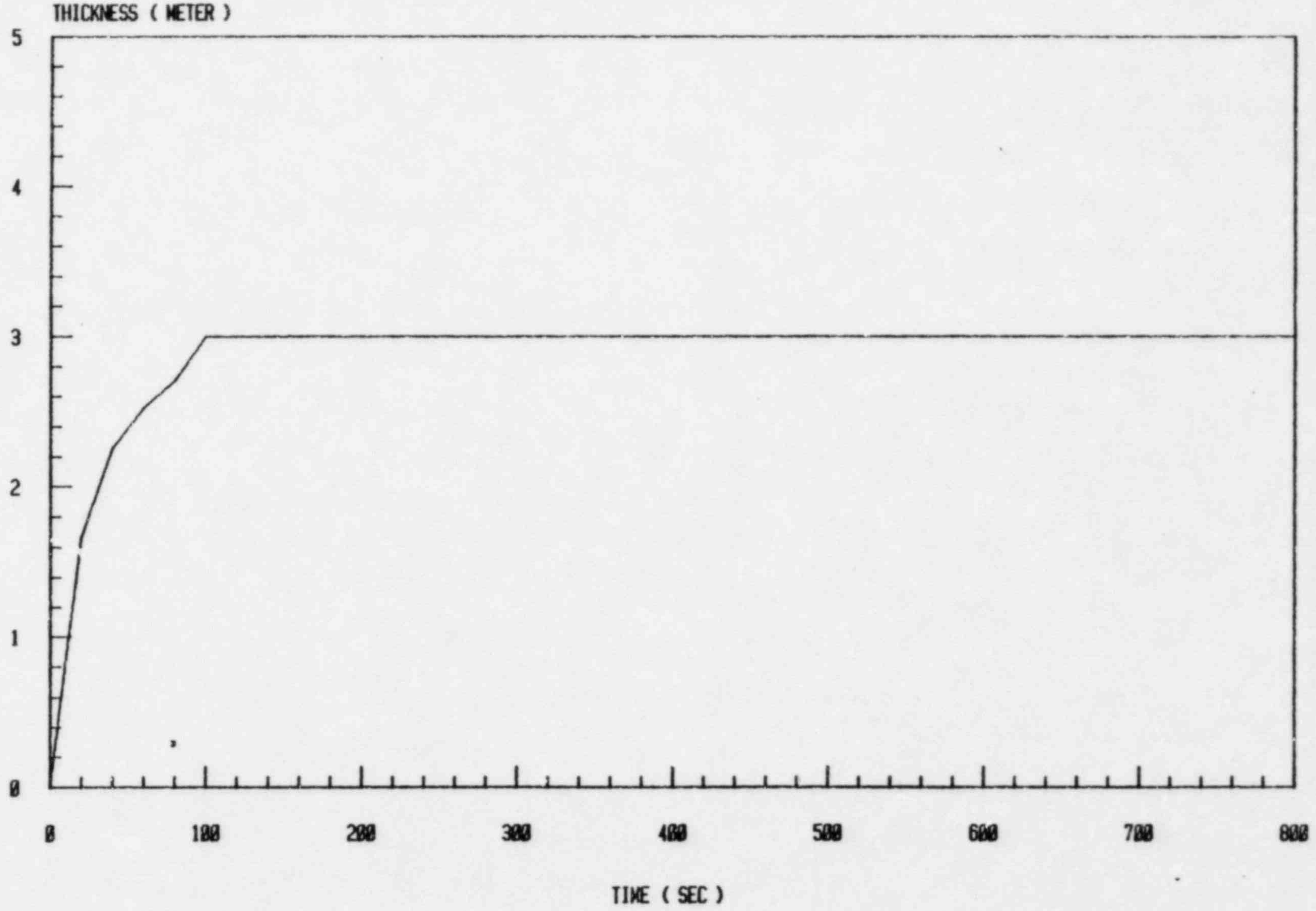
Height of the Burning Surface - 0.25m

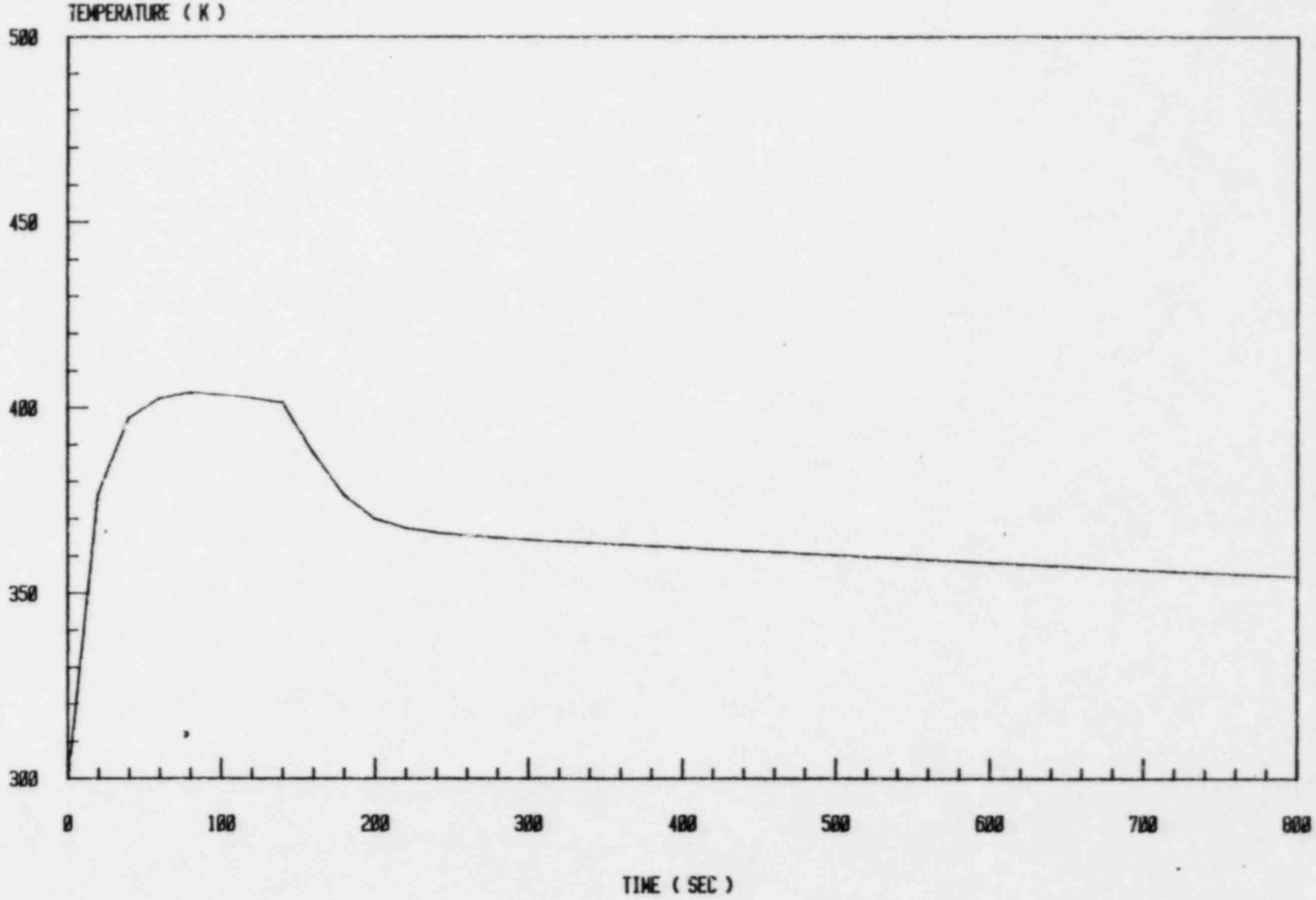
Parameters for Filter Flow Resistance (2' x 2')

1. β = 0.067
2. α = 0.018

THICKNESS OF HOTLAYER .VS. TIME

Burning of Contaminated Boxes of Rags



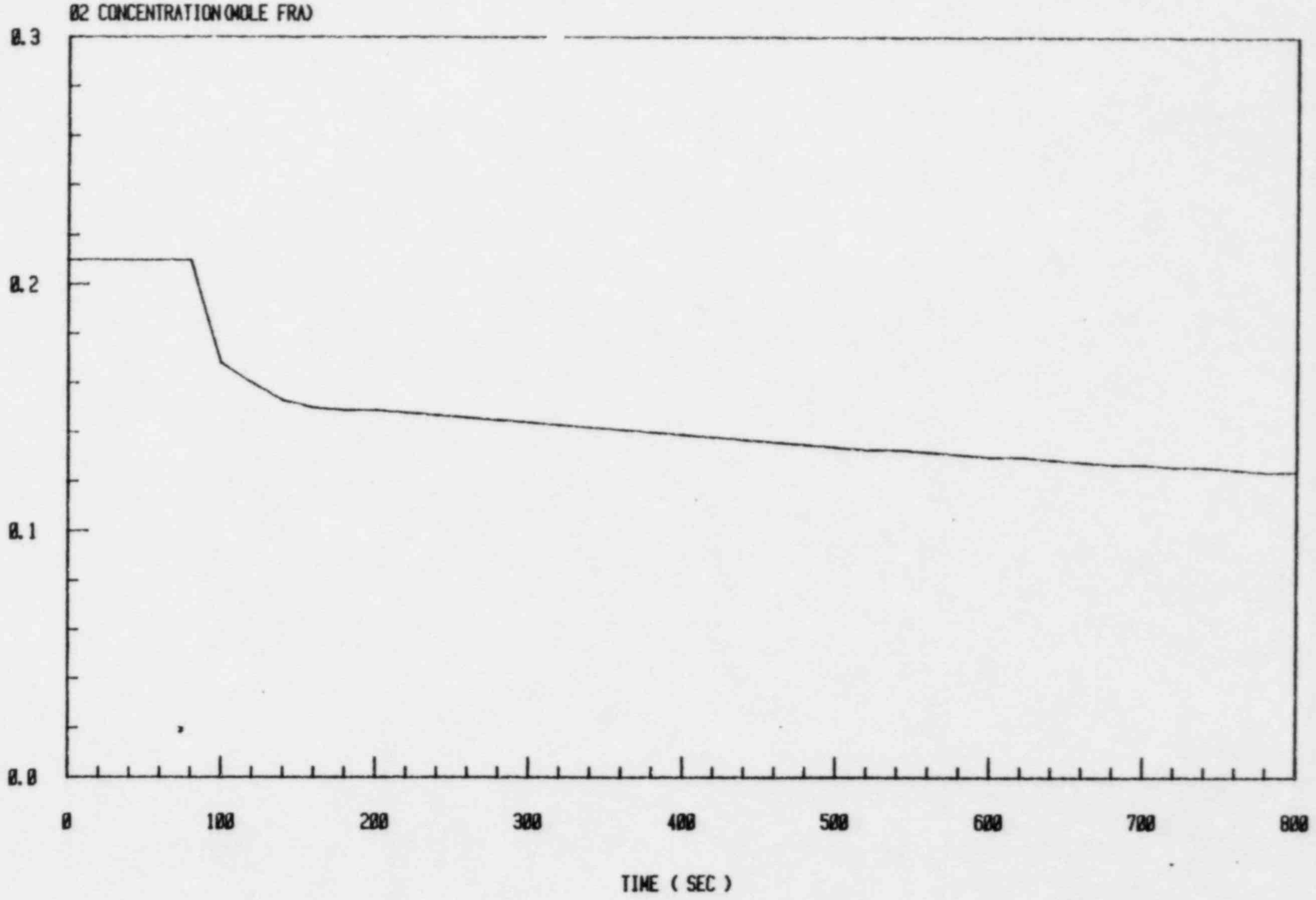


TEMPERATURE OF HOTLAYER .VS. TIME

Burning of Contaminated Boxes of Rags

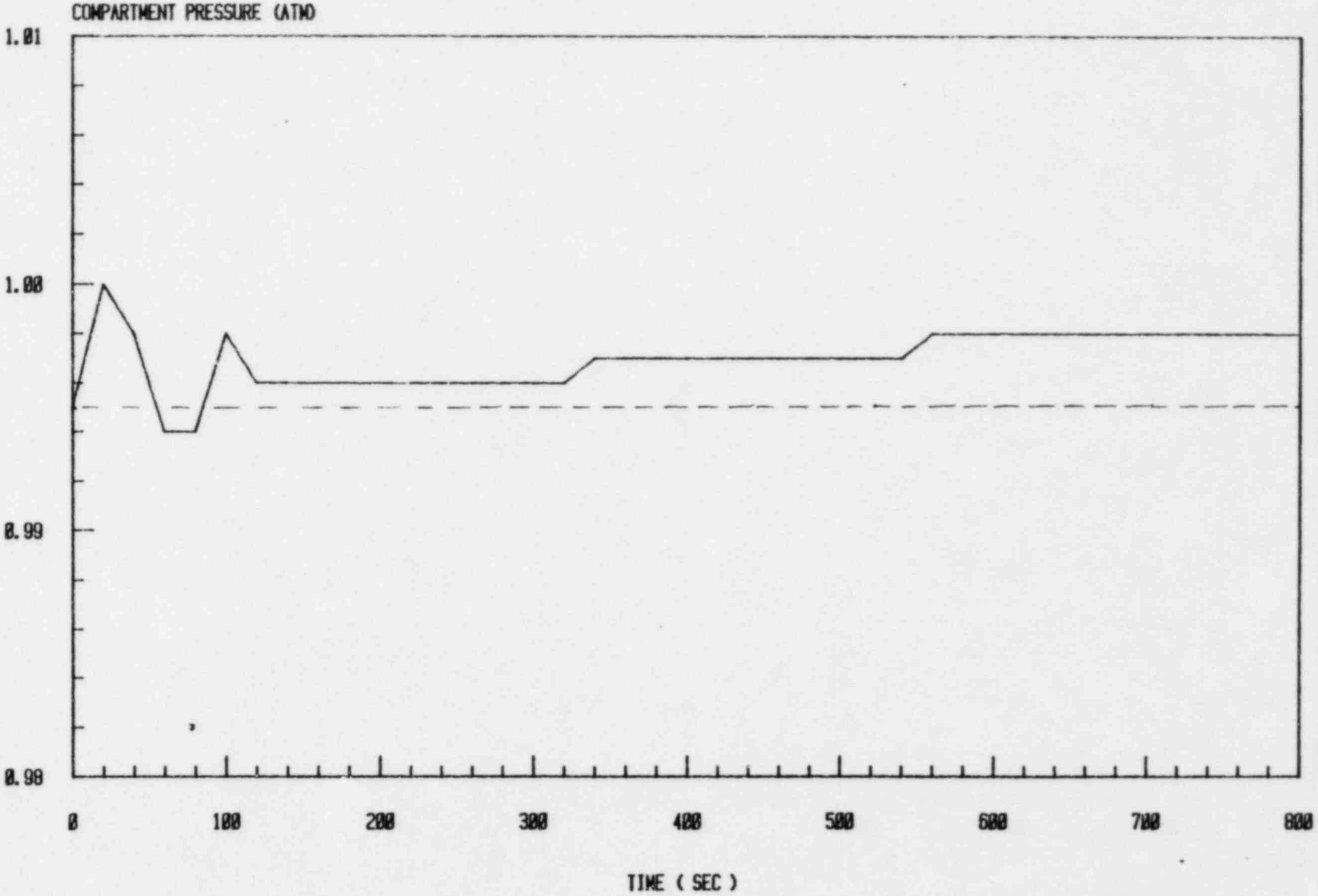
AVALIABLE OXYGEN CONCENTRATION .VS. TIME

Burning of Contaminated Boxes of Rags



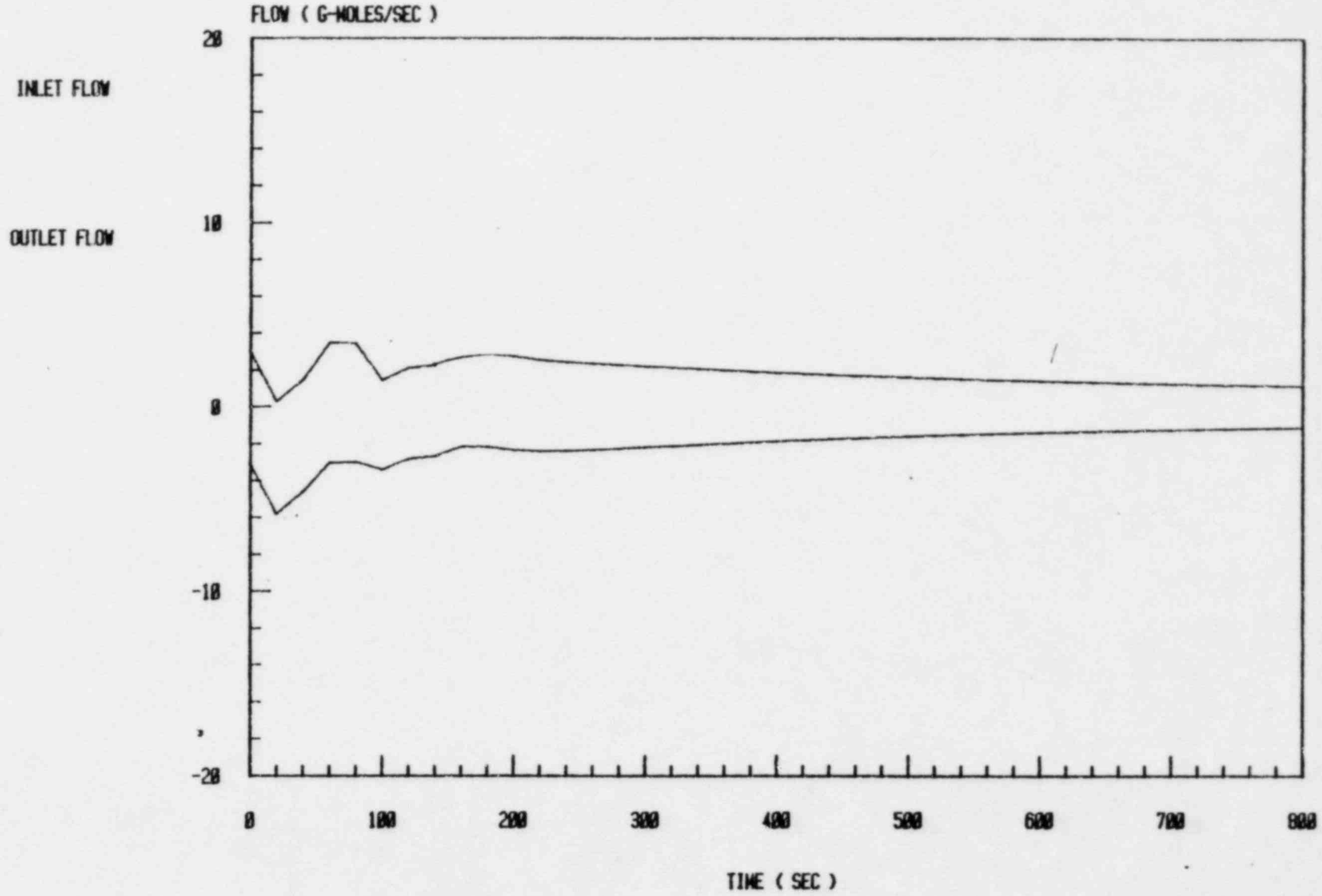
FIRE COMPARTMENT PRESSURE .VS. TIME

Burning of Contaminated Boxes of Rags



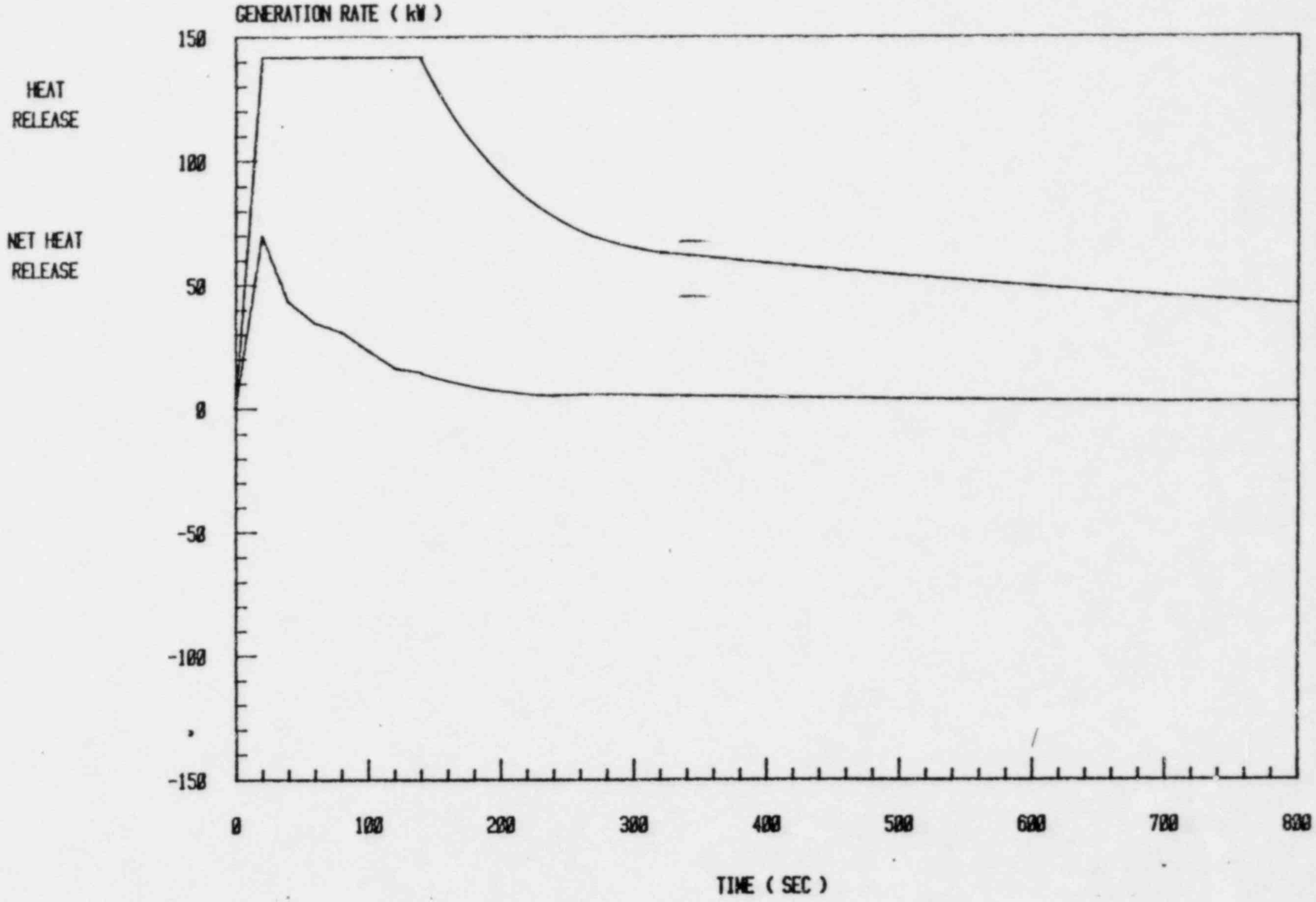
COMPARTMENT FLOW .VS. TIME

Burning of Contaminated Boxes of Rags



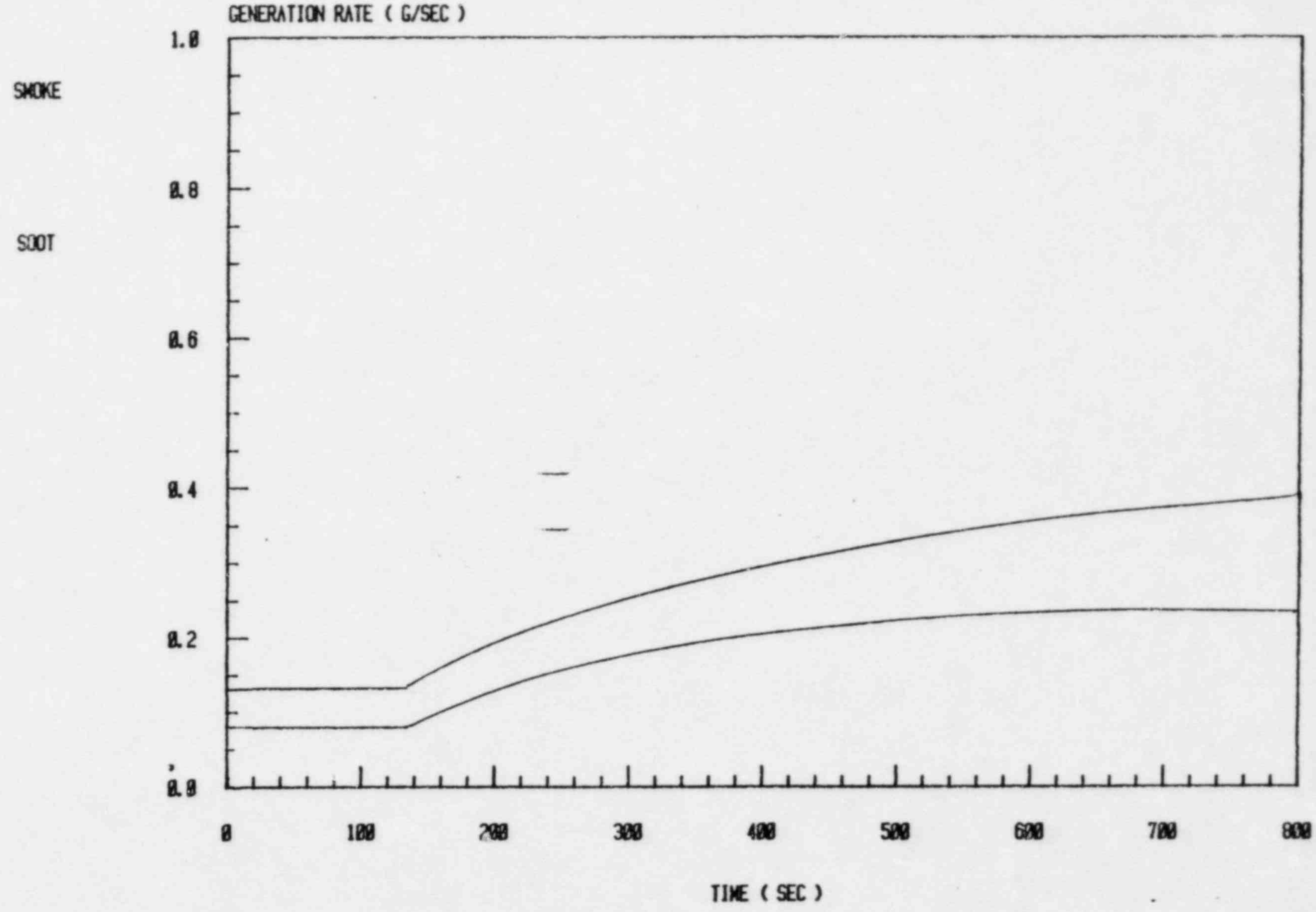
HEAT GENERATION RATE .VS. TIME

Burning of Contaminated Boxes of Rags



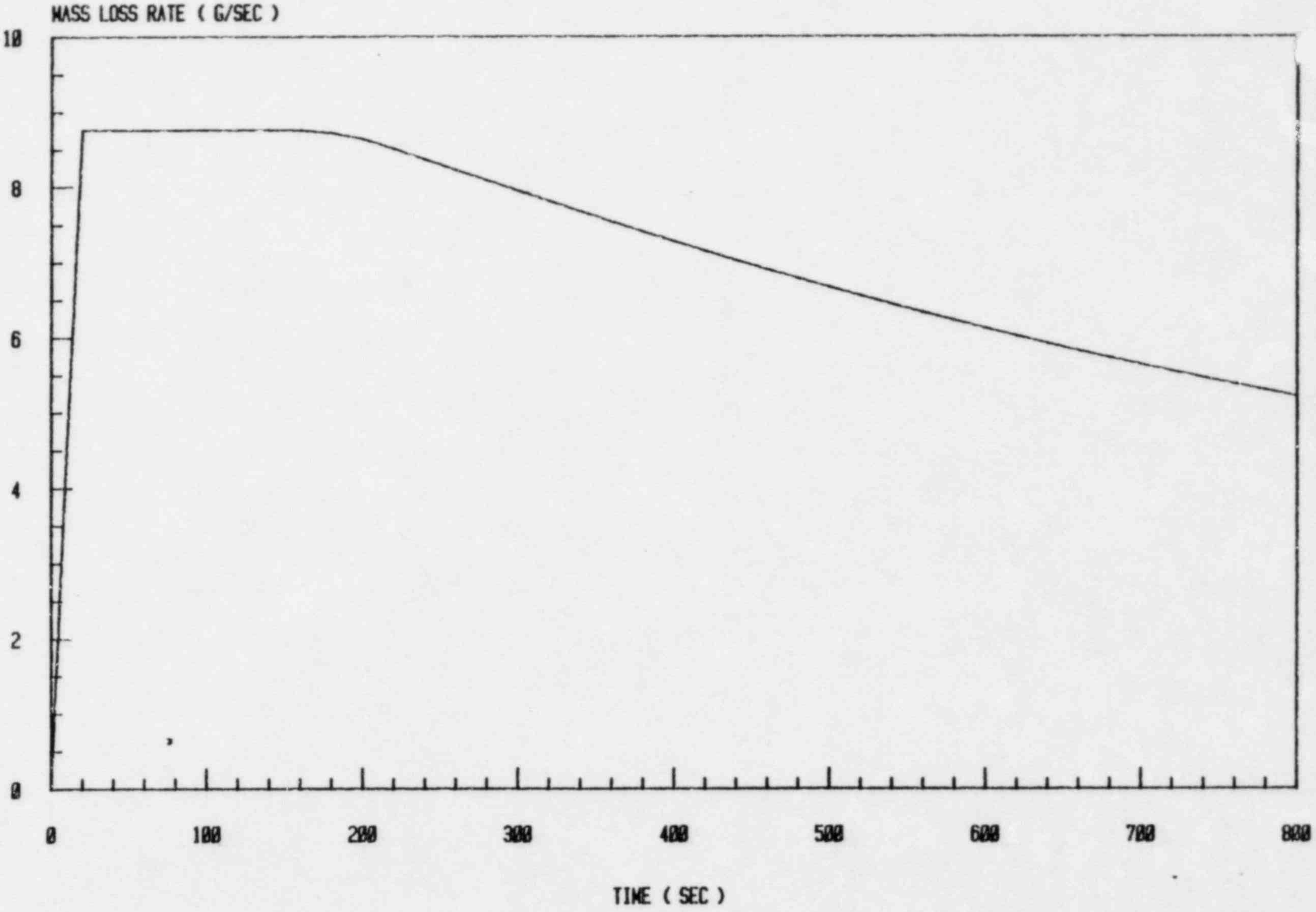
SMOKE AND SOOT GENERATION RATE .VS. TIME

Burning of Contaminated Boxes of Rags



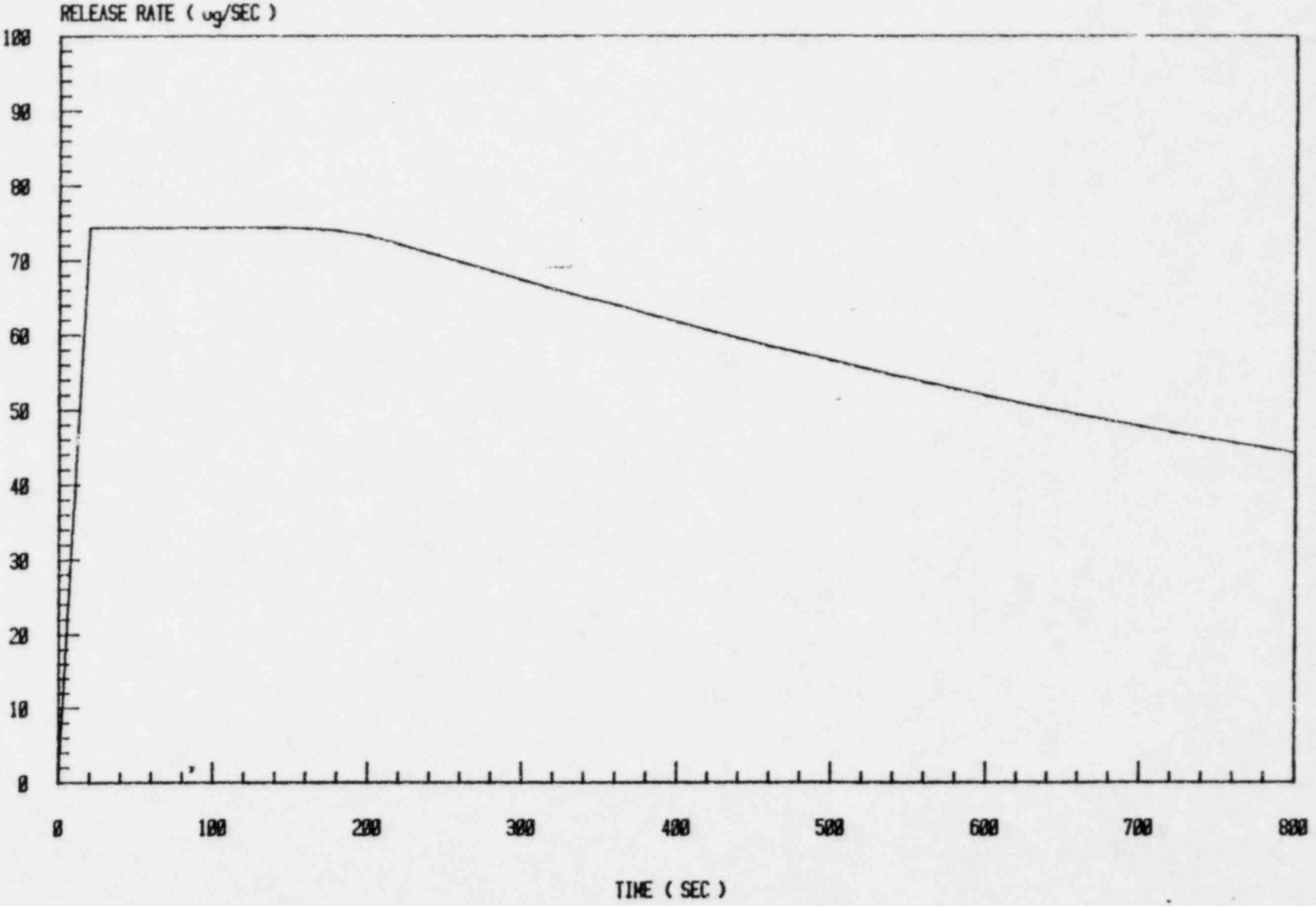
MASS LOSS RATE .VS. TIME

Burning of Contaminated Boxes of Rags



TOTAL UO2 RELEASE RATE .VS. TIME

Burning of Contaminated Boxes of Rags



Experimental Conditions (to simulate approximate fire conditions):

	q''_e (external heat flux)	inlet gas temperature	inlet gas composition
a)	(3 w/cm^2)	Ambient temperature	Normal air composition
b)	(5 w/cm^2)	Ambient temperature	Normal air composition
c)	(7 w/cm^2)	Ambient temperature	Normal air composition
d)	5 w/cm^2	100°C	(normal air composition)
e)	5 w/cm^2	100°C	(reduced O_2; enhanced CO_2/CO)**
f)	5 w/cm^2	(200°C)	Normal air composition
g)	(3 w/cm^2)	Ambient temperature	Normal air composition

** 14% by volume of O_2, 7% CO_2, 0.2% CO and 79% N_2.

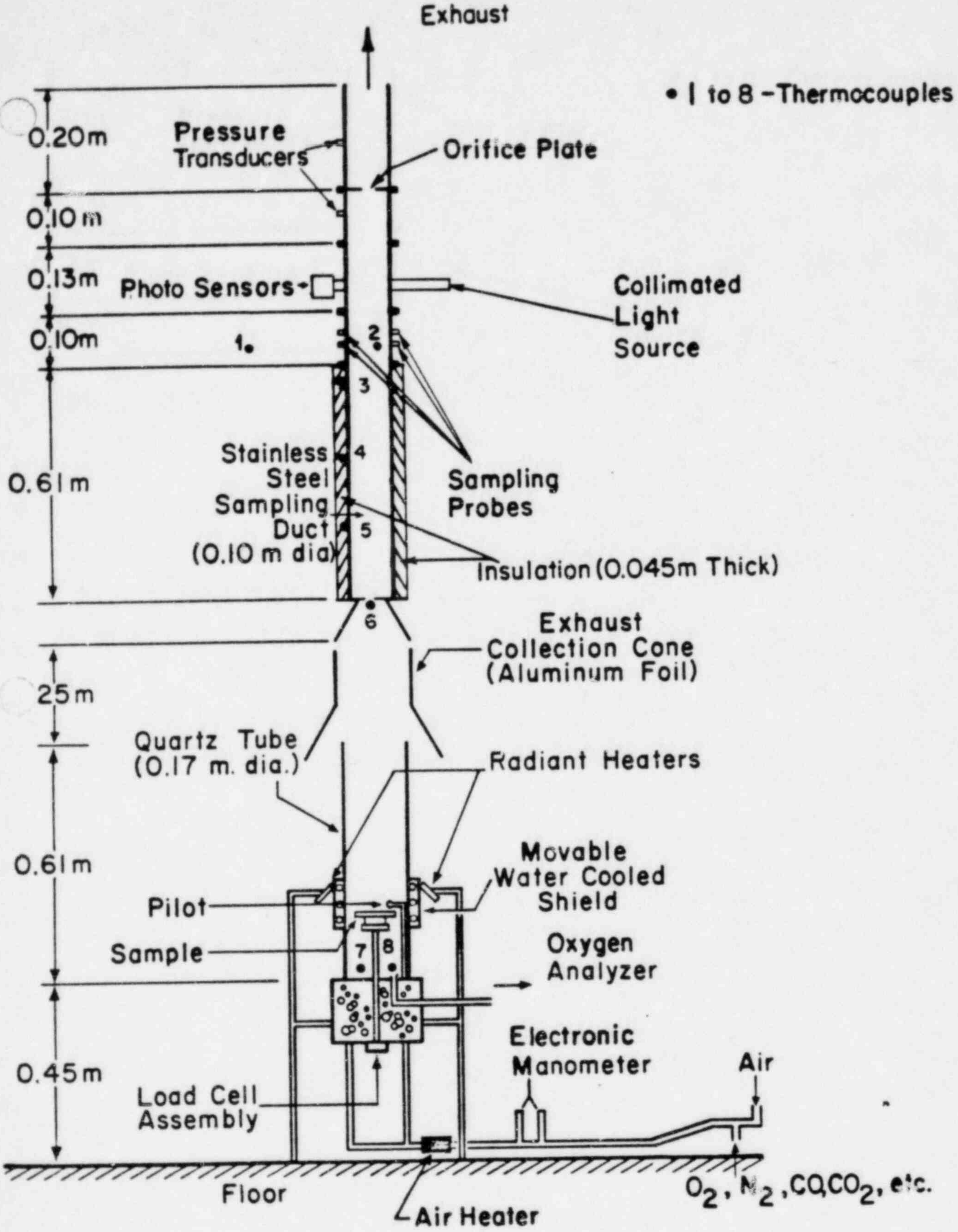

Exhaust
• 1 to 8 -Thermocouples
0.20m
Pressure Transducers
Orifice Plate
0.10m
0.13m
Photo Sensors
Collimated Light Source
0.10m
1
2
3
4
5
6
7
8
Stainless Steel Sampling Duct (0.10 m dia)
Sampling Probes
0.61m
Insulation (0.045m Thick)
Exhaust Collection Cone (Aluminum Foil)
25m
Quartz Tube (0.17 m. dia.)
Radiant Heaters
0.61m
Movable Water Cooled Shield
Pilot
Sample
Oxygen Analyzer
Electronic Manometer
Air
0.45m
Load Cell Assembly
Floor
Air Heater
O_2, N_2, CO, CO_2, etc.

TABLE I

ELEMENTAL COMPOSITION AND HEAT OF COMBUSTION OF MATERIALS USED IN FUEL CYCLE FACILITIES

Combustible	Chemical Formula	Heat of Complete Combustion (kJ/g)
Polymethylmethacrylate (PMMA)	$CH_{1.6}O_{0.4}$	25.2
Polyvinyl Chloride (PVC)	$CH_{1.5}Cl_{0.5}$	16.4
Polystyrene (PS)	CH	39.2
Polychloroprene (PC)	$CH_{1.25}Cl_{0.25}$	27
Cellulose	$CH_{1.67}O_{0.83}$	16.2
Kerosene	$CH_{1.8}$	47.9
Mixture	$CH_{1.56}O_{0.41}Cl_{0.086}$	23.1

TABLE II

STOICHIOMETRIC PRODUCT YIELD (k)

Combustible	k_{CO_2}	k_{CO}	k_{O_2}	k_{HC}	k_{SOOT} (=C)
PMMA	2.2	1.4	1.44	0.08	0.60
PVC	1.42	0.9	1.42	0.19	0.39
PS	3.38	2.15	3.04	0.31	0.92
PC	2.0	1.27	1.91	0.23	0.55
Cellulose	1.63	1.04	1.19	0.25	0.44
Kerosene	3.19	2.03	3.36	0.52	0.87
Mixture	1.90	1.21	1.64	0.27	0.52

Composition of "Typical Mixture"

"Typical Mixture", a representing fraction of combustible materials found in Fuel Cycle Facilities, is defined (by PNL) as follows:

Combustibles	Weight Percent
Polymethylmethacrylate (PMMA)	45
Polyvinyl Chloride (PVC)	8
Cellulosic Material	26
Elastomer*	18
Polystyrene (PS)	1
Hydraulic Fluids*	2
	100%

*For elastomer - use neoprene
For hydraulic fluids - substitute with kerosene

TABLE III

MASS LOSS RATE AND GENERATION RATES OF HEAT AND CHEMICAL COMPOUNDS AT 50 kW/m^2 IN AMBIENT AIR

Combustible	$\dot{m}''_b$(g/m^{2}s)	$\dot{G}''_{CO_2}$(g/m^{2}s)	$\dot{G}''_{CO}$(g/m^{2}s)	$\dot{G}''_{HC}$(g/m^{2}s)	$\dot{Q}_A$(kW/m^2)	$\dot{Q}_C$(kW/m^2)	$\dot{Q}_R$(kW/m^2)
PMMA	34	70	.4	.02	820	560	260
PVC	22.7	14.4	1.6	0.5	175	145	40
PS	40	75	3.3	1.6	930	325	615
PC	30	21.8	2.5	1.25	333	120	213
Cellulose	17.5	25	.04	.01	290	190	100
Kerosene[a]	11	31	.32	.01	480	300	180
Mixture	18.0	30.0	0.5	0.14	300	200	100

---

[a] fuel burned in Pyrex dish

TABLE IV

FRACTIONAL YIELDS AND COMBUSTION EFFICIENCY AT 50 kW/m^2 IN AMBIENT AIR

Combustible	$\dot{f}_{CO_2}$	$\dot{f}_{CO}$	$\dot{f}_{HC}$	χ_A	χ_C	χ_R
PMMA	.91	.01	-[a]	.95	.65	.30
PVC	.44	.08	.22	.47	.40	.07
PS	.68	.044	.16	.71	.22	.51
PC	.45	.08	.18	.48	.15	.37
Cellulose	1.0	-[a]	-[a]	1.0	.63	.35
Kerosene[b]	.88	.014	-[a]	.91	.57	.34
Mixture	0.74	0.02	0.01	0.68	0.46	0.22

---

[a] values are less than 0.002

[b] fuel burned in Pyrex dish

TABLE V

MASS LOSS RATE AND GENERATION RATES OF HEAT AND CHEMICAL COMPOUNDS OF MIXTURE IN AMBIENT AIR

$\dot{q}''_e$ (kW/m^2)	$\dot{m}''_b$ (g/m^{2}s)	$\dot{G}''_{CO_2}$ (g/m^{2}s)	$\dot{G}''_{CO}$ (g/m^{2}s)	$\dot{C}''_{HC}$ (g/m^{2}s)	$\dot{Q}_A$ (kW/m^2)	$\dot{Q}_C$ (kW/m^2)	$\dot{Q}_R$ (kW/m^2)
30	14	18	0.3	0.06	220	150	70
50	18	30	0.5	0.14	300	200	100
66.5	22	28	1.3	0.3	400	325	75

TABLE VI

FRACTIONAL YIELDS AND COMBUSTION EFFICIENCY OF MIXTURE IN AMBIENT AIR

$\dot{q}''_e$(kW/m^2)	$\dot{f}_{CO_2}$	$\dot{f}_{CO}$	$\dot{f}_{HC}$	χ_A	χ_C	χ_R
30	0.74	0.02	0.01	0.68	0.46	0.22
50	0.79	0.02	0.01	0.72	0.48	0.24
66.5	0.79	0.02	0.01	0.78	0.64	0.15

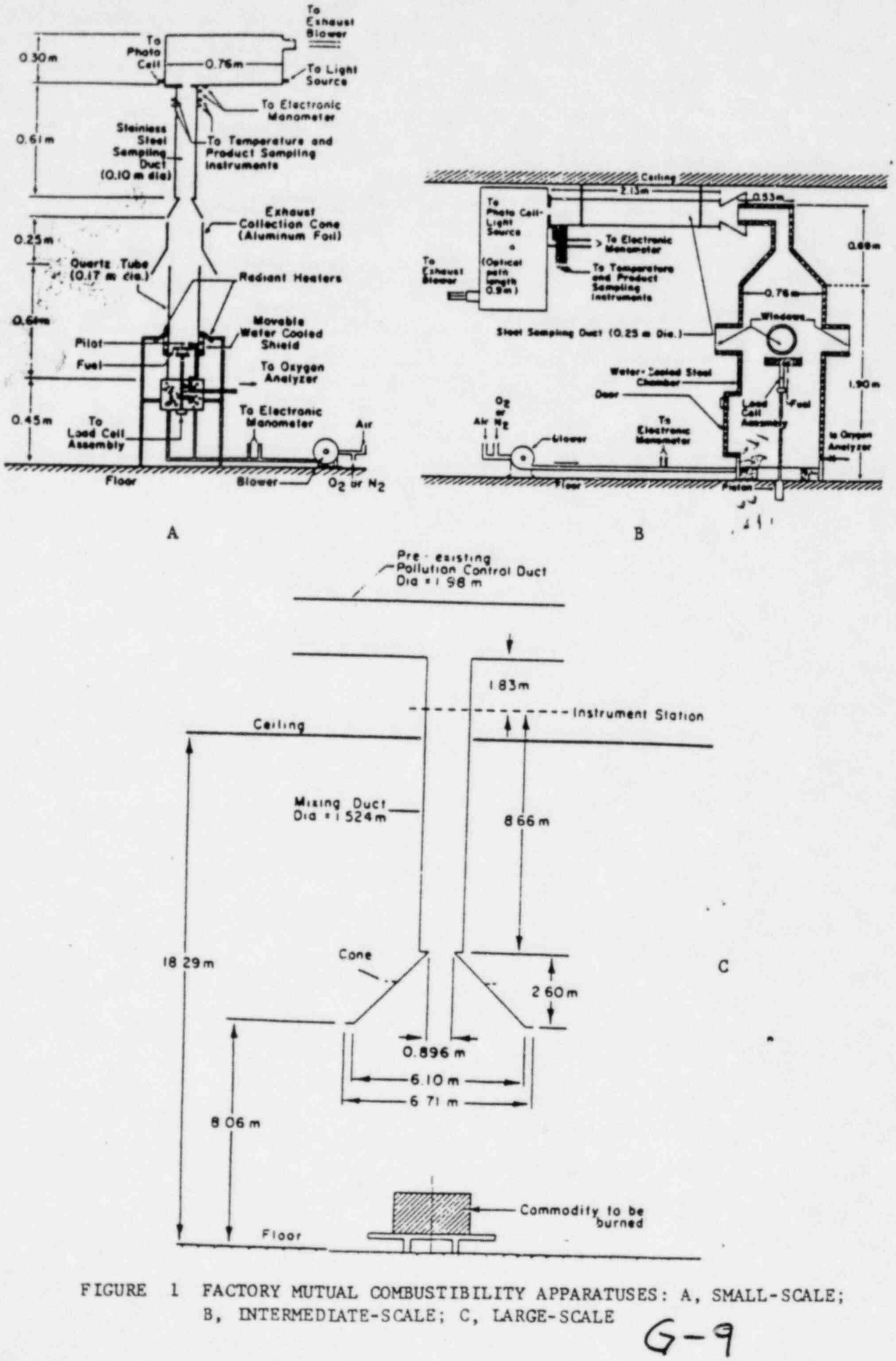


FIGURE 1 FACTORY MUTUAL COMBUSTIBILITY APPARATUSES: A, SMALL-SCALE; B, INTERMEDIATE-SCALE; C, LARGE-SCALE

TABLE II

ASYMPTOTIC VALUES OF FUEL GENERATION RATES IN POOL FIRES

	Measured in Large-Scale Apparatus		Small-Scale Apparatus-Radiation-Scaling	
	Pool Area (m^2)	$\dot{G}''_{fuel,comb}$ (g/m^2s)	Pool Area (m^2)	$\dot{G}''_{fuel,comb}$ (g/m^2s)
Methanol	2.37	20	0.008	20
PMMA	2.37	30	0.008	28
PS	0.93	34	0.008	38
Heptane	1.17	66	0.008	≥ 63

TABLE III

Y_j VALUES FOR OVERVENTILATED POOL FIRES

Fuel	Pool Area (m^2)	CO_2	CO	HCN
Methanol	4.68[a]	1.29	< 0.001	-
	2.32[a]	1.30	< 0.001	-
	0.008[c]	1.32	< 0.001	-
PMMA	2.37[a]	2.11	0.008	-
	0.073[b]	2.10	0.010	-
	0.008[c]	2.15	0.011	-
Heptane	0.93[a]	2.83	0.015	-
	0.008[c]	2.80	0.034	-
Rigid Polyurethane Foam	~ 7[a]	1.50	0.027	0.010
	0.008[c]	1.51	0.036	0.012

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[a] From large-scale combustibility apparatus

[b] From intermediate-scale combustibility apparatus

[c] From small-scale combustibility apparatus

TABLE IV

HEAT OF COMBUSTION OF FUELS FOR VARIOUS FUEL SIZES FOR OVERVENTILATED CONDITIONS

Fuel	Apparatus	Pool Area (m^2)	Heat of Combustion (kJ/g)		
			Actual	Convective	Radiative
Rigid Polyurethane Foam	Large	~ 7	16.4	10.8	5.6
	Small	0.008	15.8	6.5	9.3
Methanol	Large	4.68	18.7	15.6	3.1
		2.32	18.8	15.7	3.1
	Small	0.008	19.4	17.1	2.3
PMMA	Large	2.37	24.2	15.8	8.4
	Intermediate	0.073	23.8	14.9	8.9
	Small	0.008	24.4	17.9	6.5
Hydrocarbon Transformer Fluid - A	Large	2.37	35.6	23.8	11.8
	Small	0.008	38.2	25.1	13.1
Heptane	Large	0.93	41.2	26.8	14.4
	Small	0.008	37.7	19.9	17.8

TABLE V

GENERATION RATES OF COMPOUNDS FROM A RIGID POLYURETHANE FOAM FIRE[a]

	Generation Rate (g/m^2s)			
	CO_2	CO	Hydrocarbons[b]	HCN
Predicted[c]	37	0.86	0.07	0.29
Measured[d]	34	0.57	0.07	0.21

---

[a] ~ 14 m^2 of fuel area was involved in the fire.

[b] total gaseous hydrocarbons

[c] from radiation-scaling of $\dot{G}''_{fuel,comb}$ and Y_j values for normal air in the small-scale apparatus

[d] in the large-scale apparatus.

TABLE VI

HEAT RELEASE RATES FOR VARIOUS FUELS

	Heat Release Rate (kW/m^2)					
	Actual		Convective		Radiative	
Fuel	Measured[a]	Predicted[b]	Measured[a]	Predicted[b]	Measured[a]	Predicted[b]
Methanol	380	390	310	340	70	50
PMMA	730	680	470	500	260	180
Heptane	2700	2400	1800	1250	900	1150
Hydrocarbon Fluids (Commercial)						
A	1000	1060	600	700	400	360
B	1070[c]	1070	650[c]	720	420	350
C	1100[c]	910	690[c]	640	410	270
D	1060[c]	1100	700[c]	750	360	350
Rigid Polyurethane Foam	547	550	334	230	213	320

---

[a] In the FM large-scale combustibility apparatus.

[b] From FM small-scale combustibility apparatus using radiation-scaling for $\dot{G}''_{fuel,comb}$ and H_i values in normal air.

[c] From the technique described in ref 31.

ORGANIZATIONS/INDIVIDUALS INVOLVED IN LOS ALAMOS FIRE RESEARCH EFFORT

- New Mexico State University
  - Fluid/Thermal Test Facility
    (P. R. Smith, D. L. Fenton, C. I. Ricketts)
- Lawrence Livermore National Laboratory
  - Fire Test Facility
    (N. Alvares)
- University of California, Berkeley
  - Combustion Theory
    (P. Pagni)
- California Institute of Technology
  - Compartment Fire Modeling
    (E. Zukoski)
- Harvard
  - Compartment Fire Modeling
    (H. Mitler)

Los Alamos

LOS ALAMOS

FIRE EXPERIMENTATION PROGRAM

New Mexico State University

- Filter Plugging Data
- Smoke Depletion/Modification Data
- Code Verification

Lawrence Livermore National Laboratory

- Idealized Compartment Fire Data
- Duct Heat Transfer Data
- Smoke Depletion/Modification
- Code Module Development

Los Alamos

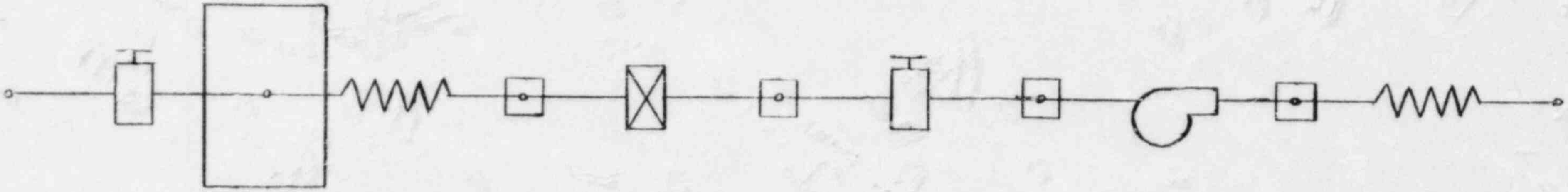
NRC PROBLEMS WITH FIRAC

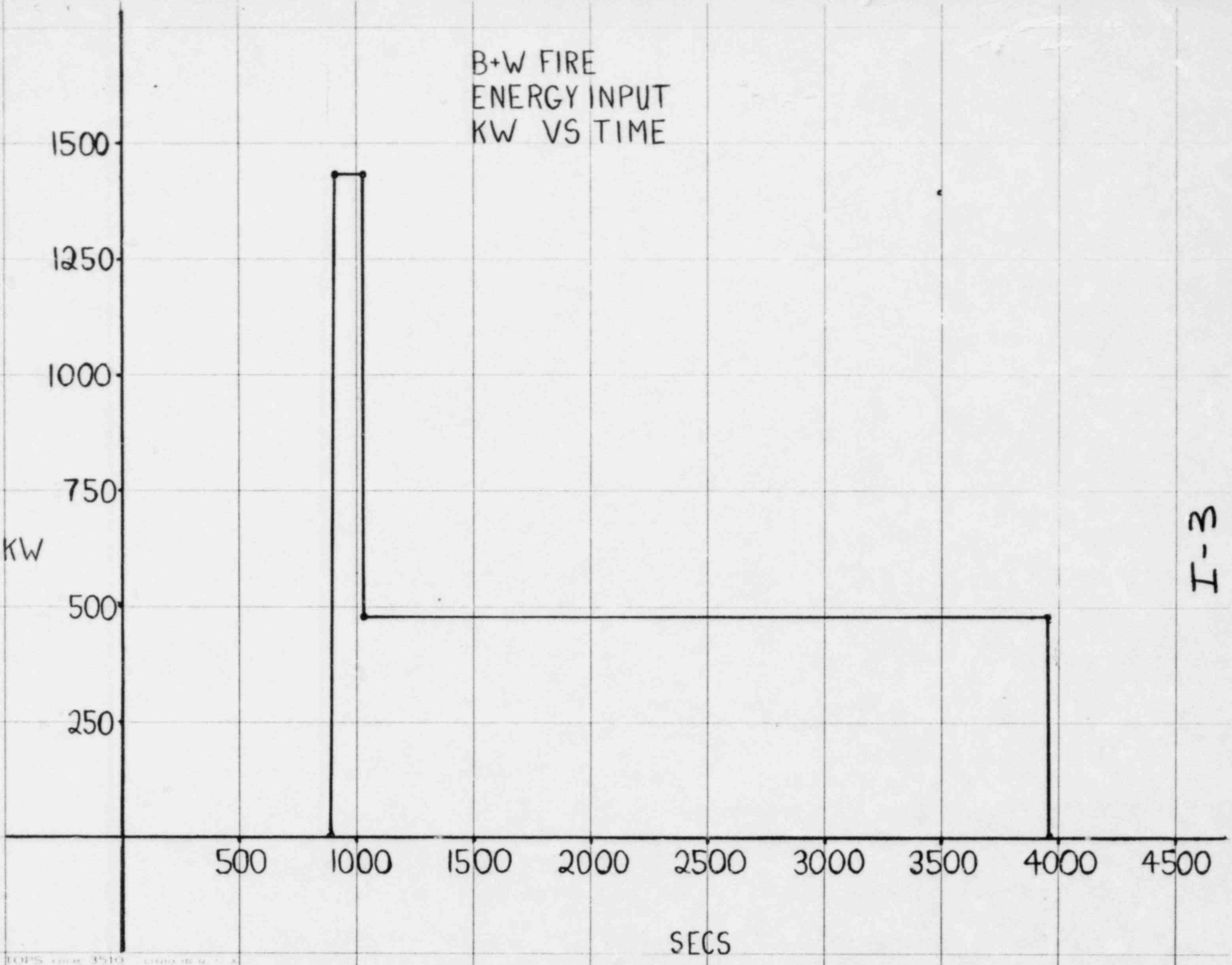
- EXCESSIVE TEMPERATURE IN BURN ROOM
- CONSERVATION OF MASS
- INCORRECT VOLUMETRIC ADDITION

TYPICAL FUEL CYCLE FACILITY LICENSING PROBLEM

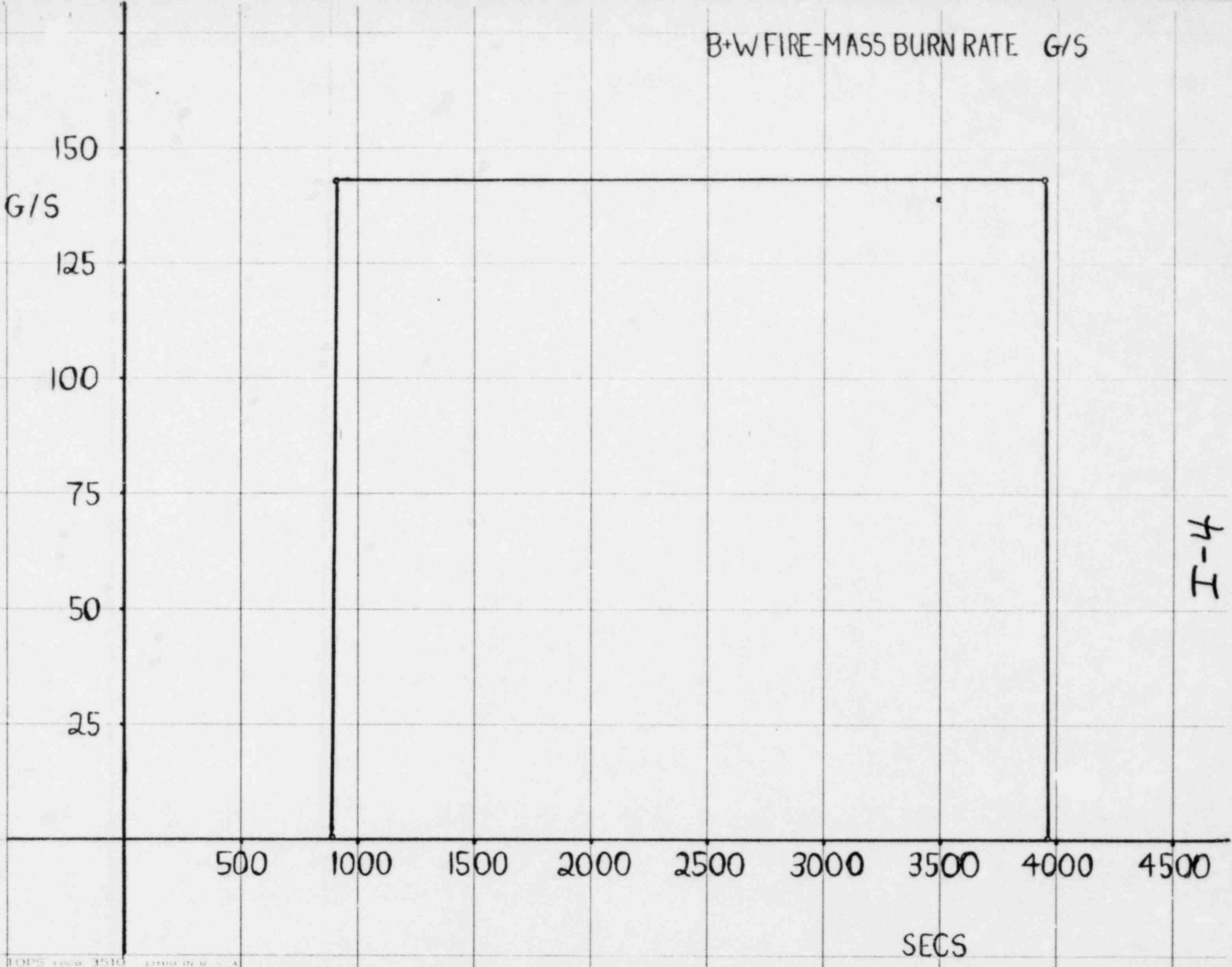
- <u>FACILITY</u>: Babcock and Wilcox

- <u>Scenario</u>: Three large crates of low level waste (contaminated paper and cellulose) catch fire. The fire burns until all the fuel has been consumed burning uncontrolled for .85 hours, in a large storage room (22425 cu. ft.). All source terms were determined through the use of methods described in the FIRAC Users Manual and the Accident Analysis Handbook.

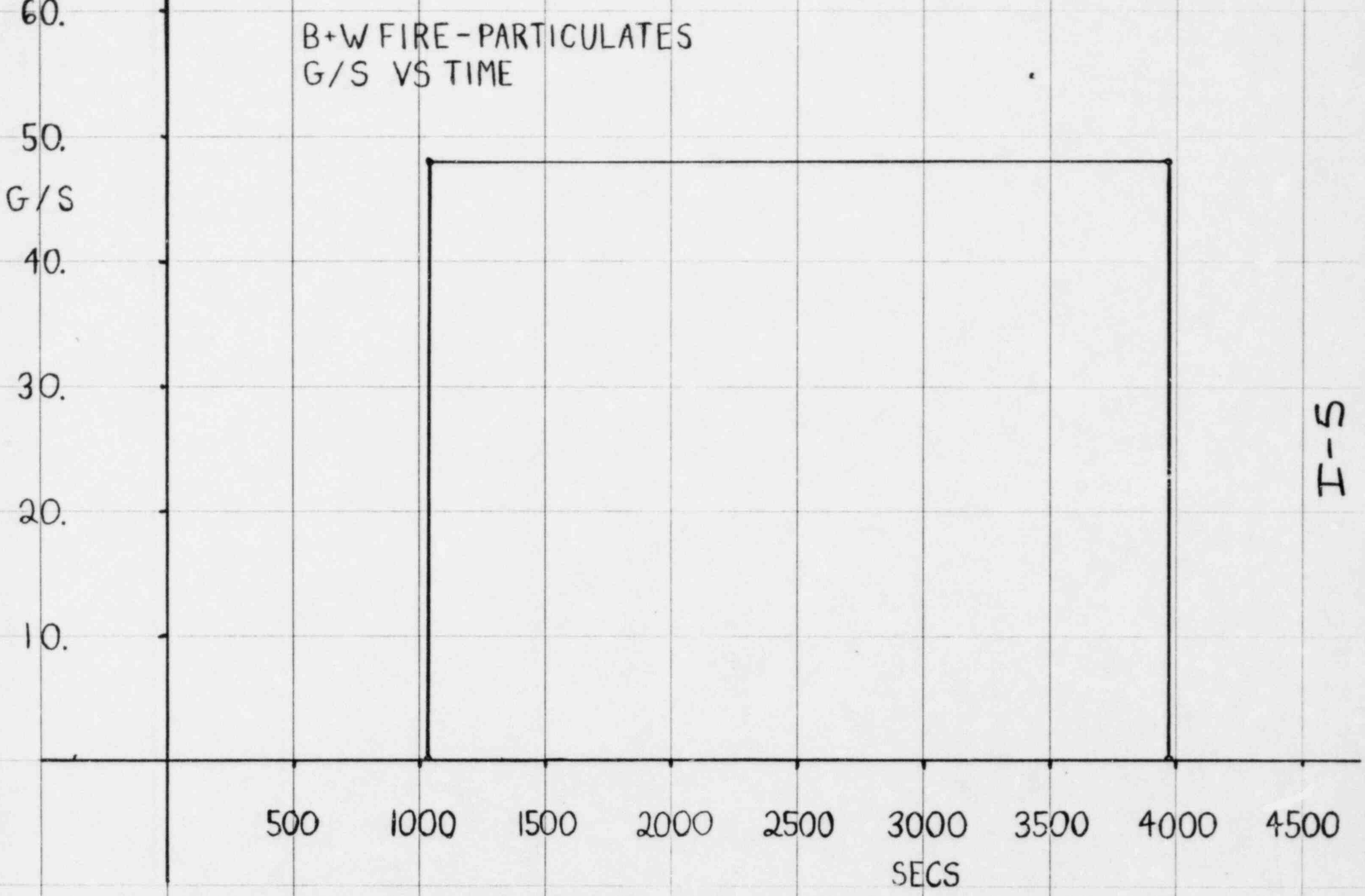



B+W FIRE
ENERGY INPUT
KW VS TIME

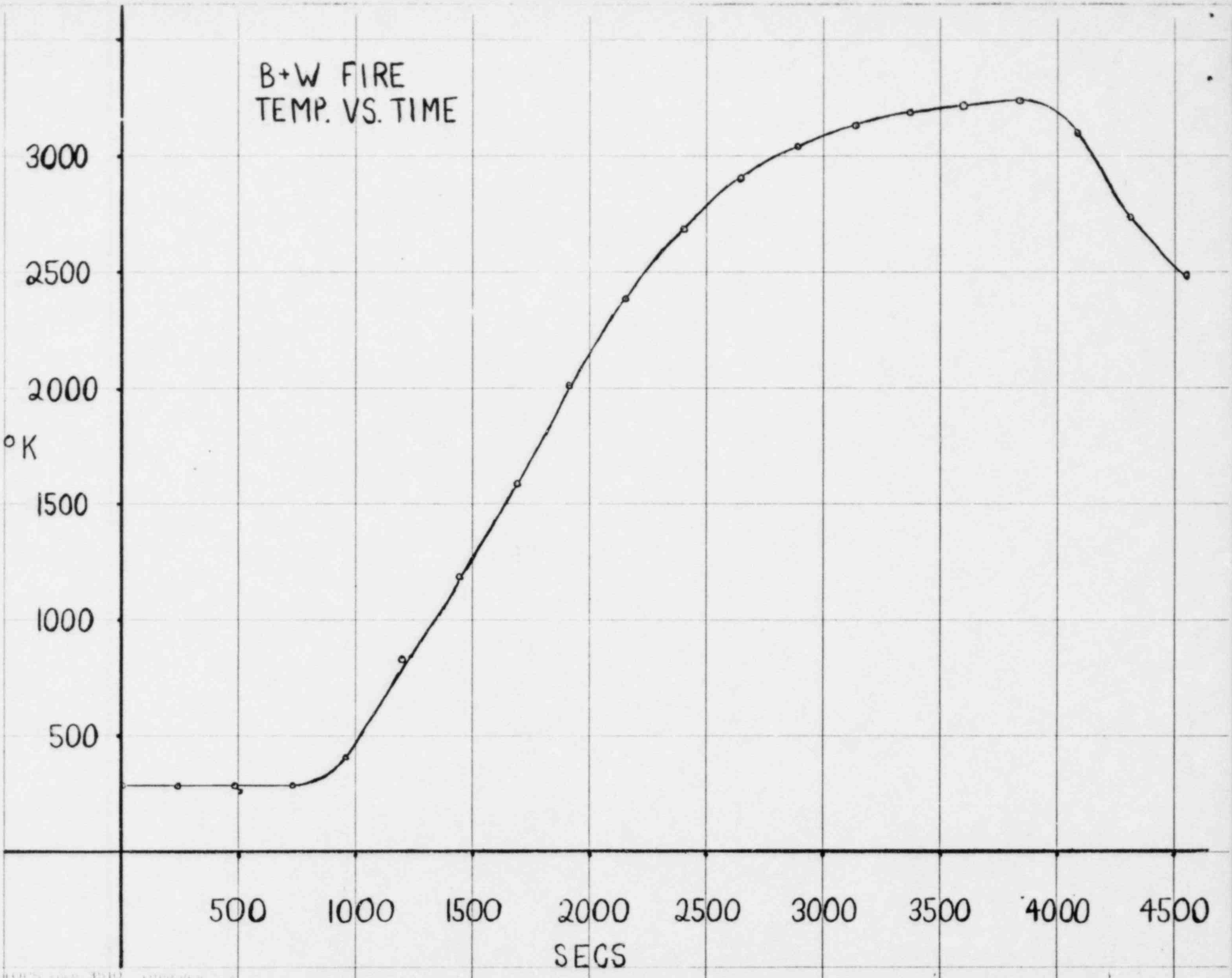
I-3



B+W FIRE-MASS BURN RATE G/S


B+W FIRE-PARTICULATES
G/S VS TIME
G/S
60.
50.
40.
30.
20.
10.
500
1000
1500
2000
2500
3000
3500
4000
4500
SECS

I-6



B+W FIRE
TEMP. VS. TIME

ADDITIONAL FIRAC RUNS

$\dot{Q}$ (KW)	$\dot{M}$ (g/s)	FACILITY TYPE	BURN TIME (Hrs)	MAXIMUM TEMP °K	ACHIEVED STEADY STATE	PARTICULATES PRESENT
25.0	10.0	S.F.	10.000	441.5°	NO	YES
25.0	10.0	R.F.	10.000	T > 344.0°	NO	YES
25.0	10.0	S.F.	10.000	315.0°	YES	NO
25.0	10.0	R.F.	10.000	312.8°	YES	NO
25.0	2.778×10^{-1}	S.F.	10.000	472.3°	NO	YES
50.0	10.0	S.F.	5.000	465.6°	NO	YES
50.0	5.556×10^{-1}	S.F.	5.000	482.2°	NO	YES
100.0	10.0	S.F.	2.500	597.7°	NO	YES
100.0	1.111	S.F.	2.500	622.4	NO	YES
200.0	10.0	S.F.	1.250	699.9	NO	YES
200.0	2.222	S.F	1.250	711.3	NO	YES

Definitions:

$\dot{M}$ = mass burning rate (g/s)

$\dot{Q}$ = energy input (KW)

T Ambient = 294.3 °K

S.F = Simple Facility

RF = Representative Facility

CONSERVATION OF MASS PROBLEM

MASS INJECTED	$\dot{Q}$ (KW)	$\dot{M}$ (g/s)	$\dot{G}$ (g/s)	MASS ON FILTERS (Kg)	MASS AIRBORN (Kg)	TOTAL (Kg)	ΔM (Kg)	% Err
0.1	25	2.778×10^{-1}	2.778×10^{-3}	.04664	.07060	.11724	.01724	17.24%
1.0	25	2.778×10^{-1}	2.778×10^{-2}	.4659	.7059	1.1718	.1718	17.18%
10.0	25	2.778×10^{-1}	2.778×10^{-1}	4.664	7.060	11.724	1.724	17.24%
0.1	50.0	5.556×10^{-1}	5.556×10^{-3}	.04436	.07510	.11946	.01946	19.46%
1.0	50.0	5.556×10^{-1}	5.556×10^{-2}	.4426	.7507	1.1933	.1933	19.33%
10.0	50.0	5.556×10^{-1}	5.556×10^{-1}	4.436	7.510	11.946	1.946	19.46%
0.1	100.0	1.111	1.111×10^{-2}	.04037	.06913	.10950	.00950	9.50%
1.0	100.0	1.111	1.111×10^{-1}	.4020	.6905	1.0925	.0925	9.25%
10.0	100.0	1.111	1.111	4.027	6.913	10.950	.950	9.50%
0.1	200.0	2.222	2.222×10^{-2}	.03823	.06643	.10466	.00466	4.66%
1.0	200.0	2.222	2.222×10^{-1}	.3794	.6628	1.0422	.0422	4.22%
10.0	200.0	2.222	2.222	3.823	6.643	10.466	.466	4.66%

Definitions:

$\dot{Q}$ = Energy Input (KW)

$\dot{M}$ = Mass Burning Rate (g/s)

$\dot{G}$ = Particulate Injection Rate (g/s)

TOTAL = MASS ON FILTERS + MASS AIRBORNE

ΔM = TOTAL − INJECTED

$$\% \text{ Err} = \frac{\Delta M}{\text{INJECTED}} \times 100$$

CONSERVATION OF MASS PROBLEM II

KG INJECTED	Q (KW)	M (g/s)	$\dot{G}$ (g/s)	MASS ON FILTERS (KG)	MASS AIRBORN (KG)	TOTAL (KG)	ΔM (KG)	% Err
0.1	25.0	10.0	2.778×10^{-3}	.04595	.06838	.11433	.01433	14.33%
1.0	25.0	10.0	2.778×10^{-2}	.4590	.6837	1.1427	.1427	14.27%
10.0	25.0	10.0	2778×10^{-1}	4.595	6.838	11.433	1.433	14.33%
0.1	50.0	10.0	5.556×10^{-3}	.04395	.07383	.11778	.01778	17.78%
1.0	50.0	10.0	5.556×10^{-2}	.4386	.7380	1.1766	.1766	17.66%
10.0	50.0	10.0	5.556×10^{-1}	4.395	7.383	11.778	1.778	17.78%
0.1	100.0	10.0	1.111×10^{-2}	.04032	.06885	.10917	.00917	9.17%
1.0	100.0	10.0	1.111×10^{-1}	.4016	.6878	1.0894	.0894	8.94
10.0	100.0	10.0	1.111	4.032	6.885	10.917	.917	9.17
0.1	200.0	10.0	2.222×10^{-2}	.03820	.06636	.10456	.00456	4.56%
1.0	200.0	10.0	2.222×10^{-1}	.3791	.6620	1.0411	.0411	4.11%
10.0	200.0	10.0	2.222	3.820	6.636	10.456	.456	4.56%

Definitions:

$\dot{Q}$ = Energy Input (KW)

ΔM = TOTAL - INJECTED

$\dot{M}$ = Mass Burning Rate (g/s)

% Err = $\frac{\Delta M}{\text{INJECTED}} \times 100$

$\dot{G}$ = Particulate Injection Rate (g/s)

TOTAL = MASS ON FILTERS + MASS AIRBORNE

INCORRECT VOLUMETERIC ADDITION

- FIRAC ASSUMPTIONS
  - BURN PRODUCTS = AIR
  - MASS OF "AIR" INJECTED = MASS OF FUEL BURNED
  - VOLUME OF "AIR" INJECTED EQUIVALENT TO MASS OF "AIR" INJECTED

- ACTUAL VOLUME INJECTED DEPENDS ON CHEMISTRY OF FIRE
  - $C + O_2 \dashrightarrow CO_2$

    1 MOLE OF BURN PRODUCTS PRODUCED FOR EACH MOLE OF O_2 CONSUMED
  - $CH_4 + 2O_2 \dashrightarrow 2H_2O + CO_2$

    1.5 MOLES OF BURN PRODUCTS PRODUCED FOR EACH MOLE OF O_2 CONSUMED
- SIGNIFICANCE OF PROBLEM?

REMAINING ISSUES

- IMPLICATIONS FOR TORAC AND EXPAC
- IS LEVEL ONE FIRAC WORKABLE WITHOUT INCORPORATION OF A FIRE COMPARTMENT MODEL?
- FIRIN 1 OUTPUT $\overset{?}{=}$ FIRAC INPUT