S

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 660156

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental ☐	CD Eggen, FFS, B4-40, 376-5450	☒ Yes ☐ No	~~04/25/00~~ 8/14/00
Direct Revision ☒	6. Project Title/No./Work Order No.	7. Bldg./Sys./Fac. No.	8. Approval Designator
Change ECN ~~☒~~	Cold Vacuum Drying Facility Fire Hazard Analysis	CVDF 142K	SFPQ S[N]
Temporary ☐	9. Document Numbers Changed by this ECN (includes sheet no. and rev.)	10. Related ECN No(s).	11. Related PO No.
Standby ☐	(See Block 13a)	N/A	N/A
Supersedure ☐			
Cancel/Void ☐			

12a. Modification Work	12b. Work Package No.	12c. Modification Work Completed	12d. Restored to Original Condition (Temp. or Standby ECNs only)
☐ Yes (fill out Blk. 12b) ☒ No (NA Blks. 12b, 12c, 12d)	N/A	N/A Design Authority/Cog. Engineer Signature & Date	N/A Design Authority/Cog. Engineer Signature & Date

13a. Description of Change — 13b. Design Baseline Document? ☒ Yes ☐ No

Update to the Fire Hazard Analysis (FHA) SNF-4268 Rev 0. GS

To account for higher allowable temperatures of safety class equipment.
Update the analysis to incorporate completed construction.
Add operation procedures and training.
Update status of recommendations.

USQ: CVD-00-1428 mm 8/30/00

14a. Justification (mark one)	14b. Justification Details
Criteria Change ☒ Design Improvement ☐ Environmental ☐ Facility Deactivation ☐ As-Found ☐ Facilitate Const. ☐ Const. Error/Omission ☐ Design Error/Omission ☐	The SEL is being updated to allow the safe temperature to be increased from 95 degrees F to 115 degrees F. This change in the acceptable distances is noted in SNF-4942 Rev 1. This revision also update the status of construction, operations and action taken to complete recommendations. DESIGN VERIFICATION METHOD FOR GS IS PER INFORMAL REVIEW IN ACCORDANCE WITH EN 6-027-01. DOCUMENTATION OF THIS REVIEW IS ACCOMPLISHED BY SIGNATURES ON PAGE 2 OF THIS ECN. HMC 8/14/00

15. Distribution (include name, MSIN, and no. of copies)

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SEP 6 2000
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ENGINEERING CHANGE NOTICE

1. ECN (use no. from pg. 1): 660156

16. Design Verification Required	17. Cost Impact — ENGINEERING	17. Cost Impact — CONSTRUCTION	18. Schedule Impact (days)
[X] Yes	Additional [ ] $ N/A	Additional [ ] $ N/A	Improvement [ ] N/A
[ ] No	Savings [ ] $	Savings [ ] $	Delay [ ]

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	[ ]	Seismic/Stress Analysis	[ ]	Tank Calibration Manual	[ ]
Functional Design Criteria	[ ]	Stress/Design Report	[ ]	Health Physics Procedure	[ ]
Operating Specification	[ ]	Interface Control Drawing	[ ]	Spares Multiple Unit Listing	[ ]
Criticality Specification	[ ]	Calibration Procedure	[ ]	Test Procedures/Specification	[ ]
Conceptual Design Report	[ ]	Installation Procedure	[ ]	Component Index	[ ]
Equipment Spec.	[ ]	Maintenance Procedure	[ ]	ASME Coded Item	[ ]
Const. Spec.	[ ]	Engineering Procedure	[ ]	Human Factor Consideration	[ ]
Procurement Spec.	[ ]	Operating Instruction	[ ]	Computer Software	[ ]
Vendor Information	[ ]	Operating Procedure	[ ]	Electric Circuit Schedule	[ ]
OM Manual	[ ]	Operational Safety Requirement	[ ]	ICRS Procedure	[ ]
FSAR/SAR	[ ]	IEFD Drawing	[ ]	Process Control Manual/Plan	[ ]
Safety Equipment List	[ ]	Cell Arrangement Drawing	[ ]	Process Flow Chart	[ ]
Radiation Work Permit	[ ]	Essential Material Specification	[ ]	Purchase Requisition	[ ]
Environmental Impact Statement	[ ]	Fac. Proc. Samp. Schedule	[ ]	Tickler File	[ ]
Environmental Report	[ ]	Inspection Plan	[ ]	None	[X]
Environmental Permit	[ ]	Inventory Adjustment Request	[ ]		[ ]

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number/Revision
N/A	N/A	N/A

21. Approvals

	Signature	Date
Design Authority	G. SINGH [signature]	8/14/00
Cog. Eng.		
Cog. Mgr.	C.S. HALLER [signature]	8/5/00
QA	H. CHAFIN Hank M. Chafin	8/14/00
Safety	J. BREHM for Mark A. Hedahl	9/2/00
Environ.		
Other SPP	David W. Mertz (INDEPENDENT REVIEWER) (DAVID MERTZ)	9-5-00

	Signature	Date
Design Agent	C.D. EGGEN [signature]	4/25/00
PE		
QA		
Safety		
Design		
Environ.		
Other		

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

DISTRIBUTION SHEET

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Project Title/Work Order		Date 9/5/00
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		ECN No. 660156

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SNF-4268
Revision 1

Fire Hazard Analysis for the Cold Vacuum Drying Facility

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford
P.O. Box 1000
Richland, Washington

Approved for public release; further dissemination unlimited

SNF-4268
Revision 1
ECN 660156

Fire Hazard Analysis for the Cold Vacuum Drying Facility

Project No: W-441 Division: SNF

G. Singh
Fluor Hanford, Inc.

Date Published
August 2000

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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Rev 1

Total Pages: 343

SNF-4268, Rev. 1

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RECORD OF REVISION

(1) Document Number
SNF-4268

Page 1

(2) Title
W-441, Fire Hazard Analysis for the Cold Vacuum Drying Facility

Change Control Record

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release	
		(5) Cog. Engr.	(6) Cog. Mgr. Date
0	(7) EDT 626881, Initial Release		
1 RS	ECN 660156, Update the Status of Construction, Operations & Action Taken to Complete Recommend.	G. Singh 9/5/00	C. Haller 9/5/00

FIRE HAZARD ANALYSIS

for the

COLD VACUUM DRYING FACILITY

Fluor Hanford Inc.

August 2000

Revised by

Clarence D. Eggen, PE

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TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

CSB	Canister Storage Building
CVDF	Cold Vacuum Drying Facility
DBA	Design basis accident
DBE	Design basis earthquake
DBF	Design basis fire
DOE	U.S. Department of Energy
DRD	Design Requirements Document
FHA	Fire Hazard Analysis
FM	FM Global
HVAC	Heating, ventilating, and air conditioning
LEL	Lower explosive limit
MCFL	Maximum credible fire loss
MPFL	Maximum probable fire loss
MCO	Multi-canister overpack
MCS	Monitoring and control system
NFPA	National Fire Protection Association
PWC	Process water conditioning
RGM	Residual gas monitoring
RL	Richland Operations Office (DOE)
RLID	RL Implementing Directive
SAR	Safety Analysis Report
SCIC	Safety Class instrumentation and control
SCHe	Safety Class helium
SNF	Spent Nuclear Fuel
SSC	Structures, systems, and components
TWS	Tempered water (annulus) system
UBC	Uniform Building Code
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
VPS	Vacuum and purge system

Fire Hazard Analysis for the Cold Vacuum Drying Facility

1.0 INTRODUCTION

The CVDF is a nonreactor nuclear facility that will process the Spent Nuclear Fuels (SNF) presently stored in the 105-KE and 105-KW SNF storage basins. Multi-canister overpacks (MCOs) will be loaded (filled) with K Basin fuel transported to the CVDF. The MCOs will be processed at the CVDF to remove free water from the fuel cells (packages). Following processing at the CVDF, the MCOs will be transported to the CSB for interim storage until a long-term storage solution can be implemented. This operation is expected to start in November 2000.

A Fire Hazard Analysis (FHA) is required for all new facilities and all nonreactor nuclear facilities, in accordance with U.S. Department of Energy (DOE) Order 5480.7A, *Fire Protection.* This FHA has been prepared in accordance with DOE 5480.7A and HNF-PRO-350, *Fire Hazard Analysis Requirements.* Additionally, requirements or criteria contained in DOE, Richland Operations Office (RL) RL Implementing Directive (RLID) 5480.7, *Fire Protection,* or other DOE documentation are cited, as applicable. This FHA comprehensively assesses the risk of fire at the CVDF to ascertain whether the specific objectives of DOE 5480.7A are met. These specific fire protection objectives are:

- Minimize the potential for the occurrence of a fire.
- Ensure that fire does not cause an onsite or offsite release of radiological and other hazardous material that will threaten the public health and safety or the environment.
- Establish requirements that will provide an acceptable degree of life safety to DOE and contractor personnel and ensure that there are no undue hazards to the public from fire and its effects in DOE facilities.
- Ensure that vital DOE programs will not suffer unacceptable delays as a result of fire and related perils.
- Ensure that property damage from fire and related perils does not exceed an acceptable level.
- Ensure that process control and safety systems are not damaged by fire or related perils.

This FHA is based on the facility as constructed and with planned operation at the time of document preparation. Changes in facility planned and actual operation require that the identified fire risks associated with the CVDF be re-evaluated. Consequently, formal documentation and future revision of this FHA may be required.

1.1 Assumptions

Some of the following assumptions are taken from Design Requirements Document (DRD) HNF-SD-SNF-DRD-002 (Parker 1999) and from the Safety Analysis Report (SAR) HNF-3553 Annex B, *Spent Nuclear Fuel Project, Cold Vacuum Drying Facility Analysis Report.*

Assumptions from the DRD include:

- The MCO will only contain SNF from the 105-KE and 105-KW Basins.

- Packages are clean of exterior contamination within the limits for transporting shipping casks containing radioactive materials.
- The design of the fire protection systems shall be in accordance with listed documents.

Assumptions for the FHA include:

- Information is based on the process, equipment, and estimated values noted in the design. This information may not be valid during operations.
- Loss potentials are based on expected combustibles in the various areas. The expected combustibles are noted later in this report. An increase in these combustibles may void the analysis of this report.
- The facility meets the minimum requirements in the construction specification. The FHA is based on the expected operation of the CVDF.
- Since CVDF is a non-revenue generating facility, loss of production and fines from other agencies were not factors in determining the loss potentials.

2.0 SUMMARY AND CONCLUSIONS

Cold vacuum drying of the MCOs is part of the process for preparing the K Basin SNF for storage at the CSB. The ignition of the SNF and combustion of hydrogen generated within the MCOs are hazards that are inherent with the storage of SNF within the MCOs and are considered transient to the CVDF.

The CVDF is of noncombustible construction except for the built-up roof of rigid foam insulation over the Bay Area. Two-hour firewall separate the process area (Bays and Bay Support Area) from the office area (Operation Support Area). The facility is protected by an automatic sprinkler system. However, only one source of water is provided to the loop.

There are several areas where this facility does not meet the design requirements of DOE Orders. These areas of concern can be segregated into the following areas.

- Lack of the required two-hour fire rated secondary confinement (building walls and roof).
- Lack of adequate fire rated separation between the Bays.
- Lack of two independent water supplies for the facility.
- The HEPA filters lack adequate automatic fire protection systems and passive fire protection features.
- Lack of passive fire protection of Safety Class Systems.

The FHA was updated just prior to the start of operations (pre-operation testing) of the facility. Concerns related to meeting DOE Orders were noted during the update. The previously noted concerns are noted as recommendation in Section 18. These recommendations are related to meeting requirements as noted in DOE Orders such as 6430.1A, 5480.7A, and RLID 5480.7. A FHA Implementation Plan, SNF- 4942, Rev. 0, was instituted to address the issues noted in Revision 0 of the FHA.

Construction features and items that could be corrected (near the end of construction) were corrected. Operational items (administrative controls) have been instituted by procedures. Strict compliance with these procedures gives a level of fire protection equal to the fire protection required by the DOE Orders. Procedures have been written and approved as part of the FHA Implementation Plan to control combustible and limit exposures to the Bays and equipment. These procedures include the following.

- *The following 2 procedures deal with FHA limits:*
  1. *CP-24-001V, Control of Combustible Materials within The Cold Vacuum Drying Facility (CVDF)*
  2. *CP-24-002V, Inspection of Vehicles Entering CVDF Bays*
- *The following 3 procedures are for in/out activities:*
  1. *OP-94-004V, Process MCO/Cask Transporter In/Out of Bay*
  2. *OP-94-011V, Verify Bay #4 is Ready for Use*
  3. *OP-94-012V, Verify Bay #5 is Ready for Use*

Fire scenarios were evaluated for fire loss (damage) potential. These scenarios include but are not limited to the following:

- A fire involving the tractor and transporter with the Bay door open,
- A fire involving the transporter only with Bay door closed, and
- A fire involving the Operation Support Area of the facility.
- A fire involving the Process Support area.

Fire modeling was done for fires that involved the tractor and transporter, and the transporter only. The fire included the combustible loading of the unit including the tires, fuel, and tractor cab. The small quantity of other combustibles in the Bay (25-kg) is insignificant and will not change the conclusions. They were not included. Fire modeling was done for the Support Areas and limited size fires were modeled in the Bays.

Mitigating features include sealing the MCO with an inert helium atmosphere thereby limiting reaction of the fuel, precluding air ingress, and minimizing the potential for accumulation of a flammable hydrogen-air mixture. Venting and purging are used during processing to maintain the hydrogen concentration below flammable limits. The removal of moisture from the MCO by cold vacuum drying is part of the process to reduce the reaction of the fuel and limit the generation of hydrogen.

Fire loss potential noted during this analysis include the following:

- The Maximum Possible Fire Loss (MPFL) is in the Bay, which is $7,661,663. A delay of 18 months was assumed for a Bay MPFL event with operations continuing in one bay.
- The MPFL for the Operations Support Area is $1,440,536. A six-month delay, affecting all CVDF processing, is assumed to be necessary to replace the Operations Support Area structure.
- The Maximum Credible Fire Loss (MCFL) for a fire in a Bay is $1,572,285. The MCFL results from the loss of use of both Bays for a period of six months to replace damaged equipment.
- For the Operations Support Area, the MCFL is $164,165, determined to be the result of a fire in the Control Room of the Operations Support Area. This fire assumes a three-month delay in the use of both Bays.

In summary, the facility meets the requirements in DOE Orders 6430.1A and 5480.7A for nuclear nonreactor facility through strict controls and administrative procedures.

A fire in the step-off pads in the Bay could cause the failure of the electrical portion of the Safety Class equipment. This could result in the facility being shut down; however, features have been instituted to mitigate this fire loss potential.

These installed Safety Significant SSCs are adequate to prevent an external hydrogen explosion in the context of the FHA.

This update, Revision 1 to the FHA includes a status of the recommendation. The recommendations noted in Revision 0 have been closed out and no new recommendations have been added.

3.0 CONSTRUCTION AND OPERATIONS DESCRIPTION

The CVDF has three primary areas: the Bays, the Bay Support Area, and the Operations Support Area. Following is a description of the facility construction and its expected operation.

3.1 Construction

The five adjacent Bays (two operation and three spares), each approximately 9.2 m (30 ft-6 in.) wide by 18.3 m (60 ft) long by 9.8 m (32 ft) high, are constructed on a concrete foundation with precast concrete exterior walls. The interior walls separating the bays are precast concrete walls up to a height of 7.1 meters (23 ft-4 in.). Joints between precast concrete panels are sealed with a Underwriters' Laboratories (UL) listed construction joint fire stopping system (ULTRABLOCK®). However, the assembly of precast concrete wall panels and balance of the building structure is not fire rated. The remaining 2.7-to 3. 7-m (9-to 12 ft) above the interior precast concrete walls to the sloped roof is constructed of Type X gypsum wallboard coped around the beams and sealed in a non-fire rated configuration. The floor is sloped to one floor drain. A 4.0-by 5. 5-m (13-by 18-ft) overhead telescoping metal door is provided for transporter entry into each bay. A "U"-shaped mezzanine is provided at the 4.4-meter (14 ft-7 in.) level of each bay to house heating, ventilating, and air-conditioning (HVAC), process equipment, and to provide support for operation and maintenance activities at the top of the MCO. The mezzanine floor is constructed of 12.7-mm (1/2-in.) steel plates. Each bay is provided with a bridge crane.

A combustible roof system is installed over the Bays. The roof deck consists of 6.3 mm (1/4 in.) by 1219 mm (4 ft) by 2438 mm (8 ft) steel plate attached to beams and angles with 4.76 mm (3/16 in.) by 38.1 mm (1-1/2 in.) long fillet welds spaced 304.8 mm (12 in.) on center, leaving open seams in the deck between the roof membrane and the Bays. Rigid Firestone RUBBERGUARD® polyisocyanurate (ISO95+) insulation (102 mm [4 in.]) is adhered (not fastened) to the steel roof deck using a roofing adhesive. A layer of 12.7-mm (1/2-in.) recover roofing substrate is adhered or fastened to the layer of rigid insulation. Then, a 45-mil thick layer of Firestone reinforced RUBBERGUARD® exposed membrane is applied. The exposed membrane is covered by a Firestone RUBBERGUARD® aesthetic top coating.

The two-story Bay Support Area is approximately 6.1 m (20 ft) wide by 51.8 m (170 ft) long by 8.5 m (28 ft) high. The area is built on a concrete foundation and is separated from the Bays by precast concrete panel walls. The process water conditioning (PWC) tank room is isolated from the rest of the facility by precast concrete interior walls. Other interior walls in this area have Type X gypsum wallboard on a metal frame construction in a non-fire rated configuration.

The exterior Bay Support Area walls are insulated metal siding. The second floor is a 10-cm (4-in.) thick concrete slab on a metal deck supported by the structural steel frame. The roof is a standing seam metal roof system on a structural steel frame. The roof is provided with fiberglass batt insulation.

The first floor of the Bay Support Area consists of a change room for each Bay and miscellaneous support rooms for decontamination activities, monitoring, and storage; and the transfer corridor. The second floor consists of a mechanical room that houses HVAC equipment.

The Operations Support Area is approximately 15.2 m (50 ft) wide by 18.3 m (60 ft) long by 3.7 m (12 ft) high. The Operations Support Area is separated from the adjacent Bay and Bay Support Area by a 2-hour fire-rated wall. The interior walls are gypsum wallboard on a metal frame. The exterior walls are insulated metal panel on a steel frame. The area has a standing seam metal roof with batt insulation. This area houses office space, locker rooms, the electrical and telecommunication room, and the control room.

A 1500 kVa transformer containing 1701 liters (450 gallons) of a less flammable insulating oil (R-Temp) and is located 8.2 m (27 ft) west of the Operations Support Area. The location of this transformer is in accordance with FM Global (FM) Loss Prevention Data Sheet 5/4/14-8, *Transformers,* and thus does not present a serious fire hazard to the building.

An 89.2m^3 (3,150-ft3) concrete water retention basin is provided west of the CVDF. This basin will collect water that may result from sprinkler system flow in the Bays during a fire. A drain sump in each Bay is automatically ported to the retention basin on receipt of a fire water system flow alarm. The basin volume will accommodate sprinkler water flow in one Bay for approximately one hour.

In accordance with the SAR, the CVDF is a Hazard Category 2 facility. The Bays are Performance Category 3. The Transfer Corridor and Process Water Conditioning room is Performance Category 2. The Operations Support Area was built to Performance Category 1. This categorization allows the project to apply Uniform Building Code (UBC) Seismic Zone 2B criteria in accordance with DOE-STD-1023-95, *Natural Phenomena Hazards Assessment Criteria.* The SAR includes the hazard analysis in Chapter 3.0. These hazards are consistent with those of the FHA as they relate to fire hazards.

3.2 Operations

CVDF operations begin with the receipt of the cask–MCO transporter at a CVDF Bay. Operators raise the door to allow backing the transporter into a predetermined position. The tractor is driven out of the bay and the bay door is closed, achieving Bay confinement. The security system is activated for the specific bay. Radiation surveys are conducted on the cask and transporter. The shipping documentation package is delivered to the CVDF shift operations manager. Two of the four Bays will be used to support MCO drying operations.

A bridge is installed from the Bay mezzanine to the transporter work platform. The top of the cask is prepared for cask lid removal.

During transport to the CVDF, the MCO is vented to the cask headspace. Internal cask pressure is expected to increase as a result of hydrogen gas generation, and temperature is expected to increase as a result of radioactive decay heat, solar heating, and water-uranium corrosion reactions.

Cask venting occurs by means of special venting hardware and flex lines connected to a cask lid port and the CVDF process ventilation system. After venting, the CVDF Bay overhead crane removes the cask lid, the process hood and seal ring are installed onto the cask, and the MCO is prepared for process operations.

MCO processing is performed at a cask-MCO water temperature not to exceed 50 °C (122 °F) per prescribed operating procedures, which include draining, drying the MCO, pressure rebound tests, and a final extended mode under vacuum. There are minimal manual operator actions in the process sequences other than field operator actions (e.g., connecting the MCO valves) or control room operator actions (e.g., acknowledging alarms or instructing the monitoring and control system (MCS) to proceed with the next step). Operators direct the MCS when to initiate a sequence. Valve state changes, water temperature control, and other process parameter changes are performed by the MCS.

Following the cold vacuum drying process and MCO testing, the cask–MCO transporter is prepared for shipment to the CSB. This operation is basically the reverse of the receipt operation. The cask-MCO is cooled, the MCO is inerted and pressurized with helium, sealed, and leak-tested. The cask annulus is drained and dried with an instrument air purge, and the cask lid is reinstalled. The bay is isolated from the ventilation systems, and the door is opened. The transporter is reconnected to the tractor and released for shipment to the CSB.

4.0 FIRE PROTECTION FEATURES

4.1 Fire Barriers

Fire-rated wall in this facility separate: the Operations Support Area from the Bay, the Bay Support Area and the operations support area. These walls are 2-hour fire-rated area separation walls.

4.2 Detection and Alarm System

The fire alarm system was designed, installed and tested in accordance with National Fire Protection Association (NFPA) 72, *National Fire Alarm Code*. Fire alarm signals are transmitted to the Hanford Fire Department via a radio fire alarm reporter (RFAR). Annunciation of separate and distinct fire, supervisory, and trouble alarms; annunciation of local building fire alarms; and shutdown of appropriate HVAC supply fans are initiated upon receipt of a fire alarm. Manual pull stations are provided at emergency exits. Fire alarm annunciating devices (audible and visible) are provided for occupant notification. Photoelectric type smoke detectors are provided in the Control Room and in the HVAC ducts of this building as required by codes.

4.3 Automatic Sprinklers

Automatic sprinkler protection has been provided throughout the facility in accordance with NFPA 13, *Installation of Sprinkler Systems*. The Operations Support Area was upgraded to an Ordinary Hazard Group 2 occupancy system. The Bays and Bay Support Area system is an Ordinary Hazard Group 2 occupancy installation. The sprinkler system has a demand of 944 gpm at 76 psi at the yard loop. This calculation includes a 500-gpm hose stream allowance.

4.4 Water Supply

Water is provided to the CVDF sprinkler system via a 150-mm (6-in.) line tapped off a 200-mm (8-in.) line looped around the facility. The loop is connected to the existing service water system at Building 165KW via a 200-mm (8-in.) line. A water flow test conducted on February 6, 1999 had a static pressure 7.72 bar (112 psi), a flow of 4201 ℓpm (1110 gpm) and a residual pressure of 6.34 bars (92 psi). The test was conducted at hydrant FH-22 in the water supply loop northwest of the facility; the pressure readings taken at hydrant FH-23, southeast of the facility. The water supply is adequate to meet the sprinkler system design flow and pressure demand plus a margin in excess of 10%.

4.5 Portable Fire Extinguishers

Portable fire extinguishers of the appropriate size and class are located in the facility in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

4.6 Fire Protection System Concerns

4.6.1 Water Supply

RLID 5480.7, Section 8.1.a, requires distribution mains that are being extended to supply water for domestic and/or process water and provides water for fire suppression systems to be at least 300-mm (12-in.) in diameter. The 200-mm (8-in.) line provides an adequate water supply based on the hydraulic calculations for the sprinkler system. The fire main is not used for domestic or process water services.

DOE 6430.1A, Section 1530-99.0, states that the permanent fire protection installation shall have a minimum of two reliable, independent sources of water. The fire water system at 100 K Area is deficient in meeting this requirement. RLID 5480.7, Section 8.1.c, requires two points of supply feeding the looped grid.

A permanent exemption from meeting these requirements was requested (Williams 1998). The requested exemption was approved subject to conditions specified in the approval letter (Sellers 1998). The exemption request was based on a MPFL of less than $50 million ($14,685,000) as determined by the *Preliminary Fire Hazard Analysis for the Cold Vacuum Drying System Facility 142K* (Sadanaga 1996). Based on this FHA, the MPFL is $7,661,663. This exemption continues to remain in force.

The approximately 150-mm (6-in.) section of the underground polyvinyl chloride (PVC) pipe that supplied the CVDF fire water supply loop has been replaced with ductile iron pipe.

4.6.2 Fire Walls

The wall between the Operations Support Area and the Bay and Bay Support Area are 2-hour fire-rated wall.

4.6.3 Separation Walls

The walls between the Bays and the Bay Support Area are concrete, precast panels held together and to structural columns with weld clips. The wall panels have 12.7-mm (1/2-in.) concrete covers over the weld studs on one side and exposed steel connection plates on the other side. Exposed steel columns support the walls and roof. The walls have ridge attachments to the foundations. Expansion of a Bay wall upward during a fire is not possible. Elongation in the steel columns, based on the fire modeled for the Bays, is estimated to be as much as 42-mm (1-5/8 in.). A fire, as modeled in scenarios 1 to 4, in a Bay could cause wall failure and may lead to failure of the roof structure.

4.6.4 Roof Construction

As installed, the roof does not meet the requirements of a FM Global Approved Class I Insulated Steel Roof Deck Assembly as noted in FM Global Loss Prevention Data Sheet 1-28, *Wind Loads to Roof Systems and Roof Deck Securement.* The installed roof assembly is a membrane roof with 100 mm (4 in.) of rigid insulation adhered to the welded steel plate deck. The construction specification (Merrick and Company 1998) requires that a FM Global Class I Insulated Steel Roof Deck Assembly be installed. A Class I roof would be expected to consist of a fluted steel deck with roofing insulation mechanically fastened to the deck, and all roofing components listed or approved for use in a FM Global -approved configuration. However, fire spread along the underside of the roof deck is not considered to be a problem under MCFL conditions as the bays are provided with automatic sprinkler protection.

The roof as constructed (see Section 3.1 for description) is considered to be a combustible roofs and will support combustion on its underside. Therefore, the roof does not meet the criteria for noncombustible or limited combustible material as specified as the minimum fire resistance ratings in accordance with 57 FR 35607, *Guidance for Fire Protection for Fuel Cycle Facilities.* General design criteria included in Code of Federal Regulations (CFR) 10 CFR 72, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste,* require the use of noncombustible and heat-resistant materials wherever practical.

Under MPFL conditions, the roof would contribute to the losses from a fire in a bay because of deformation and melting of the insulation. A roof fire will contribute to the fire. Damage to the roof is included as part of the structural losses in calculations performed in this FHA.

5.0 SAFETY SYSTEMS, STRUCTURES AND COMPONENTS (SSC)

Safety structures, systems, and components (SSC) (includes safety class (SC) and safety significant (SS) SSCs) are defined as design features and controls that the facility will rely on to mitigate the frequency or consequence of identified hazardous conditions based on their importance and significance to safety. Determination of safety classification follows a graded approach using risk evaluation guidelines contained in HNF-PRO-704 *Hazard and Accident Analysis Process*. SSCs not classified as SC or SS are considered to be general service (GS) SSCs. These systems are described in the Safety Analysis Report (SAR), HNF-3553.

5.1 Safety SSCs

The SAR identifies the SC and SS SSCs at the CVDF. The structure, fire protection systems, and other systems associated with the CVDF are classified as GS systems.

The accident analysis contained in Chapter 3.0 of the SAR identifies six design basis accidents whose unmitigated consequences bound all accident sequences and scenarios identified in the hazard analysis process. Based on the SAR, design basis accidents are adequately mitigated.

5.2 Description of Safety SSCs

A complete description of safety SSCs is contained in the SAR. The following is a list of these systems:

1. SCIC System
2. SCHe System
3. Cask-MCO System
4. Tempered Water (Annulus) System
5. VPS and PWC Systems
6. Bay Structure and PWC Tank Room Structure
7. Bay Local Exhaust HVAC System
8. Process General Exhaust System
9. Reference Air System

5.3 Vulnerability of Safety SSCs to Fire

HNF-PRO-704 requires that all credible fire-related failure modes of safety SSCs be considered. Fire-induced electrical faults may trip upstream electrical disconnect devices in such a way as to render inoperable other safety SSCs not located in the affected fire area. The potential for spurious electrical signals, combustion products, manual fire fighting efforts, and the activation of automatic fire suppression systems, which may cause the malfunction of the operations of the safety SSCs, is also considered. Electrical interfaces between the Control Room MCS in the Operations Support Area and SCIC local control panels in each Bay are provided by cables routed in tray through the balance of the Operations Support Area and Bay Support Area. Local Bay SCIC panels, and associated Bay instrumentation, control, and detection systems, override MCS signals upon detection of off-normal MCO process conditions.

A fire in the Operations Support Area or Bay Support Area, that affects electrical cables between the MCS and local SCIC or other local process control systems, would have no affect on the safety function and automatic protective actions provided by the local Bay SCIC system. Spurious MCS signals, open, or short circuits, may detrimentally affect MCO process control functions, but detection of off-normal conditions by the local SCIC system in each Bay would cause an automatic SCIC system trip. The SCIC system trip would place the affected MCO in a safe and stable condition.

Electrical components associated with safety SSCs are protected from water spray by NEMA 4 watertight enclosures and conduit.

Safety class SSCs related to a particular CVDF Bay are located in the same fire area. For redundant safety class SSCs, such as SCIC and SCHe, this configuration does not meet the requirements of DOE 6430.1A for providing appropriate separation against fire, explosion, and failure of fire suppression systems. Also, the requirement stated in DOE 5480.7A for redundant safety class equipment to be located in separate fire areas is not met.

The CVDF is described as a mild environment as defined in IEEE-323 *Qualifying Class 1E Equipment for Nuclear Power Generating Stations* (IEEE 1983), and safety SSCs are qualified to a specified environmental condition in accordance with HNF-SD-SNF-SEL-002 *Safety Equipment List* (Irwin 1999). All of the safety SSCs are rated for 115°F except for two pressure instruments that are rated for 105°F. At these relatively low temperatures, any fire in a Bay (by virtue of increasing general area temperatures in excess of 46.1°C range) has the potential for affecting a safety SSC that may be relied on to prevent or mitigate one of the accidents described in the previous section

The CVDF Bay walls are not fire rated and the entire Bay and Bay Support Area are one fire area. The primary confinement function provided by the safety class flexible hoses used to make up the processing connection between the MCO and processing equipment are at risk of failure during a fire. These flexible hoses are rated for 177°C (350°F) and could be exposed to temperatures in excess of 800°C (1,472°F) during the MPFL fire for this facility unless mitigating features are provided. The MPFL fire is developed in conjunction with the MPFL for a fire area and is described in section 10.0 of the FHA.

Redundant safety class isolation valves are located in the same vicinity and are not protected from the damage caused by the MPFL fire unless mitigating features are provided. Although these isolation valves are spring loaded to fail closed on loss of air or electrical power, the risk of mechanical failure due to fire is present. There are also other Safety Class SSCs relied upon for primary confinement that are at risk during the MPFL fire. There are also other safety class SSCs relied upon for primary confinement that are at risk during the MPFL fire.

The shipping cask-MCO system is designed to withstand radiant exposure to 800°C (1,472°F) for a period of 30 minutes. The MPFL fire for a Bay would expose the cask-MCO to temperatures in excess of 800°C (1,472°F) for periods less than 30 minutes followed by elevated temperatures for an extended period of time.

The SNF Project Safety Analysis Group has performed a simplified analysis of the exposure of a shipping cask containing a nominal MCO to MPFL fire conditions in a CVDF Bay. Section 10.0, and Appendices B, D, and E provide additional information regarding this analysis. The results of this analysis indicate that the cask-MCO would not experience a thermal runaway reaction caused by this exposure. Overpressurization of the cask with the potential for release of a small quantity of hydrogen gas is possible when the MCO process connections are closed. No release of radionuclides to the environment is predicted.

The secondary and tertiary confinement functions provided by the Local and General Exhaust HVAC Systems and building structural shell are also at risk of failure during the MPFL fire. The 2-hour fire rated secondary confinement required by DOE Order 6430.1 Paragraph 0110-99.0.6 has not been provided.

The ductwork and ductwork supports associated with the safety significant Local and General Exhaust HVAC Systems are at risk during the MPFL fire. The walls between the Bays and Bay Support Areas are not fire-rated and fire dampers are not installed in duct penetrations through these walls. All Bays are effectively connected by the existing configuration of Local and General Exhaust HVAC System ductwork. The final HEPA filters in each of these systems could be exposed to hot gas and smoke from the MPFL fire in a Bay.

The present design of the Local and General Exhaust HEPA filtration systems includes the following fire protection features:

- Fire screens installed upstream of filter housings,
- Nuclear grade isolation dampers installed upstream and downstream of the filter housings, and
- Rate compensated thermal detectors, set at 90°C (190°F) or a rate of rise of 20°C (30°F) in 10 seconds, installed upstream of each filter housing. When activated, the Local Exhaust System detector closes the process hood isolation dampers upstream of the process exhaust connection to the Local Exhaust System. In this manner, the MCO is allowed to continue to vent through the filtered Local Exhaust System path although forced flow will have ceased and the Bay airspace will be isolated from the vent path. A rate of rise temperature trip on the General Exhaust System shuts down system fans and isolates the General Exhaust System from the Bay by shutting the nuclear grade isolation damper at the wall between the Bay and Bay Support Area. However, the dampers are not fire rated.

Appendix D addresses the affect of aerosol loading on the safety significant Local and General Exhaust HEPA filters as a result of MPFL fire conditions. The time to loss of ventilation is important during a fire in a Bay to assess the impact of the fire on loss of confinement due to HEPA filter plugging or blowout due to development of high differential pressure. Loss of HEPA filtration causes a loss of secondary confinement, which is required to be maintained during a fire in a Bay. During a MPFL fire, the time to reach 127 mm (5 in.) w.g. differential pressure across the General and Local Exhaust HEPA filters is calculated to be 3 hours and 19 minutes, respectively. Appendix D also addresses the affect of aerosol loading on these HEPA filters for lesser fires in a Bay.

The present facility design does not comply with the DOE Filter Plenum Criteria as required by RLID 5480.7. However, the DOE Filter Plenum Criteria do not limit the application of other fire protection methods when unique situations or hazards warrant an alternate approach. The alternate method must provide an equivalent level of fire protection when compared to the criteria provided and be approved by the DOE authority having jurisdiction.

The filter banks are located in an area that does not provide protection from an external fire threat under MPFL conditions. The HVAC equipment is located on the second floor mechanical room of the Bay Support Area. This is an area of noncombustible construction and has minimal fixed combustible fire loading. This area is separated from the Bays by precast concrete panel walls. However, the panels don't have a two-hour fire rating. Automatic sprinkler protection is provided for the mechanical room.

The Local and General Exhaust System HEPA filters are UL listed and comply with the DOE Filter Plenum Criteria as required by RLID 5480.7.

The hazard to Local and General HEPA filter media during the MPFL fire is hot gas and smoke. Likewise, a smoke and hot gas hazard to adjacent Bays through the Local and Exhaust HVAC System ductwork is also a concern. These HVAC fans will automatically shutdown on high gas temperatures. This detector is located at the inlet ducting to the HEPA filters. When the fans shutdown, isolation dampers in each Bay exhaust path close to isolate the Bays from the HVAC system and from one another. The smoke and hot gases will not travel to other bays.

The MPFL fire for a CVDF Bay fire does not involve the presence of flames in the vicinity of the Local or General Exhaust HVAC wall penetrations. The nuclear grade isolation dampers located near the Bay and Bay Support Area wall are substantial and may provide superior protection against passage of hot gas and smoke through the Local and General Exhaust HVAC System ductwork to their respective HEPA filtration media. However, these dampers do not include documentation that proves their effectiveness and survivability during MPFL fire conditions. In addition, the lack of fire resistive construction, through which the Local and General Exhaust HVAC System ductwork passes, means that these wall penetrations cannot be adequately protected against damage caused by the MPFL fire.

The Local and General Exhaust HEPA Filtration Plenums are not enclosed in 2-hour fire rated construction. Although the expected fire loading in the Bay Support Area and mechanical equipment room is very low, the walls between the Bays and the Bay Support Area are not of fire rated construction. Strict control on combustibles and administrative procedures are being used to overcome this concern.

5.4 Vulnerability of Electrical Equipment to Fire

Some of the SC equipment is provided with electrical power that is routed between the bays. Wiring is located in metal conduit. As noted in the fire modeling, a single step-off pad fire will raise the bay temperature above 93°C. Temperatures above 93°C can lead to failures of the wiring. This would effect the ability of the SC equipment to function. The results of this fire are not acceptable

6.0 DESCRIPTION OF FIRE HAZARDS

6.1 SNF Ignition

SNF ignition is avoided by preventing oxygen from entering the MCO and by keeping the SNF below its lower ignition temperature of 275 °C (527 °F). The SAR does not address SNF ignition, however, it is analogous to and is bounded by the thermal runaway accident evaluated in the SAR, Chapter 3. MCO thermal runaway is prevented by the automatic operation of redundant Safety Class SSCs, specifically the SCIC system, the SCHe system, and portions of the TWS. These systems automatically take action to remove external heat sources from affecting the SNF in the MCO and to initiate a helium purge for removal of heat and hydrogen gas generated inside the MCO. The Safety Class primary confinement provided by the MCO boundary and the process exhaust vent path, including Safety Class piping, valves, and flexible hoses, precludes the introduction of oxygen into the MCO. The FHA takes credit for the Safety Class systems designed to prevent a thermal runaway accident as effective in the prevention of SNF ignition.

6.2 Hydrogen

While transporting the cask-MCO containing SNF to the CVDF, hydrogen gas is generated inside the MCO by radiolysis, degradation of uranium hydride, and by the corrosion reaction between water and uranium. The cask–MCO is shipped with the MCO process vent port-plug valve in the open position, which allows the cask headspace to pressurize and collect hydrogen during shipping. In this manner, hydrogen gas is contained within the Safety Class cask boundary. Prior to cask lid removal, the cask headspace may be sampled (primarily for hydrogen concentration), and the cask is then vented through the process vent system to the local exhaust HVAC system by means of special venting hardware and flexible lines connected to a cask lid port.

Following venting, the cask lid is removed, the process hood and seal ring are installed onto the cask, the process vent plug valve on the MCO is closed, and the MCO is prepared for process operations. During MCO processing, hydrogen gas concentrations in the process lines are controlled by compliance with NFPA 69, *Standard on Explosion Prevention Systems.*

Non-explosive hydrogen concentrations are maintained during processing in the following equipment:

- In the process vent lines—by limiting oxygen concentration to less than 25% of the LEL using a helium purge in the process gas stream following the guidance of NFPA 69.
- In the local exhaust HVAC system—by dilution with forced air flow such that the concentration of hydrogen is maintained less than 25% of the lower explosive limit (LEL) following the guidance of NFPA 69. Dilution airflow is maintained during a loss of normal electrical power by a diesel-backed standby power system installed to preclude potentially flammable concentrations of hydrogen within the local exhaust HVAC system. The required minimum dilution airflow rate is restored by the standby power system within 60 seconds following loss of normal electrical power to the local exhaust fans. (Prior to the discharge of accumulation of hydrogen from the MCO.)
- In the PWC system piping and tanks—by limiting the quantity of oxygen present to maintained less than 25% of LEL using a helium purge in the process gas stream following the guidance of NFPA 69.

The residual gas monitoring (RGM) system continuously monitors MCO offgas composition to assist in evaluation of fuel drying effectiveness and to detect gas concentrations outside the expected values. The RGM subsystems, one in each active Bay, are present in the CVDF. A residual gas sample is drawn from the MCO vent line and analyzed for hydrogen, nitrogen, oxygen, argon, helium, water vapor, krypton, and xenon. The results of RGM are used with pressure and temperature measurements of MCO gases to evaluate the following:

- Adequacy of the vacuum conditioning process in removing water from the MCO fuel.
- Air in leakage to the system.

- Presence of radioactive gas species. Normal RGM system operation interfaces with the MCS allowing operators to monitor flammable gas concentrations in the process stream.

The FHA concludes that hydrogen gas hazards at the CVDF are controlled adequately by design and noted in Chapter 3.0 of the SAR.

Bounding accidents involving hydrogen are addressed in the SAR. The SAR evaluates the following accidents:

- MCO internal hydrogen explosion
- MCO external hydrogen explosion
- MCO overpressurization accident.

The Safety Class SSCs installed to prevent the MCO thermal runaway and overpressurization accidents prevent the MCO internal hydrogen explosion and overpressurization accidents and will not be considered further by the FHA.

Safety significant SSCs installed to prevent the MCO external hydrogen explosion accident include:

- The Bay local exhaust HVAC and process vent system provides a cask venting connection with a flow restricting orifice to keep concentrations of hydrogen below the flammable limit with at least 1,000 ft^3/min of flow in the ductwork.
- A shutoff valve interlocked to the local exhaust low-flow alarm is provided because flammable concentrations would be generated almost instantaneously if the cask were vented into a stagnant local exhaust duct. Low flow alarms are above 1,000 ft^3/min. to ensure a minimum flow rate is available. The flow switch is interlocked with the shutoff valve.
- The Bay local exhaust HVAC and process vent system mitigates a gaseous release into the Bay by sweeping it through HEPA filters before it is discharged outside the facility.
- The reference air system ensures maintenance of negative pressure in the Bays and process water tank room by providing differential pressure indication and alarms to the control room for operator response.
- The Safety Class cask–MCO provides a pressure boundary for confinement of gaseous radioactive materials during processing; its integrity prevents a gaseous release.

These installed Safety Significant SSCs are adequate to prevent an external hydrogen explosion in the context of the FHA. This is further explained in SNF-5100, Cold Vacuum Drying Electrical Equipment (Hydrogen) Protection, Appendix H.

6.3 Fuel Oil

Diesel fuel from the MCO tractor or other vehicles is a potential fire hazard. Fire model scenarios 1, 2, and 3 involve a tractor fire in or near a Bay and its affect on the CVDF structure. In all cases, the resulting upper (hot) gas layer temperature in the bay exceeded the temperature at which structural steel columns are expected to begin to lose their load carrying capacity. These fires involved other tractor and transporter materials including the tractor cab and tires however the affect of diesel fuel burning was a major factor in the severity of these fires.

The diesel fuel and the tractor combustibles can be removed from the fire scenarios by keeping the truck at least 3.6-m (12-ft) from the building during loading trailer movement operations. This can be accomplished by the use of a dolly with a long tongue, more than 3.6-m (12-ft) to separate the tractor and the trailer.

6.4 Ordinary Combustibles

The quantity of ordinary combustibles anticipated to be present in the Bays and Bay Support Area will include cable, piping and duct insulation, anti-c clothing, storage of items required for operations, and minimal transient combustible material. Twelve transporter tires will be in the Bay when an MCO is in the bay. These transporter tires are the largest, single, combustible loading anticipated to be present in a Bay during processing.

Combustible materials assumed to be located in the CVDF Bays and other CVDF areas are listed In Table 3.1 in the FHA Implementation Plan, SNF-4942, Rev. 1.

7.0 LIFE SAFETY CONSIDERATIONS

The emergency egress of the design was evaluated against the requirements of NFPA 101, *Life Safety Code*. The Bays and the Bay Support Area of the CVDF are classified as a special purpose industrial facility. There are at least two means of egress from the CVDF. Both stairwells from the second floor mechanical room (207) open to the first floor transfer corridor area, in addition to the outside. Both stairwells serving the first and second floors of the Bay Support Area are exterior to the building and are totally enclosed by non-combustible construction.

NFPA 101, Paragraph 5-2.2.6.4 requires that unenclosed outside stairs be separated from the interior of the building by 1-hour fire-rated construction with Exception No. 2 stating that outside stairs may be permitted to be unprotected when serving no more than two adjacent stories. This situation meets Exception No. 2. However, since the stairs are fully enclosed, a basic level of smoke protection is required. Smoke seals are being provided to ensure adequate egress from the upper floor during emergency conditions.

The elevated mezzanine areas in the Bays were evaluated against NFPA 101 due to the single means of egress from these elevated areas. The areas involved meet the "openness" criteria of NFPA 101, Paragraph 6-2.5.3, and classification of the facility as a special purpose industrial occupancy allows the mezzanine area to be greater than 1/3 the aggregate area of the Bay per Exception No. 1 of Paragraph 6-2.5.2.1. As a mezzanine, the elevated area is treated no differently than any area on the ground floor. The distance from the most remote point on the mezzanine subject to occupancy to the bottom of the stairs where two separate routes to an exit are available is within the allowable common path of travel of 30.5 m (100 ft).

Emergency lighting, exit signs, and exit directional signs are provided and positioned as required. Exit signs include integral chargers, batteries, and relays to provide illumination in the emergency mode.

Emergency lighting in areas with fluorescent lighting is provided by use of fluorescent fixtures with integrally mounted backup battery packs.

The construction specification (Merrick and Company 1998) for the interior finishes meets the flame spread and smoke development criteria for Class A interior wall and ceiling finish. The floors meet the critical radiant flux criterion for a Class I interior floor finish.

Employee notification of a fire is accomplished by audible and visible signals initiated by the fire detection and alarm system. Fire alarm bells/strobes are installed throughout the facility. Manual pull boxes are provided at the facility exits.

8.0 CRITICAL PROCESS EQUIPMENT

Critical process equipment includes any equipment designated by DOE to be vital to the Hanford Site mission. Presently, no such equipment has been identified for the CVDF. However, the equipment necessary to operate the CVDF is very specialized. In some cases, loss of equipment due to fire would require long lead times with loss of program continuity. Equipment in the CVDF is protected by the installed sprinkler system.

9.0 HIGH-VALUE EQUIPMENT

A single piece of equipment valued at $1,000,000 or more is considered to be high-value equipment. There are no single pieces of equipment within the CVDF that approach this figure. However, the close proximity of equipment to other equipment necessary to operate the CVDF, taken as a group, would exceed the $1,000,000 threshold for high-value equipment. Equipment in the CVDF is protected by the installed sprinkler system.

10.0 DAMAGE POTENTIAL

10.1 Maximum Possible Fire Loss

DOE 6430.1A defines the Maximum Possible Fire Loss (MPFL) as "A fire that is the most severe design basis accident of this type defines the bounding fire event also referred to as a Design Basis Fire. In postulating such a fire, failure of automatic and manual suppression provisions shall be assumed except for those safety class items/systems that are specifically designed to remain available (structurally or functionally) through the event." Further, the MPFL is defined as "The value of property, excluding land, within a fire area, unless a fire hazards analysis demonstrates a lesser (or greater) loss potential. This assumes the failure of both automatic fire suppression systems and manual fire fighting efforts." Guidance for the determination of MPFL for a facility is taken from WHC-SD-GN-FHA-30001 *Integration of Fire Hazards Analysis and Safety Analysis Report Requirements* in accordance with HNF-PRO-350.

MPFL, as defined in DOE 5480.7A, considers the following costs resulting from a bounding fire event:

(1) Property replacement costs, less salvage value.
(2) Decontamination and cleanup costs (including burial).

(3) Facility restart costs.
(4) Loss of production or program continuity.
(5) Cost to restore damaged property to it pre-occurrence condition irrespective of whether this is actually done.

Item (4) above is only being applied to revenue generating facilities.

The MPFL excludes the following from a loss as defined in DOE 5484.1, *Environmental Protection, Safety and Health Protection Information Report Requirements.*

1) Property that is scheduled for demolition.
2) Property (a) decommissioned and not carried on the books as a value, or (b) where there is no loss potential.
3) Expenses directly resulting solely from loss of the use or occupancy of facilities affected by the occurrence (a CVDF exclusion).

10.1.1 Fire Walls

The CVDF will be divided into two fire areas separated by a 2-hour fire rated wall. This firewall has not been provided as designed. However, for the purpose of determining the MPFL, it is assumed that the firewall will be adequate. These two fire areas are:

(1) The Operations Support Area, and
(2) The Bay Support Area and Bay Areas.

10.1.2 Operations Support Area

The entire Operations Support Area is assumed to be involved in this fire event. The expected low combustible loading and construction using fire retardant gypsum wallboard make this a conservative assumption. The fire loss consists of reconstruction of this part of the facility and replacement of damaged systems. The property and cleanup losses for this event are estimated at $1,100,000. Facility restart costs are $327,833. Suspended operations are estimated to be six months in all the bays. Appendix C addresses MCFL in greater detail. The MPFL for the Operations Support Area fire event is broken down as follows:

Maximum Possible Fire Loss – Operations Support Area:

Property replacement/restoration cost	=	$1,100,000
Demolition cost	=	$ 12,703
Facility Restart cost	=	<u>$ 327,833</u>
Total Operations Support Area MPFL	=	$1,440,536

10.1.3 Bay Support Area and Bay Areas

Fire scenarios involving the Bay Areas are modeled in support of this FHA using computer fire modeling software. The software used, *FAST: Engineering Tools for Estimating Fire Growth and*

Smoke Transport, was developed by the U.S. Department of Commerce, National Institute of Standards and Technology (NIST). Use of FAST fire modeling software is an acceptable tool in the development of an FHA for facilities at the Hanford Site as described by Project Hanford Procedures, HNF-PRO-350, when applied by qualified fire protection engineers and as approved by the RL authority having jurisdiction. The specific software version of FAST used for these models is FAST Version 3.1.3 dated April 1, 1998. Approval of the RL authority having jurisdiction is accomplished upon RL's approval of the FHA.

The fire scenarios modeled are briefly described below. Fires are assumed to grow in each case to peak heat release rate, burn at peak heat release rate, and then burn to completion with a 30-second decay period. The transporter tires are located beneath the transporter deck, are located approximately 7 m (25 ft.) from the nearest tractor surface, and are shielded from exposure to a fire involving the tractor by the massive Cask/MCO and associated structural steel, the steel transporter deck, and transporter structural steel. A tractor fire outdoors would not be expected to ignite transporter tires. Fire models development, input, and output, for each of the fire scenarios modeled, is included in Appendix A, *Fire Models*. These fire scenarios looked at the results of a fire if the combustibles were ignited. Ignition sources are not included nor are any mitigation of the fire.

Fire Scenario 1.

Scenario 1 occurs with the tractor and transporter backing into, or parked in, a CVDF processing bay. The large bay door is open, the MCO is not connected to any processing equipment, and HVAC systems are assumed OFF. The tractor cab is assumed to ignite by an electrical short circuit in the tractor wiring. The resulting fire begins in the cab and spreads to the engine compartment, front tractor tires, diesel fuel, rear tractor tires, and transporter tires. The fire is modeled assuming that the cab, engine compartment, and all tires are lumped combustibles. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. Ignition and instantaneous fire growth of diesel fuel to steady state peak heat release rate is assumed to occur upon fire growth to the peak heat release rate corresponding to the lumped combustibles without diesel fuel. The fire is assumed to burn to completion with a 30-second decay period for lumped combustibles and instantaneous decay for diesel fuel.

Discussion

The tractor and transporter are connected, the large Bay door is open, the transporter is completely within the bay, the tractor is partially within the bay, and the MCO is not connected to processing equipment in the bay. The fire is assumed to ignite within the tractor and grow to involve all of the major combustibles in an around the tractor cab. Most of the combustible materials involved on the tractor and transporter are inside the bay and all of the combustible materials associated with the tractor are assumed to affect the bay. The fire is calculated to be a 40 minute fire with peak Bay temperatures reaching 850°C (1,563°F) 26 minutes following ignition with the upper gas layer descended to a level 0.85 m (2.75 ft.) above the floor. After one hour, upper gas layer temperature in the Bay is calculated to be to 262°C (503°F) with the interface between upper and lower layers at a height of 6.3 m (21 ft.) above the floor. The MPFL fire associated with a tractor fire will do significant damage to the facility and associated equipment is expected.

The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR and Appendix E.

Fire Scenario 2.

Scenario 2 is the same as Scenario 1 except that the transporter tires are treated separately and assumed to ignite 20 minutes after ignition of the lumped tractor cab, engine compartment, front and rear tires.

Discussion

The tractor and transporter are connected, the large Bay door is open, the transporter is completely within the bay, the tractor is partially within the bay, and the MCO is not connected to processing equipment in the bay. The fire is assumed to ignite within the tractor and grow to involve all of the major combustibles in an around the tractor cab. Most of the combustible materials involved on the tractor and transporter are inside the bay and all of the combustible materials associated with the tractor are assumed to affect the bay. The MPFL fire associated with a tractor fire will do significant damage to the facility and associated equipment is expected.

The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR and Appendix E.

Fire Scenario 3.

Scenario 3 is the same as Scenarios 1 and 2 except that ignition and fire involving the tractor cab, engine compartment, front tires, diesel fuel, and rear tires, is not assumed to spread to the transporter tires.

Discussion

The tractor and transporter are connected, the large Bay door is open, the transporter is completely within the bay, the tractor is partially within the bay, and the MCO is not connected to processing equipment in the bay. The fire is assumed to ignite within the tractor and grow to involve all of the major combustibles in an around the tractor cab. Most of the combustible materials involved on the tractor and transporter are inside the bay and all of the combustible materials associated with the tractor are assumed to affect the bay. However, with the tractor and transporter in the building, ignition of the transporter tires is uncertain due to eventual and prolonged exposure to hot gas from a tractor fire.

The fire model output for fire scenario 3 indicates that the upper gas layer temperature in the Bay will peak at 878°K (605°C) 24 minutes into the fire. Flashover (i.e., the point at which all combustibles in a room or confined space have been heated to the point that they are giving off vapors that will support combustion, and all combustibles ignite simultaneously) occurs when any two of the following conditions have been attained:

- Heat release rate exceeds 1 MW
- Heat flux at the floor exceeds 20 kW/m^2
- Average upper layer temperature exceeds 600°C (1112°F)
- Flames exit doorway
- Auto-ignition of paper target on floor occurs

The results of this fire indicate that it would be possible to achieve flashover conditions within a CVDF Bay as a result of a tractor only fire. Therefore, ignition of transporter tires should be considered as part of the MPFL fire for this facility.

The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR and Appendix E.

Fire Scenario 4.

Scenario 4 occurs with the transporter inside a CVDF processing bay. The large bay door is closed and the MCO is connected to processing equipment. An ignition source with sufficient power is assumed to exist and ignite the transporter tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. The fire is unconstrained with unlimited oxygen supply. The transporter tire fire is assumed to burn to completion with a 30-second decay period. This fire involves only the twelve tires associated with the transporter. The MPFL fire is a separate case since the MCO is being processed during this fire with the large Bay door closed.

Discussion

During scenario 4, the upper gas layer drops to floor level within 6 minutes of ignition. The hot gas layer remains at floor level over the 24-minute duration of the fire. Left unmitigated, with doors closed, the hot gas layer remains at floor level. Bay temperatures are predicted by the computer model to peak at 660°C (1,220°F) 24 minutes into the fire, and to decline to approximately 188°C (370°F) after one hour.

Temperatures in the Bay during this fire would be detrimental to all contents in the Bay, including instrumentation and controls, rubber, plastic, and like components. The MCO process vent lines are connected to processing equipment by flexible hoses described by Specification W-441-C1, Section 11100, as "smooth Teflon tube bonded to a rubber hose with multiple reinforcement, double wire helix supported..... temperature rating 350°F to -40°F". These connections are considered to be at risk to fail during this fire scenario due to high temperature. The flexible hoses (reinforced Teflon) making the connection between the MCO and processing equipment are assumed to completely lose their integrity during a fire event. These hoses would be subjected to temperatures in excess of 600°C (1,112°F) during a transporter tire fire.

The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR and Appendix E.

Fire Scenario 5.

CVDF Fire Scenario 5 is identical to Fire Scenario 4, except that the oxygen supply is assumed to be limited to the oxygen available in the Bay at the time of the fire. The fire occurs with the transporter inside a CVDF Bay. The large bay door is closed and the MCO is connected to processing equipment. An ignition source with sufficient power is assumed to exist and ignite the transporter tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. The transporter tire fire is assumed to burn to completion with a 30-second decay period.

Discussion

Fire scenario 5 involves an oxygen-constrained fire using the same FAST inputs as fire scenario 4. Scenario 5 may be more appropriate since the Bay is closed during the fire with ventilation systems automatically shutting down due to hot gas introduction into the HEPA filter plenums. The oxygen constrained case reduces the maximum temperature in the Process to 407°C (765°F), below the 538°C at which the structural integrity of the columns is not assured, however, the roof remains threatened by temperatures in excess of 400°C (752°F), the flexible hoses connecting the MCO to processing equipment are threatened at 177°C (351°F), and safety class equipment may be threatened at temperatures above 46.1°C (115°F). Fire scenario 5 is examined in detail in Appendix A.

The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR.

Fire Scenario 6.

This fire scenario consists of several cases involving combustion of materials present in the CVDF during operations and maintenance. Each case is conservatively assumed to occur with unlimited oxygen supply (unless otherwise noted), with doors to the space closed, vents closed and ventilation off. The local and general area affect of each case is examined. These affects depend on the location of the materials relative to the building structure, transporter tires, and safety class equipment. The fire is assumed to grow in each case to peak heat release rate in 30 seconds, burn at peak heat release rate, and then burn to completion with a 30-second decay period.

Discussion

Fire scenario 6 examines the placement of step off pads in a Bay so that the Bay walls, structural steel columns, and mezzanine vertical supports are not affected by a step off pad fire. Scenario 6 also evaluates the radiant effect of a fire exposure to transporter tires from a step off pad fire necessary to ignite the tires. This radiant exposure is determined albeit conservatively to be 4.3 kW/m². The required step off pad distance to prevent exposure of tires to 4.3 kW/m² is 2.1 m (7 ft) with the short dimension of the step off pad facing the tires, and 3.8 m (12 ft 6 in.) with the long dimension of the step off pad facing the transporter tires.

There are no identifiable ignition sources for transporter tires inside a CVDF Bay except for a potential exposure fire, such as a step off pad, which may burn in the vicinity of the tires. Permanent process equipment is not capable of providing the necessary radiant energy to transporter tires for ignition. One source of ignition may be a hot brake or overheated tire resulting during shipment of the cask-MCO from the K Basins. This ignition source may be eliminated by requiring a period of time for cool down of tires outside of the Bay prior to placement of the transporter into the bay and requiring a temperature check of the tires.

Scenario 6 has also determined limiting distances of a step off pad to Bay walls, structural columns, and mezzanine vertical supporting steel. These limiting distances vary depending on the orientation and type of step off pad in use with respect to walls, columns, and vertical supports. Appendix A, scenario 6, should be consulted for these limitations.

The fire scenarios modeled in a Bay, from a 20 MW tractor and transporter tire fire to a small 387 kW step off pad fire, produce Bay temperatures that are not acceptable to redundant trains of safety class equipment in the affected bay.

Fire Scenario 7.

This fire scenario evaluates a fire in a Bay Support Area change room in an oxygen-limited condition. Each case assumes that combustible loading associated with a standard step off pad (previously developed in fire scenario 6) in the "standard load" configuration, wood storage shelves and cabinets containing stored clean personnel contamination clothing, and the equivalent of 5 additional "standard loads" of material representing anticipated miscellaneous storage in support of operations and maintenance. It is assumed to occur with doors to the space closed, vents closed and ventilation off.

Discussion

Scenario 7 evaluates the damage to the facility due to a fire in a Bay Support Area change room. The change room was assumed to be a 2-hour fire rated room, which is not presently the installed configuration in the CVDF facility. Without a 2-hour fire rated room, a fire in the Bay Support Area has significant potential to damage Bay walls, and spread throughout the Bay Support Area. The second level mechanical room of the Bay Support Area contains the Local and General Exhaust HEPA filtration systems. Without severely limiting the quantity of combustible material in this part of the facility, a fire could detrimentally affect the building structure and HEPA filtration systems that provide for secondary confinement of the building, Bays, and process vent system.

A significant quantity of personnel contamination clothing, wood shelving, step off pad material, and operations and maintenance material storage is assumed to be present in each Bay Support Area change room. When modeled as a fire unconstrained by oxygen in the room, this fire, with the combustible loading assumed, exceeds the capability of the 2-hour fire rated construction. However, with the fire constrained to the oxygen supply available in the change room, oxygen is quickly consumed such that the temperature peaks at 212°C (414°F) then falls rapidly in the oxygen starved space. A 2-hour fire rated room would be required to be shutoff from sources of ventilation to preclude entry of oxygen into the room. Self-closing fire doors would also be required.

10.1.4 General Effects of the MPFL Fire

ASTM Specification E119, *Standard Methods of Fire Tests of Building Construction and Materials* contains procedures for testing of structural steel elements located inside a building and exposed to a fire. The temperature criterion used during the ASTM E119 test requires that the average temperature reading of a steel member not exceed 538°C (1,000°F) for columns and 593°C (1,100°F) for beams. The criteria also stipulates that an individual temperature reading may not exceed 593°C (1,100°F) for columns and 649°C (1,200°F) for beams. This FHA considers exposure of a structural steel member in a Bay to temperatures in excess of 538°C (1,000°F) for a period in excess of 10 minutes to be a reasonable approximation to conclude that failure of a structural steel member is impending. The actual temperature at which collapse of structural steel components would occur is dependent on load, support, dimensions, and geometry of structural steel members. Structural steel members located in the vicinity of the fire will be directly affected due to radiant exposure to flames. Steel columns supporting mezzanine areas are located such that they are particularly susceptible to the direct affect of radiant heat exposure to flames.

The critical temperature, 538°C (1,000°F), is exceeded in each of the three fire scenarios involving the tractor, as well as for the fire scenario involving the transporter only, for a minimum of 10 minutes. It is concluded that structural damage will result from a MPFL in a Bay. All unprotected steel structural members will be affected, including mezzanine supporting steel, and members supporting the roof and steel roof deck. The extent of damage is expected to include deformation, sagging, or collapse, of steel structural elements, with significant potential for collapse of mezzanine areas. Bay walls are attached by welding to unprotected vertical steel columns by steel clips, the integrity of the Bay walls supported by these columns is also at risk during a fire.

The American Institute of Steel Construction Inc. (AISC) *Manual of Steel Construction, Ninth Edition*, states that the coefficient of expansion (ϵ) for structural steel between 38°C (100°F) and 649°C (1,200°F) is given by the formula:

$$\epsilon = (6.1 + 0.0019t) \times 10\text{-}6 \text{ per °C (or °F)}$$

where: t = temperature in °F

When heated to temperatures in excess of 538°C (1,000°F), as predicted for a Bay in all fire scenarios, the change in length of a structural steel column is expected to be:

$$\epsilon lT = [(6.1 + 0.0019t) \times 10\text{-}6 \text{ per °C}] \times l \times T$$

where: t = 1,000° F

T = 538° C

l = 9.8 m (32 ft.)

$$\epsilon lT = 0.042 \text{ m} = 4.2 \text{ cm (1.7 in)}$$

A change in length of a structural column of 4.2 cm (1.7 in) due to the expected heat generated in a Bay during a fire may cause failure of the welded attachments to the precast concrete walls. Ultimately, Bay walls may loose lateral support, tip, or fall over. Failure of welded connections during a fire threatens Bay walls between bays and between the affected Bay and Bay Support Area.

Damage from a MPFL fire in CVDF could effect the Bay of fire origin, adjacent Bay or Bays, the mechanical equipment room, the transfer corridor, associated equipment, and change rooms. The MPFL for the CVDF Bay and Bay Support Areas is $7,661,663. MPFL calculations are included in Appendix B.

10.1.5 Effects of a Fire on the HEPA Filter

Calculations relating to mass loading on the Local and General Exhaust HEPA filters as a result of a fire are included in Appendix D. The affect of smoke generated by 20 MW, 12 MW, and 400 kW fires in a Bay were considered in this analysis. Results are summarized below:

SYSTEM	FIRE	DIA (m)	MASS FLOW grams/m)	TOTAL FILTER AREA Ft^2	HOURS To Reach 5" wg
General	20 MW	.0002	44.1	2640	3
General	12 MW	.0002	6.40	2640	21
General	.40MW	.0003	2.90	2640	57
Local	20 MW	.0002	67.5	1320	0.32
Local	12 MW	.0002	9.8	1320	2
Local	.40MW	.0003	4.40	1320	6

Based on this data, it is predicted that the Local Exhaust HEPA filter will become plugged in approximately 19 minutes during a 20 MW tire fire. The same fire is predicted to cause the General

Exhaust HEPA to become plugged in approximately 3 hours. Temperatures corresponding to hot upper gas layer temperatures for a 20 MW fire would be detrimental to the integrity of the HEPA filters. These HEPA filtration systems are designed to shutdown when high temperatures are detected in the airflow stream. Temperatures on the order of 100°C (212°F) that correspond to the smaller 400 kW fire in a Bay do not present a significant threat to HEPA filter integrity and allows a forced ventilation path to remain open to maintain secondary confinement pressures in the affected Bay during the fire. There is incentive to reduce fire loading in the facility to reduce the detrimental impact on unprotected HEPA filtration systems during a fire.

10.1.6 Discussion of Cask Damage from All Fire Models

A simplified analysis of the affect of heat generated by a scenario 1 and 4 fire on the SNF contained in a cask and nominal the Nuclear Safety Analyst responsible for the HANSF code in the SNF Project Safety Analysis Group performed MCO. This analysis was done using Hanford Spent Fuel (HANSF) computer code (see Appendix E *Effect of Fire on Cask-MCO* for description and results). A thermal runaway reaction is not predicted for these fire scenarios.

For a scenario 1 tractor and transporter tire fire, this analysis concludes that the pressure within a the closed cask would reach approximately 11 bar (150 psig) design pressure 3 to 3½ hours following the start of a fire. Pressure in the cask is expected to peak at approximately 15 bar (205 psig) 8 hours following ignition of the fire. Thermal runaway of the fuel contained in the MCO is not expected.

Cask pressure in excess of design pressure may cause the cask to leak and to release H_2 gas into the affected Bay area. The maximum quantity of H_2 gas that could be released into the Bay from the scenario 1 fire is predicted to be 32 g (360 liters) with an additional 32 g (360 liters) released over the following 8 hours. In the absence of a thermal runaway reaction, release of significant quantities of radionuclides is not expected to occur with the leaking H_2 gas. The affect on the facility structure of an explosion involving 720 liters of hydrogen gas may be put into perspective by comparison with the hydrogen explosion involving 2,000 liters of hydrogen inside of a Bay as evaluated by the SAR for the MCO overpressurization accident.

The SAR description of the MCO overpressurization accident describes a hydrogen explosion within a Bay involving up to 2 m^3 (2,000 liters) of hydrogen gas, small quantities of helium, and air. The SAR evaluation concludes that average pressure increase in the Bay resulting from such an explosion would be less than 0.024 bar (0.35 psi). According to *Chemical Process Safety Fundamentals with Applications* (Crowl 1990), this overpressure condition is not expected to cause significant building damage.

Since thermal runaway is not predicted for a scenario 1 fire, release of significant quantities of radionuclides from the cask is not expected. Accordingly, decontamination of the affected Bay is not expected as a result of a tractor and transporter tire fire.

For a scenario 4 fire, the analysis performed by the SNF Safety Analysis Group concludes that the pressure within the MCO (the cask lid is removed and MCO is processing) would not exceed 1 bar (14.6 psig) since a continuous vent path would be established due to loss of flexible hose integrity. The analysis does not predict thermal runaway of the fuel, a cask or MCO overpressure condition, accumulation and release of significant quantities of hydrogen gas into the Bay area, or release of radionuclides to the Bay or to the environment. The heat released by this fire scenario will generate bay temperatures in excess of 600°C and, has the potential to cause fire related structural damage to the unprotected steel components present in each Bay, and destruction of all equipment within the affected bay. Additionally, structural and fire damage may extend to adjacent Bays and building areas given the extent of unprotected structural steel components and roof system, and the lack of fire rated construction of the CVDF. No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire as noted in Chapter 3 of the SAR and Appendix E.

The MPFL fire loss consists of reconstruction of 3 Bays with one bay a complete loss and 25% of the equipment in the two adjacent bays salvageable. The cost to rebuild this part of the CVDF and to replace damaged systems is $4,478,000. Decontamination and cleanup costs are $142,300 and facility restart costs are $3,041,333. This MPFL fire would suspend SNF operations for 18 months and involve 3 Bays. The MPFL for the Bay and Bay Support Area fire is tabulated as follows:

Maximum Possible Fire Loss is as noted:

Property replacement/restoration cost	=	$4,478,000
Decontamination and cleanup costs	=	$ 42,300
Facility Restart cost	=	$3,041,333
Total Bay and Bay Support Area MPFL	=	$7,661,663

10.2 Maximum Credible Fire Loss

Maximum Credible Fire Loss (MCFL) is defined as "The property damage that would be expected from a fire, assuming that:

(1) All installed fire protection systems function as designed.
(2) The effect of emergency response is omitted except for post-fire actions such as salvage work, shutting down water systems, and restoring operation."

Operations Support Area

The MCFL for the Operations Support Area is assumed to occur in the area containing the highest concentration of high value equipment. This area is taken to be the control room, containing the Monitoring and Control System (MCS) associated MCS and SCIC panels, and furniture. A fire in the control room is assumed to actuate the automatic sprinkler system. The sprinkler system will control the fire in the area of the control room to prevent fire spread to other parts of the facility, but will damage and require replacement of control room equipment.
The MCFL for this area consists of reconstruction of the control room and replacement of damaged property and equipment and cleanup. The losses for this event are estimated at $164,165, with suspended operations for an estimated three months. This fire would effect all four Bays. (See Appendix C *Maximum Credible Fire Loss*).

Operations Support Area MCFL is calculated to be:

Equipment	$ 150,000
Furnishings	$ 10,000
Cleanup	$ 4,165
Total Operations Support Area MCFL =	$ 164,165

Bay Support Area and Bay Areas

The Bay and Bay Support Areas MCFL involves a tractor fire with bay overhead door open or a transporter tire fire with the bay overhead door closed. In both cases, the automatic sprinkler system in the affected bay is assumed to initiate to control the fire. A tractor fire would not spread to transporter tires, as would occur during the MPFL fire scenario. The tractor fire would expose adjacent mezzanine supports, one train of the SCHe system, and the 0.25 m (10 in) thick exterior precast concrete panel in the vicinity of the overhead door to intense heat. Due to sprinkler system initiation, the Bay walls and roof are not expected to sustain significant damage, and the structural integrity of the bay is not expected to be threatened.

A transporter tire fire would burn beneath the transporter, shielded by the transporter deck. The presence of the transporter deck between the fire and automatic sprinkler spray detrimentally affects the ability of the sprinkler system to suppress this fire. The sprinkler system controls and confines the tire fire to the area beneath the transporter. The roof and walls would be protected by water spray from the automatic sprinkler system. Equipment in the vicinity of the burning transporter tires would by damaged and require replacement. Equipment in this vicinity includes adjacent mezzanine supports, one train of the SCHe system, the Process Equipment Skid, and SCIC system.

MCFL is calculated for the transporter tire fire due to the larger potential for damaged equipment and MCO in process status. The MCFL for the Bay and Bay Support Areas consists of partial reconstruction of a single Bay, repair, or replacement, of damaged equipment. The property and cleanup losses for this fire are estimated to be $1,512,285. Suspended operations is estimated to be six months and affect two Bays due to loss of safety class equipment required to operate two bays. (See Appendix C).

Bay and Bay Support Area MCFL is calculated to be:

SCHe		$ 235,000
SCIC		$ 380,000
Process Equipment Skid		$ 550,000
Bay Damage		$ 300,000
Cleanup		$ 47,285
Total Bay and Bay Support Area MCFL	=	$1,512,285

11.0 HANFORD FIRE DEPARTMENT RESPONSE

A properly equipped and adequately trained fire department is an essential part of a redundant fire protection system, in accordance with DOE 5480.7A. The Hanford Fire Department meets these requirements and credit is given for their response within 20 minutes as part of the redundant fire protection system at the CVDF. The fire department is fully staffed, trained, and equipped. Fire department vehicle access to the CVDF is provided by paved or graveled roads.

The primary response to an alarm condition in the 100-K Area by the Hanford Fire Department is from the 100 Area Fire Station. The station is manned Monday through Friday from 0700 to 1700 hours. Response time to the CVDF is approximately 5 minutes. Simultaneously, a crew from the 200 Area Fire Station is dispatched to the CVDF; their estimated response time is 15 to 20 minutes. The 100 Area Fire Station, including personnel, trucks, and equipment, is expected to relocate to an undetermined site in the 100-K or 100-N Areas. During the time when the 100 Area Fire Station is not manned, the 200 Area Fire Station will be the primary responder.

The Hanford Fire Department has prepared a pre-fire plan for the CVDF.

12.0 RECOVERY POTENTIAL

Bays and Process Support Area

It is estimated that it would take up to 18 months to completely recover from an MPFL event in these areas. A schedule delay for cold vacuum drying of the MCOs would be expected. The MPFL event could impact three Bays for 18 months for procurement of replacement equipment, repairs, installation, and testing. Recovery from the MCFL event is estimated at 6 months for procurement, salvage, installation, and testing of damaged control system equipment in a single bay.

Operations Support Area

Recovery from the control room MPFL event is estimated at 6 months for procurement, salvage, installation, and testing of damaged control system equipment. Any event that delays processing of the SNF from the K-Basins could jeopardize timely completion of milestones associated with fuel, sludge, and debris removal. Recovery from the MCFL event is estimated at 3 months for procurement, salvage, installation, and testing of damaged control system equipment.

13.0 POTENTIAL FOR A TOXICOLOGICAL, BIOLOGICAL, AND/OR RADIOLOGICAL INCIDENT DUE TO A FIRE

13.1 Toxicological Release

There are no process chemicals or waste chemicals present in the CVDF. There are no processing activities or generation of waste streams in this facility. Ordinary industrial chemicals may be allowed at the facility, such as solvents and cleaners, paint, printer toner, etc. Specific chemicals have not been identified nor are there any expected unacceptable hazards associated with these chemicals. Unless these chemicals are brought into the facility in inordinate quantities, they represent hazards that are accepted on a daily basis by the general public and, therefore, are outside the scope of this FHA.

13.2 Biological Release

Biological processes are not part of project and therefore the potential for fire-induced releases is considered minimal.

13.3 Radiological Release

A simplified analysis of the effect of heat generated by a Scenario 1 and Scenario 4 fire on the SNF contained in a cask and nominal MCO was performed using the HANSF computer code. See Appendix E.

Release of radionuclides into the environment from the cask and MCO is not expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire.

However, it is possible that up to 0.094g SNF could be released by a fire breaching the local or general exhaust system HEPA filters as noted in the SAR Appendix B, section B3.4.2.3.4. This limit was determined by the SAR review of the HVAC system based on technical safety requirements of build up on the filters.

14.0 EMERGENCY PLANNING

A Building Emergency Plan has been prepared to address potential emergency conditions (including fire) and the proper responses to minimize dangerous condition and damage, see HNF-IP-0263-SNF, Rev. 2, Building Emergency Plan for 100K Basins and Cold Vacuum Drying Facility.

15.0 SECURITY AND SAFEGUARDS CONSIDERATIONS RELATED TO FIRE PROTECTION

Access to the CVDF site will be controlled. The Hanford Fire Department will have possession of a grand master key that will allow access to the CVDF and yard in response to an alarm. There are no special security requirements that would effect fire department access to, or personnel egress from this facility.

16.0 NATURAL HAZARDS IMPACT ON FIRE SAFETY

Natural phenomena hazards design requirements are discussed in WHC-SD-SNF-DB-0010, *Cold Vacuum Dry System Natural Phenomena Hazards*. Fire safety impacts are not expected to the CVDF due to natural phenomena hazards.

16.1 Floods

The CVDF finished floor elevation as shown on Drawing H-1-82092 is 142.4 m (476 ft). The maximum flood for a PC2 facility is 131.06 m (430 ft) and 138.68 m (455 ft) for a PC3 facility as noted in Table 10 of HNF-PRO-097, *Engineering Design and Evaluation*. The CVDF is 6.4 m (21 ft) higher than the postulated flood elevation for the 100-K Area. Therefore, the CVDF area is out of the flood plain and there is no postulated flood that would compromise fire safety.

16.2 Tornadoes

The Hanford Site is not in a tornado area as noted in HNF-PRO-097 and changes are not warranted to protect against tornadoes.

16.3 Earthquakes

The building and its components are reportedly designed for a seismic event in accordance with UBC and Hanford Site requirements. However, an evaluation of the seismic design is on going. A fire following an earthquake is not considered a credible event as the CVDF lacks easily ignitable materials, such as flammable liquids.

16.4 Lightning

A direct strike to a building could cause structural damage to the point of impact and would also cause a voltage surge through the structural frame of the building or equipment. These voltage surges could cause substantial damage to electronic components. Lightning protection meets the requirements of NFPA 780, *Installation of Lightning Protection Systems*

17.0 EXPOSURE FIRE POTENTIAL

The fire exposures to and from the CVDF were reviewed in accordance with NFPA 80A, *Exterior Fire Exposures*. NFPA 80A is intended to combat the ignition of combustibles by means of radiate heat, in or on exposed buildings, by providing adequate separation. Separation distance is calculated by multiplying a guide number by the lesser dimension, then adding 5 ft (determined from NFPA 80A, Table 2-3, based on width versus height or height versus width ratios). NFPA 80A allows certain exceptions and reductions of separation distances.

The CVDF is not considered an exposing hazard due to the sprinkler coverage to be provided throughout the facility. No buildings that would pose an exposure hazard exist or are planned to be located in the vicinity of the CVDF.

Range fire presents an exposure potential at the Hanford Site. A clear space of at least 7.5 m (25 ft) is provided from the south wall of the CVDF to the security fence. At least twice that distance of clear space is provided from other sides of the facility to the fence. Vegetation within the 46 m (150 ft) wide space between the security fence and the 100-K Area perimeter fence is insufficient to present a fire threat to the CVDF. However, minimal damage would be expected due to the noncombustible construction of the building walls.

18.0 FINDINGS, RECOMMENDATIONS, AND ACTIONS

Concerns were identified during the preparation of Revision 0 of the FHA. Most of these concerns dealt with the areas of design and construction of the CVDF. The original design of the CVDF did not comply with DOE Order requirements. Corrective action during the end of the construction closed most out of these concerns.

The fire modeling has shown that even a fire as small as that of a "standard step-off pad" with three barrels of SWP clothing can result in building and equipment damage. In addition, even a fire smaller than described above can raise the bay temperatures to a point that may the operation of the SC equipment in all of the bays is questionable due to the electrical power. This supply could be lost due to insulation failure in the conduits. A combustible control program has been instituted to reduce the impact if a fire was started.

The completion of the recommendations brings the CVDF into compliance with the DOE Orders. The facility will be operated under restrictions, such as stringent limits on combustible or other administrative controls.

Agreement has been received from DOE RL. The agreement for the deviations and exemptions, along with administrative controls is noted in DOE Letter No. 995692, dated September 23, 1999, P. G. Loscoe to R. D. Hanson, attached as Appendix I Implementation of the performance-based program referred to below requires that combustible materials be limited to the amounts listed in Table 3.1 in the CVD FHA Implementation Plan, SNF-4942, Rev. 1.

The following is the status of the previous Finding and Recommendations.

Finding 18.1

A MPFL type fire as noted in the fire models will cause a major loss of this facility. The operations could be shut down for up to 18 months as the result of major building and equipment damage. Even a small fire could cause the shut down of operations due to potential damage to the electrical supply for the SC systems.

Recommendation 18.1

Provide two-hour fire rated enclosures for the storage of anti-C clothing (SWPs) and other combustible throughout the Bay Support Area and the Bays. This would also include the upgrading of the anterooms into the Bays to two-hour fire rated construction. In addition, combustible must be limited to those as noted in Table 3.1 in the CVD FHA Implementation Plan, SNF-4942, Rev. 1.

Status of Recommendation 18.1

This recommendation has been completed. DCN W-441-281 was completed that installed the required firewalls. The performance-based program to control combustibles within the limits noted in Table 3.1 in the CVD FHA Implementation Plan, SNF-4942, Rev. 1 has been instituted by Spent Nuclear Fuel Project Administrative Procedure FP-4-014-2, Fire Protection Programs effective date 3/23/00.

Finding 18.2

The HEPA filters lack adequate automatic fire protection systems, drains, 2-hour fire-rated enclosures, and heat detection. RLID 5480.7 requires fire protection of the final exhaust and confinement HEPA filters in nuclear facilities as identified in RLID 5480.7, Section 8.2.c, *Filter Plenum Fire Protection Criteria.*

Recommendation 18.2

The required final HEPA filter plenum fire protection features need to be installed to protect the HEPA filters as outlined in DOE–STD-1066-97, Appendix C.

Note: The installation of a deluge system and other devices will not eliminate the possibility of plugging the filters by particles in the smoke. The postulated release is within the onsite and offsite release dose rate without protection being installed.

Status of Recommendation 18.2

The control of combustibles as noted in Procedure FP-4-014-2 and the DOE RL approval of the exemption request noted in DOE Letter 9956962 provides a level of fire protection equal to that as required by DOE Orders. This action satisfies the intent of this recommendation but does not correct the noted deficiency.

Finding 18.3

The fire modeling indicates that the tractor fire will cause unacceptable damage levels to the Bays.

Recommendation 18.3

The tractor needs to be unhooked from the trailer unit as soon as possible after the trailer has been placed into the bay. In addition, a "long tongue dolly" is required for the movement of the trailer into the bay. The tractor needs to be kept at least 3.6-m (12-ft) from the building.

Status of Recommendation 18.3

Operations has developed a AP for tractor docking control, Spent Nuclear Fuel Project Procedures, *CP-24-002V, Inspection of Vehicles Entering CVDF Bays, OP-94-004V, Process MCO/Cask Transporter In/Out of Bay, OP-94-011V, Verify Bay #4 is Ready for Use, and OP-94-012V, Verify Bay #5 is Ready for Use. This procedure* has been instituted to control truck-trailer movement into and out of the Bays. This procedure establishes the operation of the tractor-trailer inspection and movement. The use of this procedure eliminates the need for the separation distance between the building and the tractor, which eliminates the need for a long tongue dolly. This procedure contains the necessary actions to assure that the fire potential has been reduced to the lowest possible level. The use of this procedure satisfies the recommendation and closes it out.

Finding 18.4

The processing bays contain Safety Class systems. These Safety Class systems are not protected from the effects of a fire event as required by DOE 6430.1A and 5480.7A.

Recommendation 18.4

The Safety Class systems need to be provided with passive protection from the effects of a fire in the processing bays. This protection needs to in the form of 2-hour fire-rated barriers that would put the Safety Class system in their own fire area.

Status of Recommendation 18.4

Fire protection of the Safety Class systems as defined by DOE 6430.1A and 5480.7A needs to be provided or protected redundant systems need to be installed

The control of combustibles as noted in Procedure CP-24-001V and the DOE RL approval of the exemption request noted in DOE Letter 9956962 provides a level of fire protection equal to that as required by DOE Orders. This action satisfies the intent of this recommendation but does not correct the noted deficiency. DOE RL approval of the exemption noted in DOE Letter 9956962 severs as to relieve the facility of obtaining a waiver for this requirement. Action on this recommendation has been completed.

Finding 18.5

DOE 6430.1A, Section 0110-99.0.6 requires that the secondary confinement (walls and roof) remain standing following a design base fire and the confinement have a minimum 2-hour fire rating. This rating shall not be achieved through the use of membrane fireproofing. However, fire-rated construction has not been provided.

Recommendation 18.5

The exterior walls and the roof of the Bays need to be upgraded to a 2-hour fire rating as required by DOE 6430.1A. This would include changes to the walls, new doors, and an upgrade to the roof. The upgrades to meet the fire resistance can't be of the membrane type. DOE 6430.1A does not allow the use of membrane as part of the secondary confinement.

Status of Recommendation 18.5

Finding 18.5 does not apply (see Appendix B of CVD FHA Implementation Plan, SNF-4942, Rev. 1, letter from DOE-Richland Operations Office to FDH).

Finding 18.6

An automatic sprinkler protection system has been provided in the Operations Support Area. The area is designed for Ordinary Hazard Group 1 occupancy in accordance with NFPA 13. However, the DRD, Sections 6.7.2.c and 6.7.4.1.g requires that the sprinkler system be designed for Ordinary Hazard Group 2 occupancy.

Recommendation 18.6

The sprinkler system in the Operations Support Area needs to be upgraded to the required design of Ordinary Hazard Group 2 occupancy.

Status of Recommendation 18.6

This recommendation has been completed. DCN W441-266 was completed which upgraded the sprinkler system to an Ordinary Hazard Group 2 occupancy installation. The drawings and calculations were updated to account for these changes.

Finding 18.7

Areas of the facility are still under construction. It is possible that changes could be made during the construction process that are not accounted for in this FHA

Recommendation 18.7

The FHA should be updated at the end of construction and again at the start of operation. This updated to the FHA will take into account any changes in the construction and operations.

Status of Recommendation 18.7

The FHA has been updated as required and issued as SNF-4268 Revision 1. This recommendation has been completed.

Finding 18.8

Areas in the Bays are lacking adequate automatic sprinkler coverage. The areas included under the walkways to the mezzanine located equipment.

Recommendation 18.8

Review the sprinkler system as installed to ensure adequate coverage is provided throughout the CVDF. Additional heads may need to be installed. If new heads are installed, the existing hydraulic calculation and drawings will require updating.

Status of Recommendation 18. 8

DCN W-441-234, DCN-W441-179, and DCN-441-192 have been completed which added the required sprinklers to the system. . The drawings and calculations were updated to account for these changes. This closes out this recommendation.

Finding 18.9

DOE 5480.7A requires that UL listed or FM approved Class A HEPA filters be installed in the HVAC filter units. The filters as installed are combustible and will and not provide the required containment.

Recommendation 18.9

Install UL listed or FM approved Class A HEPA filters in the HEPA units.

Status of Recommendation 18.9

UL listed Class A HEPA filters were procured. These filters were noted to be on-site and will be installed prior to operations, thus this recommendation is closed.

Finding 18.10

RLID 5480.7, Paragraph 8.1.e requires that fire department standpipe connections be provided in areas that have the potential of radioactive contamination. These standpipes need to be UL listed or FM approved and installed to allow the fire hoses into the confinement structure without blocking open doors.

Recommendation 18.10

Install UL listed or FM approved fire department standpipe connections in the Bays.

Status of Recommendation 18.10

This recommendation has been exempted as noted in DOE letter number 9956962, dated September 23, 1999.

Finding 18.11

Structural steel building frame members in the Bay Support Area were noted to be entering the firewall at the interface with the Operations Support Area and were connected to the steel wall frame members. To be considered a 2-hour fire-rated wall, all connecting steel to the wall needs to be provided with fire-rated materials in compliance with the UBC. This protection is usually provided back to the next column line and also may include a fire-rated covering for the columns and intermediate steel.

This 2-hour fire-rated wall extends 738 mm (27 in.) above the Office Support Area roof, then becomes a non-fire rated insulated metal wall that continues up the remaining 4.2 m (13 ft 8 in.) to the level of the Bay Support Area roof. The UBC requires that, where an area separation wall separates portions of buildings of different heights, such wall may terminate at a point 762 mm (30 in.) above the lower roof level, provided the exterior wall for a height of 3048 mm (10 ft) above the lower roof is of 1-hour fire-resistive construction with openings protected by assemblies having a 3/4-hour fire-protection rating. The CVDF does not meet this UBC requirement.

Also, it has been noted that the pre-cast concrete panel separating Bay 5 from the Operations Support Area may not be 2-hour fire rated as required by UBC and CVDF design criteria.

Recommendation 18.11

Provide a 2-hour fire rated configuration.

Status of Recommendation 18.11

This recommendation has been completed. DCN W-441-292 was completed which upgraded the wall to a 2-hour fire rating.

Finding 18.12

A section of PVC piping was installed where the feed main for the CVDF fire main loop passes through the tunnel wall of the 165KW building. This arrangement is not acceptable. The Uniform Plumbing Code requires that a metal pipe be installed rather than the plastic piping.

Recommendation 18.12

Replace the PVC pipe with a UL listed or FM approved metal pipe such ductile iron pipe.

Status of Recommendation 18.12

This recommendation has been completed. DCN W-441-266 replaced the 6-inch section of PVC pipe with ductile iron pipe. This work has been accomplished.

19.0 REFERENCES

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APPENDIX A

FIRE MODELS

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PURPOSE

The attached fire scenarios, assumptions, and computer fire modeling inputs and results, establish the basis for the unmitigated design basis fire (DBF) at the Cold Vacuum Drying Facility (CVDF). The results of each model and conclusions drawn are intended for input to the CVDF Fire Hazard Analysis (FHA) and Safety Analysis Report (SAR).

DESCRIPTION

The attached fire scenarios have been developed by evaluating the characteristics, quantity, location, and burning behavior, of a fire involving the anticipated combustible material in a CVDF processing bay during CVDF operation. Only significant quantities of combustible materials are evaluated. Minor quantities of combustible materials will be controlled separately by combustible load limits imposed on the CVDF by the FHA.

The computer fire modeling software used, *FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport*, was developed by the U.S. Department of Commerce, National Institute of Standards and Technology (NIST). Use of FAST fire modeling software is an acceptable tool in the development of an FHA for facilities at the Hanford Site as described by Project Hanford Procedures, HNF-PRO-350, *Fire Hazard Analysis Requirements*, when applied by qualified fire protection engineers and as approved by the RL authority having jurisdiction. The specific software version of FAST used for these models is FAST Version 3.1.3 dated April 1, 1998. Approval of the RL authority having jurisdiction is accomplished upon RL's approval of the FHA.

Unmitigated fire scenarios are evaluated for the CVDF. Each scenario is briefly described below.

Fire Scenario 1

Scenario 1 occurs with the tractor and transporter backing into, or parked in, a CVDF processing bay. The large bay door is open, the MCO is not connected to any processing equipment, and HVAC systems are assumed OFF. The tractor cab is assumed to ignite by an electrical short circuit in the tractor wiring. The resulting fire begins in the cab and spreads to the engine compartment, front tractor tires, diesel fuel, rear tractor tires, and transporter tires. The fire is modeled assuming that the cab, engine compartment, and all tires are lumped combustibles. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. Ignition and instantaneous fire growth of diesel fuel to steady state peak heat release rate is assumed to occur upon fire growth to the peak heat release rate corresponding to the lumped combustibles without diesel fuel. The fire is assumed to burn to completion with a 30 second decay period for lumped combustibles and instantaneous decay for diesel fuel.

Fire Scenario 2

Scenario 2 is the same as Scenario 1 except that the transporter tires are treated separately and assumed to ignite 20 minutes after ignition of the lumped tractor cab, engine compartment, front and rear tires.

Fire Scenario 3

Scenario 3 is the same as Scenarios 1 and 2 except that ignition and fire involing the tractor cab, engine compartment, front tires, diesel fuel, and rear tires, is not assumed to spread to the transporter tires.

Fire Scenario 4

Scenario 4 occurs with the transporter inside a CVDF processing bay. The large bay door is closed and the MCO is connected to processing equipment. There is no viable ignition source for the transporter tires in a CVDF processing bay, however, since the CVDF is a non-reactor nuclear facility, an ignition source with sufficient power is assumed to exist and ignite the transporter tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. The fire is unconstrained with unlimited oxygen supply. The transporter tire fire is assumed to burn to completion with a 30 second decay period.

Fire Scenario 5

Scenario 5 is identical to fire scenario 4, except that the oxygen supply is limited due to the closed process bay.

Fire Scenario 6

Scenario 6:

- Characterizes and evaluates the affect on a Process Bay of a step off pad fire.
- Determines the distance of a step off pad arrangement in a CVDF Process Bay from walls, structural columns, and mezzanine supports, to prevent damage to walls and to maintain structural integrity during a fire.
- Examines and determines the radiative heat transfer rate necessary to ignite transporter tires in a Process Bay, including the minimum required distance of a step off pad from the transporter tires to prevent ignition during an step off pad exposure fire.

Fire Scenario 7

Fire scenario 7 examines the affect of a fire in a Process Bay Support Area change room. This room is a relatively small volume and is assumed to be a 2-hour fire rated room.

GENERAL ASSUMPTIONS

1. Tractor is H.O.#68E-2498.

2. Two (2) front tractor tires are Goodyear size 385/65R22.5.

3. Eight (8) rear tractor tires are Goodyear size 11R22.5.

4. Twelve (12) transporter tires are Bridgestone size 275/70R22.5.

5. Combustible parts of the tires consist of 100% polychloroprene (neoprene).

6. Tractor cab and engine compartment equivalent combustible loading consists of a 100 kg (220 lbs.) sofa with polyurethane foam padding, cotton and rayon fabric, and non-combustible frame.

7. Typical tractor includes two 378 liter (100 gal) diesel fuel oil tanks, located just behind the cab, and just forward of the rear tires. Assume that administrative controls are in place to limit diesel fuel inventory to one filled diesel fuel oil tank.

8. Kerosene and its associated material properties is assumed to represent diesel fuel oil. Kerosene is slightly more volatile than diesel fuel oil. Flashpoint of diesel fuel is 54.4°C (130°F). Flashpoint of Kerosene is 37.8°C (100°F).

9. Fire growth is assumed to follow the power-law fire growth model ($Q = \alpha t^2$) for cab, engine compartment, and tires, with power intensity coefficient for a medium-fast growth fire ($\alpha = 0.0469$ kW/sec^2).

10. Fire decay time is modeled as 30 seconds for cab, engine compartment, and tires.

11. Instantaneous rate of fire growth is assumed for diesel fuel oil fire.

12. Fire decay time is modeled as instantaneous for diesel fuel oil fire.

13. Assume diesel fuel burns in a pool on the ground. Area of diesel fuel burn is assumed to be the equivalent area of a circle of diameter equal to tractor width [2.4 m (8 ft.)].

14. Ignition of tractor cab, or engine compartment, is by electrical short circuit. Fire propagates freely between cab and engine compartment.

15. Ignition of front tires is by radiant and hot gas exposure to cab and engine compartment fire.

16. Ignition of diesel fuel is by radiant exposure to cab, engine compartment, front tire, and rear tire fire.

17. Ignition of tractor rear tires is by radiant exposure to cab, engine compartment, front tires, diesel fuel fire and upper hot gas layer that develops in the CVDF processing bay.

18. Once ignited, the fire grows to peak heat release rate and burns to completion. Ignition of diesel fuel is assumed to occur at the onset of peak heat release of the tractor cab, engine compartment, front tire, and rear tire fire. Growth and decay of the diesel fuel fire is instantaneous and diesel fuel burns to completion.

19. Other miscellaneous combustibles in the Process Bay, including lubricants, oils, rubber hoses, recirculation HEPA filters, wiring in conduit, and minimal transient combustibles, are not a significant fire load compared to tractor and transporter combustibles. These other combustibles are not included in the fire modeling effort and would not change the conclusion drawn by fire modeling.

DATA

1. Material Quantities and Properties

Material Description	Mass (M)	Ignition Temperature	Mass Loss Rate (M_b)	Heat of Combustion (H_c)	Peak Heat Release Rate (Q)	Reference
Tractor Front Tires (385/65R22.5)	82.3 kg (181 lbs.)/tire	$T_{surface}$ = 350°C (662°F)	26.7 g/sec-m²	34,815 kJ/kg (15,000 Btu/lb.)	M_b x H_c = 929,560 W/m²	NRC, 1988 Goodyear Product Catalog NFPA, 1994 SFPE, 1988
Tractor Rear Tires (11R22.5)	58.6 kg (129 lbs.)/tire	$T_{surface}$ = 350°C (662°F)	26.7 g/sec-m²	34,815 kJ/kg (15,000 Btu/lb.)	M_b x H_c = 929,560 W/m²	NRC, 1988 Goodyear Product Catalog NFPA, 1994 SFPE, 1988
Transporter Tires (275/70R22.5)	50 kg (110 lbs.)/tire	$T_{surface}$ = 350°C (662°F)	26.7 g/sec-m²	34,815 kJ/kg (15,000 Btu/lb.)	M_b x H_c = 929,560 W/m²	NRC, 1988 Bridgestone Product Catalog NFPA, 1994 SFPE, 1988
Diesel Fuel (Kerosene)	378 l (100 gal.) 312 kg (686 lbs.)	210°C (410°F)	49.0 g/sec-m²	40,800 kJ/kg	1,999 kW/m²	NFPA, 1991 SFPE, 1988
Cab and Engine Compartment	100 kg (220 lbs.)	--	--	23,000 kJ/kg	3,000 kW	SFPE, 1988

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CVDF Fire Scenario 1

Fire Modeling and Evaluation
of a Fire Involving
Tractor Cab, Engine Compartment, Front and Rear Tires, Diesel Fuel, and Transporter
Tires
in a Cold Vacuum Drying Facility Processing Bay

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CVDF Fire Scenario 1

DISCUSSION

CVDF Fire Scenario 1 occurs with the tractor and transporter backing into, or parked in, a CVDF processing bay. The large bay door is open, the MCO is not connected to any processing equipment, and HVAC systems are assumed OFF. The tractor cab is assumed to ignite by an electrical short circuit in the tractor wiring. The resulting fire begins in the cab and spreads to the engine compartment, front tractor tires, diesel fuel, rear tractor tires, and transporter tires. The fire is modeled assuming that the cab, engine compartment, and all tires are lumped combustibles. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. Ignition and instantaneous fire growth of diesel fuel to steady state peak heat release rate is assumed to occur upon fire growth to the peak heat release rate corresponding to the lumped combustibles without diesel fuel. The fire is assumed to burn to completion with a 30 second decay period for lumped combustibles and instantaneous decay for diesel fuel.

DETERMINE DATA FOR INPUT TO FAST COMPUTER FIRE MODELING SOFTWARE

1. Determine initial combustible material inventory (I_o) in kJ:

   a. Tractor Cab and Engine Compartment:

      $M = 100$ kg

      $H_c = 23{,}000$ kJ/kg

      $I_o = M\,H_c = 2{,}300{,}000$ kJ

   b. Tractor Front Tires

      $M = (2)(82.3\text{ kg}) = 164.6$ kg

      $H_c = 34{,}815$ kJ/kg

      $I_o = M\,H_c = 5{,}730{,}549$ kJ

   c. Tractor Rear Tires:

      $M = (8)(58.6\text{ kg}) = 468.8$ kg

      $H_c = 34{,}815$ kJ/kg

      $I_o = M\,H_c = 16{,}321{,}272$ kJ

d. Transporter Tires:

$M = (12)(50.0 \text{ kg}) = 600 \text{ kg}$

$H_c = 34{,}815 \text{ kJ/kg}$

$I_o = M\,H_c = 20{,}889{,}000 \text{ kJ}$

e. Diesel Fuel:

$M = 312 \text{ kg}$

$H_c = 40{,}800 \text{ kJ/kg}$

$I_o = M\,H_c = 12{,}729{,}600 \text{ kJ}$

Material Description	I_o
Tractor Cab/Engine Compartment	2,300,000 kJ
Front Tires	5,730,549 kJ
Rear Tires	16,321,272 kJ
Transporter Tires	20,889,000 kJ
Sub-Total ($I_{olumped}$)	45,240,821 kJ
Diesel Fuel	12,729,600 kJ
Total	57,970,421 kJ

2. Develop heat release rate and combustible inventory vs. time:

a. Calculate peak heat release rate:

$$Q_{peak} = Q_{cab/enginecompt} + Q_{fronttires} + Q_{reartires} + Q_{transportertires} + Q_{dieselfuel}$$

$$Q_{cab/enginecompt} = 3{,}000 \text{ kW}$$

$$Q_{fronttires} = (q_{fronttires})(A_{fronttires})$$

$$q_{fronttires} = 929{,}560 \text{ W/m}^2$$

$$A_{fronttires} = (2 \text{ tires})\{(2\pi r_o w) + 2[\pi(r_o^2 - r_i^2)]\}$$

For Goodyear 385/65R22.5 tires:

$r_o = 0.54 \text{ m (21.2 in.)}$

$r_i = 0.29 \text{ m (11.25 in.)}$

$w = 0.38$ m (14.9 in.)

$A_{fronttires} = 5.2\ m^2$

$Q_{fronttires} = 4{,}834$ kW

$Q_{reartires} = (q_{reartires})(A_{reartires})$

$q_{reartires} = 929{,}560\ W/m^2$

$A_{reartires} = (8\ \text{tires})\{(2\pi r_o w) + 2[\pi(r_o^2 - r_i^2)]\}$

For Goodyear 11R22.5 tires:

$r_o = 0.53$ m (21.0 in.)

$r_i = 0.29$ m (11.25 in.)

$w = 0.28$ m (10.9 in.)

$A_{reartires} = 17.4\ m^2$

$Q_{reartires} = 16{,}175$ kW

$Q_{transportertires} = (q_{transportertires})(A_{transporttires})$

$q_{transportertires} = 929{,}560\ W/m^2$

$A_{transportertires} = (12\ \text{tires})\{(2\pi r_o w) + 2[\pi(r_o^2 - r_i^2)]\}$

For Bridgestone 275/70R22.5 tires:

$r_o = 0.48$ m (19.0 in.)

$r_i = 0.29$ m (11.25 in.)

$w = 0.29$ m (11.4 in.)

$A_{transportertires} = 21.5\ m^2$

$Q_{transportertires} = 19{,}986$ kW

$Q_{dieselfuel} = (q_{dieselfuel})(A_{dieselfuel})$

$q_{dieselfuel} = 1{,}999\ kW/m^2$

$A_{dieselfuel} = (\pi d^2)/4$

$d = 2.4$ m

$A_{dieselfuel} = 4.5$ m^2

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{peak} = 3{,}000$ kW + 4,834 kW + 16,175 kW + 19,986 kW + 8,996 kW

$Q_{peak} = 52{,}991$ kW

b. Calculate time to reach peak heat release rate:

$Q_{peak} = \alpha t^2 + Q_{dieselfuel}$

$Q_{lumped} = Q_{peak} - Q_{dieselfuel} = \alpha t^2$

$t = [(Q_{lumped})/\alpha]^{1/2}$

$Q_{peak} = 52{,}991$ kW

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{lumped} = 43{,}995$ kW

$\alpha = 0.0469$ kW/sec^2

$t = 968$ sec

c. Designate period of fire growth (i.e., t = 0 seconds to t = 968 seconds) as Period I.

d. Energy expended during Period I:

$$E_I = \int_0^t \alpha t^2 dt = \left.\frac{\alpha t^3}{3}\right|_0^t$$

$t = 968$ sec

$\alpha = 0.0469$ kW/sec^2

$E_I = 14{,}180{,}047$ kJ

e. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fI}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped)	45,240,821 kJ	14,180,047 kJ	31,060,774 kJ
Diesel Fuel	12,729,600 kJ	0 kJ	12,729,600 kJ
Total	57,970,421 kJ	14,180,047 kJ	43,790,374 kJ

f. Determine time from reaching Q_{peak} to burnout of diesel fuel:

(1) Diesel Fuel:

$$t = [(I_{fIdieselfuel})/Q_{dieselfuel}]$$

$$I_{fIdieselfuel} = 12{,}729{,}600 \text{ kJ}$$

$$Q_{dieselfuel} = 8{,}996 \text{ kW}$$

$$t = 1{,}415 \text{ sec}$$

g. Determine time from reaching Q_{peak} to beginning of 30 second decay at peak heat release rate for lumped materials:

(1) Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped):

$$t = [(I_{fIlumped} - (30 \text{ sec})(0.5)(Q_{lumped}))/Q_{lumped}]$$

$$I_{fIlumped} = 31{,}060{,}774 \text{ kJ}$$

$$Q_{lumped} = 43{,}995 \text{ kW}$$

$$t = 691 \text{ sec}$$

h. Designate period of steady state burning at Q_{peak} (i.e., t = 968 seconds to t = 1,659 seconds) as Period II.

i. Determine energy expended during Period II by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped):

$E_{IIlumped} = I_{fIlumped} - (30\ sec)(0.5)(Q_{lumped})$

$I_{fIlumped} = 31{,}060{,}774\ kJ$

$Q_{lumped} = 43{,}995\ kW$

$E_{IIlumped} = 30{,}400{,}849\ kJ$

(2) Diesel Fuel:

$E_{IIdieselfuel} = (Q_{dieselfuel})(t)$

$t = 691\ sec$

$Q_{dieselfuel} = 8{,}996\ kW$

$E_{IIdieselfuel} = 6{,}216{,}236\ kJ$

j. Tabulate change in combustible material inventory during Period II:

Material Description	I_{fI}	$E_{II}(\Delta I)$	I_{fII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped)	31,060,774 kJ	30,400,849 kJ	659,925 kJ
Diesel Fuel	12,729,600 kJ	6,216,236 kJ	6,513,364 kJ
Total	43,790,374 kJ	36,617,085 kJ	7,173,289 kJ

k. Designate 30 second decay period of lumped combustibles and steady state burning at $Q_{dieselfuel}$ (i.e., t = 1,659 seconds to t = 1,689 seconds) as Period III.

l. Determine energy expended during Period III:

(1) Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped):

$E_{IIIlumped} = (30\ sec)(0.5)(Q_{lumped})$

$Q_{lumped} = 43{,}995\ kW$

$E_{IIIlumped} = 659{,}925\ kJ$

(2) Diesel Fuel:

$E_{IIIdieselfuel} = (Q_{dieselfuel})(t)$

$t = 30$ sec

$Q_{dieselfuel} = 8{,}996$ kW

$E_{IIIdieselfuel} = 269{,}880$ kJ

m. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires	659,925 kJ	659,925 kJ	0 kJ
Diesel Fuel	6,513,364 kJ	269,880 kJ	6,243,484 kJ
Total	7,173,289 kJ	929,805 kJ	6,243,484 kJ

n. Determine time to burnout of diesel fuel:

(1) Diesel Fuel:

$t = [(I_{fIIIdieselfuel})/Q_{dieselfuel}]$

$I_{fIIIdieselfuel} = 6{,}243{,}484$ kJ

$Q_{dieselfuel} = 8{,}996$ kW

$t = 694$ sec

o. Designate time of steady state burning at $Q_{dieselfuel}$ (i.e., t = 1,689 seconds to t = 2,383 seconds) as Period IV.

p. Determine energy expended during Period IV:

(1) Diesel Fuel:

$E_{IVdieselfuel} = (Q_{dieselfuel})(t)$

$t = 694$ sec

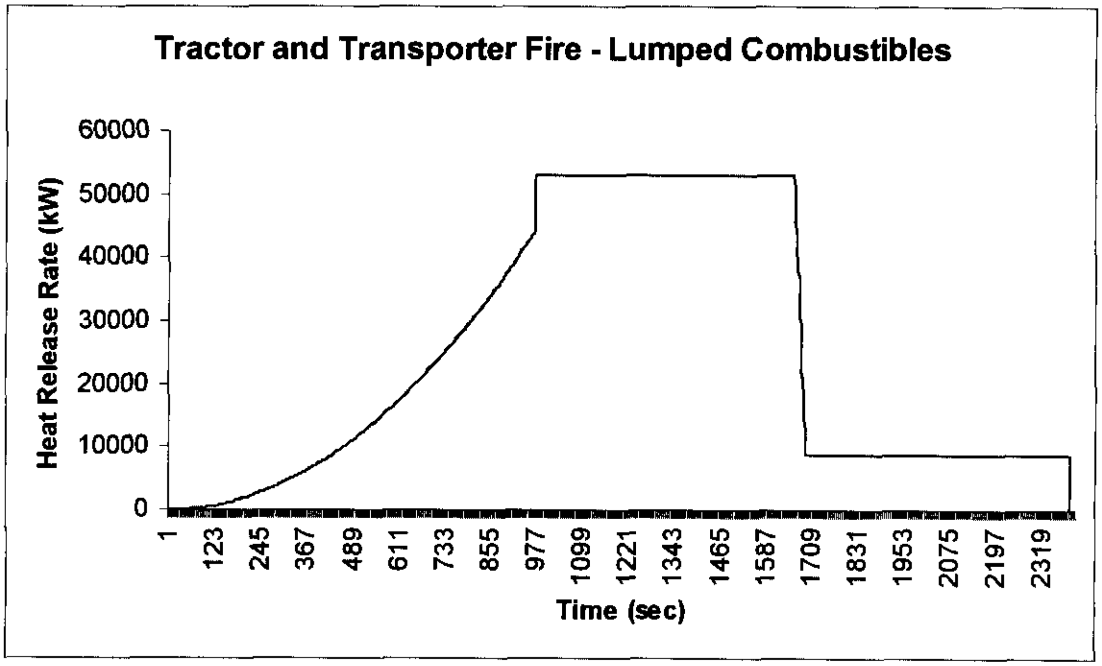
$Q_{dieselfuel} = 8{,}996$ kW

$E_{IIIdieselfuel} = 6{,}243{,}484$ kJ

q. Tabulate change in combustible material inventory during Period IV:

Material Description	I_{fIII}	$E_{IV}(\Delta I)$	I_{fIV}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires + Transporter Tires (lumped)	0 kJ	0 kJ	0 kJ
Diesel Fuel	6,243,484 kJ	6,243,484 kJ	0 kJ
Total	6,243,484 kJ	6,243,484 kJ	0 kJ

3. Resulting Heat Release Rate Curve:



4. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through IV):

a. Mass Loss Rate – Equation

(1) $M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

b. Period I (t = 0 seconds through t = 968 seconds):

(1) $M_{bI} = Q_I/H_{cI}$

(2) Determine weighted H_{cI}:

(a) Tires:

H_{ctires} = 34,815 kJ/kg

Mass:

(2 Front Tires)(82.3 kg/tire)	= 164.6 kg
(8 Rear Tires)(58.6 kg/tire)	= 468.8 kg
(12 Transporter Tires)(50 kg/tire)	= 600.0 kg

Total Tire Mass (M_{tires}) = 1,233.4 kg

(b) Cab and Engine Compartment:

$H_{ccab/enginecompt}$ = 23,000 kJ/kg

Cab/Engine Compt Mass ($M_{cab/enginecompt}$) = 100 kg

(c) Weighted H_{cI}:

$$H_{cI} = [M_{tires}/(M_{tires} + M_{cab/enginecompt})][H_{ctires}] + [M_{cab/enginecompt}/(M_{tires} + M_{cab/enginecompt})][H_{ccab/enginecompt}]$$

H_{cI} = 32,204 kJ/kg + 1,725 kJ/kg

H_{cI} = 33,929 kJ/ kg

(3) Determine Q_I at various times t:

$$Q_I = \alpha t^2$$

α = 0.0469 kW/sec²

(4) Determine M_{bI} and tabulate:

t (seconds)	Q_I (kW)	M_{bI} (kg/sec)
0	0	0
121	687	0.020
242	2750	0.081
363	6,187	0.182
484	10,999	0.324
605	17,186	0.507
726	24,747	0.729
847	33,684	0.993
968	43,995	1.297

c. Period II (t = 968 seconds through t = 1,659 seconds):

(1) $M_{bII} = Q_{IIlumped}/H_{cIIlumped} + Q_{dieselfuel}/H_{cdieselfuel}$

(a) Determine $H_{cIIlumped}$:

$H_{cIIlumped} = H_{cI}$

$H_{cIIlumped} = 33{,}929$ kJ/kg

(b) Determine $H_{cdieselfuel}$:

$H_{cdieselfuel} = 40{,}800$ kJ/kg

(c) Determine Q_{II}:

$Q_{II} = Q_{IIlumped} + Q_{dieselfuel}$

$Q_{IIlumped} = 43{,}995$ kW

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{II} = Q_{IIlumped} + Q_{dieselfuel}$

(2) Determine M_{bII} and tabulate:

t (seconds)	Q_{II} (kW)	M_{bII} (kg/sec)
969	52,991	1.517
1,659	52,991	1.517

d. Period III (t = 1,659 seconds through t = 1,689 seconds):

(1) $M_{bIII} = Q_{IIIlumped}/H_{cIIIlumped} + Q_{dieselfuel}/H_{cdieselfuel}$

(a) Determine $H_{cIIIlumped}$:

$H_{cIIIlumped} = H_{cIIlumped} = 33{,}929$ kJ/ kg

$H_{cdieselfuel} = 40{,}800$ kJ/kg

(b) Determine Q_{III}:

At t = 1,659, $Q_{IIIlumped} = Q_{IIlumped} = 43{,}995$ kW

At t = 1,689, $Q_{IIIlumped} = 0$ kW

$Q_{dieselfuel} = 8{,}996$ kW

(2) Determine M_{bIII} and tabulate:

t (seconds)	Q_{III} (kW)	M_{bIII} (kg/sec)
1,659	52,991	1.517
1,689	8,996	0.220

e. Period IV (t = 1,689 seconds to t = 2,383 seconds):

(1) $M_{bIV} = Q_{dieselfuel}/H_{cdieselfuel}$

$H_{cdieselfuel} = 40{,}800$ kJ/kg

$Q_{dieselfuel} = 8{,}996$ kW:

(2) Determine M_{bIV} and tabulate:

t (seconds)	Q_{IV} (kW)	M_{bIV} (kg/sec)
1,689	8,996	0.220
2,383	8,996	0.220
2,383	0	0

5. FAST Input Data:

```
VERSN    3TRACTOR AND TRANSPORTER FIRE - LUMPED
#VERSN 3 TRACTOR AND TRANSPORTER FIRE - LUMPED
TIMES   3600      0     120     20      0
DUMPR S1.HI
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.30000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
HVENT  1  2  1  3.96000  5.49000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1       1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.43500E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       121.000       242.000       363.000       484.000       605.000
726.000       847.000       968.000       969.000       1659.00       1689.00
2383.00       2384.00
FMASS      0.000000     0.0200000     0.0810000      0.182000      0.324000
0.507000      0.729000      0.993000       1.29700       1.50000       1.50000
0.220000      0.220000      0.000000
FQDOT      0.000000       687000.  2.75000E+006  6.18700E+006  1.09990E+007
1.71860E+007  2.47470E+007  3.36840E+007  4.39950E+007  5.29910E+007
5.29910E+007  8.99600E+006  8.99600E+006      0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
WINDOW    0.    0. -100. 1280. 1024. 1100.
LABEL  1  970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
GRAPH  1  100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2  100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3  720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4  720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3   1 U
TEMPE  0 0 0 0 2   1 U
INTER  0 0 0 0 1   1 U
O2     0 0 0 0 4   1 U
```

6. FAST Output:

```
CFAST V  3.1 Created  4/1/98,  Run  2/1/99


Time =      0.0 seconds.

Compartment    Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
               Temp.   Temp.   Height  Rate       Size                  Target
               (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
-------------------------------------------------------------------------------
   1           293.1   293.1   9.8     0.000E+00  0.000E+00 3.668E-21 1.137E-13
 Outside                                          0.000E+00


Time =    120.0 seconds.

Compartment    Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
               Temp.   Temp.   Height  Rate       Size                  Target
               (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
-------------------------------------------------------------------------------
   1           313.1   293.6   3.6     1.983E-02  6.813E+05-0.128        83.4
 Outside                                          0.000E+00


Time =    240.0 seconds.

Compartment    Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
               Temp.   Temp.   Height  Rate       Size                  Target
               (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
-------------------------------------------------------------------------------
   1           381.3   296.3   3.5     7.999E-02  2.716E+06-0.619        500.
 Outside                                          0.000E+00


Time =    360.0 seconds.

Compartment    Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
               Temp.   Temp.   Height  Rate       Size                  Target
               (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
-------------------------------------------------------------------------------
   1           471.8   302.6   3.2     0.179      6.100E+06 -1.63      1.556E+03
 Outside                                          0.000E+00


Time =    480.0 seconds.

Compartment    Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
               Temp.   Temp.   Height  Rate       Size                  Target
               (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
-------------------------------------------------------------------------------
   1           558.9   312.8   2.8     0.319      1.083E+07 -3.10      3.453E+03
 Outside                                          0.000E+00
```

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	638.3	330.3	2.3	0.499	1.691E+07	-5.54	6.441E+03
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	722.5	354.0	1.7	0.718	2.433E+07	-8.39	1.134E+04
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	811.4	380.8	1.3	0.978	3.308E+07	-11.0	1.902E+04
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	905.3	424.3	1.0	1.28	4.314E+07	-13.1	3.075E+04
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1005.2	474.4	0.84	1.50	5.272E+07	-14.7	4.877E+04
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1038.3	488.8	0.85	1.50	5.269E+07	-14.9	5.705E+04
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1068.2	501.6	0.85	1.50	5.267E+07	-15.0	6.525E+04
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1096.5	513.7	0.85	1.50	5.266E+07	-15.2	7.367E+04
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1123.6	525.4	0.85	1.50	5.264E+07	-15.3	8.236E+04
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	1029.3	458.7	1.7	0.604	2.209E+07	-14.8	6.144E+04
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	829.1	391.8	3.7	0.220	8.974E+06	-7.48	2.695E+04
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	773.7	374.4	3.5	0.220	8.978E+06	-6.61	2.029E+04
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	741.9	365.3	3.4	0.220	8.980E+06	-6.16	1.707E+04
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	720.1	359.2	3.3	0.220	8.981E+06	-5.86	1.507E+04
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	703.4	354.7	3.2	0.220	8.982E+06	-5.63	1.365E+04
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	675.4	350.0	4.9	0.000E+00	0.000E+00	-5.38	1.160E+04
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	639.4	359.6	5.6	0.000E+00	0.000E+00	-5.77	9.477E+03
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	620.1	356.2	5.7	0.000E+00	0.000E+00	-5.53	8.313E+03
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	604.4	353.4	5.8	0.000E+00	0.000E+00	-5.33	7.453E+03
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	590.9	351.0	5.9	0.000E+00	0.000E+00	-5.16	6.766E+03
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	579.0	348.9	6.0	0.000E+00	0.000E+00	-5.00	6.198E+03
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	568.3	347.0	6.1	0.000E+00	0.000E+00	-4.86	5.718E+03
Outside					0.000E+00		

Time = 3240.0 seconds.

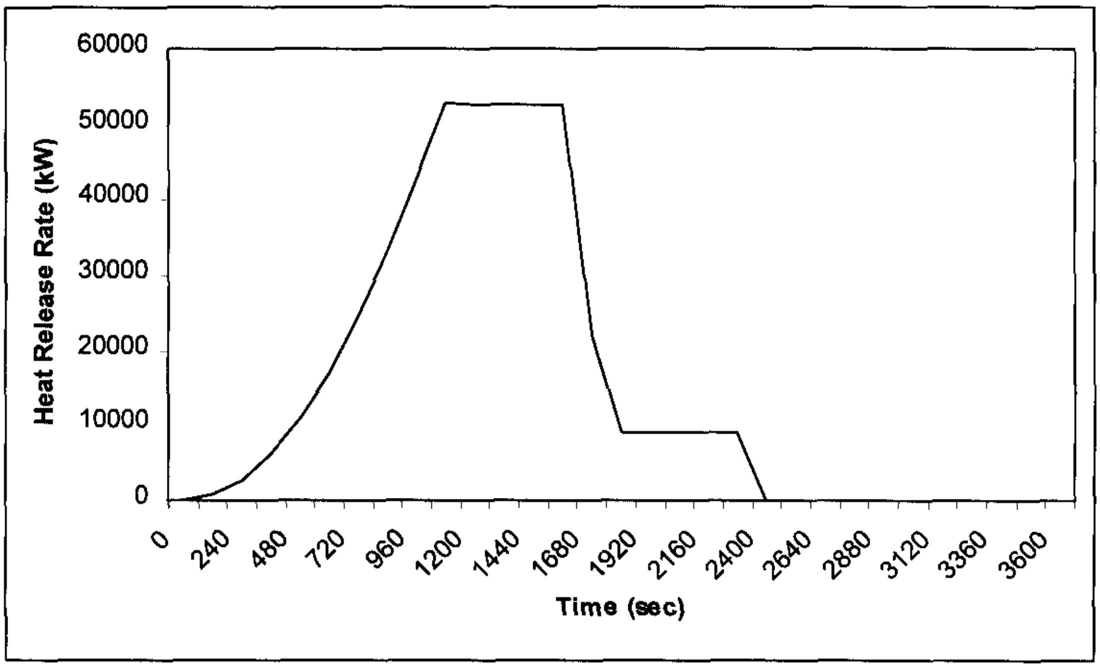
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	558.6	345.3	6.1	0.000E+00	0.000E+00	-4.74	5.306E+03
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	549.8	343.7	6.2	0.000E+00	0.000E+00	-4.62	4.949E+03
Outside					0.000E+00		

Time = 3480.0 seconds.

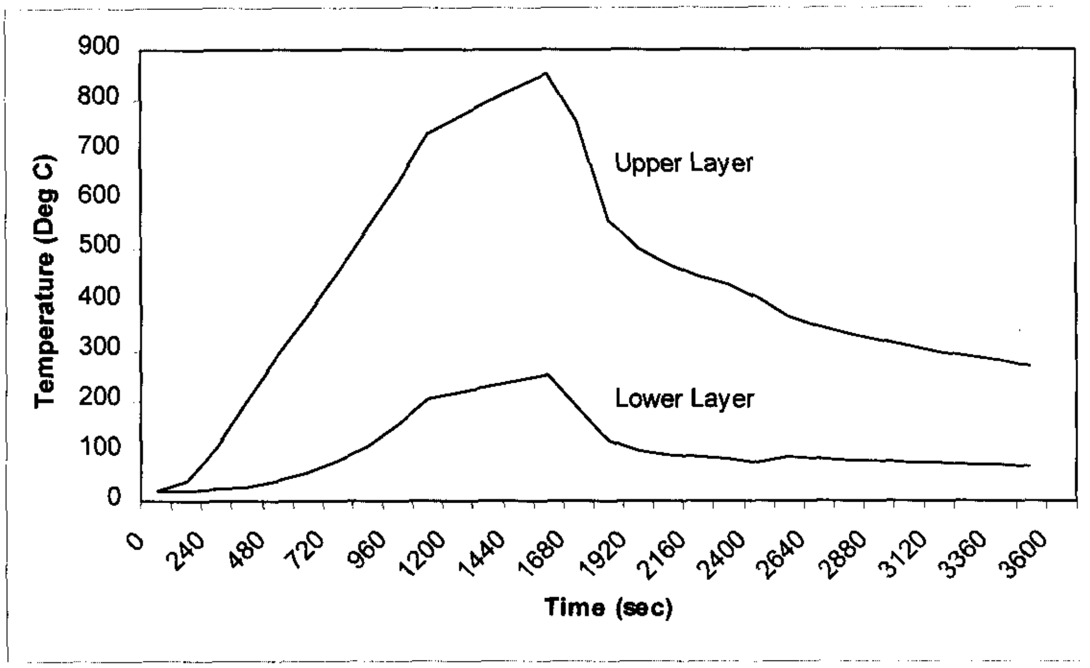
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	541.7	342.3	6.3	0.000E+00	0.000E+00	-4.51	4.637E+03
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Tractor and Transporter (Lumped)

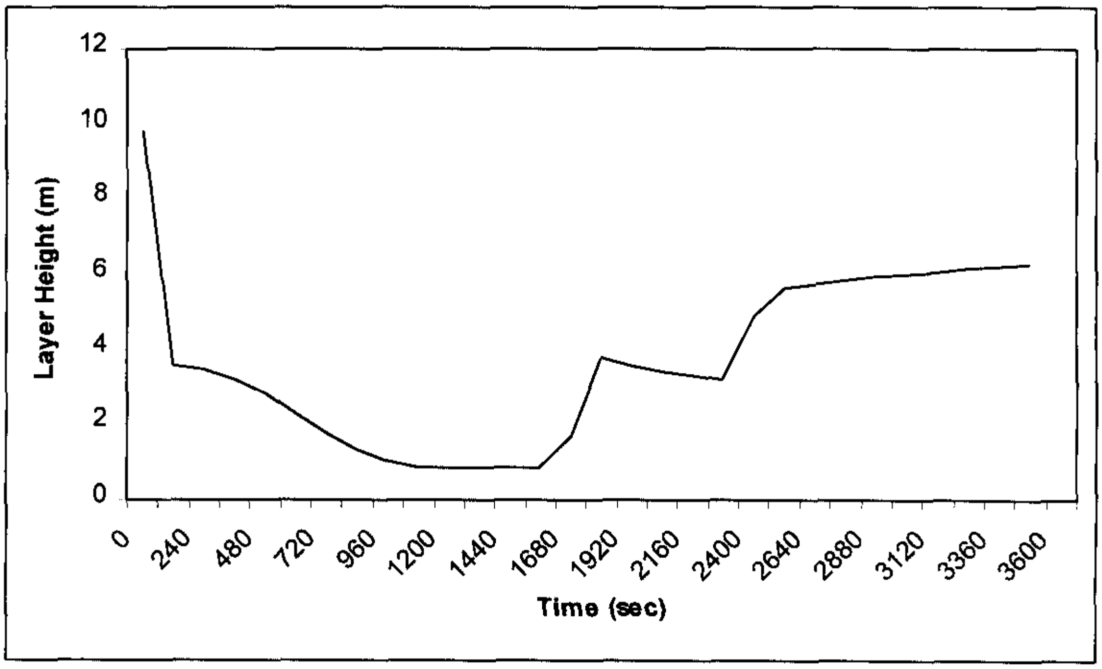
Figure A-1



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Tractor and Transporter (Lumped)

Figure A-2



CFAST Output: Layer Height vs. Time

Tractor and Transporter (Lumped)

Figure A-3

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CVDF Fire Scenario 2

Fire Modeling and Evaluation of a Fire Involving
Tractor Cab, Engine Compartment, Front and Rear Tires, and Diesel Fuel, with a
20-minute delay in ignition of Transporter Tires
in a Cold Vacuum Drying Facility Processing Bay

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CVDF Fire Scenario 2

DISCUSSION

CVDF Fire Scenario 2 occurs with the tractor and transporter backing into, or parked in, a CVDF processing bay. The large bay door is open, the MCO is not connected to any processing equipment, and HVAC systems are assumed OFF. The tractor cab is assumed to ignite by an electrical short circuit in the tractor wiring. The resulting fire begins in the cab and spreads to the engine compartment, front tractor tires, diesel fuel, rear tractor tires, and transporter tires. The fire is modeled assuming that the cab, engine compartment, and all tractor (front and rear) tires are lumped combustibles. The transporter tires are treated separately and assumed to ignite 20 minutes after ignition of the lumped tractor cab, engine compartment, front and rear tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. Ignition and instantaneous fire growth of diesel fuel to steady state peak heat release rate is assumed to occur upon fire growth to the peak heat release rate corresponding to the lumped combustibles without diesel fuel. The fire is assumed to burn to completion with a 30 second decay period for lumped combustibles, instantaneous decay for diesel fuel, and 30 second decay period for transporter tires.

DETERMINE DATA FOR INPUT TO FAST COMPUTER FIRE MODELING SOFTWARE

1. Summarize initial combustible material inventory (I_o) in kJ (see Fire Scenario 1 for details):

Material Description	I_o
Tractor Cab/Engine Compartment	2,300,000 kJ
Front Tires	5,730,549 kJ
Rear Tires	16,321,272 kJ
Transporter Tires	20,889,000 kJ
Sub-Total ($I_{olumped}$)	45,240,821 kJ
Diesel Fuel	12,729,600 kJ
Total	57,970,421 kJ

2. Develop heat release rate and combustible inventory vs. time (see Fire Scenario 1 for details):

   a. Summarize peak heat release rate:

$$Q_{peak} = Q_{cab/enginecompt} + Q_{fronttires} + Q_{reartires} + Q_{transportertires} + Q_{dieselfuel}$$

$$Q_{cab/enginecompt} = 3{,}000 \text{ kW}$$

$$Q_{fronttires} = 4{,}834 \text{ kW}$$

$Q_{reartires} = 16{,}175$ kW

$Q_{transportertires} = 19{,}986$ kW

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{peak} = 52{,}991$ kW

b. Determine time to reach $Q_{peak} - Q_{dieselfuel} - Q_{transportertires}$:

$Q_{peak} = \alpha t^2 + Q_{dieselfuel} + Q_{transportertires}$

$Q_{lumped} = Q_{peak} - Q_{dieselfuel} - Q_{transportertires} = \alpha t^2$

$t = [(Q_{lumped})/\alpha]^{1/2}$

$Q_{peak} = 52{,}991$ kW

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{transportertires} = 19{,}986$ kW

$Q_{lumped} = 24{,}009$ kW

$\alpha = 0.0469$ kW/sec²

t = 715 sec

c. Designate period of fire growth (i.e., t = 0 seconds to t = 715 seconds) as Period I.

d. Energy expended during Period I:

$$E_I = \int_0^t \alpha t^2 dt = \left.\frac{\alpha t^3}{3}\right|_0^t$$

t = 715 sec

$\alpha = 0.0469$ kW/sec²

$E_I = 5{,}714{,}388$ kJ

e. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fI}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	24,351,821 kJ	5,714,388 kJ	18,637,433 kJ
Transporter Tires	20,889,000 kJ	0 kJ	20,889,000 kJ
Diesel Fuel	12,729,600 kJ	0 kJ	12,729,600 kJ
Total	57,970,421 kJ	5,714,388 kJ	52,256,033 kJ

f. Determine time from reaching Q_{peak} - $Q_{transportertires}$ to ignition of transporter tires:

$t = 1{,}200 \text{ sec} - 715 \text{ sec}$

$t = 485 \text{ seconds}$

g. Designate period of steady state burning at Q_{peak} - $Q_{transportertires}$ (i.e., t = 715 seconds to t = 1,200 seconds) as Period II.

h. Determine energy expended during Period II by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$E_{IIlumped} = (Q_{lumped})(t)$

$t = 485 \text{ sec}$

$Q_{lumped} = 24{,}009 \text{ kW}$

$E_{IIlumped} = 11{,}644{,}365 \text{ kJ}$

(2) Diesel Fuel:

$E_{IIdieselfuel} = (Q_{dieselfuel})(t)$

$t = 485 \text{ sec}$

$Q_{dieselfuel} = 8{,}996 \text{ kW}$

$E_{IIdieselfuel} = 4{,}363{,}060 \text{ kJ}$

i. Tabulate change in combustible material inventory during Period II:

Material Description	I_{fI}	$E_{II}(\Delta I)$	I_{fII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	18,637,433 kJ	11,644,365 kJ	6,993,068 kJ
Transporter Tires	20,889,000 kJ	0 kJ	20,889,000 kJ
Diesel Fuel	12,729,600 kJ	4,363,060 kJ	8,366,540 kJ
Total	52,256,033 kJ	16,007,425 kJ	36,248,608 kJ

j. Determine time from reaching ignition of transporter tires to beginning of 30 second decay at peak heat release rate for lumped materials:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$t = [(I_{fIIlumped} - (30\text{ sec})(0.5)(Q_{lumped}))/Q_{lumped}]$

$I_{fIIlumped} = 6{,}993{,}068$ kJ

$Q_{lumped} = 24{,}009$ kW

$t = 276$ sec

k. Designate period of steady state burning at $Q_{peak} - Q_{transportertires}$ (i.e., t = 1,200 seconds to t = 1,476 seconds) as Period III.

l. Determine energy expended during Period III by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$E_{IIIlumped} = I_{fIIlumped} - (30\text{ sec})(0.5)(Q_{lumped})$

$I_{fIIlumped} = 6{,}993{,}068$ kJ

$Q_{lumped} = 24{,}009$ kW

$E_{IIIlumped} = 6{,}632{,}933$ kJ

(2) Diesel Fuel:

$E_{IIIdieselfuel} = (Q_{dieselfuel})(t)$

$t = 276$ sec

$Q_{dieselfuel}$ = 8,996 kW

$E_{IIIdieselfuel}$ = 2,482,896 kJ

(3) Transporter Tires:

$$E_{III} = \int_0^t \alpha t^2 dt = \frac{\alpha t^3}{3}\bigg|_0^t$$

t = 276 sec

α = 0.0469 kW/sec²

$E_{IIItransportertires}$ = 328,684 kJ

m. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	6,993,068 kJ	6,632,933 kJ	360,135 kJ
Transporter Tires	20,889,000 kJ	328,684 kJ	20,560,316 kJ
Diesel Fuel	8,366,540 kJ	2,482,896 kJ	5,883,644 kJ
Total	36,248,608 kJ	9,444,513 kJ	26,804,095 kJ

n. Designate 30 second decay period of lumped combustibles, steady state burning at $Q_{dieselfuel}$, and growth of transporter tire fire, (i.e., t = 1,476 seconds to t = 1,506 seconds) as Period IV.

o. Determine energy expended during Period IV by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$E_{IVlumped}$ = (30 sec)(0.5)(Q_{lumped})

Q_{lumped} = 24,009 kW

$E_{IVlumped}$ = 360,135 kJ

(2) Diesel Fuel:

$E_{IVdieselfuel}$ = ($Q_{dieselfuel}$)(t)

$t = 30$ sec

$Q_{dieselfuel} = 8{,}996$ kW

$E_{IVdieselfuel} = 269{,}880$ kJ

(3) Transporter Tires:

$$E_{IV} = \int_{i}^{f} \alpha t^2 dt = \left.\frac{\alpha t^3}{3}\right|_{t_i}^{t_f}$$

$t_f = t_i + 30$ seconds

$t_i = 276$ sec

$t_f = 306$ seconds

$\alpha = 0.0469$ kW/sec²

$E_{IVtransportertires} = 119{,}252$ kJ

p. Tabulate change in combustible material inventory during Period IV:

Material Description	I_{fIII}	$E_{IV}(\Delta I)$	I_{fIV}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	360,135 kJ	360,135 kJ	0 kJ
Transporter Tires	20,560,316 kJ	119,252 kJ	20,441,064 kJ
Diesel Fuel	5,883,644 kJ	269,880 kJ	5,613,764 kJ
Total	26,804,095 kJ	749,267 kJ	26,054,828 kJ

q. Determine time from ignition of transporter tires to reach $Q_{transportertires}$:

$Q_{transportertires} = \alpha t^2$

$t = [(Q_{transportertires})/\alpha]^{1/2}$

$Q_{transportertires} = 19{,}986$ kW

$\alpha = 0.0469$ kW/sec²

$t = 653$ sec

r. Determine time from burnout of lumped materials to reach $Q_{transportertires}$:

$t = t_{ignitiontransportertires} + 653 \text{ seconds} - t_{burnoutlumped}$

$t_{ignitiontransportertires} = 1{,}200$ seconds

$t_{burnoutlumped} = 1{,}506$ seconds

$t = 347$ seconds

s. Designate period of fire growth (i.e., t = 1,506 seconds to t = 1,853 seconds) as Period V.

t. Energy expended during Period V:

(1) Diesel Fuel:

$E_{Vdieselfuel} = (Q_{dieselfuel})(t)$

$t = 347$ sec

$Q_{dieselfuel} = 8{,}996$ kW

$E_{Vdieselfuel} = 3{,}121{,}612$ kJ

(2) Transporter Tires:

$$E_V = \int_{t_i}^{t_f} \alpha t^2 dt = \left.\frac{\alpha t^3}{3}\right|_{t_i}^{t_f}$$

$t_f = 653$ seconds

$t_i = t_f - 347$ seconds

$t_i = 306$ seconds

$\alpha = 0.0469 \text{ kW/sec}^2$

$E_{Vtransportertires} = 3{,}699{,}833$ kJ

u. Tabulate change in combustible material inventory during Period V:

Material Description	I_{fIV}	$E_V(\Delta I)$	I_{fV}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires	0 kJ	0 kJ	0 kJ
Transporter Tires	20,441,064 kJ	3,699,833 kJ	16,741,231 kJ
Diesel Fuel	5,613,764 kJ	3,121,612 kJ	2,492,152 kJ
Total	26,054,828 kJ	6,821,445 kJ	19,233,383 kJ

v. Determine time to burnout of diesel fuel:

(1) Diesel Fuel:

$t = (I_{fVdieselfuel})/(Q_{dieselfuel})$

$I_{fVdieselfuel} = 2{,}492{,}152$ kJ

$Q_{dieselfuel} = 8{,}996$ kW

$t = 277$ seconds

w. Designate period of steady state burning at $Q_{dieselfuel} + Q_{transportertires}$ (i.e., t = 1,853 seconds to t = 2,130 seconds) as Period VI.

x. Determine energy expended during Period VI:

(1) Diesel Fuel:

$E_{VIdieselfuel} = I_{fVdieselfuel}$

$I_{fVdieselfuel} = 2{,}492{,}152$ kJ

$E_{Vdieselfuel} = 2{,}492{,}152$ kJ

(2) Transporter Tires:

$E_{VItransportertires} = (Q_{transportertires})(t)$

$t = 277$ sec

$Q_{transportertires} = 19{,}986$ kW

$E_{VItransportertires} = 5{,}536{,}122$ kJ

y. Tabulate change in combustible material inventory during Period VI:

Material Description	I_{fV}	$E_{VI}(\Delta I)$	I_{fVI}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires	0 kJ	0 kJ	0 kJ
Transporter Tires	16,741,231 kJ	5,536,122 kJ	11,205,109 kJ
Diesel Fuel	2,492,152 kJ	2,492,152 kJ	0 kJ
Total	19,233,383 kJ	8,028,274 kJ	11,205,109 kJ

z. Determine time from burnout of diesel fuel to beginning of 30 second decay for transporter tires:

(1) Transporter Tires:

$$t = [(I_{fVItransportertires} - (30\text{ sec})(0.5)(Q_{transportertires}))/Q_{transportertires}]$$

$I_{fVItransportertires} = 11{,}205{,}109$ kJ

$Q_{transportertires} = 19{,}986$ kW

$t = 546$ sec

aa. Designate period of steady state burning at $Q_{transportertires}$ (i.e., t = 2,130 seconds to t = 2,676 seconds) as Period VII.

bb. Determine energy expended during Period VII:

(1) Transporter Tires:

$$E_{VIItransportertires} = I_{fVItransportertires} - (30\text{ sec})(0.5)(Q_{transportertires})$$

$I_{fVItransportertires} = 11{,}205{,}109$ kJ

$Q_{transportertires} = 19{,}986$ kW

$E_{VIItransportertires} = 10{,}905{,}319$ kJ cc. Tabulate change in combustible material inventory during Period VII:

Material Description	I_{fVI}	$E_{VII}(\Delta I)$	I_{fVII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires	0 kJ	0 kJ	0 kJ
Transporter Tires	11,205,109 kJ	10,905,319 kJ	299,790 kJ
Diesel Fuel	0 kJ	0 kJ	0 kJ
Total	11,205,109 kJ	10,905,319 kJ	299,790 kJ

dd. Designate 30 second decay period of transporter tire fire (i.e., t = 2,676 seconds to t = 2,706 seconds) as Period VIII.

ee. Determine energy expended during Period VIII:

(1) Transporter Tires:

$$E_{VIIItransportertires} = (30\,sec)(0.5)(Q_{transportertires})$$

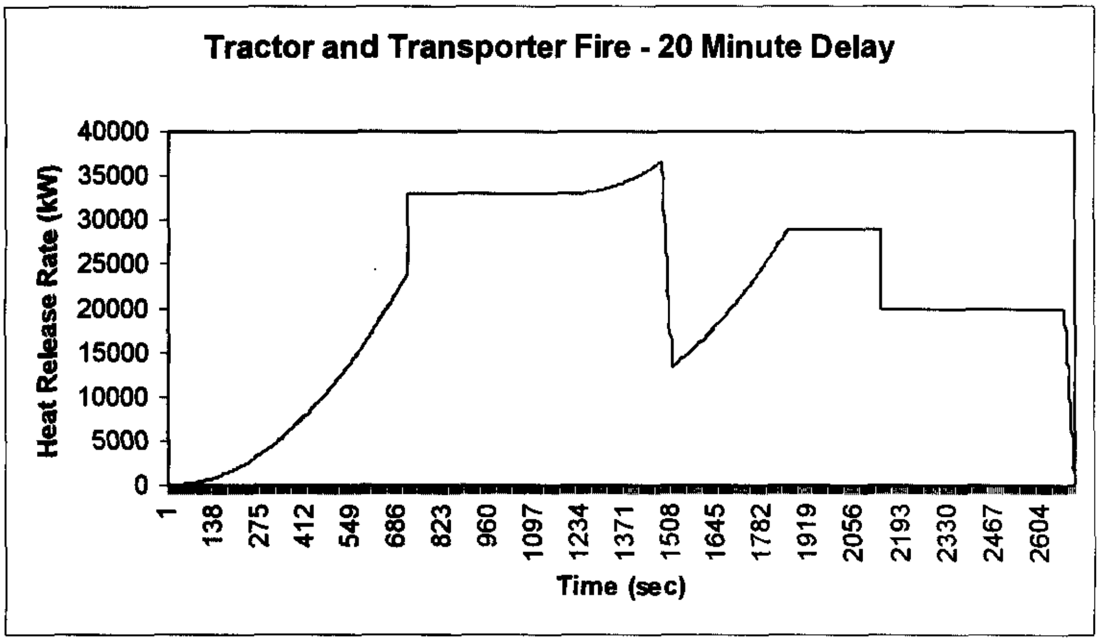
$$Q_{transportertires} = 19{,}986\ kW$$

$$E_{VIIItransportertires} = 299{,}790\ kJ$$

ff. Tabulate change in combustible material inventory during Period VIII:

Material Description	I_{fVII}	$E_{VIII}(\Delta I)$	I_{fVIII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires	0 kJ	0 kJ	0 kJ
Transporter Tires	299,790 kJ	299,790 kJ	0 kJ
Diesel Fuel	0 kJ	0 kJ	0 kJ
Total	299,790 kJ	299,790 kJ	0 kJ

3. Resulting Heat Release Rate Curve:



4. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through VIII):

a. Mass Loss Rate – Equation

(1) $M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

b. Period I (t = 0 seconds through t = 715 seconds):

(1) Determine M_{bI}:

$M_{bI} = (Q_{Itires/cab/enginecompt})/(\text{weighted } H_{cI})$

(a) Tires:

H_{ctires} = 34,815 kJ/kg

Mass:

(2 Front Tires)(82.3 kg/tire) = 164.6 kg

(8 Rear Tires)(58.6 kg/tire) = 468.8 kg

Total Tire Mass (M_{tires}) = 633.4 kg

(b) Cab and Engine Compartment:

$H_{ccab/enginecompt} = 23{,}000$ kJ/kg

Cab/Engine Compt Mass ($M_{cab/enginecompt}$) = 100 kg

(c) Weighted H_{cI}:

$$H_{cI} = [M_{tires}/(M_{tires} + M_{cab/enginecompt})][H_{ctires}] + [M_{cab/enginecompt}/(M_{tires} + M_{cab/enginecompt})][H_{ccab/enginecompt}]$$

$H_{cI} =$ 30,068 kJ/kg + 3,631 kJ/kg

$H_{cI} =$ 33,699 kJ/ kg

(d) Determine $Q_{Itires/cab/enginecompt}$ at various times t:

$Q_{Itires/cab/enginecompt} = \alpha t^2$

$\alpha = 0.0469$ kW/sec²

(2) Determine Q_I and M_{bI} and tabulate:

t (seconds)	Q_I (kW)	M_{bI} (kg/sec)
0	0	0
143	960	0.028
286	3,841	0.114
429	8,643	0.256
572	15,366	0.456
715	24,009	0.712

c. Period II (t = 715 seconds through t = 1,200 seconds):

(1) Determine M_{bII}:

$$M_{bII} = (Q_{IItires/cab/enginecompt})/(H_{cIItires/cab/enginecompt}) + (Q_{dieselfuel}/H_{cdieselfuel})$$

(a) Diesel Fuel:

$H_{cdieselfuel}$ = 40,800 kJ/kg

(b) Weighted $H_{cIItires/cab/enginecompt}$:

$H_{cIItires/cab/enginecompt} = H_{cI}$

$H_{cIItires/cab/enginecompt}$ = 33,699 kJ/ kg

(3) Determine Q_{II}:

$Q_{II} = Q_{IItires/cab/enginecompt} + Q_{dieselfuel}$

$Q_{IItires/cab/enginecompt}$ = 24,009 kW

$Q_{dieselfuel}$ = 8,996 kW

Q_{II} = 33,005 kW

(4) Tabulate:

t (seconds)	Q_{II} (kW)	M_{bII} (kg/sec)
715	33,005	0.934
1,200	33,005	0.934

d. Period III (t = 1,200 seconds through t = 1,476 seconds):

(1) Determine M_{bIII}:

$$M_{bIII} = (Q_{IIItires/cab/enginecompt})/(H_{ctires/cab/enginecompt}) + (Q_{dieselfuel}/H_{cdieselfuel}) + Q_{IIItransportertires}/H_{ctransportertires})$$

(a) Diesel Fuel:

$H_{cdieselfuel}$ = 40,800 kJ/kg

(b) Tires/Cab/Engine Compartment:

$H_{ctires/cab/enginecompt}$ = 33,699 kJ/ kg

(c) Transporter Tires:

$H_{ctransportertires}$ = 34,815 kJ/kg

(2) Determine Q_{III}:

(a) $Q_{III} = Q_{IIItires/cab/enginecompt} + Q_{dieselfuel} + Q_{IIItransportertires}$

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{IIItires/cab/enginecompt} = 24{,}009$ kW

$Q_{IIItransportertires} = \alpha(t - 1{,}200)^2$

$\alpha = 0.0469$ kW/sec^2

(3) Determine Q_{III} and M_{bIII}, and tabulate:

t (seconds)	Q_{III} (kW)	M_{bIII} (kg/sec)
1,200	33,005	0.934
1,269	33,228	0.940
1,338	33,898	0.960
1,407	35,015	0.992
1,476	36,578	1.037

e. Period IV (t = 1,476 seconds through t = 1,506 seconds):

(1) Determine M_{bIV}:

$$M_{bIV} = (Q_{IVtires/cab/enginecompt})/(H_{ctires/cab/enginecompt}) + (Q_{dieselfuel}/H_{cdieselfuel}) + (Q_{IVtransportertires}/H_{ctransportertires})$$

(a) Diesel Fuel:

$H_{cdieselfuel} = 40{,}800$ kJ/kg

(b) Tires/Cab/Engine Compartment:

$H_{ctires/cab/enginecompt} = 33{,}699$ kJ/ kg

(c) Transporter Tires:

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_{IV}:

(a) $Q_{IV} = Q_{IVtires/cab/enginecompt} + Q_{dieselfuel} + Q_{IVtransportertires}$

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{IVtires/cab/enginecompt} = 24{,}009 \text{ kW} - (24{,}009 \text{ kW}/30 \text{ sec})(t - 1476 \text{ sec})$

$Q_{IVtransportertires} = \alpha(t - 1{,}200)^2$

$\alpha = 0.0469 \text{ kW/sec}^2$

(3) Determine Q_{IV} and M_{bIV}, and tabulate:

t (seconds)	Q_{IV} (kW)	M_{bIV} (kg/sec)
1,476	36,578	1.037
1,506	13,385	0.347

f. Period V (t = 1,506 seconds to t = 1,853 seconds):

(1) Determine M_{bV}:

$M_{bV} = (Q_{dieselfuel}/H_{cdieselfuel}) + (Q_{Vtransportertires}/H_{ctransportertires})$

(a) Diesel Fuel:

$H_{cdieselfuel} = 40{,}800$ kJ/kg

(b) Transporter Tires:

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_V:

(a) $Q_V = Q_{dieselfuel} + Q_{transportertires}$

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{transportertires} = \alpha(t - 1{,}200)^2$

$\alpha = 0.0469 \text{ kW/sec}^2$

(3) Determine Q_V and M_{bV}, and tabulate:

t (seconds)	Q_V (kW)	M_{bV} (kg/sec)
1,506	13,385	0.347
1,566	15,274	0.401
1,626	17,502	0.465
1,686	20,067	0.538
1,746	22,969	0.622
1,806	26,208	0.715
1,853	28,982	0.795

g. Period VI (t = 1,853 seconds to t = 2,130 seconds):

(1) Determine M_{bVI}:

$M_{bV} = (Q_{dieselfuel}/H_{cdieselfuel}) + (Q_{VItransportertires}/H_{ctransportertires})$

(a) Diesel Fuel:

$H_{cdieselfuel} = 40,800$ kJ/kg

(b) Transporter Tires:

$H_{ctransportertires} = 34,815$ kJ/kg

(2) Determine Q_{VI}:

(a) $Q_{VI} = Q_{dieselfuel} + Q_{VItransportertires}$

$Q_{dieselfuel} = 8,996$ kW

$Q_{VItransportertires} = 19,986$ kW

$Q_{VI} = 28,982$ kW

(3) Determine Q_{VI} and M_{bVI}, and tabulate:

t (seconds)	Q_V (kW)	M_{bV} (kg/sec)
1,853	28,982	0.795
2,130	28,982	0.795

h. Period VII (t = 2,130 to t = 2,676 seconds):

(1) Determine M_{bVII}:

$M_{bVII} = (Q_{VIItransportertires}/H_{ctransportertires})$

(a) Transporter Tires:

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_{VII}:

(b) $Q_{VII} = Q_{VIItransportertires}$

$Q_{transportertires} = 19{,}986$ kW

$Q_{VII} = 19{,}986$ kW

(3) Determine Q_{VII} and M_{bVII}, and tabulate:

t (seconds)	Q_{VII} (kW)	M_{bVII} (kg/sec)
2,130	19,986	0.574
2,676	19,986	0.574

i. Period VIII (t = 2,676 to t = 2,706 seconds):

(1) Determine M_{bVIII}:

$M_{bVIII} = (Q_{VIIItransportertires}/H_{ctransportertires})$

(a) Transporter Tires:

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_{VIII}:

(b) $Q_{VIII} = Q_{VIIItransportertires} - (Q_{VIIItransportertires}/30 \text{ sec})(t - 2{,}676 \text{ sec})$

$Q_{VIIItransportertires} = 19{,}986$ kW

(3) Determine Q_{VIII} and M_{bVIII}, and tabulate:

t (seconds)	Q_{VII} (kW)	M_{bVII} (kg/sec)
2,676	19,986	0.574
2,706	0	0

5. FAST Input Data:

```
VERSN    3TRACTOR + TRANSPORTER - 20 MINUTE DELAY
#VERSN 3 TRACTOR + TRANSPORTER - 20 MINUTE DELAY
TIMES  3600      0    120     20      0
DUMPR S2.HI
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.30000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
HVENT  1  2  1  3.96000  5.49000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1        1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000       1.00000
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.42857E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME        143.000       286.000       429.000       572.000       715.000
716.000       1200.00       1269.00       1338.00       1407.00       1476.00
1506.00       1566.00       1686.00       1746.00       1853.00       2130.00
2131.00       2676.00       2706.00
FMASS      0.000000     0.0280000      0.114000      0.256000      0.456000
0.712000      0.934000      0.934000      0.940000      0.960000      0.992000
1.03700      0.347000      0.401000      0.538000      0.622000      0.795000
0.795000      0.574000      0.574000      0.000000
FQDOT      0.000000      960000.  3.84100E+006  8.64300E+006  1.53660E+007
2.40090E+007  3.30050E+007  3.30050E+007  3.32280E+007  3.38980E+007
3.50150E+007  3.65780E+007  1.33850E+007  1.52740E+007  2.00670E+007
2.29690E+007  2.89820E+007  2.89820E+007  1.99860E+007  1.99860E+007
0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
WINDOW    0.    0. -100. 1280. 1024. 1100.
LABEL  1  970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
```

```
GRAPH  1  100.    50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2  100.   550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3  720.    50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4  720.   550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3   1 U
TEMPE  0 0 0 0 2   1 U
INTER  0 0 0 0 1   1 U
O2     0 0 0 0 4   1 U
```

6. FAST Output:

```
CFAST V  3.1 Created  4/1/98,  Run  1/29/99


Time =      0.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           293.1   293.1   9.8     0.000E+00  0.000E+00 3.668E-21 1.137E-13
 Outside                                         0.000E+00


Time =    120.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           316.5   293.7   3.5     2.350E-02  8.056E+05-0.152        99.4
 Outside                                         0.000E+00


Time =    240.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           384.6   296.5   3.4     8.634E-02  2.914E+06-0.649        529.
 Outside                                         0.000E+00


Time =    360.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           473.9   302.7   3.1     0.187      6.324E+06 -1.65       1.594E+03
 Outside                                         0.000E+00
```

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	559.9	312.8	2.8	0.327	1.103E+07	-3.12	3.488E+03
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	638.5	330.3	2.3	0.506	1.704E+07	-5.52	6.456E+03
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	748.1	359.3	1.4	0.934	3.294E+07	-7.61	1.332E+04
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	819.2	384.6	1.3	0.934	3.292E+07	-11.3	1.991E+04
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	833.0	390.4	1.3	0.934	3.291E+07	-11.5	2.180E+04
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	845.1	395.2	1.3	0.934	3.291E+07	-11.6	2.354E+04
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	856.4	399.4	1.3	0.934	3.290E+07	-11.7	2.525E+04
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	872.4	405.6	1.3	0.955	3.361E+07	-11.9	2.760E+04
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	899.4	417.0	1.2	1.01	3.564E+07	-12.4	3.160E+04
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	727.9	359.5	2.5	0.396	1.506E+07	-6.74	1.453E+04
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	755.7	366.1	2.1	0.531	1.979E+07	-8.06	1.602E+04
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	812.0	381.3	1.6	0.709	2.594E+07	-9.91	2.106E+04
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	853.1	394.7	1.5	0.795	2.890E+07	-11.0	2.591E+04
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	863.6	398.0	1.5	0.795	2.890E+07	-11.1	2.754E+04
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	802.2	377.9	2.1	0.574	1.994E+07	-8.77	2.139E+04
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	789.6	374.6	2.0	0.574	1.994E+07	-8.62	1.986E+04
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	787.4	374.0	2.0	0.574	1.994E+07	-8.59	1.958E+04
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	787.3	373.9	2.0	0.574	1.994E+07	-8.59	1.957E+04
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	788.1	374.1	2.0	0.574	1.994E+07	-8.59	1.967E+04
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	656.4	361.5	5.6	0.000E+00	0.000E+00	-5.92	1.077E+04
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	618.5	357.6	5.8	0.000E+00	0.000E+00	-5.64	8.454E+03
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	596.3	353.5	5.9	0.000E+00	0.000E+00	-5.34	7.248E+03
Outside					0.000E+00		

Time = 3120.0 seconds.

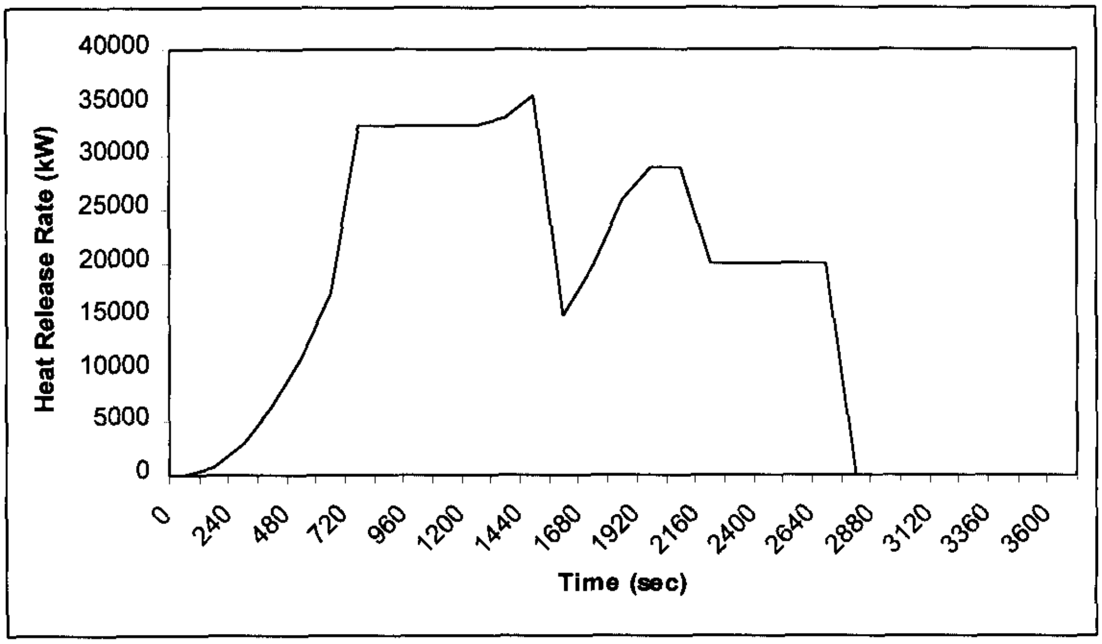
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	579.9	350.5	6.1	0.000E+00	0.000E+00	-5.12	6.434E+03
Outside					0.000E+00		

Time = 3240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	566.5	348.0	6.1	0.000E+00	0.000E+00	-4.94	5.815E+03
Outside					0.000E+00		

Time = 3360.0 seconds.

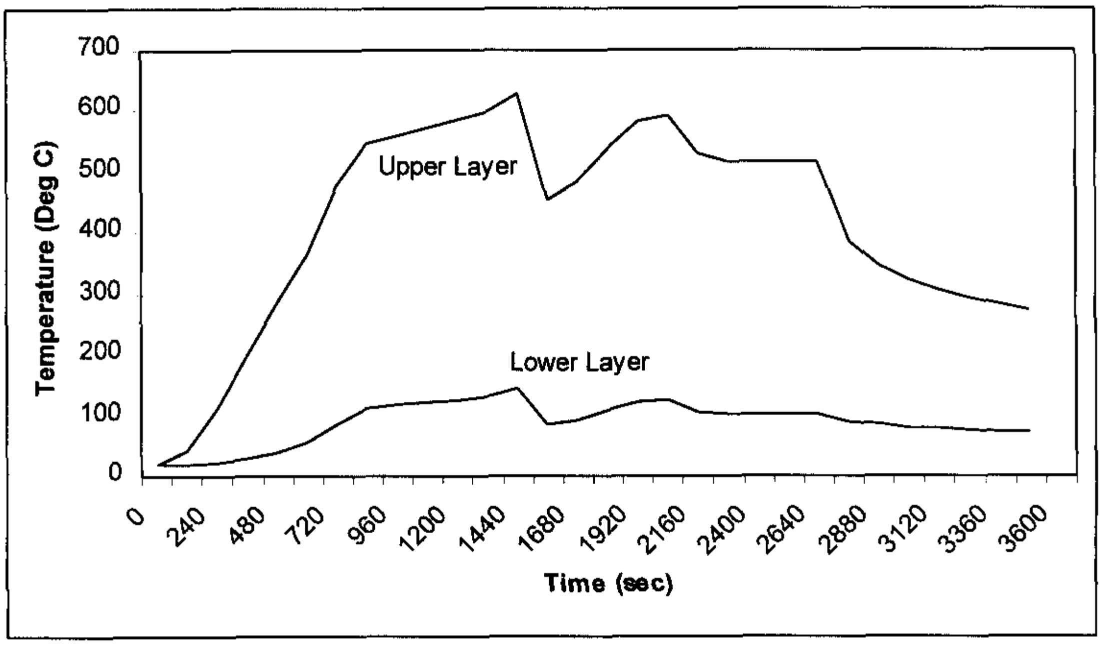
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	555.0	345.9	6.2	0.000E+00	0.000E+00	-4.78	5.316E+03
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Tractor and Transporter (20 Minute Delay)

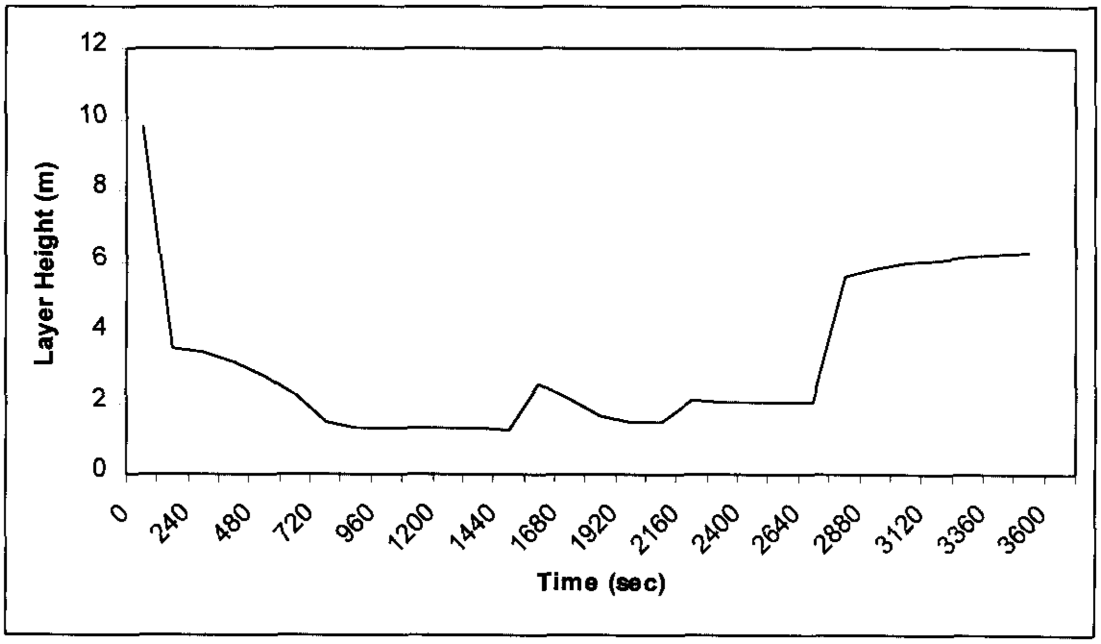
Figure A-4



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Tractor and Transporter (20 Minute Delay)

Figure A-5



CFAST Output: Layer Height vs. Time

Tractor and Transporter (20 Minute Delay)

Figure A-6

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CVDF Fire Scenario 3

Fire Modeling and Evaluation of a Fire Involving
Tractor Cab, Engine Compartment, Front and Rear Tires, and Diesel Fuel
in a Cold Vacuum Drying Facility Processing Bay

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CVDF Fire Scenario 3

DISCUSSION

CVDF Fire Scenario 3 occurs with the tractor and transporter backing into, or parked in, a CVDF processing bay. The large bay door is open, the MCO is not connected to any processing equipment, and HVAC systems are assumed OFF. The tractor cab is assumed to ignite by an electrical short circuit in the tractor wiring. The resulting fire begins in the cab and spreads to the engine compartment, front tractor tires, diesel fuel, and rear tractor tires. The transporter tires are assumed not to ignite due to insufficient exposure to the tractor fire. The fire is modeled assuming that the cab, engine compartment, and all tractor (front and rear) tires are lumped combustibles. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. Ignition and instantaneous fire growth of diesel fuel to steady state peak heat release rate is assumed to occur upon fire growth to the peak heat release rate corresponding to the lumped combustibles without diesel fuel. The fire is assumed to burn to completion with a 30 second decay period for lumped combustibles and an instantaneous decay for diesel fuel.

DETERMINE DATA FOR INPUT TO FAST COMPUTER FIRE MODELING SOFTWARE

1. Summarize initial combustible material inventory (I_o) in kJ (see Fire Scenario 1 for details):

Material Description	I_o
Tractor Cab/Engine Compartment	2,300,000 kJ
Front Tires	5,730,549 kJ
Rear Tires	16,321,272 kJ
Sub-Total ($I_{olumped}$)	24,351,821 kJ
Diesel Fuel	12,729,600 kJ
Total	37,081,421 kJ

2. Develop heat release rate and combustible inventory vs. time (see Fire Scenario 1 for details):

   a. Summarize peak heat release rate:

$$Q_{peak} = Q_{cab/enginecompt} + Q_{fronttires} + Q_{reartires} + Q_{dieselfuel}$$

$$Q_{cab/enginecompt} = 3{,}000 \text{ kW}$$

$$Q_{fronttires} = 4{,}834 \text{ kW}$$

$$Q_{reartires} = 16{,}175 \text{ kW}$$

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{peak} = 3{,}000$ kW + 4,834 kW + 16,175 kW + 8,996 kW

$Q_{peak} = 33{,}005$ kW

b. Determine time to reach $Q_{peak} - Q_{dieselfuel}$:

$Q_{peak} = \alpha t^2 + Q_{dieselfuel}$

$Q_{lumped} = Q_{peak} - Q_{dieselfuel} = \alpha t^2$

$t = [(Q_{lumped})/\alpha]^{1/2}$

$Q_{peak} = 33{,}005$ kW

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{lumped} = 24{,}009$ kW

$\alpha = 0.0469$ kW/sec²

t = 715 sec

c. Designate period of fire growth (i.e., t = 0 seconds to t = 715 seconds) as Period I.

d. Energy expended during Period I:

$$E_I = \int \alpha t^2 dt = \left. \frac{\alpha t^3}{3} \right|_0^t$$

t = 715 sec

$\alpha = 0.0469$ kW/sec²

$E_{Ilumped} = 5{,}714{,}388$ kJ

e. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fI}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	24,351,821 kJ	5,714,388 kJ	18,637,433 kJ
Diesel Fuel	12,729,600 kJ	0 kJ	12,729,600 kJ
Total	37,081,421 kJ	5,714,388 kJ	31,367,033 kJ

f. Determine time from reaching Q_{peak} to beginning of 30 second decay for lumped materials:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$t = [(I_{fIlumped} - (30\ sec)(0.5)(Q_{lumped}))/Q_{lumped}]$

$I_{fIlumped} = 18{,}637{,}433\ kJ$

$Q_{lumped} = 24{,}009\ kW$

$t = 761\ sec$

g. Designate period of steady state burning at Q_{peak} (i.e., t = 715 seconds to t = 1,476 seconds) as Period II.

h. Determine energy expended during Period II by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$E_{IIlumped} = (I_{fIlumped} - (30\ sec)(0.5)(Q_{lumped}))$

$I_{fIlumped} = 18{,}637{,}433\ kJ$

$Q_{lumped} = 24{,}009\ kW$

$E_{IIlumped} = 18{,}277{,}298\ kJ$

(2) Diesel Fuel:

$E_{IIdieselfuel} = (Q_{dieselfuel})(t)$

$t = 761\ sec$

$Q_{dieselfuel} = 8,996$ kW

$E_{IIdieselfuel} = 6,845,956$ kJ

i. Tabulate change in combustible material inventory during Period II:

Material Description	I_{fI}	$E_{II}(\Delta I)$	I_{fII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	18,637,433 kJ	18,277,298 kJ	360,135 kJ
Diesel Fuel	12,729,600 kJ	6,845,956 kJ	5,883,644 kJ
Total	31,367,033 kJ	25,123,254 kJ	6,243,779 kJ

j. Designate 30 second decay period of lumped combustibles and steady state burning at $Q_{dieselfuel}$ (i.e., t = 1,476 seconds to t = 1,506 seconds) as Period III.

k. Determine energy expended during Period III by material:

(1) Cab/Engine Compartment + Front Tires + Rear Tires (lumped):

$E_{IIIlumped} = (30 \text{ sec})(0.5)(Q_{lumped})$

$Q_{lumped} = 24,009$ kW

$E_{IIIlumped} = 360,135$ kJ

(2) Diesel Fuel:

$E_{IIIdieselfuel} = (Q_{dieselfuel})(t)$

t = 30 sec

$Q_{dieselfuel} = 8,996$ kW

$E_{IIIdieselfuel} = 269,880$ kJ

l. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires (lumped)	360,135 kJ	360,135 kJ	0 kJ
Diesel Fuel	5,883,644 kJ	269,880 kJ	5,613,764 kJ
Total	6,243,779 kJ	630,015 kJ	5,613,764 kJ

m. Determine time to burnout of diesel fuel:

(1) Diesel Fuel:

$t = (I_{fIIIdieselfuel})/(Q_{dieselfuel})$

$I_{fIIIdieselfuel} = 5{,}613{,}764$ kJ

$Q_{dieselfuel} = 8{,}996$ kW

$t = 624$ seconds

n. Designate period of steady state burning at $Q_{dieselfuel}$ (i.e., t = 1,506 seconds to t = 2,100 seconds) as Period IV.

o. Determine energy expended during Period IV:

(1) Diesel Fuel:

$E_{IVdieselfuel} = I_{fIIIdieselfuel}$

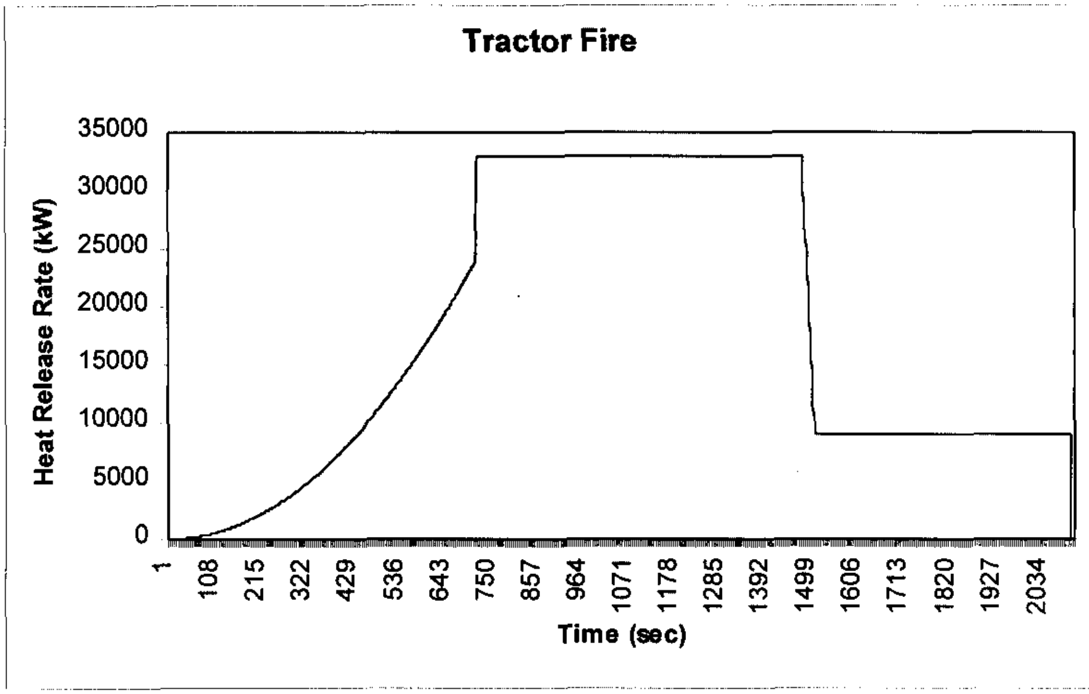
$I_{fIIIdieselfuel} = 5{,}613{,}764$ kJ

$E_{IVdieselfuel} = 5{,}613{,}764$ kJ

p. Tabulate change in combustible material inventory during Period IV:

Material Description	I_{fIII}	$E_{IV}(\Delta I)$	I_{fIV}
Tractor Cab/Engine Compartment + Front Tires + Rear Tires	0 kJ	0 kJ	0 kJ
Diesel Fuel	5,613,764 kJ	5,613,764 kJ	0 kJ
Total	5,613,764 kJ	5,613,764 kJ	0 kJ

3. Resulting Heat Release Rate Curve:



4. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through IV):

a. Mass Loss Rate – Equation

(1) $M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

b. Period I (t = 0 seconds through t = 715 seconds):

(1) Determine M_{bI}:

$M_{bI} = (Q_{tires/cab/enginecompt})/(\text{weighted } H_{cI})$

(a) Tires:

H_{ctires} = 34,815 kJ/kg

Mass:

(2 Front Tires)(82.3 kg/tire) = 164.6 kg

(8 Rear Tires)(58.6 kg/tire) = 468.8 kg

Total Tire Mass (M_{tires}) = 633.4 kg

(b) Cab and Engine Compartment:

$H_{ccab/enginecompt}$ = 23,000 kJ/kg

Cab/Engine Compt Mass ($M_{cab/enginecompt}$) = 100 kg

(c) Weighted H_{cI}:

$$H_{cI} = [M_{tires}/(M_{tires} + M_{cab/enginecompt})][H_{ctires}] + [M_{cab/enginecompt}/(M_{tires} + M_{cab/enginecompt})][H_{ccab/enginecompt}]$$

H_{cI} = 30,068 kJ/kg + 3,631 kJ/kg

H_{cI} = 33,699 kJ/ kg

(2) Determine Q_I at various times t:

$Q_I = \alpha t^2$

$\alpha = 0.0469$ kW/sec²

(3) Determine M_{bI} and tabulate:

t (seconds)	Q_I (kW)	M_{bI} (kg/sec)
0	0	0
143	960	0.028
286	3,841	0.114
429	8,643	0.256
572	15,366	0.456
715	24,009	0.712

c. Period II (t = 715 seconds through t = 1476 seconds):

(1) Determine M_{bII}:

$M_{bII} = (Q_{tires/cab/enginecompt})/(H_{cII}) + (Q_{dieselfuel}/H_{cdieselfuel})$

(a) Diesel Fuel:

$H_{cdieselfuel} = 40,800$ kJ/kg

(b) $H_{cIItires/cab/enginecompt}$:

$H_{cIItires/cab/enginecompt} = H_{cI}$

$H_{cIItires/cab/enginecompt} =$ 33,699 kJ/ kg

(2) Determine Q_{II}:

$Q_{II} = Q_{tires/cab/enginecompt} + Q_{dieselfuel}$

$Q_{tires/cab/enginecompt} = 24,009$ kW

$Q_{dieselfuel} = 8,996$ kW

$Q_{II} = 33,005$ kW

(3) Determine M_{bII}:

$$M_{bII} = (Q_{tires/cab/enginecompt}/H_{cIItires/cab/enginecompt}) + (Q_{dieselfuel}/ H_{cIIdieselfuel})$$

(4) Tabulate:

t (seconds)	Q_{II} (kW)	M_{bII} (kg/sec)
715	33,005	0.934
1,476	33,005	0.934

d. Period III (t = 1,476 seconds through t = 1,506 seconds):

(1) Determine M_{bIII}:

$M_{bIII} = (Q_{tires/cab/enginecompt})/(H_{cIII}) + (Q_{dieselfuel}/H_{cdieselfuel})$

(a) Diesel Fuel:

$H_{cIIIdieselfuel} = 40,800$ kJ/kg

(b) $H_{cIIItires/cab/enginecompt}$:

$H_{cIIItires/cab/enginecompt} = H_{cI}$

$H_{cIIItires/cab/enginecompt} =$ 33,699 kJ/ kg

(2) Determine Q_{III}:

(a) $Q_{III} = Q_{tires/cab/enginecompt} + Q_{dieselfuel}$

$Q_{dieselfuel} = 8{,}996$ kW

$Q_{tires/cab/enginecompt} = 24{,}009$ kW – (24,009 kW/30 sec)(t – 1476 sec)

(3) Determine Q_{III} and M_{bIII}, and tabulate:

t (seconds)	Q_{III} (kW)	M_{bIII} (kg/sec)
1,476	33,005	0.934
1,506	8,996	0.220

e. Period IV (t = 1,506 seconds to t = 2,100 seconds):

(1) Determine M_{bIV}:

$M_{bIV} = (Q_{dieselfuel}/H_{cdieselfuel})$

(a) Diesel Fuel:

$H_{cdieselfuel} = 40{,}800$ kJ/kg

(2) Determine Q_{IV}:

(a) $Q_{IV} = Q_{dieselfuel}$

$Q_{dieselfuel} = 8{,}996$ kW

(3) Determine Q_{IV} and M_{bIV}, and tabulate:

t (seconds)	Q_{IV} (kW)	M_{bIV} (kg/sec)
1,506	8,996	0.220
2,100	8,996	0.220
2,100	0	0

5. FAST Input Data:

```
VERSN    3TRACTOR ONLY
#VERSN 3 TRACTOR ONLY
TIMES   3600      0    120     20      0
DUMPR S3.HI
TAMB  293.150       101300. 0.000000
EAMB  293.150       101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.30000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
HVENT  1  2  1  3.96000  5.49000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1       1.00000       1.00000       1.00000       1.00000
1.00000       1.00000       1.00000       1.00000       1.00000       1.00000
1.00000
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.42857E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       143.000       286.000       429.000       572.000       715.000
716.000       1476.00       1506.00       2100.00       2101.00
FMASS      0.000000      0.0280000      0.114000      0.256000      0.456000
0.712000      0.934000      0.934000      0.220000      0.220000      0.000000
FQDOT      0.000000       960000.  3.84100E+006  8.64300E+006  1.53660E+007
2.40090E+007  3.30050E+007  3.30050E+007  8.99600E+006  8.99600E+006
0.000000
HCR        0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
OD         0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
CO         0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
```

6. FAST Output:

CFAST V 3.1 Created 4/1/98, Run 2/1/99

Time = 0.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	293.1	293.1	9.8	0.000E+00	0.000E+00	3.668E-21	1.137E-13
Outside					0.000E+00		

Time = 120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	316.5	293.7	3.5	2.350E-02	8.056E+05	-0.152	99.4
Outside					0.000E+00		

Time = 240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	384.6	296.5	3.4	8.634E-02	2.914E+06	-0.649	529.
Outside					0.000E+00		

Time = 360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	473.9	302.7	3.1	0.187	6.324E+06	-1.65	1.594E+03
Outside					0.000E+00		

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	559.9	312.8	2.8	0.327	1.103E+07	-3.12	3.488E+03
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	638.5	330.3	2.3	0.506	1.704E+07	-5.52	6.456E+03
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	748.1	359.3	1.4	0.934	3.294E+07	-7.61	1.332E+04
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	819.2	384.6	1.3	0.934	3.292E+07	-11.3	1.991E+04
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	833.0	390.4	1.3	0.934	3.291E+07	-11.5	2.180E+04
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	845.1	395.2	1.3	0.934	3.291E+07	-11.6	2.354E+04
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	856.4	399.4	1.3	0.934	3.290E+07	-11.7	2.525E+04
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	867.3	403.3	1.3	0.934	3.290E+07	-11.8	2.696E+04
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	878.0	407.0	1.3	0.934	3.290E+07	-11.9	2.869E+04
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	666.0	349.1	3.1	0.220	8.984E+06	-5.40	1.077E+04
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	639.0	339.3	3.1	0.220	8.986E+06	-4.77	8.693E+03
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	628.4	336.2	3.0	0.220	8.986E+06	-4.56	7.932E+03
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	622.8	335.5	3.0	0.220	8.987E+06	-4.51	7.540E+03
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	619.2	334.9	3.0	0.220	8.987E+06	-4.47	7.289E+03
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	549.2	338.1	5.5	0.000E+00	0.000E+00	-4.22	4.927E+03
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	518.1	337.9	5.8	0.000E+00	0.000E+00	-4.18	4.005E+03
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	502.8	335.5	5.9	0.000E+00	0.000E+00	-3.99	3.518E+03
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	491.3	333.5	6.0	0.000E+00	0.000E+00	-3.83	3.172E+03
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	481.9	331.9	6.1	0.000E+00	0.000E+00	-3.69	2.900E+03
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	473.7	330.5	6.1	0.000E+00	0.000E+00	-3.57	2.677E+03
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	466.5	329.2	6.2	0.000E+00	0.000E+00	-3.46	2.488E+03
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	460.1	328.0	6.2	0.000E+00	0.000E+00	-3.36	2.326E+03
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	454.2	326.9	6.3	0.000E+00	0.000E+00	-3.27	2.185E+03
Outside					0.000E+00		

Time = 3240.0 seconds.

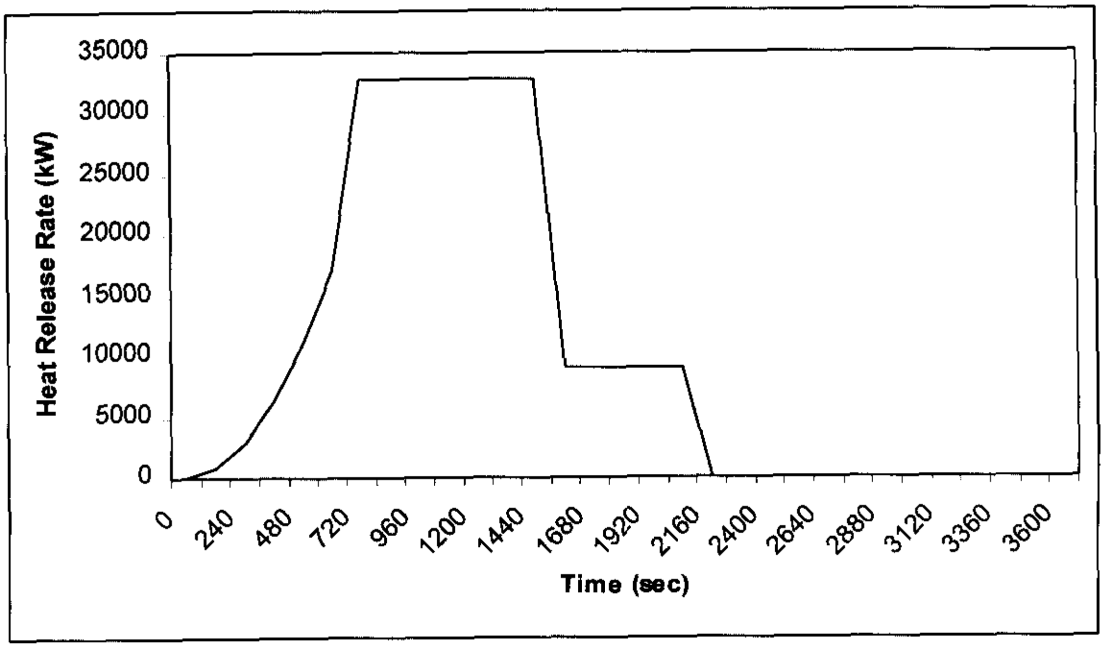
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	448.9	326.0	6.3	0.000E+00	0.000E+00	-3.19	2.062E+03
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	444.0	325.1	6.4	0.000E+00	0.000E+00	-3.11	1.953E+03
Outside					0.000E+00		

Time = 3480.0 seconds.

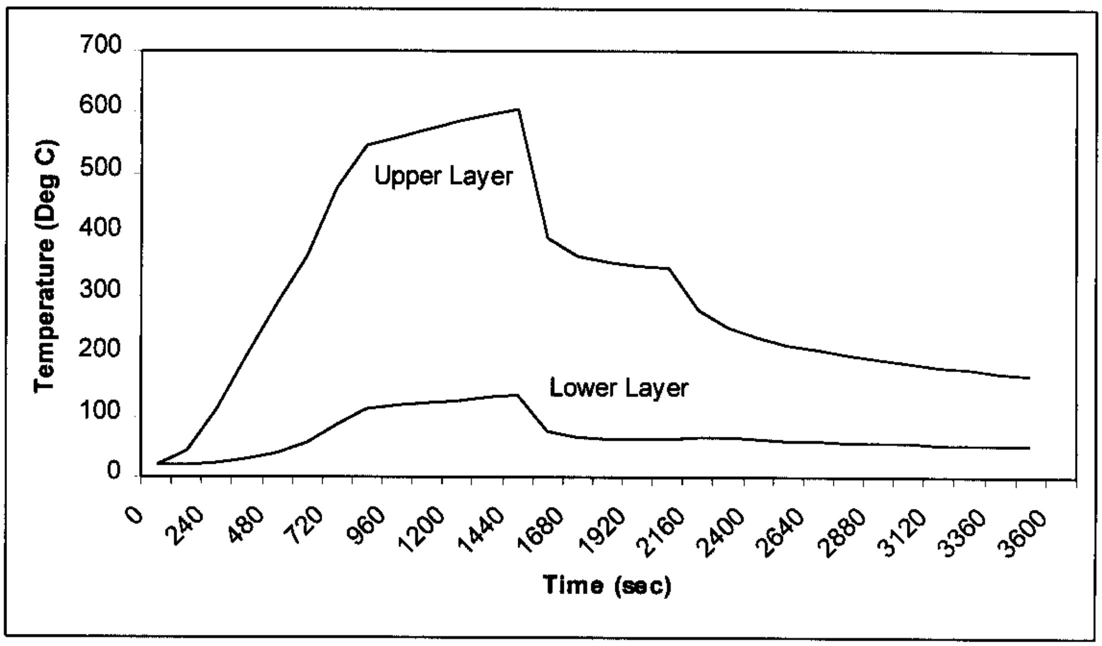
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	439.5	324.2	6.4	0.000E+00	0.000E+00	-3.04	1.855E+03
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Tractor Only

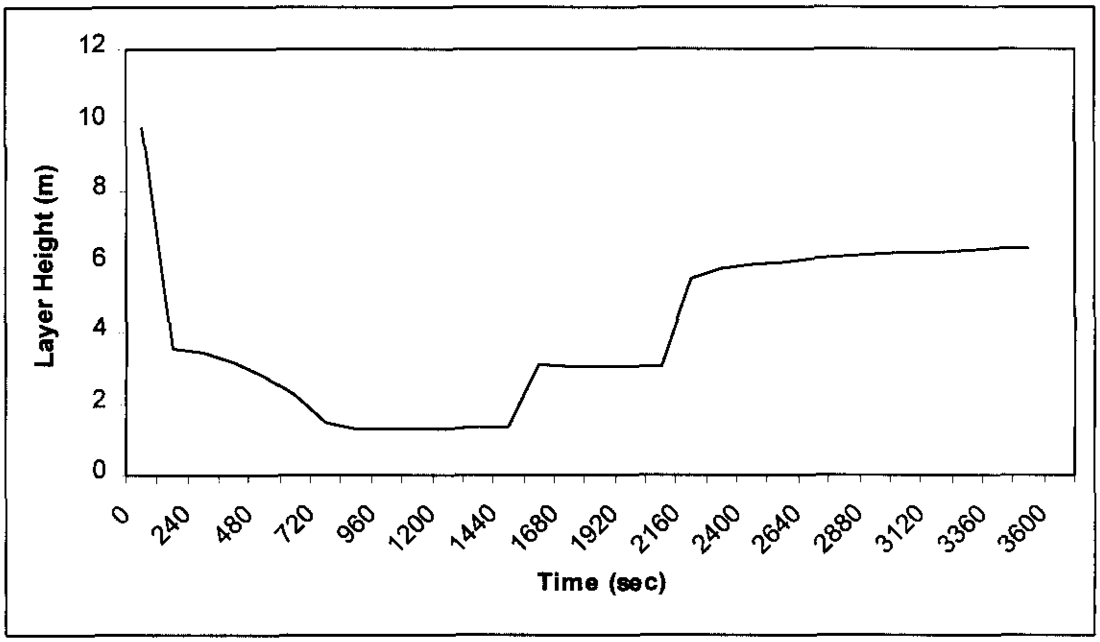
Figure A-7



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Tractor Only

Figure A-8



CFAST Output: Layer Height vs. Time

Tractor Only

Figure A-9

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CVDF Fire Scenario 4

Fire Modeling and Evaluation of a Fire Involving Transporter Tires Only – Oxygen Supply Not Limited in a Cold Vacuum Drying Facility Processing Bay

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CVDF Fire Scenario 4

DISCUSSION

CVDF Fire Scenario 4 occurs with the transporter inside a CVDF process bay. The large bay door is closed and the MCO is connected to processing equipment. The supply of oxygen to this fire scenario is not assumed to be limited to the oxygen available in the closed process bay at the time of the fire. There is no viable ignition source for the transporter tires in a CVDF processing bay, however, since the CVDF is a non-reactor nuclear facility, an ignition source with sufficient power is assumed to exist and ignite the transporter tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. The transporter tire fire is assumed to burn to completion with a 30 second decay period.

DETERMINE DATA FOR INPUT TO FAST COMPUTER FIRE MODELING SOFTWARE

1. Determine initial combustible material inventory (I_o) in kJ:

   a. Transporter Tires:

   $M = (12)(50.0\ kg) = 600\ kg$

   $H_c = 34{,}815\ kJ/kg$

   $I_o = M\ H_c = 20{,}889{,}000\ kJ$

Material Description	I_o
Transporter Tires	20,889,000 kJ
Total	20,889,000 kJ

2. Develop heat release rate and combustible inventory vs. time:

   a. Calculate peak heat release rate:

   $Q_{peak} = Q_{transportertires}$

   $Q_{transportertires} = (q_{transportertires})(A_{transporttires})$

   $q_{transportertires} = 929{,}560\ W/m^2$

   $A_{transportertires} = (12\ tires)\{(2\pi r_o w) + 2[\pi(r_o^2 - r_i^2)]\}$

   For Bridgestone 275/70R22.5 tires:

   $r_o = 0.48\ m\ (19.0\ in.)$

$r_i = 0.29$ m (11.25 in.)

$w = 0.29$ m (11.4 in.)

$A_{transportertires} = 21.5\ m^2$

$Q_{transportertires} = 19{,}986$ kW

$Q_{peak} = 19{,}986$ kW

b. Determine time to reach Q_{peak}:

$Q_{peak} = Q_{transportertires} = \alpha t^2$

$t = [(Q_{transportertires})/\alpha]^{1/2}$

$Q_{transportertires} = 19{,}986$ kW

$\alpha = 0.0469\ kW/sec^2$

$t = 653$ sec

c. Designate period of fire growth (i.e., t = 0 seconds to t = 653 seconds) as Period I.

d. Energy expended during Period I:

$$E_I = \int_0^t \alpha t^2 dt = \frac{\alpha t^3}{3}\Big|_0^t$$

$t = 653$ sec

$\alpha = 0.0469\ kW/sec^2$

$E_I = 4{,}353{,}025$ kJ

e. Tabulate change in combustible material inventory during Period I:

Material Description	I_0	$E_I(\Delta I)$	I_{fI}
Transporter Tires	20,889,000 kJ	4,353,025 kJ	16,535,975 kJ
Total	20,889,000 kJ	4,353,025 kJ	16,535,975 kJ

f. Determine time from reaching Q_{peak} to beginning of 30 second decay for transporter tires:

(1) Transporter Tires:

$t = [(I_{fItransportertires} - (30\ sec)(0.5)(Q_{transportertires}))/Q_{transportertires}]$

$I_{fItransportertires} = 16{,}535{,}975\ kJ$

$Q_{transportertires} = 19{,}986\ kW$

$t = 812\ sec$

g. Designate period of steady state burning at $Q_{transportertires}$ (i.e., t = 653 seconds to t = 1,465 seconds) as Period II.

h. Determine energy expended during Period II:

(1) Transporter Tires:

$E_{IItransportertires} = I_{fItransportertires} - (30\ sec)(0.5)(Q_{transportertires})$

$I_{fItransportertires} = 16{,}535{,}975\ kJ$

$Q_{transportertires} = 19{,}986\ kW$

$E_{IItransportertires} = 16{,}236{,}185\ kJ$

i. Tabulate change in combustible material inventory during Period II:

Material Description	I_{fI}	$E_{II}(\Delta I)$	I_{fII}
Transporter Tires	16,535,975 kJ	16,236,185 kJ	299,790 kJ
Total	16,535,975 kJ	16,236,185 kJ	299,790 kJ

j. Designate 30 second decay period of transporter tire fire (i.e., t = 1,465 seconds to t = 1,495 seconds) as Period III.

k. Determine energy expended during Period III:

(1) Transporter Tires:

$E_{IIItransportertires} = (30\ sec)(0.5)(Q_{transportertires})$

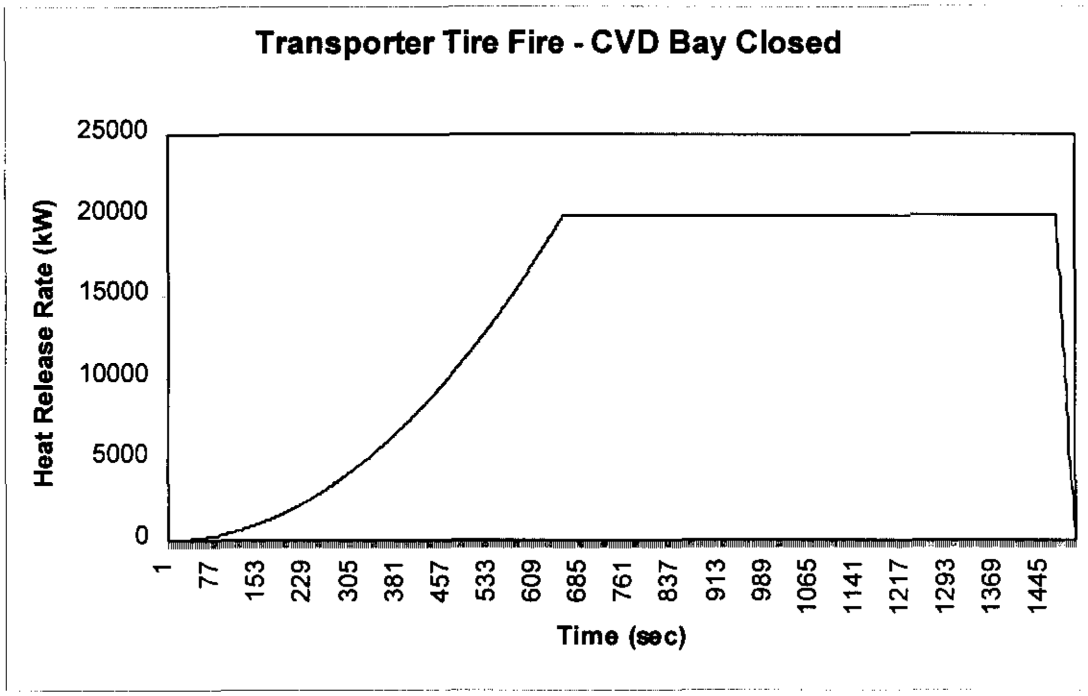
$Q_{transportertires} = 19{,}986\ kW$

$E_{IIItransportertires} = 299{,}790\ kJ$

1. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Transporter Tires	299,790 kJ	299,790 kJ	0 kJ
Total	299,790 kJ	299,790 kJ	0 kJ

3. Resulting Heat Release Rate Curve:



4. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through III):

a. Mass Loss Rate – Equation

(1) $M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

b. Period I (t = 0 seconds through t = 653 seconds):

(1) Determine M_{bI}:

$M_{bI} = (Q_{transportertires})/(H_{ctransportertires})$

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_I at various times t:

$Q_I = \alpha t^2$

$\alpha = 0.0469$ kW/sec²

(3) Determine M_{bI} and tabulate:

t (seconds)	Q_I (kW)	M_{bI} (kg/sec)
0	0	0
120	675	0.019
240	2,700	0.078
360	6,074	0.174
480	10,799	0.310
600	16,873	0.485
653	19,986	0.574

c. Period II (t = 653 seconds through t = 1,465 seconds):

$M_{bII} = (Q_{transportertires})/(H_{ctransportertires})$

$H_{ctransportertires} = 34{,}815$ kJ/kg

(1) Determine Q_{II}:

$Q_{II} = Q_{transportertires}$

$Q_{transportertires} = 19{,}986$ kW

$Q_{II} = 19{,}986$ kW

(2) Determine M_{bII} and tabulate:

t (seconds)	Q_{II} (kW)	M_{bII} (kg/sec)
653	19,986	0.574
1,465	19,986	0.574

d. Period III (t = 1,465 to t = 1,495 seconds):

(1) Determine M_{bIII}:

$$M_{bIII} = (Q_{transportertires}/H_{ctransportertires})$$

$$H_{ctransportertires} = 34{,}815 \text{ kJ/kg}$$

(2) Determine Q_{III}:

$$Q_{III} = Q_{transportertires} - (Q_{transportertires}/30 \text{ sec})(t - 1{,}465 \text{ sec})$$

$$Q_{transportertires} = 19{,}986 \text{ kW}$$

(3) Determine Q_{III} and M_{bIII}, and tabulate:

t (seconds)	Q_{III} (kW)	M_{bIII} (kg/sec)
1,465	19,986	0.574
1,495	0	0

5. FAST Input Data:

```
VERSN    3TRANSPORTER TIRES ONLY - DOOR CLOSED, OXYGEN SUPPLY NOT LIMITED
#VERSN 3 TRANSPORTER TIRES ONLY - DOOR CLOSED, OXYGEN SUPPLY NOT LIMITED
TIMES   3600      0     120      20       0
DUMPR S4.HI
TAMB  293.150         101300. 0.000000
EAMB  293.150         101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.30000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.55263E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME       120.000       240.000       360.000       480.000       600.000
653.000       1465.00       1495.00
FMASS      0.000000     0.0190000     0.0780000     0.174000      0.310000
0.485000      0.574000      0.574000      0.000000
FQDOT      0.000000      675000.  2.70000E+006  6.07400E+006  1.07990E+007
1.68730E+007  1.99860E+007  1.99860E+007      0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
```

6. FAST Output:

CFAST V 3.1 Created 4/1/98, Run 2/1/99

Time = 0.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	293.1	293.1	9.8	0.000E+00	0.000E+00	0.000E+00	1.137E-13
Outside					0.000E+00		

Time = 120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	317.2	298.4	3.0	1.900E-02	6.749E+05	6.308E+03	117.
Outside					0.000E+00		

Time = 240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	396.6	318.0	0.74	7.800E-02	2.698E+06	3.372E+04	866.
Outside					0.000E+00		

Time = 360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	531.6	339.2	1.54E-03	0.174	6.066E+06	8.442E+04	3.563E+03
Outside					0.000E+00		

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	665.2	403.3	1.39E-03	0.310	1.076E+07	1.344E+05	9.341E+03
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	771.1	499.9	1.45E-03	0.485	1.677E+07	1.783E+05	1.736E+04
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	835.8	605.0	1.57E-03	0.574	1.980E+07	2.115E+05	2.450E+04
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	854.0	668.7	1.65E-03	0.574	1.977E+07	2.285E+05	2.722E+04
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	870.2	715.5	1.68E-03	0.574	1.974E+07	2.451E+05	2.975E+04
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	886.0	754.0	1.68E-03	0.574	1.972E+07	2.620E+05	3.231E+04
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	901.7	787.4	1.68E-03	0.574	1.970E+07	2.792E+05	3.498E+04
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	917.5	817.3	1.67E-03	0.574	1.968E+07	2.968E+05	3.778E+04
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	933.3	844.4	1.65E-03	0.574	1.967E+07	3.148E+05	4.073E+04
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	718.8	726.8	1.36E-03	0.000E+00	0.000E+00	2.220E+05	1.660E+04
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	642.2	659.5	1.38E-03	0.000E+00	0.000E+00	1.876E+05	1.116E+04
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	604.4	623.5	1.39E-03	0.000E+00	0.000E+00	1.706E+05	8.998E+03
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	580.0	599.3	1.39E-03	0.000E+00	0.000E+00	1.596E+05	7.759E+03
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	562.0	580.8	1.39E-03	0.000E+00	0.000E+00	1.515E+05	6.917E+03
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	547.5	565.5	1.39E-03	0.000E+00	0.000E+00	1.450E+05	6.285E+03
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	535.4	552.4	1.39E-03	0.000E+00	0.000E+00	1.395E+05	5.781E+03
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	524.9	541.0	1.39E-03	0.000E+00	0.000E+00	1.348E+05	5.365E+03
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	515.6	531.0	1.38E-03	0.000E+00	0.000E+00	1.306E+05	5.014E+03
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	507.3	522.0	1.38E-03	0.000E+00	0.000E+00	1.269E+05	4.712E+03
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	499.9	513.9	1.38E-03	0.000E+00	0.000E+00	1.236E+05	4.450E+03
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	493.1	506.6	1.38E-03	0.000E+00	0.000E+00	1.205E+05	4.220E+03
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	487.0	499.9	1.38E-03	0.000E+00	0.000E+00	1.178E+05	4.016E+03
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	481.3	493.8	1.38E-03	0.000E+00	0.000E+00	1.152E+05	3.835E+03
Outside					0.000E+00		

Time = 3240.0 seconds.

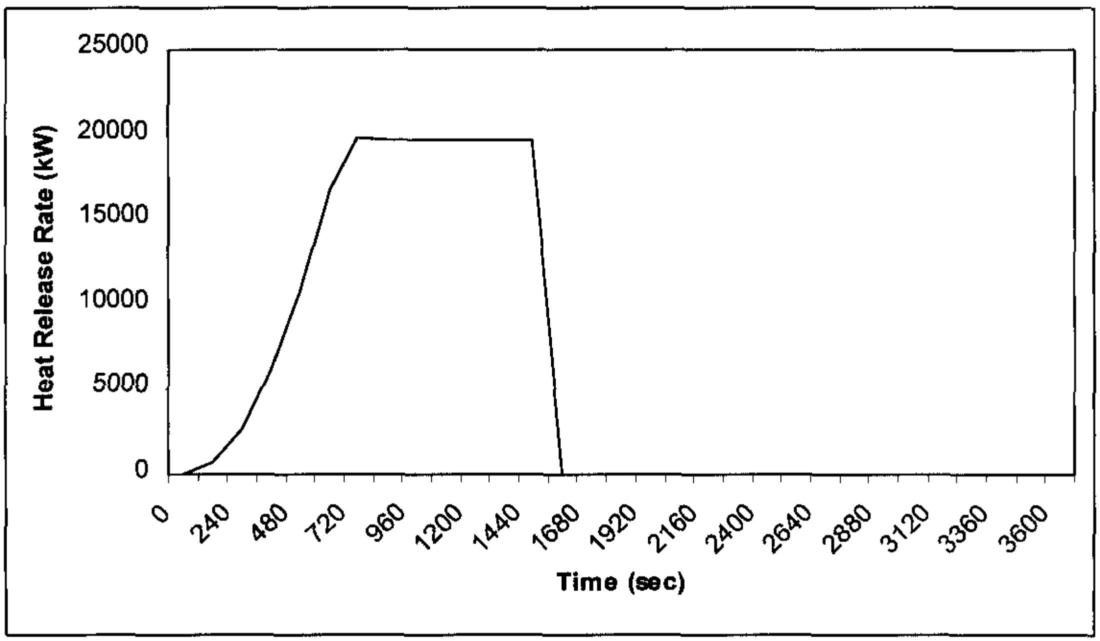
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	476.1	488.2	1.38E-03	0.000E+00	0.000E+00	1.129E+05	3.671E+03
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	471.3	483.0	1.38E-03	0.000E+00	0.000E+00	1.107E+05	3.524E+03
Outside					0.000E+00		

Time = 3480.0 seconds.

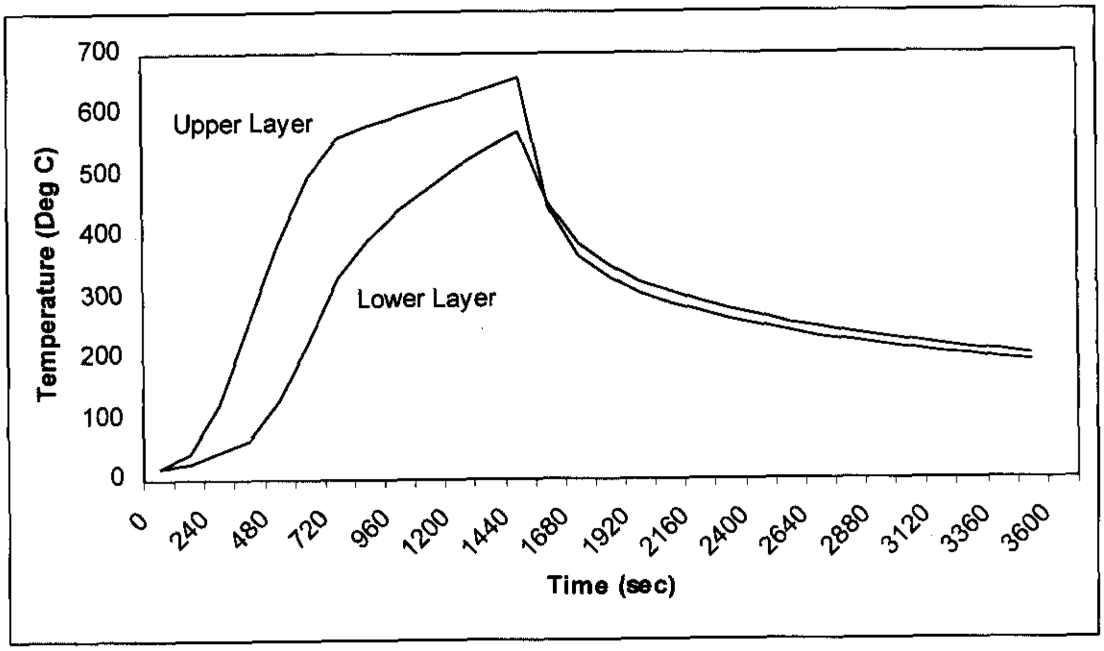
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	466.8	478.2	1.38E-03	0.000E+00	0.000E+00	1.087E+05	3.390E+03
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Transporter Tires Only, Oxygen Supply Not Limited

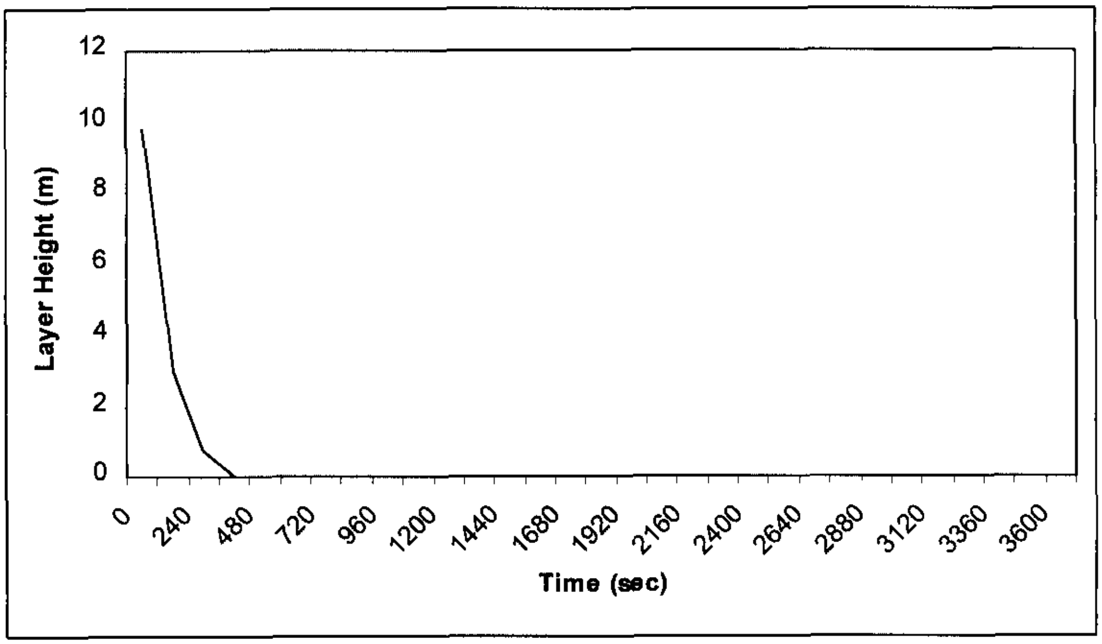
Figure A-10



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Transporter Tires Only, Oxygen Supply Not Limited

Figure A-11



CFAST Output: Layer Height vs. Time

Transporter Tires Only, Oxygen Supply Not Limited

Figure A-12

CVDF Fire Scenario 5

Fire Modeling and Evaluation of a Fire Involving
Transporter Tires Only – Oxygen Supply Limited
in a Cold Vacuum Drying Facility Processing Bay

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CVDF Fire Scenario 5

DISCUSSION

CVDF Fire Scenario 5 is identical to Fire Scenario 4, except that the oxygen supply is assumed to be limited to the oxygen available in the process bay at the time of the fire. The fire occurs with the transporter inside a CVDF process bay. The large bay door is closed and the MCO is connected to processing equipment. There is no viable ignition source for the transporter tires in a CVDF processing bay, however, since the CVDF is a non-reactor nuclear facility, an ignition source with sufficient power is assumed to exist and ignite the transporter tires. The rate of fire growth is assumed to follow the power-law fire growth model with a medium-fast fire intensity coefficient. The transporter tire fire is assumed to burn to completion with a 30 second decay period.

DETERMINE DATA FOR INPUT TO FAST COMPUTER FIRE MODELING SOFTWARE

1. Determine initial combustible material inventory (I_o) in kJ:

   a. Transporter Tires:

   $M = (12)(50.0 \text{ kg}) = 600 \text{ kg}$

   $H_c = 34{,}815 \text{ kJ/kg}$

   $I_o = M\, H_c = 20{,}889{,}000 \text{ kJ}$

Material Description	I_o
Transporter Tires	20,889,000 kJ
Total	20,889,000 kJ

2. Develop heat release rate and combustible inventory vs. time:

   1. Calculate peak heat release rate:

$Q_{peak} = Q_{transportertires}$

$Q_{transportertires} = (q_{transportertires})(A_{transporttires})$

$q_{transportertires} = 929{,}560 \text{ W/m}^2$

$A_{transportertires} = (12 \text{ tires})\{(2\pi r_o w) + 2[\pi(r_o^2 - r_i^2)]\}$

For Bridgestone 275/70R22.5 tires:

$r_o = 0.48 \text{ m } (19.0 \text{ in.})$

$r_i = 0.29$ m (11.25 in.)

$w = 0.29$ m (11.4 in.)

$A_{transportertires} = 21.5\ m^2$

$Q_{transportertires} = 19{,}986$ kW

$Q_{peak} = 19{,}986$ kW

2. Determine time to reach Q_{peak}:

$Q_{peak} = Q_{transportertires} = \alpha t^2$

$t = [(Q_{transportertires})/\alpha]^{1/2}$

$Q_{transportertires} = 19{,}986$ kW

$\alpha = 0.0469\ kW/sec^2$

$t = 653$ sec

3. Designate period of fire growth (i.e., t = 0 seconds to t = 653 seconds) as Period I.

4. Energy expended during Period I:

$$E_I = \int_0^t \alpha t^2 dt = \left.\frac{\alpha t^3}{3}\right|_0^t$$

$t = 653$ sec

$\alpha = 0.0469\ kW/sec^2$

$E_I = 4{,}353{,}025$ kJ

5. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fl}
Transporter Tires	20,889,000 kJ	4,353,025 kJ	16,535,975 kJ
Total	20,889,000 kJ	4,353,025 kJ	16,535,975 kJ

6. Determine time from reaching Q_{peak} to beginning of 30 second decay for transporter tires:

(1) Transporter Tires:

$t = [(I_{fItransportertires} - (30\ sec)(0.5)(Q_{transportertires}))/Q_{transportertires}]$

$I_{fItransportertires} = 16{,}535{,}975\ kJ$

$Q_{transportertires} = 19{,}986\ kW$

$t = 812\ sec$

7. Designate period of steady state burning at $Q_{transportertires}$ (i.e., t = 653 seconds to t = 1,465 seconds) as Period II.

8. Determine energy expended during Period II:

(2) Transporter Tires:

$E_{IItransportertires} = I_{fItransportertires} - (30\ sec)(0.5)(Q_{transportertires})$

$I_{fItransportertires} = 16{,}535{,}975\ kJ$

$Q_{transportertires} = 19{,}986\ kW$

$E_{IItransportertires} = 16{,}236{,}185\ kJ$

9. Tabulate change in combustible material inventory during Period II:

Material Description	I_{fI}	$E_{II}(\Delta I)$	I_{fII}
Transporter Tires	16,535,975 kJ	16,236,185 kJ	299,790 kJ
Total	16,535,975 kJ	16,236,185 kJ	299,790 kJ

10. Designate 30 second decay period of transporter tire fire (i.e., t = 1,465 seconds to t = 1,495 seconds) as Period III.

11. Determine energy expended during Period III:

(1) Transporter Tires:

$E_{IIItransportertires} = (30\ sec)(0.5)(Q_{transportertires})$

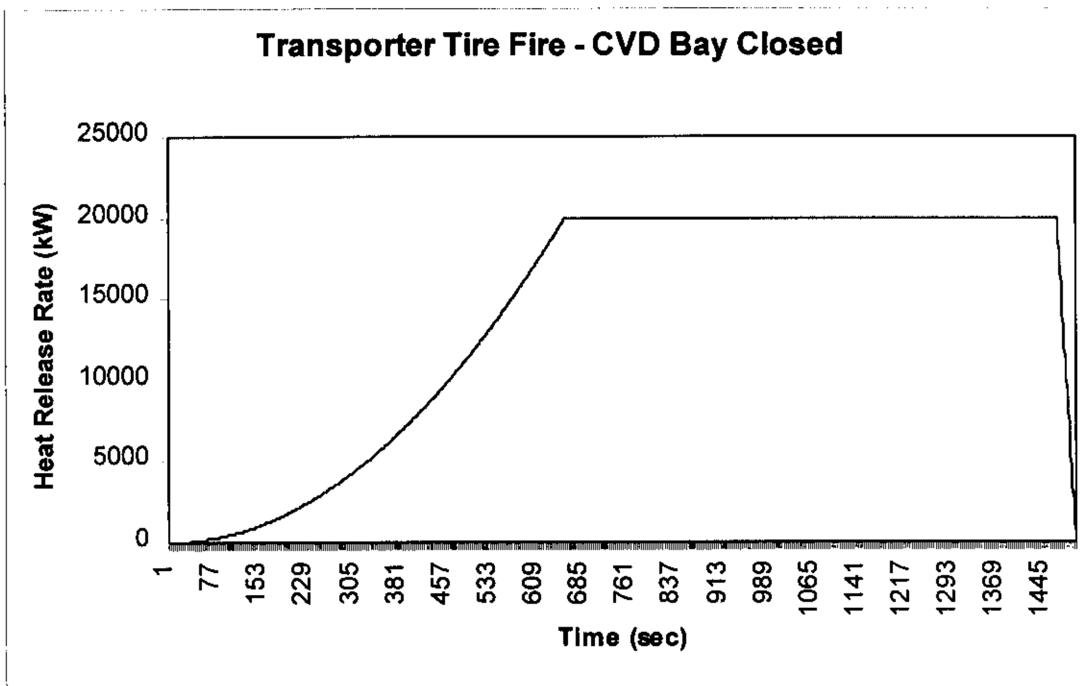
$Q_{transportertires} = 19{,}986\ kW$

$E_{IIItransportertires} = 299{,}790\ kJ$

12. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Transporter Tires	299,790 kJ	299,790 kJ	0 kJ
Total	299,790 kJ	299,790 kJ	0 kJ

3. Resulting Heat Release Rate Curve:



4. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through III):

a. Mass Loss Rate – Equation

(1) $M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

b. Period I (t = 0 seconds through t = 653 seconds):

(1) Determine M_{bI}:

$M_{bI} = (Q_{transportertires})/(H_{ctransportertires})$

$H_{ctransportertires} = 34{,}815$ kJ/kg

(2) Determine Q_I at various times t:

$Q_I = \alpha t^2$

$\alpha = 0.0469$ kW/sec²

(3) Determine M_{bI} and tabulate:

t (seconds)	Q_I (kW)	M_{bI} (kg/sec)
0	0	0
120	675	0.019
240	2,700	0.078
360	6,074	0.174
480	10,799	0.310
600	16,873	0.485
653	19,986	0.574

c. Period II (t = 653 seconds through t = 1,465 seconds):

$M_{bII} = (Q_{transportertires})/(H_{ctransportertires})$

$H_{ctransportertires} = 34{,}815$ kJ/kg

(1) Determine Q_{II}:

$Q_{II} = Q_{transportertires}$

$Q_{transportertires} = 19{,}986$ kW

$Q_{II} = 19{,}986$ kW

(2) Determine M_{bII} and tabulate:

t (seconds)	Q_{II} (kW)	M_{bII} (kg/sec)
653	19,986	0.574
1,465	19,986	0.574

d. Period III (t = 1,465 to t = 1,495 seconds):

(1) Determine M_{bIII}:

$$M_{bIII} = (Q_{transportertires}/H_{ctransportertires})$$

$$H_{ctransportertires} = 34{,}815 \text{ kJ/kg}$$

(2) Determine Q_{III}:

$$Q_{III} = Q_{transportertires} - (Q_{transportertires}/30 \text{ sec})(t - 1{,}465 \text{ sec})$$

$$Q_{transportertires} = 19{,}986 \text{ kW}$$

(3) Determine Q_{III} and M_{bIII}, and tabulate:

t (seconds)	Q_{III} (kW)	M_{bIII} (kg/sec)
1,465	19,986	0.574
1,495	0	0

3. FAST Input Data:

```
VERSN    3TRANSPORTER TIRES ONLY - DOOR CLOSED, OXYGEN SUPPLY LIMITED
#VERSN 3 TRANSPORTER TIRES ONLY - DOOR CLOSED, OXYGEN SUPPLY LIMITED
TIMES  3600      0    120     20      0
DUMPR S5.HI
ADUMP S5.XLS N
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.30000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.55263E+007  293.150  493.150 0.300000
LFBO 1
LFBT 2
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       120.000       240.000       360.000       480.000       600.000
653.000       1465.00       1495.00
FMASS      0.000000     0.0190000     0.0780000      0.174000      0.310000
0.485000      0.574000      0.574000      0.000000
FQDOT      0.000000       675000.  2.70000E+006  6.07400E+006  1.07990E+007
1.68730E+007  1.99860E+007  1.99860E+007      0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000     0.0800000
0.0800000     0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000     0.0300000
0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
```

4. FAST Output:

```
CFAST V  3.1 Created  4/1/98,  Run  4/23/99


Time =       0.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           293.1   293.1   9.8     0.000E+00 0.000E+00 0.000E+00 1.137E-13
 Outside                                        0.000E+00


Time =     120.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           317.9   298.5   3.0     1.900E-02 6.749E+05 6.476E+03  120.
 Outside                                        0.000E+00


Time =     240.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           398.6   317.9  0.74     7.800E-02 2.698E+06 3.434E+04  886.
 Outside                                        0.000E+00


Time =     360.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           531.5   338.0  1.87E-02 0.174     6.066E+06 8.420E+04 3.551E+03
 Outside                                        0.000E+00


Time =     480.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire       Pressure   Ambient
              Temp.   Temp.   Height  Rate       Size                  Target
              (K)     (K)     (m)     (kg/s)     (W)        (Pa)       (W/m^2)
------------------------------------------------------------------------------
  1           666.4   399.5  1.18E-02 0.310     1.077E+07 1.347E+05 9.372E+03
 Outside                                        0.000E+00
```

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	680.7	467.2	1.32E-02	0.485	7.496E+05	1.454E+05	1.076E+04
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	467.8	401.5	1.56E-02	0.574	2.269E+05	7.371E+04	2.610E+03
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	416.9	378.4	1.51E-02	0.574	1.653E+05	5.967E+04	1.616E+03
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	391.3	366.7	1.48E-02	0.574	9.840E+04	5.448E+04	1.214E+03
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	375.3	359.4	1.45E-02	0.574	4.554E+04	5.257E+04	992.
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	363.7	354.1	1.43E-02	0.574	4.455E-07	5.217E+04	845.
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.6	350.0	1.41E-02	0.574	1.355E-08	5.300E+04	745.
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	350.1	346.6	1.38E-02	0.574	0.000E+00	5.479E+04	675.
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	348.6	344.0	1.17E-02	0.000E+00	0.000E+00	5.550E+04	644.
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	343.1	341.4	1.18E-02	0.000E+00	0.000E+00	5.305E+04	584.
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	339.2	339.2	1.19E-02	0.000E+00	0.000E+00	5.127E+04	539.
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.1	337.2	1.19E-02	0.000E+00	0.000E+00	4.990E+04	504.
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	333.6	335.5	1.20E-02	0.000E+00	0.000E+00	4.879E+04	474.
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	331.6	333.9	1.20E-02	0.000E+00	0.000E+00	4.788E+04	449.
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	329.9	332.5	1.20E-02	0.000E+00	0.000E+00	4.710E+04	428.
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	328.4	331.2	1.20E-02	0.000E+00	0.000E+00	4.642E+04	409.
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	327.1	330.0	1.20E-02	0.000E+00	0.000E+00	4.583E+04	392.
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	325.9	328.9	1.20E-02	0.000E+00	0.000E+00	4.529E+04	378.
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	324.8	327.9	1.20E-02	0.000E+00	0.000E+00	4.481E+04	364.
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	323.8	327.0	1.20E-02	0.000E+00	0.000E+00	4.438E+04	352.
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	322.9	326.2	1.20E-02	0.000E+00	0.000E+00	4.398E+04	340.
Outside					0.000E+00		

Time = 3120.0 seconds.

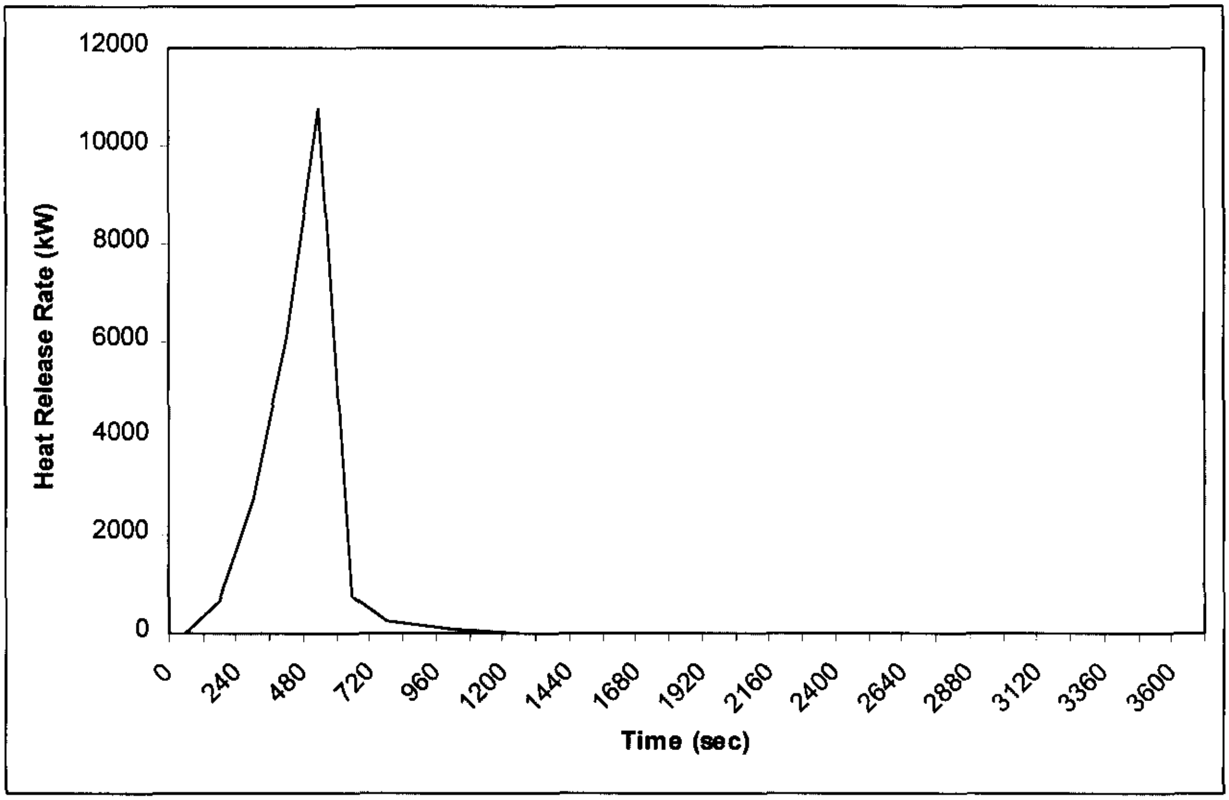
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	322.1	325.4	1.20E-02	0.000E+00	0.000E+00	4.361E+04	330.
Outside					0.000E+00		

Time = 3240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	321.4	324.6	1.20E-02	0.000E+00	0.000E+00	4.326E+04	320.
Outside					0.000E+00		

Time = 3360.0 seconds.

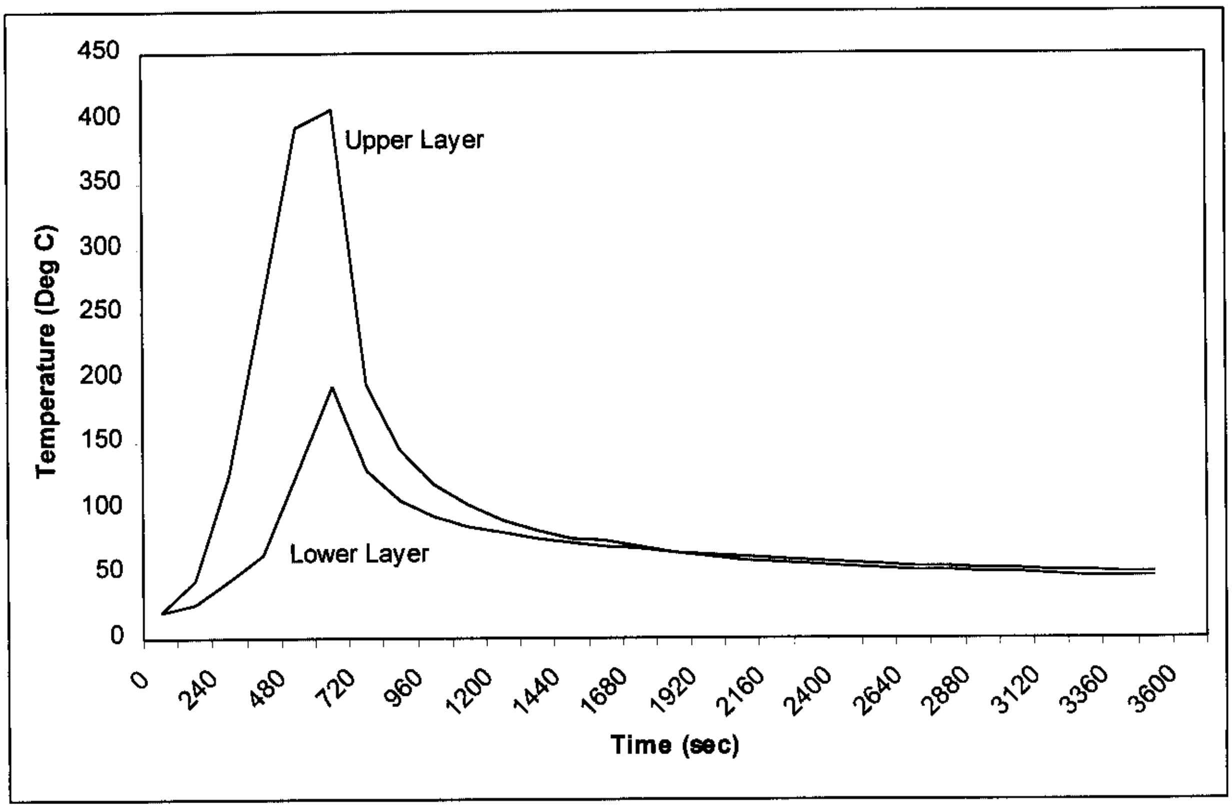
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	320.7	323.9	1.20E-02	0.000E+00	0.000E+00	4.295E+04	311.
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Transporter Tires Only, Oxygen Supply Limited

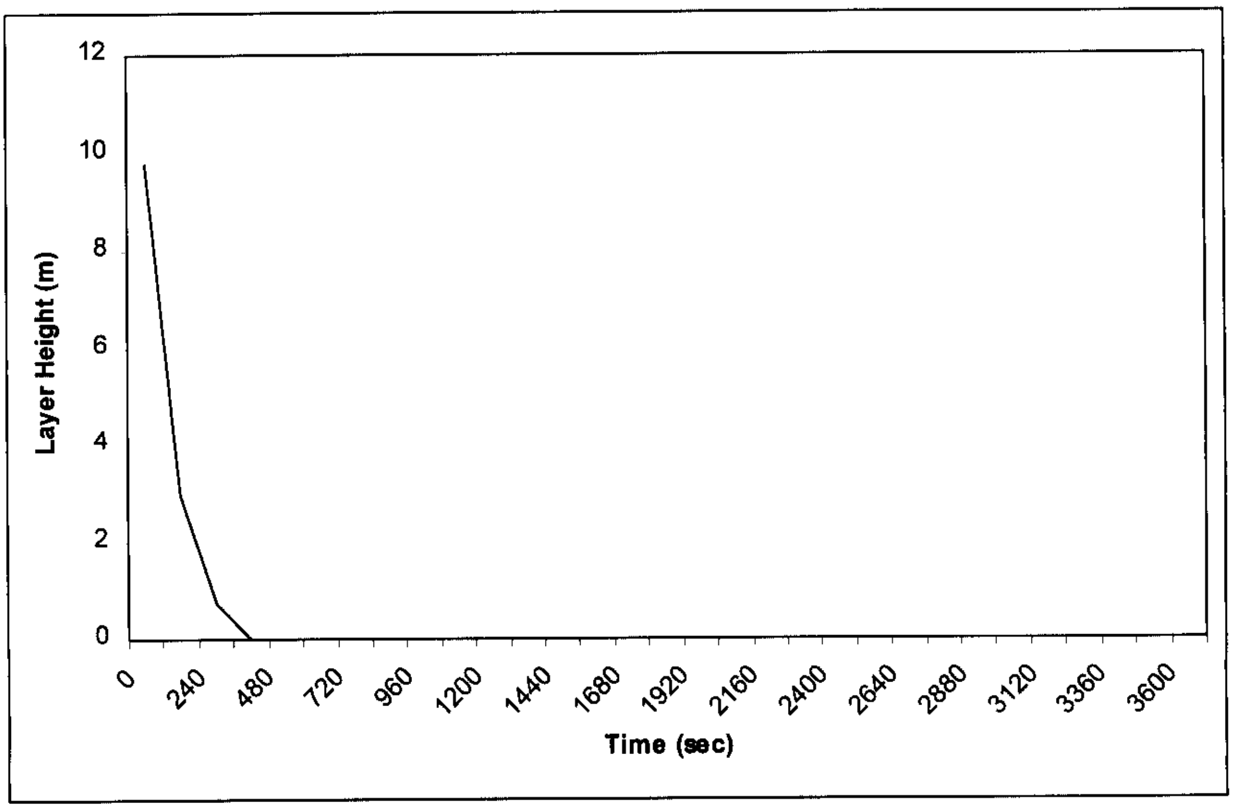
Figure A-13



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Transporter Tires Only, Oxygen Supply Limited

Figure A-14



CFAST Output: Layer Height vs. Time

Transporter Tires Only, Oxygen Supply Limited

Figure A-15

CVDF Fire Scenario 6

Fire Modeling and Evaluation
of a Fire Involving a Step Off Pad Arrangement
in the CVDF Processing Bay

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CVDF Fire Scenario 6

DISCUSSION

CVDF Fire Scenario 6 consists of several cases involving combustion of materials present in the CVDF during operations and maintenance. Each case is conservatively assumed to occur with unlimited oxygen supply (unless otherwise noted), with doors to the space closed, vents closed and ventilation off.

The local and general area affect of each case will be examined. These affects depend on the location of the materials relative to the building structure, transporter tires, and safety class equipment.

The fire is assumed to grow in each case to peak heat release rate in 30 seconds, burn at peak heat release rate, then burn to completion with a 30 second decay period.

COMBUSTIBLE LOADING

The following combustible loading estimate for the CVDF has been provided by SNF Project Operations:

Estimates for combustible loading at CVD.

Assumptions/Definitions

- All 4 bays are used for processing
- The general area in a bay is non zone
- PWC room will probably be an SCA
- Step-Off pad = Paper or plastic pad and 2 clothing hampers and 1 trash bin

Normal Operation

- Each operating bay will have one complete step-off pad at the mezzanine only during the processing of MCO. (Install/removing the hood from the MCO/CASK).
- Each MCO trailer (top platform only) will be covered with silver paper or plastic.
- Each operating bay will have at least one more complete step-off pad on the ground level only during processing of an MCO. (Cask lid seal inspection/repair)
- We are not sure if the lower annulus hose hookup will require an SCA.
- The rooms used for dressing prior to entry to the bays and PWC (118, 121,124, 127, 130) will have bins for complete supply of clean Anti-C clothing. These rooms will also have a clean waste bin and a RAD box for damaged/unusable clean Anti-C clothing.

Liquid Waste Operations

- Bay 1 will require a complete step-off pad once per month during loading of liquid waste tank car.
- PWC room will probably require a complete step-off pad because of continuous sample bottle change out and possibly IXM change out.

Maintenance
• Each bay will require a complete step-off pad during HEPA filter change out. • Second floor equipment room will require a complete step-off pad during HEPA filter change out.

CHARACTERIZE A STEP OFF PAD FIRE

An actual step-off pad includes:

1. One paper or plastic pad on the floor measuring approximately 0.7 m (27 in.) wide by 0.9 m (36 in.) long;
2. Two clothing hampers, each on a rectangular rack measuring approximately 0.6 m (24 in.) wide, by 0.7 m (28 in.) long, by 0.9 m (36 in.) high, and;
3. One trash bin measuring approximately 0.5 m (18½ in.) square by 0.8 m (30 in.) high.

Step off pad area (neglect paper or plastic pad) and equivalent diameter are calculated to be:

Area = (2 hampers x 0.6 m x 0.7 m) + (1 trash bin x 0.5 m x 0.5 m)

= 1.09 m^2 (11.7 ft^2)

Equivalent Diameter (D_{eq})

$$= 2 \times (\text{Area}/\pi)^{1/2} = 2 \times (1.09\ m^2/\pi)^{1/2}$$

= 1.19 m (3.9 ft)

An alternate step off pad arrangement may substitute three 55-gallon drums for the two hampers and trash bin described above. Each 55-gallon drum has a diameter of 0.61 m (24 in.). The area and equivalent diameter of this alternate arrangement are calculated to be:

Area = 3 drums x $\pi/4$ x $(0.61\ m)^2$

= 0.9 m^2 (9.7 ft^2)

Equivalent Diameter (D_{eq})

$$= 2 \times (\text{Area}/\pi)^{1/2} = 2 \times (0.9\ m^2/\pi)^{1/2}$$

= 1.07 m (3.9 ft)

WHC-SD-WM-TRP-233, *Analytical and Experimental Evaluation of Solid Waste Drum Fire Performance*, (Rhodes, B. T., 1995), documents full scale fire testing of a single 55-gallon drum with no lid and loaded with combustible materials in a "standard load" configuration. A "standard load" is represented in (Rhodes 1995) as consisting of the following materials:

Rubber	2.7 kg (6.0 lb.)	10.4%
Plastic	13.4 kg (29.5 lb.)	51.7%
Paper	6.6 kg (14.5 lb.)	25.5%
Cotton	3.2 kg (7.0 lb.)	12.4%
Total	25.9 kg (57.0 lb.)	100.0%

Wood is assumed to constitute less than 1% of the total combustible content of a "standard load."

The volume of a single 55-gallon drum is a nominal 0.2 m³ (55 gal.). For the fire tests documented by (Rhodes 1995), the "standard load" was compressed to allow the full "standard load" to be placed inside of the drum. As such, the fuel loading was quite dense, on the order of 130 kg/m³ (7.8 lb/ft³). (Rhodes 1995) states that the compression process is considered to have had little impact on the results of the full scale fire testing.

In contrast, the volume of a single clothing hamper is 0.4 m³ (13.4 ft³), or twice the volume of the 55-gallon drum containing the "standard load." The combustible load contained in a clothing hamper is not compressed. For fire modeling purposes, it is assumed that each hamper making up part of a step off pad contains one "standard load" of combustible material.

The step off pad trash bin, at 0.2 m³, is approximately the same size as a 55 gallon drum, and using the same assumption stated for hampers, contains one-half of the mass of a "standard load."

The quantity of combustible material associated with a step off pad is taken to be 3 times the mass of material in the "standard load," or 77.7 kg (171 lb.).

Since the total volume of a step off pad is equivalent to five (5) 55 gallon drums, or 1 m³, the density of the combustible materials is calculated to be 77.7 kg/m³.

(Rhodes 1995) calculates the heat of combustion (ΔH_c) of a "standard load" to be 31.2 kJ/g. A "standard load" contains 808,080 kJ of energy. Three "standard loads" contain 2,424,240 kJ.

(Rhodes 1995) documents the estimated peak heat release rate for open single drum burning test SWD-1, containing one "standard load" ignited from the top, to be 129 kW. The estimated average heat release rate was documented to be 45 kW from the results of test SWD-1.

Using (Rhodes 1995) as the basis for step off pad heat release rate input to a fire model, and volume (the equivalent of 5 volumes of 55 gallon drums) burning simultaneously, the maximum peak heat release rate for a step off pad fire is expected to be:

129 kW x 5 "standard load"s = <u>645 kW</u>

Using mass as a basis, the assumed equivalent mass of mass of 3 "standard loads" burning simultaneously yields:

129 kW x 3 "standard load"s = <u>387 kW</u>

The 645 kW case represents the standard step off pad arrangement described above. The 387 kW case represents a step off pad arrangement consisting of three 55-gallon drums used to contain 3 "standard loads".

For comparison purposes, a separate source of fire data is available from the (SFPE Handbook). Chapter 2-1 contains burning rate data for fires involving several different types of commodities and materials. Among this data are peak heat release rates for a fire involving mail bags, stacked 1.5 m high (400 kW/m^2), and for trash fires of 30 kg/m^3 and 100 kg/m^3 effective diameter, respectively.

The floor area of a step off pad fire is calculated to be:

2 x [0.6 m (24 in.) wide x 0.7 m (28 in.) long]
+ [0.5 m (18½ in.) x 0.5 m (18½ in.)] = 1.1 m^2 (11.8 ft^2)

The effective diameter (r) is calculated to be:

$$1.1 \text{ m}^2 = \pi r^2$$

$$r = 0.6 \text{ m } (1.9 \text{ ft})$$

The peak heat release rate for a mail bag fire over 1.1 m^2 is calculated to be:

400 kW x 1.1 m^2 = <u>440 kW</u>

The peak heat release rate of a trash bag fire, given the density of combustible material associated with a step off pad (64.8 kg/m^3), effective diameter (0.6 m), and graphical data contained on Figure 2-1.21(a) for trash densities of 30 kg/m^3 and 100 kg/m^3, is calculated to be:

Density	Peak Heat Release Rate
30 kg/m^3	350 kW

64.8 kg/m³	X
100 kg/m³	100 kW

Interpolating to solve for X:

$$X = \underline{225 \text{ kW}}$$

The peak heat release rates (645 kW and 387 kW) used to represent the step off pad fire cases are greater than the peak heat release rates computed using alternative methods and are therefore conservative.

For the purpose of input to CFAST, the step off pad fire is assumed to grow to a peak heat release rate (645 kW or 387 kW) over 30 seconds, burn at peak heat release rate, then burn to completion over a 30 second decay period.

<u>645 kW CASE – STEP OFF PADS IN PROCESS BAYS (FLOOR AND MEZZANINE)</u>

1. Tabulate initial combustible material inventory (I_o) in kJ:

Material Description	I_o
Standard Load	2,424,240 kJ

2. Designate 30 second period of fire growth (i.e., t = 0 seconds to t = 30 seconds) as Period I.

3. Energy expended during Period I:

$$Q_{peak} = 645 \text{ kW}$$

$$E_I = \tfrac{1}{2}t\, Q_{peak}$$

$$t = 30 \text{ sec}$$

$$E_I = \tfrac{1}{2}(30 \text{ sec})(645 \text{ kW})$$

$$= 9{,}675 \text{ kJ}$$

4. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fI}
Standard Load	2,424,240 kJ	9,675 kJ	2,414,565 kJ

5. Determine time from reaching Q_{peak} to beginning of 30 second decay at peak heat release rate for lumped materials:

$t = [(I_{fI} - (30\ sec)(0.5)(Q_{peak}))/Q_{peak}]$

$I_{fI} = 2{,}414{,}565\ kJ$

$t = 3{,}728\ sec$

6. Designate period of steady state burning at Q_{peak} (i.e., t = 30 seconds to t = 3,758 seconds) as Period II.

7. Energy expended during Period II:

$E_{II} = t\ Q_{peak}$

$t = 3{,}728\ sec$

$E_{II} = 2{,}404{,}890\ kJ$

8. Tabulate change in combustible material inventory during Period II:

Material Description	I_I	$E_{II}(\Delta I)$	I_{fII}
Standard Load	2,414,565 kJ	2,404,890 kJ	9,675 kJ

9. Designate 30 second decay period of lumped combustibles and steady state burning at Q_{peak} (i.e., t = 3,758 seconds to t = 3,788 seconds) as Period III.

10. Determine energy expended during Period III:

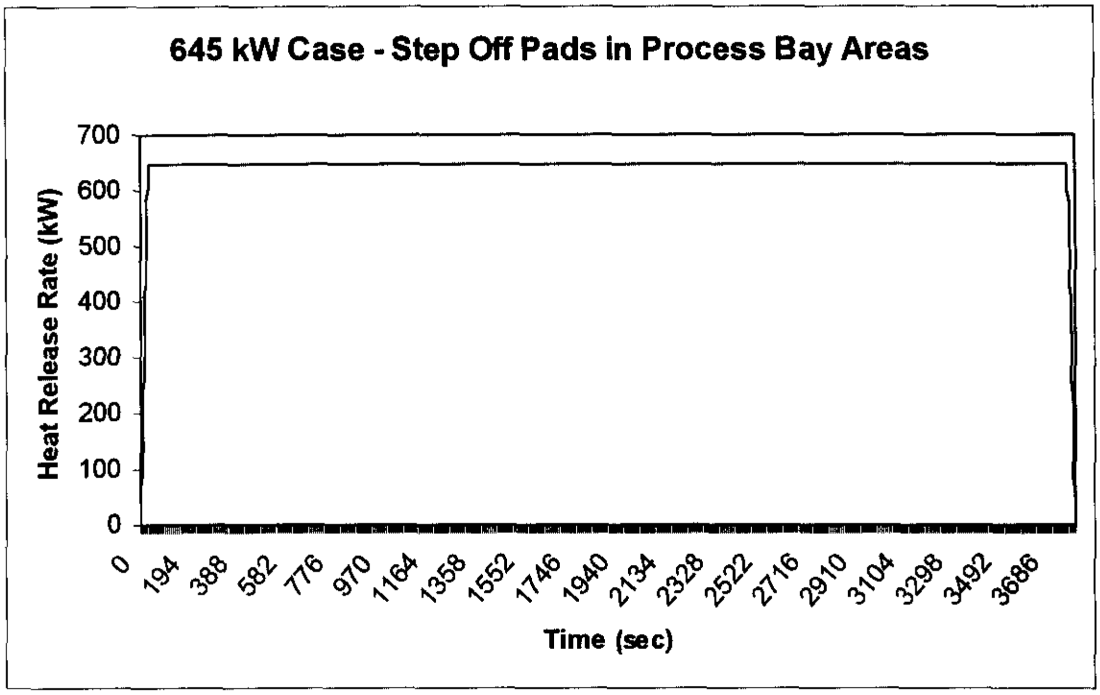
$E_{III} = (30\ sec)(0.5)(Q_{peak})$

$E_{III} = 9{,}675\ kJ$

11. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Standard Load	9,675 kJ	9,675 kJ	0 kJ

12. Resulting Heat Release Rate Curve:



13. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through III):

a. Mass Loss Rate – Equation

$M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

1. Determine Q at t = 0, t = 30, t = 3,758, and t = 3,788:

At t = 0, Q = 0 kW

At t = 30, Q = 645 kW

At t = 3,758, Q = 645 kW

At t = 3,788, Q = 0 kW

2. Determine M_b and tabulate:

t (seconds)	Q (kW)	M_b (kg/sec)
0	0	0
30	645	0.0207
3758	645	0.0207
3788	0	0

14. 645 kW Case - FAST Input Data:

```
VERSN    3645 KW - STEP OFF PAD IN PROCESS BAY (FLOOR AND MEZZANINE)
UNCONSTRAINED
#VERSN 3 645 KW - STEP OFF PAD IN PROCESS BAY (FLOOR AND MEZZANINE)
UNCONSTRAINED
TIMES   5400      0    120     20      0
DUMPR S71U.HI
ADUMP S71U.XLS N
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.20000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
#WALLS CONCRETE
#FLOOR CONCRETE
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.10577E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       30.0000      3758.00       3788.00
FMASS      0.000000    0.0207678    0.0207678      0.000000
FQDOT      0.000000      645000.      645000.      0.000000
HCR       0.0800000    0.0800000    0.0800000     0.0800000
OD        0.0300000    0.0300000    0.0300000     0.0300000
CO        0.0300000    0.0300000    0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
```

15. 645 kW - FAST Output:

CFAST V 3.1 Created 4/1/98, Run 5/1/99

Time = 0.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	293.1	293.1	9.8	0.000E+00	0.000E+00	0.000E+00	5.684E-14
Outside					0.000E+00		

Time = 120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	329.6	301.2	2.6	2.077E-02	6.448E+05	9.916E+03	192.
Outside					0.000E+00		

Time = 240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	346.9	305.7	1.3	2.077E-02	6.447E+05	1.675E+04	342.
Outside					0.000E+00		

Time = 360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.3	307.2	0.63	2.077E-02	6.447E+05	2.069E+04	430.
Outside					0.000E+00		

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	359.9	307.0	0.25	2.077E-02	6.447E+05	2.313E+04	479.
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	363.0	306.0	5.56E-02	2.077E-02	6.447E+05	2.477E+04	508.
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	365.4	307.0	2.38E-03	2.077E-02	6.447E+05	2.589E+04	537.
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	367.2	308.4	9.80E-04	2.077E-02	6.447E+05	2.669E+04	561.
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	368.5	309.7	9.80E-04	2.077E-02	6.447E+05	2.732E+04	581.
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	369.6	310.9	9.80E-04	2.077E-02	6.446E+05	2.786E+04	598.
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	370.5	312.1	9.80E-04	2.077E-02	6.446E+05	2.835E+04	613.
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	371.4	313.2	9.80E-04	2.077E-02	6.446E+05	2.881E+04	627.
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	372.1	314.2	9.80E-04	2.077E-02	6.446E+05	2.924E+04	641.
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	372.8	315.2	9.80E-04	2.077E-02	6.445E+05	2.966E+04	654.
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	373.5	316.1	9.80E-04	2.077E-02	6.445E+05	3.006E+04	666.
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	374.1	317.0	9.80E-04	2.077E-02	6.445E+05	3.046E+04	678.
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	374.8	317.9	9.80E-04	2.077E-02	6.445E+05	3.084E+04	689.
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	375.3	318.8	9.80E-04	2.077E-02	6.445E+05	3.122E+04	700.
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	375.9	319.6	9.80E-04	2.077E-02	6.444E+05	3.158E+04	711.
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	376.4	320.4	9.80E-04	2.077E-02	6.444E+05	3.194E+04	722.
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	377.0	321.2	9.80E-04	2.077E-02	6.444E+05	3.230E+04	732.
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	377.5	321.9	9.80E-04	2.077E-02	6.444E+05	3.265E+04	742.
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	378.0	322.7	9.80E-04	2.077E-02	6.444E+05	3.300E+04	752.
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	378.5	323.4	9.80E-04	2.077E-02	6.444E+05	3.334E+04	762.
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	378.9	324.1	9.80E-04	2.077E-02	6.443E+05	3.368E+04	771.
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	379.4	324.8	9.80E-04	2.077E-02	6.443E+05	3.401E+04	781.
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	379.8	325.5	9.80E-04	2.077E-02	6.443E+05	3.434E+04	790.
Outside					0.000E+00		

Time = 3240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	380.3	326.2	9.80E-04	2.077E-02	6.443E+05	3.467E+04	799.
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	380.7	326.8	9.80E-04	2.077E-02	6.443E+05	3.499E+04	808.
Outside					0.000E+00		

Time = 3480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	381.1	327.4	9.80E-04	2.077E-02	6.443E+05	3.532E+04	816.
Outside					0.000E+00		

Time = 3600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	381.6	328.1	9.80E-04	2.077E-02	6.443E+05	3.563E+04	825.
Outside					0.000E+00		

Time = 3720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	382.0	328.7	9.80E-04	2.077E-02	6.443E+05	3.595E+04	833.
Outside					0.000E+00		

Time = 3840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	363.0	326.1	9.80E-04	0.000E+00	0.000E+00	2.922E+04	638.
Outside					0.000E+00		

Time = 3960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	343.9	323.6	9.80E-04	0.000E+00	0.000E+00	2.233E+04	467.
Outside					0.000E+00		

Time = 4080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	333.7	321.7	9.80E-04	0.000E+00	0.000E+00	1.866E+04	382.
Outside					0.000E+00		

Time = 4200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	327.6	320.3	9.80E-04	0.000E+00	0.000E+00	1.648E+04	333.
Outside					0.000E+00		

Time = 4320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	323.7	319.1	9.80E-04	0.000E+00	0.000E+00	1.507E+04	300.
Outside					0.000E+00		

Time = 4440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	321.0	318.1	9.80E-04	0.000E+00	0.000E+00	1.410E+04	277.
Outside					0.000E+00		

Time = 4560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	319.0	317.3	9.80E-04	0.000E+00	0.000E+00	1.339E+04	260.
Outside					0.000E+00		

Time = 4680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	317.5	316.5	9.80E-04	0.000E+00	0.000E+00	1.285E+04	246.
Outside					0.000E+00		

Time = 4800.0 seconds.

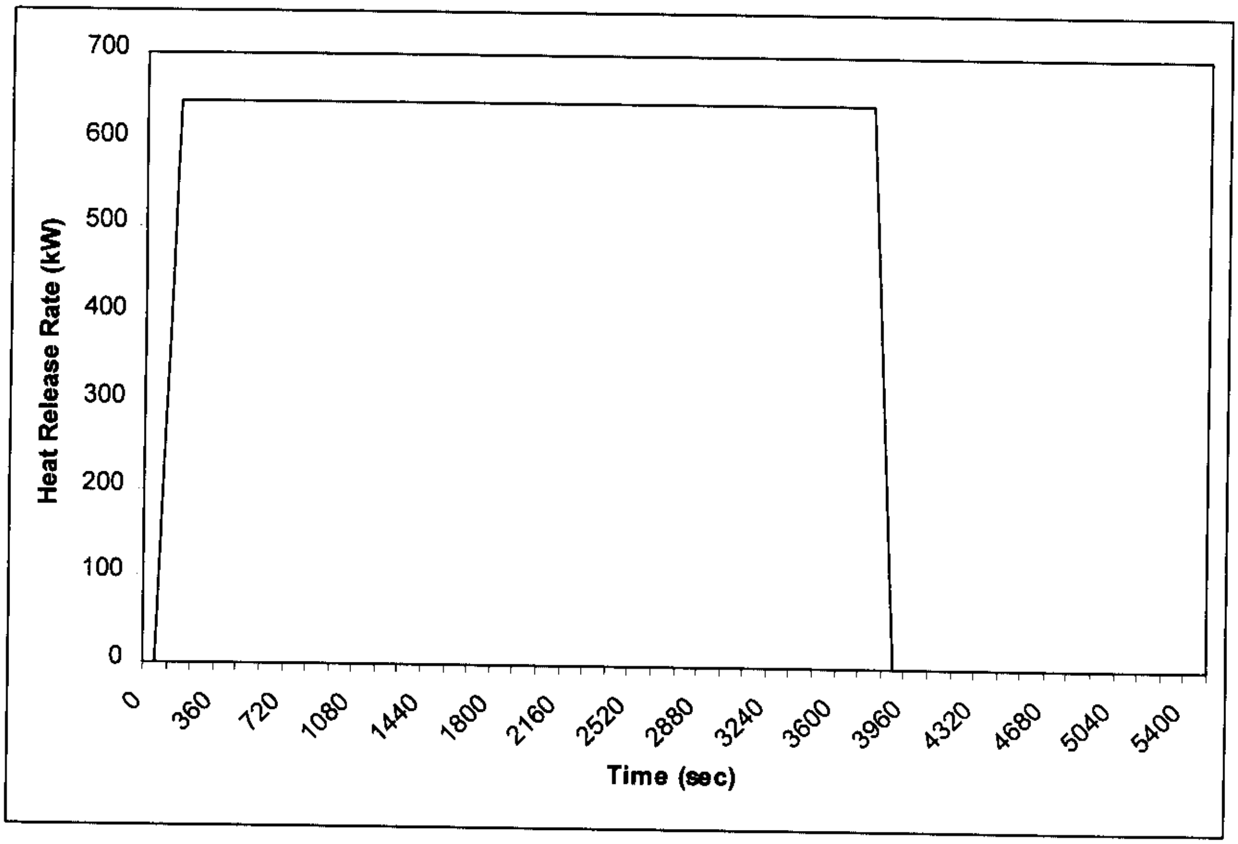
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	316.3	315.9	9.80E-04	0.000E+00	0.000E+00	1.242E+04	235.
Outside					0.000E+00		

Time = 4920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	315.3	315.3	9.80E-04	0.000E+00	0.000E+00	1.206E+04	226.
Outside					0.000E+00		

Time = 5040.0 seconds.

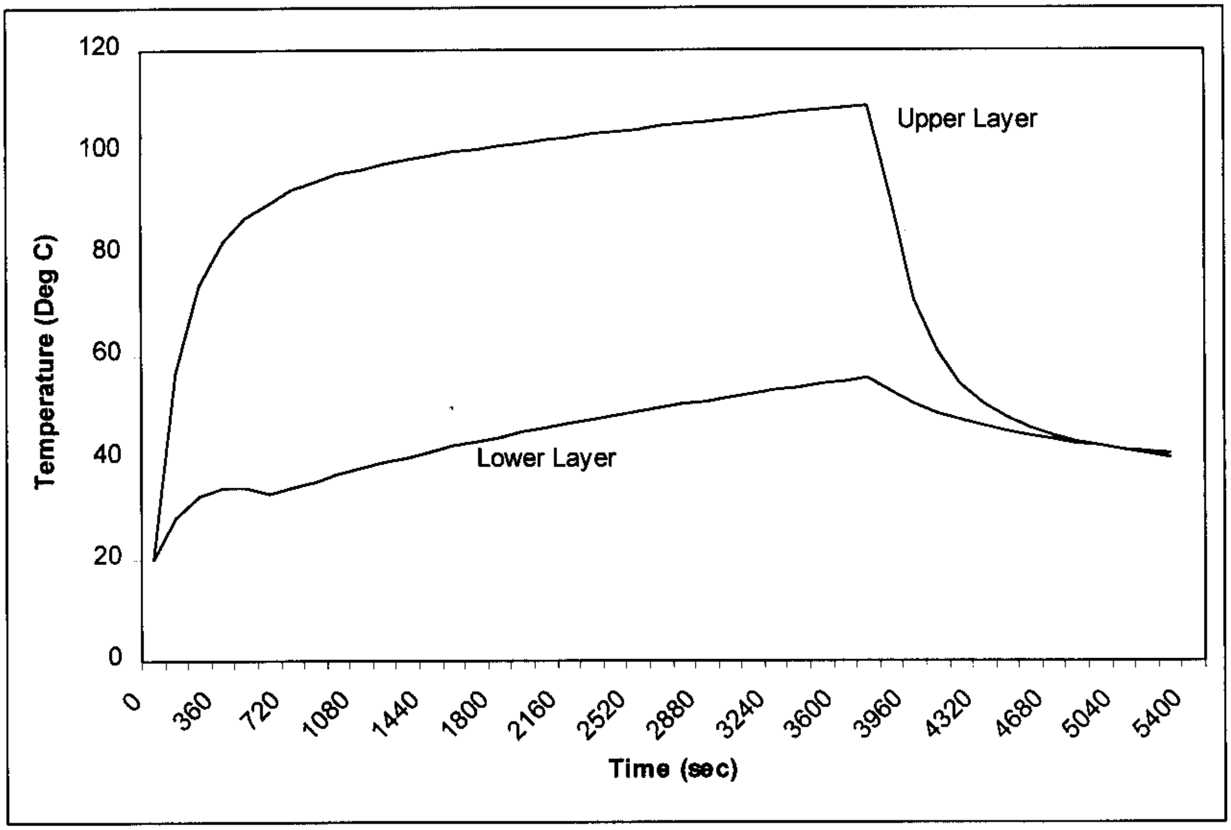
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	314.5	314.7	9.80E-04	0.000E+00	0.000E+00	1.176E+04	217.
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

645 kW Case – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

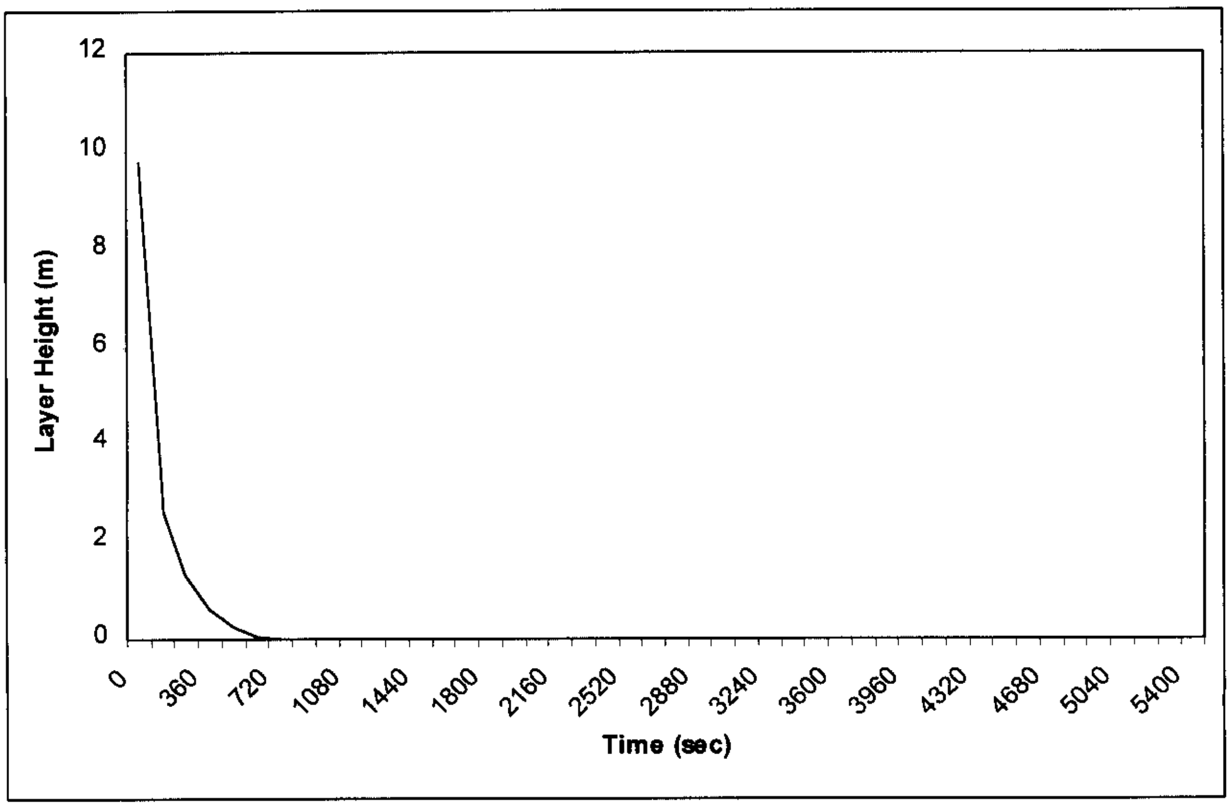
Figure A-16



CFAST Output: Upper and Lower Layer Temperatures vs. Time

645 kW – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

Figure A-17



CFAST Output: Layer Height vs. Time

645 kW – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

Figure A-18

387 kW CASE – STEP OFF PADS IN PROCESS BAYS (FLOOR AND MEZZANINE)

16. Tabulate initial combustible material inventory (I_o) in kJ:

Material Description	I_o
Standard Loads	2,424,240 kJ

17. Designate 30 second period of fire growth (i.e., t = 0 seconds to t = 30 seconds) as Period I.

18. Energy expended during Period I:

Q_{peak} = 387 kW

E_I = ½t Q_{peak}

t = 30 sec

E_I = ½(30 sec)(387 kW)

= 5,805 kJ

19. Tabulate change in combustible material inventory during Period I:

Material Description	I_o	$E_I(\Delta I)$	I_{fI}
Standard Load	2,424,240 kJ	5,805 kJ	2,418,435 kJ

20. Determine time from reaching Q_{peak} to beginning of 30 second decay at peak heat release rate for lumped materials:

t = $[(I_{fI} - (30\ sec)(0.5)(Q_{peak}))/Q_{peak}]$

I_{fI} = 2,418,435 kJ

t = 6,234 sec

21. Designate period of steady state burning at Q_{peak} (i.e., t = 30 seconds to t = 6,264 seconds) as Period II.

22. Energy expended during Period II:

E_{II} = t Q_{peak}

t = 6,234 sec

E_{II} = 2,412,627 kJ

23. Tabulate change in combustible material inventory during Period II:

Material Description	I_I	$E_{II}(\Delta I)$	I_{fII}
Standard Load	2,418,435 kJ	2,412,627 kJ	5,805 kJ

24. Designate 30 second decay period of lumped combustibles and steady state burning at Q_{peak} (i.e., t = 6,264 seconds to t = 6,294 seconds) as Period III.

25. Determine energy expended during Period III:

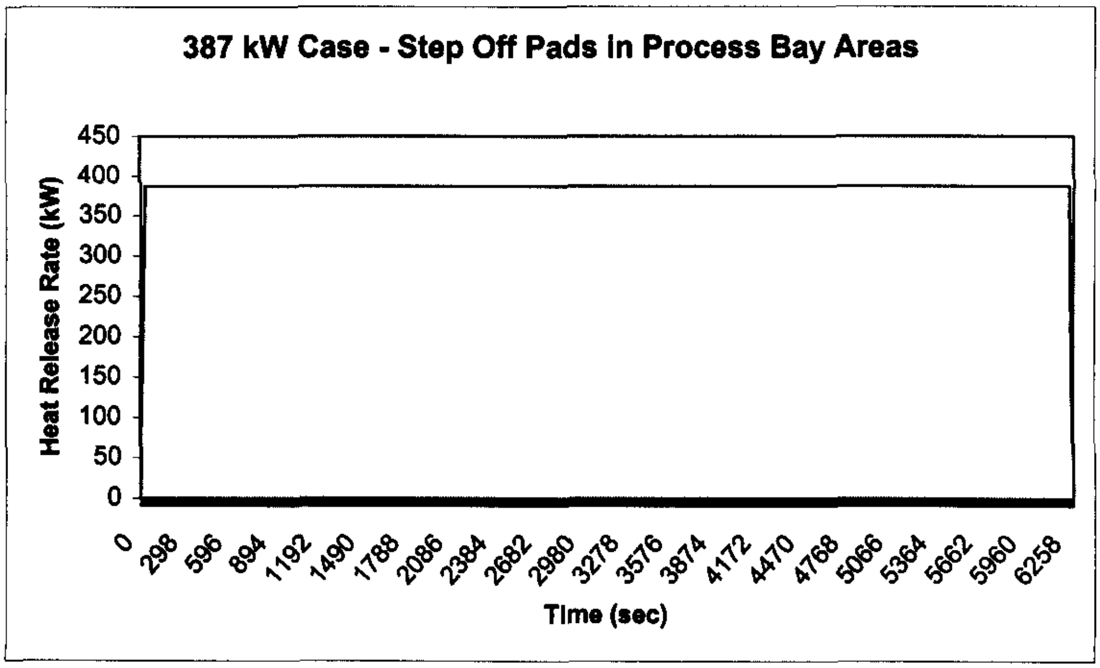
$$E_{III} = (30\ sec)(0.5)(Q_{peak})$$

$$E_{III} = 5{,}805\ kJ$$

26. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Standard Load	5,805 kJ	5,805 kJ	0 kJ

27. Resulting Heat Release Rate Curve:



28. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through III):

a. Mass Loss Rate – Equation

$M_b = Q/H_c$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = heat of combustion (kJ/kg)

1. Determine Q at t = 0, t = 30, t = 6,264, and t = 6,294:

At t = 0, Q = 0 kW

At t = 30, Q = 387 kW

At t = 6,264, Q = 387 kW

At t = 6,294, Q = 0 kW

2. Determine M_b and tabulate:

t (seconds)	Q (kW)	M_b (kg/sec)
0	0	0
30	387	0.0124
6264	387	0.0124
6294	0	0

29. 387 kW Case - FAST Input Data:

```
VERSN    3387 KW - STEP OFF PAD IN PROCESS BAY (FLOOR AND MEZZANINE)
UNCONSTRAINED
#VERSN 3 387 KW - STEP OFF PAD IN PROCESS BAY (FLOOR AND MEZZANINE)
UNCONSTRAINED
TIMES    7200      0    120     20      0
DUMPR S72U.HI
ADUMP S72U.XLS N
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  9.20000
DEPTH  18.3000
HEIGH  9.80000
CEILI GLASFIBR
WALLS CONCRETE
FLOOR CONCRETE
#CEILI GLASFIBR
```

```
#WALLS CONCRETE
#FLOOR CONCRETE
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 3.10577E+007  293.150  493.150 0.300000
LFBO 1
LFBT 1
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       30.0000      6264.00       6294.00
FMASS      0.000000     0.0124607     0.0124607     0.000000
FQDOT      0.000000      387000.       387000.      0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
#GRAPHICS ON
DEVICE 1
```

30. 387 kW - FAST Output:

CFAST V 3.1 Created 4/1/98, Run 5/1/99

Time = 0.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	293.1	293.1	9.8	0.000E+00	0.000E+00	0.000E+00	5.684E-14
Outside					0.000E+00		

Time = 120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	315.8	298.1	2.9	1.246E-02	3.869E+05	6.015E+03	108.
Outside					0.000E+00		

Time = 240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	327.4	301.1	1.6	1.246E-02	3.869E+05	1.039E+04	192.
Outside					0.000E+00		

Time = 360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	333.5	302.4	0.96	1.246E-02	3.869E+05	1.303E+04	245.
Outside					0.000E+00		

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.9	302.6	0.57	1.246E-02	3.869E+05	1.470E+04	276.
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	339.0	302.3	0.30	1.246E-02	3.869E+05	1.585E+04	295.
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	340.5	301.9	0.12	1.246E-02	3.869E+05	1.669E+04	308.
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	341.7	302.2	3.16E-02	1.246E-02	3.869E+05	1.734E+04	320.
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	342.7	303.0	2.48E-03	1.246E-02	3.869E+05	1.784E+04	332.
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	343.6	303.7	9.80E-04	1.246E-02	3.869E+05	1.824E+04	342.
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	344.3	304.4	9.80E-04	1.246E-02	3.869E+05	1.858E+04	351.
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	344.9	305.0	9.80E-04	1.246E-02	3.869E+05	1.888E+04	359.
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	345.5	305.6	9.80E-04	1.246E-02	3.868E+05	1.916E+04	367.
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	346.0	306.2	9.80E-04	1.246E-02	3.868E+05	1.943E+04	373.
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	346.4	306.8	9.80E-04	1.246E-02	3.868E+05	1.968E+04	380.
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	346.8	307.3	9.80E-04	1.246E-02	3.868E+05	1.993E+04	386.
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	347.3	307.8	9.80E-04	1.246E-02	3.868E+05	2.017E+04	392.
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	347.7	308.3	9.80E-04	1.246E-02	3.868E+05	2.040E+04	398.
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	348.0	308.8	9.80E-04	1.246E-02	3.868E+05	2.063E+04	404.
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	348.4	309.3	9.80E-04	1.246E-02	3.868E+05	2.085E+04	410.
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	348.8	309.8	9.80E-04	1.246E-02	3.868E+05	2.107E+04	415.
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	349.1	310.2	9.80E-04	1.246E-02	3.868E+05	2.129E+04	420.
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	349.4	310.7	9.80E-04	1.246E-02	3.868E+05	2.150E+04	426.
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	349.8	311.1	9.80E-04	1.246E-02	3.868E+05	2.171E+04	431.
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	350.1	311.5	9.80E-04	1.246E-02	3.868E+05	2.191E+04	436.
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	350.4	311.9	9.80E-04	1.246E-02	3.868E+05	2.211E+04	440.
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	350.7	312.3	9.80E-04	1.246E-02	3.868E+05	2.231E+04	445.
Outside					0.000E+00		

Time = 3240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	351.0	312.7	9.80E-04	1.246E-02	3.868E+05	2.251E+04	450.
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	351.3	313.1	9.80E-04	1.246E-02	3.867E+05	2.271E+04	455.
Outside					0.000E+00		

Time = 3480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	351.5	313.5	9.80E-04	1.246E-02	3.867E+05	2.290E+04	459.
Outside					0.000E+00		

Time = 3600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	351.8	313.9	9.80E-04	1.246E-02	3.867E+05	2.310E+04	464.
Outside					0.000E+00		

Time = 3720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	352.1	314.2	9.80E-04	1.246E-02	3.867E+05	2.329E+04	468.
Outside					0.000E+00		

Time = 3840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	352.3	314.6	9.80E-04	1.246E-02	3.867E+05	2.348E+04	472.
Outside					0.000E+00		

```
Time =    3960.0 seconds.

Compartment   Upper   Lower   Inter.   Pyrol      Fire       Pressure  Ambient
              Temp.   Temp.   Height   Rate       Size                 Target
              (K)     (K)     (m)      (kg/s)     (W)        (Pa)      (W/m^2)
------------------------------------------------------------------------------
   1          352.6   314.9   9.80E-04 1.246E-02 3.867E+05 2.366E+04   477.
 Outside                                         0.000E+00


Time =    4080.0 seconds.

Compartment   Upper   Lower   Inter.   Pyrol      Fire       Pressure  Ambient
              Temp.   Temp.   Height   Rate       Size                 Target
              (K)     (K)     (m)      (kg/s)     (W)        (Pa)      (W/m^2)
------------------------------------------------------------------------------
   1          352.9   315.3   9.80E-04 1.246E-02 3.867E+05 2.385E+04   481.
 Outside                                         0.000E+00


Time =    4200.0 seconds.

Compartment   Upper   Lower   Inter.   Pyrol      Fire       Pressure  Ambient
              Temp.   Temp.   Height   Rate       Size                 Target
              (K)     (K)     (m)      (kg/s)     (W)        (Pa)      (W/m^2)
------------------------------------------------------------------------------
   1          353.1   315.6   9.80E-04 1.246E-02 3.867E+05 2.403E+04   485.
 Outside                                         0.000E+00


Time =    4320.0 seconds.

Compartment   Upper   Lower   Inter.   Pyrol      Fire       Pressure  Ambient
              Temp.   Temp.   Height   Rate       Size                 Target
              (K)     (K)     (m)      (kg/s)     (W)        (Pa)      (W/m^2)
------------------------------------------------------------------------------
   1          353.3   316.0   9.80E-04 1.246E-02 3.867E+05 2.422E+04   489.
 Outside                                         0.000E+00


Time =    4440.0 seconds.

Compartment   Upper   Lower   Inter.   Pyrol      Fire       Pressure  Ambient
              Temp.   Temp.   Height   Rate       Size                 Target
              (K)     (K)     (m)      (kg/s)     (W)        (Pa)      (W/m^2)
------------------------------------------------------------------------------
   1          353.6   316.3   9.80E-04 1.246E-02 3.867E+05 2.440E+04   493.
 Outside                                         0.000E+00
```

Time = 4560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	353.8	316.6	9.80E-04	1.246E-02	3.867E+05	2.458E+04	497.
Outside					0.000E+00		

Time = 4680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	354.1	317.0	9.80E-04	1.246E-02	3.867E+05	2.476E+04	501.
Outside					0.000E+00		

Time = 4800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	354.3	317.3	9.80E-04	1.246E-02	3.867E+05	2.494E+04	505.
Outside					0.000E+00		

Time = 4920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	354.5	317.6	9.80E-04	1.246E-02	3.867E+05	2.512E+04	509.
Outside					0.000E+00		

Time = 5040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	354.8	317.9	9.80E-04	1.246E-02	3.867E+05	2.529E+04	513.
Outside					0.000E+00		

Time = 5160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.0	318.2	9.80E-04	1.246E-02	3.867E+05	2.547E+04	517.
Outside					0.000E+00		

Time = 5280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.2	318.5	9.80E-04	1.246E-02	3.867E+05	2.564E+04	521.
Outside					0.000E+00		

Time = 5400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.4	318.8	9.80E-04	1.246E-02	3.867E+05	2.582E+04	524.
Outside					0.000E+00		

Time = 5520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.6	319.1	9.80E-04	1.246E-02	3.867E+05	2.599E+04	528.
Outside					0.000E+00		

Time = 5640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	355.8	319.4	9.80E-04	1.246E-02	3.867E+05	2.616E+04	532.
Outside					0.000E+00		

Time = 5760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.0	319.7	9.80E-04	1.246E-02	3.867E+05	2.633E+04	535.
Outside					0.000E+00		

Time = 5880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.3	320.0	9.80E-04	1.246E-02	3.867E+05	2.650E+04	539.
Outside					0.000E+00		

Time = 6000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.5	320.3	9.80E-04	1.246E-02	3.867E+05	2.667E+04	542.
Outside					0.000E+00		

Time = 6120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.7	320.6	9.80E-04	1.246E-02	3.867E+05	2.684E+04	546.
Outside					0.000E+00		

Time = 6240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.9	320.9	9.80E-04	1.246E-02	3.867E+05	2.701E+04	550.
Outside					0.000E+00		

Time = 6360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	343.1	319.0	9.80E-04	0.000E+00	0.000E+00	2.211E+04	431.
Outside					0.000E+00		

Time = 6480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	331.4	317.6	9.80E-04	0.000E+00	0.000E+00	1.788E+04	340.
Outside					0.000E+00		

Time = 6600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	324.7	316.4	9.80E-04	0.000E+00	0.000E+00	1.549E+04	290.
Outside					0.000E+00		

Time = 6720.0 seconds.

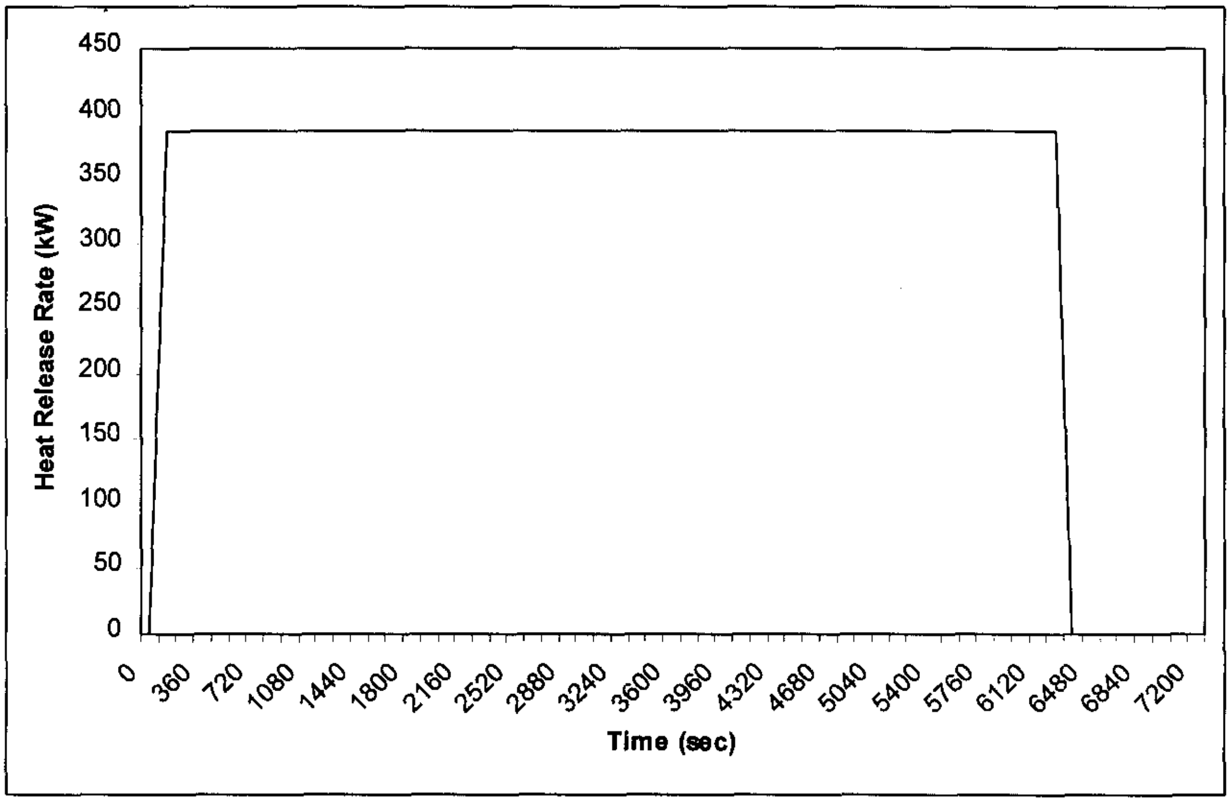
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	320.6	315.5	9.80E-04	0.000E+00	0.000E+00	1.401E+04	258.
Outside					0.000E+00		

Time = 6840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	317.9	314.7	9.80E-04	0.000E+00	0.000E+00	1.303E+04	237.
Outside					0.000E+00		

Time = 6960.0 seconds.

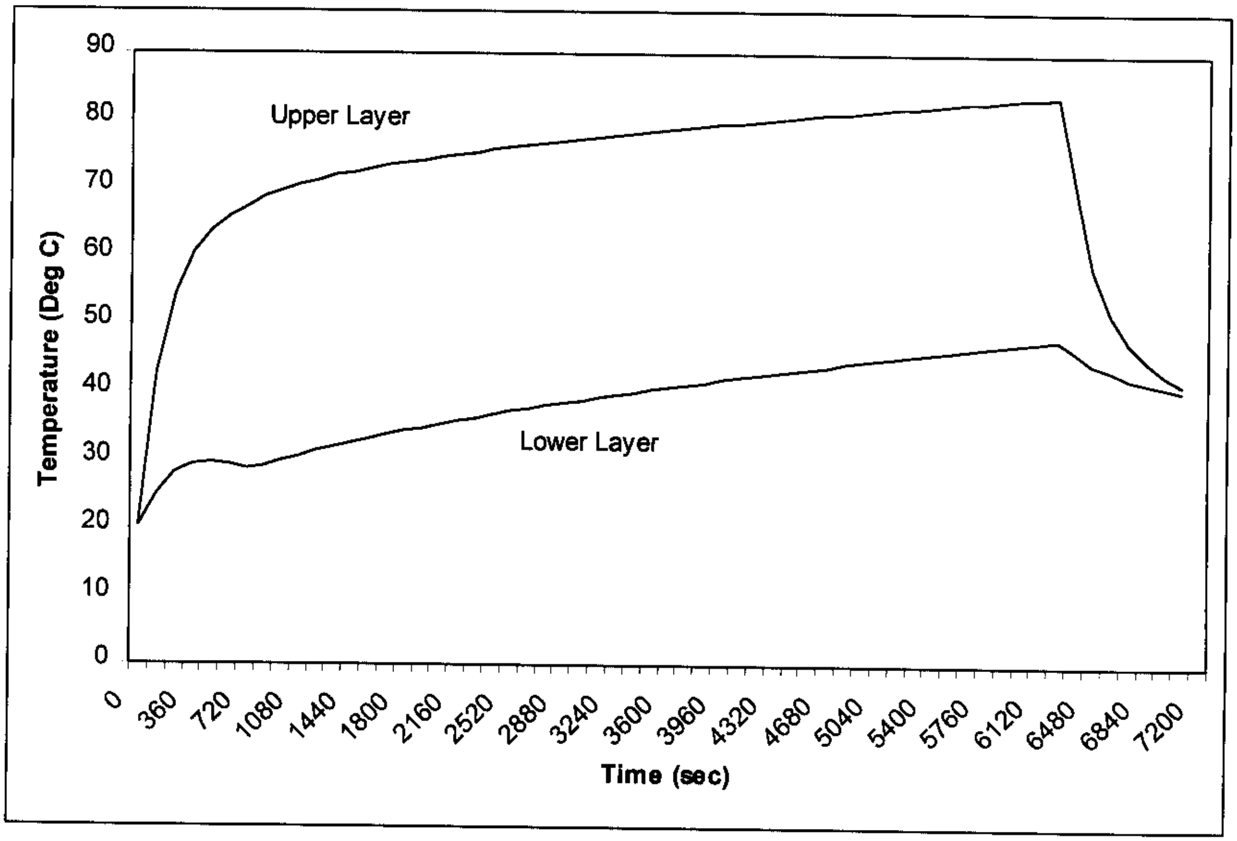
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	316.0	314.1	9.80E-04	0.000E+00	0.000E+00	1.235E+04	222.
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

387 kW Case – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

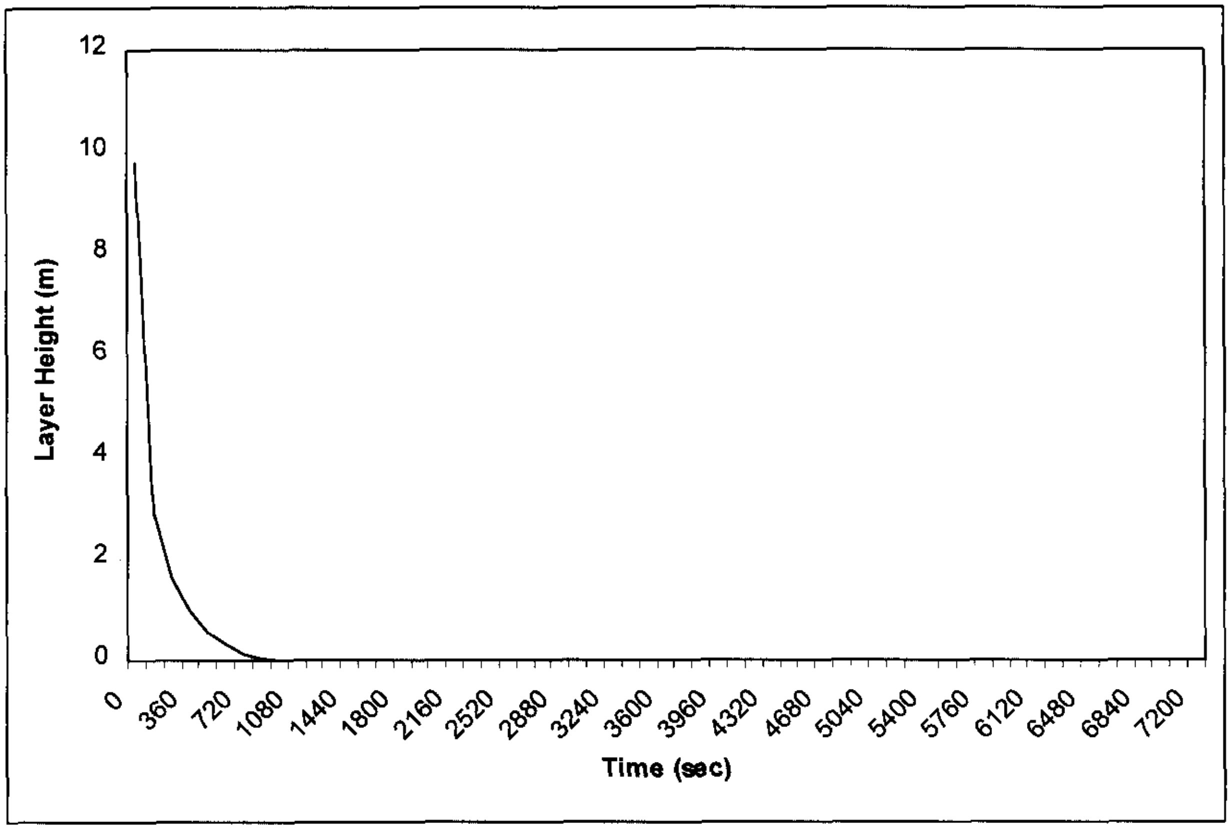
Figure A-19



CFAST Output: Upper and Lower Layer Temperatures vs. Time

387 kW – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

Figure A-20



CFAST Output: Layer Height vs. Time

387 kW – Step Off Pad Fire in Process Bay (Floor and Mezzanine)

Figure A-21

31. Determine Adiabatic Flame Temperature for Step Off Pad Fire

a. Combustion Reactions:

(1) For cotton and paper (cellulose), the combustion reaction is taken to be:

$$C_6H_{10}O_5 + 6O_2 + (6 \times 3.76)N_2 \rightarrow 6CO_2 + 5H_2O + (6 \times 3.76)N_2$$

(2) For rubber (neoprene), the combustion reaction is taken to be:

$$2C_5H_5Cl + 12O_2 + (6 \times 3.76)N_2 \rightarrow 10CO_2 + 2HCl + 4H_2O + (6 \times 3.76)N_2$$

(3) For plastic (polyurethane), the combustion reaction is taken to be:

$$2C_2H_4 + 6O_2 + (6 \times 3.76)N_2 \rightarrow 4CO_2 + 4H_2O + (6 \times 3.76)N_2$$

b. Tabulate material, mass, molecular weight, g-mole, % g-mole/g-mole fuel, and g fuel/g-mole, for one "standard load" (Rhodes, 1995):

Material	Mass	Molecular Weight	g-mole	% g-mole/ g-mole fuel	g/g-mole fuel
Cotton	3.2 kg	100 g/g-mole	32.0 g-mole	5.4%	5.4 g
Paper	6.6 kg	100 g/g-mole	66.0 g-mole	11.1%	11.1 g
Rubber	2.7 kg	162 g/g-mole	16.7 g-mole	2.8%	4.5 g
Plastic	13.4 kg	28 g/g-mole	478.6 g-mole	80.7%	22.6 g
TOTAL			593.3 g-mole	100.0%	43.6 g

c. Combustion Reaction for one g-mole "standard load":

$$[0.03C_6H_{10}O_5 + 0.16C_5H_5Cl + 0.81C_2H_4] + 3.57O_2 + (3.57 \times 3.76)N_2 \rightarrow$$

$$2.60CO_2 + 0.16HCl + 2.09H_2O + (3.57 \times 3.76)N_2$$

d. Determine maximum energy released by burning 1 g-mole (43.6 g) of "standard load" materials:

$$E = m \times H_c$$

$$= 43.6 \text{ g} \times 31.2 \text{ kJ/g} \quad \text{(Rhodes 1995)}$$

$$E = 1{,}360 \text{ kJ}$$

e. Determine heat capacity of combustion products:

Product	# g-moles	J/g-mole-°K[1]	J/°K
CO_2	2.60 g-mole	54.3 J/g-mole-°K	141.2 J/°K
HCl	0.16 g-mole	29.2 J/g-mole-°K	4.7 J/°K
H_2O	2.09 g-mole	41.2 J/g-mole-°K	86.1 J/°K
N_2	(3.57 x 3.76) g-mole	32.7 J/g-mole-°K	438.9J/°K
			670.9 J/°K

[1] Refs: (SFPE 1988) and (Dean 1985)

f. Calculate Adiabatic Flame Temperature (referenced to ambient):

ΔT = (1,360,000 J)/(670.9 J/°K)

ΔT = 2,027 °K

32. Affect of Step Off Pad Fire on Process Bay Walls

a. Criteria: Based on ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, Conditions of Acceptance, for a bearing wall (not including hose stream test):

(1) Prevent passage of flame or gas hot enough to ignite cotton waste for a period equal to that for which classification is desired,

(2) Temperature on unexposed wall surface not to exceed 139°C (412°K) (250°F) above its initial temperature.

b. Data:

(1) Ignition temperature of cotton fibers = 255°C (528°K) (490°F) (NFPA Handbook, 17th Edition)

(2) Wall panels are 7.1 m (23 ft 4 in.) high and 3.0 m (10 ft) wide (Yakima Precast, Job No. 5541, Drawing Sheet E-20 and Shop Detail WP-54)

(3) Wall panels are pre-cast concrete (thermal conductivity k = 1.37 W/m-°K) reinforced with steel (k = 54 W/m-°K) (Yakima Precast, Job No. 5541, Drawing Sheet E-20 and Shop Detail WP-54)

(4) Wall panels weigh 8,250 kg (18,150 lb.) each, consisting of approximately 682 kg (1,500 lb.) of steel and 7,568 kg (16,650 lb.)

of concrete (Yakima Precast, Job No. 5541, Drawing Sheet E-20 and Shop Detail WP-54)

c. Preventing the passage of flames and hot gas through a process bay wall hot enough to ignite cotton waste is accomplished by limiting the combustible content and location of the Step Off Pad.

(1) The maximum upper gas layer temperatures for a step off pad fire are tabulated in the CFAST Outputs for each case (387 kW and 645 kW):

	645 kW Case	387 kW Case
Maximum Upper Gas Layer Temperature	382°K (109°C)	357°K (84°C)

(2) In both cases, gas layer temperature (382°K and 357°K) is less than the ignition temperature of cotton (412°K).

(3) Locating step off pads a sufficient distance from process bay walls is adequate to prevent flames from a fire from penetrating the wall. This required distance is taken to be the same distance that is calculated (below) to prevent heat up of the unexposed side of the wall to 139°C (412°K) (250°F) above its initial temperature during a fire.

d. Determine radiative and convective heat transfer losses required at an adjacent process bay wall surface to remove heat transferred through the wall from a step off pad fire:

$$q_{adjbayloss}/A = q_{adjbayconv}/A + q_{adjbayrad}/A$$

Convective Heat Loss $q_{adjbayconv}/A = h(T_{w2} - T_{\infty 2})$

where:

$h = 1.42(\Delta T/L)^{1/4}$ (Holman 1976) (laminar flow assumed)

$\Delta T = T_{w2} - T_{\infty 2}$

$L = 7.1$ m (concrete panel height)

$T_{w2} = [(139°C + T_{\infty 2}) + 273°C]$ °K

$T_{\infty 2} = [20°C + 273°C]$ °K $= 293$°K

$h = 1.42(139°K/7.1\ m)^{1/4}$

$h = 2.99\ W/m^2\text{-}°K$

$q_{adjbayconv}/A = 2.99\ W/m^2\text{-}°K\ (432°K - 293°K)$

$= 415.6\ W/m^2$

Radiative Heat Loss $q_{adjbayrad}/A = \sigma F(T_{w2}^4 - T_{\infty 2}^4)$

where:

$\sigma = 5.669 \times 10^{-8}\ W/m^2\text{-}°K^4$

$F = 1.0$ (assumed)

$T_{w2} = 432°K$

$T_{\infty 2} = 293°K$

$q_{adjbayrad}/A = (5.669 \times 10^{-8}\ W/m^2\text{-}°K^4)(1.0)(432°K^4 - 293°K^4)$

$= 1{,}556.6\ W/m^2$

$q_{adjbayloss}/A = 415.6\ W/m^2 + 1{,}556.6\ W/m^2$

$= 1{,}972\ W/m^2$

e. Determine limiting wall temperature in exposed process bay:

Conduction Heat Transfer $q_{cond}/A = k(T_{w1} - T_{w2})/x$

where:

$q_{cond}/A = q_{adjbayloss}/A = 1{,}972\ W/m^2$

$k = (\%steel)k_{steel} + (\%concrete)k_{concrete}$

Mass Precast Wall Panel = 8,250 kg

Mass Concrete in Wall Panel = 7,568 kg

%concrete = 92%
$k_{concrete} = 1.37\ W/m\text{-}°K$

Mass Concrete in Wall Panel = 682 kg

%steel = 8%

k_{steel} = 54 W/m-°K

k = (0.08)(54 W/m-°K) + (0.92)1.37 W/m-°K

= 1.26 W/m-°K

T_{w2} = 432°K

x = 0.15 m (6 in.)

T_{w1} = $(q_{cond}/A)(x)/(k)$ + T_{w2}

= (1,972 W/m²)(0.15 m)/(1.26 W/m-°K) + 432°K

T_{w1} = 667°K

f. Determine radiative and convective heat transfer losses from exposed process bay wall:

$q_{expbayloss}/A = q_{expbayconv}/A + q_{expbayrad}/A$

Convective Heat Loss $q_{expbayconv}/A = h(T_{w1} - T_{\infty 1})$

where:

$h = 1.42(\Delta T/L)^{1/4}$ (Holman 1976)
(laminar flow assumed)

$\Delta T = T_{w1} - T_{\infty 1}$

L = 7.1 m (concrete panel height)

T_{w1} = 667°K

$T_{\infty 1}$ = depends on fire size (387 kW or 645 kW) taken from CFAST Output:

	387 kW	645 kW
$T_{\infty 1}$	357°K (84°C)	382°K (109°C)

$h_{387kW} = 1.42[(667°K - 357°K)/7.1\ m]^{1/4}$

$h_{645kW} = 1.42[(667°K - 382°K)/7.1\ m]^{1/4}$

	387 kW	645 kW
h	3.65 W/m²-°K	3.57 W/m²-°K

$q_{expbayconv387kW}/A$ = (3.65 W/m²-°K)(667°K - 357°K)

$q_{expbayconv645kW}/A$ = (3.57 W/m²-°K)(667°K - 382°K)

	387 kW	645 kW
$q_{expbayconv}/A$	1,132 W/m²	1,017 W/m²

Radiative Heat Loss $q_{expbayrad}/A = \sigma F(T_{w1}^4 - T_{\infty 1}^4)$

where:

σ = 5.669×10^{-8} W/m²-°K⁴

F = 1.0 (assumed)

T_{w1} = 667°K

$T_{\infty 1}$ = depends on fire size (387 kW or 645 kW) taken from CFAST Output:

	387 kW	645 kW
$T_{\infty 1}$	357°K (84°C)	382°K (109°C)

$q_{expbayrad387kW}/A$ = $(5.669 \times 10^{-8}\ W/m^2\text{-}°K^4)(1.0)(667°K^4 - 357°K^4)$

$q_{expbayrad645kW}/A$ = $(5.669 \times 10^{-8}\ W/m^2\text{-}°K^4)(1.0)(667°K^4 - 382°K^4)$

	387 kW	645 kW
$q_{expbayrad}/A$	10,300 W/m²	10,013 W/m²

$q_{expbayloss}/A = q_{expbayconv}/A + q_{expbayrad}/A$

	387 kW	645 kW
$q_{expbayloss}/A$	11,432 W/m²	11,030 W/m²

g. Determine radiation shape factor for the limiting radiative heat transfer rate from a step off pad fire to exposed process bay wall:

Heat Balance:

$q_{radfire}/A \quad = \quad \sigma F(T_f^4 - T_{wl}^4) \quad = \quad q_{expbayloss}/A + q_{adjbayloss}/A$

where:

σ = 5.669×10^{-8} W/m²-°K^4

F = Shape Factor – To Be Determined

T_{wl} = 667°K

T_f = depends on fire size (387 kW or 645 kW) and plume radius:

(1) $b_{\Delta T} = 0.12(T_o/T_\infty)^{1/2}(z - z_o)$ (SFPE 1988)

where:

$b_{\Delta T}$ = Plume radius to the point where temperature rise has declined to 0.5 T_o

T_∞ = depends on fire size (387 kW or 645 kW) taken from CFAST Output:

	387 kW	645 kW
T_∞	357°K (84°C)	382°K (109°C)

T_o = Plume centerline temperature; assumed to be adiabatic flame temperature calculated above

= $\Delta T + T_\infty$

= 2,027°K + 84°C (387kW case)

= 2,027°K + 109°C (645kW case)

	387 kW	645 kW
T_o	2,111°K (1,838°C)	2,136°K (1,863°C)

z = Elevation above the fire source; taken to be 0.5 flame height (L)

$L = -1.02D_{eq} + 0.235Q^{2/5}$ (SFPE 1988)

where:

D_{eq} = Equivalent diameter of fire area (see previous calculations)

= 1.07 m for 387kW case

= 1.19 m for 645kW case

$$z_{387kW} = 0.5[-1.02(1.07\ m) + 0.235(387kW)^{2/5}]$$

$$= 0.73\ m$$

$$z_{645kW} = 0.5[-1.02(1.19\ m) + 0.235(645kW)^{2/5}]$$

$$= 0.96\ m$$

z_o = Elevation of the virtual origin above the fire source

$$= -1.02D_{eq} + 0.083Q^{2/5} \text{ (SFPE 1988)}$$

$$z_{o387kW} = -1.02(1.07\ m) + 0.083(387kW)^{2/5}$$

$$= -0.19\ m$$

$$z_{o645kW} = -1.02(1.19\ m) + 0.083(645kW)^{2/5}$$

$$= -0.11\ m$$

$$b_{\Delta T387kW} = 0.12(2{,}111°K/357°K)^{½} [0.73\ m - (-0.19\ m)]$$

$$b_{\Delta T645kW} = 0.12(2{,}136°K/382°K)^{½} [0.96\ m - (-0.11\ m)]$$

	387 kW	645 kW
$b_{\Delta T}$	0.27 m (10 in.)	0.30 m (12 in.)

T_{f387kW} = $0.5\ T_{o387kW}$ at 0.27 m

T_{f645kW} = $0.5\ T_{o645kW}$ at 0.30 m

	387 kW	645 kW
T_f	1,056°K	1,068°K

$q_{expbayloss}/A$ =

	387 kW	645 kW
$q_{expbayloss}/A$	11,432 W/m²	11,030 W/m²

$q_{adjbayloss}/A$ = 1,972 W/m²

$\sigma F(T_f^4 - T_{wl}^4)$ = $q_{expbayloss}/A + q_{adjbayloss}/A$

$F \preceq [q_{expbayloss}/A + q_{adjbayloss}/A]/\ [\sigma(T_f^4 - T_{wl}^4)]$

$F_{387kW} \preceq$ [11,432 W/m² + 1,972 W/m²]/
[5.669 x 10^{-8} W/m²-°K^4
(1,056°K^4 – 667°K^4)]

$F_{645kW} \preceq$ [11,030 W/m² + 1,972 W/m²]/
[5.669 x 10^{-8} W/m²-°K^4
(1,068°K^4 – 667°K^4)]

	387 kW	645 kW
$F \preceq$	0.23	0.21

h. Determine limiting distance between a step off pad fire and a process bay wall:

(1) Solve for R in the the following equation for radiation shape factor between two stacked cylinders and a point on the process bay wall, (represents shape factor between short dimension of step off pad and process bay wall):

$$F = 2\left(\frac{1}{\pi H}\tan^{-1}\left[\frac{L}{\sqrt{H^2-1}}\right] + \frac{L}{\pi}\left\{\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right\}\right)$$

(SFPE 1988)

where:

F = Radiation Shape Factor

$F_{387kW} \preceq$ 0.23

$F_{645kW} \preceq$ 0.21

H = R/r

R = Radius from plume centerline to wall

r = Distance from plume centerline to surface of cylinder formed by plume

= $b_{\Delta T}$

r_{387kW} = 0.27 m

r_{645kW} = 0.30 m

L = h/r

h = ½ height of cylinder formed by flame height and r

h_{387kW} = 0.73 m

h_{645kW} = 0.96 m

L_{387kW} = 2.70

L_{645kW} = 3.20

$X = (1 + H)^2 + L^2$

$X_{387kW} = (1 + H)^2 + 7.29$

$X_{645kW} = (1 + H)^2 + 10.24$

$Y = (1 - H)^2 + L^2$

$Y_{387kW} = (1 - H)^2 + 7.29$

$Y_{645kW} = (1 - H)^2 + 10.24$

Try R = 3 m:

	387 kW	645 kW
R	3.0	3.0
H	11.1	10.0
L	2.7	3.2
X	153.7	131.2
Y	109.3	91.2
F	0.03 < 0.23 (O.K.)	0.04 < 0.21 (O.K.)

Try R = 2 m:

	387 kW	645 kW
R	2.0	2.0
H	7.4	6.7
L	2.7	3.2
X	77.8	69.5
Y	48.2	42.7
F	0.06 < 0.23 (O.K.)	0.09 < 0.21 (O.K.)

Try R = 1 m:

	387 kW	645 kW
R	1.0	1.0
H	3.7	3.3
L	2.7	3.2
X	29.4	28.7
Y	14.6	15.5
F	0.22 < 0.23 (O.K.)	0.27 > 0.21 (N.G.)

Try R = 1.5 m:

	387 kW	645 kW
R		1.5
H		5.0
L		3.2
X		46.2
Y		26.2
F		0.14 < 0.21 (O.K..)

Try R = 1.2 m:

	387 kW	645 kW
R		1.2
H		4.0
L		3.2
X		35.2
Y		19.2
F		0.20 < 0.21 (O.K..)

(2) The minimum required distance of a step off pad from a process bay wall (short dimension of step off pad towards wall) is calculated to be:

$$\text{Limiting Distance} = R - b_{\Delta T} - (r_{end} - b_{\Delta T})$$

$$= R - r_{end}$$

where:

	387 kW	645 kW
R	1.0 m	1.2 m

$$r_{end} = 0.61 \text{ m}/2$$

$$= 0.30 \text{ m}$$

Limiting Distance:

	387 kW	645 kW
Limiting Distance for short dimension of step off pad to process bay wall	0.7 m (2 ft 4 in.)	0.9 m (3 ft 0 in.)

(3) Solve for c in the the following equation for radiation shape factor between step off pad and a point on the process bay wall, (represents shape factor between long dimension of step off pad and process bay wall):

$$F = \frac{4}{2\pi}\left\{\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left[\frac{Y}{\sqrt{1+X^2}}\right] + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left[\frac{X}{\sqrt{1+Y^2}}\right]\right\}$$

(SFPE 1988)

where:

F = Radiation Shape Factor (limiting value previously determined)

$F_{387kW} \leq$ 0.23

$F_{645kW} \leq$ 0.21

X = a/c

Y = b/c

a = Vertical dimension of plane surface facing the process bay wall taken to be ½ of the vertical dimension (½ of flame height (L))

= 0.5 x L (L previously determined)

	387 kW	645 kW
a	0.73 m	0.96 m

b = Horizontal dimension of plane surface facing the process bay wall taken to be ½ of the step off pad long dimension

	387 kW (3) 55-gallon drums	645 kW Frame and trash bin
Long Dimension	1.83 m (6 ft)	1.90 m (6 ft 3 in)
b	0.92 m	0.95 m

c = Distance from surface of cylinder formed by the step off pad fire to the process bay wall

Try c = 2 m:

	387 kW	645 kW
X	0.37	0.48
Y	0.46	0.48
F	0.17< 0.23 (O.K.)	0.22 > 0.21 (N.G.)

Try c = 2.1 m:

	387 kW	645 kW
X		0.46
Y		0.45
F		0.207 < 0.21 (O.K.)

Try c = 1.5 m:

	387 kW	645 kW
X	0.49	
Y	0.61	
F	0.27 > 0.23 (N.G.)	

Try c = 1.7 m:

	387 kW	645 kW
X	0.43	
Y	0.54	
F	0.225 < 0.23 (O.K.)	

Try c = 1.6 m:

	387 kW	645 kW
X	0.46	
Y	0.58	
F	0.25 > 0.23 (N.G.)	

(4) The minimum required distance of a step off pad from a process bay wall (long dimension of step off pad towards wall) is calculated to be:

$$\text{Limiting Distance} = c - b_{\Delta T} - (r_{side} - b_{\Delta T})$$

$$= c - r_{side}$$

where:

	387 kW	645 kW
c	1.7 m	2.1 m

r_{side} = 0.61 m/2

= 0.30 m

Limiting Distance:

	387 kW	645 kW
Limiting Distance	1.4 m (4 ft 8 in.)	1.8 m (6 ft)

33. Affect of Step Off Pad Fire on Structural Steel Columns and Mezzanine Vertical Supports

a. Assumption: The failure temperature of structural steel columns and mezzanine vertical supports is taken to be 538°C (811°K). ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, Alternative Test of Protection for Structural Steel Columns.

b. Determine radiative and convective heat transfer losses from a structural steel column and mezzanine vertical support:

$q_{steelloss}/A = q_{steelconv}/A + q_{steelrad}/A$

Convective Heat Loss $q_{steelconv}/A = h(T_s - T_{\infty 1})$

where:

$h = 1.42(\Delta T/L)^{1/4}$ (Holman 1976)
(laminar flow assumed)

$\Delta T = T_s - T_{\infty 1}$

L = 4.4 m (length of mezzanine vertical supporting steel)

T_s = Failure temperature of steel columns

= 811°K (538°C)

$T_{\infty 1}$ = depends on fire size (387 kW or 645 kW) taken from CFAST Output:

	387 kW	645 kW
$T_{\infty 1}$	357°K (84°C)	382°K (109°C)

h_{387kW} = $1.42[(811°K - 357°K)/4.4\ m]^{1/4}$

h_{645kW} = $1.42[(811°K - 382°K)/4.4\ m]^{1/4}$

	387 kW	645 kW
h	4.53 W/m²-°K	6.46 W/m²-°K

$q_{steelconv387kW}/A$= (4.53 W/m²-°K)(811°K - 357°K)

$q_{steelconv645kW}/A$= (6.46 W/m²-°K)(811°K - 382°K)

	387 kW	645 kW
$q_{steelconv}/A$	2,057 W/m²	2,771 W/m²

Radiative Heat Loss $q_{steelrad}/A$ = $\sigma F(T_s^4 - T_{\infty 1}^4)$

where:

σ = 5.669×10^{-8} W/m²-°K^4

F = 1.0 (assumed)

T_s = 811°K

$T_{\infty 1}$ = depends on fire size (387 kW or 645 kW) taken from CFAST Output:

	387 kW	645 kW
$T_{\infty 1}$	357°K (84°C)	382°K (109°C)

$q_{steelrad387kW}/A$ = $(5.669 \times 10^{-8}$ W/m²-°K$^4)(1.0)$ $(811°K^4 - 357°K^4)$

$q_{steelrad645kW}/A$ = $(5.669 \times 10^{-8}$ W/m²-°K$^4)(1.0)$ $(811°K^4 - 382°K^4)$

	387 kW	645 kW
$q_{expbayrad}/A$	23,603 W/m²	23,317 W/m²

$q_{steelloss}/A$ = $q_{steelconv}/A + q_{steelrad}/A$

	387 kW	645 kW
$q_{steelloss}/A$	25,660 W/m²	26,088 W/m²

c. Determine radiation shape factor for the limiting radiative heat transfer rate from a step off pad fire to exposed process bay wall:

Heat Balance:

$q_{radfire}/A = \sigma F(T_f^4 - T_s^4) = q_{steelloss}/A$

where:

σ = 5.669×10^{-8} W/m²-°K⁴

F = Shape Factor – To Be Determined

T_s = 811°K

T_f = depends on fire size (387 kW or 645 kW) and plume radius

where (data developed previously):

	387 kW	645 kW
T_o	2,111°K (1,838°C)	2,136°K (1,863°C)

	387 kW	645 kW
T_f	1,056°K	1,068°K

	387 kW	645 kW
$q_{steelloss}/A$	25,660 W/m²	26,088 W/m²

$\sigma F(T_f^4 - T_s^4) = q_{steelloss}/A$

$F \preceq [q_{steelloss}/A]/[\sigma(T_f^4 - T_s^4)]$

$F_{387kW} \preceq [25{,}660\ W/m^2]/[5.669 \times 10^{-8}\ W/m^2\text{-}°K^4\ (1{,}056°K^4 - 811°K^4)]$

$F_{645kW} \preceq [26{,}088\ W/m^2]/[5.669 \times 10^{-8}\ W/m^2\text{-}°K^4\ (1{,}068°K^4 - 811°K^4)]$

	387 kW	645 kW
$F \preceq$	0.56	0.53

d. Determine limiting distance between a step off pad fire and a process bay structural steel column or mezzanine vertical support:

(1) Solve for R in the the following equation for radiation shape factor between two stacked cylinders and a point on the process bay structural steel column or mezzanine vertical support (represents shape factor between short dimension of step off pad and process bay structural steel column or mezzanine vertical support)::

$$F = 2\left(\frac{1}{\pi H}\tan^{-1}\left[\frac{L}{\sqrt{H^2-1}}\right] + \frac{L}{\pi}\left\{\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right\}\right)$$

(SFPE 1988)

where (some data determined previously):

F = Radiation Shape Factor

$F_{387kW} \preceq$ 0.56

$F_{645kW} \preceq$ 0.53

H = R/r

r_{387kW} = 0.27 m

r_{645kW} = 0.30 m

L_{387kW} = 2.70

L_{645kW} = 3.20

$X_{387kW} = (1 + H)^2 + 7.29$

$X_{645kW} = (1 + H)^2 + 10.24$

$Y_{387kW} = (1 - H)^2 + 7.29$

$Y_{645kW} = (1 - H)^2 + 10.24$

Try R = 1 m:

	387 kW	645 kW
R	1.0	1.0
H	3.7	3.3
L	2.7	3.2
X	29.4	28.7
Y	14.6	15.5
F	0.22 < 0.56 (O.K.)	0.27 < 0.53 (O.K.)

Try R = 0.5 m:

	387 kW	645 kW
R	0.5	0.5
H	1.8	1.7
L	2.7	3.2
X	15.1	17.5
Y	7.9	10.7
F	0.55 < 0.56 (O.K.)	0.58 > 0.53 (N.G.)

Try R = 0.7 m:

	387 kW	645 kW
R		0.7
H		2.3
L		3.2
X		21.1
Y		11.9
F		0.42 < 0.53 (O.K.)

Try R = 0.6 m:

	387 kW	645 kW
R		0.6
H		2.0
L		3.2
X		19.2
Y		11.2
F		0.49 < 0.53 (O.K..)

(5) Minimum required distance of a step off pad from a structural steel column or mezzanine vertical support (short dimension of step off pad towards structural steel column or mezzanine vertical support) is calculated to be:

$$\text{Limiting Distance} = R - b_{\Delta T} - (r_{end} - b_{\Delta T})$$

$$= R - r_{end}$$

where:

	387 kW	645 kW
R	0.5 m	0.6 m

$$r_{end} = 0.61\ \text{m}/2$$

$$= 0.30\ \text{m}$$

Limiting Distance:

	387 kW	645 kW
Limiting Distance for short dimension of step off pad to structural steel column or mezzanine vertical support	0.2 m (8 in.)	0.3 m (1 ft)

(6) Solve for c in the the following equation for radiation shape factor between step off pad and a point on a structural steel column or mezzanine vertical support (represents shape factor between long dimension of step off pad and process bay wall):

$$F = \frac{4}{2\pi}\left\{\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left[\frac{Y}{\sqrt{1+X^2}}\right] + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left[\frac{X}{\sqrt{1+Y^2}}\right]\right\}$$

(SFPE 1988)

where:

F = Radiation Shape Factor (limiting value previously determined)

$$F_{387kW} \leq 0.56$$

$F_{645kW} \leq$ 0.53

X = a/c

Y = b/c

a = Vertical dimension of plane surface facing the process bay wall taken to be ½ of the vertical dimension (½ of flame height (L))

= 0.5 x L (L previously determined)

	387 kW	645 kW
a	0.73 m	0.96 m

b = Horizontal dimension of plane surface facing the process bay wall taken to be ½ of the step off pad long dimension (previously determined)

	387 kW (3) 55-gallon drums	645 kW Frame and trash bin
b	0.92 m	0.95 m

c = Distance from surface of cylinder formed by the step off pad fire to the process bay wall

Try c = 1 m:

	387 kW	645 kW
X	0.73	0.96
Y	0.92	0.95
F	0.45< 0.56 (O.K.)	0.532 > 0.53 (N.G.)

Try c = 1.1 m:

	387 kW	645 kW
X		0.87
Y		0.86
F		0.48 < 0.53 (O.K.)

Try c = 0.9 m:

	387 kW	645 kW
X	1.23	
Y	1.02	
F	0.60 > 0.56 (N.G.)	

(7) The minimum required distance of a step off pad from a process bay structural steel column or mezzanine vertical support (long dimension of step off pad towards structural steel column or mezzanine vertical support) is calculated to be:

$$\text{Limiting Distance} = c - b_{\Delta T} - (r_{side} - b_{\Delta T})$$

$$= c - r_{side}$$

where:

	387 kW	645 kW
c	1.0 m	1.1 m

$$r_{side} = 0.61\ \text{m}/2$$

$$= 0.30\ \text{m}$$

Limiting Distance:

	387 kW	645 kW
Limiting Distance for long dimension of step off pad to structural steel column or mezzanine vertical support	0.7 m (2 ft 4 in.)	0.8 m (2 ft 8 in.)

34. Affect of Step Off Pad Fire on Transporter Tires

a. Describe and develop ignition criteria for transporter tires:

A simplified mathematical model for determining the energy needed for ignition of solid fuels, such as rubber, is contained in (SFPE 1988- Section 1/Chapter 21).

Ignition is defined by the SFPE Handbook as " . . . the stage beyond which the associated fuel/oxidant system is capable of supporting a sustained exothermic reaction." The Handbook develops and presents a conservative model with a graphical representation (SFPE 1988 - Figure 1-21.3) that may be applied to solid materials exposed to a heat source to determine if ignition is possible.

Ignition is assumed to occur when a material's surface is heated to a predetermined critical ignition temperature. For rubber tires, this critical ignition temperature is 350°C (623°K)(662°F) which is taken from information provided by the tire manufacturer (Bridgestone). Also, NFPA 53 *Guide on Fire Hazards in Oxygen-Enriched Atmospheres*, lists the minimum hot plate ignition temperature for rubber to be 430°C (703°K)(806°F) in one atmosphere pressure.

Although ignition is possible when the surface temperature reaches its critical ignition temperature, the resulting combustion reaction would not sustain itself if the source of exposure were to be removed. Persistent ignition would require heating of the solid, over a minimum thickness near its exposed surface, to a mean temperature in excess of the material's characteristic pyrolysis temperature to ensure continued pyrolysis. This would presumably mean that a higher surface temperature than the critical ignition temperature would be required.

Conservatively, ignition of the transporter tires is predicted to occur when the tire surface reaches a critical ignition temperature of 350°C (623°K)(662°F) using the model described above, taking into consideration the distance of the tires from the fire, the time of exposure, and fire intensity.

On (SFPE 1988 - Figure 1-21.3), various solutions to the heat transfer problem relating to exposure of a slab of material to radiant heat and cooled by convective heat loss are plotted. The dimensionless Biot number takes the thickness of the material and other material properties related to heat transfer into account. The heat transfer solution for critical surface temperature at constant Biot number is plotted as a solid line on (SFPE 1988 - Figure 1-21.3). The dashed line represents the heat transfer solution for critical average material temperature for a constant Biot number. Points above the dashed line are indicative of heat transfer conditions favorable to self-sustaining or persistent ignition and combustion of the material. Points above or to the right of the solid line represent conditions favorable to piloted ignition and combustion of the material.

For this evaluation, a finding of "not viable", as applied to ignition of the twelve rubber transporter tires in a CVDF Process Bay, requires that the specific exposure condition fall beneath and to the left of the solid line of constant Biot number on (SFPE 1988 - Figure 1-23.1).

b. Describe and develop model and method for ignition of transporter tires:

(SFPE 1988) develops the solution (Equation 14) to the transient heat transfer problem relating to ignition of a solid material based on critical surface temperature:

$$\frac{T_s - T_{so}}{\left(\frac{i_o}{h}\right) + T_\infty - T_{so}} = 1 - \sum_{n=1}^{\infty} \frac{2Bi\sec(a_n)\cos\left(\frac{a_n y}{\ell}\right)}{Bi(Bi+1) + a_n^2} \exp\left(-\frac{a_n^2 \alpha_s t}{\ell^2}\right)$$

(Equation 14)

where:

T_s = critical surface temperature (°K)

T_{so} = initial surface temperature (°K)

i_o = exposure irradiance (W/m^2)

h = convective heat transfer coefficient (W/m^2-°K)

= $1.42\left(\frac{\Delta T}{L}\right)^{1/4}$ (Laminar, Holman, 4th Edition)

= $0.95(\Delta T)^{1/3}$ (Turbulent, Holman, 4th Edition)

where:

ΔT = $T_s - T_\infty$ (°K)

L = vertical dimension (m)

T_∞ = ambient temperature (°K)

Bi = Biot number = $h\ell/K_s$

where:

ℓ = thickness of solid material (m)

K_s = thermal conductivity (W/m-°K)

a_n = positive roots of atan(a) = Bi, n = 1, 2, . . . ,∞

(The first 6 of these roots are given in (SFPE 1988 - Table 1-21.1)

y = coordinate normal to surface (m)

α_s = thermal diffusivity (m^2/sec) = $K_s/\rho c$

where:

ρ = density (kg/m^3)

c = specific heat (J/kg-°K)

t = time (sec)

In (SFPE 1988), Equation 14 is solved for various values of t to trace out the solid curve on (SFPE 1988 - Figure 1-21.3) corresponding to constant Biot number. The coordinates used on this figure are:

x-coordinate: $$\frac{i_o \ell}{K_s(T_s - T_{so})} \equiv Bi \Big/ \frac{T_s - T_{so}}{\frac{i_o}{h} + T_\infty - T_{so}}$$

y-coordinate: $$\frac{i_o \alpha_s t}{K_s(T_s - T_{so})\ell} \equiv \frac{\alpha_s t}{\ell^2} \bullet x - \text{coordinate}$$

For constant Biot number, exposure of the transporter tires to an irradiance i_0 for a period of time t defines the value of the x- and y-coordinates falling on the solid curve used by this evaluation to conclude that the transporter tires will ignite.

From these equations and (SFPE 1988 - Equation 14), the value of i_0 can be determined for a given t.

Knowing the configuration and heat release rate of potential exposure fire packages in a CVDF Process Bay, with the limiting values of i_0 and t, allows the use of exposure calculations to determine the required distance between combustibles in the Process Bay and transporter tires to prevent ignition.

c. Assumptions:

(1) Convective heat transfer coefficient (h) is based on laminar flow.

(2) Thickness of rubber tires is 0.010 m (approx. 3/8 in.)

(3) Use of the first six roots (a_n) of the transcendental Equation (interpolated from(SFPE 1988 - Table 1-21.1) are adequate to solve the equation.

(4) Convective and radiative heat transfer losses from transporter tires are assumed to be 0 W/m².

d. Data:

(1) Critical ignition temperature for rubber tires is 350°C (623°K)(662°F) based on information provided by the tire manufacturer (Bridgestone).

(2) Transporter tires are 1.02 m (40 in.) in diameter.

e. Determine (net) radiant heat rate from an exposure fire (step off pad) necessary to ignite transporter tires:

(1) The Biot number for rubber tires is calculated to be:

$$Bi = h\ell/K_s$$

where:

$$h = 1.42\left(\frac{\Delta T}{L}\right)^{1/4}$$

where:

$\Delta T = T_s - T_\infty$

$T_s = 350°C = 623°K$

$T_{\infty 387kW} = 84°C\ (357°K)$

$T_{\infty 645kW} = 109°C\ (382°K)$

$\Delta T_{387kW} = 266°K$

$\Delta T_{645kW} = 241°K$

L = tire diameter = 1.02 m

$h_{387kW} = 5.7\ W/m^2\text{-}°K$

h_{645kW} = 5.6 W/m²-°K

(Assume that h = 5.6 W/m²-°K for both the 387 kW and 645 kW cases)

ℓ = 0.010 m

K_s = 0.14 W/m-°K (0.08 Btu/hr-ft-°F) (Avallone 1987)

Bi = 0.40 (for both the 387 kW and 645 kW cases)

(2) The value of the x-coordinate is determined for each of the exposure fire packages described above from the following equation:

x-coordinate =

$$Bi \Big/ 1 - \sum_{n=1}^{6} \frac{2Bi \sec(a_n)\cos\left(a_n y/\ell\right)}{Bi(Bi+1)+a_n^2} \exp\left(-a_n^2 \alpha_s t/\ell^2\right)$$

where:

Bi = 0.40

a_n = a_1, a_2, a_3, a_4, a_5, and a_6

Take data from (SFPE 1988 - Table 1-21.1), interpolate, determine a_1, a_2, a_3, a_4, a_5, and a_6:

atan(a)	Bi = 0.1	Bi = 0.40	Bi = 1.0
a_1	0.3111	0.494	0.8603
a_2	3.1731	3.257	3.4256
a_3	6.2991	6.345	6.4373
a_4	9.4354	9.467	9.5293
a_5	12.5743	12.598	12.6453
a_6	15.7143	15.733	15.7713

y = ℓ = 0.010 m

α_s = $K_s/\rho c$

where:

ρ = 1.5×10^6 g/m³ (Avallone 1987) c = 2.01 J/g-°K (Avallone 1987)

α_s = 4.64 x 10^{-8} m²/sec

t = 6,294 seconds (for 387 kW step off pad fire), or 3,788 seconds (for 645 kW step off pad fire), as applicable

(3) Since y = ℓ, $\sec(a_n)\cos(a_n y/\ell) = 1$, and the equation given for the x-coordinate is reduced to be:

$$\text{x-coordinate} = \mathrm{Bi} \Big/ 1 - \sum_{n=1}^{6} \frac{2\mathrm{Bi}}{\mathrm{Bi}(\mathrm{Bi}+1) + a_n^2} \exp\left(-a_n^2 \alpha_s t \big/ \ell^2 \right)$$

(4) The value of the x-coordinate for a 387 kW step off pad fire (t = 6,294 seconds) is calculated to be:

x-coordinate = Bi/(1 - ∑ 5.72 x 10^{-1} + 2.52 x 10^{-15} + 1.70 x 10^{-53} + · · ·)

= 0.40/0.428

= 0.94

$i_o \ell / K_s(T_s - T_{so})$ = 0.94 (SFPE 1988 – Figure 1-21.3)

Solve for i_o:

i_o = $0.94[K_s(T_s - T_{so})]/\ell$

where:

ℓ = 0.01 m

K_s = 0.14 W/m-°K

T_s = 623°K

T_{so} = 293°K

i_o = 4,343 W/m²

(5) The value of the x-coordinate for a 645 kW step off pad fire (t = 3,788 seconds) is calculated to be:

x-coordinate = $Bi/(1 - \sum 6.48 \times 10^{-1} + 5.72 \times 10^{-10} + 3.64 \times 10^{-33} + \cdots)$

= 0.40/0.352

= 1.14

$i_o \ell / K_s(T_s - T_{so})$ = 1.14 (SFPE 1988 – Figure 1-21.3)

Solve for i_o:

i_o = $1.14[K_s(T_s - T_{so})]/\ell$

where:

ℓ = 0.01 m

K_s = 0.14 W/m-°K

T_s = 623°K

T_{so} = 293°K

i_o = 5,266 W/m²

f. The limiting radiative heat flux from a step off pad fire to a transporter tire is conservatively taken to correspond to i_o for the 387 kW case (due to the longer fire duration):

$q_{radtirelimit}$ = 4,343 W/m²

g. Determine radiation shape factor for the limiting radiative heat transfer rate from a step off pad fire to exposed process bay wall:

Heat Balance:

$q_{radfire}/A = \sigma F(T_f^4 - T_s^4) = q_{radtirelimit} = 4{,}343$ W/m²

where:

σ = 5.669×10^{-8} W/m²-°K⁴

F	=	Shape Factor – To Be Determined
T_s	=	623°K
T_f	=	depends on fire size (387 kW or 645 kW) and plume radius

where (data developed previously):

	387 kW	645 kW
T_f	1,056°K	1,068°K

$\sigma F(T_f^4 - T_s^4)$ = 4,343 W/m²

$F \preceq [4{,}343\ W/m^2]/[\sigma(T_f^4 - T_s^4)]$

$F_{387kW} \preceq [4{,}343\ W/m^2]/[5.669 \times 10^{-8}\ W/m^2\text{-}°K^4\ (1{,}056°K^4 - 623°K^4)]$

$F_{645kW} \preceq [4{,}343\ W/m^2]/[5.669 \times 10^{-8}\ W/m^2\text{-}°K^4\ (1{,}068°K^4 - 623°K^4)]$

	387 kW	645 kW
$F \preceq$	0.070	0..067

h. Determine limiting distance between a step off pad fire and transporter tires:

(1) Solve for R in the the following equation for radiation shape factor between two stacked cylinders and a point on a transporter tire (represents shape factor between short dimension of step off pad and a transporter tire):

$$F = 2\left(\frac{1}{\pi H}\tan^{-1}\left[\frac{L}{\sqrt{H^2-1}}\right] + \frac{L}{\pi}\left\{\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right\}\right)$$

(SFPE 1988)

where (some data determined previously):

F = Radiation Shape Factor

$F_{387kW} \preceq$ 0.070

$F_{645kW} \preceq$ 0.067

(Use $F \leq 0.067$ for both cases)

$H = R/r$

$r_{387kW} = 0.27$ m

$r_{645kW} = 0.30$ m

(Use r = 0.30 m for both cases)

$L_{387kW} = 2.70$

$L_{645kW} = 3.20$

(Use L = 3.20 m for both cases)

$X = (1 + H)^2 + L^2$

$Y = (1 - H)^2 + L^2$

Try R = 2 m:

R	2.0
H	6.7
L	3.2
X	69.5
Y	42.7
F	0.087 > 0.067 (N.G..)

Try R = 2.5 m:

R	2.5
H	8.3
L	3.2
X	96.7
Y	63.5
F	0.058 < 0.067 (O.K.)

Try R = 2.4 m:

R	2.4
H	8.0
L	3.2
X	91.2
Y	59.2
F	0.063 < 0.067 (O.K.)

(2) Minimum required distance of a step off pad from a transporter tire (short dimension of step off pad towards transporter tire) is calculated to be:

Limiting Distance $= R - b_{\Delta T} - (r_{end} - b_{\Delta T})$

$= R - r_{end}$

where:

$r_{end} = 0.61 \text{ m}/2$

$= 0.30 \text{ m}$

$R = 2.4 \text{ m}$

Limiting Distance:

Limiting Distance for short dimension of step off pad to transporter tire	2.1 m (7 ft)

(3) Solve for c in the the following equation for radiation shape factor between step off pad and a transporter tire (represents shape factor between long dimension of step off pad and transporter tire):

$$F = \frac{4}{2\pi}\left\{\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left[\frac{Y}{\sqrt{1+X^2}}\right] + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left[\frac{X}{\sqrt{1+Y^2}}\right]\right\}$$

(SFPE 1988)

where:

F = Radiation Shape Factor (limiting value previously determined)

F $\leq$ 0.067

X = a/c

Y = b/c

a = Vertical dimension of plane surface facing the transporter tires taken to be ½ of the vertical dimension (½ of flame height (L))

= 0.5 x L (L previously determined)

(Use a = 0.96 m for both cases)

b = Horizontal dimension of plane surface facing the transporter tires taken to be ½ of the step off pad long dimension (previously determined)

(Use a = 0.95 m for both cases)

c = Distance from surface of cylinder formed by the step off pad fire to the transporter tires

Try c = 3 m:

X	0.32
Y	0.32
F	0.115 > 0.067 (N.G.)

Try c = 3.5 m:

X	0.27
Y	0.27
F	0.085 > 0.067 (N.G.)

Try c = 4.0 m:

X	0.24
Y	0.24
F	0.068 > 0.067 (N.G.)

Try c = 4.1 m:

X	0.23
Y	0.23
F	0.063 < 0.067 (O.K.)

(4) The minimum required distance of a step off pad from a transporter tire (long dimension of step off pad towards transporter tires) is calculated to be:

Limiting Distance = $c - b_{\Delta T} - (r_{side} - b_{\Delta T})$

= $c - r_{side}$

where:

c = 4.1 m

r_{side} = 0.30 m

= 4.1 m – 0.30 m

Limiting distance between the long dimension of a step off pad towards transporter tires = 3.8 m (12 ft 6 in)

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CVDF Fire Scenario 7

Fire Modeling and Evaluation of a Fire Involving
Miscellaneous Combustibles in a Change Room
in the Cold Vacuum Drying Facility
Processing Bay Support Area
with Constrained Oxygen

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CVDF Fire Scenario 8

DISCUSSION

CVDF Fire Scenario 8 evaluates a fire in a Process Bay Support Area change room in an oxygen limited condition. Each case will assume combustible loading associated with a standard step off pad (previously developed in fire scenario 6) in the "standard load" configuration, wood storage shelves and cabinets containing stored clean personnel contamination clothing, and the equivalent of 5 additional "standard loads" of material representing anticipated miscellaneous storage in support of operations and maintenance. Each case is assumed to occur with doors to the space closed, vents closed and ventilation off.

The fire is assumed to grow in each case to peak heat release rate in 30 seconds, burn at peak heat release rate, then burn to completion with a 30 second decay period.

COMBUSTIBLE MATERIAL INVENTORY

1. Step off pad arrangement consists of 3 "standard loads" (see scenario 6)

2. Operations and maintenance storage consists of 5 additional "standard loads"

3. Calculate the volume of personnel contamination clothing contained on shelving:

   a. From drawing H-1-82107 the available shelving and cabinet volume is calculated to be:

      Upper shelves: 3'-3" x 9'-5 3/8" x 1'-0" = 30.7 ft³ (0.87 m³)

      Countertop: 1'-9" x 9'-5 3/8" x 2'-0" = 33.1 ft³ (0.94 m³)

      Cabinet: 3'-0" x 9'-5 3/8" x 2'-0" = 56.7 ft³ (1.61 m³)

      Total: 120.5 ft³ (3.42 m³)

   b. One "standard load" is equivalent to one 55-gallon (0.21 m³) volume. Therefore, the volume of personnel contamination clothing is calculated to be equivalent to:

      $3.42\ m^3/0.21\ m^3 = 16.3$ "standard loads"

4. Calculate the volume of wood shelving and benches:

   a. Upper shelves: 4 x [(1 ½")/12] x 9'-5 3/8" x 1'-0" = 4.7 ft³ (0.13 m³)

b. Backboard: 1 x [(1 ½")/12] x 9'-5 3/8" x 8'-0"
= 9.4 ft³ (0.26 m³)

c. Upper sides: 2 x [(1 ½")/12] x 3'-3" x 1'-0"
= 0.8 ft³ (0.03 m³)

d. Cabinet shelves: 2 x [(1 ½")/12] x 9'-5 3/8" x 2'-0" +
1 x [(2")/12] x 9'-5 3/8" x 2'-0"
= 7.9 ft³ (0.22 m³)

e. Cabinet front: 1 x [(1 ½")/12] x 9'-5 3/8" x 3'-0"
= 3.5 ft³ (0.10 m³)

f. Cabinet sides: 2 x [(1 ½")/12] x 3'-0" x 2'-0"
= 1.5 ft³ (0.04 m³)

g. Benches: 2 x [(2")/12] x 3'-0" x 1'-0"
= 1.0 ft³ (0.03 m³)

Total: 28.8 ft³ (0.81 m³)

5. Determine the combustion properties of wood:

a. Density of wood is taken to be that of fir:

$\rho = 513$ kg/m³ (Avallone 1987)

b. Mass of wood shelves:

volume x ρ = 0.81 m³ x 513 kg/m³

= 415.5 kg

c. Heat of combustion of wood shelves:

$H_c = 17.5$ MJ/kg (NFPA 1991)

d. Total energy content of shelves:

$E = H_c$ x mass

E = 17.5 MJ/kg x 415.5 kg

E = 7,271 MJ

e. Determine energy release rate for wood shelves. Assume that wood shelves are equivalent of a particleboard wardrobe.

$$Q = 1900 \text{ kW} \qquad \text{(SFPE 1988 – Table 2-1.6) :}$$

6. Tabulate combustion characteristics:

"Standard load" mass = 25.9 kg

Heat Release Rate = # "standard loads" x 129 kW (See scenario 6)

Heat of Combustion of "standard load" = 31.2 MJ/kg (See scenario 6)

Load	Quantity	Mass	Heat Release Rate	Heat of Combustion	Energy Content
Step Off Pads	3 "standard loads"	77.7 kg	387 kW	31.2 MJ/kg	2,424 MJ
Ops/Maintenance Storage	5 "standard loads"	129.5 kg	645 kW	31.2 MJ/kg	4,040 MJ
Personnel Contamination Clothing	16.3 "standard loads"	422.2 kg	2,103 kW	31.2 MJ/kg	13,173 MJ
Wood Shelving	--	415.5 kg	1,900 kW	17.5 MJ/kg	7,271 MJ
TOTAL		1,044.9 kg	5,035 kW		26,908 MJ

7. Determine weighted Heat of Combustion:

$$H_c = [(77.7 + 129.5 + 422.2)/1,044.9] \times 31.2 + (415.5/1044.9) \times 17.5$$

$$H_c = 25.8 \text{ MJ/kg}$$

For the purpose of input to CFAST, the step off pad fire is assumed to grow to a peak heat release rate (5,035 kW) over 30 seconds, burn at peak heat release rate, then burn to completion over a 30 second decay period.

DETERMINE INVENTORY VS. TIME

8. Tabulate initial combustible material inventory (I_o) in kJ:

I_o
26,908,000 kJ

9. Designate 30 second period of fire growth (i.e., t = 0 seconds to t = 30 seconds) as Period I.

10. Energy expended during Period I:

Q_{peak} = 5,035 kW

E_I = ½t Q_{peak}

t = 30 sec

E_I = ½(30 sec)(5,035 kW)

= 75,525 kJ

11. Tabulate change in combustible material inventory during Period I:

I_o	$E_I(\Delta I)$	I_{fI}
26,908,000 kJ	75,525 kJ	26,832,475 kJ

12. Determine time from reaching Q_{peak} to beginning of 30 second decay at peak heat release rate for lumped materials:

t = $[(I_{fI} - (30\ sec)(0.5)(Q_{peak}))/Q_{peak}]$

I_{fI} = 26,832,475 kJ

t = 5,314 sec

13. Designate period of steady state burning at Q_{peak} (i.e., t = 30 seconds to t = 5,344 seconds) as Period II.

14. Energy expended during Period II:

E_{II} = t Q_{peak}

t = 5,314 sec

E_{II} = 26,756,950 kJ

15. Tabulate change in combustible material inventory during Period II:

Material Description	I_I	$E_{II}(\Delta I)$	I_{fII}
Standard Load	26,832,475 kJ	26,756,950 kJ	75,525 kJ

16. Designate 30 second decay period of lumped combustibles and steady state burning at Q_{peak} (i.e., t = 5,344 seconds to t = 5,374 seconds) as Period III.

17. Determine energy expended during Period III:

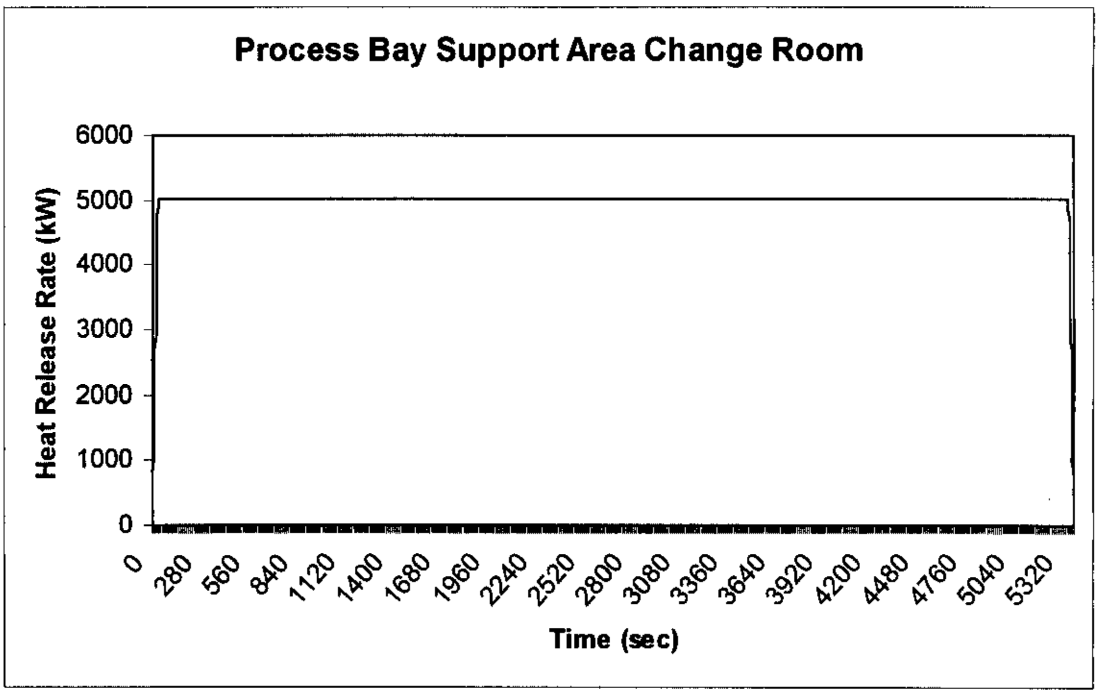
$$E_{III} = (30\ sec)(0.5)(Q_{peak})$$

$$E_{III} = 75{,}525\ kJ$$

18. Tabulate change in combustible material inventory during Period III:

Material Description	I_{fII}	$E_{III}(\Delta I)$	I_{fIII}
Standard Load	75,525 kJ	75,525 kJ	0 kJ

19. Resulting Heat Release Rate Curve:



20. Determine CFAST inputs (heat release rate (Q) and mass loss rate (M_b) during periods I through III):

a. Mass Loss Rate – Equation

$$M_b = Q/H_c$$

where:

M_b = mass loss rate at time t (kg/sec)

Q = heat release rate at time t (kW)

H_c = weighted heat of combustion (kJ/kg)

= 25,800 kJ/kg

(1) Determine Q at t = 0, t = 30, t = 3,758, and t = 3,788:

At t = 0, Q = 0 kW

At t = 30, Q = 5,035 kW

At t = 5,344, Q = 5,035 kW

At t = 5,374, Q = 0 kW

(2) Determine M_b and tabulate:

t (seconds)	Q (kW)	M_b (kg/sec)
0	0	0
30	5035	0.1952
5344	5035	0.1952
5374	0	0

b. Change room size:

18'-9" (5.72 m) depth
10'-0" (3.05 m) wide
8'-0" (2.44 m) high

c. Change room walls and ceiling are gypsum board.

d. The Process Bay Support Area Change Room is assumed to be a 2-hour fire rated room with self-closing doors fire dampers installed.

e. CFAST is run as an oxygen limited case due to small room involved. An unconstrained case is too demanding on the 2-hour fire rating of the room.

21. Process Bay Change Room - FAST Input Data:

```
VERSN    3PROCESS BAY SUPPORT AREA CHANGE ROOM - CONSTRAINED
#VERSN 3 PROCESS BAY SUPPORT AREA CHANGE ROOM - CONSTRAINED
TIMES   7200      0     120     120      0
DUMPR CASE8B.HI
ADUMP CASE8B.XLS N
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF THERMAL.DF
HI/F  0.000000
WIDTH  3.05000
DEPTH  5.72000
HEIGH  2.44000
CEILI GYPSUM
WALLS GYPSUM
FLOOR CONCRETE
#CEILI GYPSUM
#WALLS GYPSUM
#FLOOR CONCRETE
CFCON  2  1 outside 1
CHEMI  16.0000  50.0000  10.0000 2.57941E+007  293.150  493.150 0.300000
LFBO 1
LFBT 2
CJET OFF
FPOS -1.00000 -1.00000 0.000000
FTIME       30.0000       5344.00       5374.00
FMASS      0.000000      0.195200      0.195200      0.000000
FQDOT      0.000000  5.03500E+006  5.03500E+006      0.000000
HCR       0.0800000     0.0800000     0.0800000     0.0800000
OD        0.0300000     0.0300000     0.0300000     0.0300000
CO        0.0300000     0.0300000     0.0300000     0.0300000
OBJFL OBJECTS.DF
SELECT 1 0 0
```

22. Process Bay Change Room - FAST Output:

```
CFAST V  3.1 Created  4/1/98,  Run  5/7/99


Time =       0.0 seconds.

Compartment   Upper   Lower   Inter.  Pyrol      Fire      Pressure  Ambient
              Temp.   Temp.   Height  Rate       Size                Target
              (K)     (K)     (m)     (kg/s)     (W)       (Pa)      (W/m^2)
-----------------------------------------------------------------------------
  1           293.1   293.1   2.4     0.000E+00 0.000E+00 0.000E+00 0.000E+00
 Outside                                        0.000E+00
```

Time = 120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	485.1	366.0	1.56E-02	0.195	1.932E+04	1.334E+05	2.720E+03
Outside					0.000E+00		

Time = 240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	408.6	342.8	1.30E-02	0.195	0.000E+00	1.615E+05	1.299E+03
Outside					0.000E+00		

Time = 360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	386.8	333.3	1.07E-02	0.195	0.000E+00	2.091E+05	966.
Outside					0.000E+00		

Time = 480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	376.5	328.1	9.05E-03	0.195	0.000E+00	2.607E+05	815.
Outside					0.000E+00		

Time = 600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	370.2	324.8	7.82E-03	0.195	0.000E+00	3.136E+05	725.
Outside					0.000E+00		

Time = 720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	365.7	322.5	6.88E-03	0.195	0.000E+00	3.668E+05	663.
Outside					0.000E+00		

Time = 840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	362.2	320.9	6.15E-03	0.195	0.000E+00	4.199E+05	616.
Outside					0.000E+00		

Time = 960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	359.3	319.7	5.56E-03	0.195	0.000E+00	4.729E+05	577.
Outside					0.000E+00		

Time = 1080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	356.8	318.7	5.08E-03	0.195	0.000E+00	5.257E+05	545.
Outside					0.000E+00		

Time = 1200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	354.7	317.9	4.67E-03	0.195	0.000E+00	5.784E+05	518.
Outside					0.000E+00		

Time = 1320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	352.8	317.1	4.33E-03	0.195	0.000E+00	6.308E+05	495.
Outside					0.000E+00		

Time = 1440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	351.1	316.5	4.03E-03	0.195	0.000E+00	6.832E+05	474.
Outside					0.000E+00		

Time = 1560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	349.6	316.0	3.77E-03	0.195	0.000E+00	7.354E+05	457.
Outside					0.000E+00		

Time = 1680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	348.2	315.5	3.55E-03	0.195	0.000E+00	7.876E+05	441.
Outside					0.000E+00		

Time = 1800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	347.0	315.1	3.34E-03	0.195	0.000E+00	8.397E+05	427.
Outside					0.000E+00		

Time = 1920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	345.9	314.7	3.17E-03	0.195	0.000E+00	8.918E+05	415.
Outside					0.000E+00		

Time = 2040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	344.9	314.3	3.00E-03	0.195	0.000E+00	9.438E+05	404.
Outside					0.000E+00		

Time = 2160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	344.0	314.0	2.86E-03	0.195	0.000E+00	9.959E+05	395.
Outside					0.000E+00		

Time = 2280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	343.2	313.7	2.73E-03	0.195	0.000E+00	1.048E+06	386.
Outside					0.000E+00		

Time = 2400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	342.5	313.4	2.61E-03	0.195	0.000E+00	1.100E+06	378.
Outside					0.000E+00		

Time = 2520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	341.8	313.2	2.50E-03	0.195	0.000E+00	1.152E+06	371.
Outside					0.000E+00		

Time = 2640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	341.2	312.9	2.39E-03	0.195	0.000E+00	1.204E+06	364.
Outside					0.000E+00		

Time = 2760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	340.7	312.7	2.30E-03	0.195	0.000E+00	1.256E+06	358.
Outside					0.000E+00		

Time = 2880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	340.2	312.5	2.21E-03	0.195	0.000E+00	1.308E+06	353.
Outside					0.000E+00		

Time = 3000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	339.7	312.3	2.13E-03	0.195	0.000E+00	1.360E+06	348.
Outside					0.000E+00		

Time = 3120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	339.3	312.2	2.06E-03	0.195	0.000E+00	1.413E+06	344.
Outside					0.000E+00		

Time = 3240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	338.9	312.0	1.99E-03	0.195	0.000E+00	1.465E+06	340.
Outside					0.000E+00		

Time = 3360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	338.5	311.9	1.93E-03	0.195	0.000E+00	1.517E+06	336.
Outside					0.000E+00		

Time = 3480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	338.2	311.7	1.86E-03	0.195	0.000E+00	1.569E+06	333.
Outside					0.000E+00		

Time = 3600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	337.9	311.6	1.81E-03	0.195	0.000E+00	1.621E+06	330.
Outside					0.000E+00		

Time = 3720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	337.6	311.5	1.75E-03	0.195	0.000E+00	1.674E+06	327.
Outside					0.000E+00		

Time = 3840.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	337.3	311.4	1.70E-03	0.195	0.000E+00	1.726E+06	324.
Outside					0.000E+00		

Time = 3960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	337.1	311.3	1.65E-03	0.195	0.000E+00	1.778E+06	322.
Outside					0.000E+00		

Time = 4080.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.9	311.2	1.61E-03	0.195	0.000E+00	1.831E+06	320.
Outside					0.000E+00		

Time = 4200.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.7	311.1	1.57E-03	0.195	0.000E+00	1.883E+06	318.
Outside					0.000E+00		

Time = 4320.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.5	311.0	1.53E-03	0.195	0.000E+00	1.936E+06	316.
Outside					0.000E+00		

Time = 4440.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.3	311.0	1.49E-03	0.195	0.000E+00	1.988E+06	314.
Outside					0.000E+00		

Time = 4560.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.1	310.9	1.45E-03	0.195	0.000E+00	2.040E+06	312.
Outside					0.000E+00		

Time = 4680.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	336.0	310.8	1.42E-03	0.195	0.000E+00	2.093E+06	311.
Outside					0.000E+00		

Time = 4800.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	335.8	310.8	1.38E-03	0.195	0.000E+00	2.145E+06	309.
Outside					0.000E+00		

Time = 4920.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	335.7	310.7	1.35E-03	0.195	0.000E+00	2.198E+06	308.
Outside					0.000E+00		

Time = 5040.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	335.6	310.7	1.32E-03	0.195	0.000E+00	2.250E+06	307.
Outside					0.000E+00		

Time = 5160.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	335.5	310.6	1.29E-03	0.195	0.000E+00	2.303E+06	306.
Outside					0.000E+00		

Time = 5280.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	335.4	310.6	1.26E-03	0.195	0.000E+00	2.356E+06	305.
Outside					0.000E+00		

Time = 5400.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	334.7	310.3	1.25E-03	0.000E+00	0.000E+00	2.386E+06	300.
Outside					0.000E+00		

Time = 5520.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	333.2	310.2	1.25E-03	0.000E+00	0.000E+00	2.374E+06	290.
Outside					0.000E+00		

Time = 5640.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	331.7	310.1	1.26E-03	0.000E+00	0.000E+00	2.364E+06	281.
Outside					0.000E+00		

Time = 5760.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	330.4	309.9	1.26E-03	0.000E+00	0.000E+00	2.354E+06	273.
Outside					0.000E+00		

Time = 5880.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	329.1	309.8	1.27E-03	0.000E+00	0.000E+00	2.344E+06	265.
Outside					0.000E+00		

Time = 6000.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	327.9	309.7	1.27E-03	0.000E+00	0.000E+00	2.336E+06	257.
Outside					0.000E+00		

Time = 6120.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	326.8	309.5	1.27E-03	0.000E+00	0.000E+00	2.327E+06	249.
Outside					0.000E+00		

Time = 6240.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	325.8	309.4	1.28E-03	0.000E+00	0.000E+00	2.319E+06	242.
Outside					0.000E+00		

Time = 6360.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	324.8	309.3	1.28E-03	0.000E+00	0.000E+00	2.312E+06	236.
Outside					0.000E+00		

Time = 6480.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	323.8	309.1	1.28E-03	0.000E+00	0.000E+00	2.305E+06	229.
Outside					0.000E+00		

Time = 6600.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	322.9	309.0	1.29E-03	0.000E+00	0.000E+00	2.298E+06	223.
Outside					0.000E+00		

Time = 6720.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	322.0	308.8	1.29E-03	0.000E+00	0.000E+00	2.292E+06	217.
Outside					0.000E+00		

Time = 6840.0 seconds.

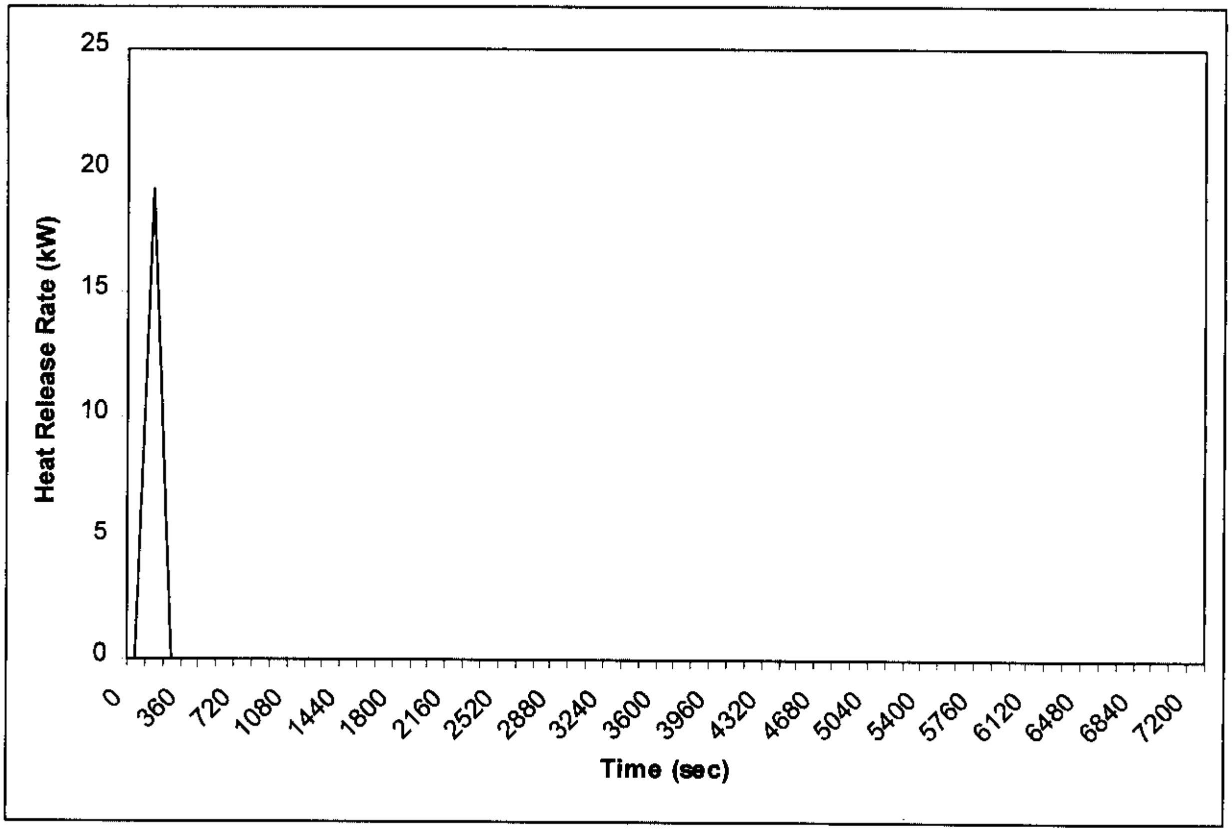
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	321.2	308.7	1.29E-03	0.000E+00	0.000E+00	2.286E+06	211.
Outside					0.000E+00		

Time = 6960.0 seconds.

Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	320.4	308.6	1.29E-03	0.000E+00	0.000E+00	2.280E+06	206.
Outside					0.000E+00		

Time = 7080.0 seconds.

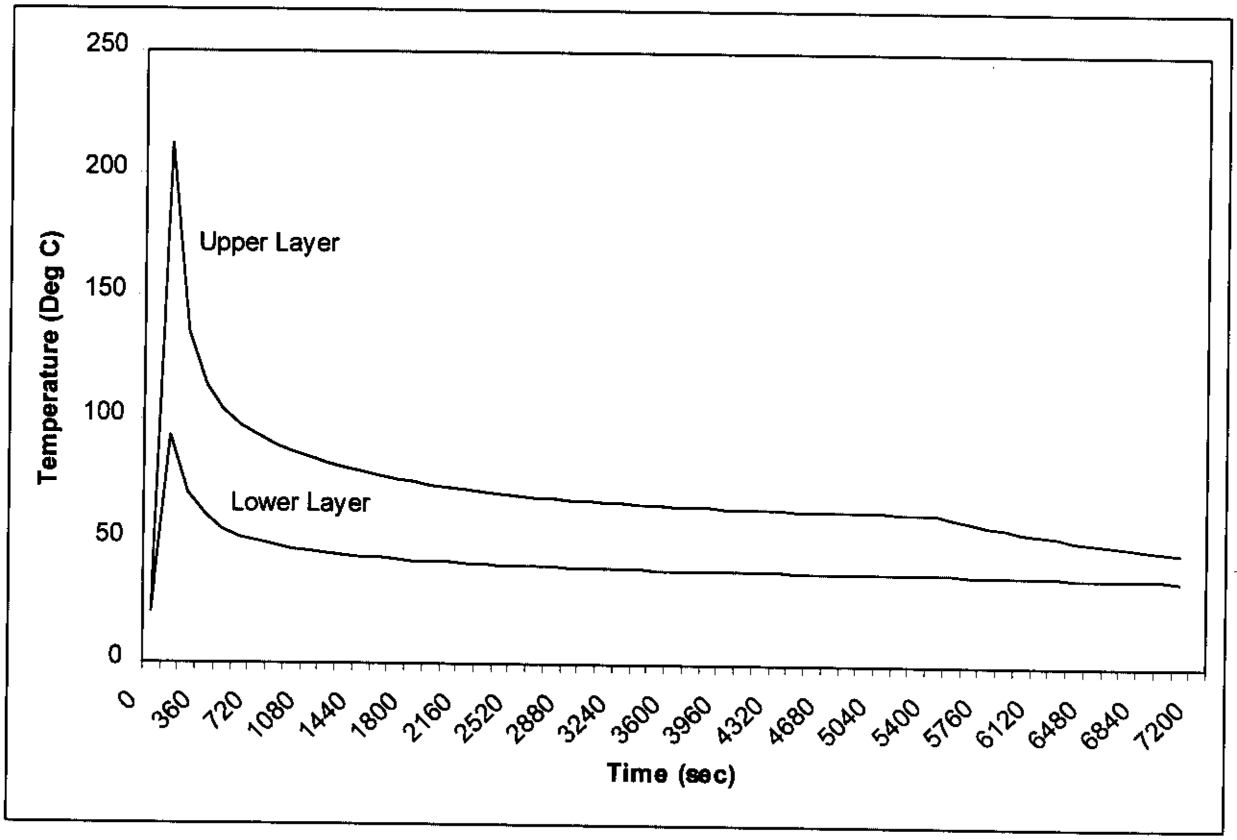
Compartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	319.6	308.4	1.30E-03	0.000E+00	0.000E+00	2.274E+06	201.
Outside					0.000E+00		



CFAST Output: Heat Release Rate vs. Time

Process Bay Support Area Change Room – Oxygen Limited

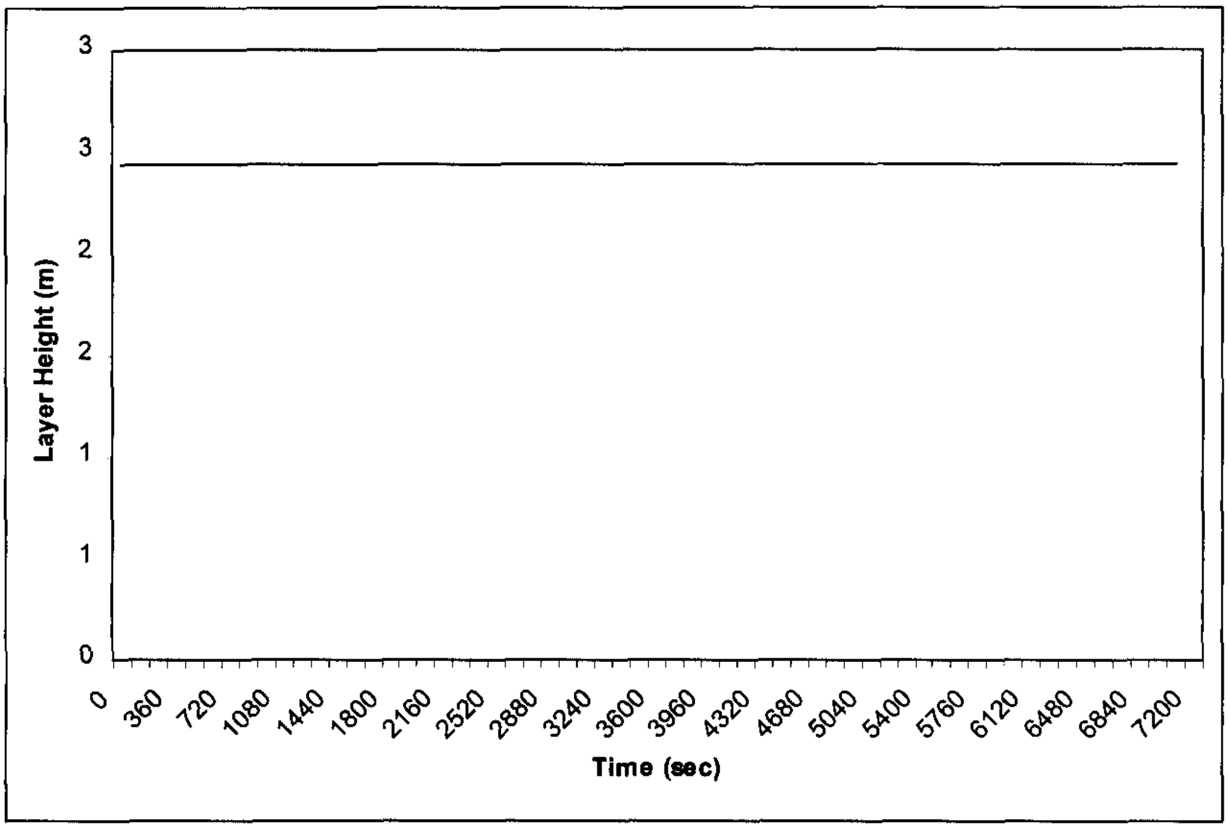
Figure A-22



CFAST Output: Upper and Lower Layer Temperatures vs. Time

Process Bay Support Area Change Room – Oxygen Limited

Figure A-23



CFAST Output: Layer Height vs. Time

Process Bay Support Area Change Room – Oxygen Limited

Figure A-24

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Appendix B

Maximum Possible Fire Loss Calculations

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Maximum Possible Fire Loss

Based on discussion with the FDNW Construction Engineer and DESH Project Controls personnel, the cost to construct CVDF to date is approximately $13 million. This figure includes an estimated $3 million related to extended overhead, field overhead, jobsite costs, and other inefficiencies not representative of the cost to rebuild the facility. The base cost for reconstruction of the CVDF, for calculation of fire loss, is taken to be $10 million.

The cost to rebuild the Office Support Area, without contents, is approximately $900,000. It is based on construction cost of roughly $2,690/m² ($250/ft²) for a 335 m² (3,600 ft²) facility.

The six areas that make up the process bay and process bay support areas (four process bays, a fifth unused process bay and adjacent PWC tank room, and the process bay support area) are assumed to be equal in terms of reconstruction cost at approximately $1.5 million each. All associated HVAC equipment, storage tanks, and utilities, are included in this reconstruction estimate for each of these six areas.

Office Support Area

The Operations Support Area is separated from the process bay and process bay support areas by a 2 hour fire rated wall. The entire area is assumed to be lost due to a fire. This area, used for administration and office space, the control room, and change rooms, coupled with construction using fire retardant gypsum wallboard, make this a conservative assumption.

The fire loss is the cost to reconstruct this part of the CVDF, replacement of damaged systems assuming no salvage value, facility restart cost, and loss of project continuity.

1. Property replacement costs, less salvage value.

   Property replacement costs are taken from discussion with DESH Project Controls, DESH Design Authorities, and FDNW Construction Engineering, assigned to the CVDF project.

   Loss of the Operations Support Area, based on construction cost of roughly $2,690/m² ($250/ft²) for a 335 m² (3,600 ft²) facility, is $900,000. Cost of reconstruction includes HVAC systems and utilities.

   Control room equipment, assumed lost during a fire, make up the largest share of dollar loss associated with Operations Support Area content at approximately $150,000.

   Other miscellaneous losses (contents) are estimated to be $ 50,000.

Item	Replacement Cost
Operations Support Area w/HVAC and Utilities	$900,000
Control Room Equipment and MCS/SCIC System	$150,000
Miscellaneous Contents	$ 50,000
Sub-total	$1,100,000
Less: Salvage Value	$0
Sub-total 1	$1,100,000

2. Decontamination and cleanup costs (including burial).

A decontamination and cleanup cost, other than the cost of demolition, is not anticipated, since the Operations Support Area is assumed to be a complete loss and rebuilt following a fire.

Means Facilities Cost Data [1997] for building demolition = $8.48/m^3 (0.24/ft^3)

Escalation at 3%/year for 5 years = 1.03^5 x $ 8.48/m^3

= $ 9.48/m^3

Volume of Office Support Area = 335 m^3 (3,600 ft^3) x 4 m (13 ft.) high

= 1,340 m^3 (46,800 ft^3)

Demolition Cost = 1,340 m^3 x $ 9.48/m^3

= $ 12,703

3. Facility restart costs.

Facility restart costs are assumed to include costs associated with facility startup, testing, training, readiness review, and oversight by higher authority.

Assume 1/3 of SNF Management Assessment/
Operational Readiness Review budget (FY 00) for 3 months:

SNF Management Assessment/
Operational Readiness Review budget (FY 00) = $ 2,934,000

$ 2,934,000 x 1/3 x 1/4 = $ 327,833

4. Loss of production or program continuity.

DESH Project Controls has provided a loss figure of $308,496 per day (based on 365 days per year) associated with SNF Project downtime in FY 01. The costs provided include:

Spent Nuclear Fuel Project
Current Baseline

	FY 00	FY 01
Project Management & Integration (less contingency)	18,973	15,621
K Basin Maint & Operations	33,956	34,740
SNF Relocation Common Ops	31,214	39,352
K Basin CVD Operations	8,642	9,837
CSB Operations	8,329	13,051
Total	101,114	112,601
Cost per day /365 days	277	308

This per day cost provided may be adjusted to take into account that the programmatic loss to the Canister Storage Building due to a fire at the CVDF is not applicable since the CSB will continue with its interim storage mission regardless of processing at the CVDF or the K Basins.

The per day cost is reduced by CSB's contribution to PM&I, SNF Relocation Common Ops, and the CSB Operations budget. The fraction of PM&I and SNF Common Relocation Ops taken out of the programmatic loss is (13,051/(34,740 + 9,837 + 13,051) = 22.6%.

The adjusted cost per day to the SNF Project due to programmatic loss resulting from a loss of the CVDF is 1000(112,601 – 13,051 - .225(15621 + 39352))/365 = 87,181,000/365 = $238,852 per day.

Recovery from an Operations Support Area fire is assumed to take six months with aggressive procurement of new building materials, HVAC equipment, electrical switchgear, and control room equipment.

Loss of program continuity = ½ year x 365 days/year x $238,852/day

= $ 43,590,490

Note: This is not a covered loss in determinig the Maximum Possible Fire Loss.

5. Cost to restore damaged property to it preoccurrence condition irrespective of whether this is actually done.

   Restoration costs are included with property replacement cost already addressed above.

6. Maximum Possible Fire Loss – Operations Support Area:

Property replacement/restoration cost	=	$ 1,100,000
Demolition cost	=	$ 12,703
Facility Restart cost	=	$ 327,833
Operations Support Area MPFL	**=**	**$ 1,440,536**

Process Bay and Process Bay Support Area

A fire in a process bay involving the tractor and/or transporter materials, as described in fire scenarios 1, 2, 3, and 4, would result in bay temperatures in excess of 538°C (1,000°F). At this temperature, structural damage is expected to include deformation, sagging, or collapse, of steel structural elements, and collapse of mezzanine areas. Deformation of the steel roof deck and supporting steel is expected. The integrity of the process bay roof and is threatened – pyrolysis products will seep through seams between the steel roof deck, ignite and burn beneath the deck. The integrity of the process bay walls supported by these columns is at risk during a fire due to type of construction. The welded connections between precast concrete panel walls and structural columns are subject to failure during a fire in a process bay. The bay walls will lose lateral support, tip, and fall over.

Fire scenario 5 involves an oxygen constrained fire using the same CFAST inputs as fire scenario 4. Scenario 5 may be more appropriate since the Process Bay is closed during the fire with ventilation systems automatically shutting down due to hot gas introduction into the HEPA filter plenums. The oxygen constrained case reduces the maximum temperature in the Process to 407°C (765°F), below the 538°C at which the structural integrity of the columns is not assured, however, the roof remains threatened by temperatures in excess of 400°C (752°F), the flexible hoses connecting the MCO to processing equipment are threatened at 177°C (351°F), and safety class equipment is threatened at 46.1°C (115°F).

Accordingly, fire damage from a fire in a CVDF process bay and process bay support areas is expected to affect the process bay in which the fire occurs, both adjacent process bays, the process bay support area, associated equipment, and change rooms. The integrity of tertiary confinement that is provided by the CVDF building is assumed to be lost.

Adjacent process bays are assumed to contain an MCO in process.

1. Property replacement costs, less salvage value:

Property replacement costs are taken from discussion with DESH Project Controls, DESH Design Authorities, and FDNW Construction Engineering, assigned to the CVDF project.

a. Complete loss (with no salvage value) of all equipment in one process bay, including the cask, transporter and tractor.

Item	Replacement Cost
Process Bay w/HVAC, Utilities, Mezzannines and Utilities	$1,500,000
Tractor	$100,000
Transporter	$180,000
Cask	$600,000
Local Exhaust Hood	$698,000
Process Equipment Skid	$550,000
SCIC System	$380,000
SCHe System	$470,000
Sub-total	$4,478,000
Less: Salvage Value	$0
Sub-total 1.a.	$4,478,000

b. Loss of adjacent process bays and process bay support area, assuming that 25% of the affected areas and associated equipment can be salvaged:

Item	Replacement Cost
Process Bay w/HVAC, Utilities, Mezzannines and Utilities (2)	$3,000,000
Transporter (2)	$360,000
Cask (2)	$1,200,000
Process Bay Support Area w/HVAC, Utilities	$1,500,000
Local Exhaust Hood (2)	$1,396,000
Process Equipment Skid (2)	$1,100,000
SCIC System (2)	$760,000
SCHe System (2)	$940,000
Sub-total	$10,256,000
Less: 25% Salvage Value	$2,564,000
Sub-total 1.b.	$7,692,000

2. Decontamination and cleanup costs (including burial):

Decontamination and cleanup, following a fire in a CVDF process bay, takes into consideration the quantity and disposal of contaminated soil outside of CVDF as well as cleanup of interior building surfaces.

The methodology contained in WHC-SD-GN-TI-20004 *A Method for Estimating Ground Areas Contaminated by a Postulated Fire in a Facility Containing Radioactive Material* is used to determine the extent of ground contamination requiring cleanup. WHC-SD-GN-TI-20004 develops several equations for estimating the extent of ground contamination that might result from a fire in a facility containing a radioactive inventory in the form of contaminated combustible material, such as radioactive waste. The means of dispersal of radioactive material to areas outside of the CVDF is assumed to be a fire in a CVDF process bay.

The model provides an estimate of the area corresponding to a minimum contamination level that may result from a fire that disperses a known inventory of radionuclides into the air based on an equivalent minimum allowable concentration of these same radionuclides. Several equations are provided:

$$\text{maximum downwind extent} = X_L = \left(64.9\frac{I}{C}A_F^{0.8407}\right)^{-\frac{1}{m}}$$

where: $m = -(0.02940 \ln A_F + 3.248)$

I	=	inventory (Ci)
C	=	contamination level (Ci/m^2)
A_F	=	fire area (m^2)

$$\text{area } (m^2) \text{ of minimum contamination level} = A_c = 0.0724\sqrt{-m}X_L^{1.903}$$

The cost of decontamination and cleanup for radionuclides released from a facility is based on cleanup of an area equal to A_c.

No release of radionuclides to the environment from the cask and MCO is expected as a result of the MPFL event due to the ability of the stainless steel cask containing a nominal MCO to withstand the effects of the fire.

A simplified analysis of the affect of heat generated by a scenario 1 and 4 fire on the spent nuclear fuel contained in a cask and nominal MCO, using Hanford Spent Fuel (HANSF) computer code (see Appendix E for description and results), was performed by the Nuclear Safety Analyst responsible for the HANSF code in the SNF Project Safety Analysis Group.

A thermal runaway reaction is not predicted for either of these fire scenarios.

For a scenario 1 tractor and transporter tire fire, this analysis concludes that the pressure within a the closed cask would reach approximately 11 bar (150 psig) design pressure 3 to 3½ hours following the start of a fire. Pressure in the cask is expected to peak at approximately 15 bar

(205 psig) 8 hours following ignition of the fire. Thermal runaway of the fuel contained in the MCO is not expected.

Cask pressure in excess of design pressure may cause the cask to leak and to release H_2 gas into the affected Process Bay area. The maximum quantity of H_2 gas that could be released into the Process Bay from the scenario 1 fire is predicted to be 32 g (360 liters) with an additional 32 g (360 liters) released over the following 8 hours. In the absence of a thermal runaway reaction, release of significant quantities of radionuclides is not expected to occur with the leaking H_2 gas.

The affect on the facility structure of an explosion involving 720 liters of hydrogen gas may be put into perspective by comparison with the hydrogen explosion involving 2,000 liters of hydrogen inside of a process bay as evaluated by the SAR for the MCO overpressurization accident.

The SAR description of the MCO overpressurization accident describes a hydrogen explosion within a Process Bay involving up to 2 m^3 (2,000 liters) of hydrogen gas, small quantities of helium, and air. The SAR evaluation concludes that average pressure increase in the process bay resulting from such an explosion would be less than 0.024 bar (0.35 psi). According to *Chemical Process Safety Fundamentals with Applications* (Crowl 1990), this overpressure condition is not expected to cause significant building damage.

Since thermal runaway is not predicted for a scenario 1 fire, release of significant quantities of radionuclides from the cask is not expected. Accordingly, decontamination of the affected Process Bay is not expected as a result of a tractor and transporter tire fire.

Likewise, for a scenario 4 fire involving transporter tires, the flexible hoses (reinforced teflon) making the connection between the MCO and processing equipment are assumed to completely lose their integrity during a fire event. These hoses are rated for operation at temperatures up to 177°C (350°F) and would be subjected to temperatures in excess of 600°C (1,112°F) during a transporter tire fire represented by scenario 4.

The analysis performed by the SNF Safety Analysis Group concludes that the pressure within a the MCO (the cask lid is removed and MCO is processing) would not exceed 1 bar (14.6 psig) due to loss of flexible hose integrity. The analysis does not predict thermal runaway of the fuel, a cask or MCO overpressure condition, accumulation and release of significant quantities of H_2 gas into the Process Bay area, or release of radionuclides to the Process Bay or the environment.

Cleanup at \$53.82/m² (\$5/ft²) is expected for the surfaces of all three affected process bays. Bays are 9.3 m (30 ft 6 in) wide x 18.3 m (60 ft) deep x 9.8 m (32 ft) high:

Surface area = 3 bays x [(2)(9.3)(18.3) + (2)(9.3)(9.8) + (2)(18.3)(9.8)]

= 2,644 m² (28,460 ft²)

Cost of cleanup at \$53.82/m²:

\$53.82/m² x 2,644 m² = \$142,300

The quantity of radionuclides at risk of release to the environment during a Process Bay fire is the Technical Safety Requirement (TSR) governed maximum allowable quantity of Uranium fuel concentration on the local exhaust HEPA filters. This quantity of fuel is assumed to be carried away once the HEPA filters are destroyed by hot gas from the fire (there is presently no fire suppression system designed into the local exhaust HEPA filter plenum). The TSR allows a maximum of 5gU on the HEPA filter:

5 gU x 1 kg/1,000 g x 1 MTU/1,000 kg = 5×10^{-6} MTU

Other radionuclides in the fuel released per Metric Ton Uranium (MTU) are taken from **(SAR)** Table 3-7.

The minimum allowable concentration for each of the other radionuclides released is taken from HNF-PRO-454 *Inactive Waste Sites* Table 1. Inaccessible Soil Concentration Limits, pCi/g.

To use the concentration limits of Table 1 with the equations above, conversion between units of pCi/g to Ci/m² is necessary. This conversion is made by assuming a soil depth of 1 cm and an average soil density of 1.6 g/cm³:

1 cm x 1.6 g/cm³ x 10,000 cm²/m² x (1×10^{-12} Ci/g)

===> 1pCi/g = 1.6×10^{-8} Ci/m²

Also, an equivalent minimum allowable concentration (C_{eq}) is calculated and substituted for C in the above equations since there is more than one radionuclide of concern, each with a different minimum allowable concentration:

$$C_{eq} = \frac{1}{\sum \frac{\%_i}{C_i}}$$

where:

$\%_i$ = percentage of Ci of radionuclide i in relation to all other radionuclides

C_i = minimum allowable concentration of radionuclide I

Radionuclide	Ci/MTU	MTU	I (Ci)	%	C (pCi/g)	C (Ci/m²)	%/C
H^{3}	26.1 E+01	5.0 E-06	1.30 E-03	1.0 E-02	1.4 E+08	2.24 E+00	4.5 E-03
C^{14}	5.53 E-01	5.0 E-06	2.76 E-06	2.2 E-05	6.2 E+05	9.92 E-03	2.2 E-03
Co^{60}	2.09 E+00	5.0 E-06	1.04 E-05	8.2 E-05	9.9 E+05	1.58 E-02	5.2 E-03
Kr^{85}	3.70 E+02	5.0 E-06	1.85 E-03	1.5 E-02	Not on Table 1	-	-
Sr^{90}	6.93 E+03	5.0 E-06	3.46 E-02	2.8 E-01	8.3 E+05	1.33 E-02	2.1 E+01
Tc^{99}	2.19 E+00	5.0 E-06	1.10 E-05	8.7 E-05	1.3 E+07	2.08 E-01	4.2 E-04
Cd^{113}	2.78 E+00	5.0 E-06	1.39 E-05	1.1 E-04	Not on Table 1	-	-
Cs^{134}	6.47 E+00	5.0 E-06	3.24 E-05	2.6 E-04	1.7 E+04	2.72 E-04	9.6 E-01
Cs^{137}	9.66 E+03	5.0 E-06	4.83 E-02	3.8 E-01	1.7 E+04	2.72 E-04	1.4 E+03
Pm^{147}	1.09 E+02	5.0 E-06	5.45 E-04	4.3 E-03	3.4 E+07	5.44 E-01	7.9 E-03
Sm^{151}	1.02 E+02	5.0 E-06	5.10 E-04	4.0 E-03	Not on Table 1	-	-
Eu^{152}	8.45 E-01	5.0 E-06	4.22 E-06	3.3 E-05	4.5 E+06	7.20 E-02	4.6 E-04
Eu^{154}	1.13 E+02	5.0 E-06	5.65 E-04	4.5 E-03	3.3 E+06	5.28 E-02	8.5 E-02
Eu^{155}	1.06 E+01	5.0 E-06	5.30 E-05	4.2 E-04	2.3 E+07	3.68 E-01	1.1 E-03
U^{234}	3.84 E-01	5.0 E-06	1.92 E-06	1.5 E-05	4.6 E+05	7.36 E-03	2.0 E-03
U^{235}	1.27 E-02	5.0 E-06	6.35 E-08	5.0 E-07	4.9 E+05	7.84 E-03	6.4 E-05
U^{236}	7.16 E-02	5.0 E-06	3.58 E-07	2.8 E-06	4.9 E+05	7.84 E-03	3.6 E-04
U^{238}	3.31 E-01	5.0 E-06	1.66 E-06	1.3 E-05	4.7 E+05	7.52 E-03	1.7 E-03
Np^{237}	4.66 E-02	5.0 E-06	2.33 E-07	1.8 E-06	Not on Table 1	-	-
Pu^{238}	1.33 E+02	5.0 E-06	6.65 E-04	5.3 E-03	1.3 E+04	2.08 E-04	2.5 E+01
Pu^{239}	1.73 E+02	5.0 E-06	8.65 E-04	6.8 E-04	1.2 E+04	1.92 E-04	3.5 E+00
Pu^{240}	1.37 E+02	5.0 E-06	6.85 E-04	5.4 E-03	1.2 E+04	1.92 E-04	2.8 E+01
Pu^{241}	6.82 E+03	5.0 E-06	3.41 E-02	2.7 E-01	6.1 E+05	9.76 E-03	2.8 E+01
Pu^{242}	8.71 E-02	5.0 E-06	4.36 E-07	3.4 E-06	Not on Table 1	-	-
Am^{241}	4.34 E+02	5.0 E-06	2.17 E-03	1.7 E-02	2.5 E+04	4.00 E-04	4.3 E+01
Am^{242}	3.72 E-01	5.0 E-06	1.86 E-06	1.5 E-05	Not on Table 1	-	-
Am^{243}	2.78 E-01	5.0 E-06	1.39 E-06	1.1 E-05	Not on Table 1	-	-
Cm^{244}	4.47 E+00	5.0 E-06	2.24 E-05	1.8 E-04	Not on Table 1	-	-
TOTAL			0.13	1.00			1,550

C_{eq} = 1/1,550

C_{eq} = 6.45 E-04 Ci/m²

Assume A_F = floor area of one process bay.

width	=	9.3 m (30 ft. 6 in.)
depth	=	18.3 m (60 ft. 0 in.)
A_F	=	170 m²

Determine m:

$$m = -(0.02940 \ln A_F + 3.248)$$

$$m = -3.399$$

Determine X_L:

$$X_L = \left(64.9 \frac{I}{C} A_F^{0.8407}\right)^{-\frac{1}{m}}$$

I	=	0.13 Ci		
C	=	C_{eq}	=	6.38 E-04 Ci/m²
m	=	-3.399		
A_F	=	170 m²		

$$X_L = 0.017$$

Determine A_c:

$$A_c = 0.0724\sqrt{-m}X_L^{1.903}$$

$$A_c = 5.86 \times 10^{-5} \text{ m}^2$$

The area external to CVDF that would require decontamination and cleanup following a CVDF process bay fire is less than 1 m². Decontamination and cleanup of this small area is negligible.

Sub-total 2. $142,300

3. Facility restart costs.

Facility restart costs are assumed to include costs associated with facility startup, testing, training, readiness review, and oversight by higher authority.

Assume 1/3 of SNF Management Assessment/
Operational Readiness Review budget (FY 00) for 1 year:

SNF Management Assessment/
Operational Readiness Review budget (FY 00) = $ 2,934,000

$ 2,934,000 x 1/3 = $ 1,311,333

Peak CVDF Startup and Testing budget (FY 99): $1,730,000

Sub-total 3. $3,041,333

4. Loss of production or program continuity.

DESH Project Controls has provided a loss figure of $308,496 per day (based on 365 days per year) associated with SNF Project downtime in FY 01. This figure is adjusted to reflect the continued operation of the CSB even though the CVDF may be lost due to fire. The revised cost per day is $238,852.

Recovery from a process bay scenario 1, 2, 3, or 4, fire is assumed to take 18 months.

The CVDF requires 3 Process Bays to meet its 2-year commitment for processing the fuel from the K Basins. If 3 Process Bays are affected by a fire as is claimed by the FHA, then the CVDF will have lost 2/3 of its required operating capacity as opposed to ¾ of required operating capacity to meet its processing schedule commitments. It is also assumed that the unaffected process bay continues to operate, leaving the SNF Project operating at 1/3 of required capacity, over this 18 month period.

Loss of program continuity = 1½ x 365 days x $238,852/day x 2/3

Sub-total 4. $87,180,980

Note: This is not a covered loss in determinig the Maximum Possible Fire Loss.

5. Cost to restore damaged property to it preoccurrence condition.

Restoration costs are included with property replacement cost already addressed above.

6. Maximum Possible Fire Loss is the sum of 1, 2, 3, 4, and 5, above:

Property replacement/restoration cost	=	$	4,478,000
Decontamination and cleanup costs	=	$	142,300
Facility Restart cost	=	$	3,041,333
Process Bay and Process Bay Support Area MPFL	**=**	**$**	**7,661,633**

Appendix C

Maximum Credible Fire Loss Calculations

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Maximum Credible Fire Loss

Operations Support Area

The MCFL for the Operations Support Area is assumed to occur in the area containing the highest concentration of high value equipment. This area is taken to be the control room, containing the Monitoring and Control System (MCS), associated MCS and SCIC panels, and furniture. A fire in the control room is assumed to actuate the automatic sprinkler system. The sprinkler system will control the fire in the area of the control room to prevent fire spread to other parts of the facility, but will damage and require replacement of control room equipment.

The value of equipment requiring replacement is valued at $150,000 based on discussion with the CVDF Design Authority. The electronic equipment in this room is similar to several off the shelf personal computers. Two SCIC panels and MCS panels are specialty equipment that would require special procurement and qualification testing.

Loss of furnishings (desks, chairs, file cabinets, office supplies) is assumed to be $10,000.

Loss of MCS equipment would cause the all processing at the CVDF to cease until it can be replaced. This period of downtime is estimated to be three months. The cost to the SNF Project due to loss of continuity is estimated by DESH Project Controls to be $308,496 per day. This per day cost has been adjusted to take into account the continued operation of the CSB mission regardless of loss of processing at the CVDF. The adjusted programmatic loss per day is $238,852. This equates to programmatic losses of:

365 days/year x $238,852 /day x 1 year/12 months x 3 months = $ 21,795,245

Note: This is not a covered loss in determinig the Maximum Credible Fire Loss.

Cleanup costs are assumed to be $53.82/m² ($5/ft²) over all room surfaces. The control room is assumed to measure 3.66 m (12 ft) wide by 4.88 (16 ft) long, with 2.44 m (8 ft) high walls, and ceiling tiles. Cleanup costs are:

$$\$53.82/m^2 \times [(2)(3.66)(4.88) + (2)(3.66)(2.44) + (2)(4.88)(2.44)]\ m^2$$

= $ 4,165

Operations Support Area MCFL is calculated to be:

Equipment	$ 150,000
Furnishings	$ 10,000
Cleanup	$ 4,165

Operations Support Area MCFL = $ 164,165

Process Bay and Process Bay Support Areas

The Process Bay and Process Bay Support Areas MCFL involves a tractor fire with bay overhead door open or a transporter tire fire with the bay overhead door closed.

In both cases, the automatic sprinkler system in the affected bay is assumed to initiate to control the fire.

A tractor fire would not spread to transporter tires, as would occur during the MPFL fire scenario due to the installed automatic sprinkler system. The tractor fire would expose adjacent mezzanine supports, one train of the SCHe system, and the 0.25 m (10 in) thick exterior precast concrete panel in the vicinity of the overhead door to intense heat. Due to sprinkler system initiation, the Process Bay walls and roof are not expected to sustain significant damage, and the structural integrity of the bay is not expected to be threatened.

A transporter tire fire would burn beneath the transporter, shielded by the transporter deck. The presence of the transporter deck between the fire and automatic sprinkler spray detrimentally affects the ability of the sprinkler system to suppress this fire. The sprinkler system control and confine the tire fire to the area beneath the transporter. The roof and walls would be protected by water spray from the automatic sprinkler system. Equipment in the vicinity of the burning transporter tires would by damaged and require replacement. Equipment in this vicinity includes adjacent mezzanine supports, one train of the SCHe system, the Process Equipment Skid, and SCIC system.

MCFL is calculated for the transporter tire fire due to the larger potential for damaged equipment and MCO in process status.

The cost to reconstruct one Process Bay is estimated by the FDNW Construction Engineer to be \$ 1,500,000. For an MCFL, the damage to the bay and associated HVAC, utilities, and mezzanine supports, is assumed to be 1/5 of the cost to reconstruct the bay:

Damage to Process Bay	=	(1/5)(\$ 1,500,000)
	=	\$ 300,000

DESH Project Controls have estimated that the cost to replace SCHe, SCIC and the Process Equipment Skid as:

Process Equipment Skid	=	\$ 550,000
One train SCHe	=	(1/2)(\$ \$470,000)
	=	\$ 235,000
SCIC	=	\$ 380,000

Loss of the use of one Process Bay equipment would cause processing to cease in two bays until the affected equipment can be replaced. Redundant trains of SCIC are contained in adjacent Process Bays. This period of downtime is estimated to be six months. The cost to the SNF Project due to loss of continuity is estimated by DESH Project Controls to be \$308,496 per day for four bays. This per day cost has been adjusted to take into account the continued operation of the CSB mission regardless of loss of processing at the CVDF. The adjusted programmatic loss per day is \$238,852

The CVDF requires 3 Process Bays to meet its 2-year commitment for processing the fuel from the K Basins. If two Process Bays are affected by a fire as is claimed by the FHA for the MCFL fire scenario, then the CVDF will be capable of continued operation at 2/3 of the capacity required to meet schedule commitments. This equates to programmatic losses for two bays over six months of:

365 days/year x \$238,852 /day x 1 year/12 months x 6 months x 2 bays/4 bays x 2/3
= \$ 14,530,163

Note: This is not a covered loss in determinig the Maximum Credible Fire Loss.

Cleanup costs are assumed to be \$53.82/m² (\$5/ft²) over all room surfaces. The affected Process Bay measures 9.30 m (30 ft 6 in) wide by 18.30 m (60 ft) long, with 9.75 m (32 ft) high walls, and ceiling. Cleanup costs are:

$$\$53.82/m^2 \times [(2)(9.30)(18.30) + (2)(9.30)(9.75) + (2)(18.30)(9.75)]\ m^2$$

= \$ 47,285

Process Bay and Process Bay Support Area MCFL is calculated to be:

SCHe	\$	235,000
SCIC	\$	380,000
Process Equipment Skid	\$	550,000
Process Bay Damage	\$	300,000
Cleanup	\$	47,285

Process Bay and Process Bay Support Area MCFL = \$ 1,512,285

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Appendix D

HEPA Filter Mass Loading Calculations

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Task

1. Calculate time to reach 5" differential pressure across HEPA filters HVAC-F-8020 and HVAC-F-8040

2. Three (3) Cases

   A. 20 MW tire fire for 25 minutes
   B. 12 MW tire fire for 6 minutes
   C. 400 kW cotton clothing/rubber/trash fire for 90 minutes

Assumptions

1. Smoke density reaching HEPA filters is based on percentage of fuel mass burned to completion divided by process bay volume (smoke is evenly distributed throughout process bay volume)
2. Mass flow rate of smoke reaching HEPA filters is based on smoke density in process bay and nominal flowrate of HVAC system
3. Smoke conversion factor for smoke production from burning tires $\varepsilon = 0.2$ (SFPE Handbook, 1st Ed., Table 1-25.1) which is greater than ε for pyrolysis of rigid polyurethane ($\varepsilon = 0.19$) and for flaming polystyrene ($\varepsilon = 0.17$)
4. Individual smoke particle size for tire fire smoke is 2×10^{-6} m (SFPE Handbook, 1st Ed., Table 1-25.3) which is greater than particle size for pyrolysis of polyurethane (1.8×10^{-6} m) and flaming polyvinylchloride (1.4×10^{-6} m)
5. Cotton clothing/rubber/trash consists of 10% rubber, 60% cotton clothing, and 30% paper

Common Data

1. Volume of process bay (V) = 1668 m³ (18.3 m x 9.3 m x 9.8 m)

2. Smoke particle density (ρ_p) = 1.95 g/cc (amorphous carbon – Lange's Handbook of Chemistry, 13th Edition)

HVAC Unit Data

1. HVAC-F-8020 nominal flowrate = 12,000 CFM (5.7 m³/sec) with 850 CFM (4.01×10^5 cc/sec) taken from affected process bay (H-1-82192 and H-1-82194)
2. HVAC-F-8040 nominal flowrate = 6000 CFM (2.8 m³/sec) with 1300 CFM (6.14×10^5 cc/sec) taken from the affected process bay (H-1-82192 and H-1-82194)
3. Fan data for each HVAC unit is attached
4. HVAC-F-8020 filter cross sectional area = 6 m² (2 m wide x 3 m high); HVAC-F-8040 filter cross sectional area = 3.2 m² (1.4 m wide x 2.3 m high)

Tire Data

1. Heat of Combustion (H_c) for tires = 32.6 MJ/kg (NFPA Handbook, 17th Ed., Table A-3)
2. 12 MW and 20 MW tire fires for 360 seconds and 1500 seconds, respectively
3. Calculated data:

Smoke Density (ρ_s) = $[\varepsilon Qt/H_c]/V$

For 20 MW fire: ρ_s = [(0.2)(20 MW)(1500 seconds)/32.6 MJ/kg]/1668 m³

= 0.110 kg/m³

= $\underline{1.1 \times 10^{-4}\ g/cc}$

For 12 MW fire: ρ_s = [(0.2)(12 MW)(360 seconds)/32.6 MJ/kg]/1668 m³

= 0.016 kg/m³

= $\underline{1.6 \times 10^{-5}\ g/cc}$

Smoke Mass Flowrate (m) = (ρ_s)(contribution to nominal flowrate)

For 20 MW fire:

HVAC-F-8020:

m = $(1.1 \times 10^{-4}$ g/cc$)(4.01 \times 10^{5}$ cc/sec)

= $\underline{44.1\ g/sec}$

HVAC-F-8040:

m = $(1.1 \times 10^{-4}$ g/cc$)(6.14 \times 10^{5}$ cc/sec)

= $\underline{67.5\ g/sec}$

For 12 MW fire:

HVAC-F-8020:

m = $(1.6 \times 10^{-5}$ g/cc$)(4.01 \times 10^{5}$ cc/sec)

= $\underline{6.4\ g/sec}$

HVAC-F-8040:

m = $(1.6 \times 10^{-5}$ g/cc$)(6.14 \times 10^{5}$ cc/sec)

= $\underline{9.8\ g/sec}$

Clothing/Trash Data

1. Cotton clothing/rubber/trash fire smoke particle size is 3×10^{-6} m (SFPE Handbook, 1st Ed., Table 1-25.3, for cellulosic insulation)
2. Heat of Combustion (H_c):

   A. Cotton clothing/paper ≈20.0 MJ/kg (NFPA Handbook, 17th Ed., Table A-3) at 90% of total volume
   B. Heat of Combustion (H_c) for rubber ≈ 35.0 MJ/kg (NFPA Handbook, 17th Ed., Table A-3, buna-N) at 10% of total volume

   Weighted H_c = (.10)(35.0 MJ/kg) + (.90)(20.0 MJ/kg)

   = 21.5 MJ/kg

3. 400 kW cotton clothing/rubber/paper fire duration is 5400 seconds
4. Calculated data:

   Smoke Density (ρ_s) = $[\varepsilon Qt/H_c]/V$

   For 0.4 MW fire: ρ_s = [(0.12)(0.4 MW)(5400 seconds)/21.5 MJ/kg]/1668 m³
   = 7.2×10^{-3} kg/m³
   = 7.2×10^{-6} g/cc

   Smoke Mass Flowrate (m) = (ρ_s)(contribution to nominal flowrate)

   For 0.4 MW fire:

   HVAC-F-8020:

   m = $(7.2 \times 10^{-6}$ g/cc$)(4.01 \times 10^{5}$ cc/sec$)$
   = 2.9 g/sec

   HVAC-F-8040:

   m = $(7.2 \times 10^{-6}$ g/cc$)(6.14 \times 10^{5}$ cc/sec$)$
   = 4.4 g/sec

MASS LOADING OF HEPA FILTERS FOR SYSTEMS HVAC-F-8020 AND HVAC-F-8040

Objective:

Determined the time the HEPA filters for system HVAC-F-8020 AND HVAC-F-8040 will reach a predetermined differential pressure caused by smoke density within the CVDF process bay.

Discussion:

The CVDF process bay could experience three varying fire scenarios.

- 20 MW tire fire for 25 minutes
- 12 MW tire fire for 6 minutes
- 400 kW cotton clothing/ rubber/ trash fire for 90 minutes.

Assumptions and Clarifications:

- Smoke density will be diluted with other airflows from the other exhausted areas within the facility.
- HEPA filter media has 220-ft^2.per filter.
- HEPA filter loading will be based on changing the filter at 5 inches water gage.
- Particle Density (P_ρ) = 1.95 g/cc based on Amorphous carbon (Lange's HANDBOOK of Chemistry 13th edition, page 4-37 Table 4-1)
- Total volumetric airflow for the 8020 systems is 12400 cfm; airflow from the CVDF process bay is 850 cfm, and 2640 ft^2 of HEPA filter media.
- Total volumetric airflow for the 8040 systems is 5200 cfm; airflow from the CVDF process bay is 1300 cfm, and 1320 ft^2 of HEPA filter media.

- Equation use to determine filter loading

$$M/A=(\Delta P-\Delta P_o)\, C P\rho\, D^{2/}V\mu\, (3.06 + 7.56 \times 10^7\, P\rho\, CD^2)$$

M/A= Particle mass loading per unit area.
Pρ=Particle density
D= Particle diameter
ΔP-ΔPo= Difference between initial pressure and finial pressure
C= Cunngingham slip factor: $1+\lambda/D[2.514+0.80^{(-0.55\, D/\lambda)}]$
λ=The mean free path of the gas (0.066μm) at standard conditions
V= Gas velocity through the media
μ= Gas viscosity

References:

1. 21st DOE/NRC NUCLEAR AIR CLEANING CONFERENCE, PAGE 782, TITLED" EFFICIENCY AND MASS LOADING CHARACTISTICS OF A TYPICAL HEPA FILTER.

2. RELATIONSHIP BETWEEN THE PRESSURE DROP ACROSS THE SAVANNAH RIVER SITE'S HEPA FILTER MATERIAL AND AEROSOL MASS LOADING (U) (WSRC-RP-90-779)

Given:

Other data provided was, the particle diameter (DIA (m)) , and the mass flow rate in grams per minute. The particle density as stated in the above assumptions is a constant in all cases.

SYSTEM	FIRE	DIA (m)	MASS FLOW grams/m)	TOTAL FILTER AREA Ft^2	TIME IN HOURS To Reach 5" wg
8020	20 MW	.0002	44.1	2640	3
8020	12 MW	.0002	6.40	2640	21
8020	.40MW	.0003	2.90	2640	57
8040	20 MW	.0002	67.5	1320	0.32
8040	12 MW	.0002	9.8	1320	2
8040	.40MW	.0003	4.40	1320	6

Conclusions:

The above table shows the time in hours to reach a differential pressure of 5"wg, The least amount of time is for the 8040 system with the 20 MW fire at 0.32 hours or approximately 19 minutes, and is cause by the larger amount of gram per minute (67.5 g/m) introduced into the airstream. The greatest amount of time to reach 5" wg is the 8020 system with the 0.4MW fire at 57 hours, with 2.9 g/m introduced into the airstream.

Appendix E
Effect of Fire on Cask-MCO

RESULTS OF TIRE FIRE AT CVDF WITH DOOR CLOSED

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INTRODUCTION

The effects of fires on the MCO under various conditions at the CVDF were modeled with version 1.31 of the HANSF code (SNF-3650). Four fire/MCO scenarios were modeled. The thermal model used in briefly described in the next section. Each scenario is described in the following sections with the results for each scenario given. The temperature and pressure plots are shown for each case at the end. Conclusions are also presented.

THERMAL MODEL

The HANSF (Hanford Spent Fuel) computer code (SNF-3650) was used to model the effects of fires on the MCO under several conditions at the CVDF. The thermal model in the code includes thermal radiation, conduction and natural convection heat transfer processes. The heat from the environment outside of the cask/MCO (under fire conditions) transfers into the cask surfaces (bottom, walls and cover when attached) and the top of the MCO if cask cover is removed, to the MCO through the annulus water, into the MCO to the fuel and gas. The fuel itself has decay heat and chemical heat from the chemical reaction with water, both of which will heat the inside of MCO. The cask wall is about 7 in. thick of stainless steel. The annulus gap between the cask and MCO is about 0.6 in. thick and contains water at the CVDF until the cask is ready for shipping to CSB. In the fuel baskets, each fuel assembly has its own radiation view factor to the MCO wall and to the center post of the MCO for thermal radiation heat transfer. Also, micro convection heat transfer is included the thermal model for heat transfer between each inner and outer fuel element of each fuel assembly and between the fuel assemblies themselves. The scrap basket heat transfer model includes conduction and radiation in the scrap, conduction from the scrap fuel to the copper fin with micro convection and radiation heat transfer from the outer fin to the MCO wall. Radiation and natural convection heat transfer from the top and bottom scrap baskets to the inner MCO shield plug (lid) and to the MCO floor (bottom), respectively, is included. An emissivity of 1.0 was assigned to all of the outer boundaries of cask and top of MCO shield plug when cask lid is removed, in order to simulate a black surface due to deposits of black carbon from the fire. The high emissivity value of 1.0 enhances the heat transfer from the bay into the fire.

The MCO is a nominal MCO with two scrap baskets. Nominal MCO properties are documented in the data technical handbook (HNF-TI-015). The most important parameters for thermal effects are the reaction surface areas (1.7 m^2 per scrap basket and 0.425 m^2 per fuel basket for a total of 4.675 m^2 per MCO) and reaction rate multipliers of 3 for the water-uranium reaction and 12 for the water-uranium hydride reaction. The decay power for five nominal fuel baskets is 403 watts.

SCENARIO BOUNDARY and INITIAL CONDITIONS

Two main fire conditions were applied to various MCO conditions at the CVDF. The calculations of two fire conditions and fire scenarios are described in SNF-4268 (1999) and are summarized in the following:

1) Lumped Tractor and Transporter Fire – The lumped tractor and transporter fire has the tractor fuel and transporter tires burning at the same time, which results in higher temperatures than other fires. The bay temperature rapidly increases to a peak value of about 850 C at about 25 minutes after the start of the fire. The CVDF bay door is open which causes a more rapid cooling than in the 'tire only' fire condition (described below) which has a closed bay door. One hour after the start of the fire, the bay gas temperature around the MCO is already down to about 67 C.

2) Tire Only Fire – The transporter tires in the CVDF process bay ignite and the bay temperature increases rapidly and peaks at 665 C in about 20 minutes after the start of the fire. The bay temperature decreases rapidly after the fire is out, but is still 90 C about 5 hours after the start of the fire. The CVDF bay door is closed which is the main reason that the bay temperature does not reach normal temperatures after the fire is out.

The MCO responses to the fire conditions above were modeled with the HANSF code (SNF-3650). The following four MCO conditions were examined:

a) Closed MCO Filled with Water, Closed Cask - The nominal MCO is closed with about 500 kg of water, and the cask lid is still on top. The initial temperature of the MCO fuel and water is 35 C. This temperature was also assumed for the cask and annulus water in the gap between MCO and cask.

b) Closed MCO Filled with Water, Open Cask – The nominal MCO is closed with about 500 kg of water, and the cask lid has been removed. The initial temperature of the MCO fuel, water and cask is 35 C.

c) Open MCO Filled with Water – The nominal MCO is open and process lines are connected, but the draining process has yet started. The heat up process is complete with the MCO fuel and water at 50 C.

d) Open Drained MCO – The nominal MCO is drained with about 11 kg of residual water remaining. The process lines are connected, but the vacuum cycle has not started. The initial temperature of MCO fuel and water is 50 C.

CASES ANALYZED

The following four cases, which include combinations of the above boundary and initial conditions, were analyzed:

1) Closed Cask with Lumped Tractor/Transporter Fire (1a, CFIREX2) – This case simulates the scenario of a Cask/MCO being received in the process bay with the bay door open and the tractor

still attached. A fuel leak causes a fire to start, burning the tractor fuel and transporter tires. This case combines fire condition 1 with MCO condition a above.

2) Closed MCO Filled with Water and Tire Only Fire (2b, CFIREX3N) – This case simulates the scenario of a Cask/MCO received in the process bay, the tractor is gone and the bay door is closed when the tire fire starts. The cask lid is removed, but the MCO is still closed and, thus, is not drained or heated yet. This case combines fire condition 2 with MCO condition b above.

3) Open MCO Filled with Water and Tire Only Fire (2c, CFIREX4) – This case simulates the scenario of a nominal MCO in the process bay with process lines connected and the MCO heated up to 50 C, but draining has not yet started when the tire fire starts. The fire burns the rubber in the flex hoses, creating an MCO open to the process bay. Since the MCO is filled with water, only the upper MCO is open to the process bay, since the water in the MCO will block gas flow through the long dip tube. This case combines fire condition 2 with MCO condition c above.

4) Open Drained MCO with Tire Only Fire (2d, CFIREX6) – This case simulates the scenario of a nominal MCO in the process bay with process lines connected and draining is complete, leaving about 11 kg of residual water in the MCO when the fire starts. The fire burns the rubber in the stainless steel flex hoses, creating an MCO open to the process bay with two orifices. Since the MCO is drained, the long dip tube permits gas flow to or from the bottom of the MCO. This case combines fire condition 2 with MCO condition d above.

Even though a fire is not expected to cause the annulus water to leak out (due to double casing), cases 2, 3 and 4 were also analyzed with the MCO-cask annulus water gone (in other words, only air in the annulus). Results are given below.

RESULTS OF CASES

The temperature and pressure responses of the nominal MCO due to the fire are described for each case:

1) Closed Cask/MCO with Lumped Tractor/Transporter Fire (2a, CFIREX2) – The maximum fuel temperatures stay below 90 C with the cask pressure surpassing 150 lb/in^2 gauge in about 3.5 hours. There is no thermal runaway. The hydrogen gas in the cask and MCO at this time is about 32 grams or about 360 liters (STP). Since there is some margin in the cask design pressure, it is difficult to estimate how much hydrogen is released if any. Hence, the hydrogen release rate was not estimated here, but could be postulated to release very quickly. Another 32 grams of hydrogen is generated over the next 4.5 hours out to 8 hours, causing the pressure to increase to about 300 lb/in^2 gauge. Since the MCO is filled with water, no particulate mass, with radionuclides, are released. Due to the tortuous path in the MCO shield plug, very little liquid water is released. See attached graphs for time history of temperatures and pressure.

2) Closed MCO Filled with Water and Tire Only Fire (2b, CFIREX3N) - The maximum fuel temperatures stay below 85 C and are steady. There is no thermal runaway with the nominal closed MCO with a tire fire in the bay. There is no thermal runaway. However, the pressure inside the MCO does exceed 150 lb/in^2 gauge in less than 3.5 hours. Hence, the 150 lb/in^2 rupture disk will

burst open and release the hydrogen gas contained in the closed MCO. The amount of hydrogen gas in the MCO at the time of the blowdown is about 20 grams; most of hydrogen enters the process bay in less than 10 seconds. Since the MCO is full of non-boiling water, there will be no release of particulate mass. Very little liquid water is released since the path through the MCO shield plug to the rupture disk orifice is very tortuous. The high MCO pressure is mainly due to hydrogen production from the fuel-water reactions. . See attached graphs for time history of temperatures and pressure.

3) Open MCO Filled with Water and Tire Only Fire (2c, CFIREX4) - The maximum fuel temperatures stay below 90 C, except for the bottom scrap basket peak fuel temperature which reaches 92 C. There is no thermal runaway. There is no pressurization since the MCO is open. About 2.7 grams of hydrogen or 30 liters (STP) are released in to the process bay during the first hour. The amount of hydrogen released during the first 8 hours is less than 70 grams or 780 liters (STP). The average hydrogen release rate is about 9.1 grams per hour or about 100 L/hr (STP) with the peak release rate about 20 g/hr happening at 3 hours. Since oxygen will flow counter current to the gases exiting the MCO, flammability conditions are reached in the MCO. Initially, oxygen enters very quickly, but hydrogen concentration is very low. After about 1.5 hours, the hydrogen mole fraction has increased to 10% and the oxygen mole fraction has decreased to 10%. The hydrogen continues to increase to about 24% at 3 hours when the oxygen mole fraction is down to 3%, which is out of the flammability range. Even though there is some time (< 1 hour) for flammability conditions, any hydrogen deflagration will be minimal because the amount of hydrogen is so small (maximum of 0.14 g at 3 hours and only 0.06 g at 1.75 hours) and is located above the water and particulate. See attached graphs for time history of temperatures, pressure, hydrogen release and gas concentrations.

4) Open Drained MCO with Tire Only Fire (2d, CFIREX6) – The maximum fuel temperatures stay below 91 C up to 8 hours and are stable, except for the top scrap basket peak fuel temperature which reaches 96 C in 8 hours. There is no thermal runaway. Only 0.15 grams of hydrogen is released into the process bay during the first hour. About 10 grams of hydrogen is released during the first 8 hours for an average release rate of about 1.2 grams per hour or about 13.5 L/hr (STP). The peak release rate is 1.9 g/hr or 21.3 L/hr (STP) at the end of the 8 hour time period. See attached graphs for time history of temperatures, pressure, and hydrogen release.

   As previously mentioned, cases 2, 3, and 4 were simulated without annulus water. Without annulus water (between MCO and cask), less heat from the fire enters the MCO. As a result, the MCO fuel temperatures are cooler by about 25 to 40 C, causing the peak pressure in case 3 to be only 75 lb/in^2 gauge at 8 hours. The cooler temperatures also decrease the hydrogen generation rate. The cases with the annulus water clearly bound the cases without annulus water in regards to temperature, pressure and hydrogen production.

SUMMARY and CONCLUSIONS

The high pressure scenarios (cases 1 and 2) appear to bound the MCO response to the fire conditions described in SNF-4268 (1999). Since the fuel temperatures do not increase above 96 C in all four cases, high fuel temperatures are not a concern. There are no thermal runaways. The high pressures in cases 1 and 2 surpass the design pressure of 150 lb/in^2 gauge for the closed cask and closed MCO, respectively. Since there is some margin in the cask design pressure, the closed MCO with its 150 lb/in^2 rupture disk is chosen as the most bounding MCO in response to a fire. If the MCO is drained, the hydrogen generation rate decreases (case 4 versus case 3), mainly because the drained MCO has two orifices such that natural circulation can take place. Natural circulation causes oxygen to enter the MCO, and oxygen poisons the uranium-water reaction and hydrogen generation. Case 3 is the only case that has internal hydrogen flammability conditions, but any hydrogen deflagration in this case would be minimal and not result in particulate release.

In summary, the fuel temperatures in a nominal MCO are stable for all fire scenarios analyzed at the CVDF. MCO pressure exceeds 150 lb/in^2 gauge when the vessel (either MCO or cask) is closed and filled with water, resulting in hydrogen being released during the blowdown, but not particulate. Furthermore, the time to reach high pressures in the MCO or cask is about 3.5 hours, which allows some time for some corrective action to take place.

REFERENCES

SNF-3650: Plys, M., S. Lee, B. Malinovic, M. Epstein & D. Duncan, 1999, "HANSF 1.3 User's Manual", SNF-3650, Rev 1, Fluor Daniel Hanford, Richland, Washington.

SNF-4268: Johnson, B., 1999, "Fire Hazard Analysis for the Cold Vacuum Drying Facility", SNF-4268, Rev 0, Fluor Daniel Hanford, Richland, Washington

TI-015: Reilly, M.A., 1998, "Spent Nuclear Fuel Project Technical Databook", HNF-SD-SNF-TI-015, Rev 6, Fluor Daniel Hanford, Richland, Washington

Appendix F
Figures

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Appendix G
NRC Equivalency Evaluation

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NRC Equivalency Evaluation

Table 1, Item 1, of WHC-SD-SNF-DB-003, Rev. 4A, *Spent Nuclear Fuel Project Path Forward Additional NRC Requirements*, states:

"The final designs of the CSB and CVD facility shall be reevaluated to reconfirm that DOE Orders 5480.7A and 6430.1A provide adequate fire protection requirements to achieve nuclear safety equivalence. Aspects of the designs to reconfirm are the use of a passive cooling system for MCO cooling in the CSB and the lack of safety-class prevention or mitigation systems in the CSB and CVD facility. For additional information refer to WHC-SD-SNF-DB-002, *Spent Nuclear Fuel Project Path Forward Nuclear Safety Equivalency to Comparable NRC-Licensed Facilities*, Table 5.b, and 10 CFR 50.48, and 10 CFR 50, Appendix R. Further, fire protection requirements considered for incorporation into the design of the CSB and CVD facility should take into account the implementation of 10 CFR 72.122(c) to date for licensed independent spent fuel storage installations."

Regarding the Cold Vacuum Drying Facility (CVDF), the discussion of Table 5.b, WHC-SD-SNF-DB-002, *Spent Nuclear Fuel Project Path Forward Nuclear Safety Equivalency to Comparable NRC-Licensed Facilities*, Rev. 2, states that:

" . . . there is not an equivalent to the power reactor requirement of achieving hot and cold shutdown. However, there are analogous situations to maintaining cold shutdown and minimizing radioactive releases to the environment. They are maintaining MCO cooling and integrity."

Process recommendations that would result in features important to fire protection in the CVDF are identified by WHC-SD-SNF-DB-002:

"• Water will be drained from the MCOs and the fuel will be vacuum dried at low temperatures (-50°C) by the CVDS. This will allow for shipment and staging of fuel with little free water present."

Further, WHC-SD-SNF-DB-002 states:

"The importance of these recommendations to fire protection equivalency is that they lead to a CSB that will not be sensitive to loss of MCO cooling from fire. This situation may exist for other new SNF Project Path Forward facilities."

Three differences between the fire protection requirements of 10 CFR 50, Appendix R and DOE Orders 5480.7A *Fire Protection* and 6430.1A *General Design Criteria* are identified by WHC-SD-SNF-DB-002 as:

"• Appendix R requires a three-hour barrier between safe shutdown paths and DOE Orders 5480.7A and 6430.1A require a two-hour barrier between redundant safety class equipment.

- Appendix R requires emergency lighting of at least 8-hour duration in all areas needed for operation of safe shutdown equipment and in access and egress routes. DOE Order 5480.7A relies on the NFPA *Life Safety Code*, which requires 1½-hour lighting to facilitate egress.

- Appendix R establishes more specific requirements for the testing of fire penetration seals than DOE Orders 5480.7A and 6430.1A."

WHC-SD-SNF-DB-002 concludes that:

"For the new SNF Project Path Forward facilities as currently defined and discussed above, the fire protection requirements of DOE Orders 5480.7A and 6430.1A should provide adequate fire protection in consideration of §50.48 and §72.122(c)."

The Actions for Consideration, listed in WHC-SD-SNF-DB-002, include:

"Consideration should be given to following the evolving designs of the new SNF Project Path Forward facilities to reconfirm that DOE Orders 5480.7A and 6430.1A provide adequate fire protection requirements to achieve nuclear safety equivalency. Aspects of the designs to reconfirm are the use of a passive cooling system for MCO cooling in the CSB and the lack of Safety Class 1 prevention and/or mitigation systems in the CSB. The need for Safety Class 1 systems for the CVDS and HCS remains to be determined. Further, fire protection requirements considered for incorporation into the design of the new SNF Project Path Forward facilities should take into account the implementation of §72.122(c) to date for licensed ISFSIs."

In response to the Actions for Consideration and other discussion contained in WHC-SD-SNF-DB-002, NRC fire protection requirements contained in

(1) 10 CFR 50, Appendix A,
(2) 10 CFR 50.48,
(3) 10 CFR 50, Appendix R,
(4) 10 CFR 72.122(c), and
(5) Branch Technical Position (BTP) CMEB 9.5-1,

as they may apply to the CVDF, are sampled and evaluated against DOE 5480.7A and 6430.1A requirements in the following table:

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
<u>10 CFR Appendix A – General Design Criteria for Nuclear Power Plants</u>	<u>DOE 6430.1A – General Design Criteria</u>	
Criterion 3 -- Fire protection.	*Section 1530-99.0 – Non-Reactor Nuclear Facilities General*	
Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions.	To ensure that redundant safety class components shall be capable of performing the necessary safety functions, the facility design shall provide appropriate separation against fire, explosion, and failure of fire suppression systems.	Equivalent
Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room.	Wherever practical, *special facilities* shall be designed and constructed using building components of fire-resistant and noncombustible material, particularly in locations vital to the functioning of confinement systems.	Equivalent
Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety.	A fire protection engineer or person knowledgeable in applying the principles of fire protection shall develop the fire protection system. To maximize the protection against fire, the system shall contain an appropriate integration of fire prevention, detection, and suppression features.	Equivalent
Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.	The operation or failure of a fire protection system that interfaces with a safety class system, such as a safety class water system, shall not prevent the safety class system from completing its safety functions when required.	Equivalent

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
10 CFR 50.48 – Fire Protection	DOE 5480.7A – Fire Protection *Paragraphs 9, 9.a, 9.b, and 9.c*	
(a) Each operating nuclear power plant must have a fire protection plan that satisfies Criterion 3 of appendix A of this part. This fire protection plan must describe the overall fire protection program for the facility, identify the various positions within the licensee's organization that are responsible for the program, state the authorities that are delegated to each of these positions to implement those responsibilities, and outline the plans for fire protection, fire detection and suppression capability, and limitation of fire damage. The plan must also describe specific features necessary to implement the program described above, such as administrative controls and personnel requirements for fire prevention and manual fire suppression activities, automatic and manually operated fire detection and suppression systems, and the means to limit fire damage to structures, systems, or components important to safety so that the capability to safely shut down the plant is ensured[3] . . . [3] Basic fire protection guidance for nuclear power plants is contained in two NRC documents: •Branch Technical Position Auxiliary Power	9. DOE FIRE PROTECTION PROGRAM REQUIREMENTS ". . . the DOE Fire Protection Program shall meet or exceed the minimum requirements established by the National Fire Protection Association . . . Basic requirements shall include: a reliable water supply or acceptable capacity for fire suppression; noncombustible construction of an acceptable nature for the occupancy of the facility; automatic fire extinguishing systems; a fully staffed, trained, and equipped emergency response force; a means to summon the emergency response force in the event of a fire; and a means to notify and evacuate building occupants in the event of a fire. . ." a. Programmatic Elements – Fire protection programs shall incorporate the following elements to ensure that the objectives of	Equivalent

CVDF Fire Protection NRC Equivalency Assessment		
NRC Requirement	DOE Requirement	Equivalency Determination
Conversion System Branch BTP APCSB 9.5 - 1, "Guidelines for Fire Protection for Nuclear Power Plants," for new plants docketed after July 1, 1976, dated May 1976. •Appendix A to BTP APCSB 9.5 - 1, "Guidelines for Fire Protection for Nuclear Power Plants Docketed Prior to July 1, 1976," for plants that were operating or under various stages of design or construction before July 1, 1976, dated August 23, 1976.	paragraph 4 are met: (1) <u>Fire Protection Criteria</u> – A documented "Fire Protection Program" which includes: (a) A statement of management commitment to achieve the above stated objectives, (b) A policy statement that implements this Order and other DOE fire protection related mandatory codes and standards, (c) Fire protection criteria that reflect site specific aspects of the fire protection program including: the organization and responsibilities of the fire protection staff, administrative aspects of the fire protection program, and requirements for physical fire protection features. (2) <u>Assessments</u> – Documented evaluations of the fire protection program, including field walkdowns of facilities, . . . (3) <u>Fire Hazards Analysis</u> – The purpose of a fire hazards analysis (FHA) is to comprehensively assess the risk from fire within individual fire areas in a DOE facility in relation to existing or proposed fire protection so as to ascertain	

CVDF Fire Protection NRC Equivalency Assessment		
NRC Requirement	DOE Requirement	Equivalency Determination
	whether the objectives of paragraph 4 are met. b. <u>Physical Features of the Program</u> – DOE facilities shall incorporate the following elements to assure that the objectives of paragraph 4 are met: (Physical Features of the Program that are addressed by DOE Order 5480.7A are listed but amplifying text is not reproduced – see DOE Order 5480.7A for a complete discussion of each feature) (1) Safety Class Equipment (2) Life Safety (3) Automatic Fire Protection (4) Redundant Fire Protection (5) Testing and Maintenance (6) Quality Construction (7) Fire Department (8) Fire Protection Water Supply (9) Underground Piping (10)Liquid Run-off Control (11)Fire Alarm Systems (12)Containment Systems for Ventilation (13)Special Hazard Protection (14)Halon Usage (15)Seismic Criteria (16)Impairment Control (17)Higher Standard of Protection c. <u>Administrative Features of the Program</u> – (Administrative Features of the Program that are addressed DOE Order 5480.7A are listed but not accompanying text is not reproduced – see DOE Order 5480.7A for a complete discussion of each feature)	

CVDF Fire Protection NRC Equivalency Assessment		
NRC Requirement	DOE Requirement	Equivalency Determination
	(1) Fire Prevention Procedures (2) Assessment Results Tracking Program (3) Interim Compensatory Measures (4) Operability Specifications (5) Emergency Planning (6) Training (7) Communications	
<u>CFR 50.48 – Fire Protection</u> (b) Appendix R to this part establishes fire protection features required to satisfy Criterion 3 of appendix A to this part with respect to certain generic issues for nuclear power plants licensed to operate prior to January 1, 1979. Except for the requirements of sections III.G, III.J, and III.O, the provisions of appendix R to	See DOE requirements equivalent to NRC Appendix R sections III.G, III.J, III.O, and BTP 9.5-1 below.	NRC Appendix R equivalency not applicable to CVDF except for sections III.G, III.J, III.O, and BTP 9.5-1 since CVDF not licensed to operate prior to January 1, 1979. See equivalency determination for applicable sections below.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
this part shall not be applicable to nuclear power plants licensed to operate prior to January 1, 1979, to the extent that fire protection features proposed or implemented by the licensee have been accepted by the NRC staff as satisfying the provisions of appendix A to Branch Technical Position BTP APCSB 9.5 - 1(4) reflected in staff fire protection safety evaluation reports issued prior to the effective date of this rule, or to the extent that fire protection features were accepted by the staff in comprehensive fire protection safety evaluation reports issued before appendix A to Branch Technical Position BTP APCSB 9.5 - 1 was published in August 1976. With respect to all other fire protection features covered by appendix R, all nuclear power plants licensed to operate prior to January 1, 1979 shall satisfy the applicable requirements of appendix R to this part, including specifically the requirements of sections III.G, III.J, and III.O.		
<u>10 CFR 50 – Appendix R – Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979</u> III.G. *Fire protection of safe shutdown capability.* 1. Fire protection features shall be provided for structures, systems, and components important to safe shutdown. These features shall be capable of limiting fire damage so that:		

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
a. One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage; and	Achieving and maintaining hot shutdown is analogous to maintaining MCO cooling at the CVDF. <u>DOE Order 6430.1A – *General Design Criteria*, section 1530-99.0</u>: To ensure that redundant safety class components shall be capable of performing the necessary safety functions, the facility design shall provide appropriate separation against fire, explosion, and failure of fire suppression systems. DOE Order 5480.7A – Fire Protection, paragraph 9.b <u>Physical Features of the Program</u>: (1) <u>Safety Class Equipment</u> – . . . For new facilities, redundant Safety Class Equipment shall be located in separate fire areas. Fire suppression systems shall be designed such that their actuation will not damage safety class equipment or cause a criticality event.	Equivalent.
b. Systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) can be repaired within 72 hours.	DOE criteria does not allow for human interaction. Actual time period to onset of MCO thermal runaway or H_2 release accidents addressed in the CVDF SAR is less than 72 hours – i.e., action is required to be taken sooner than 72 hours to protect integrity of MCO.	Equivalent (DOE requirement is more restrictive). Ability to take actions to repair systems to protect MCO integrity within specified time period is not known. Cooling of MCO to protect integrity in the event that all mitigating safety systems are lost and cannot be repaired is available by applying a hose stream to the cask exterior.
2. Except as provided for in paragraph G.3 of this section, where cables or equipment, including associated non-safety circuits that could prevent operation or cause maloperation due to hot shorts, open circuits, or shorts to ground, of	Achieving and maintaining hot shutdown is analogous to maintaining MCO cooling at the CVDF. <u>DOE Order 6430.1A – General Design Criteria:</u>	Equivalent.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
redundant trains of systems necessary to achieve and maintain hot shutdown conditions are located within the same fire area outside of primary containment, one of the following means of ensuring that one of the redundant trains is free of fire damage shall be provided:	Section 1530-99.0: To ensure that redundant safety class components shall be capable of performing the necessary safety functions, the facility design shall provide appropriate separation against fire, explosion, and failure of fire suppression systems.	
a. Separation of cables and equipment and associated non-safety circuits of redundant trains by a fire barrier having a 3-hour rating. Structural steel forming a part of or supporting such fire barriers shall be protected to provide fire resistance equivalent to that required of the barrier; b. Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance of more than 20 feet with no intervening combustible or fire hazards. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area; or	Section 0110-99.0.6 - Fire Resistance: Development of the DBF shall include consideration of conditions that may exist during normal operations and special situations (e.g., during periods of decontamination, renovation, modification, repair, and maintenance). The structural shell surrounding the critical areas and their supporting members shall remain standing and continue to act as a confinement structure during the DBF under conditions of failure of any fire suppression system not designed as a safety class item. Fire resistance of this shell shall be attained by an integral part of the structure (concrete slabs, walls, beams, and columns) and not by a composite assembly (membrane fireproofing). In no event	
c. Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour rating, In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area;	shall the fire resistance rating be less than two hours under conditions of failure of any fire suppression system not designed as a safety class item. Penetrations in this shell shall incorporate, as a minimum, protection against DBF exposures unless greater protection is required by other sections of these criteria.	
Inside noninerted containments one of the fire protection means specified above or one of the following fire protection means shall be provided:	<u>DOE Order 5480.7A – Fire Protection</u>: Paragraph 9.b <u>Physical Features of the Program</u>:	
d. Separation of cables and equipment and associated non-safety circuits of redundant	(1) Safety Class Equipment – . . . For new facilities, redundant Safety Class Equipment	

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
trains by a horizontal distance of more than 20 feet with no intervening combustibles or fire hazards; e. Installation of fire detectors and an automatic fire suppression system in the fire area; or f. Separation of cables and equipment and associated non-safety circuits of redundant trains by a noncombustible radiant energy shield.	shall be located in separate fire areas. Fire suppression systems shall be designed such that their actuation will not damage safety class equipment or cause a criticality event. (4) Redundant Fire Protection – (b) When MPFL exceeds $150 million, a redundant fire protection system and a 3-hour fire barrier are required to limit the maximum possible loss to $150 million. Fire barrier rating is dependent on MPFL and conditions that may exist resulting from a fire. FHA determines fire barrier rating.	
3. Alternative or dedicated shutdown capability and its associated circuits,(2) independent of cables, systems or components in the area, room or zone under consideration, shall be provided:		
a. Where the protection of systems whose *function is required for hot shutdown does* not satisfy the requirement of paragraph G.2 of this section; or	See response to G.2.	Equivalent. DOE requirements are equivalent to paragraph G.2.
b. Where redundant trains of systems required for hot shutdown located in the same fire area may be subject to damage from fire suppression activities or from the rupture or inadvertent operation of fire suppression systems.	<u>DOE 6430.1A, General Design Criteria</u>: Section 1530-99.0: Fire protection systems shall not: (1) prevent a facility from achieving and maintaining a safe shutdown condition, (2) prevent the mitigation of DBA consequences, or (3)	Equivalent.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
In addition, fire detection and a fixed fire suppression system shall be installed in the area, room, or zone under consideration.	cause an inadvertent nuclear criticality. <u>DOE Order 5480.7A – Fire Protection</u>: Paragraph 9.b <u>Physical Features of the Program</u>: Safety Class Equipment – In areas where a fire could cause damage to safety class equipment and where no redundant safety capability exists, a redundant fire protection system shall be provided for the safety class equipment. For new facilities, redundant Safety Class Equipment shall be located in separate fire areas. Fire suppression systems shall be designed such that their actuation will not damage safety class equipment or cause a criticality event.	
<u>10 CFR 50 – Appendix R – Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979</u> III.J. *Emergency lighting*. Emergency lighting units with at least an 8-hour battery power supply shall be provided in all areas needed for operation of safe shutdown equipment and in access and egress routes thereto	<u>DOE 6430.1A – General Design Criteria</u> <u>1300-2.4.3 Environmental Considerations Emergency Lighting</u> Emergency lighting systems shall be provided as required by NFPA 101. A control room emergency lighting system shall be automatically activated and immediately available for a stated minimum length of time on failure of the normal lighting system. The emergency lighting system for vital areas shall be an electrically independent system that is not degraded by failure of the normal lighting system. Control room emergency lighting levels shall be in accordance with NUREG 0700, Section 6.1.5.4.	Equivalent. 8-hour battery power supply in commercial nuclear facility is to ensure egress and <u>access</u> to vital plant equipment. NFPA 101 criteria (90 minutes) is for egress only. DOE criteria for control room lighting or for lighting to vital areas is not necessarily determined by NFPA 101 – "a stated minimum length of time". For other vital DOE plant areas, DOE requires an "electrically independent system".

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
<u>10 CFR 50 – Appendix R – Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979</u> III.O. *Oil Collection System for Reactor Coolant Pump*	Not applicable to CVDF (no oil in reactor coolant pumps)	Not applicable to CVDF (no oil in reactor coolant pumps)
<u>NRC Branch Technical Position (BTP) 9.5-1 FIRE PROTECTION PROGRAM</u> BTP addresses fire protection programs for safety-related systems and equipment and for other plant areas containing fire hazards that could adversely affect safety-related systems.	<u>DOE Order 6430.1A – General Design Criteria</u> DOE 6430.1A Section 1530 – Fire Protection addresses fire protection requirements in terms of "improved risk" concept based on maximum possible fire loss. Fire protection for nuclear facilities are addressed in 1530-99.0.	NRC BTP 9.5-1 places all emphasis on fire protection for safety-related SSCs. DOE 6430.1A and 5480.7A place emphasis and base fire protection related decisions on potential for property loss, life safety, and protection of safety class SSCs. NRC BTP 9.5-1 goes into much more detail regarding protection of safety related SSCs than does DOE 6430.1A and 5480.7A.
Defense-in-Depth approach: 1. Preventing fires from starting; 2. Detecting fires quickly, suppressing those fires that do occur, putting them out quickly, and limiting their damage; and	DOE Order 5480.7A – Fire Protection OBJECTIVES: 1. Minimize the potential for occurrence of a fire 2. Ensure that fire does not cause an on-site or off-site release of radiological and other hazardous material that will threaten the public	NRC Defense-in-Depth approach and DOE Fire Protection Objectives are Equivalent.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
3. Designing plant safety systems so that a fire that starts in spite of the fire prevention program and burns for a considerable time in spite of fire protection activities will not prevent essential plant safety functions from being performed.	health and safety or the environment 3. Establish requirements that will provide an acceptable degree of life safety to DOE and contractor personnel and that there are no undue hazards to the public from fire and its effects in DOE facilities 4. Ensure that process control and safety systems are not damaged by fire or related perils 5. Ensure that vital DOE programs will not suffer unacceptable delays as a result of fire and its effects 6. Ensure that property damage from fire and related perils does not exceed an acceptable level.	
C. POSITION	DOE Order 5480.7A – Fire Protection contains requirements for:	
1. Fire Protection Program Requirements a) Fire Protection Program b) Fire Hazards Analysis c) Fire Suppression System Design Basis d) Alternative or Dedicated Shutdown e) Implementation of Fire Protection Programs 2. Administrative Controls 3. Fire Brigade 4. Quality Assurance Program 5. General Plant Guidelines 1. Building Design 2. Safe Shutdown Capability 3. Alternative or Dedicated Shutdown Capability	9. Fire Protection Program Requirements – a. Programmatic elements 1) Fire Protection Criteria 2) Assessments 3) Fire Hazards Analyses b. Physical Features of the Program 1) Safety Class Equipment 2) Life Safety 3) Automatic Fire Protection 4) Redundant Fire Protection 5) Testing and Maintenance 6) Quality Construction 7) Fire Department 8) Fire Protection Water Supply 9) Underground Piping 10) Liquid Run-off Control 11) Fire Alarm Systems 12) Containment Systems for Ventilation	NRC BTP 9.5-1 places all emphasis on fire protection for safety-related SSCs. DOE 6430.1A and 5480.7A place emphasis and base fire protection related decisions on potential for property loss, life safety, and protection of safety class SSCs. NRC BTP 9.5-1 goes into much more detail regarding protection of safety related SSCs than does DOE 6430.1A and 5480.7A. NRC BTP 9.5-1 is specific and applicable to commercial nuclear reactors with the potential for much more severe consequences to the public resulting from a fire caused accident than would result from fire at CVDF. Conclusion: 1. The NRC fire protection program based on BTP 9.5-1 meets or exceeds DOE requirements

CVDF Fire Protection NRC Equivalency Assessment		
NRC Requirement	DOE Requirement	Equivalency Determination
4. Control of Combustibles 5. Electrical Cable Construction, Cable Trays, and Cable Penetrations 6. Ventilation 7. Lighting and Communication 6. Fire Detection and Suppression a) Fire Detection b) Fire Protection Water Supply Systems c) Water Sprinkler and Hose Standpipe Systems d) Halon Suppression Systems e) Carbon Dioxide Suppression Systems f) Portable Extinguishers 7. Guidelines for Specific Plant Areas a) Primary and Secondary Containment b) Control Room Complex c) Cable Spreading Room d) Plant Computer Rooms e) Switchgear Rooms f) Remote Safety-Related Panels g) Safety-Related Battery Rooms h) Turbine Building i) Diesel Generator Areas j) Diesel Fuel Oil Storage Areas k) Safety-Related Pumps l) New Fuel Area m) Spent Fuel Pool Area n) Radwaste and Decontamination Areas o) Safety-Related Water Tanks p) Records Storage Areas q) Cooling Towers r) Miscellaneous Areas 8. Special Protection Guidelines a) Storage of Acetylene-Oxygen Fuel Gases b) Storage Areas for Ion Exchange Resins	13) Special Hazard Protection 14) Halon Usage 15) Seismic Criteria 16) Impairment Control 17) Higher Standard of Protection c. Administrative Features of the Program 1) Fire Prevention Procedures 2) Assessment Results Tracking Program 3) Interim Compensatory Measures 4) Operability Specifications 5) Emergency Planning 6) Training 7) Communications	for protection of SSCs at a nuclear facility. 2. The DOE fire protection program based on DOE 6430.1A and 5480.7A does not meet the fire protection program standards of an NRC licensed commercial nuclear facility. 3. Taking a graded approach, considering CVDF's small-scale operation when compared to that of a commercial nuclear power plant, the DOE Fire Protection Program is equivalent to the NRC Fire Protection Program.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
c) Hazardous Chemicals d) Materials Containing Radioactivity		
<u>10 CFR 72 – Licensing Requirements for Independent Storage or Spent Nuclear Fuel and High Level Radioactive Waste</u> <u>10 CFR 72.122 Overall Requirements</u> c. *Protection against fires and explosions.* Structures, systems, and components important to safety must be designed and located so that they can continue to perform their safety functions effectively under credible fire and explosion exposure conditions. Noncombustible and heat-resistant materials must be used wherever practical throughout the ISFSI or MRS, particularly in locations vital to the control of radioactive materials and to the maintenance of safety control functions. Explosion and fire detection, alarm, and suppression systems shall be designed and provided with sufficient capacity and capability to minimize the adverse effects of fires and explosions on structures, systems, and components important to safety. The design of the ISFSI or MRS must include provisions to protect against adverse effects that might result from either the operation or the failure of the fire suppression system	<u>DOE Order 6430.1A – General Design Criteria:</u> *Section 1530-99.0 – Non-Reactor Nuclear Facilities General:* To ensure that redundant safety class components shall be capable of performing the necessary safety functions, the facility design shall provide appropriate separation against fire, explosion, and failure of fire suppression systems Wherever practical, special facilities shall be designed and constructed using building components of fire-resistant and noncombustible material, particularly in locations vital to the functioning of confinement systems. A fire protection engineer or person knowledgeable in applying the principles of fire protection shall develop the fire protection system. To maximize the protection against fire, the system shall contain an appropriate integration of fire prevention, detection, and suppression features.	Equivalent.

CVDF Fire Protection
NRC Equivalency Assessment

NRC Requirement	DOE Requirement	Equivalency Determination
	The operation or failure of a fire protection system that interfaces with a safety class system, such as a safety class water system, shall not prevent the safety class system from completing its safety functions when required.	
(Note: <u>10 CFR 72.3 – Definitions:</u> *Structures, systems, and components important to safety* mean those features of the ISFSI or MRS whose function is: (1) To maintain the conditions required to store spent fuel or high-level radioactive waste safely, (2) To prevent damage to the spent fuel or the high-level radioactive waste container during handling and storage, or (3) To provide reasonable assurance that spent fuel or high-level radioactive waste can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.	<u>DOE Order 5480.7A – Fire Protection</u>: Paragraph 9.b <u>Physical Features of the Program</u>: Safety Class Equipment – In areas where a fire could cause damage to safety class equipment and where no redundant safety capability exists, a redundant fire protection system shall be provided for the safety class equipment. For new facilities, redundant Safety Class Equipment shall be located in separate fire areas. Fire suppression systems shall be designed such that their actuation will not damage safety class equipment or cause a criticality event.	

It is concluded that DOE fire protection criteria found in DOE Orders 6430.1A and 5480.7A are equivalent to fire protection criteria found in 10 CFR 50, Appendix A, 10 CFR 50.48, 10 CFR 50, Appendix R, NRC BTP 9.5-1, and 10 CFR 72.122, for the CVDF project.

This conclusion is based on a graded comparison of NRC and DOE criteria as described in the table above. NRC fire protection criteria contained in 10 CFR 50 and NRC BTP 9.5-1 is intended for protecting safety-related SSCs from the affects of fire at commercial nuclear power plants. Application of this specific fire protection criteria is intended to protect the public from a nuclear reactor that cannot be safely shutdown and maintained in a safe shutdown condition due to a fire. A commercial nuclear reactor has the potential to release millions of curies to the environment. The detrimental impact to the public resulting from such an event and release is orders of magnitude greater than the impact of a similar fire initiated event and release at the CVDF.

APPENDIX H

COLD VACUUM DRYING (CVD) ELECTRICAL EQUIPMENT (HYDROGEN) HAZARD PROTECTION

SNF-5100, Rev. 0

COGEMA
ENGINEERING CORP.

COLD VACUUM DRYING (CVD) ELECTRICAL EQUIPMENT (HYDROGEN) HAZARD PROTECTION

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SNF-5100, Rev. 0

COLD VACUUM DRYING (CVD) ELECTRICAL EQUIPMENT (HYDROGEN) HAZARD PROTECTION

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January 2000

SNF-5100, Rev. 0

TABLE OF CONTENTS

Table of Figures

SNF-5100, Rev. 0

COLD VACUUM DRYING (CVD) ELECTRICAL EQUIPMENT (HYDROGEN) HAZARD PROTECTION

1.0 INTRODUCTION

The purpose of this document is to document the adequacy of the flammable gas (hydrogen) protections in place for the electrical equipment used within the Cold Vacuum Drying (CVD) process while the multi-canister overpack (MCO) is connected.

2.0 SUMMARY

With the use of a helium purge and adequate controls, the systems attached to the MCO are not in a flammable environment. Effective safeguards against ventilation (purge) failure are provided which reduces the classification within a protected enclosure from Class I, Division 2/Zone 2, to unclassified based on Type X Pressurization (isolated MCO) and Type Z Pressurization[1].

The normal MCO process environment is an inert gas (helium). This environment consists of a general service helium (He) purge to flush hydrogen from the system or to maintain positive pressure to preclude air (oxygen) ingress. Automatic safeguards are in place to initiate a safety-class helium (SCHe) purge and MCO isolation before hydrogen levels in the system can reach hazardous concentrations. Intrinsically safe components are not necessary for this system. Adding safeguards against purge failure has mitigated the flammability hazard. Note: the concept of intrinsic safety only applies to electrical equipment, not mechanical parts and thermal sources (MCO).

With no protections in place (i.e., a MCO connected to a system with an environment of helium), the Hazardous location classification for the CVD process would be defined as either Class I, Division 2, Group B (hydrogen) *NFPA 70-1993 Article 500-5(b)* or as Class I, *Zone 2 NFPA 496 (1-4)*. A Division 2/Zone 2 location could have ignitable concentrations of hydrogen gas under normal conditions that are normally contained (separated from an oxygen source). Air (oxygen) ingress must be precluded because the MCO is a thermal source and could initiate an internal event. Only in the case of an accidental rupture or breakdown of the system can the hydrogen escape to the environment or can the system have oxygen ingress.

3.0 BACKGROUND

The vapor space in the MCO is a Class I, Division 2, Group B (hydrogen) location per *NFPA 70-1993 Article 500-5(b)*, i.e., "A Class 1, Division 2 location is a location:

(1) in which volatile flammable liquids or flammable gases are handled, processed or used, but in which the liquids, vapors, or gases will normally be contained within closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems, or in case of abnormal operation of equipment; or

[1] NFPA 496-98 Standard for Purged and Pressurized Enclosures for Electrical Equipment

(2) in which ignitable concentrations of gases or vapors are normally prevented by positive mechanical ventilation, and which might become hazardous through failure or abnormal operation of the ventilation equipment...". The potential exists that the hydrogen generated in the MCO vapor space could, in the presence of an oxidizing medium, be within the lower and upper flammability limits.

The National Electrical Code, NFPA 70-1993 Article 500-2 Location and General Requirements, states that " hazards may be reduced or hazardous (classified) location limited or eliminated by adequate positive-pressure ventilation from a source of clean air in conjunction with effective safeguards against ventilation failure". NFPA 70 does not go into detail on purged systems because it is primarily concerned with electrical systems and a purge is mechanical. The standard directs the reader to NFPA 496 for further information for hazard reduction. NFPA 496 (Chapter 6) requirements are being used to mitigate a potentially flammable gas hazard situation instead of NFPA 70 because of several reasons:

- Standard 496 chapter 6 applies to enclosed environments with an internal source of flammable gas, i.e., the MCO is generating the hydrogen gas.
- The MCO is a non-electrical spark source.
- Intrinsically safe equipment for a hydrogen hazardous gas environment is not always available and other techniques must be used.

Note: Where a release of flammable gas occurs within the enclosure under normal or abnormal conditions, NFPA 496 (6) includes the additional requirement of an inert purge gas to reduce oxygen content in the enclosure to less than 5 percent by volume.

Because the MCO generates hydrogen gas and no explosive reaction can be tolerated, inert atmospheres must be used. When the MCO is placed in the Cold Vacuum Drying Facility (CVDF) with a helium purge, the systems and associated piping can be regarded as non-classified, even though NFPA 496 does not directly apply to non-electrical ignition sources such as the MCO. A fail-safe, above atmospheric pressure, He purge system is provided for normal operations, with safety-class Helium (SCHe) purge and Safety-Class Instrumentation and Control (SCIC) provided for safeguards during accident situations as a method for expelling any buildup of hydrogen from the MCO and associated piping. During all operational periods, the SCIC system monitors process parameters and will initiate the SCHe when required. For example, the SCIC monitors the following parameters: MCO pressure, length of time under vacuum , and time to reach a vacuum level (indicates potential inleakage of air). If a value exceeds the specified limits, the SCIC system will trip the safety-class isolation and system purge and return the MCO to a protected "safe" state. Because of the drying process, there are times that the system is under vacuum and the purge system is not utilized. During this time, hydrogen is limited by maintaining low vacuum pressure, with insignificant hydrogen to support combustion should an air leak occur.

3.1 INERT ATMOSPHERE

Helium is the chosen inerting agent for the CVDF. In general, helium is less effective than nitrogen or carbon dioxide for inerting. However, helium is more effective for cooling, either for flame suppression (cools gas to below ignition temperature) or MCO fuel cooling. The cooling aspect makes it more effective than nitrogen or carbon dioxide for flame suppression in narrow piping (less than 2.2 cm diameter[2]).

The addition of a chemically inert substance, helium, in the CVD process piping, MCO, and ventilation systems causes the upper and lower flammability limits of the gas to approach each other. Experiments using helium (worst case situation), have shown that the lowest hydrogen value that is flammable when mixed in air is 8.7 % H_2 and 91.3 % He[3]. At atmospheric pressure, this mixture can support a flame when mixed with air. The upper and lower flammability limit for this blend is 69.8% [3] of the H_2-He mixture in a balance of air. This means that the environment will become flammable if there is 8.7% H_2 in Helium in the MCO and a leak into the MCO occurs which allows the environment to become 30.2% air. Therefore, to protect from an explosion, the trip functions of the SCIC must purge and re-pressurize the system before hydrogen can accumulate to the lower flammability level (8.7%).

3.2 FLAME SUPPRESSION

For intrinsically safe systems, both electrical and thermal energy must be limited to a level below the amount necessary to ignite the gas mixture's most easily ignitable concentration. The majority of equipment that is classified as intrinsically safe is only rated for gasses in Groups C and D categories because of the low ignition energy for Group A and B.[4]

(1) Group A (Acetylene – ignition energy 0.017 mW/s)
(2) Group B (example Hydrogen - ignition energy 0.017 mW/s).
(3) Group C (example: Ethylene - ignition energy 0.08 mW/s) or
(4) Group D (example: Methane – ignition energy 0.3 mW/s)

For cases where the electrical and thermal sources cannot be rendered intrinsically safe, flame suppression techniques (inerting gasses, restrictions, flame arrestors) can be used effectively. The minimum amount of energy necessary to ignite a hydrogen mixture and initiate combustion (deflagration) is 0.011mJ[5]. Because of the low ignition energy, a hydrogen flame will burn through the restriction or flame arrestor. However, changing the gas mixture, i.e., through adding a sufficient amount of inert gas, can eliminate the gas ignition hazard. "Inert atmospheres must be used when not even a small explosive reaction can be tolerated." [6]

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[2] Pg. 5 Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*, Bureau of Mines Bulletin 503, United States Government Printing Office, Washington D.C., 1952.

[3] Pg. 22 Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*.

[4] Svacina, B., *Understanding Hazardous Area Sensing*, TURCK, Inc, Minneapolis, Minnesota, 1994.

[5] Magison, E. C., *Electrical Instruments in Hazardous Locations*, 3rd Edition, Instrument Society of America, 1978.

[6] Pg. 18 Zabetakis, M. G., *Flammability Characteristics of Combustible Gases and Vapors*, Bureau of Mines Bulletin 627, United States Government Printing Office, Washington D. C., 1964, updated 1976.

3.3 CLASSIFICATION USING TYPE X and Z PURGE/PRESSURIZATION

Based on NFPA 496-98 (1-4) Standard for Purged and Pressurized Enclosures for Electrical Equipment, the CVD process environment is a Class I, Zone 2 location, i.e., A location

> "...(2) in which volatile flammable liquids, flammable gases, or flammable vapors are handled, processed or used, but in which the liquids, gases, or vapors normally are confined within closed containers or closed systems from which they can escape only as the result of the abnormal operation of the equipment with which the liquids or gases are handled, processed, or used; or in which ignitable concentrations of flammable gases or vapors normally are prevented by positive mechanical ventilation, but which may become hazardous as a result of failure or abnormal operation of ventilation equipment;..."

3.3.1 TYPE X PRESSURIZATION

Type X Pressurization is used for protecting the MCO for safety considerations, even though the MCO is included as part of the Class 1, Division 2/Zone 2 environment. A Type X purge is typically used for Class 1 Division 1/Zone 1 environments that contain a source of ignition (such as the fuel in the MCO) and contain a source of flammable gas during normal operations. This type of purge provides the most protection and alarms, and can be used to reduce classification for electrical equipment requirements from a ***Division 1 location*** to a ***non-hazardous location***.

The elements that constitute a Type X purge/pressurization system include the basic requirements for a pressurized enclosure, such as:

(1) Constructed from material that is not likely to be damaged under normal conditions

All piping, valves, and equipment that are a portion of the CVD system pressure boundary are rated to 150 lb/in^2 gauge.

(2) Precautions provided to protect the enclosure from excess pressure

A safety-class system consisting of a rupture disk and check valve is installed in the short process tube process connector to provide protection from overpressurization of the MCO. The 30 lb/in^2 gauge vent path is used as a backup to the SCHe system vent path to ensure the pressure will not reach the MCO 150 lb/in^2 gauge rupture disc rating.

as well as alarms and a cut-off switch, such as:

(3) Alarms in a constantly attended location

The SCIC provides safety class alarms to the CVDF control room such as low water level in the Cask/MCO annulus, activation of the SCIC MCO isolation and SCHe system purge (ISO&PURGE), and PWC Purge failures. The SCIC system also provides non-safety-class signals to the facility Monitoring and Control System (MCS) for normal control, indication, and alarms. The signals from the SCIC include all analog signals (flow and pressure), SCIC internal logic trip, alarm contact status and seismic trip contacts.

(4) A cutoff switch to de-energize power automatically (flow or pressure actuated) from all electrical elements not approved for Division 1/Zone 1 upon failure of the protective gas supply (or other trip situations)

Under normal conditions, the MCS controls all eight MCO isolation valves. The SCIC system will automatically isolate MCO (spark source and flammable gas source) and initiate the SCHe purge during process upset conditions. The portions of any equipment within the gas stream inside the isolation boundary do not contain any spark sources and do not need to be de-energized.

3.3.2 TYPE Z PRESSURIZATION

The balance of the CVD piping and process systems outside of the isolation boundary is protected (flammable gas) using Type Z Purge/Pressurization. Type Z purge/pressurization can be used to reduce a ***Class I, Division 2/Zone 2 location*** within a protected enclosure with no flammable gas under normal conditions to ***unclassified.*** With Type Z purging, a hazard is created only if the purge/pressurization system fails at the same time that a normally non-hazardous area becomes hazardous. For this reason, it is not considered necessary to remove power from equipment.

The general requirements for a Type Z pressurized system include the basic requirements for a pressurized enclosure (see Section 3.3.1 above), as well as alarms, such as the following:

Safety Class Alarms in CVD Control room – activation of the SCIC MCO isolation and SCHe system purge, and PWC Purge failure alarms.

4.0 SAFEGUARDS

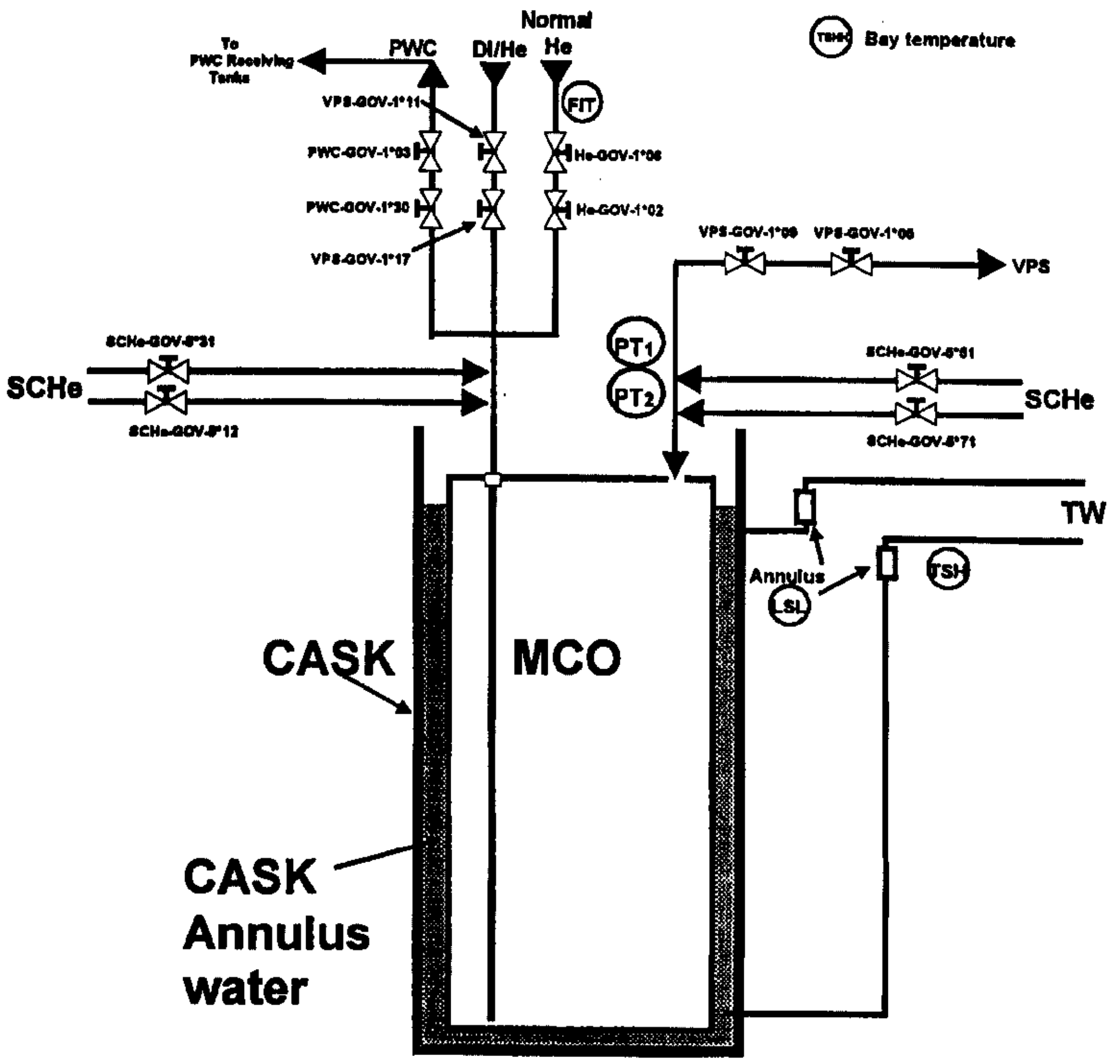
For the following discussions, see Figure 4-1.

4.1 DEFINITIONS

ISO & PURGE TRIP: This action is a result of contacts opening in the SCIC to de-energize the eight MCO isolation valves and four SCHe isolation valves. Since the eight valves are fail-closed, the MCO is isolated from the general service and non-seismically qualified portions of the process systems: the Vacuum Purge System (VPS) (System 07), the He system (System 13-1), and the Process Water Conditioning (PWC) System (System 46). The SCHe purge is enabled when the SCHe valves are de-energized open (fail-open on loss of power). This opens two valves on the long dip tube process connector and two on the short dip tube side.

PWC LOW FLOW: This alarm signifies that, during the PWC pre-purge or post-purge, either there was a low-flow rate or the minimum time for the purge was not met.

Figure 4-1. Cold Vacuum Drying Process Connections and Instrument Basics



Note: All instruments, PT, FIT, TSH and LSL have two components per bay.

PT1: Pressure Transmitter (PT 1*36, 1*37)
PT2: Pressure Transmitter (Vacuum) (PT 1*08, 1*10)
FIT: Flow Indicating Transmitter (FIT 1*20, 1*21)
TSH: Temperature Switch High (TSH 1*28, 1*29)
LSL: Level Switch Low (LSL 1*24, 1*25)
TSHH: Bay Temperature Switch High High (TSHH 1*38, 1*39)

Note: The * represents 2 through 5 for bays 2 - 5

4.2 GENERAL SERVICE HELIUM PURGE

The He system is a general service inert gas purging system that contains safety-class components required to ensure the safe operation of the CVDF. The Monitoring and Control System (MCS) monitors He system parameters and provides process control signals. The He purge flow rate is a safety-class input to the SCIC system.

During normal operations the He system provides helium for purging the cask headspace before removing the cask lid, purging the VPS and MCO prior to draining, backfilling the MCO headspace during draining, purging the MCO during vacuum dying, and backfilling the MCO and the cask annulus at the completion of CVDF processing. It also provides helium for purging VPS equipment and for purging PWC lines and tanks, as well as for leak testing valves and process seals. Following a SCIC actuation (MCO isolation and purge trip), the He system can supply helium to the SCHe if the He system was not affected by the event causing the SCIC actuation.

4.3 SAFETY CLASS HELIUM PURGE

The SCHe system is a dedicated safety-class, inert gas purge system that can be actuated automatically by a SCIC signal in response to predetermined process parameter setpoints, a seismic event, or manually via buttons in the control room or in the bay. Due to its fail-safe design, the SCHe system will also be initiated if there is a loss of control air or if power is lost to the valves or the SCIC system. The essential function of the SCHe system is to purge and pressurize the MCO with helium, and to provide a ventilation path following a system trip to the local exhaust system.

Each process bay has its own redundant SCHe system. Two separate locations are provided for the SCHe bottle storage and SCHe equipment panels in each bay.

4.4 SAFETY CLASS INSTRUMENTATION AND CONTROL SYSTEM (SCIC)

The SCIC system provides safety sensing, actuation logic, actuation signals, and control interfaces to prevent a MCO fuel runaway reaction (over temperature and pressure blowdown) or a hydrogen explosion within the MCO. Additional features provide protection from both external hydrogen explosion and spray leak accidents, i.e., (1) SCIC detection of process upset or (2) bay temperature detection. Both are used to initiate a process shutdown using isolation and purge.

The SCIC system provides active detection and response to process anomalies that, if unmitigated, could result in unacceptable consequences. To perform these functions, the SCIC system monitors process parameters, detects off-normal conditions, and actuates relays to de-energize the MCO isolation valves, SCHe isolation valves, and tempered water heater.

The SCIC system is a fully automatic system that requires no operator action to detect and respond to process upsets within the process parameters that the SCIC controls. The SCIC system provides safety-class alarms to the CVDF control room for those events that require operator actions, including MCO isolation and purge (ISO & PURGE) and ANNULUS LOW LEVEL.

4.4.1 SCIC TRIP CONDITIONS

The SCIC system isolates the MCO and initiates a SCHe system purge if any of the following occur:

- Loss of power (fail-safe condition)
- Manually-initiated safety-class isolation and SCHe purge from one of the SCIC ISO & PURGE buttons (administratively-controlled)
- Exceeding eight hours at vacuum during the first vacuum cycle or four hours of vacuum during all subsequent vacuum cycles without re-pressurizing the MCO for a minimum of four hours. This is referred to as the 8/4/4 requirement and provides thermal reset within the MCO
- MCO below atmospheric pressure and the helium flow below the minimum required to keep hydrogen less than 8% in He by volume. When MCO total pressure is below 12 torr, there is insufficient hydrogen to exceed the 8% level and no purge is required. Note that even for hydrogen in air mixtures, no mixture below 50 torr will propagate a flame[7]. A five-minute time delay on low-flow allows flow to be stopped in order to reach < 12 torr. In addition, after the 12 torr is achieved, a two-minute delay is provided to re-establish normal flow without a false trip condition
- MCO above the high-pressure setpoint
- The transition from above atmosphere SCIC actuation point (0.5 psig) to vacuum, time to reach less than -11.7 psig (~155 torr) exceeds five minutes
- The transition from below -11.1 psig (~185 torr) back to greater than 0.5 psig pressure exceeds five minutes
- MCO reaches an incorrect pressure state without adequate, verified purge volume. The MCO must be maintained above a positive pressure (approximately 0.5 psig) to prevent oxygen ingress unless a purge of adequate volume has been completed. During bulk water draining and the subsequence rinse, the MCO must remain above atmospheric pressure
- Bay temperature exceeds the high-temperature parameter limit of 105°F, which impacts safety-class instrument calibration
- Seismic event of sufficient magnitude (below Uniform Building Code levels)

[7] Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*, Bureau of Mines Bulletin 503, United States Government Printing Office, Washington D.C., 1952.

4.5 SYSTEM RELIABILITY

The SCIC system requires that two SCIC safety-class trains monitor each process bay. This includes the portion that contains the MCO ISO & PURGE trip, the tempered water trip, and the seismic monitoring trip. Each has two independent systems that are capable of independent action to perform their respective safety feature. All signals are through redundant transmitters or switches and all critical shutoffs are provided by at least two independent isolation valves for the ISO & PURGE trip and two independent starters for the tempered water heater for the trip. The valves and tempered water heater are designed to fail-safe in the event of loss of power or, in the case of the isolation valves, loss of instrument air.

SCHe system purge is accomplished by two separate supply systems with two parallel purge valves in each system. These valves are designed to open on failure or loss of power.

5.0 CONCLUSIONS

The CVD process piping, MCO, and ventilation systems is classified as a Class I, Division 2, Group B hazardous environment. However, by incorporating "effective safeguards against ventilation failure" (NFPA 70-1993 Article 500-2) the hazard has been reduced or eliminated. The requirements for Type X Pressurization are used near the MCO (ignition source and flammable gas source) and the requirements for Type Z pressurization are used for the balance of the system (NFPA 496). All situations where hydrogen is known to accumulate during normal operations are mitigated with limiting time for hydrogen accumulation, providing a positive pressure purge, or maintaining an above atmospheric pressure in the MCO. Accident conditions automatically initiate an MCO ISO & PURGE, which mitigates the situation with a positive pressure purge. Alarms are provided to a continuously staffed control room for off-normal notification.

6.0 REFERENCES

NFPA 496-98 Standard for Purged and Pressurized Enclosures for Electrical Equipment.

Coward, H. F., and G. W. Jones, *Limits of Flammability of Gases and Vapors*, Bureau of Mines Bulletin 503, United States Government Printing Office, Washington D.C., 1952.

Svacina, B., *Understanding Hazardous Area Sensing*, TURCK, Inc, Minneapolis, Minnesota, 1994.

Magison, E. C., *Electrical Instruments in Hazardous Locations*, 3rd Edition, Instrument Society of America, 1978.

Zabetakis, M. G., *Flammability Characteristics of Combustible Gases and Vapors*, Bureau of Mines Bulletin 627, United States Government Printing Office, Washington D. C., 1964, updated 1976.

Broschka, G. L., et al., *A Study of Flame Arrestors in Piping Systems*, Plant/Operations Progress, Vol. 2, No. 1, January 1983, pp. 5-12.

Department of Energy
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9956962
CC RECD: 09/24/99

99-SFD-185

SEP 2 3 1999

Mr. R. D. Hanson, President
Fluor Daniel Hanford, Inc.
Richland, Washington 99352

Dear Mr. Hanson:

CONTRACT NO. DE-AC06-96RL13200 – COLD VACUUM DRYING (CVD) FACILITY FIRE HAZARD ANALYSIS (FHA) RESOLUTION OF FINDINGS/SUBMITTAL OF REQUESTS FOR EQUIVALENCY, EXEMPTION, AND DEVIATION

Fluor Daniel Hanford, Inc. (FDH) letter to P. G. Loscoe, U.S. Department of Energy, Richland Operations Office (RL), from R. B. Wilkinson, same subject as above, FDH-9956370 R1, dated September 16, 1999, requests RL approval of four equivalency, one deviation, and one exemption requests for FHA Findings 18.1, 18.2, 18.4, 18.10 and 18.11.

As required by RL Implementing Directive 420.1, Section 8.9 c, the RL Spent Nuclear Fuels Project Division has completed a technical review of these requests with the assistance of a qualified fire protection engineer. Based on the support information contained in the approved FHA (SNF-4268, Rev 0.), and justifications contained within the requests, the requests are approved subject to the constraints, assumptions, and administrative combustible controls described in the requests.

FDH is reminded that the performance-based approach, described in the FHA Implementation Plan (SNF-4942, Rev. 0), and the requests for limiting combustible materials and preventing ignition of unacceptable fire scenarios, must be implemented by facility procedures and strictly adhered to throughout operations.

FDH is also directed to reference the approval of these requests as an author's note in the next update to the fire protection section of the Spent Nuclear Fuel Project Standards/Requirements Identification Document.

Mr. R. D. Hanson
99-SFD-185

-2-

SEP 23 1999

If any directions is provided by the Contracting Officer's Representative (COR) which your company believes exceeds the COR's authority, you are to immediately notify the Contracting Officer and request clarification prior to complying with the direction.

If you have any questions, please contact me, or you may contact J. Brian Sullivan of my staff on (509) 372-2573.

Sincerely,

P. G. Loscoe, Acting Director
Spent Nuclear Fuels Project Division

SFD:JBS

cc: J. W. Foster, DESH
R. P. Ruth, DESH
J. A. Swenson, DESH
R. B. Wilkinson, DESH
R. E. Jordan, DYN
H. M Bucci, FDH
C. S. Haller, FDH
R. G. Jones, FDH
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FLUOR DANIEL

Fluor Daniel Hanford, Inc.
P.O. Box 1000
Richland, WA 99352

September 16, 1999 FDH-9956370 R1

Dr. P. G. Loscoe, Acting Director
Spent Nuclear Fuels Project Division
U.S. Department of Energy
Richland Operations Office
Post Office Box 550
Richland, Washington 99352

Dear Dr. Loscoe:

CONTRACT DE-AC06-96RL13200 - COLD VACUUM DRYING FACILITY FIRE HAZARDS ANALYSIS RESOLUTION OF FINDINGS - SUBMITTAL OF REQUESTS FOR EQUIVALENCY, EXEMPTION, AND DEVIATION

References:

(1) Letter, P. G. Loscoe, RL, to R. D. Hanson, FDH, "Cold Vacuum Drying (CVD) Facility Fire Hazard Analysis (FHA) Implementation Plan," 99-SFD-178/9956370A, dated September 9, 1999.

(2) SNF-4268, Rev. 0, *Fire Hazard Analysis for the Cold Vacuum Drying Facility*, Fluor Daniel Northwest, Inc, Richland, Washington.

(3) SNF-4942, Rev. 0, *Spent Nuclear Fuel Cold Vacuum Drying Facility Implementation Plan for Fire Hazard Analysis Suggested Actions*, ARES Corporation, Richland, Washington.

In response to Reference 1, Fluor Daniel Hanford, Inc. (FDH) submits the following fire protection equivalency, deviation, and exemption requests for your review and approval. These requests are resolutions to their respective findings as described in Reference 2:

- Four equivalency requests to resolve Fire Hazard Analysis (FHA) findings 18.1, 18.2, 18.4, and 18.11,
- A request for deviation to resolve FHA finding 18.4, and
- A request for exemption to resolve FHA finding 18.10.

Dr. P. G. Loscoe FDH-9956370 R1
Page 2
September 16, 1999

These requests were developed through team meetings involving the FDH Spent Nuclear Fuel (SNF) Project, CVD Facility Design Authority, S. A. Brisbin; Hanford Site Fire Prevention Group, Hanford Fire Marshal, R. E. Jordan; the U.S. Department of Energy, Richland Operations Office (RL), Fire Protection Engineer, C. P. Christenson; and the RL SNF Project Division, Facilities Project Team Leader, J. B. Sullivan.

Reference 3 provides the plan that would implement all 12 findings in the FHA. (Only 5 of the 12 findings resulted in requests.) The requests are separate issues and the approval/disapproval of one does not depend on the approval/disapproval of another. The requests are provided as four separate attachments that are summarized as follows:

Attachment 1 is an Equivalency Request to Resolve FHA Finding 18.2

RLID 5480.7, Paragraph 8.2.c, requires that nuclear facility final exhaust/confinement high-efficiency particulate air (HEPA) filters be protected from failure due to a fire. The equivalency is for Operations to implement a performance based approach to limit the amount of combustibles within the Cold Vacuum Drying (CVD) Facility to below that which would cause fire damage to the Heating, Ventilation, and Air Conditioning (HVAC) HEPA filters.

Attachment 2 is an Equivalency and Deviation Request Packaged Together to Resolve FHA Finding 18.4

RLID 5480.7, Paragraph 9.b.(1), and DOE 6430.1A, Criterion 1530-99.0, require that redundant safety class components have appropriate separation against fire, ensuring that a fire cannot result in a common mode failure. The equivalency and deviation is for Operations to implement a performance-based approach to limit the amount of combustibles within the CVD Facility ensuring that a fire would not exceed the manufacturer's temperature rating of the safety class components. In addition to the performance-based approach, heat shielding is required for the used anti-contamination Special Work Permit (SWP) barrels on the mezzanine of the CVD Facility Process Bays.

Attachment 3 is an Exemption Request to Resolve FHA Finding 18.10

RLID 5480.7 Paragraph 8.1.e, requires that nuclear facility containment/confinement structures be provided with fire department standpipe connections, to help maintain the integrity of the confinement structure during manual fire fighting efforts. The exemption is based on (1) the commitment and ability of Operations to implement a performance based approach to limit the amount of combustibles within the CVD Facility to a level below that which would prevent facility structural damage, and (2) the ability of the Hanford Fire Department to extinguish a facility fire.

Dr. P. G. Loscoe
Page 3
September 16, 1999

FDH-9956370 R1

Attachment 4 is an Equivalency Request To Resolve FHA Findings 18.1 and 18.11:

RL Order 6430.1A, section 0110.6.3, Fire Resistance Ratings, requires that untested, unrated, or unapproved assemblies be approved by the cognizant RL fire protection authority before being considered for use as a fire rated assembly in an RL facility. The SNF Project is requesting approval by, as the cognizant fire protection authority at the Hanford Site, of proposed equivalent fire rated construction of specific walls and ceilings within the CVD Facility.

The total cost avoidance in granting approval of the requests in Attachments 1 through 4 is estimated to be $440,177.

We request your approval by October 15, 1999, based on the attached data. After approval, the pertinent information of the requests will be incorporated in the next revision of the FHA.

If you have any questions, please contact Mr. C. S. Haller at 373-1765.

Very truly yours,

R. B. Wilkinson, Acting Project Director
Spent Nuclear Fuel Project

Attachments (4)