Fire Hazards Analysis

for the

BaBar Detector Project

Prepared for

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1.0 INTRODUCTION

A Fire Hazards Analysis (FHA) was performed for the BaBar Detector Project at the Stanford Linear Accelerator Center (SLAC). BaBar will be located in the existing PEP-II Research Hall at Interaction Region 2 (IR-2). IR-2 and all PEP-II facilities are located inside the SLAC Radiological Control Area. The purpose of this FHA was to assess the risk of fire associated with BaBar and support equipment or facilities in relation to existing and planned fire protection features. This FHA was prepared in accordance with DOE Order 5480.7A, Fire Protection [DOE, 1993], and the applicable fire protection requirements of DOE Order 6430.1A, General Design Criteria [DOE, 1989].

Analyses were performed to ensure that the objectives outlined in Paragraph 4 of the Department of Energy (DOE) Fire Protection Order 5480.7A will be met. The objectives of Paragraph 4 include the following:

- Minimizing the potential for the occurrence of a fire;
- Ensuring that a fire does not cause an on-site or off-site release of radiological and other hazardous material that will threaten the public health and safety or the environment;
- Establishing requirements that will provide an acceptable degree of life safety to DOE and contract personnel and that there are no undue hazards to the public from fire and its effects in DOE facilities;

- Ensuring that process control and safety systems are not damaged by fire or related perils;

- Ensuring that vital DOE programs will not suffer unacceptable delays as a result of fire and its effects; and

- Ensuring that property damage from fire and related perils do not exceed an acceptable level.

1.1 Scope

This FHA includes evaluation of BaBar and related support equipment and facilities both within IR-2 and outside the structure. A separate FHA has been completed for PEP-II, including the IR-2 hall and the beam housing and will be referenced where appropriate [SLAC, 1995]. This FHA focusses only on the equipment and facilities directly associated with the BaBar Detector Project or modifications to the IR-2 hall associated with the project that may alter the fire risk significantly from that outlined in the PEP-II FHA. The results of the analyses are presented in terms of the potential fire hazards associated with BaBar and its support facilities, the potential extent of fire damage, the impact on employee and public safety, and the impact of the facilities' fire protection features.

A graded approach was used to the extent that representative worst case fire hazards are assessed and considered to bound all other potential fire hazards. Resulting conclusions and recommendations apply only to the areas within the scope of this FHA. The maximum possible fire loss is estimated by determining the replacement cost of the damaged structure and equipment, and the cost of down time associated with the interruption of the experiment. Clean-up costs associated with contamination were not considered. The FHA addresses the following elements as required by DOE Order 5480.7A for typical Fire Hazard Analyses (FHAs):

- Description of construction;
- Protection of essential safety class equipment;

- Fire protection features;
- Description of fire hazards;
- Life safety considerations;
- Critical process equipment;
- High value property;
- Damage potential: Maximum Credible Fire Loss (MCFL) and Maximum Possible Fire Loss (MPFL);
- Fire department response;
- Recovery potential;
- potential for a toxic, biological and/or radiation incident due to a fire;
- Emergency planning;
- Security considerations related for fire protection;
- Natural hazards (earthquake, flood, wind) impact on fire safety; and
- Exposure fire potential, including the potential for fire spread between fire areas.

1.2 Approach

National Fire Protection Association (NFPA) and DOE orders were used as the baseline documents (the minimum acceptable criteria) for this FHA. Data were gathered for this effort through field walk-through surveys of PEP-II and the IR-2 facilities, meetings with each of the BaBar subsystem teams and review of available drawings, reports, and related documents. Where required, selected analyses were performed using recognized engineering methods, including handbook correlations and computer based fire models.

1.3 Assumptions and Limitations

Assumptions regarding processes, equipment, and operations of the BaBar Detector Project and its supporting facilities were intended to be representative of actual conditions that will exist during the project as documented in the information provided by the BaBar project team at this time. It is emphasized that changes in the design of BaBar or the support facilities may require additional analyses to assess whether these changes impact the conclusions and recommendations set forth in this document.

No tests were performed to confirm functionality of existing fire suppression and alarm systems. Modifications are likely to be made to existing systems as outlined in this FHA to accommodate the BaBar project. Therefore, fire protection system testing will be performed by the SLAC Safety and Plant Offices at a later date.

The Maximum Possible Fire Loss (MPFL) estimate was based on the assumption that <u>no</u> firefighting or fire suppression occurs (i.e., failure of fire protection plans and strategies). The Maximum Credible Fire Loss (MCFL) was determined based on the assumptions that the installed fire protection features operate as intended and that emergency response and "limited" firefighting occurs.

2.0 SUMMARY AND CONCLUSIONS

A Fire Hazards Analysis (FHA) was performed for the BaBar Detector Project, to be located in the existing IR-2 hall. The FHA was developed in accordance with the criteria set forth in DOE Order 5480.7A, Fire Protection [DOE, 1993] and is intended to address the major fire hazards inherent in the Detector project.

2.1 Fire Hazards

Potential fire hazards were evaluated in terms of the damage potential to the Detector, the IR-2 hall, and other high value property (e.g., Electronics House). Candidate incidents included the potential for fires in the Detector, exposure fires in the support equipment and transient combustibles fires.

The results of computer based analyses indicate that structural damage is unlikely due to occurrence of any of these fires. Separation distances on the order of 2 m between these types of fuels and the Electronics House will minimize the potential for damage to the Electronics House.

The cable tray fire scenario poses a potential exposure problem for the Detector. It is recommended that thermal detection, limited thermal radiation shielding, and firestopping be installed to protect the Detector from a fire in the cable trays directly adjacent to the Detector. Fire barrier separation of each of the cable trays to prevent tray to tray fire spread may be utilized as an alternative to thermal radiation shielding. The separations would provide additional benefit in limiting the extent of damage to cables as well as a reduction in the radiant exposure to BaBar.

A fire involving as little as 23 kg (50 lb) of paper or trash in the Electronics House can result in flashover of the House and exposure of the Detector to high temperatures and corrosive gases (when the concrete curtain is not in place). Effective protection of the Electronics House and controls on amounts of exposed ordinary combustibles are required.

Incidental fires in adjacent spaces outside IR-2 are not expected to impact the IR-2 hall or the Detector. The fuel loading is too low to result in an extended fire duration provided available fire suppression systems operate, and the site Fire Department responds.

2.2 Fire Protection

The impact of existing and proposed fire protection features was evaluated. Fires occurring in the Detector do not represent a severe exposure to the IR-2 hall. However, due to the value of the Detector and the demanding experimental schedule, strategies are recommended for minimizing the impact of such an incident on the Detector itself. Since the use of conventional fire protection is impractical, strategies include (1) limiting the flammability of materials, (2) installation of High Sensitivity Smoke Detection (HSSD), and (3) control systems that continuously monitor temperature, pressure, oxygen, and gas mixture composition in the Detector.

Project support equipment and facilities were evaluated and recommended protection strategies provided. Most of these strategies have already been integrated into the Project.

The automatic sprinkler system in the Counting House will be modified from a wet type system to a preaction system. This change will not adversely affect the level of fire safety in the Counting House and will reduce the potential for inadvertent water damage to the support systems. A preaction system will also be installed in the Electronics House.

Consideration is also being given to taking the sprinkler system out of service on the west side of the shield wall in the Detector area. Due to the low fuel loading, high ceiling and number of obstructions, the sprinkler system is not expected to be effective. Incidental fires, if they occur, will be too small to result in timely response by the sprinkler system. And, most fires will occur in highly obstructed areas, including in the Detector, in support electronics racks or in the cable trays. Water sprays from ceiling level sprinklers will have little or no effect on such fires. These fires are not expected to result in extensive damage to the IR-2 hall due to the inherent fire resistance of the construction. In addition to the lack of effectiveness, the crystals located in the calorimeter subsystem of the Detector are highly susceptible to hygroscopic damage. Minor amounts of water can effectively result in BaBar being out of service for an extended period.

2.3 Property and Equipment Criticality

There are no safety class items (SCI) or vital safety systems (VSS) located in the IR-2 hall or as part of the BaBar Detector Project. The risk of significant threats to public safety or the environment are considered negligible. High value property is defined in DOE Order 5480.7A as property with a replacement cost of $1 million or greater. The Detector (BaBar) ($70 M), the Electronics House ($10 M), and the Cryogenics Plant ($3 M) are considered high value properties. The estimated replacement value of IR-2 is $10 M.

As defined in DOE 5480.7A, critical process equipment in excess of six months to be replaced if damaged or destroyed, and is normally associated with equipment used in processing Special Nuclear Materials (SNM). There is no critical process equipment associated with the

BaBar Detector Project. However, it should be noted that several components of the Project including the Detector (BaBar), Electronics House, and the Cryogenics Plant, if exposed to a serious fire, would require in excess of six months to restore/replace.

2.4 Life Safety

The BaBar facility is classified as a Special Purpose Industrial occupancy in accordance with NFPA 101, "The Life Safety Code" (LSC). Based on this classification and review of the existing and planned contents, the facility's level of hazard from contents is *Ordinary*. The normal working staff in the facility during installation and operation of the Detector is significantly below limits established in the LSC for this type of occupancy. However, if large tours are scheduled that increase the number of facility occupants such events should be coordinated with the SLAC Fire Protection Engineer and Fire Department. Based on requirements in the LSC for Special Purpose Industrial occupancies, the facility has adequate provisions for egress, including travel distances, number and location of exits, avoidance of dead-end travel paths, and lighting and marking of exits.

Under operating conditions, personnel will not be located on the west side of the shield wall. Therefore, there are no life safety problems other than to ensure that these restrictions are maintained. During periods when the Detector is shut down for maintenance or modifications, personnel will be located in the area where the Detector is located. In addition, personnel will be required to enter the Detector (while in the open position) to perform necessary adjustments on the subsystems. This area is identified as a "permit required" confined space. Appropriate safety precautions and procedures will be developed.

An analysis of the fire exposure risk to individuals working inside the Detector is outside the scope of this FHA and dependent on the final Detector subsystem designs. However, it is recommended that under situations when one individual is working inside the Detector both rescue procedures and rapid fire extinguishment capabilities be provided.

2.5 Fire Loss Estimates

The MPFL for the BaBar Detector Project involves a fire in the Detector while open. The damage resulting from this fire scenario will include loss of several, if not all, of the subsystems and require considerable resources for restoration. Significant structural damage to the IR-2 hall is not expected. The replacement cost for BaBar is estimated at $70 M. Clean-up costs for thermal and corrosion damage to the support equipment in the IR-2 hall and the PEP-II tunnel is estimated at $8.0 M, resulting in a total MPFL of approximately $78.0 M.

The MCFL for the BaBar Detector Project also involves a Detector fire. However, the use of flammability requirements, HSSD detection, and machine control systems is expected to limit the damage somewhat. Replacement costs are estimated at $35 M or less, depending on the extent of implementation of these fire protection features. In addition, extensive damage to the PEP-II tunnel and support equipment is not expected. Clean-up costs are still estimated at $8.0 M, resulting in a total MCFL of $43.0 M.

2.6 Fire Department Response

SLAC operates an on-site, fully staffed and well trained fire department. The department is capable of handling a fire in the IR-2 hall. The response time is estimated at from 3.5 to 4 minutes, with an additional 3 to 5 minutes for staging activities and initiation of interior firefighting.

2.7 Recovery Potential

The limited combustible loading minimizes the severity of anticipated fires in the buildings associated with the BaBar Detector Project. The heavy reinforced construction of the west end of IR-2 is unlikely to sustain significant damage, even by the most severe fires that were considered possible under the planned occupancy. In addition, current anticipated combustible loadings for the east end of IR-2 as well as in the adjacent buildings (Buildings 621, 624, and

Cryogenics Control Room) are low enough that clean up and repair due to an incidental fire will be an acceptable strategy.

2.8 Potential for Toxic, Biological, and Radiation Incident Due to Fire

There are no biological agents stored or used in this facility. The potential for a toxic materials incident due to fire is limited. Ignition and burning of wire and cable insulation, ignition of a limited volume of flammable gas or liquid or burning of incidental Class A materials will generate some amount of toxic combustion products. The hazard associated with these releases depend on the ignition scenario, the location of the incident, and the proximity of occupants but is expected to be confined to the building.

There are three radiation source terms associated with BaBar, including the beam radiation, the induced activity of the BaBar component, and the D-T generator system. Based on evaluation of potential accident scenarios, the dose consequences are considered negligible in terms of exposure of workers or fire department personnel.

In the event of a fire, the beam is interrupted. In addition, there are redundant entry doors that automatically interrupt the beam when opened. It has been determined that in an emergency, the Fire Department can enter the west end of IR-2 after the beam is interrupted with negligible radiation exposure hazard.

2.9 Emergency Planning

The BaBar Safety Officer will prepare a comprehensive Emergency Plan for the BaBar Detector Project. The Plan will include guidance for evacuation and emergency procedures for the IR-2 hall and support buildings associated with BaBar.

2.10 Security Considerations

The security measures currently contemplated for BaBar including restricted access during Detector operation, will not compromise fire protection or life safety considerations.

2.11 Natural Hazards Impact on Fire Safety

The IR-2 hall and related facilities were constructed to requirements which exceeded the Uniform Building Code for Zone 4 seismic protection and wind loading. Modifications and new construction will meet the current UBC requirements.

2.12 Exposure Fire Protection

Adequate separation distances are provided to prevent fire spread from nearby structures to the IR-2 hall. A major earthquake and subsequent wildland fire could expose the IR-2 hall. However, such an event is considered rare and would not expose the public.

2.13 Recommendations

The fire hazards and associated risks which are identified in this FHA warrant preventative or mitigative measures consistent with the loss limitations stipulated in DOE Order 5480.7A, Fire Protection [DOE, 1993]. However, the nature of the BaBar Detector Project affects literal compliance with the requirements in DOE 5480.7A in specific areas. Therefore, the recommendations outlined in Section 17 reflect an attempt to achieve literal compliance for the majority of requirements in DOE 5480.7A and equivalent compliance where literal compliance cannot be achieved.

3.0 SITE DESCRIPTION, FACILITIES, AND OPERATIONS

3.1 General Site Description

The Stanford Linear Accelerator Center (SLAC) is situated on 426 acres of land owned by Stanford University and leased to DOE for purposes of research. The site, at 2575 Sand Hill Road, Menlo Park, California, is in a belt of low foothills between the alluvial plain bordering San Francisco Bay and the Santa Cruz Mountains to the west. The site elevation varies between 175 to 375 feet above sea level. The neighboring land to the south is largely open space. Office buildings exist on the parcel immediately to the west of the entrance gate, and a housing development exists at the northeast corner of the site. The site is bordered on the north side by a four-lane expressway.

The San Andreas fault passes within a quarter mile of the western boundary of the site. The San Andreas fault is, at this latitude, considered to be a probable source of a major (> Magnitude 7) earthquake within the next few decades. Other related faults, such as the Hayward fault 15 miles east of the site, and the Calaveras fault a similar distance to the southeast, are also considered active and likely to be the source of major earthquakes.

These proximities make it probable that a major earthquake on one or more of these faults will occur, requiring special consideration for construction of the facilities as well as fire protection systems. The laboratory has designed its structures, including the PEP-II Research Hall, to criteria which are more conservative that the Uniform Building Code. Structural design standards at SLAC are intended to prevent loss of life and to minimize equipment and building damage.

3.2 BaBar Facility

3.2.1 General

The BaBar Detector Project will be assembled and operated in the existing PEP-II Research Hall at IR-2 (reference Figure 3-1). This facility is large enough to accommodate the Detector, the radiation shield wall, and the support services. It includes the main high bay area (Building 620), a control center adjacent to the planned cryogenics pad, the PEP magnet power supply room (Building 624), and the two-story Counting House (Building 621). A tool shed is located outside IR-2 directly adjacent to the east outside wall of IR-2 between the two roll-up access doors.

In addition to the primary facility, a structure will be constructed to provide gas mixing for the Detector. And, primary site power will be fed to the facility from Building 625. Both of these structures are located west of the IR-2 hall on top of the adjacent hill. Gas storage will be located remotely from the gas mixing house with the gas supplies piped into the gas house, mixed, and then piped to the IR-2 hall.

Site utilities, including power, water and sewer, are provided to the IR-2 facility. Supply air for the IR-2 hall is provided from the PEP-II tunnel ventilation system. Exhaust is also provided in the tunnel along with manually operated powered vents located on the roof of the IR-2 hall. The two-story Counting House has an independent HVAC system.

The IR-2 hall will be divided into two separate areas by a 7.9 m (26 ft) high radiation shield wall as depicted in Figure 3-1. During operation of BaBar, a concrete curtain wall will be placed on top of the shield wall, essentially providing a floor to roof barrier. At times when the Detector is being serviced, the concrete curtain wall may be removed for crane access. When this occurs, there will be a 5.8 m (19 ft) high opening between the top of the shield wall and the roof.

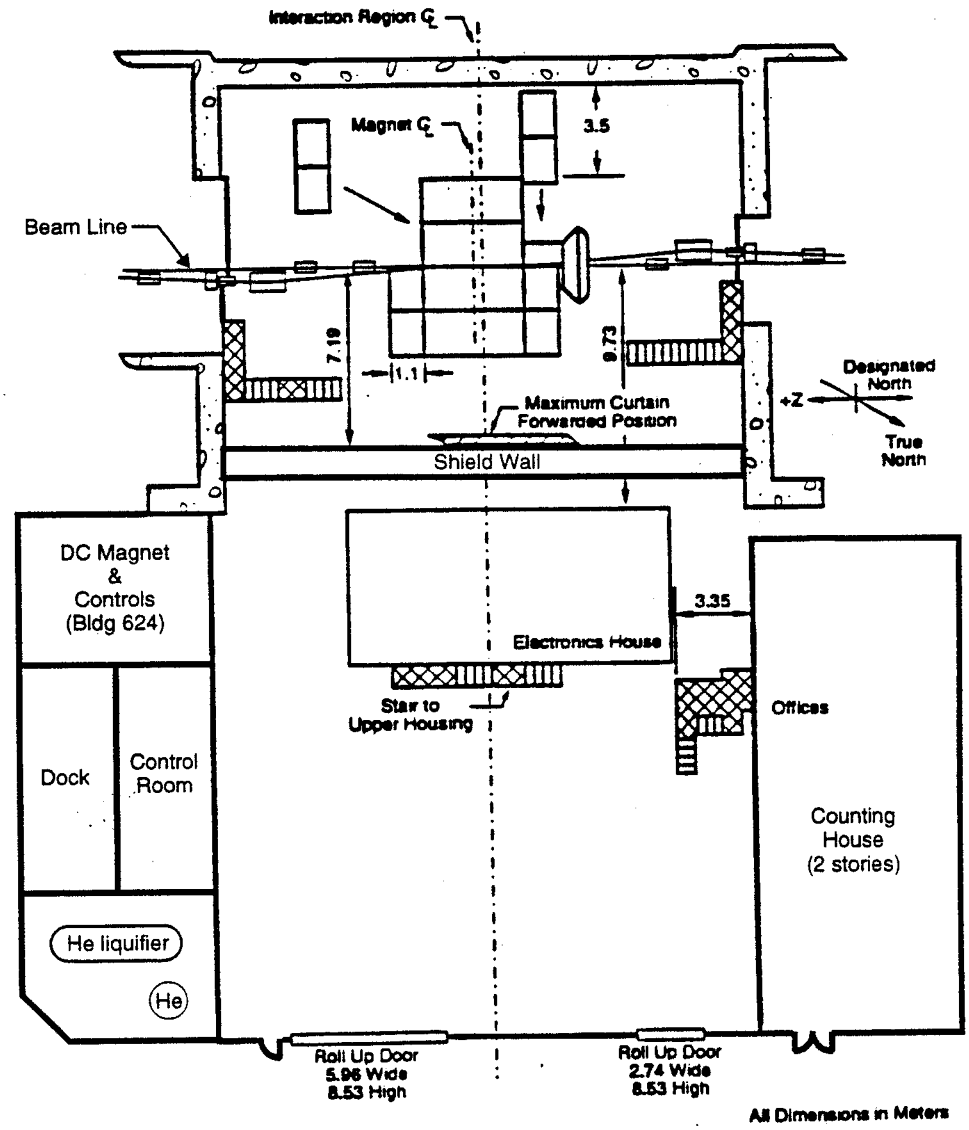

Figure 3-1. Plan view of IR-2 Hall with BaBar and Electronics House in operating position

Initially, the Detector will be assembled and tested in the area east of the shield wall. The Detector will then be permanently located on the west side of the shield wall, aligned with the beam line. After BaBar has been commissioned and experiments begun, the east part of IR-2 will house electrical and data analysis support systems (i.e., Electronics House), electrical panels and motor control equipment, equipment staging areas, and limited fabrication capabilities. Additional offices for support personnel as well as the main control room and an electronics shop will be located in the adjacent two-story Counting Building (Building 621) along the north wall of the IR-2 hall.

3.2.2 Construction/Occupancy Classification

The IR-2 hall is essentially a single-story structure with a floor area of approximately 897 m^2 (9,660 ft^2) and ceiling height of 13.7 m (45 ft). The structure is built of a combination of reinforced concrete and insulated steel panels on structural steel framing. The reinforced concrete is part of the PEP-II construction with a steel framed extension. The adjacent spaces, including the Counting House and the cryogenics control room, are also constructed of steel panels on a structural steel frame.

The construction type is a mix of Type II(111) and Type II(000) in accordance with NFPA 220, Standard on the Types of Building Construction [NFPA, 1995]. Both classes of construction are noncombustible. The comparable construction types under the Uniform Building Code are II (1 hour) and II-N.

The IR-2 facility is classified as a Mixed Occupancy under the provisions of the NFPA Life Safety Code, NFPA 101 [NFPA, 1994]. The counting house (Building 621) which houses the control center, electronics shop, and support offices is classified as a Business or Laboratory Occupancy. The remainder of the facility is classified as a Special Purpose Industrial Occupancy. In general, the construction meets the requirements of the NFPA 101 Life Safety Code and the Uniform Building Code in terms of fire resistance, separation of fire areas, and egress capacity.

The interior finish observed in the facility includes painted and unpainted poured concrete walls, painted metal wall panels and painted gypsum board panels. The ceiling of the high bay area includes concrete panels on the west side of the shield wall and steel panels on the east side of the wall where the IR-2 hall is constructed with a structural steel frame. Mineral fiber acoustical tiles and laid-in steel panels are also present in the Counting House (Building 621). The ceilings of the remaining enclosures are painted undersides of insulated roof panels. The interior finish materials currently present in the IR-2 facility meet the egress requirements of the NFPA 101 Life Safety Code for use of Class A, B or C materials in corridors and support rooms (e.g., control room, shops, offices, conference rooms).

3.3 BaBar Equipment/Systems

A detailed description of the Detector design is provided in the Preliminary Safety Assessment Document-BaBar [SLAC, 1996]. The Detector design consists of a silicon vertex detector, a drift chamber, a particle identification system, a cesium iodide (CsI) electromagnetic calorimeter, a magnet with an instrumented flux return, electronics, and computing systems.

The detector weighs approximately 1,000 tons and is approximately 6.7 m in height, 9.5 m in width, and 8.3 m in length. Detector support equipment includes the following:

(1) a cryogenic plant and storage dewars,
(2) electronic signal processing equipment,
(3) power supplies,
(4) control systems,
(5) mechanical support systems,
(6) computing systems,
(7) an electronics house, and
(8) a detector transport system.

A brief description of each of the detector components follows. More detailed operating descriptions are documented in the Preliminary Safety Assessment Document [SLAC, 1996].

3.3.1 Silicon Vertex Tracker (SVT)

The tracking system in BaBar consists of the vertex detector and a drift chamber. It is used to measure the impact parameters for charged tracks and also provides the measurements of production angles. The SVT consists of double-sided silicon microstrip detectors and readout electronics assembled into mechanical modules. These modules are glued to low-mass beams constructed of carbon and Kevlar fiber-epoxy laminates. Support cones, a low-mass space frame, a cooling system, power supplies, and a distribution system for power and signals make up the remainder of the SVT components. The silicon detectors are biased at an operating voltage less than 60 V, with a current less than 100 mA.

Each detector module consists of two electrically isolated halves consisting of silicon wafers and associated electronics, called Read-out Modules. One is for the forward direction and one for the backward direction.

The data from each Read-out Module (one-half of a detector module) will be transmitted from the hybrid on a flexible cable to a matching card located approximately 40 cm away, where the signals are impedance-matched to a twisted pair cable. Four twisted pair cables per readout section are used to transmit the signals a distance of many meters to crate-based Multiplexing (MUX) cards located near the detector. DC power is also routed through and capacitively decoupled by the MUX cards. There are two crates of MUX cards, one at each end of the detector. Signals between the MUX cards and the DAQ system in the electronics building are carried by optical fibers.

3.3.2 Drift Chamber

The drift chamber measures the trajectories of particles that emanate from the interaction region and have passed through the vertex detector and the support tube. The trajectories are measured by a large number of sense wires located in the chamber volume. The drift chamber occupies the radial space from 0.235 to 0.810 m, and has a length of approximately 2.76 m. It surrounds the support tube and is situated inside of the DIRC. The drift chamber consists of a carbon-fiber outer cylinder, aluminum end plates, beryllium inner cylinder, sense and field wires, signal electronics, power supplies, and a gas system. The 7,104 sense wires are stretched longitudinally along the axis of the chamber, and arranged in 40 concentric layers. Each sense wire is surrounded by six field wires. A voltage +2000 V is applied to the sense wires, while the field wires are at ground (some at a few hundred volts). Preamplified circuit boards are mounted on the backward end plate to amplify these sense wire signals and transmit them to the electronics house.

3.3.3 Particle Identification - DIRC

Particle identification will be provided by the DIRC – named for the detection of internally reflected Cherenkov light. The DIRC system consists of 156 rectangular quartz bars of 4.7 m in length, oriented parallel to the z axis of the detector, forming a 12-sided polygon. The bars are physically connected (by a glued quartz window) to the standoff box, which is a steel tank filled with approximately 5 tons of water. Approximately 10,600 PMTs (photomultiplier tubes) cover the rear toroidal surface of the standoff box in a close-packed array. A steel box encloses the standoff box to shield the PMTs from magnetic fields. Additional systems that make up the DIRC include a calibration system, a high-voltage system for the PMTs, electronics, a water conditioning system, and a cable plant.

3.3.4 Electromagnetic Calorimeter

The BaBar Electromagnetic Barrel and forward endcap calorimeter consists of thallium-doped cesium iodide (CsI(TI)) scintillating crystals designed to measure electromagnetic (electron and gamma ray) energy by converting this energy into visible scintillation light which is efficiently collected. There are 5,760 crystals in the barrel calorimeter arranged with 120 crystals in each of 43 azimuthal rings. The forward endcap is arranged in a conical package that mates with the barrel and contains 820 crystals in eight rings. The weight of the calorimeter barrel is approximately 23 tons and the endcap is approximately 3 tons. The barrel and endcap calorimeters are mechanically separate assemblies and are attached to the flux return steel by means of end flanges. The assemblies are enclosed in two environmental shields. Services penetrate the environmental shield and include all electronics power and fiber optic signal cables, fluorinert and water cooling, and environmental monitors for temperature and humidity. Digitizing electronic cards are mounted between the nested environmental shields in the end flanges. The assembly is purged constantly with nitrogen gas to protect the crystals from moisture damage.

The calorimeter requires active cooling for electronics contained in the environmental enclosure as well as for the digitizing electronics located at the extreme forward and backward end of the barrel and forward endcap. Cooling is accomplished by piping fluorinert along each strongback and water to a fully trapped channel in the end flange for the converter (ADC) and I/O cards.

3.3.5 Muon and Neutral Hadron Detector

Muon identification and neutral hadron detection are provided by the Instrumented Flux Return (IFR). Resistive Plate Chambers (RPCs) will be inserted in the gaps between the iron plates of the flux return of the superconducting solenoid. The RPC is essentially a gas gap at atmospheric pressure enclosed between two Bakelite (phenolic polymer) plates coated with graphite. These thin graphite surfaces are connected to high voltage and ground, respectively. A charged particle crossing the chamber produces a quenched spark which produces signals on external pickup electrodes. Charged tracks found in the central drift chamber will be matched to tracks in the IFR.

These RPCs consist of large area parallel plate electrodes, held apart with spacer buttons and filled with a gas mixture. The electrode plates are made of 2 mm-thick Bakelite. Additional components include a gas mixing and delivery system, power supplies, electronics, and cables. The gas mixture under consideration includes Halon 134A, argon, and isobutane. A detailed flammability evaluation is provided in Appendix A.

3.3.6 Magnet Coil and Flux Return

The magnet system consists of a 1.5-Tesla superconducting solenoid set within a hexagonal flux return. The superconducting solenoid consists of the coil in a cryostat, the cryogenic system, the power supply, the quench detection and protection system, and the control system. The barrel sits on earthquake isolation supports. The endcaps are divided into four separate sections which can be rolled away from the barrel. This subsystem has associated with it a helium plant and a liquid nitrogen supply.

3.3.7 Electronics

Detector electronics system designs will make use of a variety of packaging strategies, location optimizations, and low-voltage power distribution techniques as dictated by the signal processing requirements. Standardized crate systems installed in racks will typically be used in close proximity to the detector and in the electronics house, on the radiation-shielded side of the radiation wall; examples are VME, CAMAC, and NIM.

Highly specialized preamplifier electronics systems will be mounted directly on silicon detectors, on wire chamber detectors, on calorimeter crystal detectors, RPCs, and on particle identification detectors.

Power sources are typically low-voltage, high-current types for reasons of efficiency and cost. For most of the electronics, these supplies can be highly efficient, small footprint switching types. For some front-end electronics, however, the supplies may be linear types due to the demanding requirements on electrical interference and noise minimization. For a given power capacity, the physical size, stored energy, and reliability of linear supplies is a strong function of the line power frequency. There is a clear optimization around 400 Hz (as used in the aircraft industry) as opposed to the electrical utility standard of 60 Hz. Consequently, the electronics systems located on or near the detector may use 400 Hz power sources to optimize the front-end system performance as well as the reliability and maintainability, if linear supplies prove to be necessary.

All of the BaBar detectors have amplifiers and other data-acquisition electronics in close proximity. Thermal polyfuses are used to "fuse" the circuit boards where appropriate. Other protection circuitry measures local temperatures and shuts down the boards where appropriate. A brief description is given of the electronics systems associated with the different detector subsystems in the PSAD [SLAC, 1996].

3.4 Support Systems/Equipment

3.4.1 Electronics House

An enclosure will be constructed and maintained on the east side of the shield wall in IR-2 to provide data collection support to BaBar. The 74.3 m^2 (780 ft^2) enclosure will be moved into place near the shield wall, and the electronics/signal cables will be extended from the Detector to the Electronics House through a floor level cable tray system that passes through the shield wall in two places. Instruments will be located in closed electronics cabinets in the Electronics House. Additional instrument cabinets, transformers, HVAC, and support equipment will be located on the roof of the House. A UPS unit for the Electronics House will be positioned along the north wall of the IR-2 hall.

Cables will enter the Electronics House into a 0.3 m (1 ft) high floor plenum and be distributed to appropriate cabinet(s). The individual cabinets as well as the enclosure will be independently cooled to insure control of ambient temperature conditions. Separate, remote exits will be provided in the Electronics House.

3.4.2 Main Control Center

The main control center for BaBar is located on the first floor of the Counting House (Building 621). Most of the signal/control cables are routed from the Detector to the Electronics House. Selected cables go from the Electronics House to the control center in cable trays.

3.4.3 Cryogenics

A helium liquifier plant, a cryogenics control room, and the PEP magnet power supply room are located outside the southeast corner of IR-2. Cables and gas supply lines are routed from the Detector to the PEP power supply room or the cryogenics control room in cable trays installed along the walls of the high bay area in IR-2. The cryogenics plant is fully automatic and is controlled/monitored in the cryogenics control room.

3.4.4 Gas Mixing House/Gas Storage

The Gas Mixing House will be located on the apron above the IR-2 hall. The House will receive make-up gases from the remote storage tanks. Mixing and control equipment, including system interlocks to shut down the mixing process and the gas supplies, will be installed. While the design of the Gas Mixing House has not been completed, it is the intent to meet the requirements of NFPA 70 (NEC) and 101 in terms of electrical safety and life safety. The SLAC electrical and fire protection engineers in cooperation with the BaBar Safety Officer will review and approve the final design.

3.4.5 Power Distribution

Building 625 houses the PEP-II power supplies and the BaBar solenoid power supply. The BaBar power supply cables are routed from Building 625 through the west exterior wall of IR-2 through cable conduits. The cables are routed in cable trays installed along the walls of the IR-2 hall.

3.4.6 Miscellaneous

A tool crib is located along the east wall of IR-2 between the two sets of roll-up doors. The shed is wood framed construction with metal panels for the roof and walls.

Other equipment located outside IR-2 includes the following:

(1) nitrogen dewar,
(2) electrical substations,
(3) chillers, and
(4) storage trailers (unoccupied).

None of these items pose a direct fire hazard to the IR-2 facility.

4.0 FIRE HAZARDS

4.1 General

A review was performed of the potential fire hazards associated with the BaBar Detector Project. The review focussed on (1) incidents that could occur in the Detector, and (2) incidents outside the Detector. In evaluating the impact of such incidents, consideration was given to potential damage to the Detector, its supporting equipment and systems, and the IR-2 facility. Adverse effects on life safety were evaluated.

4.2 BaBar Fires

The current design and planned operation of the Detector represent unique fire protection challenges. A fire event in the Detector could result in significant damage to the Detector itself and extended down time associated with repairs. In addition, while fire detection will be incorporated into the Detector, access for either automatic or manual fire suppression action is limited. As a result of these problems, emphasis must be placed on minimizing the likelihood of a fire incident in the Detector as well as significantly limiting the potential for fire spread due to a small ignition.

It is difficult to accurately simulate typical fires which might start inside the Detector. However, it is unlikely that such fires would result in significant damage to the IR-2 hall. The hall is constructed of reinforced concrete in the area where the Detector will be located.

While limited structural damage would occur to the IR-2 hall, particulate and corrosive/toxic gases would spread into the PEP-II tunnel. The PEP-II tunnel is protected, limiting the extent of damage. And, the immediate area of the Detector as well as the PEP-II tunnel will not be occupied while the Detector is operating. Therefore, the impact of a fire in the Detector on life safety under these conditions is negligible. Fire impact on the east side of the shield wall is also expected to be negligible.

The likelihood of a fire incident as well as the resulting impact is considerably greater when the Detector is open for repairs, maintenance, and adjustments. An incident which occurs during these periods will not extensively damage the IR-2 hall. But, higher burning rates and faster flame spread rates will occur, resulting in higher volumes of smoke particulate and combustion gases and higher temperatures. Damage to support equipment in the area of the Detector and in the PEP-II tunnel would be greater under these conditions.

The risk of injury or death to individuals located in the Detector area and in the tunnel near IR-2 is relatively low provided appropriate egress procedures are followed. However, the risk to an individual working inside the Detector is considerably higher. This area is identified as a "permit required" confined space. Appropriate safety precautions and procedures will be developed.

The dominant fire hazard scenarios associated with the Detector include ignition and burning of (1) electrical/electronic components, (2) materials such as wire and cable insulation or thermal insulation, and (3) gas mixtures piped through the Detector. Such fires will result in the production of heat and toxic/corrosive combustion gases, potentially damaging the Detector subsystems and exposing the IR-2 hall to hazardous conditions.

4.2.1 Wire and Cable Fires

The primary sources of fuel for fire propagation from a small incidental ignition are the wire and cable insulation and jacketing. BaBar involves several integrated subsystems requiring power, control, and instrumentation cables that will be installed inside the Detector. Typical types of wire/cable include high voltage power (coaxial), low voltage power (coaxial), flat ribbon signal cable, fiber optic cable, shielded control cable (twisted pairs), fire alarm cable, and temperature transducers. Typically, if cables are properly sized for the voltage and power requirements, fires do not start in the cable, but are more often the result of an overheated connector or electronic/electrical component or exposure to a separate ignition.

Many factors influence the fire performance of cable materials under in situ conditions. Key factors associated with incidental exposure fires that are independent of the cable properties include (1) the energy or location of the ignition, (2) the cable geometry (e.g., single stranded, bundled, or mixed), (3) the enclosure geometry, and (4) the atmosphere (e.g., oxygen concentration). Important fire characteristics of the cable itself include ignitability, heat release rate, flame spread, smoke generation, and corrosive gas production.

There are several fire performance parameters associated with wire and cable flammability that can affect the potential impact of a fire incident in the Detector. Included are the following:

(1) Ignitability,
(2) Heat release rate, and
(3) Flame spread.

Each of these parameters directly influences the fire performance of wire and cable materials relevant to ignition prevention and limiting fire propagation. Smoke corrosivity is also an important parameter in terms of damageability, particularly for energized electronics, but is less significant if the objective is to prevent ignition and restrict fire size.

In the absence of very rapid, automatic suppression, it is necessary to restrict the ignition and flame spread characteristics of wire and cable materials installed in the Detector. Such restrictions will limit the extend of damage and potentially reduce interruption of the experimental program in the event of an incidental electrical ignition in the Detector. Recommended flammability requirements for wire and cable materials are provided in a memorandum report [HAI, 1996]. See Appendix C for BaBar Memorandum, "BaBar Fire Protection Requirements for Wire and Cable."

4.2.2 Gas Mixture Fires

Isobutane in combination with other gases will be used in two areas of the Detector, the Drift Chamber, and the RPC chamber. Since isobutane is a flammable gas, its use raises safety concerns for the Detector and the facility. Ignition of a flammable gas mixture in the Detector will result in a very high speed propagating flame and most likely a deflagration (a reaction process which propagates at less than the speed of sound).

Isobutane has been proposed for use in the Drift Chamber in a 20 percent isobutane/80 percent helium mixture. The RPC chamber design includes consideration for the use of mixtures of isobutane with argon and Halon 134a ($C_2H_2F_4$) ranging from 1 percent to 15 percent isobutane depending on safety and detection requirements. The isobutane mixtures for the RPC chamber will contain 30 percent Halon 134a and balance argon.

An analysis was performed to determine the flammability hazard associated with using isobutane as a component in the gas mixtures for both the Drift Chamber and the RPC. This analysis examined 20 percent isobutane/80 percent helium mixtures for use in the Drift Chamber and a range of isobutane/30 percent Halon 134a/balance argon mixtures for use in the RPC chamber. A detailed discussion of this analysis is provided in Appendix A.

The 20 percent isobutane/80 percent helium mixture is outside the rich flammable limit and cannot burn as a premixed flame. A mixture containing about 6 percent isobutane is required to reach the Upper Flammable Limit (UFL) for this mixture. This corresponds to approximately a 3 to 1 dilution of the butane-helium mixture with air.

The range of premixed flammable mixtures from 6 to 1.8 percent butane would apply to either the case of air leaking into the Drift Chamber containing the butane-helium mixture or to a leak of the butane-helium mixture into the area outside the chamber once it was well mixed with air. However, because the percent butane in the original butane-helium mixture is above the rich limit, any leak out of the chamber could result in a diffusion flame supported by the butane fuel. Such a jet flame could have the potential to act as an ignition source for other fuels or to damage nearby equipment by the heat generated from the flame.

Adiabatic flame temperatures were determined for a range of butane/argon/C_2F_6/air mixtures. Perfluoroethane (C_2F_6) was used as a surrogate for Halon 134a in these calculations because thermodynamic data for Halon 134a was not available over the temperature range of interest. Since C_2F_6 is very similar to Halon 134a especially in heat capacity, its use should introduce little error in the analysis. Based on this analysis, mixtures of isobutane/argon/Halon 134a containing up to 6.6 percent isobutane are not considered flammable. The accuracy of the measurements associated with the experiment are highly sensitive to maintaining the gas mixture at the prescribed component volume and mass fractions. Continuous monitoring of the gas mixture along with immediate shutdown capability will be provided, with constituent gas monitoring accuracy at ±0.1 percent.

Under these conditions, it is conservative to envoke a 50 percent safety factor, which would allow gas mixtures with up to 4 percent isobutane to be used safely in the experiment. In addition, since the LFL was approximated, higher volume fractions of isobutane can be considered if the LFL is measured. If the actual LFL is measured and known, concentrations of isobutane up to an amount corresponding to 1 percent below the LFL would be acceptable.

4.3 Exposure Fires

With the exception of the cable trays and the Electronics House, the support equipment in IR-2 does not represent significant fire hazards. In addition, combustible loading in the adjacent buildings (Buildings 621 and 624) is too low to result in a fire which will spread into the IR-2 hall. Therefore, the dominant exposure fire scenarios will result from combustibles brought into IR-2 during maintenance, testing, and repairs.

Several candidate exposure fire scenarios were considered. These scenarios involved ignition and burning of materials either in the immediate vicinity of the Detector, or on the east side of the shield wall in the area of the IR-2 hall that will include the Electronics House. For part of the analysis, it was assumed that none of the existing or planned fire protection features would operate and effect the growth of the fire or the hazard to the Detector, the support equipment, or the IR-2 hall. Included were the following candidate scenarios:

(1) cable tray fires adjacent to BaBar (west IR-2),
(2) wood storage/equipment crates (east IR-2),
(3) flammable liquid spills (east IR-2),
(4) Class A combustibles in open metal drums (east IR-2), and
(5) Class A combustibles in the Electronics House (east IR-2).

The impact on these candidate fire scenarios was based on the following effects:

(1) exposure damage to high value equipment,
(2) exposure damage to structural elements,
(3) potential exposure damage to the Detector, and
(4) adverse life safety conditions.

Appendix B provides a detailed documentation of the analyses related to the potential impact of the candidate fire scenarios. A summary of the results of those analyses is presented here.

4.3.1 Flammable Liquid Pool Fires

Minor amounts of flammable liquids will be temporarily used and stored in IR-2 for repairs, maintenance, and fabrication activities. Calculations were performed to estimate the impact of a spill fire associated with either 7.6 L (2 gal) or 18.9 L (5 gal) of a flammable liquid.

If the concrete curtain is not in place above the shield wall for the larger 18.9 L (5 gal) spill fire, enough heated gases and combustion products will be transported to the west side of the IR-2 hall to expose the Detector. However, the exposure is expected to be minor, and temperatures are not expected to exceed 120°C at the Detector.

Damage to the IR-2 hall is expected to be minor. However, if the spills occur within 1.5-2 m from vertical steel columns, the columns could be exposed to temperatures in excess of the failure temperature for steel (i.e., 593°C). In addition, pool fires closer than 2 to 3 m from the Electronics House will result in thermal radiation levels high enough to ignite typical siding materials and damage both electronics and machine equipment.

4.3.2 Wood Storage Crate Fires

Common miscellaneous combustibles include wood crates used to ship and store equipment. A series of calculations were performed to estimate the impact of a fire involving from 1 to 6 such crates. It was assumed that these crates would only be located on the east side of the shielded wall.

The results of the analysis indicate that a fire involving six wood crates could result in flashover in the IR-2 hall and severe damage to the contents. However, serious damage to the IR-2 hall is not expected unless the crates are located within 1 to 3 m of the steel support columns, depending on the number of crates. In addition, crates located within 1.5 to 4 m of the Electronics House will result in damage to the House due to thermal radiation.

It should be noted that one or two crates do not pose a hazard to the IR-2 hall or the contents provided they are spaced far enough from the columns and other combustibles.

4.3.3 Steel Drum Fires

Steel drums are commonly used for storage of miscellaneous materials and trash. Fires involving 1, 2, 4, or 6 drums were considered. Estimated peak burning rates ranged from 130 to 775 kW which were considerably lower than the burning rates for the crate and flammable liquid pool fires.

Fires in steel drums containing trash and solid materials will not likely result in an exposure hazard to the Detector or other support equipment unless they are positioned directly adjacent to them.

4.3.4 Cable Tray Fires

Both vertical and horizontal arrays of cable trays are located adjacent to the Detector along the west and south walls of IR-2. The peak estimated heat release rate from the horizontal configuration was about 2 MW. The rate for vertical orientation was somewhat higher at 2.3 MW due to vertical flame spread effects.

Under the assumptions made regarding the number of cables in the trays, the fire propagation rate for "tray rated" cables and the orientation of the Detector, the results indicated that a cable tray fire may or may not directly expose the Detector to thermal radiation high enough to result in the onset of damage. Ventilation of the fire into the PEP-II tunnel assisted in reducing the hazard exposure to the Detector. However, with the concrete curtain in place forming a separate, smaller area in the IR-2 hall, the heated gas layer could potentially expose the Detector before the fuel in the cable trays is consumed.

4.3.5 Electronics House

The Electronics House, if fully involved in a fire that starts inside the House, represents a serious hazard to the IR-2 hall and the Detector. However, there is a limited amount of combustible loading anticipated for the Electronics House. Calculations documented in Appendix B indicate that it will be difficult to achieve flashover in the Electronics House if the doors are closed due to oxygen depletion during the initial growth of the fire. It was estimated that at least 23 kg (50 lb) of ordinary combustible materials would have to be burned to reach flashover and extensive fire spread in the Electronics House if a door was left open, providing additional ventilation.

5.0 FIRE PROTECTION FEATURES

Both active and passive fire protection features will be relied upon for protection of BaBar and the IR-2 facility. Included are (1) a fire protection water supply, (2) fire hydrants, (3) automatic fire sprinkler systems, (4) fire detection, alarm, and reporting systems, (5) fire barrier systems, (6) portable extinguishers, and (7) ventilation exhaust systems.

5.1 Existing Fire Protection

5.1.1 Water Supply

The fire protection water supply is part of a combined domestic/fire water system which is supplied from Menlo Park, a local community. The site water supply is a looped system, connected at two separate locations to the Menlo Park system by 24 inch supply mains.

The water supply meets DOE Order 5480.7A requirements for supplying the fire protection water demand for a minimum of two hours. The looped system provides redundant, although not totally independent, water supplies. A loss of supply from one of the primary feeders will not result in a loss of site fire protection water. The water supply from the community has independent sources, including storage tanks and reservoirs.

5.1.2 Fire Hydrants

Fire hydrants are located at 1/5 of a mile intervals along the ring road, including adjacent to IR-2. Hydrant #1404 is located on the west side of the building, at a distance of 15 m (50 ft). Hydrant #1403 is located near the north-east corner of the building, 12 m (40 ft) from the Counting House (Building 621). Two additional hydrants are located along the ring road, less than 91.5 m (300 ft) from IR-2.

The hydrant spacing in the vicinity of IR-2 meets the requirements of DOE Order 6430.1A, Section 0266-4, which stipulates coverage of at least two hydrants, each required to be within 91.5 m (300 ft) of IR-2.

5.1.3 Suppression Systems and Equipment

5.1.3.1 Automatic Sprinkler Systems

The main IR-2 hall is protected by a wet pipe automatic sprinkler system. The sprinkler system was installed during construction of IR-2 and is essentially in compliance with NFPA 13, "Standard for the Installation of Sprinklers Systems," including the 1994 edition [NFPA 13, 1994]. The sprinkler heads are standard type with a 12.7 mm (0.5 in.) orifice and 74°C (165°F) temperature rating.

The sprinkler system is hydraulically designed to provide a water spray density of 6.1 Lpm/m^2 (0.15 gpm/ft^2) over a 139 m^2 (1500 ft^2) operating area. The capability meets the requirements in NFPA 13 for "Ordinary" hazard protection which was determined to be appropriate for this occupancy (refer to Section 5).

The Counting House (Building 621), the Cryogenic Control center, and the power supply building (Building 625) are also currently protected by "wet" automatic sprinkler systems, and the PEP magnet power supply room will be protected by "wet" automatic sprinklers. These systems are also designed to protect "ordinary" hazard occupancies and meet the design requirements of NFPA 13. The sprinkler heads are standard, 12.7 mm (0.5 in.) orifice, 74°C (165°F) temperature rated.

Consideration is being given to converting the sprinkler system for the Counting House to a preaction type system. This is discussed further in Section 6.2.

It should be noted that a wet sprinkler system is installed throughout PEP-II to protect the beam tunnel, including at the entrances of IR-2. The system uses 12.7 mm (0.5 in.) orifice quick response sprinklers with a 100°C (212°F) temperature rating.

5.1.3.2 Standpipes

There are no standpipes in the IR-2 hall or adjacent buildings that would be used for firefighting. Standpipes are considered unnecessary due to access to fire hydrants at both the upper and lower level of the IR-2 hall. Standpipes with fire hose connections are installed in the beam tunnel where fire department access to the ring road hydrant system is limited.

5.1.3.3 Fire Extinguishers

Fire extinguishers are located in each of the facility buildings. The number and location of the extinguishers are in compliance with the requirements of NFPA 10, "Portable Fire Extinguishers," [NFPA 10, 1994]. Most of the extinguishers are CO_2 type due to the effectiveness of CO_2 suppressant on electrical/electronics fires.

5.1.4 Alarm System

The existing alarm system for IR-2 is high voltage technology. The system is connected to the site-wide fire alarm system and the Palo Alto Fire Department dispatch center. The existing alarm system is obsolete and will be replaced.

5.1.5 Smoke Detectors

The existing smoke detectors in the IR-2 hall and Counting House are high voltage type. These detectors are obsolete and will be replaced.

5.1.6 Pull Stations

Manual fire alarm pull stations are located in IR-2 and the Counting House. The pull stations are connected to the site-wide fire alarm system.

5.1.7 Smoke Control/Ventilation

There are two roof-mounted, manually operable exhaust fans in the IR-2 hall. The fan capacities are 18,400 cfm each. One is located on each side of the shield wall. They are automatically shut off in the event of a fire alarm and can be reactivated by the fire department.

Supply ventilation and additional exhaust are provided to IR-2 from the PEP-II beam tunnel. The fans in the tunnel are also shut off in the event of a fire alarm. The fire department can restart these fans as well as the fans in IR-2 to assist in smoke evacuation of the tunnel or the IR-2 hall.

5.1.8 Fire and Smoke Barriers

The walls between the IR-2 hall and adjacent spaces are not rated fire barriers. Under the occupancy use and anticipated combustible loading, there are no requirements to subdivide the

IR-2 hall or separate it from the other buildings. Life safety requirements are also met without further subdivision.

5.1.9 Emergency Response and Training

The SLAC site maintains a professionally trained fire department on a 24-hour basis, seven days a week. Operations within the Department include fire suppression, emergency medical, hazardous materials response, and training/preplanning. Fire department response time to the IR-2 hall is estimated at 3.5 to 4 minutes.

5.1.10 Fire Protection Related Run-off Concerns

None of the building areas reviewed as part of this FHA have "loose" contamination which could be spread by automatic sprinkler or firefighting efforts. While the design limit for sprinkler flow for a 20-minute period is a little over 4,500 gallons, this represents an extreme worst case. Based on the combustible loading and sprinkler proximity in each of the sprinklered areas, it is unlikely that more than one or two sprinklers will activate. Assuming a 20-minute duration for two sprinklers, the total water discharge is closer to 750 gallons.

5.1.11 Recovery Potential

The limited combustible loading minimizes the severity of anticipated fires in the buildings associated with the BaBar Detector Project. The heavy reinforced construction of the west end of IR-2 is unlikely to sustain significant damage, even by the most severe fires that were considered possible under the planned occupancy. In addition, current anticipated combustible loadings for the east end of IR-2 as well as in the adjacent buildings (Buildings 621, 624, and Cryogenics Control Room) are low enough that clean up and repair due to an incidental fire will be an acceptable strategy.

5.1.12 Fire Protection Programmatic Issues

A building emergency plan and a fire department preplan do not exist yet for the BaBar Detector Project. These will be developed before commissioning and operation of the Detector.

5.2 Planned Fire Protection

Specific fire protection features are planned or under consideration specifically for the BaBar Detector Project. These features will require modifications to existing fire protection features as well as incorporation of new protection systems.

5.2.1 Main IR-2 Hall

The primary fire alarm system in IR-2 will be replaced with Pyrotronics addressable fire alarm panels and devices. The panels will be connected to the site-wide fire alarm system and the Palo Alto Fire Department dispatch center. The ionization smoke detectors will be replaced by system compatible, single-station photoelectric smoke detectors.

In addition, an HSSD (High Sensitivity Smoke Detector) system will be installed at the ceiling and two intermediate levels in the west end of the main IR-2 hall, above the Detector. This system is capable of multiple pre-alarm and alarm points, which can be adjusted to sensitivities appropriate for the performance requirements during the BaBar Detector Project.

Consideration is being given to removal of the automatic sprinkler system on the west side of the shield wall. Due to the low fuel loading, high ceiling and number of obstructions, the sprinkler system is not expected to be effective. Incidental fires, if they occur, will be too small to result in timely response by the sprinkler system. And, most fires will occur in highly obstructed areas, including in the Detector, in support electronics racks or in the cable trays. Water sprays from ceiling level sprinklers will have little or no effect on such fires. These fires are not expected to result in extensive damage to the IR-2 hall due to the inherent fire resistance of the construction. In addition to the lack of effectiveness, the crystals located in the calorimeter subsystem of the Detector are highly susceptible to hygroscopic damage. Minor amounts of water can effectively result in BaBar being out of service for an extended period.

5.2.2 Electronics House

Both fire detection and suppression systems will be installed in the Electronics House. It is critical to continued operation of the BaBar Detector Project that the impact of any incidental fires in the Electronics House be minimized. Based on discussions with the designers of the Electronics House and several of the users, the fire protection design has been developed to ensure that damage from fires is limited to only part of an electronics rack, whether the fire starts in a rack or outside the rack in the enclosure.

Very early detection is necessary in order to have any chance of meeting such an objective. HSSD systems will be installed in each electronics rack. Selected electronics racks located on the roof of the enclosure will also utilize HSSD detection. Such systems are capable of detecting initial pyrolysis products at order of magnitude less concentrations than conventional smoke detection while minimizing false alarms.

CO_2 suppression systems will be installed to protect the inside of each electronics rack and in the underfloor cable plenum. The systems will be discharged following detection by the HSSD systems (in the racks), or photoelectric detection in the underfloor plenum.

In addition to these features, single-station photoelectric smoke detectors and preaction automatic sprinklers will be installed in the Electronics House. The preaction valve will be operated as a result of detection by the photoelectric detector system, charging the sprinkler system piping with water. The detection systems will be connected to the primary fire alarm system. It is recommended that the sprinkler heads installed in the Electronics House be of the standard spray, quick response type in order to extinguish ordinary combustible fires in their incipient stage of burning.

Power and signal interruption will be automatic, tied to temperature monitoring of the electronics or smoke detection interlock. Power interruption will also include most of the electronics racks supplied by the UPS systems provided in support of the Electronics House. There will be several racks that cannot be de-energized automatically due to the potential for considerable damage to the Detector and selected support equipment.

5.2.3 Counting House (Building 621)

An addressable fire alarm system with single-station photoelectric smoke detectors will be installed throughout the Counting House, in compliance with NFPA 72. The wet pipe sprinkler system will be modified to perform as a preaction system. The preaction valve will be operated based on smoke detector response.

5.2.4 Cryogenics Control/PEP Magnet Power Supply (Building 624)

The cryogenics control room and the PEP magnet power supply room are adjacent to each other on the south side of the IR-2 hall. These spaces will be protected by wet sprinkler systems, designed to protect ordinary hazards. The sprinklers will be 12.7 mm (0.5 in.) orifice with a temperature rating of 74°C (165°F).

5.2.5 Tool Shed

An existing shed located on the east outside wall of IR-2 between the two roll-up doors will be used as a tool shed. The shed will be protected by a standard wet pipe sprinkler system. The system will use standard 12.7 mm (0.5 in.) orifice sprinklers with a 74°C (165°F) temperature rating.

5.2.6 PEP-II Power/BaBar Solenoid Power Building (Building 625)

The currently installed wet pipe sprinkler system will remain in service in this building. In addition, photoelectric smoke detectors will be installed and connected to an addressable fire alarm panel for signaling to the site wide fire alarm system.

5.2.7 Gas Mixing House

The final design of the Gas Mixing House has not been completed. Current plans include volumetric and mass flow monitoring form the Gas House to the Detector, including in the recirculation system, with automatic interlock to shut down gas flow. Consideration should also be given to gas detection, automatic ventilation (interlocked), smoke detection, and automatic sprinklers in this building.

5.2.8 BaBar Fire Protection

A brief description of the BaBar subsystems is provided in Section 3. A discussion of the dominant fire hazards associated with the Detector, including potential hazards in the Detector and exposure hazards in the IR-2 hall are discussed in Section 7. In summary, the dominate fire hazards are associated with electrical/electronic ignition sources, flammable materials such as cable jacket insulation, polystyrene thermal insulation, and the gas systems. The discussion presented in this section is limited to the fire safety features currently included in the Detector design or under consideration.

Due to equipment sensitivity, performance demands and space restrictions within the Detector, the use of conventional fire protection systems to protect the Detector from an internal fire would not be performance or cost effective. The use of water based or gaseous suppression systems in the Detector is not recommended. The introduction of water into the Detector subsystems (intentionally or accidentally) will result in significant damage. In addition, overpressure conditions resulting from internal injection of gaseous suppression agents will result in considerable damage in the Drift Chamber. As a result of these problems, alternative fire protection features will be used. A more appropriate approach involves fire prevention, passive methods to limit fire growth, and very early detection.

5.2.8.1 Limiting Materials' Flammability

The materials used in the Detector will be restricted in terms of their flammability characteristics in order to minimize the ignition potential and limit the fire growth and spread rate potential. Insulating materials will be fire retardant treated, with the exception of a limited number of applications where fire retardant additives could react adversely due to the environment in the Detector. An example is in the Drift Chamber where conventional bromated materials would absorb free electrons.

5.2.8.2 Cable and Wire Flammability Specification

A wire and cable specification has been developed and implemented to limit potential ignition and fire propagation in the Detector (reference Appendix C). These insulating materials comprise the largest source of fuel for an internal fire in the Detector. Therefore, the specification was developed to restrict the flammability of wire and cable insulation wherever practical.

It should be noted that minor deviations are expected on a case by case basis due to availability problems associated with limited quantities of special purpose wire and cable. Each deviation must be approved by the BaBar Control Board in consultation with the BaBar Safety Officer and the SLAC fire protection engineer.

5.2.8.3 Gas Systems

The gas systems to be used in the Drift Chamber and the RPC Chamber will be formulated to ensure that the resulting gas mixtures are outside the flammable limits under normal operation of the Detector. The current anticipated mixture for the Drift Chamber includes 80 percent helium and 20 percent isobutane. The 20 percent isobutane results in this mixture being above the upper flammable limit (UFL) and, therefore, will not burn. The isobutane volume in the mixture must be reduced to 6 percent (vol) to have a flammable mixture. This corresponds to approximately a 3 to 1 dilution of the butane-helium mixture with air.

The candidate gas mixture for the RPC is comprised of isobutane, argon, and Halon 134A. The Halon 134A is fixed at 30 percent (vol). The volume concentrations of the isobutane and argon are still being evaluated. The flammability of the mixture will be kept below the Lower Flammable Limit (LFL). A detailed analysis of the flammability hazards of the gas mixtures was performed as part of this effort and is provided in Appendix A.

5.2.8.4 Process/Detector Safety Controls

A dominant safety feature that will be employed is process control. Thermal conditions, pressure variation, gas detection, gas compound mass and volume flow rates, and oxygen depletion will be monitored continuously. Interlock systems will be installed that will shut down parts or all of the Detector as well as power and gas supplies if conditions vary outside established operational and safety limits.

5.2.8.5 Smoke Detection

High sensitivity smoke detection (HSSD) will be installed in the Detector, providing shutdown capability and a fire alarm signal. This system will be adjusted to detect very low concentrations of combustion products.

5.2.8.6 Nitrogen Inerting

During operation, the calorimeter will be inerted with nitrogen (N_2). However, when the Detector is open for maintenance or modifications the N_2 may be replaced by dry air. This will increase the risk somewhat.

5.2.8.7 Electrical/Signaling Systems

All power and signaling systems supporting the Detector will be grounded and tested in accordance with NFPA 70, The National Electrical Code [NFPA 70, 1996], before initial Detector operation.

5.2.8.8 Electronics Support Racks

Approximately ten enclosed racks will be located adjacent to the Detector. These racks will be protected by HSSD detection. Consideration will also being given to installation of a CO_2 suppression system to protect these racks where appropriate.

5.2.8.9 Cable Tunnel Protection

Two cable tunnels which connect the electronics from the Detector to the Electronics House will be firestopped at each end with vermiculite bags. The objective is to minimize the potential exposure of the Detector to a cable fire which propagates from the Electronics House side of the shield wall.

5.2.9 BaBar Exposure Protection

The primary exposure hazards to BaBar are (1) a potential cable tray fire, and (2) an equipment or maintenance activity fire outside the Detector.

5.2.9.1 Cable Tray Protection

The horizontal cable trays on the west wall of the IR-2 hall will be firestopped every 6.1 m (20 ft) using vermiculite filled bags or equivalent to limit both vertical and horizontal fire propagation. The vertical trays will be firestopped every 3 m (10 ft). In addition, thermal radiation shielding will be installed between the Detector and the PEP cable trays on the west side of the Detector. This is the location that is closest to the cable tray array that runs along the west wall and is most vulnerable to damage due to thermal radiation from a propagating fire in the cable trays. An alternative option to thermal shielding under consideration is to install fire barrier separations between the cable trays along the west wall of IR-2 to limit the potential for tray to tray fire spread. This would considerably limit the extent of damage to the cables in the event of an incidental ignition in one of the trays as well as reduce the thermal exposure to BaBar.

It is also recommended that thermal detector wire be installed in each cable tray and connected to the BaBar control panel and the addressable fire alarm system. This will provide detection of "hot" spots in the cable trays prior to flaming conditions. BaBar shutdown and intervention can be achieved before it is exposed to contaminating combustion products, including acid gases and particulates.

5.2.9.2 Electrical/Support Equipment

All equipment located permanently or temporarily adjacent to the Detector will be installed and operated in compliance with NFPA 70. As discussed in Section 6.2.8, electronics racks will be protected by photoelectric detection. Localized in-cabinet CO_2 suppression is under consideration.

5.2.10 Housekeeping and Administrative Controls

Procedures will be developed by the BaBar Safety Officer to address general housekeeping in the Detector area, limits on combustibles, and operation and maintenance activities. Implementation of standard industrial practices regarding hazardous processes will be done in cooperation with the SLAC Safety Health and Assurance Department. Equipment that pose specific fire exposure hazards such as propane fueled forklifts and welding equipment will be removed from the Detector area after any needed use. The use of such equipment will be monitored closely to ensure compliance with industrial safety practices.

6.0 PROPERTY AND EQUIPMENT

6.1 Safety Class Equipment/Vital Safety Systems

DOE is in the process of redefining Safety Class items or systems. For purposes of this analysis, it was assumed that Safety Class is any system, component, or structure, including portions of process systems, whose failure could cause undue risk to the environment or the safety and health of the public. Safety Class items are subject to the appropriate higher quality design, fabrication, and industrial test standards and codes per DOE Order 6430.1A or to other compatible safety-related codes and standards that are appropriate for the system being designed. Safety Class items must be controlled by a comprehensive quality assurance program consistent with the requirements of Quality Assurance Program Requirements for Nuclear Facilities (ANSI/ASME NQA-1).

There are no safety class items (SCI) or vital safety systems (VSS) located in the IR-2 hall or as part of the BaBar Detector Project. The Project has not been designated as a "Vital Program" by the Department of Energy (DOE) since no special nuclear materials (SNM) will be located, handled, or transported from the IR-2 hall as a result of this project. The risk of significant threats to public safety or the environment are considered negligible for the Project.

6.2 High Value Property

High value property is defined as having a replacement cost of $1 million or greater. In the context of the BaBar Detector Project, the Detector (BaBar), the Electronics House, and the Cryogenics Plant are considered high value properties. While no single instrument or equipment item in the Electronics House exceeds the criterion, the configuration of this space requires consideration of the value of all the instruments or equipment in the space. A significant fire incident in the Electronics House could destroy most or all of the equipment in the space at a replacement cost in excess of $1 million. Cost estimates for replacement of these items include the following:

BaBar	$70 M,
Electronics House	$10 M, and
Cryogenics Plant	$3 M.

The estimated replacement cost of the IR-2 hall is $10 million. In addition, the PEP-II beam line is considered a high value property. An evaluation of the beam line and its concomitant cable plant is included in the FHA for PEP-II [SLAC, 1995].

6.3 Critical Process Equipment

Critical process equipment normally refers to equipment associated with processing of special nuclear materials, including process waste. It is defined in DOE Order 5480.7A as equipment would require more than six months to replace if damaged or destroyed.

There is no critical process equipment associated with the BaBar Detector Project. However, it should be noted that several components of the Project including the Detector (BaBar), Electronics House, and the Cryogenics Plant, if exposed to a serious fire, would require in excess of six months to restore/replace.

7.0 LIFE SAFETY CONSIDERATIONS

The evaluation of life safety was based on the facility features, potential fire severity, locations of fire barriers, occupant density, and operational requirements. The requirements in NFPA 101, The Life Safety Code [NFPA 101, 1994], were used as the primary basis for evaluation of the life safety features.

7.1 Occupancy and Hazard Classification (*Special Purpose Industrial*)

7.1.1 Classification of Occupancy

Under the provisions of NFPA 101, the BaBar facility is classified as a "Mixed" Occupancy; the main IR-2 hall is a Special Purpose Industrial Occupancy while the immediately adjacent structures (Buildings 621 and 624) are mixed business, laboratory, and industrial spaces. The beam line tunnel is also considered a Special Purpose Industrial Occupancy.

For purposes of this analysis, it was appropriate to classify all of the areas associated with the BaBar Detector Project as a Special Purpose Industrial Occupancy, characterized by ordinary or low hazard industrial operations.

7.1.2 Hazard of Contents (*Ordinary*)

The level of hazard of contents was based on the combustibility characteristics of the contents. The hazard classes include the following:

Low: Low hazard contents are those of such low combustibility that self-propagating fires cannot occur;

Ordinary: Ordinary hazard contents are those that are likely to burn with moderate intensity and/or potentially give off a considerable volume of smoke; and

High: High hazard combustibles are those that are likely to burn with extreme rapidity or from which explosions are likely.

Both low and ordinary hazard contents are present in the IR-2 hall as well as the adjacent spaces. Therefore, the BaBar facility was appropriately classified as Ordinary.

7.2 Occupant Load (*Low*)

The occupant load is the number of persons for which egress capacity must be provided. Under NFPA 101, for a Special Purpose Industrial Occupancy, the occupant load is one occupant per 9.3 m^2 (100 ft^2) of gross floor area. The gross floor area and the associated maximum allowable occupant load for the three primary spaces associated with the location of the Detector in the IR-2 Hall are summarized below:

Building Number	Description	Gross Area m^2 (ft^2)	Maximum Occupant Load
620	IR-2 Hall	752 (8092)	80
621	Counting House	385 (4060)	40
624	PEP Magnet Power	68 (732)	7

The normal working occupancy for these spaces during installation and operation of BaBar experiments is significantly below these limits. In fact, the normal number of personnel assigned to this facility is estimated at less than 35 based on input from the BaBar Safety Officer. The IR-2 hall will normally have 5 to 7 persons working on the Detector and in the Electronics House once fabrication is completed. The largest occupant load will be in the offices, shop, and control center of the Counting House, estimated at between 20 and 25 persons. Due to congested conditions, visitor access to the west side of the IR-2 hall will be limited.

7.3 Capacity of Means of Egress (*Adequate*)

Egress capacities were calculated based on requirements in paragraph 5-3.3.1 of NFPA 101. The egress factor for stairs is 0.3 in. per person and level exits is 0.2 in. per person. The width of the exit is divided by the appropriate factor to determine the capacity of the exit.

The capacity of the means of egress from the primary areas (Buildings 620, 621, and 624) is far in excess of the anticipated or maximum allowable occupant load. Exit access widths exceed 28 in. throughout these areas. And, headroom along means of egress is greater than the 6 ft 8 in. minimum required by NFPA 101.

7.4 Number/Location of Means of Egress (*Adequate*)

A minimum of two widely spaced means of egress are required and are provided in the IR-2 hall, and Buildings 621 and 624. During periods of installation and maintenance of the Detector, egress paths will be available toward the west and east ends of the IR-2 hall. The beam tunnel represents the west exits and would have to be used by persons evacuating from the west side of the shield wall if a fire blocked egress to the east. When the Detector is operating, the shield wall is in place, and no personnel will be located on the west side of the wall.

Small structures such as the tool shed are only required to have one means of egress. Building 625 (PEP-II Power and BaBar Solenoid Power Supply) has two remote exits. And, the planned Gas Mixing House will have two remote exit doors.

7.5 Dead Ends and Common Path of Travel (*Adequate*)

NFPA 101 permits dead end corridors of up to 15 m (50 ft) in length in Industrial Occupancies. It also permits common paths of travel up to 15 m (50 ft) in unsprinklered and 30 m (100 ft) in sprinklered buildings. There are no dead-end corridors in excess of 15 m (50 ft). In addition, storage of combustibles or items that restrict egress paths will not be permitted.

7.6 Travel Distance to Exits (*Adequate*)

The travel distance is defined as the length of a path from the point farthest in the building to its nearest exit. Normal exits for the individual areas (buildings) are exit doors which open to the outside or to a separate building/fire area.

The maximum allowable travel distances are not exceeded with the exception of the exit path from the IR-2 Hall through the beam tunnel to the closest exit in the PEP-II ring housing.

The number of personnel being required to consider this as a means of egress is very small. In addition, these individuals will only occupy these areas infrequently, normally to perform maintenance. The primary escape route, the limited number of occupants, their familiarity with the occupancy, the existence of automatic sprinklers in the beam tunnel, and restrictions on storage of combustibles provide adequate safeguards to meet NFPA 101.

7.7 Lighting and Marking of Exits (*Adequate*)

Doors and exit access hallways are clearly marked with exit signs. The doors will be kept unobstructed. Normal illumination in the IR-2 hall and adjacent spaces is powered by site power. Emergency lighting is provided by wall-mounted dual-lamp sealed-beam battery-powered units, and emergency backup power to the building lighting system.

7.8 Minimum Construction Requirements (*None*)

There are no minimum construction requirements for Special Purpose Industrial Occupancies.

7.9 Exposure to BaBar

Under operating conditions, personnel will not be located on the west side of the shield wall. Therefore, there are no life safety problems other than to ensure that these restrictions are maintained.

During periods when the Detector is shut down for maintenance or modifications, personnel will be located in the area where the Detector is located. In addition, personnel will be required to enter the Detector (while in the open position) to perform necessary adjustments on the subsystems. The area inside the Detector is a "permit required" confined space, and appropriate procedures for entry will be developed.

An analysis of the fire exposure risk to individuals working inside the Detector is outside the scope of this FHA and dependent on the final Detector subsystem designs.

8.0 MAXIMUM POSSIBLE FIRE LOSS (MPFL)

The MPFL estimate is based on the assumption that both automatic suppression and manual firefighting efforts have no impact. The MPFL for the BaBar Detector Project involves a fire in the Detector while open. The damage resulting from this fire scenario will include loss of several, if not all, of the subsystems and require considerable resources for restoration. Significant structural damage to the IR-2 hall is not expected.

The replacement cost for BaBar is estimated at $70 M. Clean-up costs for thermal and corrosion damage to the support equipment in the IR-2 hall and the PEP-II tunnel is estimated at $8.0 M, resulting in a total MPFL of approximately $78.0 M.

9.0 MAXIMUM CREDIBLE FIRE LOSS (MCFL)

The MCFL for the BaBar Detector Project also involves a Detector fire. However, the use of flammability requirements, HSSD detection, and machine control systems is expected to limit the damage somewhat. Replacement costs are estimated at $35 M or less, depending on the extent of implementation of these fire protection features. In addition, extensive damage to the PEP-II tunnel and support equipment is not expected. Clean-up costs are still estimated at $8.0 M, resulting in a total MCFL of $43.0 M.

10.0 FIRE DEPARTMENT RESPONSE

SLAC operates an on-site, fully staffed and well trained fire department. The department is capable of handling a fire in the IR-2 hall. The response time is estimated at from 3.5 to 4 minutes, with an additional 3 to 5 minutes for staging activities and initiation of interior firefighting.

11.0 RECOVERY POTENTIAL

The limited combustible loading minimizes the severity of anticipated fires in the buildings associated with the BaBar Detector Project. The heavy reinforced construction of the west end of IR-2 is unlikely to sustain significant damage, even by the most severe fires that were considered possible under the planned occupancy. In addition, current anticipated combustible loadings for the east end of IR-2 as well as in the adjacent buildings (Buildings 621, 624, and Cryogenics Control Room) are low enough that clean up and repair due to an incidental fire will be an acceptable strategy.

12.0 POTENTIAL FOR TOXIC, BIOLOGICAL, AND RADIATION INCIDENT DUE TO FIRE

There are no biological agents stored or used in this facility. The potential for a toxic materials incident due to fire is limited. Ignition and burning of wire and cable insulation, ignition of a limited volume of flammable gas or liquid or burning of incidental Class A materials will generate some amount of toxic combustion products. The hazard associated with these releases depend on the ignition scenario, the location of the incident, and the proximity of occupants but is expected to be confined to the building.

There are three radiation source terms to be considered: the beam radiation, the induced activity of the BaBar component, and the D-T generator system. The first source term should contribute no dose to any worker or firefighter. This is because the beam is contained inside the shielding house. In case of fire, either the operators will turn the machine and the beam off or the PPS (Personnel Protection System), a fail-safe interlocked system, will turn the machine and beam off long before an individual can enter the housing.

The induced activity of the BaBar component mainly concentrates on the metal parts (magnet and pipe) of the detector. A previous analysis showed that the maximum activity is around a few mCi, and the resulting maximum dose rate at 1 m away from the sources are a few mrem/h (including the short-lived isotopes). The external dose consequence to firefighters is, therefore, small. Since the metals are not flammable, internal contamination to workers due to release of induced activity caused by fire should be minimal.

The D-T generator, the last source term, is used to generate 14-MeV neutrons to activate freon liquid so that the high-energy gammas from activated fluid can be used to calibrate the CsI calorimeter. The issue has been reviewed and approved by the SLAC Radiation Safety Committee. Again, the generator will be shielded with 3-ft thick concrete (or 1 ft Fe and 1 ft polyethylene and then a thin Al or SS metal cover). The generator is also interlocked with the shielding. Therefore, the only concern is the activity in the fluid and the 2 Ci H-3 target inside the SS accelerator head. The major induced isotope in the freon fluid is very short-lived N-16 (7 s half-life). Therefore, the activity should disappear quickly and contributes no dose to workers.

The other concern was what if the D-T generator is damaged during the fire and what is the consequence of tritium release from the head. According to NCRP Report 72, "Radiation Protection and Measurement for Low-voltage Neutron Generators" [1983], in the case of breakage of the head, a few mCi of tritium gas (for a tritium target activity of a few Ci level) will be released into the air. If it is assumed that all the tritium gas immediately becomes tritiated water (which is more hazardous than tritium gas) and all the tritiated water is inhaled by a worker nearby the leak, this worst integrated dose turns out to be about 1 rem. Considering the scenario, the dose consequence should be acceptable.

In addition, in the event of a fire, the beam is interrupted. Also, there are redundant entry doors that automatically interrupt the beam when opened. It has been determined that in an emergency the Fire Department can enter the west end of IR-2 after the beam is interrupted with negligible radiation exposure hazard.

13.0 EMERGENCY PLANNING

The BaBar Safety Officer will prepare a comprehensive Emergency Plan for the BaBar Detector Project. The Plan will include guidance for evacuation and emergency procedures for the IR-2 hall and support buildings associated with BaBar.

14.0 SECURITY CONSIDERATIONS

The security measures currently contemplated for BaBar including restricted access during Detector operation, will not compromise fire protection or life safety considerations.

15.0 NATURAL HAZARDS IMPACT ON FIRE SAFETY

The SLAC site is located near an active earthquake fault. The area is classified as a seismic zone 4 under the Uniform Building Code (UBC). The IR-2 hall was constructed in accordance with the requirements in the UBC for Zone 4 seismic design, including the automatic sprinkler systems. The IR-2 hall is also constructed to withstand winds in excess of the geographical wind loading (70 mph) designated in the UBC at the time of construction.

Modifications to existing structures and fire protection features as well as new construction (i.e., Gas Mixing House) will be completed in accordance with UBC requirements for seismic and wind loading.

16.0 EXPOSURE FIRE PROTECTION

Adequate distances exist to adjacent structures to prevent fire spread from one of these structures to the IR-2 hall. Fire spread from the PEP-tunnel to the IR-2 hall is possible, but would be of limited impact. The combustible loading in the PEP-II tunnel is relatively low, and the tunnel is protected by automatic sprinklers.

In the event of a major earthquake, the IR-2 hall could be exposed to a wildland fire of such a magnitude that the site Fire Department's resources would be overrun. However, while such an event may lead to fire spread to IR-2 and extended damage, the exposure to the public would remain negligible.

17.0 CONCLUSIONS AND RECOMMENDATIONS

The fire hazards and associated risks related to the BaBar Detector Project warrant preventative or mitigative strategies consistent with the loss limitations stipulated in DOE 5480.7A. The following recommendations result from the analysis outlined in the FHA, consideration for cost-effective strategies to maintain the BaBar Detector Project for an extended period without significant interruption, and assurance of adequate life safety.

Consideration should be given to all of the following recommendations. Failure to implement a particular recommendation should be carefully reviewed since trade-offs and dependencies are affected.

<u>General</u>

(1) Prepare an emergency preplan for the Project.

(2) Establish administrative controls to limit combustibles and hazardous processes.

Main IR-2 Hall

(1) Install addressable fire alarm system, connected to site-wide fire alarm system and the Palo Alto Fire Department dispatch center.

(2) Install two HSSD systems in IR-2. Locate HSSD detectors at the ceiling and two intermediate levels on the east and west sides of the shield wall.

(3) Maintain wet automatic sprinkler system on east side of IR-2. Replace lower level heads with fast response type sprinklers.

(4) Removal of the automatic sprinkler system on the west side of the shield wall can be done if all of the recommendations associated with BaBar and the cable trays are implemented.

(5) Install thermal detection wire in the cable trays along the walls near the Detector and in trays that supply cables to the Detector.

(6) Install a thermal radiation barrier between the Detector and the horizontal cable tray array located on the west wall of IR-2, or provide fire barrier separations between each cable tray along the west wall to limit the potential for fire spread to adjacent trays.

(7) Provide firestopping at 3 m (10 ft) intervals for vertical cable trays and 6 m (20 ft) for horizontal cable trays in the west area of IR-2 to reduce the potential fire exposure to the Detector in the event of an ignition in a cable tray.

(8) Restrict combustibles in the IR-2 hall. Limit flammable liquids to 7.6 L (2 gal) quantities in any single unprotected area (i.e., outside a listed flammable liquids cabinet). Also, restrict the number of wood packing crates and similar materials to

400-500 kg (900-1000 lb) in any single area. (This is roughly equivalent to two of the large crates analyzed in Appendix B of the FHA.)

(9) Provide a 2 m (6.6 ft) separation distance from combustibles and the Electronics House and structural columns.

(10) Maintain manually operated roof exhausts with controls accessible to the fire department.

(11) Leave the entrances to the PEP-II tunnel open to take advantage of the tunnel volume for ventilating fire gases away from the Detector. Calculations indicate that for several plausible exposure fire scenarios an additional three to ten minutes will be available before exposure of BaBar to high temperatures and corrosive gases from a descending hot gas layer. (Note that the PEP-II tunnel is protected by automatic sprinklers and will not sustain serious damage under this strategy.)

<u>Electronics House</u>

(1) Install preaction sprinklers (quick response type) and photoelectric smoke detectors in the enclosure. The preaction sprinkler valve should be operated based on smoke detector activation.

(2) Install HSSD detection in each enclosed double rack. Install photoelectric smoke detectors in the underfloor cable plenum.

(3) Install automatic CO_2 suppression for the enclosed racks and underfloor plenum.

(4) Provide for automatic power and signal interruption tied to electronics temperature monitors and the smoke detector system.

(5) Restrict the amount of ordinary combustibles (i.e., <23 kg (50 lb) stored outside metal cabinets in the Electronics House.

Counting House (Building 621)

(1) Install addressable fire alarm system with single-station, photoelectric smoke detectors throughout in accordance with NFPA 72.

(2) Convert automatic sprinkler system to a preaction type; the system valve will be operated as a result of detection by the photoelectric smoke detectors.

(3) Restrict storage of combustibles and obstructions along egress paths.

Cryogenics Control/PEP Magnet Power Supplies (Building 624)

(1) Install standard wet automatic sprinkler protection in PEP Magnet Power supply room.

(2) Maintain existing automatic sprinkler system in the Cryogenics Control Room.

(3) Install photoelectric smoke detectors and addressable fire alarm in both spaces.

Tool Shed

(1) Protect with standard wet automatic sprinkler systems.

PEP-II Power/BaBar Solenoid Power (Building 625)

(1) Install photoelectric smoke detectors and addressable fire alarm.

(2) Maintain existing standard automatic sprinkler system.

Gas Mixing House

(1) Design in accordance with NFPA 101 and 70, including grounding and explosion protection for equipment.

(2) Provide gas flow control, continuous monitoring, and automatic gas flow interruption.

(3) Include smoke detection, automatic sprinklers, and automatic ventilation (interlocked).

(4) Construct in accordance with the Uniform Building Code.

BaBar

(1) Limit wire and cable flammability as outlined in memorandum: "BaBar Fire Protection Requirements for Wire and Cable" (Appendix C).

(2) Minimize the use of non-fire retardant insulation materials.

(3) Maintain gas compounds outside the flammability limits. For the Drift Chamber, the proposed 20 percent isobutane/80 percent helium mixture is above the UFL and cannot burn as a premixed flame. The isobutane would have to be reduced to a 6 percent volume concentration to reach the UFL.

For the RPC, the maximum volume concentration of isobutane is 4 percent, which will maintain the mixture below the LFL. If the LFL for the mixture is measured by testing, it is possible that the 4 percent limit could be raised, provided the volume concentration of isobutane is maintained at a level that is at least 1 percent below the level associated with the LFL for the mixture.

(4) Maintain process control through use of temperature, pressure, and oxygen monitoring, gas detection, and gas compound mass and volume flow rates. Incorporate interlocks to interrupt gas flow, power and affected parts of the Detector if conditions vary outside established operational and safety limits.

(5) Install HSSD smoke detection in the Detector, providing shut down and alarm signaling.

(6) During operation, inert the calorimeter with nitrogen to an oxygen concentration below 10 percent (vol).

(7) Provide photoelectric detection and consider automatic CO_2 suppression in the enclosed support electronics racks adjacent to BaBar.

(8) Protect the cable tunnels which connects BaBar to the Electronics House at each end with firestopping.

18.0 REFERENCES

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Appendix A

Analysis of Flammability Hazards Associated with the Use of Butane Gas Mixtures in BaBar

Analysis of Flammability Hazards Associated with the Use of Butane Gas Mixtures in BaBar

The Stanford Linear Accelerator Center (SLAC) has designed a new detector (BaBar) for use at the accelerator center. Isobutane in combination with other gasses will be used in two areas of the Detector, the Drift chamber and the RPC chamber. Since isobutane is a flammable gas, its use raises safety concerns for the facility. Isobutane has been proposed for use in the drift chamber in a 20% isobutane/80% helium mixture. The RPC chamber design calls for the use of mixtures of isobutane with argon and Halon 134a ($C_2H_2F_4$) ranging from 1% to 15% isobutane depending on safety and detection requirements. The isobutane mixtures for the RPC Chamber will contain 30% Halon 134a and the balance argon.

An analysis was performed to determine the flammability hazard associated with using isobutane as a component in the gas mixtures for both the Drift chamber and the RPC. This analysis examined 20% isobutane/80% helium mixtures for use in the drift chamber and a range of isobutane/30% Halon 134a/balance argon mixtures for use in the RPC chamber. Flammability data for butane/air/inert gas mixtures were obtained from Bulletin 627, Bureau of Mines by Zabetakis [1].

Figure A1 shows a flammability diagram for butane obtained from Zabetakis [1]. The diagram includes flammability limits for mixtures of butane and either carbon dioxide (CO_2) or nitrogen (N_2) in air. The stoichiometric line (C_{st}) passes through the flammability region. The point at which the stoichiometric line intersects the boundary of the flammability region is known as the stoichiometric limit (SL), which represents the most dilute stoichiometric mixture that will propagate a flame. Figure A2 shows a similar diagram for methane which includes helium as an inerting agent. As can be seen in the diagram, the flammability limits in helium are larger than in either CO_2 or N_2. This is due to the lower heat capacity of helium relative to N_2 and CO_2.

A similar diagram for pentane is shown in Figure A3. Note that the pentane diagram includes curves for several fluorine compounds in addition to those for N_2 and CO_2. As can be seen in this diagram, all of the fluorine compounds have narrower flammability limits as compared to N_2 or CO_2. This again is largely related to the higher heat capacities associated with these compounds when compared to CO_2, N_2, or Helium.

Since neither a helium diagram or a Halon 134a diagram was available for butane, it was necessary to construct these diagrams in order to performed the required safety analysis. A thermodynamic analysis, as described below, was used to determine the approximate location of these curves on the butane flammability diagram.

The flammability limits for mixtures of butane in either helium or Halon 134a/argon were determined based on adiabatic flame temperatures. Research has shown that adiabatic flame temperatures at the flammability limits are insensitive to the inert compounds (see Beyler [2] for a good review). Thus, for the purposes of this analysis, it was assumed that the adiabatic flame temperature of any butane/inert gas/air mixture was the same at the flammability limits regardless of the inert compound.

The adiabatic flame temperatures for a range of limit mixtures of butane/air with either N_2 or CO_2 as an inert gas were calculated. These calculations showed that rich limit flame temperatures were typically 1200K to 1300K and lean limit temperatures were 1600K to 1700K, as expected. Next, adiabatic flame temperatures were determined for a range of butane/helium/air mixtures and for butane/argon/C_2F_6/air mixtures. Perfluoroethane (C_2F_6) was used as a surrogate for Halon 134a in these calculations because thermodynamic data for Halon 134a were not available over the temperature range of interest. Since C_2F_6 is very similar to Halon 134a especially in heat capacity, its use should introduce little error in the analysis.

Those mixtures which gave adiabatic flame temperatures in the ranges identified for CO_2 or N_2 mixtures were used to construct limit diagrams for the two inert systems. It should be noted that for the butane/argon/C_2F_6/air mixtures, the amount of C_2F_6 prior to dilution with air was kept at 30% while the amount of argon was varied depending on the percent butane in the mixture. This was based on the design requirements for the RPC chamber which specify a 30% Halon 134a concentration in the mixture regardless of the butane concentration.

Figure A4 shows the flammability limit curve for butane/helium mixtures as determined by the procedure given above. As can be seen in the figure, the helium limit curve lies outside the nitrogen limit curve. This is to be expected based on the methane results shown in Figure A2 and the fact that helium has a lower heat capacity than N_2.

Figure A5 shows a similar flammability limit curve determined for the butane/C_2F_6/argon/air mixtures. As can be seen in the diagram, this curve lies between the N_2 and CO_2 limit curves. This result is expected based on the fact that the argon/C_2F_6 mixture heat capacity lies between those of N_2 and CO_2. Once these limit curves were established, an analysis of the flammability hazard associated with the chamber mixtures was performed, as discussed below.

Line A on Figure A4 shows the range of mixtures of butane/helium/air that can be obtained by diluting a 20% butane/80% helium mixture with air. Point B on line A represents a 50% butane-helium/50% air mixture. As can be seen, this mixture is outside the rich flammable limit and thus cannot burn as a premixed flame. The point where line A crosses the upper flammable limit line for helium (point C) is the first mixture which becomes flammable. This mixture contains about 6% butane and corresponds to approximately a 3 to 1 dilution of the butane-helium mixture with air. Further dilution by air will result in a flammable mixture until point D (where line A crosses the lean limit). This point corresponds to about 1.8% butane in the mixture and a dilution of the original butane-helium mixture by approximately 11 to 1 with air. Beyond this point, any further dilution with air would produce a mixture outside the lean flammable limit and thus incapable of burning.

The range of premixed flammable mixtures identified above would apply to either the case of air leaking into the Drift Chamber containing the butane-helium mixture or to a leak of the butane-helium mixture into the area outside the chamber, once it was well mixed with air. However, because the percent butane in the original butane-helium mixture is above the rich limit, any leak out of the chamber could result in a diffusion flame supported by the butane fuel. Such a jet flame could have the potential to act as an ignition source for other fuels or to damage nearby equipment by the heat generated from the flame.

The four lines shown in the lower part of Figure A5 correspond to the range of mixtures obtained from different initial butane-argon-halon 134a mixtures. The numbers given at the right of each line denote the initial butane concentration in each mixture. As can be seen from the figure, the 1% and 4% butane mixtures never cross any of the flammability limit diagrams including the one for helium. Thus, these mixtures are not capable of burning either as premixed or diffusion flames. The third line indicates the initial butane concentration (approximately 6.5%) in a mixture with argon/Halon 134a which results in a marginally flammable mixture. This mixture touches the flammability limit line at a butane concentration of about 2.2% corresponding to a 3 to 1 dilution of the original mixture by air. The final line shows the range of mixtures obtained from a 15% initial butane concentration in argon/Halon 134a. As the figure clearly shows, this mixture is initially outside the rich flammable limit and result in a range of mixtures within the flammable limits. Thus, this initial butane/argon/Halon 134a mixture could produce either a diffusion flame or a premixed flame.

Based on the above analysis and envoking a 50 percent safety factor, mixtures of isobutane/argon/Halon 134a containing up to 4% isobutane can be used in the RPC chamber without hazard of fire or explosion. Although the normal factor of safety for flammable gases is four (i.e., the mixture is maintained at 25% of the lean flammable limit (LFL)), a safety factor of 50 % should be sufficient in this case due to the accuracy of continuous monitoring and gas shutdown capabilities which will measure the gas constituents to ±0.1%. The use of flammable mixtures requires additional safeguards since these mixtures are capable of creating a detonation in the confined space of either chamber.

An interlock systems should be considered for the Drift chamber (and for the RPC chamber if it uses greater than 4% butane) which prevents filling of the chamber with the butane mixture until the chamber has been fully purged with inert gas. The purge should be monitor by measuring the oxygen concentration in the chamber. Purging of the chamber with inert gas should continue until the oxygen measurement consistently reads below 1%. Once this reading is obtained, the chamber can be filled with the butane mixture. Oxygen monitoring should also be used during operation of the chamber to warn of an air leak into the chamber which could produce a flammable condition.

If the area immediately outside either of these chambers is confined such that flammable vapors could accumulate, then each of these areas should be monitored with a flammable gas detector in order to protect against the development of an explosive atmosphere.

References

1.) Zabetakis, M. G., "Flammability Characteristics of Combustible Gases and Vapors," Bulletin 627, Bureau of Mines, U.S. Dept. of the Interior, 1965.

2.) Beyler, C. L., "Flammability Limits of Premixed and Diffusion Flames," Section 2, Chapter 9, *The SFPE Handbook of Fire Protection Engineering*, Second Edition, DiNenno et al., Eds., National Fire Protection Association, Quincy, MA, 1995.

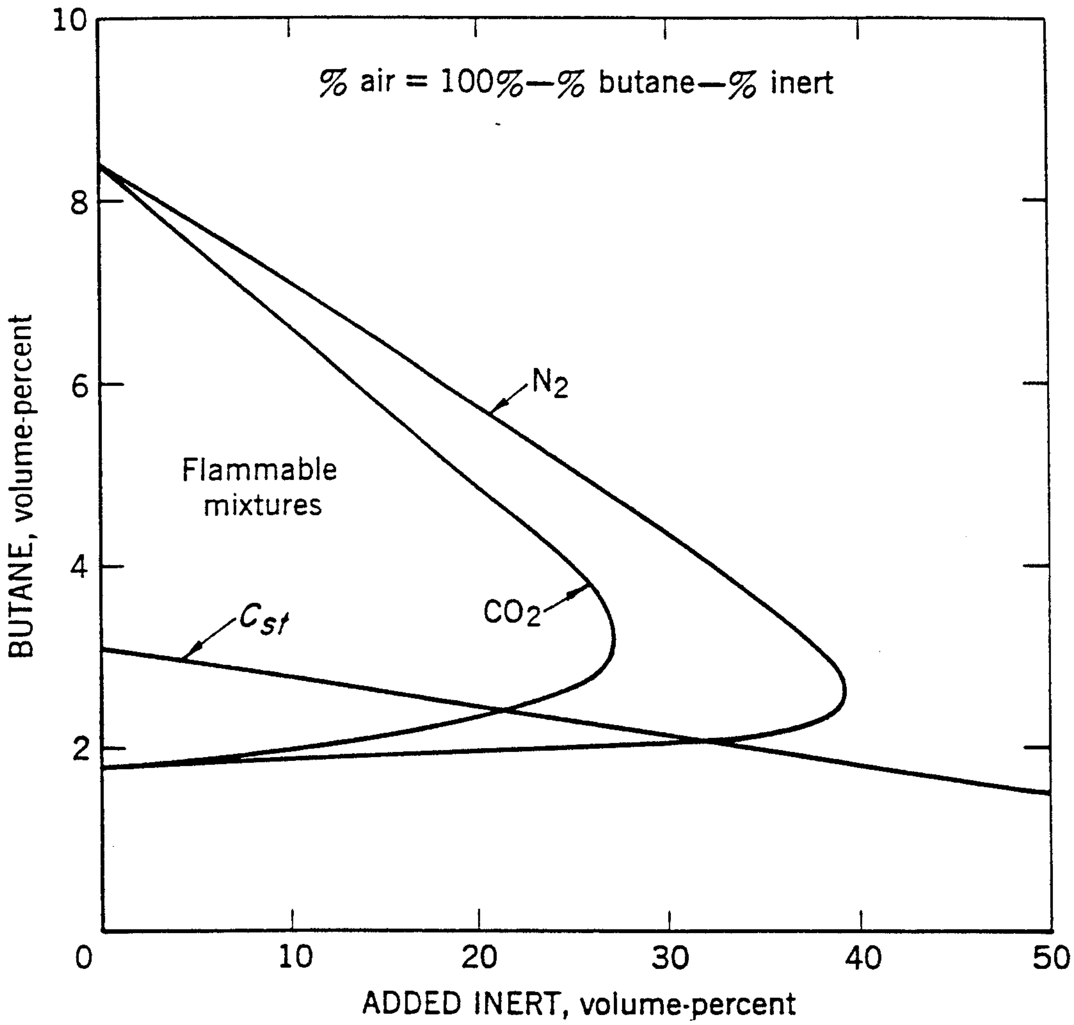


FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A1. Flammability Diagram for Butane from Zabetakis [1].

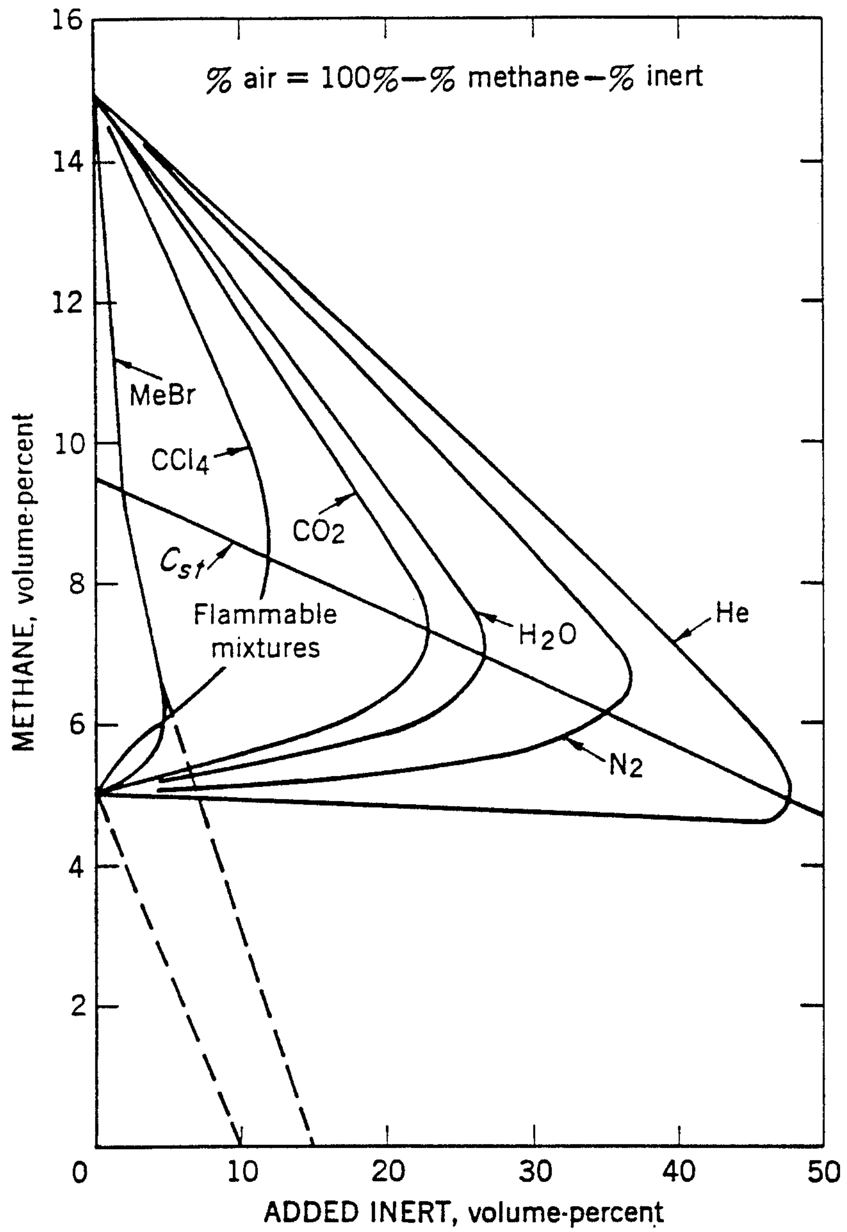


FIGURE 28.—Limits of Flammability of Various Methane-Inert Gas-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A2. Flammability Diagram for Methane from Zabetakis [1].

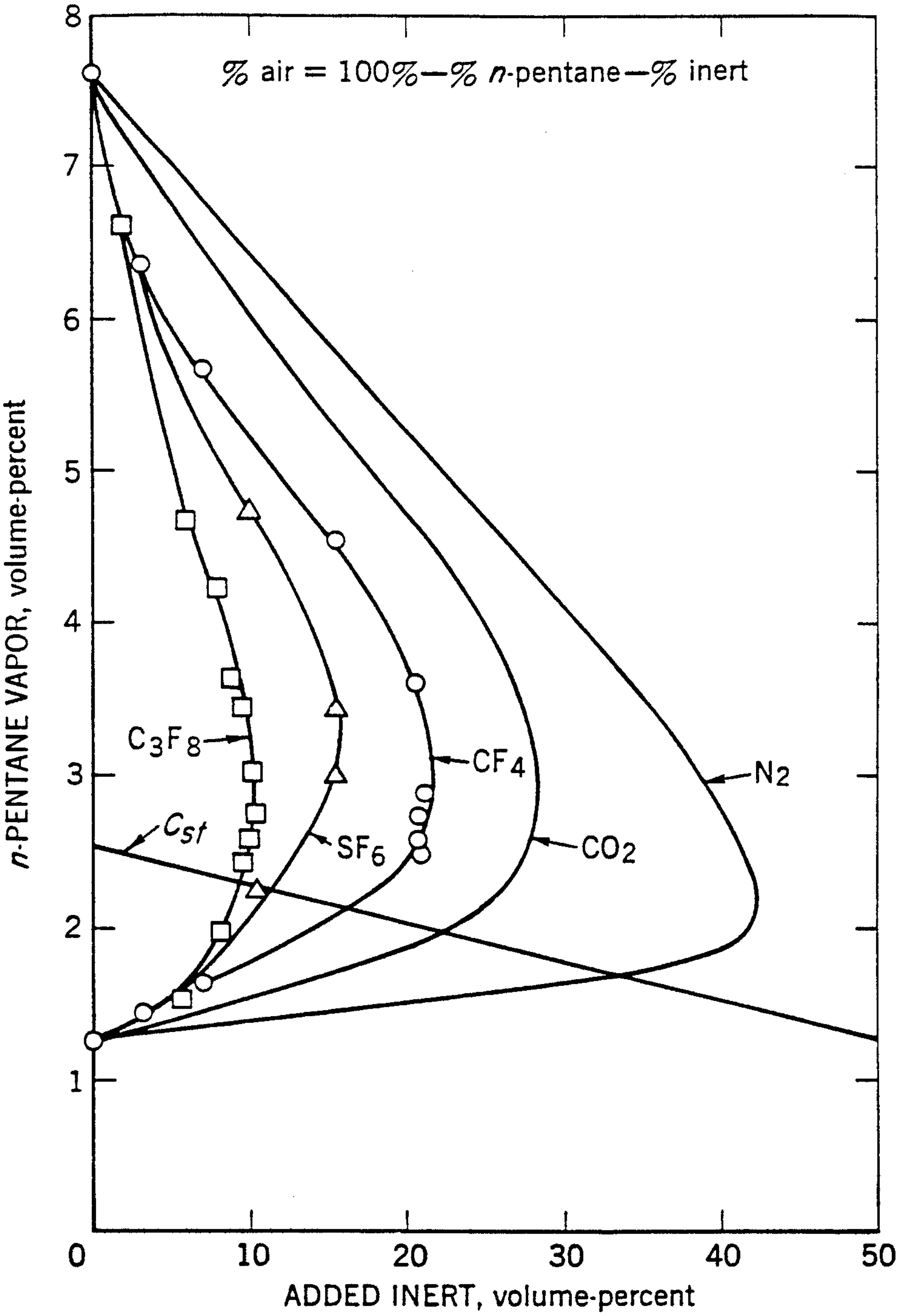


Figure 32.—Limits of Flammability of Various n-Pentane-Inert Gas-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A3. Flammability Diagram for Propane from Zabetakis [1].

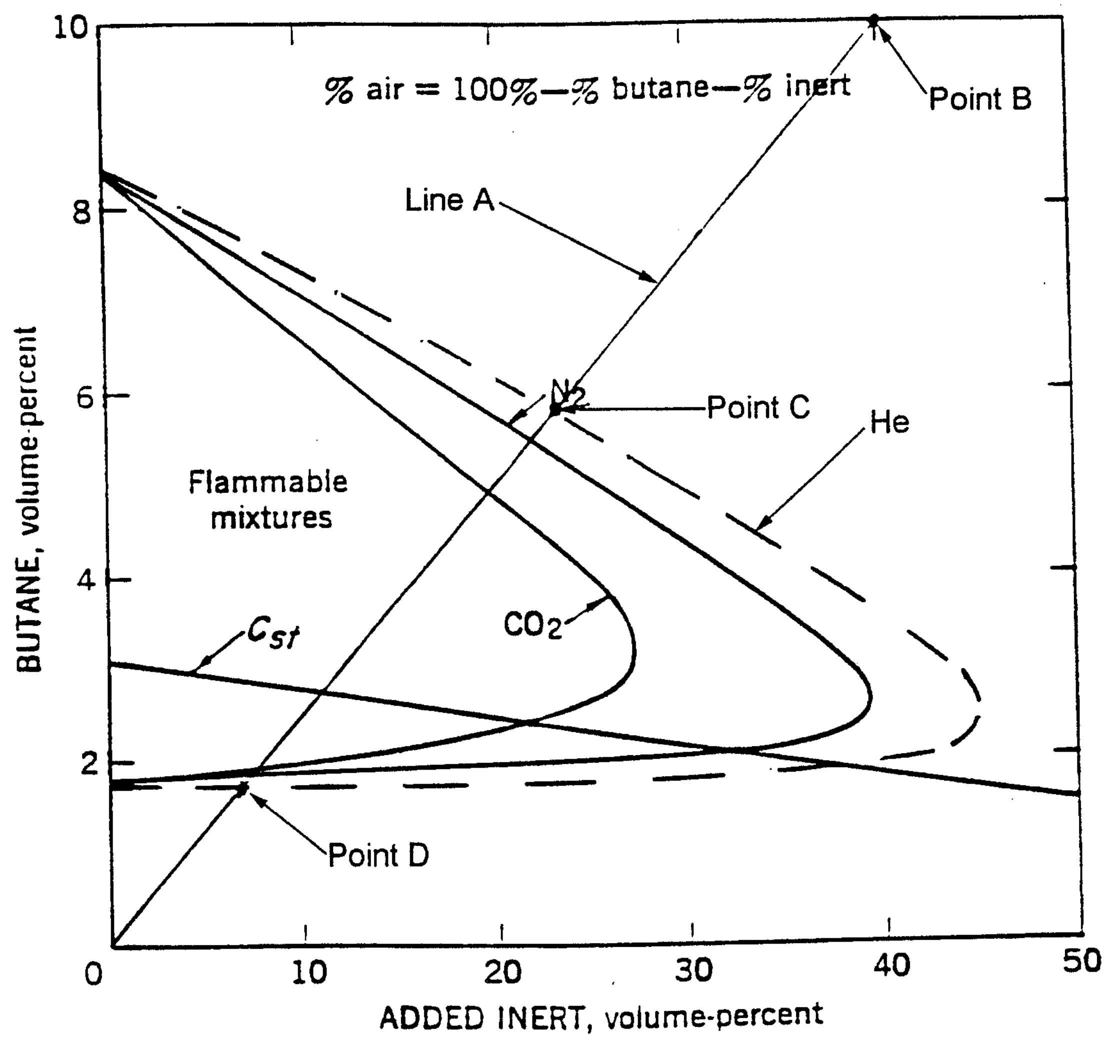


FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A4. Flammability Diagram for Butane with Helium Curve Added.

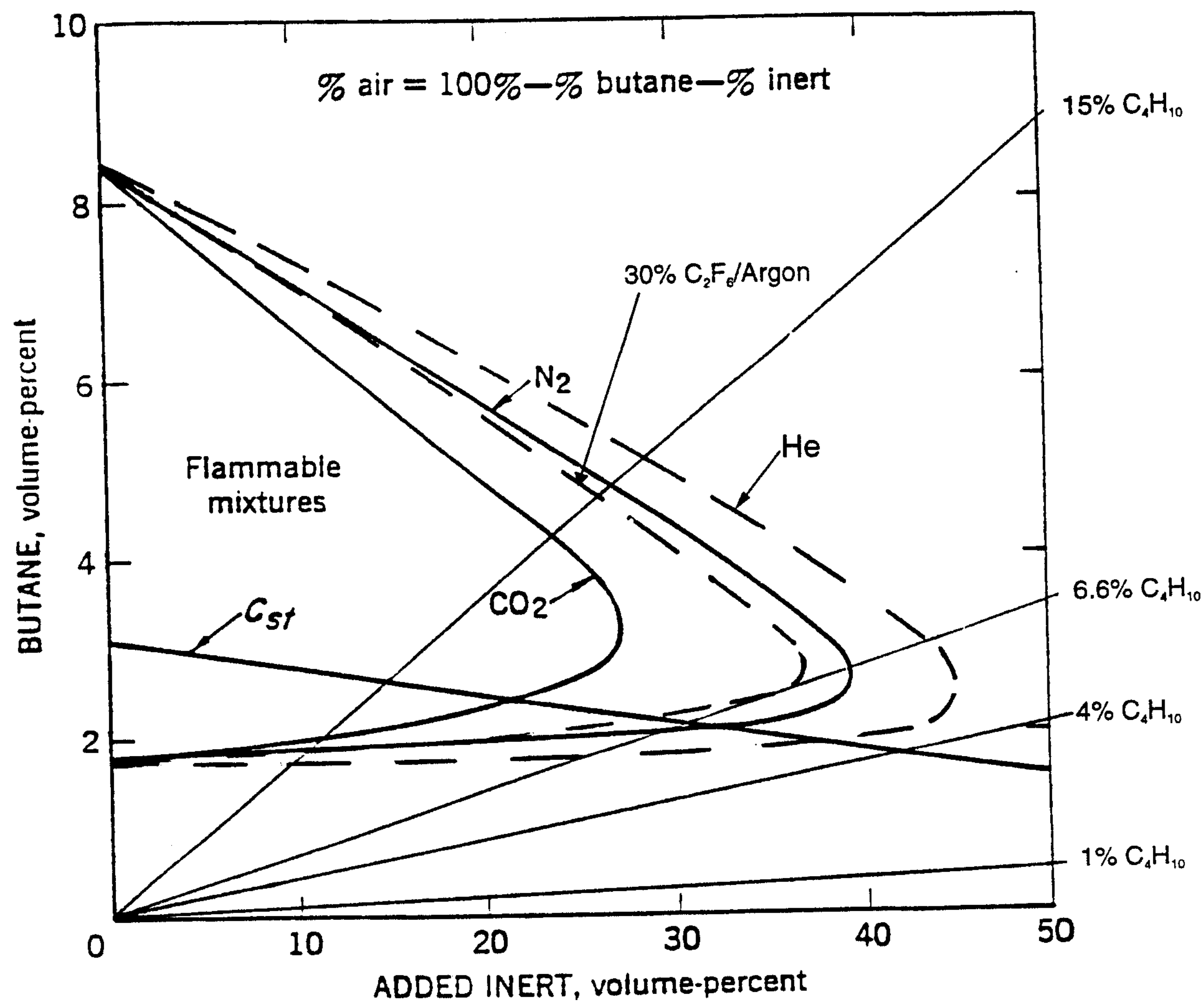


FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A5. Flammability Diagram for Butane with Argon/C_2F_6 Curve Added.

Appendix B

Calculations

B1.0 QUANTIFICATION OF CANDIDATE FIRE SCENARIOS

B1.1 General

The IR-2 hall has a partial concrete shield wall separating the room into east and west sections. A retractable concrete curtain exists between the top of the wall (7.9 m) and the bottom of the ceiling (13.7 m). When the Detector is operating, the concrete curtain is in place on top of the shield wall. However, the curtain will be moved when necessary during maintenance and servicing of the Detector. When the curtain is in the closed position, there is a gap between the ceiling and the top of the curtain approximately 0.3 m high and running for the length of the curtain. In addition, a small gap was assumed between the curtain and the top of the concrete shield wall to account for minor leakage.

Several candidate fire scenarios have been identified for the east and west portions of the IR-2 hall. These fire scenarios were selected based on existing conditions and assumptions about possible transient fuel loads. These are summarized in Table B1-1. Figure B1-1 depicts the assumed locations of the fire scenarios selected for purposes of the analysis. Precise locations are not significant in the context of this analysis.

Table B1-1. Fuel Sources and Fire Scenarios

Fuel Source	Quantity	Location
Wood Crates	1 - 6	East IR-2
Flammable Liquid	7.6 L - 18.9 L	East IR-2
Metal Drums/Combustibles	1-6	East IR-2
Combustible Materials	N/A	Electronics House in East IR-2
Cable Trays	Up to (6) 0.91 m Wide Cable Trays	West IR-2

The wood crates were assumed to be constructed of 0.016 m thick plywood and measured 2.44 m long, 1.22 m tall and 1.22 m wide. The crates were also assumed to contain non-combustible contents such as replacement equipment parts and were not stacked. Four scenarios were examined: 1, 2, 4, and 6 adjacent crates. Crate fires were initiated by some external ignition source and assumed to burn until all of the plywood was consumed.

Kerosene was assumed to be representative of flammable liquids that may be present in the IR-2 hall. A total of four flammable liquid fires were considered: a 0.0076 m^3 small diameter pool fire, a 0.0076 m^3 large diameter pool fire, a 0.019 m^3 small diameter pool fire, and a 0.019 m^3 large diameter pool fire. Since the diameter of a pool fire spill is dependant on a number of parameters such as the spill rate, the number of objects in the vicinity of the spill, and the contour of the floor in the vicinity of the spill, it was not possible to assume a single diameter for a given volume of flammable liquid. Instead, the diameters were bounded with a thin pool -large diameter - high heat release rate - short duration, and a thick pool - small diameter - low heat release rate -

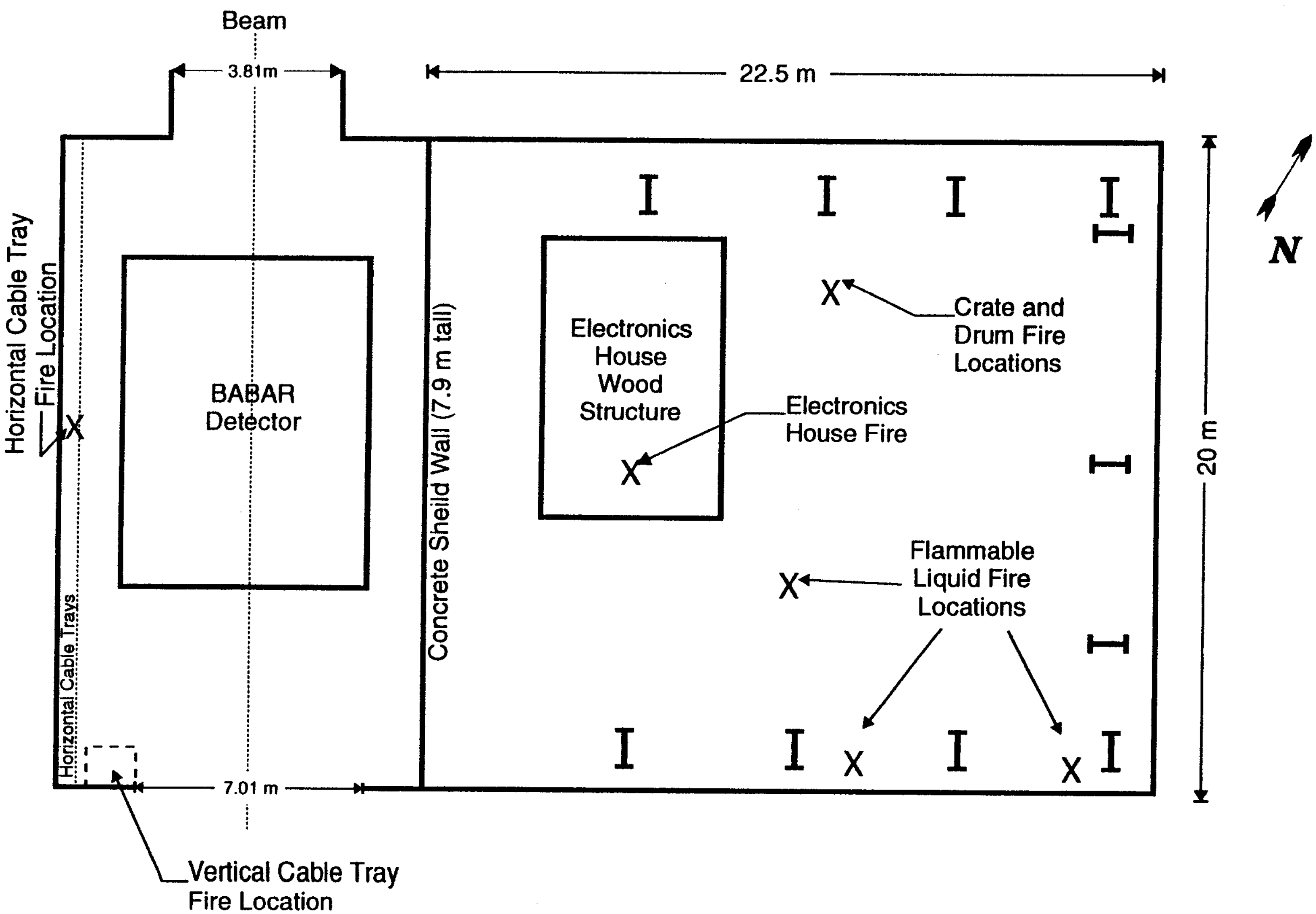


Figure B1-1. Plan view of IR-2 Hall showing typical fire scenario locations long duration fire for a given volume of flammable liquid. This effectively bounded the anticipated scenarios.

The metal drum fire calculations involved 0.21 m^3 metal drums containing Class A combustible materials (paper, rags, etc). The drums were assumed to measure 0.61 m in diameter and 0.86 m high. Burning rate data for the drum fire scenarios were taken from full scale burn tests conducted at Hughes Associates, Inc. [HAI, 1995]. Six drum fire scenarios were evaluated: 1, 2, 4, and 6 drums.

The Electronics House fire scenario involved determining the minimum amount of Class A combustible material that could cause flashover within the space as well as calculating the internal conditions at the anticipated smoke detector and sprinkler actuation times. These values were used in turn to evaluate the damage possibility for several Electronics House fire scenarios.

Two cable tray fires were considered in the west section of IR-2. Both attempt to quantify the worst case thermal exposure to the Detector in horizontal and vertical cable trays. As will be shown, the fire development in the two types of trays is quite different and in order to completely review all the potential hazards, one of each was analyzed.

B1.2 Heat Release Rate Estimates of Candidate Fire Scenarios

B1.2.1 General

An essential component of a fire hazard analysis is the determination of the heat release rate characteristics of the candidate fuel packages. Elements of the heat release rate include the initial fire growth, the peak burning rate, and the duration of burning associated with a particular fuel package. This basic information is needed in order to calculate temperatures, radiant heat flux, and products of combustion that can cause damage to exposed equipment and materials.

The heat release rate is not a fundamental property of a fuel package and, therefore, cannot be calculated from basic material properties. It depends on a number of factors including the fire environment, the manner in which the fuel is volatized, and the combustion efficiency. Burning rate data may be obtained for specific fuels by laboratory testing. Work has led to a number of specific burning rate curves for selected fuels as well as correlations for burning rates of wood cribs, wood pallets, and flammable liquid pools. In the absence of such information, one must estimate the heat release rate history for particular fuels and fuel configurations. While not as accurate as laboratory testing, information and engineering methods exist in the literature that permit estimation of the initial fire growth, peak heat release rate, and fire duration for selected fuels and geometries.

B1.2.2 Flammable Liquid Pool Fire Scenarios

Four pool fire scenarios were considered for this analysis. These scenarios represented bounding cases with respect to the burning duration and the peak heat release rate. In general, for a given volume of flammable liquid, the larger the diameter, the larger the peak heat release rate. However, due to the increased mass loss rate, the overall exposure duration is brief. Hence, it is of interest to examine a large and small pool fire for a given volume of flammable liquid. In this analysis, two flammable liquid volumes are examined: 7.6 L and 18.9 L. For a given volume of spilled flammable liquid, V_L (m^3), the maximum possible pool diameter is given by the following [Mudan and Croce, 1988]:

$$D_{max} = 2.66\left(\frac{V_L^3}{\nu^2}\right)^{1/8} \text{ (m)} \qquad \text{(B1-1)}$$

where D_{max} is the maximum pool diameter (m) and ν is the regression rate (i.e., the rate the pool thickness declines) of the flammable liquid (m/s). For pool fires greater than 0.8 m in diameter, the regression rate remains a constant 6.7E-5 m/s [Mudan and Croce., 1988]. The maximum pool diameters for the 7.6 L and 18.9 L pool fires are shown in Table B1-2 along with the surface area. The minimum pool diameter is estimated assuming that the pool fire will not exceed 0.0127 m in thickness. These results area also shown in Table B1-2.

Table B1-2. Flammable Liquid Pool Fire Dimensions

Volume (L (m^3))	Maximum Diameter (m)	Maximum Area (m^2)	Minimum Diameter (m)	Minimum Area (m^2)
7.6 (0.0076)	1.42	1.58	0.87	0.60
18.9 (0.019)	2.0	3.14	1.38	1.49

The peak heat release rate was calculated from the specific material properties of the fuel and the total surface area of the pool. The following equation computes the peak heat release rate, $\dot{Q}_p$ (kW), for a flammable liquid pool fire [Babrauskas, 1986]:

$$\dot{Q}_p = \Delta H_c \nu \rho A_{pool} \text{ (kW)} \qquad \text{(B1-2)}$$

where ΔH_c is the heat of combustion (kJ/kg), ρ is the fuel density (kg/m^3), and A_{pool} is the pool surface area (m^2) as listed in Table B1-2. For Kerosene, the heat of combustion is 45,900 kJ/kg and the density is 820 kg/m^3 [Babrauskas, 1986].

For this analysis, the fire was assumed to instantly reach the peak heat release rate. This is conservative in that the fire is constantly burning at the peak heat release rate and no fuel is spent during the growth phase. As a result, the burn time at the peak heat release rate, t_p (s), is also the total burn time of the fire. This is given by the following equation:

$$t_p = \frac{V_L \rho \Delta H_c}{\dot{Q}_p} \text{ (sec)} \tag{B1-3}$$

Table B1-3 summarizes the heat release rate results for the pool fires. Figure B1-2 shows the bounding heat release rate curves for the flammable liquid fire scenarios in the east section of IR-2.

Table B1-3. Summary of Flammable Liquid Pool Fire Characteristics

Pool Fire	D (m)	A_{pool} (m^2)	$\dot{Q}_p$ (kW)	t_d (sec)
7.6 L Large Diameter	1.42	1.58	3,965	72
7.6 L Small Diameter	0.87	0.6	1,498	190
18.9 L Large Diameter	2.0	3.14	7,880	91
18.9 L Small Diameter	1.38	1.49	3,743	190

B1.2.3 Crate Fire Heat Release Rates

Unlike the pool fire scenarios, the growth period for wood crates represents a substantial portion of the heat release rate curve. Evaluation of data on burning rates for a wide range of fuel packages indicates that the initial period of fire growth may be approximated as follows [Evans, 1988]:

$$\dot{Q}(t) = \alpha t^2 \text{ (kW)} \tag{B1-4}$$

where $\dot{Q}(t)$ is the heat release rate as a function of time, t (s), and α is the growth coefficient (kW/s^2). Growth coefficients for various fuels may be found in Evans [1988] and NFPA 72 [Appendix B, 1993]. Selection of a particular growth rate coefficient to approximate the initial burning rate of a fuel is dependent on the fuel flammability characteristics and the fuel configuration. The growth rates used in this analysis represent the most conservative (i.e., most rapid growth rate) value possible. Based on the available data, plywood crates may be most conservatively represented by a 'medium' growth coefficient, that is α equal to 0.01172 kW/m^2.

The peak heat release rate for the crates was calculated from the total exposed surface area, A_f (m^2). In this analysis, all external surface areas are assumed to contribute to the fire, or

$$A_f = N_{cr} \cdot (2LH + 2WH + LW) \text{ (m}^2\text{)} \tag{B1-5}$$

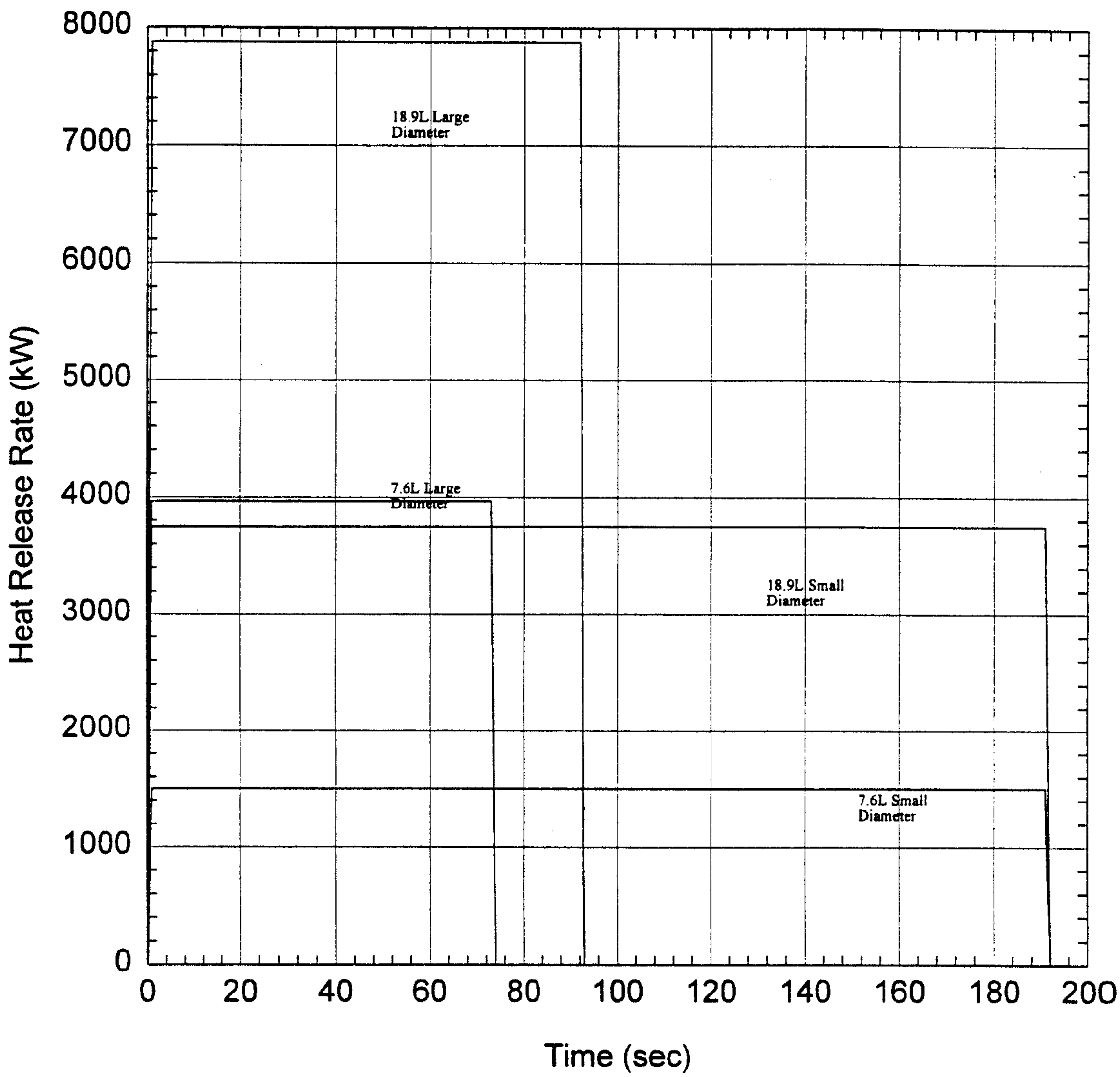


Figure B1-2. Heat release rate curves for flammable liquid pool fires in east IR-2 facility where N_{cr} is the number of crates, L is the length of the crate (2.44 m), H is the height of the crate (1.22 m), and W is the width of the crate (1.22 m). The peak heat release rate is given by the following:

$$\dot{Q}_p = \dot{Q}_p^{//} A_f \text{ (kW)} \tag{B1-6}$$

where $\dot{Q}_p''$ is the peak heat release rate per unit area for plywood and is about 250 kW/m^2 [Budnick and Perrault, 1990]. The time required to reach the peak heat release rate is found using the following equation:

$$t_p = \left(\frac{\dot{Q}_p}{\alpha} \right)^{0.5} \text{ (sec)} \tag{B1-7}$$

If it is assumed that there is no decay period (that is, once the fire has attained its peak burning rate it remains at this rate until all of the fuel is consumed), the duration the fire at the peak, t_d (s), may be calculated with the following equation:

$$t_d = \frac{(M_T - M_L)\Delta H_c}{\dot{Q}_p} \text{ (sec)} \tag{B1-8}$$

where M_T is the total mass of plywood (kg), M_L is the mass of plywood burned during the growth phase (kg), and the heat of combustion for the plywood, ΔH_c, is 19,500 kJ/kg [Babrauskas, 1986]. The total mass of plywood is just the volume multiplied by the density, ρ (640 kg/m^3 [Drysdale, 1985]), or

$$M_T = 2 \cdot \rho\, th (LW + LH + WH) \cdot N_{cr} \text{ (kg)} \tag{B1-9}$$

where *th* is the thickness of the plywood (0.0191 m). The mass lost during the growth phase is calculated by integrating the time dependent mass loss rate between 0 and the time to reach the peak heat release rate, or

$$M_L = \int_0^{t_p} \dot{m}(t)\, dt = \int_0^{t_p} \frac{\dot{Q}(t)}{\Delta H_c} dt = \frac{\alpha t_p^3}{3 \Delta H_c} \text{ (kg)} \tag{B1-10}$$

Application of the above equations allows one to calculate a heat release rate curve for any number of plywood crates. Table B1-4 summarizes the heat release rate data for 1, 2, 4, and 6 plywood crates. Figure B1-3 shows the four heat release rate curves as a function of time.

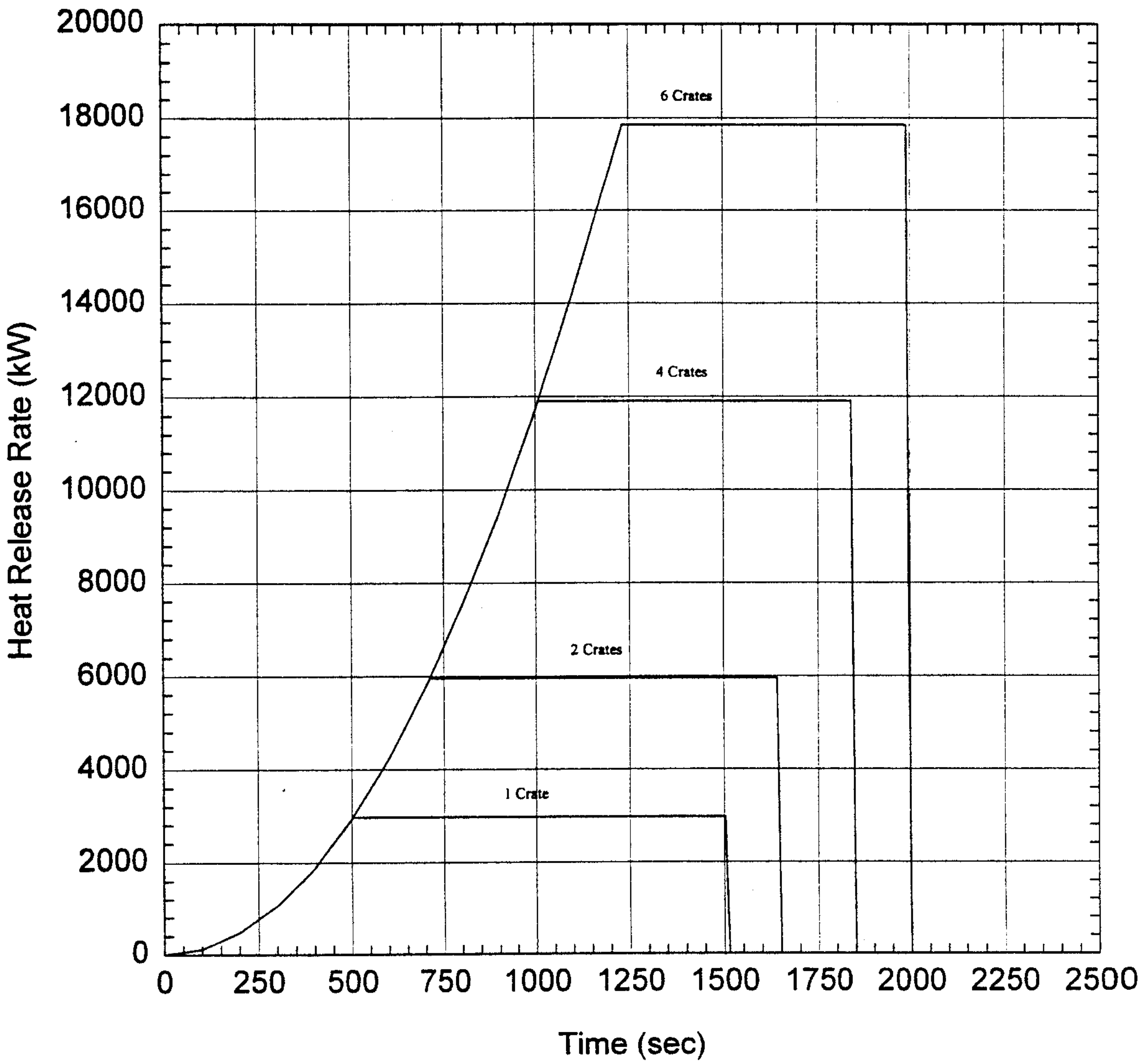


Figure B1-3. Heat release rate curves for plywood crates in east IR-2 hall

Table B1-4. Summary of Crate Fire Characteristics

Number of Crates	Total Surface Area (A_f (m^2))	Total Mass (M_T (kg))	$\dot{Q}_p$ (kW)	Time to Peak (t_p (s))	M_L (kg)	Duration at Peak (t_d (s))
1	11.9	181	2,975	504	26	1,016
2	23.8	362	5,950	713	73	947
4	47.6	724	11,900	1,007	205	850
6	71.4	1,086	17,850	1,234	376	776

B1.2.3 Drum Fire Heat Release Rates

The heat release rates for the drum fire scenarios were calculated in a manner similar to the crates. However, some of the information is obtained from specific laboratory tests [HAI, 1995] rather than calculated.

Tests conducted on 208 L, 0.61 m diameter, metal drums containing miscellaneous Class A combustible materials with no lid indicated that the average mass of combustible materials is about 5 kg per drum and that the peak heat release rate is approximately 129 kW per drum. If it is assumed that the heat release growth rate may be calculated using Equation B1-4 with a growth coefficient corresponding to a medium fire (0.01172 kW/s^2), the time to peak heat release rate, the duration at the peak heat release rate, and the mass lost during the growth rate may be calculated using Equations B1-7, B1-8, and B1-10, respectively. Table B1-5 summarizes the heat release rate characteristics for four drum fire scenarios, and Figure B1-4 shows the heat release rate curves for these fires.

Table B1-5. Summary of Drum Fire Characteristics

Number of Crates	Total Mass (M_T (kg))	$\dot{Q}_p$ (kW)	Time to Peak (t_p (s))	M_L (kg)	Duration at Peak (t_d (s))
1	5	129	105	0.23	721
2	10	258	148	0.65	707
4	20	516	210	1.9	686
6	30	774	257	3.4	670

B1.2.4 Electronics House Heat Release Rate

The fire scenario in the Electronics House involves estimating the minimum quantity of Class A combustible materials that could cause the room to reach flashover conditions (gas layer temperature between 500 °C and 600 °C [Budnick and Evans, 1986]). This is determined by modeling the room conditions using the zone computer model CFAST [Peacock et al., 1993] and will be discussed in the next section. The heat release rate is assumed to grow according to

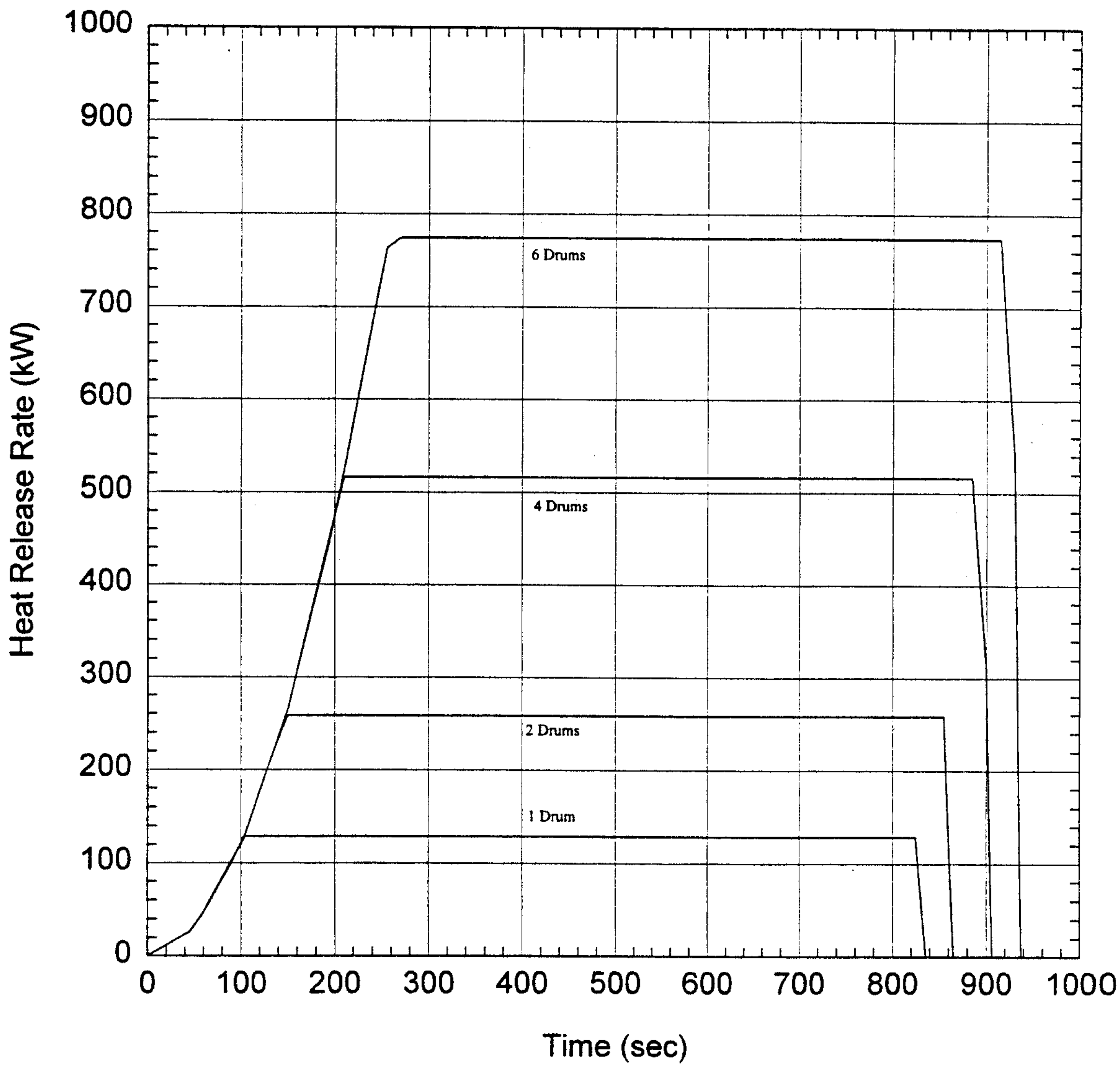


Figure B1-4. Heat release rates for drum fires in east IR-2

Equation B1-4 until flashover occurs in the compartment or there is insufficient oxygen to support further fire growth (i.e., ventilation limited conditions). The burning steel mass to reach flashover is then calculated using Equation B1-10. Figure B1-5 shows Equation B1-4 for the first 300 seconds of fire growth. The compartment either runs out of oxygen or reaches flashover temperatures before 300 seconds, depending on the ventilation conditions.

B1.2.5 Cable Tray Heat Release Rate and Flame Spread

Several potential cable tray fires may pose a hazard to the Detector. Since horizontal and vertical cable tray fires burn quite differently, the most conservative approach is to select the worst case scenario for a horizontal cable tray and for a vertical cable tray. The worst case scenario is dominated by the cable trays that are closest to the Detector. However, the mass loading is also significant. As the case presents itself, the most heavily concentrated cable loadings are also the closest to the Detector, simplifying the analysis.

The worst case horizontal cable tray fire involves the six cable trays along the west wall closest to the Detector. This location is shown in Figure B1-1 and consists of the following cable trays: TBF/TE2R, TB2G2/TE2H1, TA2G1, TA2G, TBABAR2, and TBABAR1 [Drawings 340-726-10-C5 Sheets 1 and 2, 1995]. With the exception of TBABAR1, all cable trays are 0.76 m wide and 0.1 m thick. TBABAR1 is 0.3 m wide and 0.1 m thick. All trays run the length of the west wall of the IR-2 Hall except for TBABAR1 which stops approximately halfway down.

The total cable load may vary considerably from tray to tray. In order to be most conservative, the most severe cable loading conditions have been assumed for all cable trays. This corresponded to the assumption that there are 0.51 cables per centimeter width of cable tray (N_c') and that the combustible mass of each cable (M_c') is 0.24 kg/cable-meter [HAI, 1996]. The total cable load per meter length of tray, m_c' (kg/m), may then be estimated from the following:

$$m_c^{/} = M_c^{/} \cdot W_{tray} N_c^{/} \text{ (kg/m)} \qquad \text{(B1-11)}$$

where W_{tray} is the width of the cable tray in centimeters. Note that the cable loading is constant for a given tray width. Table B1-6 summarizes the horizontal cable tray fire scenario loading and location information.

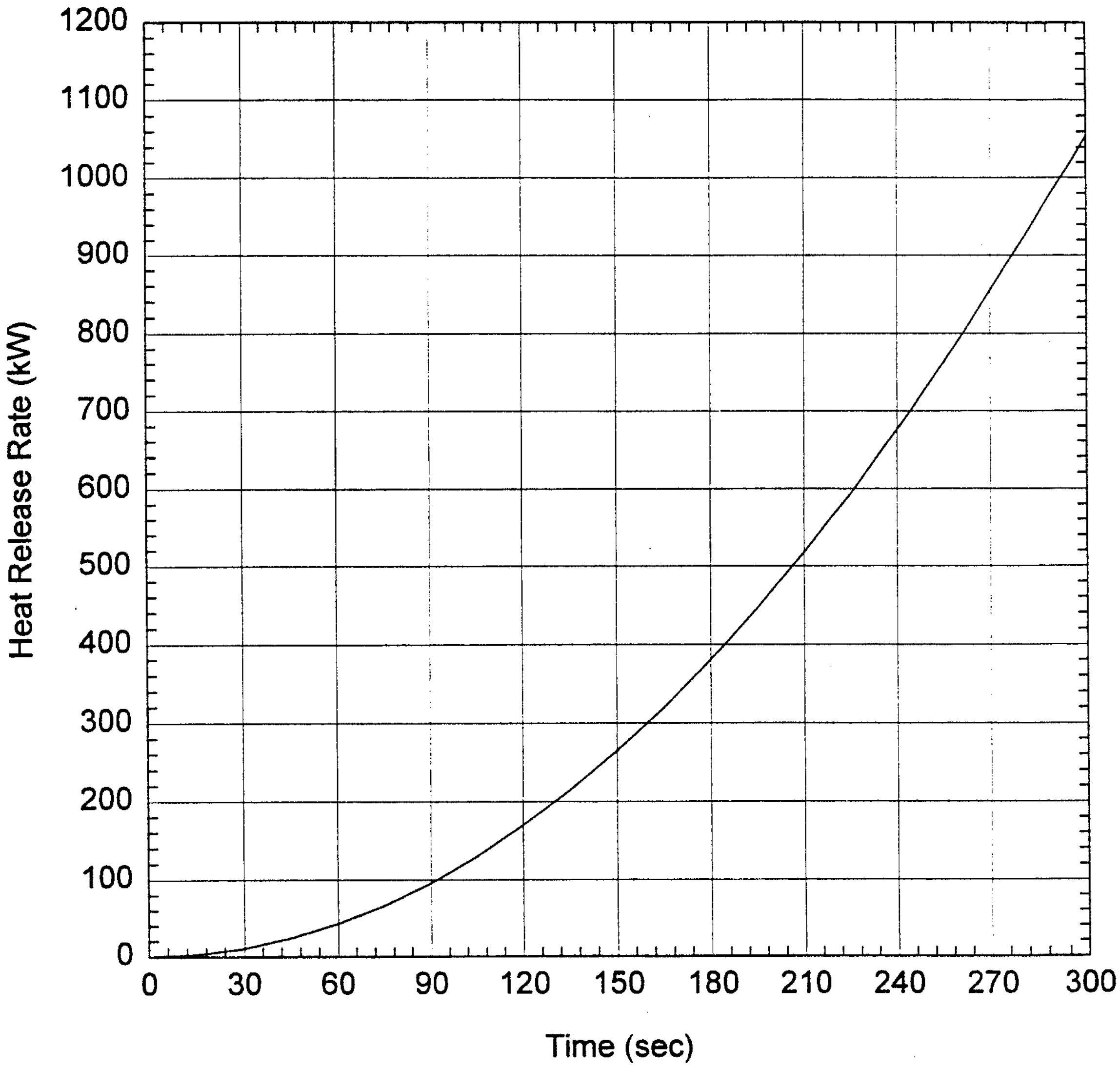


Figure B1-5. Electronics House assumed heat release rate located in east IR-2 hall

Table B1-6. Summary of Horizontal Cable Tray Fire Scenario Cable Loading

Cable Tray ID	Width (cm)	Bottom Elevation (m)	Number of Cables in Tray	Mass of Combustibles per Tray Length (kg/m)
TB2F/TE2R	76.2	5.77	38.9	9.3
TB2G1/TE2H1	76.2	6.07	38.9	9.3
TA2G1	76.2	6.38	38.9	9.3
TA2G	76.2	6.68	38.9	9.3
TBABAR2	76.2	6.99	38.9	9.3
TBABAR1	30.5	7.55	15.6	3.7
Total			210	50.3

Horizontal cable trays have a "slow" flame spread and heat release growth rate associated with them [Factory Mutual Research Corporation, 1981]. As the fire slowly spreads horizontally away from the origin, the initial portions ignited will exhaust their fuel supply and extinguish. Once this occurs, the total heat release rate stops increasing and the burnout front moves with the same horizontal speed as the flame spread front. Figure B1-6 depicts this phenomenon.

The peak heat release rate from a horizontal cable tray fire may be estimated by determining the maximum length of cable tray involved (L_I (m) in Figure B1-6) based on the horizontal spread rate, V_H (m/s) and the mass loading of cables per unit length of cable tray. In this analysis, all cable trays were assumed to be involved in the fire and the spread rate is the same for all trays. The maximum length of cable trays ignited before burnout, t_b (s), occurs is as follows [Cleary and Quintiere, 1991]:

$$L_I = V_H t_b \text{ (m)} \qquad \text{(B1-12)}$$

and

$$t_b = \frac{\Delta H_c m_c' \sum_i W_i}{\dot{q}_p''} \text{ (sec)} \qquad \text{(B1-13)}$$

where W_i is the width of the *i*th cable tray (m), $\dot{q}_p''$ is the peak heat release rate per unit area for cable tray fires (kW/m^2) and the heat of combustion, ΔH_c, for the cables is 22,500 kJ/kg [Braun et al., 1989]. Note that the time for the cables to burn out is also the time to reach the peak heat release rate, t_p (s). The peak heat release rate is given by

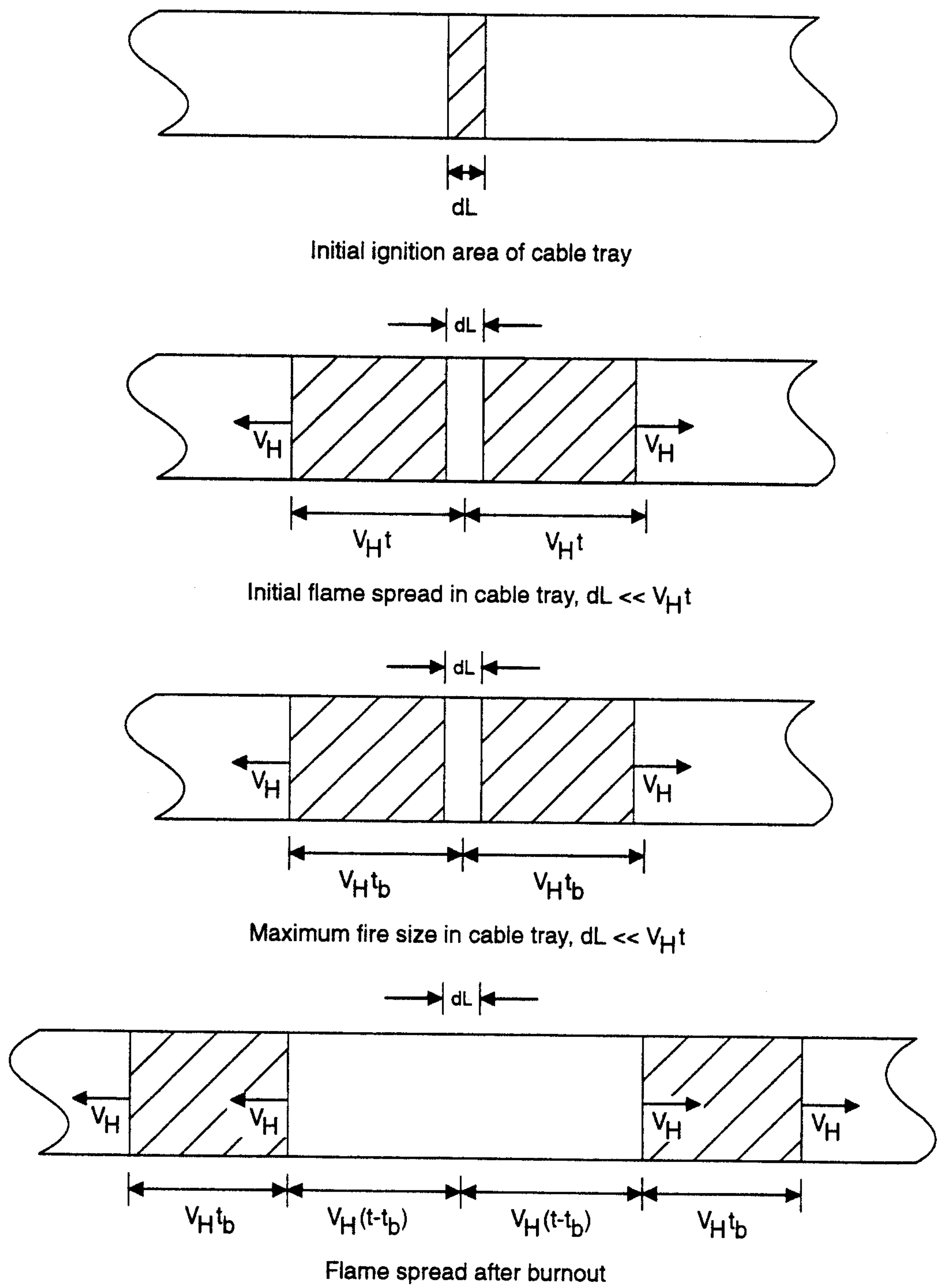


Figure B1-6. Flame spread phenomena in cable trays

$$\dot{Q}_p = \left(\sum_i W_i \right) L_l \dot{q}_p'' \text{ (kW)} \qquad \text{(B1-14)}$$

where $\dot{Q}_p$ is the peak heat release rate (kW).

Test data on a large number of cable tray configurations and cable types demonstrate that the peak heat release rate per unit area and the horizontal flame propagation rate vary considerably [Braun et al., 1989]. For the purposes of this analysis, average values were assumed which resulted in a peak heat release rate of 130 kW/m^2 and a horizontal flame propagation rate of 8.47E-4 m/s. Since the propagation occurs at the same rate in opposite directions, the effective flame spread rate is thus 1.69E-3 m/s. The growth rate for the cable tray fires is linear as a result of the linear flame spread velocity. The heat release rate at any time less than the time to reach the peak heat release rate, t_p (s), is therefore

$$\dot{Q}(t) = \left(\frac{t_p - t}{t_p} \right) \cdot \dot{Q}_p \qquad \text{(B1-15)}$$

Table B1-7 summarizes the heat release rate results and Figure B1-7 shows the heat release rate curve for the horizontal cable tray fires.

Table B1-7. Summary of Horizontal Cable Tray Heat Release Rate

ΔH_c (kJ/kg)	q_p'' (kW/m^2)	V_H (m/s)	L_l (m)	t_p (s)	Q_p (kW)
22,500	130	1.69E-3	3.56	2100	1,905

The worst case vertical cable tray fire involves the five cable trays in the southwest corner of the IR-2 Hall. The cable tray array is approximately 3.67 m from the Detector. This is depicted in Figure B1-1 and consists of the following cable trays: TBABAR2, TA2G, TA2G1, TB2G2/TERH1, and TB2F/TE2P [Drawings 340-726-10-C5 Sheets 1 and 2, 1995]. All cable trays are 00.61 m wide and 0.1 m thick. The trays run from 0.051 m above the floor to 7.0 m above the floor.

The total cable load is calculated in the same manner as the horizontal cable trays using equation B1-11. Table B1-8 summarizes the vertical cable tray fire scenario loading and location information.

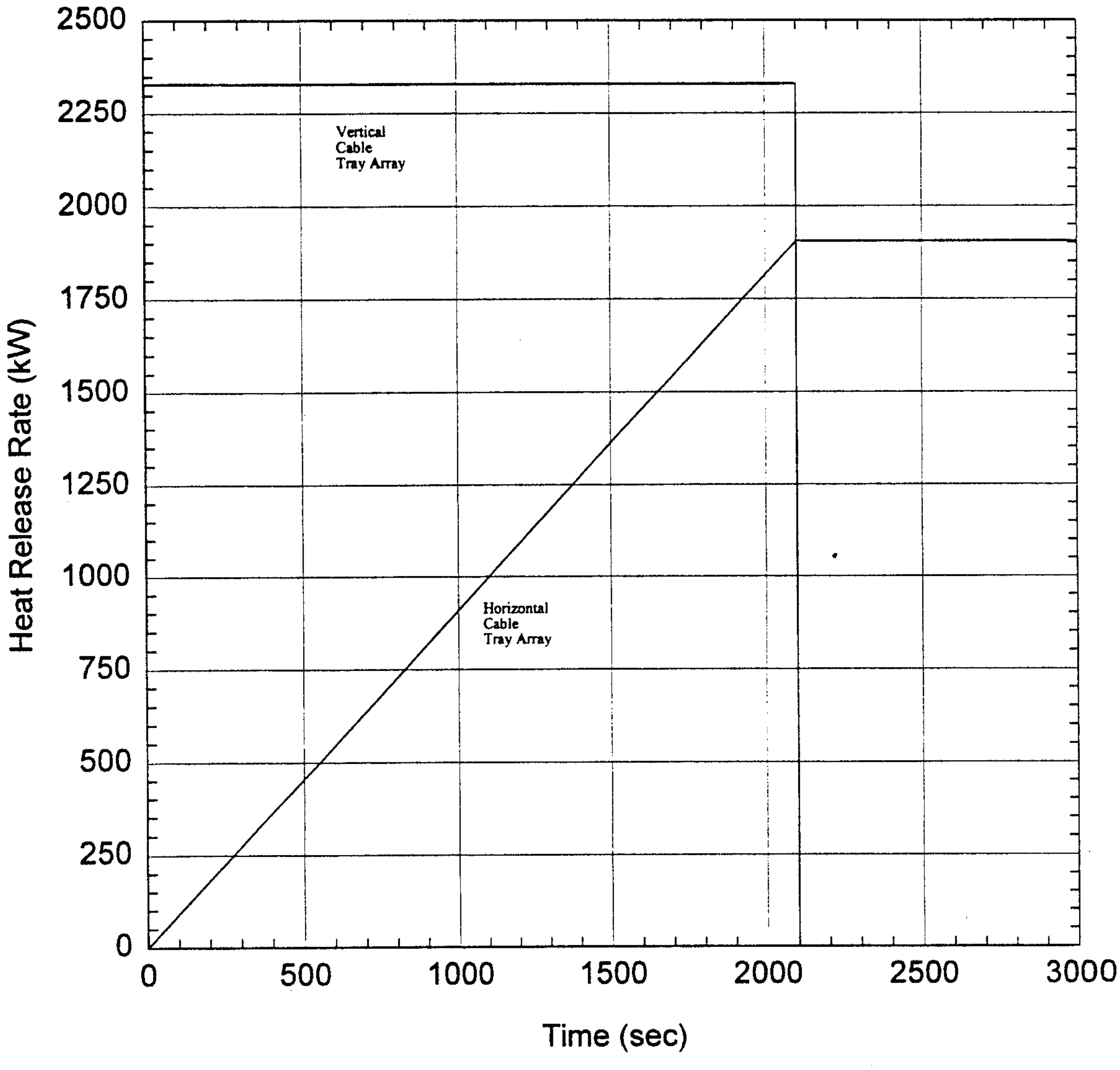


Figure B1-7. Heat release rate curves for cable tray fires in west IR-2 hall

Table B1-8. Summary of Vertical Cable Tray Fire Scenario Cable Loading

Cable Tray ID	Width (cm)	Bottom Elevation (m)	Number of Cables in Tray	Mass of Combustibles per Tray Length (kg/m)
TB2F/TE2R	61.0	0.051	31.1	7.5
TB2G1/TE2H1	61.0	0.28	31.1	7.5
TA2G1	61.0	0.51	31.1	7.5
TA2G	61.0	0.74	31.1	7.5
TBABAR2	61.0	0.97	31.1	7.5
	Total		156	37.5

Vertical cable trays burn in a similar fashion as the horizontal cable trays, except that the propagation rate is much greater than 1.69E-3 m/s. For this analysis, the propagation rate is assumed nearly instantaneous and that an entire vertical cable tray array ignites at essentially the same time. Additionally, as a worst case scenario, the cable trays are assumed to ignite at the bottom of the lowest tray. This means that the entire vertical will burn, producing a larger peak heat release rate. With the exception of calculating the length of cable tray arrays involved (L_T is equal to the height of the cable tray array), and the heat release rate growth rate, the determination of the heat release rate for the vertical cable tray array follows that of the horizontal cable tray heat release rate calculation. The growth rate is assumed instantaneous, and the duration of the fire is just the burnout time, t_b (s). The results are summarized in Table B1-9 and also are depicted in Figure B1-7.

Table B1-9. Summary of Vertical Cable Tray Heat Release Rate

ΔH_c (kJ/kg)	$\dot{q}_n''$ (kW/m^2)	V_H (m/s)	L_T (m)	t_b (s)	$\dot{Q}_p$ (kW)
22,500	130	1.69E-3	5.87	2100	2,330

B2.0 FIRE HAZARD ASSESSMENT

Typically, a fire hazard assessment involves selecting a set of critical criteria and determining if the potential fire scenarios result in hazards exceeding these criteria. In this section, the critical criteria, the critical parameters, and the calculation methods necessary to determine these are discussed.

B2.1 Hazard Criteria

There are several potential means of creating an unacceptable risk either to the Detector or to the structure itself. These included the following:

(1) Hot gas layer in excess of 150 °C in contact with the Detector;

(2) Heat flux in excess of 15 kW/m^2 exposing the Detector;

(3) Temperature in excess of 593 °C at the ceiling of the East side of the IR-2 facility;

(4) Average column temperature in excess of 593 °C due to flame impingement;

(5) Exposure to the Electronics House to possible ignition exposures; and

(6) Flashover within the Electronics House or the east side of the IR-2 facility.

Based on discussions with Stanford personnel, it has been determined that the Detector should remain functional after exposure to temperatures as high as 150 °C. Beyond this substantial repairs may be necessary. As such, if a hot gas layer that is in excess of 150 °C descends to the Detector, the onset of a hazard condition is assumed. In addition to hot gas layer immersion, a heat flux exposure of 15 kW/m^2 is assumed as the threshold for radiant exposures. Although this corresponds to an equilibrium surface temperature greater than 150 °C, the time dependance of the surface temperature rise and the time duration of the fire exposures permit allowing a greater radiative heat flux.

Failure criteria for structural exposure are listed in ASTM E119 [ASTM, 1993]. Since only the east side of the IR-2 facility is constructed with unexposed steel members, this criteria does not pertain to the West side of the facility. For flammable liquid pool fires, heat transfer calculations are performed directly on the smallest potential column supporting the structure in order to evaluate the thermal response. Crate and drum fires burn much longer, and minimum distance to maintain between the fuel sources and a column is of interest. Roof temperatures are estimated using standard plume centerline temperature calculations.

Flashover in the Electronics House is considered a critical hazard since this would result in considerable damage to the electronics as well as a severe exposure fire to the Detector if the curtain is not in place on top of the shield wall.

B2.2 Evaluation of Critical Parameters

There are four means that the critical criteria may be exceeded due to a fire in the IR-2 facility. These are:

(1) Direct flame impingement;

(2) Fire plume heating;

(3) Upper gas layer heating; and

(4) Radiant heating.

Direct flame impingement on the Detector or the overhead unprotected structural steel will cause rapid heating and is considered a failure point without further analysis. An exception to this is flame impingement on the concrete ceiling on the west side of the structure. Concrete ceilings of similar thicknesses have been shown to remain structurally functional for exposure times on the order of several hours [BOCA, 1994]. As a result, flame heights have been estimated for each of the fire scenarios in the east side of IR-2.

If direct flame impingement does not occur, overhead and adjacent targets may still be heated from the hot gas plume rising above the flame. Plume centerline temperatures have thus been calculated for each scenario. Centerline temperatures represent the maximum plume temperatures. A critical temperature of 593 °C is used for the overhead structural members. No fuel sources are close enough to the Detector to pose a hazard in this manner.

The temperature and rate of descent of a hot gas layer is calculated using the computer model CFAST [Peacock et al., 1993]. Immersion of the Detector in a layer with a temperature greater than 150 °C is considered a hazard. Flashover in any compartment is a structural hazard, though this criterion will only be a factor when the concrete curtain is closed; the 150 °C criterion will, in general, be limiting.

The critical radiant flux is the energy flux necessary at the surface of a target to cause failure. This varies from target to target. For structural steel this is the minimum energy necessary to raise the surface temperature to 593 °C, or about 20 kW/m^2. For exposure to the Electronics House or other fuel sources, it is the minimum energy necessary to cause Class A combustibles to ignite. For long burning fires (i.e., the crate and drum fires), this is about 15 kW/m^2, and for short fires (i.e., the flammable liquid fires), it is dependent on the fire duration. The maximum exposure flux for the Detector was selected at 15 kW/m^2.

B2.3 Method of Analysis

This section describes the calculation procedures necessary to evaluate the exposure conditions in the IR-2 hall. Quantification of each critical parameter is discussed in detail.

B2.3.1 Flame Height

The continuous flame height, F_h, associated with a burning fuel package is estimated using the following correlation [Beyler, 1986]:

$$F_h = 0.11\,\dot{Q}_p^{2/5} \ \ \text{(m)} \qquad \text{(B2-1)}$$

where the peak heat release rate is obtained from the heat release rate data discussed in Section B1 for each fire scenario. This correlation is valid for fires that are not adjacent to walls and corners. Due to the locations of the columns in the east site of the structure, the crate and drum fires are expected to be in the open. However, it is possible that a flammable liquid may spill near a wall. In such case, the flame height is given as

$$F_h = 0.14\dot{Q}_p^{2/5} \text{ (m)} \tag{B2-2}$$

and is valid for fires adjacent to a wall. As will be shown, there is the possibility that the columns could fail if they are engulfed in a pool fire. Since the corners of the building contain structural columns, it is not expected that a flammable liquid pool fire will occur in a corner assuming that the recommended minimum distance is maintained.

B2.3.2 Fire Plume Temperatures

Plume centerline temperatures are significantly less than flame temperatures due to the entrainment of air. If the heat release rate of a fire is high enough, the gas temperature above the flame may be sufficiently high to result in heating of an overhead target to failure. The plume centerline temperature, $T_{℄}$ (°C) is calculated from the following [Beyler, 1986]:

$$T_{℄} = 23.1\dot{Q}_p^{2/3}(Z - z_o)^{-5/3} + T_\infty \text{ (°C)} \tag{B2-3}$$

for open fires. For wall fires, the following expression is used:

$$T_{℄} = 43\dot{Q}_p^{2/3}(Z - z_o)^{-5/3} + T_\infty \text{ (°C)} \tag{B2-4}$$

where Z is the height of the ceiling above the fuel source (m), z_o is the height of the virtual origin (m) above the floor, a correction for the point source approximation used in the equation, and T_∞ is the initial temperature (25 °C). The virtual origin is calculated with the following for both open and wall fires [Heskestad, 1983]:

$$z_o = -1.02D_{eff} + 0.083\dot{Q}_p^{0.4} \text{ (m)} \tag{B2-5}$$

where D_{eff} is the effective diameter of the fire (m). The effective diameter may be estimated as follows:

$$D_{eff} = \left(\frac{4A_f}{\pi}\right)^{0.5} \text{ (m)} \tag{B2-6}$$

where A_f is the horizontal surface area of the fire (m^2).

B2.3.3 Upper Gas Layer Temperature

The upper gas layer build-up and temperature in the IR-2 facility is calculated using the computer model CFAST [Peacock et al., 1993]. CFAST is a two layer zone model fire simulation computer program capable of modeling steady state and non-steady state burning rates in enclosures (Refer to Section B5 for a more detailed description of the CFAST modeling and sample input data). Input information includes the room dimensions, the size and locations of any openings, mechanical ventilation information, room material thermal properties, the burning rate, and several fuel specific parameters including the heat of combustion, fuel burning area, and the ratio of hydrogen to carbon in the fuel.

In this analysis, four general configurations were modeled in the IR-2 facility:

(1) Concrete curtain closed; no mechanical ventilation; tunnels blocked off;

(2) Concrete curtain open; no mechanical ventilation; tunnels blocked off;

(3) Concrete curtain open; no mechanical ventilation; tunnels open; and

(4) Concrete curtain open; mechanical ventilation on; tunnels open.

The above scenarios are ordered in the approximate severity of the compartment conditions. Note, however, that when the concrete curtain is closed and the fire is located in the east portion of the building, the flow of combustion products into the west portion of the building is restricted (though not prevented) and the conditions are actually favorable in terms of exposing the Detector. Additional scenarios include modeling a class A combustible fire in the electronics house with the door open and with the door closed, and modeling the cable fires in the west part of IR-2 with the concrete curtain closed and the tunnels open.

The most dominant feature in reducing the upper gas layer temperature is the tunnel. Due to the large size (4.27 m by 3.84 m and 4.27 m by 7.01 m), the north and south entries into the PEP-II tunnel vent a great deal of the combustion products out of the IR-2 hall. The roof mounted mechanical ventilation also has a favorable effect on the descent of the gas layer. According to information provided by Stanford, there is one 8.74 m^3/s manually operated exhaust fan in the west side of IR-2 and one in the east side, providing a total exhaust capacity at room temperature of 17.48 m^3/s.

B2.3.4 Radiant Heat Flux

Two calculation procedures are used to calculate the radiant heat flux to a target: one for fixed sources and one for movable sources. The only fixed fuel sources in this analysis are the cable tray fires. The calculation for a moveable fuel source involves determining the horizontal separation distance at which the exposure flux is exactly the critical flux. This value is then used as the recommended minimum separation distance between fuel and target. The calculation procedure for the fixed fuel sources involves determining the flux to the target given the separation distance.

For moveable fuel sources, the radiative flux, $\dot{q}_r''$ (kW/m^2), as a function of the separation is given by the following [Budnick and Perrault, 1990]:

$$\dot{q}_r'' = \frac{\chi \dot{Q}_p}{4\pi (L + D_{eff}/2)^2} \ \text{(kW/m}^2\text{)} \qquad \text{(B2-7)}$$

where χ is the fraction of the heat release rate released as radiation, L is the distance between the edge of the pool fire and the target, and the effective diameter, D_{eff} (m) is as given by Equation B2-6. If is assumed that the fraction of energy released as radiation is 0.4 [Tewarson, 1996], then the minimum distance between the edge of a fuel packet and a target is given as

$$L = 0.18\,\dot{Q}_p^{0.5} - D_{eff}/2 \ \text{(m)} \qquad \text{(B2-8)}$$

As discussed earlier, the minimum heat flux to the Detector is 15 kW/m^2, to the columns 20 kW/m^2, and to class A combustible materials 15 kW/m^2. Exceptions to this include short duration fires where the exposure flux may be increased to account for the short duration.

The incident heat flux, $\dot{q}_{inc}''$ (kW/m^2) to the Detector from the cable tray fires is calculated from the following [Siegel and Howell, 1980]:

$$\dot{q}_{inc}'' = \epsilon \sigma F_{s,t}(T_f^4 - T_\infty^4) \ \text{(kW/m}^2\text{)} \qquad \text{(B2-9)}$$

where ϵ is the emissivity of the fire (0.8), σ is the Stefan-Boltzmann constant (5.669E-11 kW/m^2-K^4), $F_{s,t}$ is the geometric configuration factor between the fire and the surface of the Detector, T_f is the flame temperature (1273 K), and T_∞ is the initial room temperature (298 K). The geometric configuration factor is calculated from the assumed geometry of the flame and the Detector. In both the vertical and horizontal cable tray scenarios, the flame is approximated as a rectangle equal to the height of the flame (F_h (m)) and the width of the exposing portion. In the case of the horizontal cable tray fire scenario, this is the maximum length of flame propagation before burnout has occurred, or L_f (m). In the case of the vertical cable tray scenario, the width is the width of the cable trays, or 0.61 m.

The Detector and the cable trays form a 31.3° angle in the case of the horizontal cable tray scenario. The corresponding equation for the geometric configuration factor is calculated from [Howell, 1982]:

$$F_{s,t} = \frac{2}{\pi}(\arctan(1/C) + \cos\frac{\phi}{Y}(\arctan((A - C\cos\phi)/Y) + \arctan(C\cos\phi/Y)) + ((\cos\phi - C)/X)\arctan(1/X)) \qquad \text{(B2-10)}$$

with

$$X = (C^2 \sin^2\phi + (A - C\cos\phi)^2)^{1/2} \tag{B2-11}$$

$$Y = (1 + C^2 \sin^2\phi)^{0.5} \tag{B2-12}$$

$$A = \frac{F_h}{L_t};\ C = \frac{R}{(1/2)L_t} \tag{B2-13}$$

and ϕ is the angle between the target and the source (radians), and R is the horizontal distance between the target and the source. The flame height for the horizontal cable trays is calculated from Tu and Quintiere [1991]:

$$F_h = 0.052\dot{Q}'^{0.667}\ \text{(m)} \tag{B2-14}$$

with $\dot{Q}'$ the heat release rate per unit tray length (kW/m) and is calculated from

$$\dot{Q}' = \frac{\dot{Q}_p}{L_t}\ \text{(kW/m)} \tag{B2-15}$$

for the horizontal cable trays.

The geometric configuration factor for the vertical cable tray is calculated in a similar manner [Howell, 1982]:

$$F_{s,t} = \frac{2}{\pi}(A/(1+A^2)^{0.5}\arctan(B/(1+A^2)^{0.5}) + B/(1+B^2)^{0.5}\arctan(A/(1+B^2)^{0.5})) \tag{B2-16}$$

where

$$A = (1/2\,W_{tray})/R;\ B = (1/2F_h)/R \tag{B2-17}$$

and all variables have been defined previously. The flame height for the vertical cable trays is also calculated using Equation B2-14. The heat release rate per unit width is calculated from

$$\dot{Q}' = \frac{\dot{Q}_p}{W_{tray}} \tag{B2-18}$$

where W_{tray} is the width of the cable trays (0.6 m).

B2.3.5 Column Temperature Calculations

The column temperatures resulting from direct flame impingement due from the flammable liquid pool fire in the east IR-2 area is computed using the finite element program STAR-CD [Computational Dynamics, 1994]. This program computes the temperature field in a column section resulting from the imposed boundary conditions. In the absence of specific column information, a conservatively small W12X40 column was chosen as being representative of the worst case scenario. The column is exposed for 190 seconds, the longest burning pool fire, at flame temperature, 1,000 °C. The boundary conditions placed on the column are as follows:

(1) Direct flame impingement on all sides;

(2) Radiation geometric shape factor of 1.0;

(3) Emissivity and absorbtivity of the steel is set at 0.6;

(4) Emissivity of the fire is set at 1.0; and

(5) A convection coefficient of 20 J/s-m^2.

The column is assumed to fail if either the average temperature exceeds 593 °C or the maximum temperature exceeds 649 °C [ASTM E119, 1993]. These are standard failure criteria for structural members.

B2.3.6 Fire Protection Features

Several fire protection features are currently installed or are planned to be installed in the IR-2 facility. These include smoke detectors, a sprinkler system in the east portion, separate sprinklers and smoke detectors in the Electronics House, and fire department intervention. Although no direct credit may be taken for these since a fire hazard analysis must assume the worst case situation that all devices fail, it is worthwhile to show what the conditions would be in the event that the fire protection features operate as designed.

Evaluation of the effectiveness of the fire protection features is accomplished by estimating the fire conditions at the time the feature operates. In the case of sprinklers, fire growth is assumed to stop and slowly decline. Additionally, once sprinklers operate, the fire department is assumed to have been notified. The operation of smoke detectors is calculated and once operating the fire department is assumed to be notified. The Electronics House has a preaction suppression system so the smoke detectors will operate and fill pipes with water.

Sprinkler and smoke detector operation were calculated using the program DETACT. This program calculates the temperature rise of a fusible link given the response time index (RTI ($m^{0.5}/s^{0.5}$)), a sprinkler specific heating constant. Smoke detector operation is also computed with DETACT. However, an artificially low RTI and a low operating temperature is used based on correlations developed previously [Evans and Stroup, 1985]. In the case of the east IR-2 facility, ordinary sprinklers are assumed, that is sprinklers with an operating temperature of 74 °C and an RTI of 100 $(m/s)^{0.5}$. In the case of the electronics house, both ordinary sprinklers and fast response sprinklers having an operating temperature of 68 °C and an RTI of 20 $(m/s)^{0.5}$ are compared. Smoke detectors assume an operating temperature of 10 °C above the initial temperature and an RTI of 1 $(m/s)^{0.5}$. According to Stanford Personnel, the fire department response time to the site should be about 3.5 to 4 minutes.

Once the response times of all the fire protection equipment is calculated, the results from CFAST may be used to determine the conditions at operation and/or fire department intervention. The key assumption when considering sprinklers is that they are adequately designed to control and suppress the fire.

B3.0 RESULTS

The results of the fire hazard calculations are presented in terms of the postulated fire scenarios. Included are the following:

(1) Flame height (m);

(2) Plume centerline temperature at the ceiling (°C);

(3) Target thermal radiation flux for the Detector (kW/m^2);

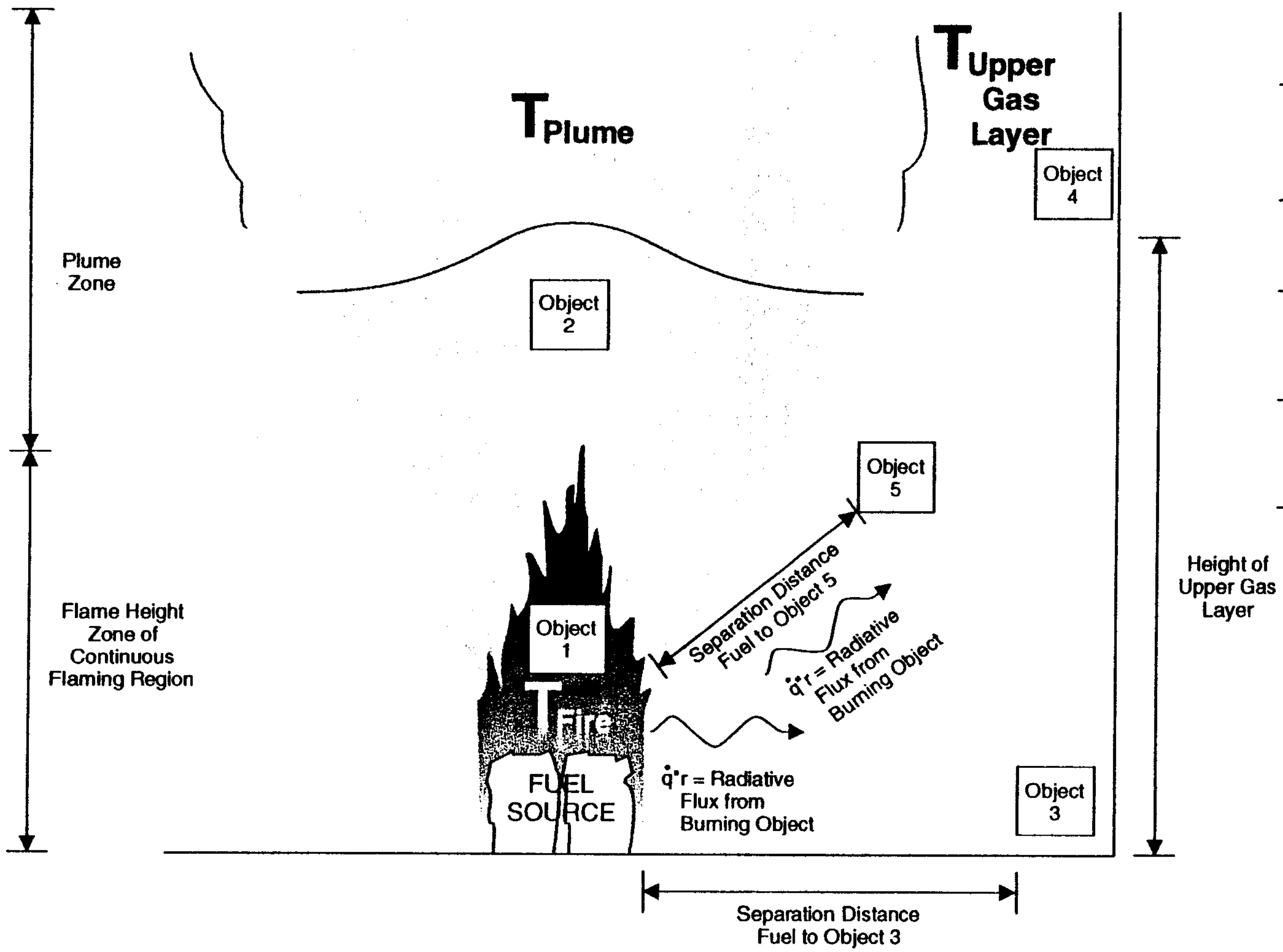
(4) Minimum separation requirements between moveable fuel sources and columns and other class A combustible materials (m);

(5) Maximum average and peak column temperatures resulting from engulfment in flammable liquid pool fire (°C);

(6) Maximum upper gas layer temperatures (°C); and

(7) Minimum gas layer depth below the ceiling (m).

Figure B3-1 illustrates the effects of interest for a typical incidental fire in the IR-2 hall. The flame height is the height of the continuous flame region above the fuel (m). Typically, the temperature within the flame zone is 1000 °C or greater [Beyler, 1986], and electrical and mechanical equipment in this zone are subject to rapid failure. Refer to Figure B3-1 for a



Object #	Condition
1	Immersed in Fire Zone
2	Immersed in Plume
3	Exposed to Radiation Heat Flux
4	Immersed in Hot Gas Layer
5	Exposed to Radiation Heat Flux

Figure B3-1. Illustration of fire source and target impact relationships depiction of fire-target interactions. The plume centerline temperature decreases with height from the tip of the continuous flame region. Calculation of the plume centerline temperature permits evaluation of the exposure conditions to equipment and materials positioned directly above a fire.

The target radiation flux (Figure B3-1) is the net incident heat flux at the surface of an object located at some distance from the fire. For this analysis the objects are primarily the Detector, the structural columns in the east portion of the building, and other ignitable materials.

A fire burning in an enclosure will usually cause a layer of hot gases to collect at the ceiling. For small enclosures and/or large fires, the temperature of this gas layer may reach or exceed established critical temperature levels. In order to evaluate the hazard from the hot gas layer, the layer temperature and depth are required. A computer model, CFAST, was used to perform these calculations.

A flammable liquid spill presents the possibility of exposing structural columns on all sides with direct flame impingement. As a result, it is necessary to determine if this will possibly cause a loss of integrity in the structural member. The most effective means to do this is to evaluate the temperature field within a column exposed on all sides to flames.

B3.1 Flammable Liquid Fire Scenarios

B3.1.1 Upper Gas Layer Results for Flammable Liquid Pool Fires

The four flammable liquid pool fire scenarios were modeled using CFAST for three geometric configurations:

(1) Concrete curtain in place, tunnel openings closed;

(2) Concrete curtain removed, tunnel openings closed; and

(3) Concrete curtain removed, tunnel openings open.

Figures B3-2 and B3-3 depict the temperature versus time and interface depth versus time in the west part of IR-2 for the 18.9 L flammable liquid fire scenarios for all three geometric configurations. Although the gas layer descends below the top portion of the Detector (approximately 6.2 m) when the concrete curtain is not in place above the shield wall, the maximum upper gas layer temperature does not exceed 120 °C. Since this is well below the maximum 150 °C, the flammable liquid pool fires are not predicted to adversely effect the Detector. As can be seen in Figure B3-2, the most pronounced effect on the upper gas layer in the west portion is the position of the curtain wall. Table B3-1 summarizes the peak upper gas layer temperatures and the maximum descent of the upper gas layer on the west side of the shield wall for all geometric configurations and flammable liquid scenarios.

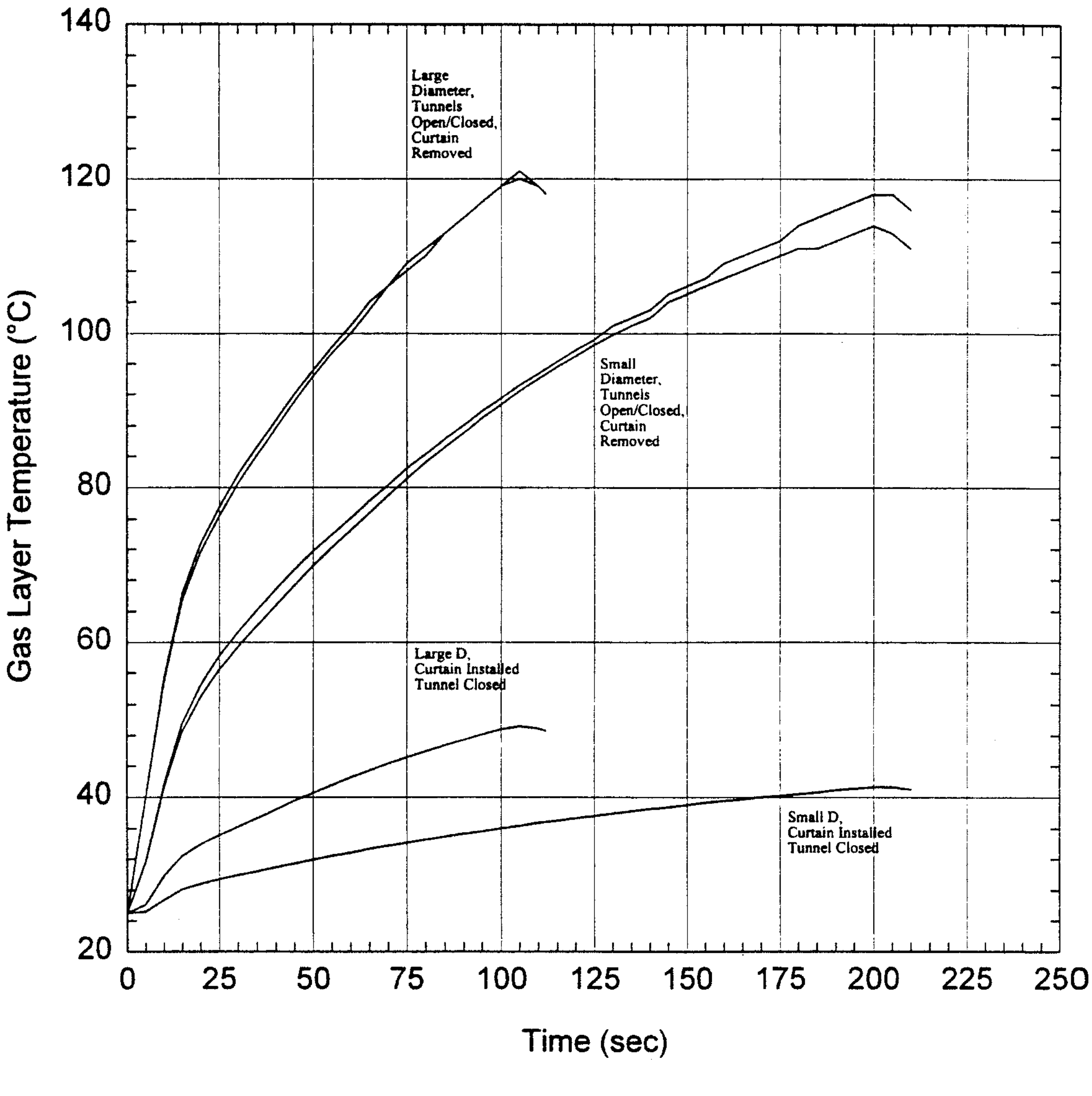


Figure B3-2. Gas layer temperatures in west IR-2 for 18.9 L flammable liquid pool fire scenarios

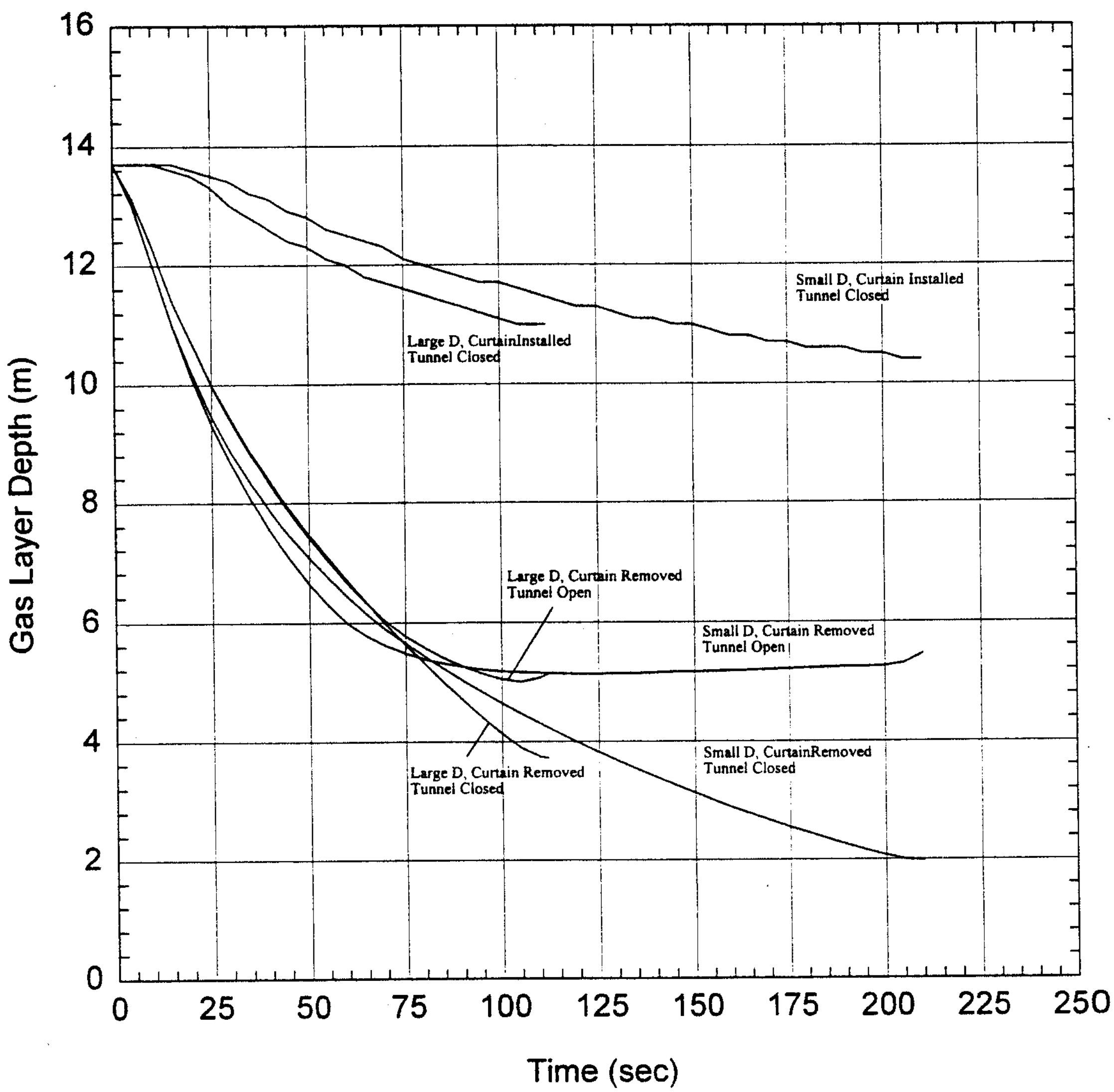


Figure B3-3. Gas layer depth vs time in west IR-2 for 18.9 L flammable liquid pool fires

Table B3-1. Summary of Flammable Liquid Pool Fire Gas Layers in the West Side of IR-2

Pool Fire	Curtain Installed; Tunnel Closed		Curtain Removed; Tunnel Closed		Curtain Removed; Tunnel Open	
	Max Temp (°C)	Max Depth (m)	Max Temp (°C)	Max Depth (m)	Max Temp (°C)	Max Depth (m)
7.6 L Large Diam	35.4	11.8	72.3	6.12	72.2	6.22
7.6 L Small Diam	31.6	10.9	66.9	3.15	64.7	5.33
18.9 L Large Diam	49.2	11.0	121	3.72	120	5.33
18.9 L Small Diam	41.3	10.4	118	1.98	114	5.46

B3.1.2 Ceiling Temperatures Under the Fire Plume for Flammable Liquid Pool Fires

The flame heights and the centerline plume temperatures for each of the four pool fire scenarios are presented in Table B3-2. Both open pool fires and pool fires against a wall are calculated. Since the flame height never reaches the ceiling (13.7 m) and the centerline plume temperature does not exceed 593 °C, no structural damage is predicted.

Table B3-2. Ceiling Conditions for Flammable Liquid Pool Fire Scenarios

Scenario	Heat Release Rate (kW)	Flame Height (m) Open (Wall)	Plume Temp at Ceiling (°C) - Open	Plume Temp at Ceiling (°C) - Wall
7.6 L Large Diam	3,965	3.02 (3.85)	96	130
7.6 L Small Diam	1,498	2.04 (2.61)	63	85
18.9 L Large Diam	7,880	3.98 (5.07)	130	177
18.9 L Small Diam	3,743	2.96 (3.76)	93	127

B3.1.3 Flammable Liquid Separation Requirements - Class A Combustibles

The separation requirements are estimated based on the heat flux necessary to ignite Class A combustible materials. This primarily concerns the electronics house and wood crates. The total separation between the flammable liquid and nearby combustibles includes the separation from the edge of the pool fire and the radius of the pool fire. This is to account for the fact that the pool will spread away from the source of the flammable liquid. Table B3-3 summarizes the separation requirements. Since the pool fires burn for a short duration, the minimum ignition flux is greater than the 15 kW/m^2 used to calculate the separation for longer duration fires. The minimum ignition flux is also reported in Table B3-3. For a given volume of liquid, the maximum separation distance should be used. Thus, for a 7.6 L flammable liquid, the minimum separation is 1.87 m and not 1.38 m.

Table B3-3. Minimum Separation Requirements for Candidate Flammable Liquid Pool Fires

Scenario	Radius (m)	Duration (s)	Minimum Ignition Flux (kW/m^2)	Minimum Separation Required (m)
7.6 L Large Diam	0.71	72	36	1.87
7.6 L Small Diam	0.436	190	25	1.38
18.9 L Large Diam	1.0	91	30	2.89
18.9 L Small Diam	0.69	190	25	2.18

B3.1.4 Flammable Liquid Separation Requirements - Columns

The separation requirements for structural columns were determined by modeling several scenarios using the finite element heat transfer program STAR-CD [Computational Dynamics, 1994]. The program calculates the time dependent temperature field withing a solid by breaking up the solid into a large number of elements (mesh) and calculating the temperature at each element. Boundary conditions are applied to the exterior of the solid and include the temperature exposure, the radiative properties of the solid, and the convective properties of the solid-gas interface. Figure B3-4 depicts the mesh used to determine the column thermal response to the pool fires. The column used in the analysis was a W12X40, which is relatively small for a 13.7 m structural column member. Heavier columns will respond more favorably in a fire environment due to the increased capacity to absorb heat. In the absence of more specific column specifications, the lighter member provides more conservative results. For this analysis, flame impingement is assumed equivalent to an exposure temperature of 1,000 °C.

Since the pool fires may burn between 72 and 190 seconds, the most conservative approach was to assume the column must not reach failure temperatures (593 °C average, 649 °C peak) for at least 190 seconds. The first case modeled was complete engulfment in a pool fire for 190 seconds. This corresponds to a 1,000 °C exposure temperature on all sides of the member. Figure B3-5 shows the peak temperature and average temperature versus time for this scenario. As can be seen in the figure, the column reaches a failure condition at approximately 130 seconds by exceeding the 649 °C peak temperature criteria. As a result, the flammable liquids should be separated at least far enough to prevent a column from being completely surrounded by a pool.

The next scenario modeled was a column exposed on only one side. This corresponds to the case where the column is at the edge of the pool fire, or the flammable liquid is separated from the column by the radius of the pool fire. Figure B3-6 shows the peak temperature and average temperature versus time. As can be seen in the figure, the peak temperature never exceeds 649 °C and the average temperature never exceeds 593 °C, indicating that this separation is sufficient

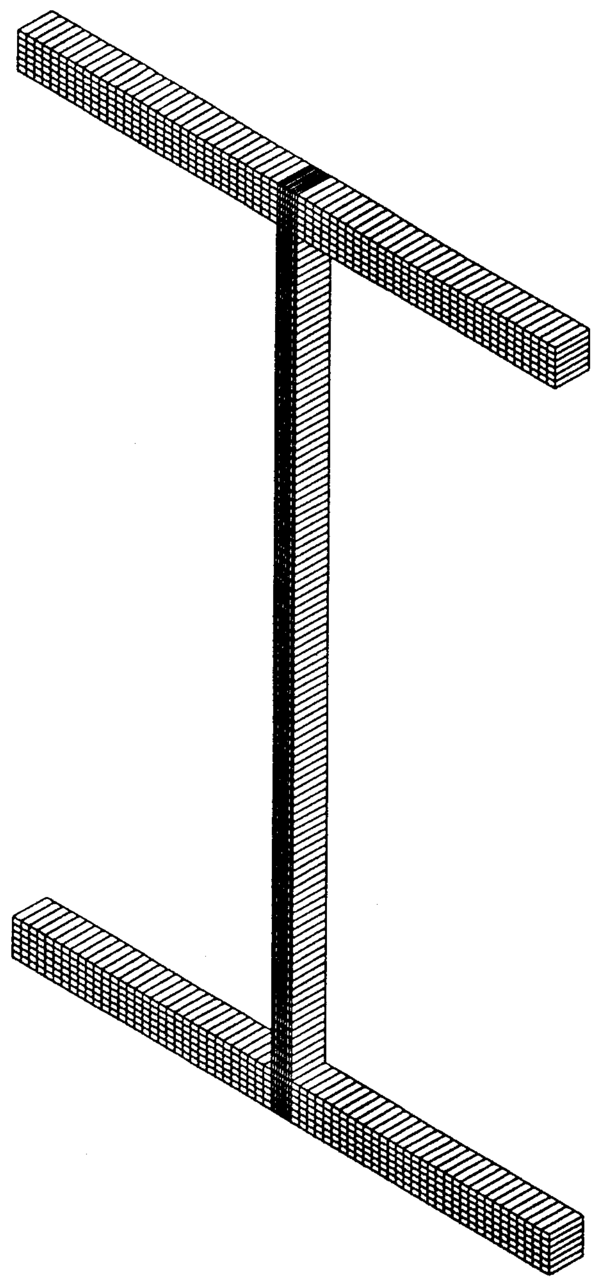


Figure B3-4. Mesh configuration for heat transfer calculations to steel column (cross section)

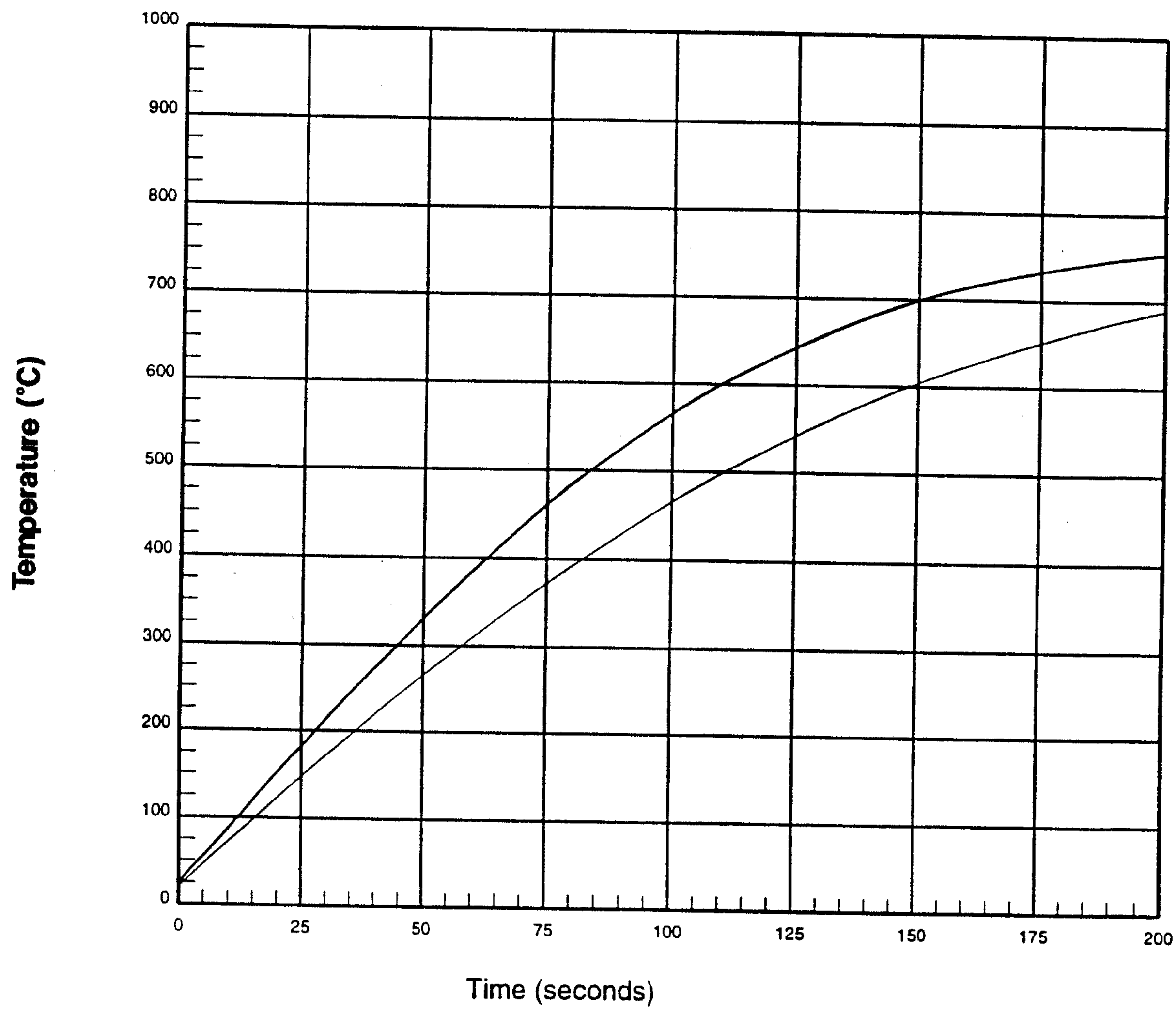


Figure B3-5. Calculated column temperatures for flame engulfed colume from pool fire

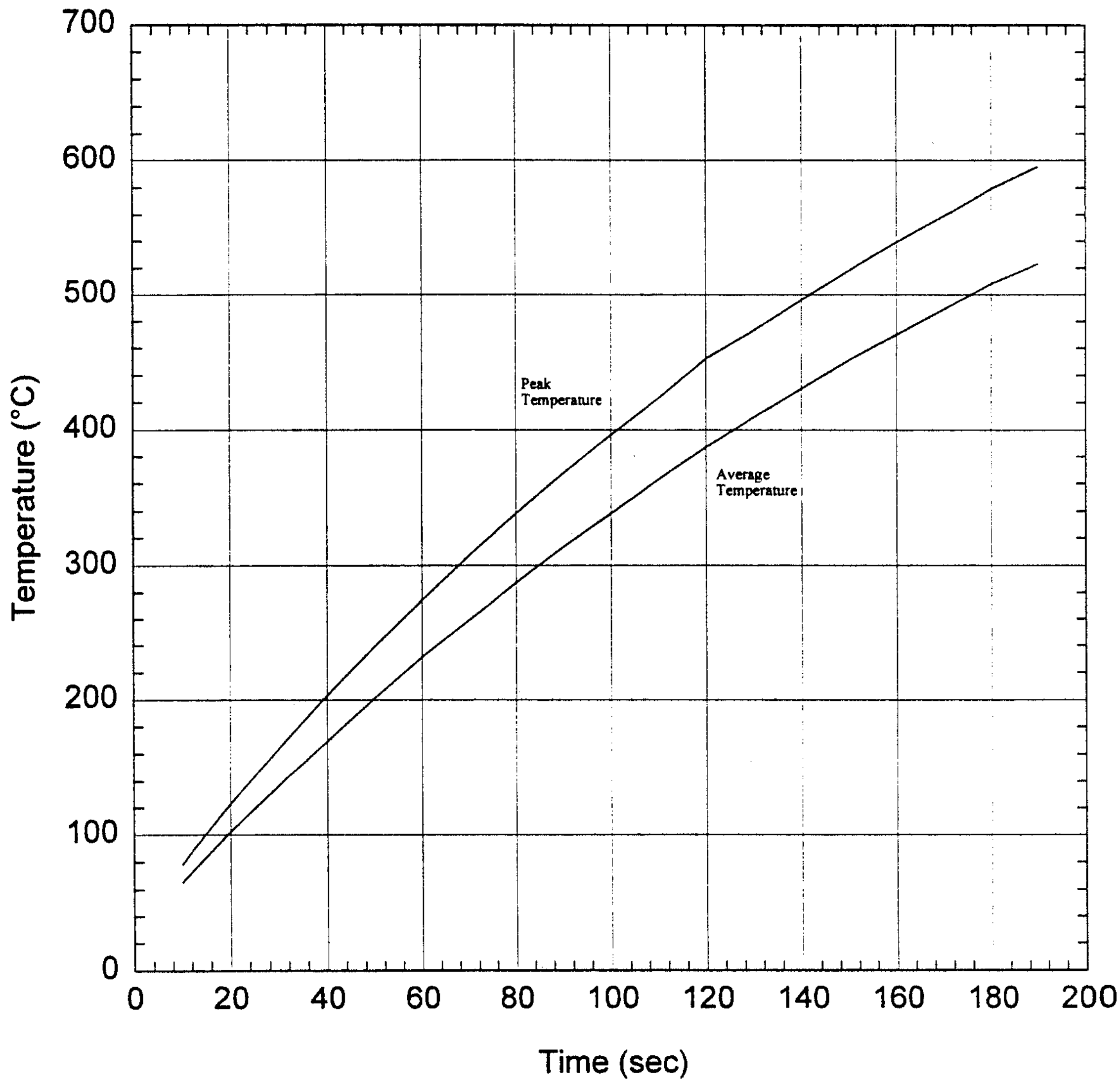


Figure B3-6. Calculated column temperatures for partial exposure of column to pool fire to prevent the structural columns from failing. Table B3-4 summarizes the flammable liquid-column separation requirements

4. Separation Requ: ns for lamı Liquids and

Liquid Volume (L)	Separation (m)
7.6	1.38
18.9	2.18

B3.1.5 Fire Protection Effects on Flammable Liquid Pool Fires

Three fire protection features are considered in this section: smoke detection, sprinklers, and fire department intervention. Smoke detection and fire department intervention are assumed to be part of the same mechanism; that is, smoke detectors alert the fire department. Since the fire department response time is 3.5 minutes, the total time to intervention is the smoke detection time plus the fire department response time.

Based on the heat release rate curves previously calculated and results from modeling response times using the computer model, DETACT, the time required for a smoke detector and sprinkler to operate can be estimated. Smoke detectors are assumed to be spaced no more than 4.3 m apart [NFPA 72, 1993], and the maximum horizontal distance to a sprinkler is assumed to be 2.16 m [NFPA 13, 1994]. The sprinkler and smoke detection operating times as predicted by DETACT for these geometric are listed in Table B3-5.

Scenario	Smoke Detection (s)	Sprinklers (s)	Fire Department (s)
7.6 L Large Diam	3	Do Not Operate	213
7.6 L Small Diam	9	Do Not Operate	219
18.9 L Large Diam	3	Do Not Operate	213
18.9 L Small Diam	4	41	214

The conditions at sprinkler operation or fire department intervention can be estimated from the CFAST output calculated previously. If it assumed that the sprinklers are designed to suppress the fire, the peak upper gas layer temperatures and the peak upper gas layer descent will be at the instant the sprinklers operate. Fire department intervention may also be evaluated in a similar manner. In this analysis it is assumed that the peak temperatures and layer descent occur at the total fire department response time. This may not be the true case, however, since there is addition time required to set up the equipment, assess the situation, and locate the fire. This will depend on the exact situation found and is beyond the scope of this analysis to evaluate. Table B3-6 summarizes the conditions at sprinkler operation and fire department arrival based on the calculations presented here.

Table B3-6. Conditions at Sprinkler Operation and Fire Department Intervention for Flammable Liquid Pool Fire Scenarios

Scenario	Conditions at Sprinkler Operation		Conditions at Fire Department Intervention	
	Gas Temp (°C)	Gas Depth (m)	Gas Temp (°C)	Gas Depth (m)
7.6 L Large Diam	Did not operate	Did not operate	Fuel consumed	Fuel consumed
7.6 L Small Diam	Did not operate	Did not operate	Fuel consumed	Fuel consumed
18.9 L Large Diam	Did not operate	Did not operate	Fuel consumed	Fuel consumed
18.9 L Small Diam	30.9[1] 66.8[2] 64.8[3]	13.1[1] 7.9[2] 7.5[3]	40.6[1] 115[2] 111[3]	10.6[1] 2.4[2] 5.23[3]

Note: [1]Curtain installed; [2]Curtain removed, tunnel closed; [3]Curtain removed, tunnel open

B3.2 Crate Fire Scenarios

B3.2.1 Upper Gas Layer Results for Crate Fire Scenarios

The four crate fire scenarios were evaluated using CFAST for four geometric configurations:

(1) Concrete curtain installed, tunnels closed;

(2) Concrete curtain removed, tunnels closed;

(3) Concrete curtain removed, tunnels open; and

(4) Concrete curtain removed, tunnels open, mechanical ventilation operating.

Figures B3-7 and B3-8 depict the temperature versus time and interface versus time in the west part if IR-2 for the 4 and 6 crate fire scenarios. All of the scenarios shown in Figures B3-7 and B3-8 expose the Detector to a hot gas layer in excess of 150 °C except for the scenario with four crates, curtain removed, open tunnel, and mechanical ventilation on. In the latter case, the layer does not descend far enough to expose the equipment. Tables B3-7a and B3-7b summarize the peak temperature and maximum layer depth for each of the crate fire scenarios and all of the geometric configurations. In addition, the time required to reach a hazardous condition at the Detector is also listed. Based on the information provided in Figures B3-7, B3-8, and Tables B3-7a and B3-7b, the earliest that any of the fire scenarios will expose the Detector to gas temperatures in excess of 150°C is 660 seconds. It is also apparent that the curtain is the most effective means of reducing the risk in the west part of the building, with only the six crate fire scenario failing after 1280 seconds for this configuration. The tunnel is next as an effective

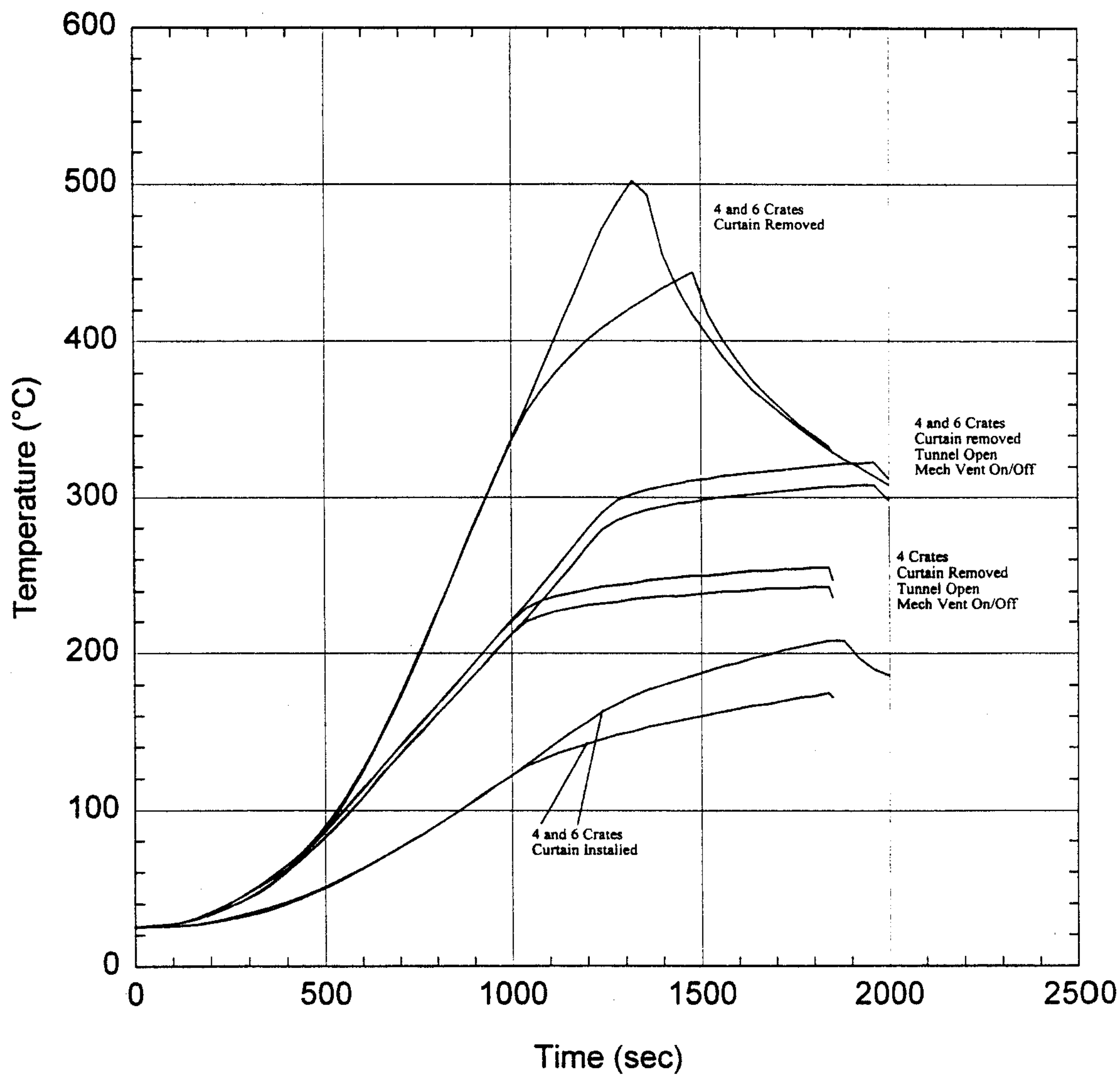


Figure B3-7. Gas layer temperatures in west IR-2 for 4 and 6 crate fire scenarios

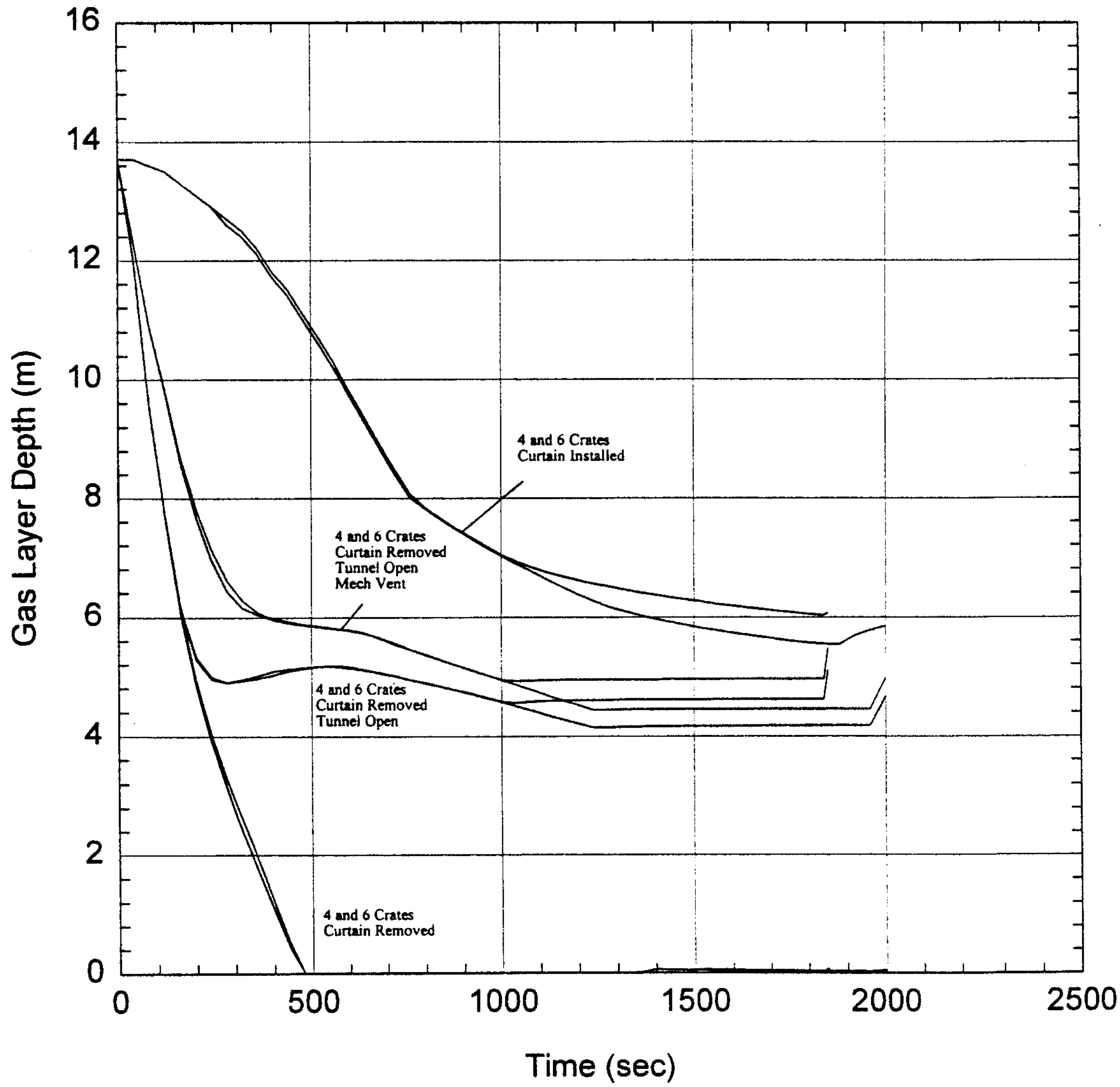


Figure B3-8. Gas layer depths in west IR-2 for 4 and 6 crate fire scenarios hazard prevention, followed by the mechanical ventilation system. Only the six crate scenario with the curtain removed, tunnel closed and no mechanical ventilation has the potential to cause flashover. Flashover occurs when the hot gas temperature is between 500 °C and 600 °C [Drysdale, 1985]. However, since this scenario was modeled as an essentially leak proof enclosure, the predicted temperatures are likely to be somewhat high.

Table B3-7a. Summary of Crate Fire Gas Layers

Scenario	Curtain Installed			Curtain Removed, Tunnel Closed, No Mech Vent		
	Peak Temp (°C)	Max Depth (m)	Time To Failure (s)	Peak Temp (°C)	Max Depth (m)	Time To Failure (s)
1 Crate	81.3	7.51	N/A	151	0	1470
2 Crates	120	6.99	N/A	242	0	805
4 Crates	175	6.22	N/A	444	0	670
6 Crates	208	5.54	1280	502	0	660

Table B3-7b. Summary of Crate Fire Gas Layers

Scenario	Curtain Removed, Tunnel Open, No Mech Vent			Curtain Installed, Tunnel Closed, Mech Vent		
	Peak Temp (°C)	Max Depth (m)	Time To Failure (s)	Peak Temp (°C)	Max Depth (m)	Time To Failure (s)
1 Crate	109	4.86	N/A	101	5.85	N/A
2 Crates	159	4.87	1085	153	5.49	1400
4 Crates	255	4.56	740	243	4.92	760
6 Crates	323	4.17	720	308	4.46	760

B3.2.2 Ceiling Temperatures Under the Fire Plume for Crate Fire Scenarios

The flame heights and centerline plume temperatures for each of the crate fire scenarios are presented in Table B3-8. Due to the location of the columns against the walls, there is no need to calculate the wall flame and plume temperature conditions. The flame height never reaches the ceiling and the plume centerline temperature never exceeds the 593 °C criteria, so that these scenarios are not structurally endangering to the roof.

Scenario	Heat Release Rate (kW)	Flame Height (m)	Plume Centerline Temperature (°C)
1 Crate	2,975	2.7	82
2 Crates	5,950	3.6	116
4 Crates	11,900	4.7	167
6 Crates	17,850	5.5	206

B3.2.3 Crate Separation Requirements

The separation requirements for the crates were calculated based the minimum heat flux necessary to ignite cellulosic fuels (wood, paper) and the minimum heat flux necessary to raise the temperature of a column to 593 °C. This corresponds to heat flux levels of 15 kW/m^2 and 20 kW/m^2 respectively. Table B3-9 summarizes the calculated separation requirements. The reported distances are interpreted from the edge of the fuel package to the edge of another fuel package or the edge of a structural column.

Table B3-9. Minimum Separation Requirements for Crates

Scenario	Duration (s)	Separation from Class A Combustibles (m)	Separation from Columns (m)
1 Crate	1000	1.54	1.21
2 Crates	929	2.17	1.7
4 Crates	833	3.08	2.41
6 Crates	757	3.77	2.95

B3.2.4 Fire Protection Effects on Crate Fires

Three fire protection features are considered in this section: smoke detection, sprinklers, and fire department intervention. Smoke detectors are assumed to alert the fire department, which has a response time of 3.5 minutes. The sprinkler actuation times and the smoke detection operation times were calculated using DETECT for the same sprinkler and smoke detector spacings described previously. Table B3-10 summarizes these times as well as the total fire department response time (which includes the smoke detector operation time).

Table B3-10. Sprinkler and Smoke Detector Operating Times for Crate Fire Scenarios

Scenario	Smoke Detection (s)	Sprinklers (s)	Fire Department (s)
1 Crate	310	N/A	490
2 Crates	310	582	490
4 Crates	310	582	490
6 Crates	310	582	490

As with the pool fire scenarios the conditions at sprinkler operation or fire department arrival may be estimated from the results of the CFAST calculations. In this case, the sprinklers are assumed to be capable of suppressing the fire and the fire department is assumed to immediately begin controlling the fire. As a result, the worst conditions will be at sprinkler operation or fire department arrival. Table B3-11 summarizes these conditions for each scenario and each geometric configuration as calculated by CFAST. Only the 1 crate fire scenario has the capacity to endanger the Detector since for all others sprinklers or intervention occur before the gas layer reaches 150 °C. But, the one crate fire scenario only poses a threat if the curtain is removed and the IR-2 hall is completely sealed off from the outside, including tunnels.

Table B3-11. Conditions at Sprinkler Operation/Fire Department Arrival - Crate Fires

Scenario	Conditions at Sprinkler Operation		Conditions at Fire Department Intervention	
	Gas Temp (°C)	Gas Depth (°C)	Gas Temp (°C)	Gas Depth (°C)
1 Crate	N/A	N/A	52[1] 69[2] 71[3] 70[4]	10.8[1] 1.2[2] 4.96[3] 5.8[4]
2 Crates	32[1] 38[2] 38[3] 38[4]	12.6[1] 4.5[2] 5.1[3] 7.0[4]	52[1] 71.7[2] 73[3] 72[4]	10.7[1] 1.04[2] 4.96[3] 5.8[4]
4 Crates	32[1] 44[2] 45[3] 44[4]	12.6[1] 3.0[2] 4.9[3] 6.3[4]	52[1] 93.1[2] 91[3] 88[4]	10.7[1] 0[2] 5.18[3] 5.94[4]
6 Crates	32[1] 48[2] 48[3] 47[4]	12.6[1] 2.6[2] 4.9[3] 6.3[4]	53[1] 96[2] 92.3[3] 88[4]	10.6[1] 0[2] 5.18[3] 5.8[4]

Notes: [1]Curtain Closed [2]Curtain Open [3]Curtain Open; Tunnel Open [4]Curtain Open; Tunnel Open; Mechanical Ventilation On

B3.3 Drum Fire Scenarios

B3.3.1 Drum Fire Upper Gas Layer Results

The four drum fire scenarios were evaluated using CFAST for three geometric configurations:

(1) Concrete curtain installed, tunnels closed;

(2) Concrete curtain removed, tunnels closed; and

(3) Concrete curtain removed, tunnels open.

Figures B3-9 and B3-10 show the upper gas layer temperature versus time and the upper gas layer depth versus time in the west part of IR-2 for the 6 drum fire scenario. None of the scenarios in the figures expose the Detector to temperatures greater than 150 °C even though the layer descends below the top elevation for the Detector for the cases where the concrete curtain is removed. Since the six drum fire scenarios are the worst case drum fires considered, it is apparent that this candidate fire scenario does not pose a risk to the Detector from a hot gas layer. Figure B3-10 demonstrates clearly the impact of closing the tunnel on the descent of the upper gas layer. Table B3-12 summarizes the peak upper gas layer temperature and the maximum level of descent for all four fire scenarios and all three geometric configurations.

Table B3-12. Summary of Drum Fire Hot Gas Layers

Scenario	Curtain Installed; Tunnel Closed		Curtain Removed, Tunnel Closed		Curtain Removed, Tunnel Open	
	Max Temp (°C)	Max Depth (m)	Max Temp (°C)	Max Depth (m)	Max Temp (°C)	Max Depth (m)
1 Drum	27.3	11.8	30.8	2.45	30.4	4.91
2 Drums	29.9	11.1	36.3	1.99	35.1	4.98
4 Drums	34.9	10.2	46.5	1.36	42.9	5.01
6 Drums	39.5	9.49	54.4	1.08	50.3	5.00

B3.3.2 Ceiling Temperatures Above the Fire Plume for the Drum Fire Scenarios

The flame heights and centerline plume temperatures for each of the drum fire scenarios are shown in Table B3-13. Due to the location of the columns against the walls and the separation requirements listed in the next section, there is no need to calculate the results for drums located against the wall. Since the flame heights never reach the ceiling and the plume centerline temperatures are below 593 °C, none of the drum fires scenarios are structurally endangering to the roof assembly.

Table B3-13. Ceiling Conditions for Drum Fire Scenarios

Scenario	Heat Release Rate (kW)	Flame Height (m)	Plume Centerline Temperature (°C)
1 Drum	129	0.76	28
2 Drums	258	1.01	33
4 Drums	516	1.34	41
6 Drums	774	1.57	47

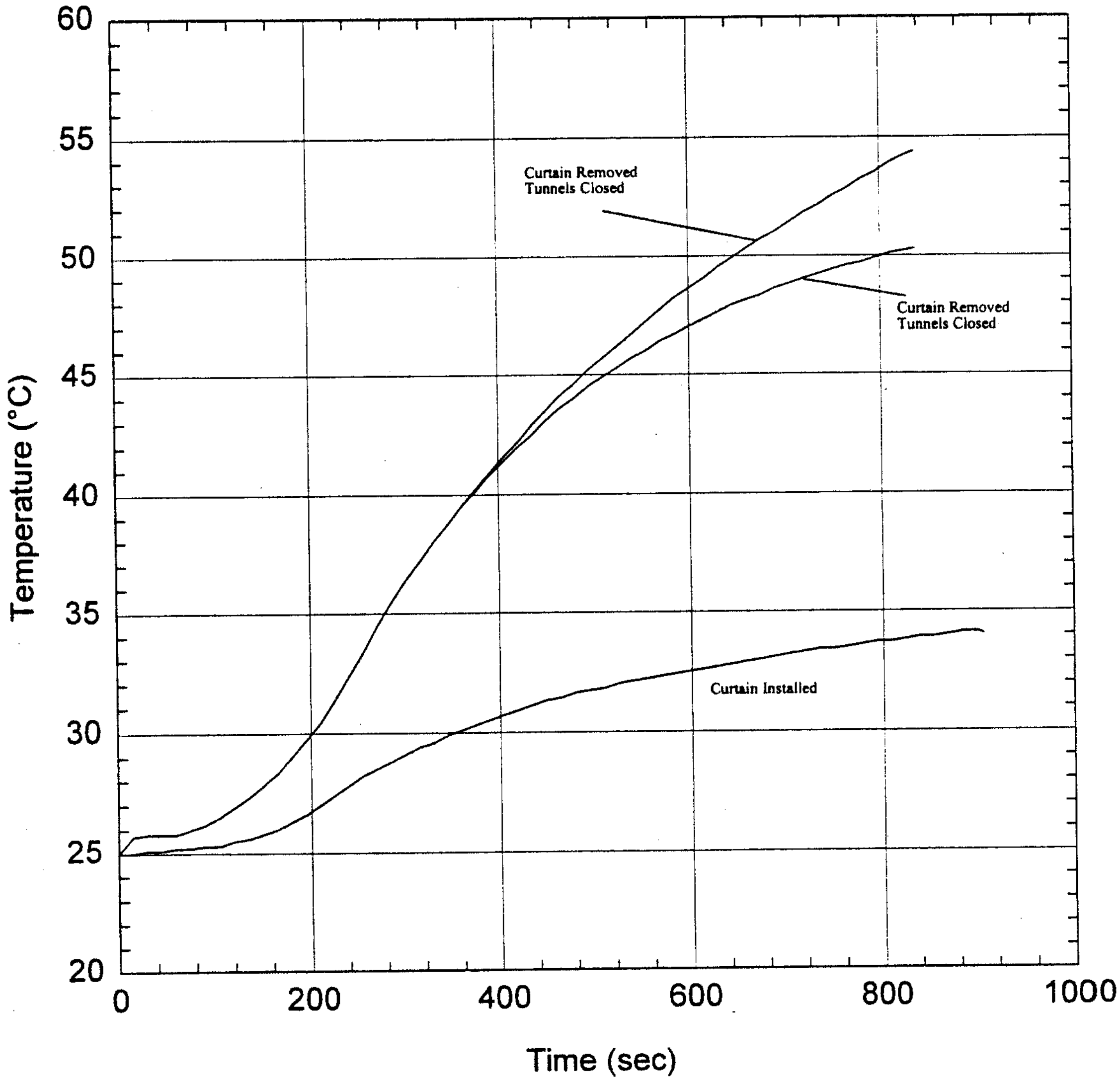


Figure B3-9. Gas layer temperatures in west IR-2 for 6 drum fire scenarios

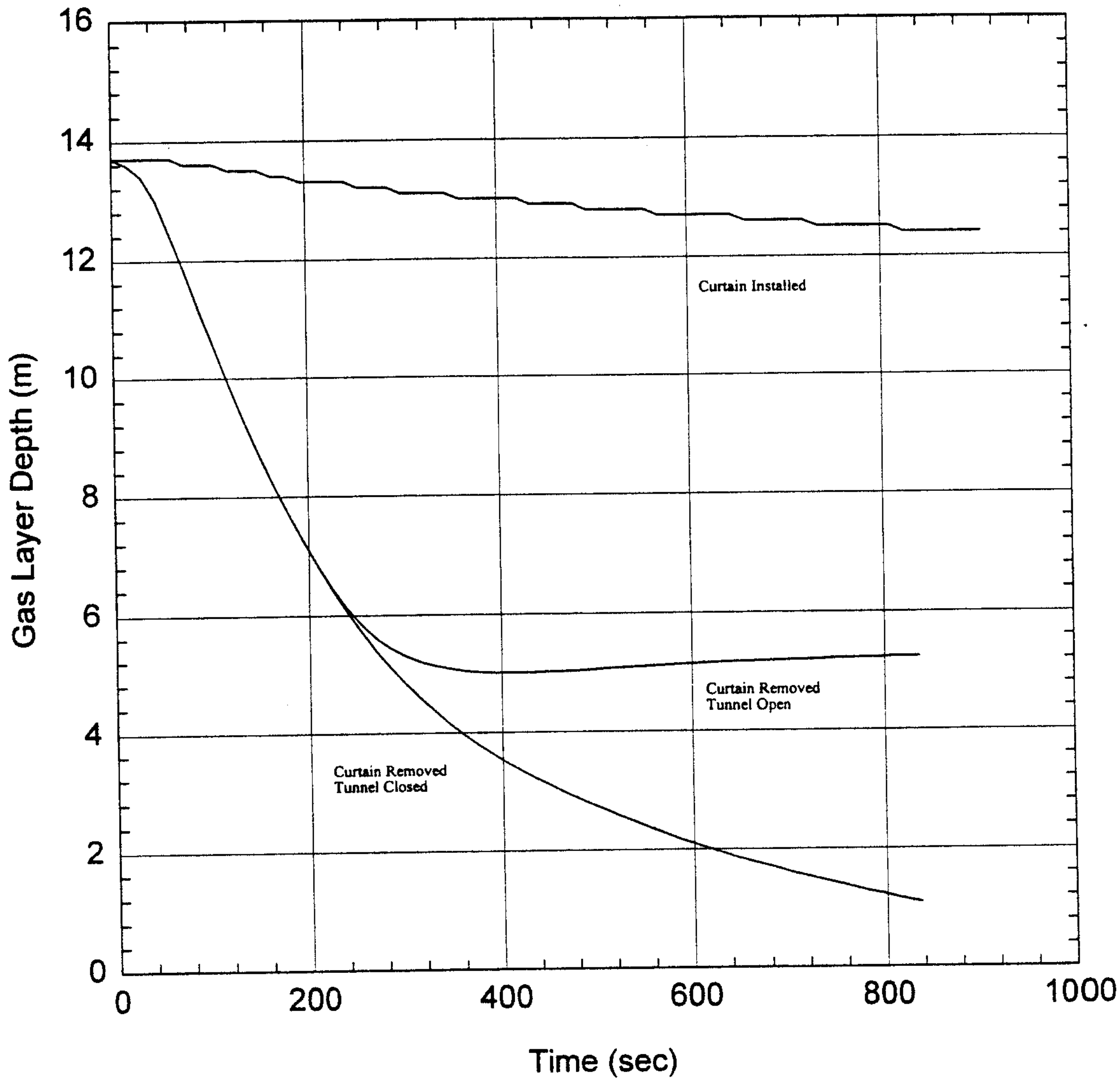


Figure B3-10. Gas layer depths in west IR-2 for 6 drum fire scenarios

B3.3.3 Drum Separation Requirements

The separation requirements for the drums are calculated based on the minimum heat flux necessary to ignite cellulosic fuels (wood, paper, trash) and the minimum heat flux capable of raising a column temperature to 593 °C. This corresponds to 15 kW/m^2 and 20 kW/m^2, respectively. Table B3-14 summarizes the separation requirements for each drum fire scenario. The distances are from the edge of a drum to the edge of the target.

Table B3-14. Minimum Separation Requirements for Drums

Scenario	Duration (s)	Separation from Class A Combustibles (m)	Separation from Columns (m)
1 Drum	806	0.22	0.15
2 Drums	855	0.31	0.21
4 Drums	896	0.44	0.30
6 Drums	927	0.54	0.36

B3.3.4 Fire Protection Effects on Drum Fires

As in the previous sections, three fire protection features are considered here: smoke detection, sprinklers, and fire department intervention. Smoke detectors are assumed to alert the fire department, which has a response time of 3.5 minutes. The sprinkler actuation times and smoke detection times were calculated with DETACT using the heat release rate curves developed in Section B1 and the sprinkler and smoke detector spacings listed in Section B3.1.5. Table B3-15 summarizes the results. Since all scenarios fail to actuate any sprinklers or smoke detectors, the fire is assumed to run its course without interference. As such, the fire protection features have no effect on the fires and the values listed in Table B3-12 are the worst case expected results.

Table B3-15. Sprinkler and Smoke Detector Operating Times for Drum Fire Scenarios

Scenario	Smoke Detection (s)	Sprinklers (s)	Fire Department (s)
1 Drums	Did not operate	Did not operate	No alarm
2 Drums	Did not operate	Did not operate	No alarm
4 Drums	Did not operate	Did not operate	No alarm
6 Drums	Did not operate	Did not operate	No alarm

B3.4 Electronics House Fire Scenarios

B3.4.1 Calculation of Minimum Fuel Load for Flashover in the Electronics House

The Electronics House on the east side of IR-2 contains approximately 30 electronics cabinets used to collect data from the Detector. The goal of this analysis is to determine the minimum amount of Class A combustible materials capable of causing flashover in the Electronics House although damage to the electronic equipment is likely at much lower temperatures. This was accomplished by modeling the growth rate curve presented in Section B1 in the Electronics House until flashover has occurred (upper gas layer temperature 550 °C or greater) and the fire ceases to grow due to lack of oxygen. If flashover occurs, the limiting mass of combustibles is given by the following:

$$M_c = \int_0^{t_f} \dot{m}(t)\,dt = \frac{\alpha t_f^3}{3\Delta H_c} \text{ (kg)} \qquad \text{(B3-1)}$$

where M_c is the mass of combustibles necessary to cause flashover, t_f is the time to flashover (s) calculated by CFAST, and the heat of combustion, ΔHc, of the class A combustibles is 19,500 kJ/kg.

Two scenarios were modeled in the electronics house: one with the door closed and one with the door open. The door was assumed to be a standard 2.13 m by 0.91 m opening. Figures B3-11, B3-12, and B3-13 show the calculated heat release rates, gas layer temperatures, and layer depths for both scenarios. The heat release rate may be different than the specified heat release rate due to the reduced concentrations of oxygen. CFAST automatically calculates this effect.

Figures B3-11 through B3-13 show that only when the door is open will the Electronics House reach flashover temperatures. This occurs at approximately 490 seconds when the fire is about 2,800 kW. This corresponds to a fuel loading of 23.6 kg. When the door is closed, the fire runs out of oxygen and rapidly diminishes. The figures also show that the gas layer descends rapidly and in the case where the door is closed is practically at the floor in 3 minutes.

B3.4.2 Fire Protection Effects on the Electronics House Fires

The Electronics House is protected with a preaction sprinkler system. The preaction system is a dry pipe sprinkler system that fills with water only when the smoke detectors operate. At this point, it is a regular wet pipe sprinkler system. In addition to filling the sprinkler system with water, the smoke detectors are also assumed to alert the fire department.

The smoke detector and the sprinkler actuation times were calculated with DETACT using the heat release rate curve developed in Section B1 and the same spacings assumed in the east IR-2 area. Two types of sprinklers are considered: ordinary sprinklers with and RTI of 100 $(m/s)^{0.5}$ and fast response sprinklers having and RTI of 25 $(m/s)^{0.5}$. Smoke detectors are assumed to have an operating temperature 10 °C greater than the initial temperature and have an RTI of

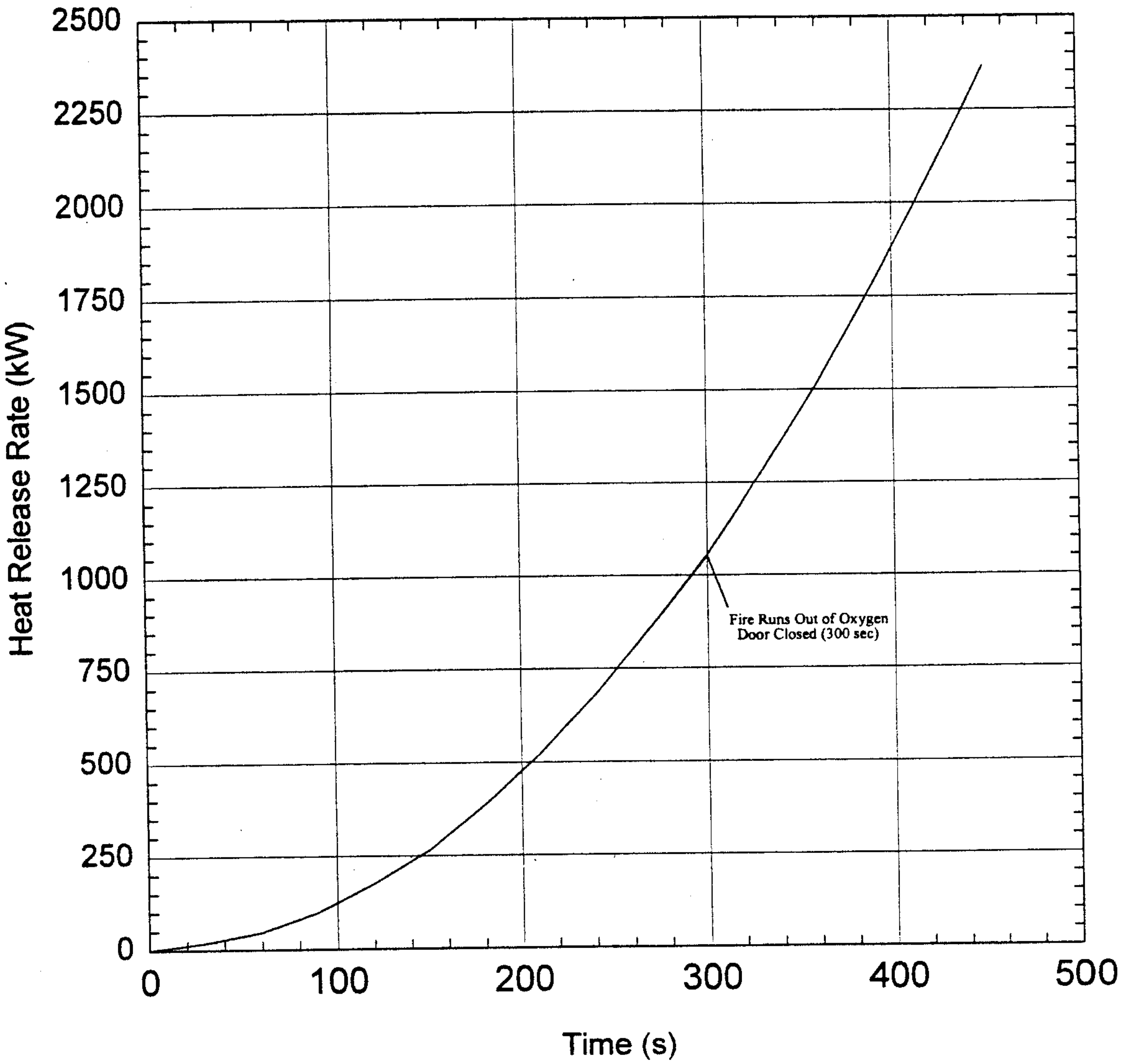


Figure B3-11. Heat release rates for Electronics House fires

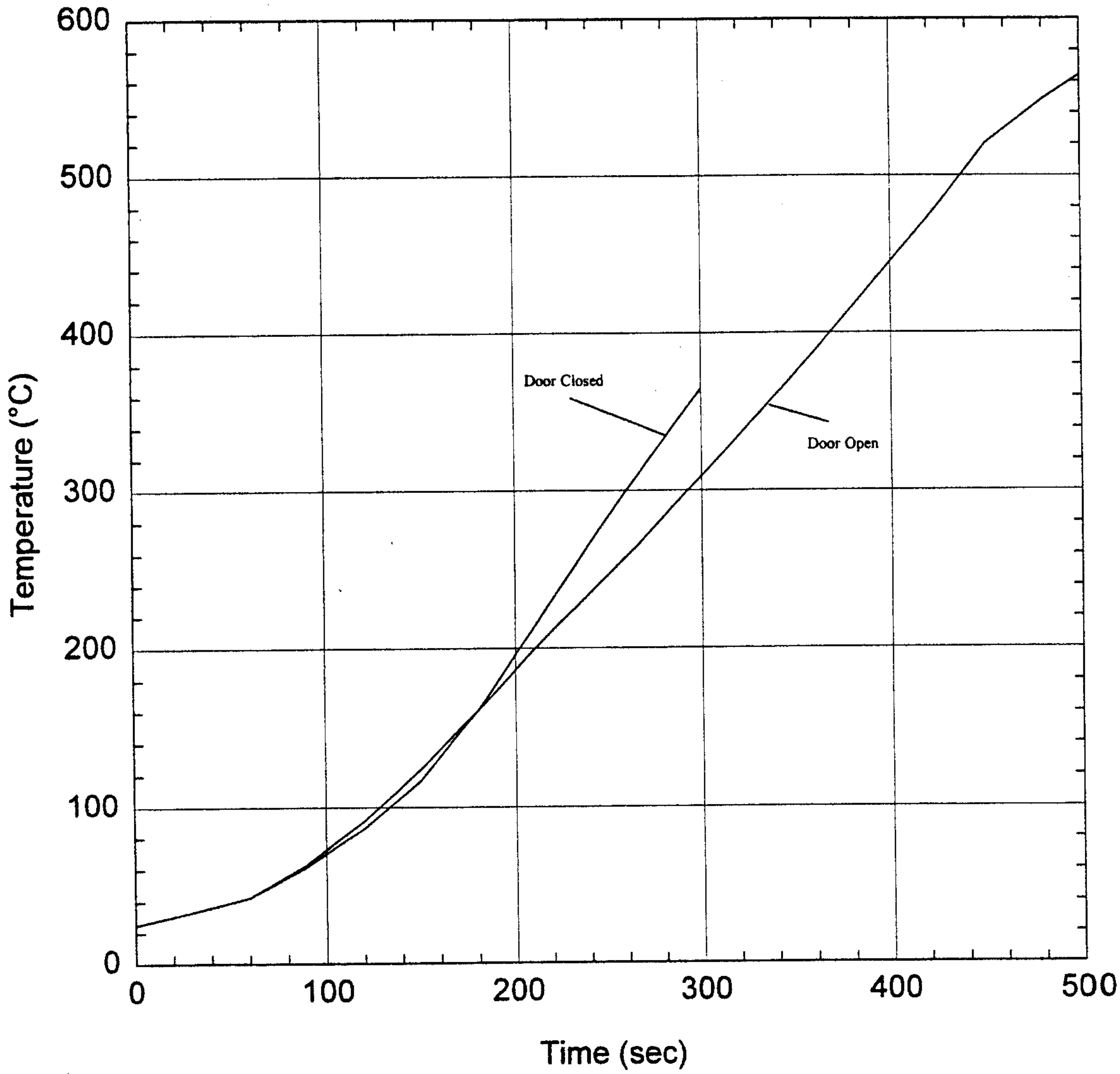


Figure B3-12. Gas layer temperatures for electronics room fires

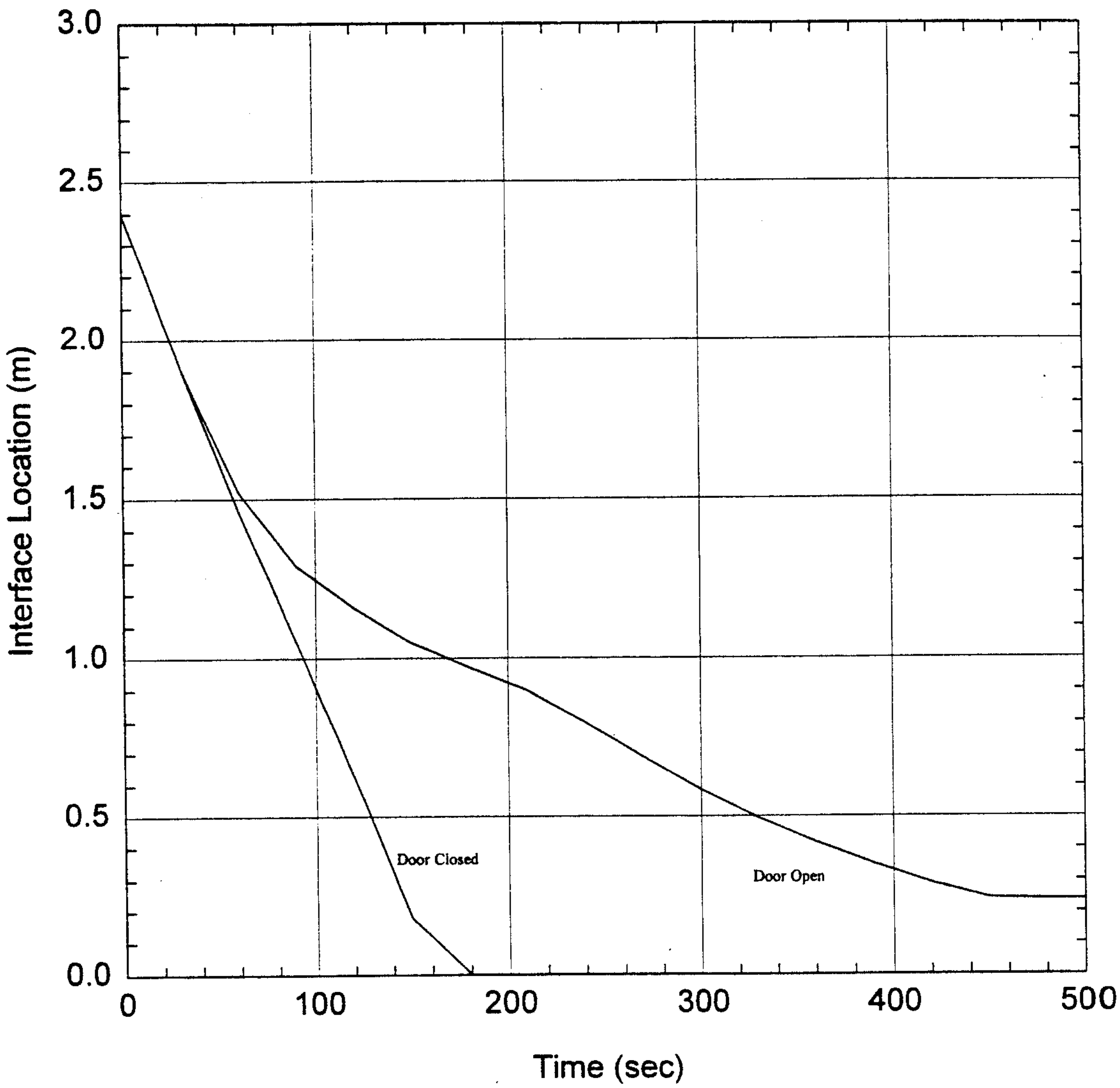


Figure B3-13. Gas layer interface locations for Electronics House fires

1 $(m/s)^{0.5}$ for purposes of the analysis. Fire department intervention is assumed to be 200 seconds after smoke detection. Table B3-16 lists the predicted operation times for all fire protection features in this space, including quick response and ordinary sprinklers.

Table B3-16. Sprinkler and Smoke Detection Operating Times in the Electronics House

Scenario	Smoke Detection (s)	Ordinary Sprinklers (s)	Quick Response Sprinklers (s)	Fire Department Intervention (s)
Door Closed	41	202	131	251
Door Open	41	202	131	251

The conditions within the Electronics House at the time of sprinkler operation or fire department intervention were estimated based on CFAST calculations. Table B3-17 summarizes these conditions. The electronics house contains approximately 30 electronics cabinets measuring 1.17 m by 0.81 m by 2.43 m high. In all cases shown in Table B3-17, the smoke layer immerses the cabinets subjecting them to possible failure. However, the temperature range is substantial with quick response sprinklers operating when the gas layer is at or below 100 °C.

Table B3-17. Conditions at Sprinkler Operation/Fire Department Intervention - Electronics House

Scenario	Ordinary Sprinklers		Fast Response Sprinklers		Fire Department Intervention	
	Gas Temp (°C)	Gas Depth (m)	Gas Temp (°C)	Gas Depth (m)	Gas Temp (°C)	Gas Depth (m)
Door Closed	200	0	93	0	267	0
Door Open	180	0.93	100	1.1	245	0.16

B3.5 Horizontal Cable Tray Fire Scenario

B3.5.1 Upper Gas Layer Results for Horizontal Cable Tray Fires

The horizontal cable tray fire scenario was evaluated using CFAST for the following geometric configurations:

(1) Concrete curtain installed, tunnel closed;

(2) Concrete curtain installed, tunnel open;

(3) Concrete curtain removed, tunnel closed off; and

(4) Concrete curtain removed, tunnel open.

Figures B3-14 and B3-15 show the gas layer temperature versus time and the interface depth. All of the scenarios shown in Figure B3-14 cause the gas layer temperature to exceed 150°C. However, only in one scenario does the layer drop below 6.2 m, the maximum height of the Detector. This is the scenario with the curtain closed and the tunnels closed off, and the time required to expose the Detector to a gas layer temperature greater than 150 °C is approximately 3200 seconds (the time required for the layer to heat up to 150 °C). Table B3-18 summarizes the horizontal cable tray layer conditions for the four geometric configurations. None of the configurations cause the gas layer to reach flashover temperatures. The layers in these scenarios do not descend below 5 m due to the height of the cable tray fires above the floor (6.85 m). This is also the reason the tunnels have only a limited impact on the layer descent and gas layer temperature in these scenarios. The dominating effect is the concrete curtain wall between the east and west areas of IR-2.

Table B3-18. Summary of Horizontal Cable Tray Gas Layers

Geometric Configuration	Peak Temperature (°C)	Maximum Gas Depth (m)	Failure Time (s)
Curtain Removed, Tunnel Closed	229	6.87	N/A
Curtain Installed, Tunnel Open	222	6.92	N/A
Curtain Removed, Tunnel Closed	156	5.14	3,200
Curtain Removed, Tunnel Open	156	6.92	N/A

B3.5.2 Ceiling Temperatures Under Fire Plume for Horizontal Cable Tray Fires

The maximum flame height and centerline plume temperature for the horizontal cable tray fire scenarios are presented in Table B3-19. Although there is no specific failure criteria in this location at the ceiling due to the concrete construction, the information is useful for evaluating the effects on potential equipment that may be placed above the cable trays.

Table B3.19. Ceiling Conditions for Horizontal Cable Tray Fire Scenarios

Peak Heat Release Rate (kW)	Flame Height Above Floor (m)	Plume Centerline Temperature (°C)
1905	9.2	390

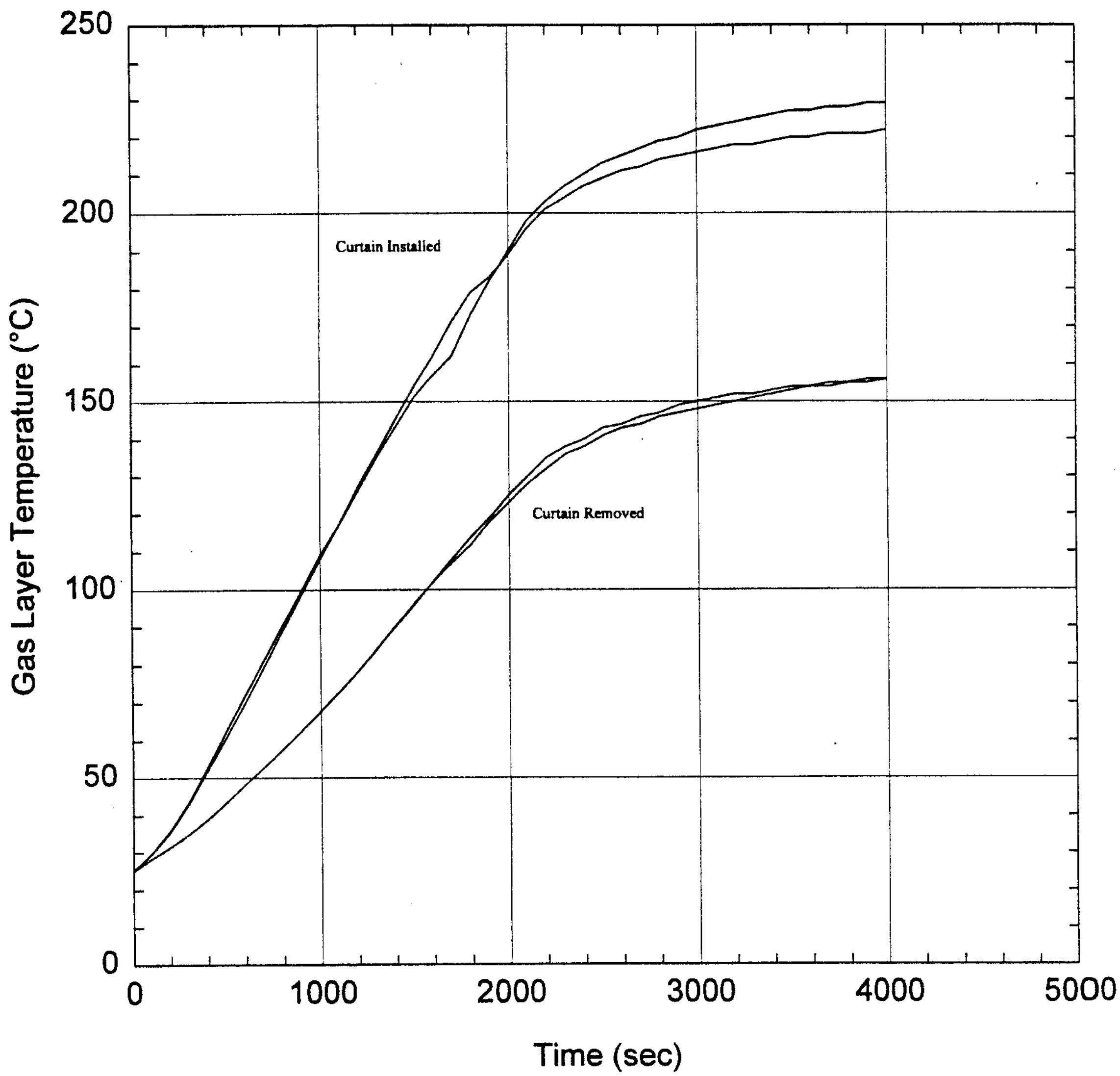


Figure B3-14. Gas layer temperatures in west IR-2 area for horizontal cable tray fire scenarios

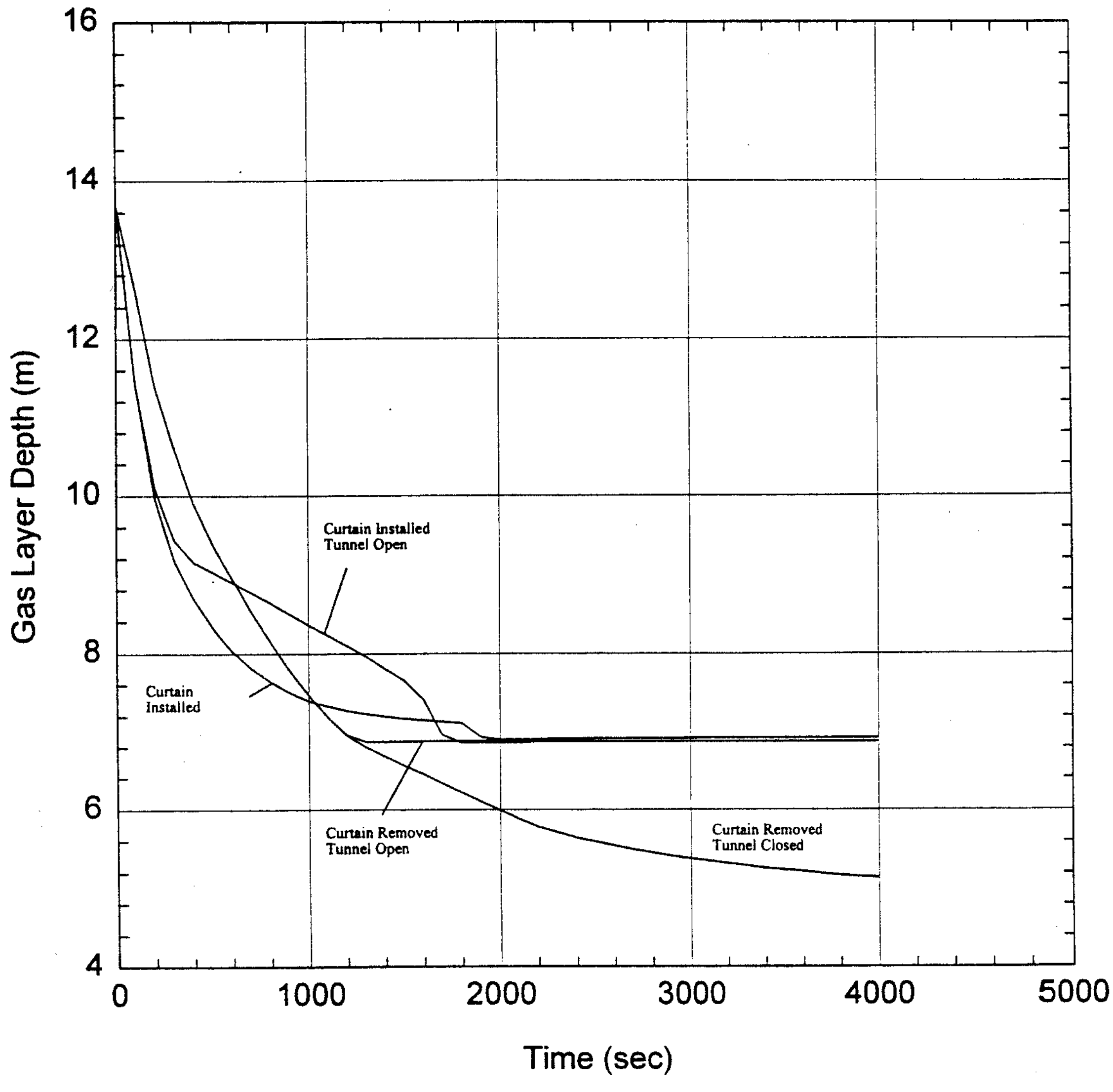


Figure B3-15. Gas layer depths in west IR-2 area for horizontal cable tray fire scenarios

B3.5.3 Radiant Exposure to Detector from Horizontal Cable Tray Fires

The total incident heat flux to the Detector is a function of the shape factor between the fire and the Detector. The worst case assumption is to assume that the cable tray fire takes the shape of a rectangle equal in width to the maximum horizontal flame spread distance (3.56 m) and height equal to the flame height (3.43 m). The cable trays are located approximately 4 m from the edge of the Detector and the Detector and the flame form an angle of about 31.3°. The resulting total incident heat flux to the surface of the Detector is 7.2 kW/m^2, about half of the assumed failure flux of 15 kW/m^2. The horizontal cable tray fire takes 2,100 seconds to reach the peak heat release rate which means that the heat flux during the growth phase is less than 7.2 kW/m^2. Once the peak heat release rate has been reached, the fire has a burnout front (see Figure B1-6) and will split into two smaller fires traveling in opposite directions. This means that after the peak heat release rate and heat flux to the Detector has been reached, the incident heat flux begins to decline as the two smaller fires move away from the Detector.

B3.5.4 Fire Protection Effects on the Horizontal Cable Tray Fire Scenarios

The only fire protection features associated with horizontal cable trays is smoke detection in the general IR-2 area. Using the same assumptions as before, the predicted operation time for the single station photoelectric smoke detectors is 410 seconds and the resulting fire department intervention time is 620 seconds. The HSSD system will likely reduce detection time by one-half, resulting in fire department intervention after 415 seconds. Table B3-20 summarizes the conditions at the estimated fire department intervention time for each horizontal cable tray fire scenario.

Table B3-20. Summary of Conditions at Fire Department Intervention for Horizontal Cable Tray Fire Scenarios

Scenario	Fire Department Intervention time (s)	Gas Layer Temperature (°C)	Gas Layer Depth (m)
Curtain Closed; Tunnel Closed	620	73	8.9
Curtain Closed; Tunnel Open	620	70	9
Curtain Open; Tunnel Closed	620	49	9
Curtain Open; Tunnel Open	620	49	9

B3.6 Vertical Cable Tray Fire Scenario

B3.6.1 Upper Gas Layer Results for Vertical Cable Tray Fires

The vertical cable tray fire discussed in Section B1 has been modeled using CFAST for the following geometric configurations:

(1) Concrete curtain installed, tunnel closed;

(2) Concrete curtain installed, tunnel open;

(3) Concrete curtain removed, tunnel closed; and

(4) Concrete curtain removed, tunnel open.

Figures B3-16 and B3-17 show the gas layer temperature versus time and the interface depth. One scenario shown in Figure B3-16 resulted in a gas layer temperature greater than 150°C. This scenario also has a layer descent below the Detector so that the Detector is exposed to temperatures greater than the assumed failure temperature. This is the scenario with the curtain installed and the tunnels closed, and the time required to expose the Detector to a gas layer temperature greater than 150 °C is approximately 200 seconds. Table B3-21 summarizes the vertical cable tray layer conditions for the four geometric configurations. None of the configurations cause the gas layer to reach flashover temperatures. The effect of the tunnels on the upper gas layer temperature and descent are quite pronounced for these fire scenarios.

Table B3-21. Summary of Vertical Cable Tray Gas Layers

Geometric Configuration	Peak Temperature (°C)	Maximum Gas Depth (m)	Failure Time (s)
Curtain Installed, Tunnel Closed	217	0	200
Curtain Installed, Tunnel Open	111	5.44	N/A
Curtain Removed, Tunnel Closed	149	0	N/A
Curtain Removed, Tunnel Open	98.6	5.44	N/A

B3.6.2 Ceiling Temperatures for Vertical Cable Tray Fires

The maximum flame height and centerline plume temperature for the vertical cable tray fire scenarios are presented in Table B3-22. Although there is no specific failure criteria in this location at the ceiling due to the concrete construction, the information is useful for evaluating the effects on potential equipment that may be placed above the cable trays.

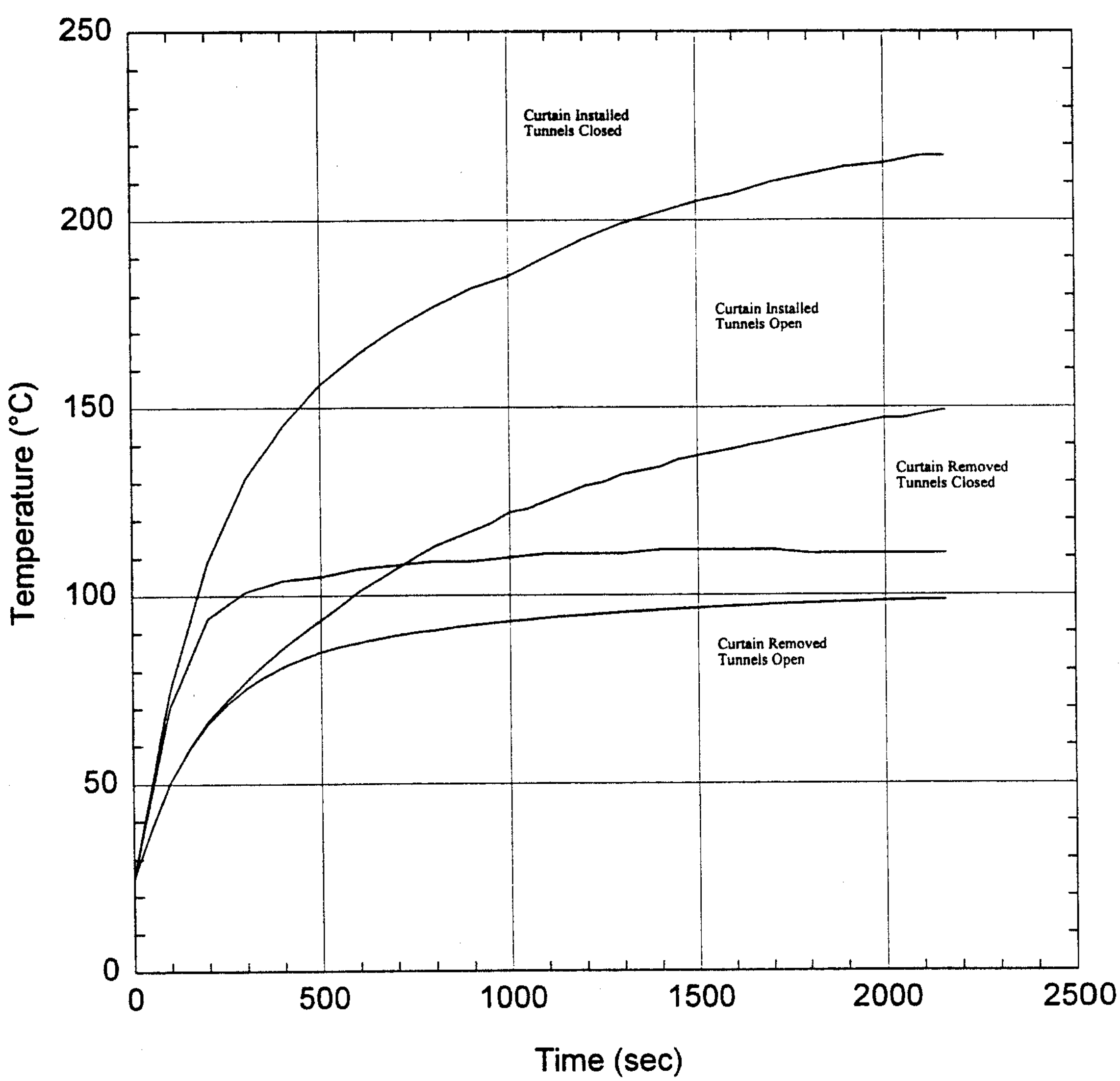


Figure B3-16. Gas layer temperature in west IR-2 area from vertical cable tray fires

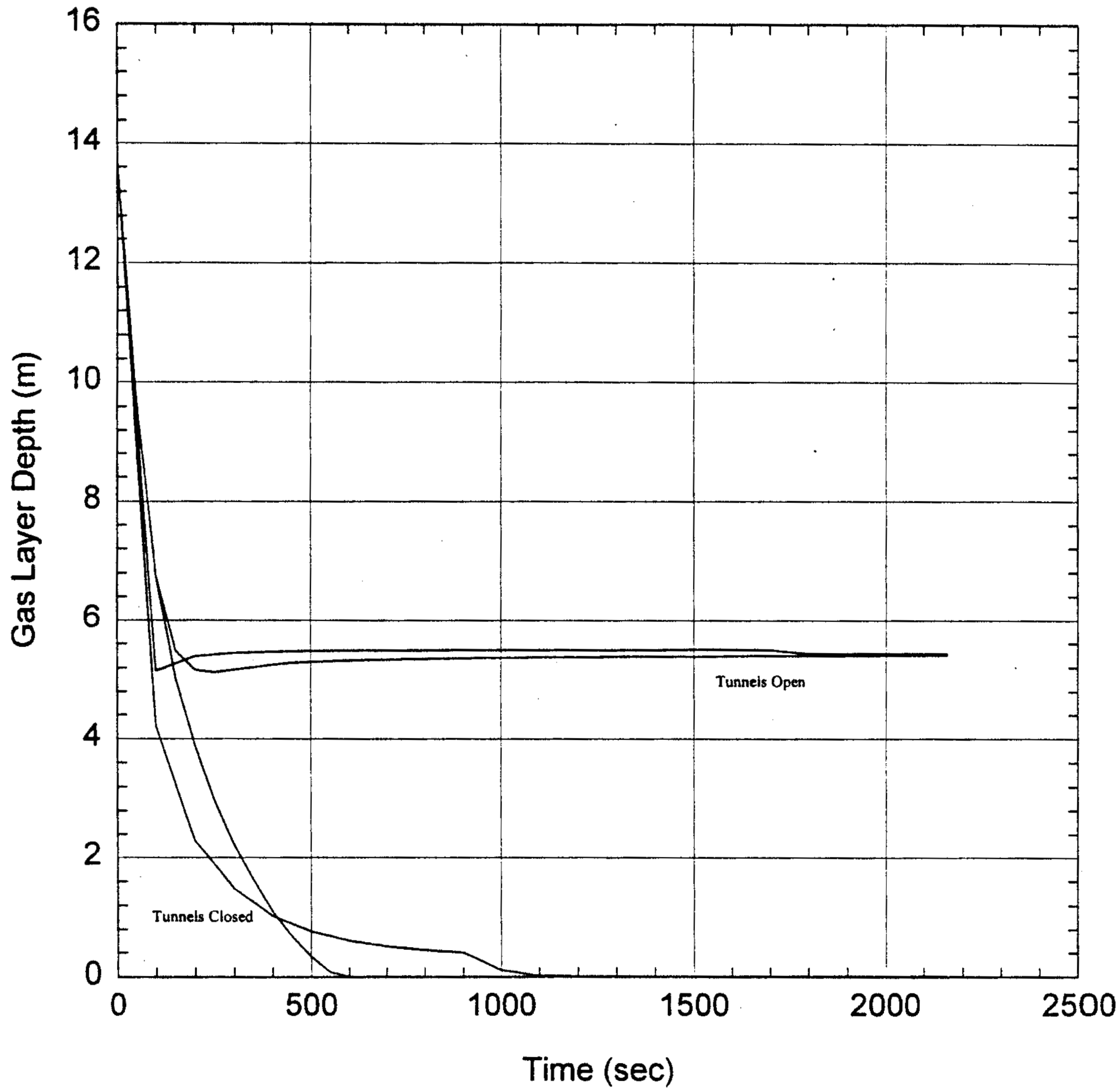


Figure B3-17. Gas layer depths in west area of IR-2 from vertical cable tray fire scenarios

Table B3-22. Ceiling Conditions for Vertical Cable Tray Fire Scenarios

Peak Heat Release Rate (kW)	Flame Height Above Floor (m)	Plume Centerline Temperature (°C)
2330	12.7	1,000

B3.6.3 Radiant Exposure to Detector from Vertical Cable Tray Fires

The total incident heat flux to the Detector is a function of the shape factor between the fire and the Detector. The worst case assumption is to assume that the cable tray fire takes the shape of a rectangle equal in width the to tray width (0.61 m) and height equal to the flame height (12.7 m). The cable trays are located approximately 3.7 m from the edge of the Detector and the Detector and the flame form a 90° angle. The resulting total incident heat flux to the surface of the Detector is 5.8 kW/m^2. The Detector is predicted to be exposed to this flux for the duration of the fire, or 2,100 seconds.

B3.6.4 Fire Protection Effects on the Vertical Cable Tray Fire Scenarios

The only fire protection features associated with vertical cable trays is smoke detection in the general IR-2 area. Using the same assumptions as before, the predicted operation time for the smoke detectors is 14 seconds and the resulting fire department intervention time is 226 seconds. Table B3-23 summarizes the conditions at the estimated fire department intervention time for each Vertical cable tray fire scenario. As can be seen in the table, none of the situations present a hazard to the Detector.

Table B3-23. Summary of Conditions at Fire Department Intervention Time of 226 s for Vertical Cable Tray Fire Scenarios

Scenario	Gas Layer Temperature (°C)	Gas Layer Depth (m)
Curtain Installed, Tunnel Closed	115	2.2
Curtain Installed, Tunnel Open	96	5.4
Curtain Removed, Tunnel Closed	69	3.4
Curtain Removed, Tunnel Open	68	5.2

B4.0 DISCUSSION/DAMAGE POTENTIAL

The primary focus of this section is to assess the scenarios that pose a hazard to the Babar Detector on the west side of the shield wall in the IR-2 facility. Besides direct contact with burning fuels, which is not considered in this analysis, damage to the Detector is assumed to occur in two manners: immersion in an upper gas layer temperature greater than 150 °C (thermal damage) and radiant exposure in excess of 15 kW/m^2. Additionally, immersion of the Detector in a gas layer cooler than 150 °C may result in exposure to corrosive gasses and has the potential to cause damage to the Detectors components. Since damage to corrosive gasses is a long term effect and can be remedied before the onset of damage, this is not used as a limiting criteria.

The results obtained in Section B3 of this appendix may be grouped into three categories: (1) normally operating conditions, (2) shut down conditions, and (3) general considerations. Normally operating conditions imply that the concrete curtain separating the west and east sides of the shield wall is installed and effectively creates two compartments. Shut down conditions mean that the concrete curtain is removed, and the east and west sides of the shield wall are treated essentially as one compartment. Finally, general considerations involve exposure of the Electronics House and fuel source placement so that the structure is not in jeopardy.

B4.1 Normally Operating Conditions

During normal operating conditions, several of the fire scenarios presented in section B3 can potentially expose the Detector to damage. These scenarios may also be broken into two groups: fire protection features not functioning (sprinklers and smoke detection) and fire protection features operate as intended. If the fire protection features do not operate the following scenarios could potentially expose the Detector to hazard conditions:

(1) 1-6 crates with the PEP-II tunnel closed off (thermal gas layer);

(2) 2,4, and 6 crates with the PEP-II tunnel open (thermal gas layer);

(3) 2,4, and 6 crates with the PEP-II tunnel closed off (thermal gas layer);

(4) Horizontal cable tray fire with the PEP-II tunnel closed off (thermal gas layer);

(5) Vertical cable tray fire with the PEP-II tunnel closed off (thermal gas layer);

(6) 7.6 L small and large diameter and 18.9 L small and large diameter flammable liquid pool fires with the PEP-II tunnel closed off (gas layer immersion);

(7) 7.6 L small diameter and 18.9 L small and large diameter with the PEP-II tunnel open (gas layer immersion only);

(8) All crate fire scenarios with the PEP-II tunnel open or closed (gas layer immersion only);

(9) All drum fire scenarios with the PEP-II tunnel open or closed off (gas layer immersion);

(10) Horizontal cable tray fire with the PEP-II tunnel closed off; and

(11) Vertical cable tray fire scenarios with the PEP-II tunnel open or closed.

If the fire protection equipment is assumed to function properly, only the following scenarios present a risk to the Detector:

(1) 7.6 L small and large diameter and 18.9 L large diameter flammable liquid pool fires with the PEP-II tunnel closed off (gas layer immersion only);

(2) 7.6 L small diameter and 18.9 L large diameter with the PEP-II tunnel open (gas layer immersion only);

(3) Six crates with PEP-II tunnel closed off (gas layer immersion only);

(4) All drum fire scenarios with the PEP-II tunnel open or closed off (gas layer immersion only); and

(5) Vertical cable tray fire scenarios with the PEP-II tunnel open and closed off (gas layer immersion only).

Several conclusions may be drawn from the scenarios that have the potential to cause damage to the Detector:

(1) The tunnel is effective for reducing the gas layer temperature and level of descent if it is left open as currently constructed;

(2) The mechanical ventilation is effective at delaying but not preventing hazardous equipment exposure;

(3) Fire protection equipment eliminates the thermal exposure hazard for all scenarios considered; however, it only has a small effect on gas layer immersion of the Detector; and

(4) None of the fire scenarios on the west side of the shield wall expose the Detector to a heat flux greater than 15 kW/m^2.

Several scenarios immerse the Detector in a gas layer but do not cause the smoke detectors to operate. This is due to the low heat release rate of the fires or short duration (flammable liquid fire and drum fires). In these cases, the gas layer is expected to be diluted and the hazard resulting from corrosive gases will be low.

B4.2 Shut Down Conditions

During shut down conditions, several of the fire scenarios presented in section B3 could potentially expose the Detector to damage. These scenarios may be broken into two groups: fire protection features not functioning (sprinklers and smoke detection) and fire protection features operate as intended. If the fire protection features do not operate the following scenarios will expose the Detector to hazardous conditions:

(1) Six crates with the PEP-II tunnel closed off (thermal gas layer);

(2) Six crates with the PEP-II tunnel closed off (gas layer immersion);

(3) Vertical cable tray fire with the PEP-II tunnel closed off (thermal gas layer); and

(4) Vertical cable tray fires with the PEP-II tunnel open or closed (gas layer immersion).

If the fire protection equipment is operational, the following scenario may expose the Detector to hazardous conditions:

(1) Vertical cable tray fires with the PEP-II tunnel open or closed off (gas layer immersion).

If the tunnels remain open, the only exposure hazard to the Detector comes from immersion in a layer less than 150 °C during a vertical cable tray fire. Fire protection equipment has no effect in this scenario.

B4.3 General Considerations

In addition to exposing the Detector to potentially hazardous conditions, several other items require consideration. The electronics house is constructed of combustible materials and itself could become a major exposure hazard to the Detector. As a result, it is desirable to prevent flashover from occurring within this compartment. Based on the results presented in Section B3, this corresponds to keeping the amount of combustible materials in any single area of the Electronics House below 23 kg (~50 lb). This will not prevent damage to the electronic equipment within the space. However, all electronics racks as well as the underfloor space are provided with a CO_2 extinguishing system. Inclusion of fast response sprinklers within the space could further ensure that equipment damage is minimized from a fire incident in the Electronics House.

In order to limit the fire size among the fuel packages, a minimum separation between one fuel package and another should be maintained. The minimum distance is such that the second fuel package will not ignite and has been determined for each fire scenario considered in Section B3. Since each fuel package has a certain separation requirement based on the expected fire size, it is most appropriate to use the largest separation for all fuel packages. For the fuel packages considered, two meters is sufficient in all cases.

Finally, the only mechanism by which structural failure could result has been shown to be direct flame impingement from a small diameter pool fire exposed to all sides of a column and direct flame impingement to the columns from a long burning fuel source (crate or drum). No structural problems have been predicted for the roof elements. Consequently, a minimum separation requirement to the columns is also necessary. Since the column heat flux threshold is greater than a combustible fuel, a separation requirement of 2 meters to the columns is sufficient.

B4.3 Conclusions

Several recommendations can be made based on the observations above and the results of analyses provided in Section B3. It should be noted that, although the scenarios were developed conservatively, there is the possibility that they could be worse, especially the cable trays. As a result, the following recommendations include a factor of safety and do not reflect the exact results of the calculations. They are as follows:

(1) Tunnels should remain open;

(2) No more than two crates should be allowed in the area east of the shield wall;

(3) Separation requirements (~2 m) between combustible fuels and columns should be maintained;

(4) Combustible fuel load in the Electronics House should be limited to 23 kg (~50 lb);

(5) Mechanical ventilation should be turned on when the fire department arrives to reduce the exposure hazards to the Detector and its support equipment;

(6) Flammable liquids should not be stored in containers greater than 7.6 L (2 gal). This is a conservative limitation since 18.9 L (5 gal) has been shown to be acceptable for thermal exposures;

(7) Vertical cable trays should be fire stopped. The recommended distance is 3 m (10 ft) since the vertical runs are typically 6 m (20 ft). This will have the effect of reducing the heat release rate by about one-half. If it is assumed that the tunnels are open, this will significantly slow down the development of a smoke layer and delay the time to immerse the Detector in the combustion gases;

(8) Horizontal cable trays should be fire stopped at approximately 6 m (20 ft) intervals. This will also delay the time to immerse the Detector;

(9) Radiation shielding should be provided between the horizontal cable trays and the Detector, or fire barrier separation should be installed between each of the cable trays to limit the maximum available fire size and resulting radiant flux to the Detector; and

(10) Thermal detection wire should be installed in the cable trays, connected to the alarm panel (and BaBar control panel if possible).

B5.0 CFAST INPUT DATA

B5.1 CFAST Overview

CFAST is a zone computer model capable of calculating the fire environment in multi-compartment spaces. A zone model assumes that there are two distinct homogeneous layers in a fire environment. CFAST permits the inclusion of a ceiling jet resulting from the fire plume momentum as an additional layer. The program calculates the smoke distribution via the upper gas layer depth, particulate concentration, and gas concentrations as well as the temperature in all zones throughout a structure. Heat loss through the walls, openings/vents, and radiation are all accounted for. The model also modifies the specified burning rate when the oxygen concentration is lowered. The model has been extensively verified for a number of geometric arrangements, representative of residential, office, and large commercial/industrial facilities [Peacock et al., 1993].

The input data necessary to model a fire include the room geometry (length, width, and height of a compartment), the opening/vent dimensions and locations, mechanical venting characteristics (fans and duct work), thermal properties of the walls, ceiling, and floor, the chemical makeup of the fuel, the quantity of the fuel, and the burning rate of fire. In addition, there are a number of control flags that determine the type of analysis that is to be performed.

B5.2 Description of the Geometric Configurations Used in the Analysis

Several geometric configurations are used in the analysis, including dividing the IR-2 facility with a concrete curtain, blocking the beam tunnels, and including mechanical ventilation. The following combinations are used:

(1) Concrete Curtain Installed, Tunnel Closed, Mechanical Fans Off;

(2) Concrete Curtain Installed, Tunnel Open, Mechanical Fans Off;

(3) Concrete Curtain Removed, Tunnel Closed, Mechanical Fans Off;

(4) Concrete Curtain Removed, Tunnel Open, Mechanical Fans Off;

(5) Concrete Curtain Removed, Tunnel Open, Mechanical Fans On;

In addition to the main IR-2 facility, the smaller electronics house was also modeled with CFAST. The Electronics House measures 7.6 m by 9.8 m by 2.4 m in height and is constructed of gypsum with wood studs. The electronics house contains 30 electronics cabinets that measure 1.17 m by 0.81 m by 2.36 m in height. The total volume occupied by the electronics cabinets is 67 m^3 and the total volume of the electronics house is 178 m^3. Since the cabinets represent nearly 40 percent of the volume of the electronics house, their presence needed to be accounted for. This was accomplished by reducing the length and the width while maintaining the same proportions so that the total volume was 112 m^3. The dimensions of the IR-2 facility used in CFAST as well as the electronics house are listed in Table B5-1. During the site survey, it was noted that there was an insulation material on the walls of the east IR-2 area and that the west IR-2 area is constructed of concrete. The floors of both sections is concrete. The wall material properties are used in CFAST to calculate the heat loss through the structure. In this analysis, the walls and ceiling of the IR-2 facility were modeled as gypsum board and the floor as concrete. The electronics house was modeled as entirely gypsum. Table B5-2 lists the thermal properties of these materials.

Table B5-1. Physical Dimensions of the IR-2 Facility

Location	Length (m)	Width (m)	Height (m)
IR-2	36.6	20.0	13.7
IR-2 East	22.5	20.0	13.7
IR-2 West	14.1	20.0	13.7
Electronics House	7.74	6.0	2.4

Table B5-2. Thermal Properties of Wall, Ceiling, and Floor Materials

Material	Conductivity (W/m-K)	Heat Capacity (J/kg-K)	Density (kg/m^3)	Thickness (m)
Gypsum	0.16	900	790	0.016
Concrete	1.75	1,000	2,200	0.15

Openings into other spaces and to the exterior of the structure determine how the smoke layer in a compartment develops. The openings depend on the specific situation being modeled. Table B5-3 lists the openings that are used in the analysis and Table B5-4 summarizes which scenarios use which openings.

Table B5-3. Vent Dimensions in IR-2 Hall

Opening Number	Width (m)	Height (m)	Base (m)	Comments
1	20.0	0.0254	0.0	Leakage from E. IR-2 to exterior
2	7.0	7.0	2.74	Large Tunnel
3	3.84	7.0	2.74	Small Tunnel
4	20.0	8.0254	8.00	Gap between bottom of curtain and top of shield
5	20.0	13.6	13.3	Gap between top of curtain and bottom of ceiling
6	0.0254	13.6	8.0	Gap between edge of curtain and wall
7	1.83	0.0254	0.0	Gap between electronics house door and E. IR-2
8	0.91	2.13	0.0	Electronics house open door

Table B5-4. Fire Scenario Openings

Scenario	Openings	Scenario	Openings
Curtain Closed; Tunnel Closed;	1, 4,5,6	Curtain Open; Tunnel Closed	1
Curtain Closed; Tunnel Open	1,2,3,4,5,6	Curtain Open; Tunnel Open	1,2,3
Curtain Open; Tunnel Open; Mech Vent	1,2,3	Electronics House - Door Open	8
Electronics House - Door Closed		7	

Mechanical ventilation is included in some scenarios as a constant flow of air out of the room. This is equivalent to 18.47 m^3/s and is withdrawn from the ceiling level. As the gas layer temperature at the ceiling increases, the same volume is withdrawn but the mass is less. These vents are assumed at all times during a fire although since they are manually operated this may not entirely be the case.

The locations of the fires within the compartments depends on the scenario. The pool fires, crate fires, drum fires, and combustible fires in the electronics house were modeled in the center of the fire compartment. The cable tray fires were modeled 0.5 m from the wall in the west IR-2 area.

B5.3 Fire Characteristics

There are two primary fire characteristics that are of interest: the heat of combustion and the hydrogen to carbon ratio in the fuel. Both of these values contribute to the rate of formation of the upper gas layer and the rate of oxygen consumption. CFAST allows entry of other fire parameters such as carbon monoxide yield, soot yield, and HCl yield, but since this analysis is not intended as a life safety analysis, inclusion of this information is extraneous.

Due to the generality of the fuels in this analysis, no specific values of the heat of combustion or hydrogen to carbon ratio could be determined. Instead, it was considered appropriate to use typical values. Typical values for the heat of combustion are as follows: flammable liquid is 45,900 kJ/kg; wood is 19,500 kJ/kg; Class A combustibles is 19,500 kJ/kg and Cables is 22,500 kJ/kg [Babrauskas, 1986; Drysdale, 1985; Braun et al., 1989]. A typical value for the hydrogen to carbon ratio in the absence of specific information is 0.33 [Peacock et al., 1993].

B5.4 Sample Input Files

Twelve sample input files are provided in this section. Each one illustrates a particular feature. They are as follows:

(1) Figure B5-1. Crate fire scenario (6 crates);

(2) Figure B5-2. Drum fire scenario (6 drums);

```
VERSN     2    6 CRATE fire in E IR-2, curtain closed
TIMES    2000   40   40   40   0
TAMB    298.  101300.    0.
EAMB    298.  101300.    0.
HI/F      0.00  0.00
WIDTH     20.0  20.0
DEPTH     22.5  14.1
HEIGH     13.7  13.7
HVENT    1  2  1    20.0    8.0254 8.00
HVENT    1  2  2    0.0254 13.6    8.0
HVENT    1  2  3    20.0    13.6    13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI      0.     0.  1.0     19500000.  300. 400. 0.000
LFBO    1
LFBT    2
FPOS     5.0  5.5    0.00
FTIME     100 400 600 800 1000 1234 1991 2000
FHIGH     0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA    17.82 17.82 17.82 17.82 17.82 17.82 17.82 17.82 17.82
FQDOT   0.00 117E3 1875E3 4219E3 7500E3 11700E3 17850E3 17850E3 0
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
DUMPR Cfire4a.hi
WINDOW        0      0  -100  1280  1024    1100
GRAPH    1  120.   300.     0.  600.   920.    10. 5 TIME   METERS
GRAPH    2  740.   300.     0.  1220.  920.    10. 5 TIME   CELSIUS
INTER    0 0 0 0 1    1 U
TEMPERA 0 0 0 0 2    1 U
TEMPERA 0 0 0 0 2    1 L
TEMPERA 0 0 0 0 2    2 L
```

Figure B5-1. Crate fire scenario (6 crates)

```
VERSN     2    6 drum fire in E IR-2, curtain closed
TIMES    937  15  15  15  0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00  0.00
WIDTH    20.0  20.0
DEPTH    22.5  14.1
HEIGH    13.7  13.7
HVENT   1  2  1   20.0   8.0254 8.00
HVENT   1  2  2   0.0254 13.6   8.0
HVENT   1  2  3   20.0   13.6   13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI     0.    0.  1.0    19500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    5.0  5.5   0.00
FTIME    50 100  150 200 257 927 937
FHIGH    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA   1.74 1.74 1.74 1.74 1.74 1.74 1.74 1.74
FQDOT  0.00 29.3E3 117E3 264E3 469E3 774E3 774E3 0.0
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
DUMPR dfire4a.hi
WINDOW       0      0  -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.   10. 5 TIME  METERS
GRAPH   2  740.  300.    0.  1220. 920.   10. 5 TIME  CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-2. Drum fire scenario (6 drums)

(3) Figure B5-3. Flammable liquid pool fire (18.9 L);

(4) Figure B5-4. Horizontal cable tray fire;

(5) Figure B5-5. Vertical cable tray fire;

(6) Figure B5-6. Electronics house with door open;

(7) Figure B5-7. Electronics house with door closed;

(8) Figure B5-8. Curtain closed, tunnels closed, mechanical vents off;

(9) Figure B5-9. Curtain closed, tunnels open, mechanical vents off;

(10) Figure B5-10. Curtain open, tunnels closed, mechanical vents off;

(11) Figure B5-11. Curtain open, tunnels open, mechanical vents off; and

(12) Figure B5-12. Curtain open, tunnels open, mechanical vents on.

```
VERSN    2   18.9L pool fire in E. IR-2. lg diam, curtain closed
TIMES   112  5  5  5  0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00  0.00
WIDTH    20.0  20.0
DEPTH    22.5  14.1
HEIGH    13.7  13.7
HVENT   1  2  1   20.0    0.0254 0.00
HVENT   1  2  2   0.0254 13.6    8.0
HVENT   1  2  3   20.0   13.6    13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI     0.     0.  1.0    45900000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    5.0  5.5   0.00
FTIME    5 10 101 112
FHIGH    0.0 0.0 0.0 0.0 0.0 0.0
FAREA   2.0 2.0 2.0 2.0 2.0 2.0
FQDOT  0.00 3000E3 7880E3 7880E3 0
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33
DUMPR fire2a.hi
WINDOW       0     0  -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.   10. 5 TIME   METERS
GRAPH   2  740.  300.    0.  1220. 920.   10. 5 TIME   CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-3. Flammable liquid pool fire (18.9 L)

```
VERSN     2   Horizontal Cable Tray Fire in W. IR-2
TIMES    4000  100 100 100 0
TAMB    298.  101300.   0.
EAMB    298.  101300.   0.
HI/F      0.00  0.00
WIDTH     20.0  20.0
DEPTH     14.1  22.5
HEIGH     13.7  13.7
HVENT    1  2  1    20.0   8.0254 8.00
HVENT    1  2  2    0.0254 13.6   8.0
HVENT    1  2  3    20.0   13.6   13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI      0.     0.  1.0    22500000.  300. 400. 0.000
LFBO    1
LFBT    2
FPOS     10.0 0.50  0.00
FTIME     2100  4000
FHIGH     6.85 6.85 6.85
FAREA    14.7 14.7 14.7
FQDOT   0.00 1905E3 1905E3
CJET OFF
HCR    0.33 0.33 0.33
DUMPR wfire1a.hi
WINDOW         0      0  -100  1280  1024   1100
GRAPH    1  120.  300.     0.  600.  920.    10. 5 TIME   METERS
GRAPH    2  740.  300.     0.  1220. 920.    10. 5 TIME   CELSIUS
INTER    0 0 0 0 1    1 U
TEMPERA 0 0 0 0 2    1 U
TEMPERA 0 0 0 0 2    1 L
TEMPERA 0 0 0 0 2    2 L
```

Figure B5-4. Horizontal cable tray fire

```
VERSN    2   Vertical Cable Tray Fire in W. IR-2; Curtain Closed
TIMES    2160  100 100 100 0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00  0.00
WIDTH    20.0  20.0
DEPTH    14.1  22.5
HEIGH    13.7  13.7
HVENT   1  2  1   20.0    8.0254 8.00
HVENT   1  2  2   0.0254 13.6    8.0
HVENT   1  2  3   20.0   13.6    13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI     0.     0.  1.0    22500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    10.0 0.50  0.00
FTIME    60  2160
FHIGH    0.00 0.00 0.00
FAREA   1.00 1.00 1.00
FQDOT  0.00 2330E3 2330E3
CJET OFF
HCR   0.33 0.33 0.33
DUMPR vfire1a.hi
WINDOW       0      0   -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.    10. 5 TIME   METERS
GRAPH   2  740.  300.    0.  1220. 920.    10. 5 TIME   CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-5. Vertical cable tray fire

```
VERSN     2   Electronics House Fire, Combustible Materials, Door Open
TIMES    600  30  30  30  0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00
WIDTH    6.0
DEPTH    7.74
HEIGH    2.4
HVENT   1  2  1   0.91  2.13   0.00
CEILI GYPSUM
WALLS GYPSUM
FLOOR GYPSUM
CHEMI     0.     0.  1.0    19500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    3.0  3.85   0.00
FTIME    50 100 150 200 250 300 350 400  600
FHIGH    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA   1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
FQDOT  0.00 29.3E3 117E3 264E3 469E3 732E3 1054E3 1435E3 1875E3 4220E3
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
STPMAX 1.0
DUMPR Efire2a.hi
WINDOW       0      0  -100  1280  1024    1100
GRAPH   1  120.  300.     0.  600.  920.    10. 5 TIME   METERS
GRAPH   2  740.  300.     0.  1220. 920.    10. 5 TIME   CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-6. Electronics house with door open

```
VERSN     2   Electronics House Fire, Combustible Materials, Door Closed
TIMES    450  30  30  30  0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00
WIDTH    6.0
DEPTH    7.74
HEIGH    2.4
HVENT   1  2  1   1.83   0.0254 0.00
CEILI GYPSUM
WALLS GYPSUM
FLOOR GYPSUM
CHEMI      0.     0.  1.0    19500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    3.0  3.85   0.00
FTIME    50 100 150 200 250 300 350 400 450
FHIGH    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA   1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
FQDOT  0.00 29.3E3 117E3 264E3 469E3 732E3 1054E3 1435E3 1875E3 2373E3
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
STPMAX 1.0
DUMPR Efire1a.hi
WINDOW       0      0  -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.   10.  5 TIME  METERS
GRAPH   2  740.  300.    0.  1220. 920.   10.  5 TIME  CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-7. Electronics house with door closed

```
VERSN     2    1 Drum Fire in the E.R. Curtain Closed
TIMES    836   15   15   15   0
TAMB    298.   101300.    0.
EAMB    298.   101300.    0.
HI/F      0.00   0.00
WIDTH     20.0   20.0
DEPTH     22.5   14.1
HEIGH     13.7   13.7
HVENT    1   2   1    20.0    8.0254 8.00
HVENT    1   2   2    0.0254 13.6    8.0
HVENT    1   2   3    20.0    13.6    13.3
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI      0.     0.   1.0     19500000.   300.  400.  0.000
LFBO    1
LFBT    2
FPOS     5.0   5.5    0.00
FTIME     50 105   826 836
FHIGH     0.0 0.0 0.0 0.0 0.0
FAREA    0.29 0.29 0.29 0.29 0.29
FQDOT   0.00 29.3E3 129E3 129E3 0.0
CJET OFF
HCR    0.33 0.33 0.33 0.33 0.33
DUMPR dfirela.hi
WINDOW        0      0   -100   1280   1024    1100
GRAPH    1   120.    300.     0.    600.    920.    10.  5 TIME   METERS
GRAPH    2   740.    300.     0.    1220.   920.    10.  5 TIME   CELSIUS
INTER    0 0 0 0 1    1 U
TEMPERA 0 0 0 0 2    1 U
TEMPERA 0 0 0 0 2    1 L
TEMPERA 0 0 0 0 2    2 L
```

Figure B5-8. Curtain closed, tunnels closed, mechanical vents off

```
VERSN     2   Horz cable fire W. IR-2, curt closed, tunnel open
TIMES   4000  100 100 100 0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F     0.00  0.00
WIDTH    20.0  20.0
DEPTH    14.1  22.5
HEIGH    13.7  13.7
HVENT   1  2  1   20.0    8.0254 8.00
HVENT   1  2  2   20.0    13.6   13.3
HVENT   1  2  3   0.0254 13.6    8.0
HVENT   1  3  1   7.01    7.01   2.74
HVENT   1  3  2   3.84    7.01   2.74
CEILI GYPSUM GYPSUM
WALLS GYPSUM GYPSUM
FLOOR CONCRETE CONCRETE
CHEMI     0.     0.  1.0    22500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    10.0 0.50  0.00
FTIME    2100  4000
FHIGH    6.85 6.85 6.85
FAREA   14.7 14.7 14.7
FQDOT  0.00 1905E3 1905E3
CJET OFF
HCR   0.33 0.33 0.33
DUMPR wfire1d.hi
WINDOW       0      0  -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.   10. 5 TIME  METERS
GRAPH   2  740.  300.    0.  1220. 920.   10. 5 TIME  CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-9. Curtain closed, tunnels open, mechanical vents off

```
VERSN     2    1 crate fire in E. IR-2, curtain open
TIMES    1514   30   30   30   0
TAMB    298.  101300.    0.
EAMB    298.  101300.    0.
HI/F      0.00
WIDTH     20.0
DEPTH     36.6
HEIGH     13.7
HVENT    1  2  1    20.0    0.0254 0.00
CEILI GYPSUM
WALLS GYPSUM
FLOOR CONCRETE
CHEMI      0.     0.  1.0     19500000.  300. 400. 0.000
LFBO    1
LFBT    2
FPOS     5.0  5.5   0.00
FTIME     100 200 300 400 504 1504 1514
FHIGH     0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA    2.97 2.97 2.97 2.97 2.97 2.97  2.97 2.97
FQDOT  0.00 117E3 469E3 1055E3 1875E3 2975E3 2975E3 0.0
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
DUMPR cfire1b.hi
WINDOW       0      0  -100  1280  1024   1100
GRAPH   1  120.  300.     0.  600.  920.    10. 5 TIME  METERS
GRAPH   2  740.  300.     0.  1220. 920.    10. 5 TIME  CELSIUS
INTER   0 0 0 0 1    1 U
TEMPERA 0 0 0 0 2    1 U
TEMPERA 0 0 0 0 2    1 L
TEMPERA 0 0 0 0 2    2 L
```

Figure B5-10. Curtain open, tunnels closed, mechanical vents off

```
VERSN     2   1 crate fire in E. IR-2, curt open; tunnels open
TIMES    1514  30  30  30  0
TAMB    298.  101300.   0.
EAMB    298.  101300.   0.
HI/F      0.00
WIDTH     20.0
DEPTH     36.6
HEIGH     13.7
HVENT    1  2  1    20.0    0.0254 0.00
HVENT    1  2  2    7.01    7.01    2.74
HVENT    1  2  3    3.84    7.01    2.74
CEILI GYPSUM
WALLS GYPSUM
FLOOR CONCRETE
CHEMI      0.     0.  1.0    19500000.  300. 400. 0.000
LFBO    1
LFBT    2
FPOS     5.0  5.5   0.00
FTIME     100 200 300 400 504 1504 1514
FHIGH     0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA    2.97 2.97 2.97 2.97 2.97 2.97  2.97 2.97
FQDOT   0.00 117E3 469E3 1055E3 1875E3 2975E3 2975E3 0.0
CJET OFF
HCR    0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
DUMPR cfire1c.hi
WINDOW       0      0  -100  1280  1024   1100
GRAPH    1  120.   300.     0.  600.  920.    10.  5 TIME   METERS
GRAPH    2  740.   300.     0.  1220. 920.    10.  5 TIME   CELSIUS
INTER    0 0 0 0 1    1 U
TEMPERA 0 0 0 0 2    1 U
TEMPERA 0 0 0 0 2    1 L
TEMPERA 0 0 0 0 2    2 L
```

Figure B5-11. Curtain open, tunnels open, mechanical vents off

```
VERSN     2   1 crate fire E IR-2, curt open; tunnels open, MV included
TIMES    1514  30  30  30  0
TAMB   298.  101300.   0.
EAMB   298.  101300.   0.
HI/F      0.00
WIDTH     20.0
DEPTH     36.6
HEIGH     13.7
HVENT   1  2  1   20.0   0.0254 0.00
HVENT   1  2  2   7.01   7.01   2.74
HVENT   1  2  3   3.84   7.01   2.74
MVOPN   1  1  V   13.0   5.0
MVOPN   2  3  V   13.0   5.0
MVDCT   1  2  0.5 2.0 0.002 0.0 1.0 0.0 1.0
MVFAN   2  3  0   500    17.42
INELV   1  13.  2  13.  3  13.
CEILI GYPSUM
WALLS GYPSUM
FLOOR CONCRETE
CHEMI     0.    0.  1.0    19500000.  300. 400. 0.000
LFBO   1
LFBT   2
FPOS    5.0  5.5   0.00
FTIME    100 200 300 400 504 1504 1514
FHIGH    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
FAREA   2.97 2.97 2.97 2.97 2.97 2.97  2.97 2.97
FQDOT  0.00 117E3 469E3 1055E3 1875E3 2975E3 2975E3 0.0
CJET OFF
HCR   0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
DUMPR cfire1d.hi
WINDOW       0     0  -100  1280  1024   1100
GRAPH   1  120.  300.    0.  600.  920.   10. 5 TIME  METERS
GRAPH   2  740.  300.    0.  1220. 920.   10. 5 TIME  CELSIUS
INTER   0 0 0 0 1   1 U
TEMPERA 0 0 0 0 2   1 U
TEMPERA 0 0 0 0 2   1 L
TEMPERA 0 0 0 0 2   2 L
```

Figure B5-12. Curtain open, tunnels open, mechanical vents on

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Appendix C

BaBar Memorandum: BaBar Fire Protection Requirement for Wire and Cable

BaBar Memorandum

To: Distribution
From: Frank O'Neill FO
Concurrence: David Hitlin DHitlin TB
Concurrence: Vera Luth V. Luth
Date: 8-6-96
Subject: BaBar Fire Protection Requirement for Wire and Cable

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This memo establishes the fire protection requirement for wire and cable insulation and jacketing inside the BaBar detector. This requirement is applicable to all cable, any portion of which is physically located inside the detector.

Rationale

The primary source of combustible fuel in the detector is wire and cable insulation and jacketing. It is impractical to incorporate automatic fire suppression inside the detector. Pressurizing the inside of the detector would damage the Drift Chamber. It is also inherently difficult to manually control or extinguish a fire in the detector. In light of this, emphasis must be placed on minimizing the likelihood of a fire incident in the detector as well as significantly limiting the potential for fire spread due to a small ignition.

Cable products that meet the standards listed below have high fire resistance characteristics, specifically low ignitability, heat release rate, flame spread, and smoke generation.

Requirement

Wire and cable used in the detector shall meet one of the following standards.

1) NFPA 262 (UL 910) "Modified Steiner Tunnel Test"
This is National Electrical Code (NEC) "plenum" rated cable.

2) Factory Mutual Standard 3972, Group 1
This is Factory Mutual Research Corporation, FMRC GP-1, cable.

3) CERN, Safety Instruction, IS 23, Rev 2
"Criteria and standard test methods for the selection of electrical cables, wires and insulated parts with respect to fire safety and radiation resistance"

4) ASTM E 1354, ISO 560
This is a cone calorimeter heat release rate test method. Passing criteria includes:

Ignitability:	2.5 < log (TTI)(S)
Peak HRR:	< kW/m^2
Smoke Factor:	1.5 > log (SMK FCT) (MW/m^2).

BaBar Memorandum

All purchase requisitions for wire and cable shall reference one of these standards. For additional information or copies of these standards please contact Frank O'Neill at (415) 926-5300.

Verification/QA

Each detector system will be required to maintain a cable file. This file will contains a list of each cable type used in their system and documentation for each cable type which will allow verification of the cable rating. This documentation will eventually be incorporated into the BaBar Quality Assurance Program central database.

Exceptions

Exceptions to this fire protection requirement can only be authorized by the BaBar Change Control Board (CCB). In such cases, alternative preventive measures will normally be required and must be carefully studied and agreed upon.

Distribution:
BaBar Technical Board
BaBar Safety Coordinators
PEP-II Management
Steve Louie
Steve McNeil