Hall B Fire Hazards Analysis

Version 1.0
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This document was prepared as part of the Hall B fire safety program. A number of authors have contributed to this effort:

Contributing Editors

W. Brooks, Staff Scientist

V. Burkert, Senior Staff Scientist

A. Freyberger, Staff Scientist

T. Hassler, Emergency Management Coordinator

B. Manzlak, EH&S Staff

B. Mecking, Senior Staff Scientist, Hall B Program Manager

M. Mestayer, Staff Scientist

J. O’Meara, Senior Engineer (retired), Hall B

E. Smith, Staff Scientist

M. Willard, Fire Protection Engineer

Managing Editor

W. Brooks

Table of Contents

List of Tables

List of Figures

Fire Hazard Analysis for Hall B

1.0 Executive Summary

1.1 Purpose

A fire hazard analysis for Jefferson Lab's experimental area Hall B has been performed. The purpose of this document is to document the results of this analysis, and demonstrate that the objective of achieving "...adequate Environment, Safety, and Health protection at the lowest practicable cost"[1] has been met and exceeded for Hall B and its associated areas.

The target outcome[2] for this fire hazard analysis is to minimize the potential for:

1) the occurrence of a fire or related event

2) a fire which threatens the health and safety of employees, users, or the public, or which causes unacceptable environmental damage

3) significant disruption of the Hall B research program

4) significant property losses, particularly with respect to detector components and electronic components.

1.2 Methodology

1.2.1 Life Safety

Life safety concerns have been addressed using standard practices wherever possible, such as provision of emergency lighting and exit signage. Two or more paths of escape have been provided on each of the commonly-accessed multilevel platforms. Because it is not possible to provide true fire and smoke separation for these exits, multiple smoke escape hoods have been stationed at each exit point, effectively increasing the safe maximum travel distance, and permitting use of alternate exits, such as the truck ramp and the upstream beam labyrinth as 'protected' escape paths.

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[1] Charter for the CEBAF Necessary and Sufficient Standards Development Process, page 7 of the "Jefferson Laboratory Work Smart Standards Documentation", August 22, 1996. See also "Contract Requirements for TJNAF Fire Safety" on page 81.

[2] For a discussion of Fire Hazard Analysis methodologies, see "Fire Hazard Analysis" by R. W. Bukowski, NFPA Fire Protection Handbook, Eighteenth Edition (1997), pg 11-70 to 11-77.

1.2.2 Fire Protection

Because of the complexity of the fire protection problem in Hall B, the approach which has been adopted is multi-tiered, incorporating the standard steps of minimizing the hazards, providing passive barriers, monitoring the status of the hazards, providing automatic suppression, and facilitating manual response to a fire.

The foreseeable fire scenarios involve ignition sources coupled to fuel supplies. In Hall B the dominant available fuel source for incipient fires is plastic material. Most of the plastic is found as cable insulation, the remainder being scintillator material, a fundamental component of several of the detectors. Flammable gas from the target constitutes a very much smaller fuel supply, but one which can be easily ignited and which poses the potential for an explosion hazard. The primary ignition sources in the hall are electrical in nature. They include the high-current fast electronics distributed in electronics rooms surrounding the detector; the drift chamber on-board electronics, both in the form of high voltage and low voltage power; sparks from the drift chamber wires themselves; high-current magnet power supplies; and phototube high voltage supplies. During maintenance periods, welding and grinding activities are plausible non-electrical ignition sources.

The complete program employed to mitigate credible fire scenarios is outlined in the following.

The hazards are minimized by removing unnecessary combustibles (housekeeping), by controlling welding and grinding activities (hot work program), by the layout of instrumental components (cable routing, chassis isolation), and by the choice of types of instrumental components (fire-rated cables, keyed power connectors, etc.). Passive barriers prevent smoke and fire from penetrating into or out of the hall, electronics on the drift chamber endplates are surrounded by inert gas, and electronic enclosures limit the damage caused from sparks due to welding or component failure. The hazards are monitored via several systems:

- sensitive commercial smoke detectors (VESDA) on all platforms and in the hall return air duct, which report to the building fire alarm system, to a PLC-based monitoring/annunciation system, and to the Hall B slow controls monitoring/annunciation system;
- fuel-specific evolved-gas incipient fire detection in each electronics area;
- linear heat detectors on all cable runs and electronics rooms, divided into 24 zones;
- fusible links on conventional wet-pipe sprinklers monitored by water flow indicators;
- internal monitoring for overtemperature, overvoltage and overcurrent on all high-current power supplies;
- closed circuit television cameras view all areas in the hall;
- heat detectors on the dome of the hall;

The safety systems which respond to alarms include an automatic power kill on a VESDA high-level alarm, an automatic power kill on a PLC high-level alarm, the hydrogen cryotarget internal safety system, the personnel safety system (which removes the electron beam from the entire accelerator), and the capability for manual beam shutdown by accelerator operators on any hall fire alarm. Automatic suppression is provided by wet-pipe automatic sprinklers in all areas of the highest risk, where both fuel and credible ignition sources are present.

Rapid and reliable manual response to a fire alarm is provided by many independent factors:

- automatic call of 911 on fire alarm for all experimental halls
- three separate fire stations located 1, 2, and 4 miles away; rapid response has been demonstrated historically
- all fire departments respond to a single point on the site
- emergency access policy enables qualified investigators to enter Hall B immediately on alarm or pre-alarm
- multiple early warning systems communicate the location of the problem directly to counting room staff or workers in the hall via a single panel
- many CO_2 fire extinguishers located throughout the hall
- two Halon 1211 wheeled streaming agent extinguishers are located on floor of hall
- dry standpipes located in hall
- regular fire department familiarization visits to site
- rapid page system and emergency call roster quickly notifies critical staff of problems

1.3 Conclusions

A significant measure of protection from serious fire loss has been obtained by the efforts documented in this analysis. These measures minimize the potential for a fire occurring, prevent unacceptable program losses, and limit the damage done by a fire. While five components of this approach have been listed above, two are emphasized in the present approach. These two components are: redundant early warning systems, and very rapid and focused manual response. Reliance on automatic suppression has been emphasized to a lesser extent because effective, off-the-shelf suppression systems which would not severely compromise the functioning of the detector are not commercially available. In addition, the level of protection afforded by the systems described here is relatively high, and is consistent with that of similar laboratories around the world. Nonetheless, there remains room for improvement. Installing a custom-engineered automatic suppression system using emerging, non-standardized technologies such as mist systems would decrease vulnerability to fire-related losses. Although properly designing such a system is a multi-year research project, an even greater degree of protection than that achieved by the present system would be attained.

2.0 Description of Hall B

2.1 CLAS

B. Mecking

The Thomas Jefferson National Accelerator Facility (‘Jefferson Lab’) is a single-purpose facility for basic research in nuclear physics. Its scientific mission is to explore the underlying structure of hadrons and nuclei using the electromagnetic probe. Its central instrument is a superconducting electron accelerator (the Continuous Electron Beam Accelerator Facility, or CEBAF) with an initial maximum energy of 4 GeV and 100% duty-cycle. The electron beam with a maximum current of 200 μA can be used simultaneously for electron scattering experiments in three experimental areas, Halls A, B, and C. Halls A and C are equipped with focusing magnetic spectrometers: Hall A with two high-resolution spectrometers (HRS), Hall C with a high-momentum spectrometer (HMS) and a short orbit spectrometer (SOS). Hall B is equipped with a large acceptance detector (CEBAF Large Acceptance Spectrometer, CLAS). Its main mission is to carry out experiments that require the detection of several, only loosely correlated particles in the hadronic final state, and measurements at limited luminosity.

The hall is a circular underground building (98' diameter) with a domed roof. A bremsstrahlung tagging spectrometer is located in an enlarged tunnel section at the entrance of the hall. Located in the center of Hall B is a toroidal multi-gap spectrometer. Its magnetic field is generated by six iron-free superconducting coils. The particle detection system consists of 18 gas-filled drift chambers (3 in each sector) to determine the trajectories of charged particles, gas Cerenkov counters for the identification of electrons, scintillation counters for the trigger and for time-of-flight measurements, and shower counters to help to identify electrons, and to detect photons and neutrons.

Hall B also includes auxiliary instrumentation such as targets, vacuum systems, cryogenic systems, beam line monitors, and a high speed trigger and data acquisition system. More details are contained in the CEBAF Conceptual Design Report[1].

2.1.1 Target and Beamline

For electron scattering experiments with CLAS, solid foil targets, and cryogenic liquid targets (hydrogen, deuterium, and helium) will be used. For real photon experiments, either solid or liquefied gas targets will be used.

The beam line instrumentation consists of beam position and beam current monitors, four Møller raster dipole magnets, two Møller quadrupole magnets, four target raster dipole magnets, a tagger magnet, two sweeping magnets, a mini-torus magnet, and the pair spectrometer dipole magnet. Due to the low beam intensities typically utilized in Hall B, the electron beam current can be measured by a Faraday cup, as well as by high-sensitivity cavity monitors along the beamline.

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1. CEBAF “Conceptual Design Report - Basic Experimental Equipment,” April 13, 1990.

2.1.2 Photon Tagging System

The system tags the energy of photons in a bremsstrahlung beam between 20% and 95% of the electron beam energy E_o, for E_o from 1 GeV to 6 GeV. The tagging spectrometer with a bend angle of 30^o uses a normal-conducting dipole magnet. The bremsstrahlung radiator is placed outside the field. Full-energy electrons are deflected downward into the tagger beam dump, while the recoiling electrons are detected along an image plane outside the field. To allow a tagging rate of about 5×10^7 /sec, the tagging detector system is segmented into 384 slightly overlapping plastic scintillators which define photon energy bins with about 0.1% resolution. These energy defining counters are backed up by 61 timing counters.

2.1.3 Drift Chambers

The drift chamber system determines the trajectory of charged particles. The incident charged particle ionizes the chamber gas. Liberated electrons drift towards the closest sense wire (held at positive potential); there is a total of 35,000 sense wires in the system. The distances of closest approach, and ultimately the trajectory location, can be reconstructed from the measured drift times.

The drift wires are arranged in 3 regions: Region I close to the target, Region II between the coils, and Region III outside of the coils. Each drift chamber region is subdivided into one axial and one (small angle) stereo superlayer, thus providing a track segment that typically consists of 6 axial and 6 stereo measurements. The mechanical structures of the Region II chambers rely on the coil cryostat for mechanical support; Regions I and III are mechanically self-supporting structures.

The nonflammable gas (90:10 argon/carbon dioxide) for the operation of the drift chambers is stored in tanks located outside of Hall B. The gas will be filtered, mixed in a gas shed (also located outside of Hall B), and then sent through stainless steel pipes down into Hall B. The flow rate is low (2 complete volume changes/day).

The drift chamber signals are amplified by 35,000 preamplifiers mounted on printed circuit boards that are attached to the chambers. Shielded twisted-pair cables (17 pairs/cable) connect the preamplifiers to the main electronics located on three platforms upstream of the CLAS magnet. The signals are conditioned in amplifier-discriminator boards (ADB) located in special VME-like crates. The drift time is digitized by standard commercial time-to-digital converters (LeCroy Fastbus module 1877).

2.1.4 Magnet Coil

The toroidal magnetic field is generated by six superconducting coils arranged around the beam line with a total current of 5×10^6 ampere-turns. Each coil is contained in its own cryostat with a common support ring in the back. Cooling of the magnet is provided by the end station refrigerator (ESR). The power supply, the control system, and all safety systems for the magnet are located on the first level of the spaceframe upstream of the magnet. The power supply provides a maximum current in the magnet of 3861 amperes; the polarity of the field can be reversed.

The mini-toroid surrounds the target for electron scattering experiments. It serves the function of bending low-energy electrons from Møller scattering events away from the Region I drift chambers. It consists of six normal-conducting coils that are located in the angular range that is already blocked by the coils of the superconducting torus. It operates at a current of up to 8000 A at 40 VDC. Its power supply is located on Level 0 of the space frame, and the power leads are routed under the floor of Level 1 to the magnet location. The same supply is used to power the downstream pair spectrometer magnet for photon beam runs.

2.1.5 Time of Flight Scintillators

The scintillation counters provide time-of-flight and trigger information. In the clear plastic material, a charged particle produces a short light flash which is then detected by photomultiplier tubes (PMT's) located at both ends of the counter. Each of the six sectors has 61 individual counters with a thickness of 5 cm, and a typical width of 20 cm; the length changes from 32 cm in the forward direction to more than 450 cm at large angles. For tagged bremsstrahlung experiments, a six-element start counter system (thickness 3 mm) located around the target will provide a start signal for the time-of-flight measurement. The PMT high voltage power is connected to power supplies on the moving carriages by RG59/U cables fitted with SHV connectors. These PMT bases normally dissipate approximately 1 W of power (0.5 mA at 2000 VDC); the maximum possible power is 1.5 mA at 3000 VDC, or 4.5 watts.

2.1.6 Calorimeters

The calorimeters are used for the identification of electrons, and the detection of high energy photons and neutrons. The forward calorimeter is a triangular structure consisting of alternating layers of 2 mm thick lead and 1 cm thick scintillation material. The scintillation light from a stack of scintillator strips is collected via light guiding fiber bundles and detected by photomultipliers. The photomultiplier tube high voltage power is connected to power supplies on the forward carriage by RG59/U cables fitted with SHV connectors.

The large angle calorimeter, developed by Italian collaborators, relies on the same sampling technique. It is, however, rectangular in shape and uses Lucite sheets to collect the scintillation light.

The data acquisition electronics for the calorimeter relies on standard commercial Fastbus modules for time and amplitude measurements. Custom circuits are used for summing and splitting analog signals.

2.1.7 Cerenkov Counters

The gas Cerenkov counters are only triggered by particles with a velocity of β 0.998. The light is collected by a mirror system and focused onto photomultipliers located in the shadow of the toroidal coils. A recirculating gas system will allow filling or emptying the Cerenkov counters with a minimum loss of the (non-flammable, but expensive) C_4F_{10} gas. The recirculating gas system for the Cerenkov counters is located in the gas shed for the drift chambers. The photomultiplier tube high voltage power is connected to power supplies on the forward carriage by RG59/U cables fitted with SHV connectors.

2.1.8 High Voltage Systems

The high voltage (HV) for all photomultiplier tubes (PMT's) is provided by a commercial (LeCroy) multi-channel system. The HV generators are located on the three carriages (for all PMT's located on the carriages), and on the spaceframe (for the last panel of time-of-flight counters that is attached to the spaceframe). The generators are connected to the PMT's via coaxial HV cable; SHV connectors are employed at both ends of the cable. The maximum possible power per channel is approximately 4.5 watts; the normal power dissipated is approximately 1 watt (40 µA at 3000 VDC).

The high voltage for all drift chambers is also provided by a commercial (CAEN) multi-channel system. The HV generators are located on the spaceframe. The generators are connected to the drift chambers via multi-strand HV cable. The maximum power delivered from this system is 0.12 watts per channel

2.2 Multi-level Platforms

B. Mecking

With the exception of the drift chambers and the panel 4 time-of-flight counters, all detectors are mounted on three independent carriages, one forward-moving carriage and two (sideways-moving) clamshell carriages. The forward carriage supports all six forward calorimeters and the corresponding scintillation and Cerenkov counters; the clamshell carriages carry the rest of the large-angle time-of-flight counters and the Italian large-angle calorimeters.

In addition to supporting the detectors, the platforms contain a large complement of electronics. This electronics is used for a variety of purposes: to 'trigger' the detector, to turn the raw signals into numerical data, and to provide power of various types to the detectors and magnets. The electronics is concentrated into areas called 'electronics rooms' located on most of the levels of these platforms; in each of these areas there is also a concentration of cables.

2.3 Cables and Cable Routing

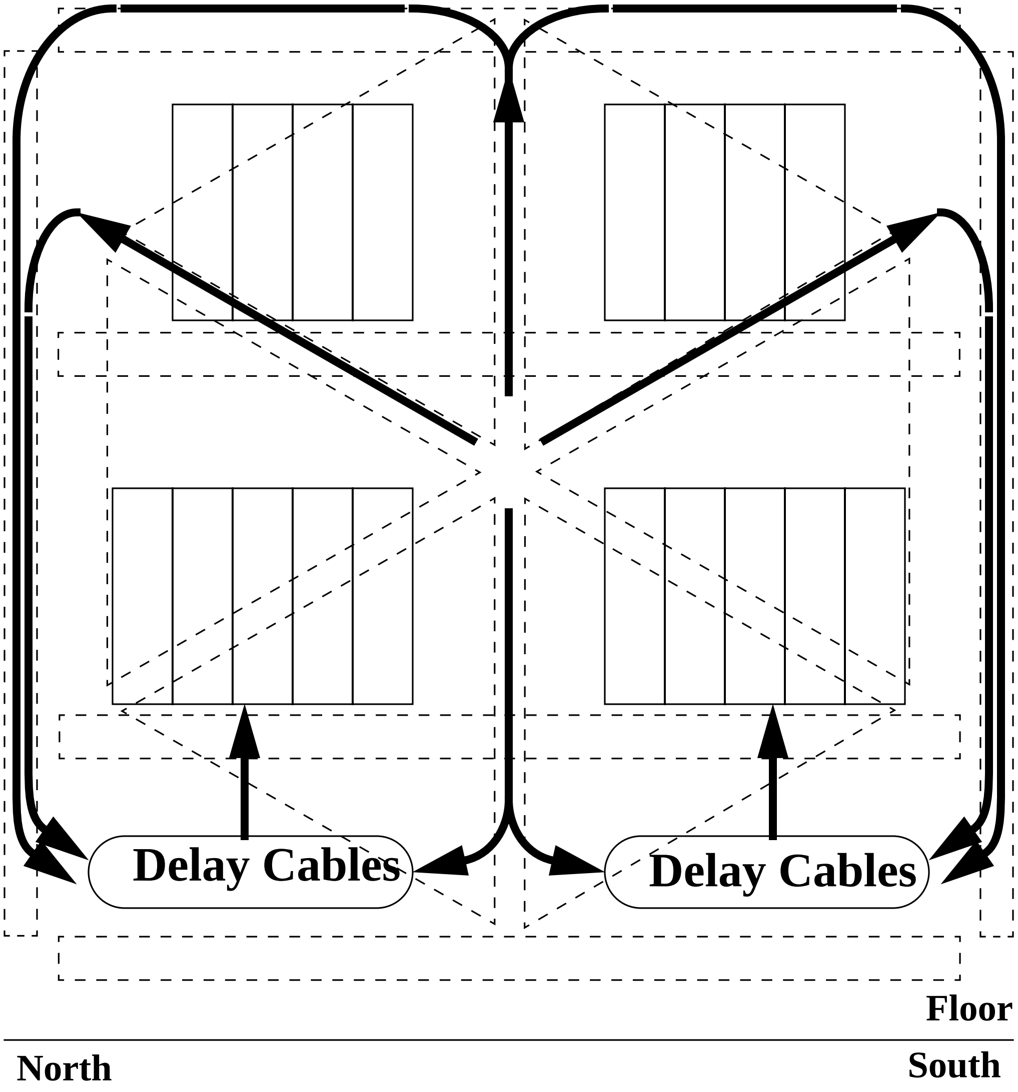
W. Brooks

The CLAS spectrometer is intended to detect multiparticle final states at high luminosity and with high acceptance. Because of this, each sector is individually instrumented, and there are a large number of detection channels; the detector components connected to these channels are distributed throughout the entire spectrometer volume. For this reason there are cables originating from points throughout the spectrometer volume, and their routing is limited to regions in the “shadow” of the coils, or behind the last detectors, as seen from the target. This puts significant constraints on how the cables may be routed to the electronics.

On the forward carriage the cables for the Cerenkov counters and the time-of-flight scintillators pass through the gaps between the forward calorimeters. These cables are distributed all along the edge of these gaps, mirroring the distribution of the phototube positions for the time-of-flight scintillators. Once these cables are behind the calorimeters, they join the calorimeter cables which are routed along the edges of the triangular modules to the subfloors of the carriage or to the vertical cable trays. A sketch of the routing for the delay cables is given in Figure 1 on page 17. The vertical runs of these cables and others routed at the same location are indicated in this figure. A similar configuration is used on the south carriage for the large-angle calorimeter cables.

For the north and south carriages, the delay and signal cables for the time-of-flight scintillators run along the shadow region to the forward carriage and join the other forward carriage cables. The high voltage cables, by contrast, run to the north and south carriages behind the time-of-flight scintillators. The trigger and high voltage cables for the large angle calorimeter on the south clamshell run from the detector to Level 1; the delay cables for this detector run from the calorimeter, to Level 0 for the long delay loop, and then up to Level 1. A small number of trigger cables run from Level 1 of the south carriage to the forward carriage.

FIGURE 1. Delay cable routing on the forward carriage.



The drift chamber cables run from points along the perimeter of each of the three regions to the space frame. All of these cables are tightly packed into the shadow region of the coils. The cable runs are surrounded by heavy iron grating for the regions 2 and 3 chambers, which provides a heat sink as well as mechanical support (in case of a fire). (These cables are captured by the Region 3 drift chambers and are not easily accessible without removing these chambers.) From the detectors, the cables run into the subflooring of all 3 levels.

All flooring which has cabling running underneath on any platform is made up of open grating, which allows water spray from the sprinkler heads to effectively sprinkle all the cables below.

2.4 Beam Dumps

B. Mecking

2.4.1 Tagging Beam Dump

For tagged photon beam operation, an underground beam dump stops the electron beam. The dump is located at the end of the shielded tagging dump tunnel. The position of the beam at the entrance to the dump can be monitored by a fluorescent screen viewed by a CCTV camera and by a four-quadrant split ion chamber. The dump can handle beams up to 1 kW power in its normal configuration. With external air cooling the dump can handle beams up to 10 kW power.

2.4.2 Faraday Cup

For electron scattering experiments, the primary electron beam is stopped in a Faraday cup to determine the electron beam current. The cup is located on a movable carriage in the beam dump tunnel. Its position along the beam line can be changed to minimize the background in CLAS while maintaining high acceptance for the primary beam. The cup consists of an electrically insulated metal core located in a vacuum enclosure.

2.5 Gas Shed

M. Mestayer

The Hall B gas shed is a separate outbuilding located just south of the counting houses. Located within it is all of the electronic and mechanical equipment to mix, filter, monitor and control the flow of both the drift chamber and Cerenkov counter gases. The shed is divided into two rooms: a 10’ X 20’ electronics room and a 20’ X 20’ gas handling room. Computers and electronic controllers are located in the electronics room while the other room contains the pumps, valves, filters, and sensors for controlling and monitoring the gas flow. At present, no flammable gases are present in the room so the fire hazards are those common to any electrical and/or mechanical equipment room. The area is equipped with sprinklers on the ceiling.

2.6 Labyrinth and Truck Access

B. Manzlak

The personnel access labyrinth connects all three halls, and is accessed from the counting house staircase and elevator. It is separated from the halls, stairwell, and vertical cable shafts by commercial fire barriers. This space permits access to the elevator equipment room and a pump room which houses valves for the sprinkler systems for all three halls. There are radiation safety barriers for all three halls between the elevator/stair doors and the section of the labyrinth adjacent to the entrance to each hall.

The truck access ramp descends from the outdoor paved road surface on the southwest side of the hall down to the floor of the hall. The ramp surface is roughened to facilitate braking control of heavy loads being taken down the ramp; the southern side of the ramp has been smoothed to a small degree to reduce trip hazards. This area normally contains no flammable materials, but during maintenance periods vehicles can be parked there on a temporary basis. The space is sprinklered with dual pre-action sprinklers triggered by heat detectors on the ceiling which are maintained by service contract.

2.7 Counting House

B. Mecking

The ‘counting house’ is a ground-level building connected via stairwell and elevator to the personnel access labyrinth. It contains a separate area for each of the three halls. The Hall B area is divided into two parts; one part contains a number of computer terminals, and this is the area normally occupied by the shift personnel. The other part contains the on-line computer system and an assortment of low-power electronics, primarily for communications and detector monitoring. The entire Hall B area in the counting house has an elevated floor through which a moderate number of cables are routed. Wet pipe sprinklers are mounted in the ceiling and within the subfloor. There are conventional smoke detectors in the ceiling of this area, and heat detectors in the subfloor.

2.8 Vertical Cable Shaft

B. Manzlak

The vertical cable shaft extends from the personnel access labyrinth up to the level of the counting house floor. Commercial fire barriers isolate this space from the labyrinth at the bottom and the counting house at the top. The fuel load in this space is relatively small. The vertical cable shaft is protected from the remainder of the building by a 1 hour rated enclosure as required by the Virginia Uniform Statewide Building Code (BOCA) Section 710.0 (a ‘sufficient’ standard which satisfies the Jefferson Lab contract with DOE, see Section F, “Contract Requirements for TJNAF Fire Safety,” on page 81).

3.0 Conduct of Operations

B. Mecking/M. Mestayer/B. Manzlak

3.1 Standard Operating Procedures

The standard operating procedures for Hall B are described in a separate document[1].

3.1.1 Operational Procedures Related to Fire Safety

There are emergency response procedures which are documented in the Emergency Procedures binder located in the Hall B counting room. Among these are procedures for responding to a fire alarm or pre-alarm in the hall during data taking conditions. There are two types of procedures: those for ‘pre-alarms’, and those for full building fire alarms. A pre-alarm is defined to be the output of the locally-designed Hall B Central Alarm Processor (‘HuBCAP’), which gathers information from a number of systems and makes decisions as to the severity of the conditions. A full building fire alarm has a different set of procedures, the first action of which is a call to 911. The procedures are described here; the official procedures are those written in the Emergency Procedures book, which may be revised as appropriate.

Due to the low thresholds used to trigger a pre-alarm, there is a high probability that the alarm was caused by electronic noise or other brief signals not related to a true fire condition. Therefore, the essence of the action on pre-alarm is to investigate the problem; during data taking, the shift leader is in charge of the situation. The problem may be investigated by a rapid access to the hall, if the alarm severity warrants it. A visual inspection of the area by a CCTV camera precedes entering the hall; the counting house, MCC, and the staff investigating the problem in the hall remain in contact by cordless emergency phones at all times, so that each party can immediately be aware of any new information such as additional alarms reporting. Electrical power may be removed from any and all areas from the Hall B counting room or locally in the hall, as warranted by the situation.

On a full building fire alarm, the crew chief is in charge of the situation. The first action taken is to call 911. If data is being taken, the beam is then removed from the hall, and the CCTV cameras are consulted. If smoke or fire are seen, no one enters the hall, but information about the situation is gathered and communicated to the crew chief. If no smoke or fire is seen, and if one suitably trained person is available, that person and one other may enter the hall on a voluntary basis to investigate the problem in parallel with the fire department driving to the site. These two investigators will be joined by two investigators from the Machine Control Center (MCC). All participants remain in contact via the emergency response phones. If, during the investigation, an actual fire is apprehended, the standard Jefferson Lab policies apply (as found in the EH&S manual). These permit employees to attempt to extinguish the fire, as long as they 1) elect to do so voluntarily, 2) they have been trained in the use of the appropriate fire extinguisher, 3) the fire is judged

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[1] Hall B Operating Safety Procedures and Conduct of Operations, presently under development.

to be limited in size and spread, 4) an escape route is guaranteed, 5) an extinguisher is close at hand, 6) their safety is guaranteed.

If the building fire alarm occurs during maintenance periods, the standard Jefferson Lab policies apply. This includes evacuation by all occupants, calling 911, notification of the crew chief and the guard at Post 2. In this situation the area safety warden has the same role as the trained person during data taking; on a voluntary basis, coordinated with the crew chief, he or she may investigate the alarm with one assistant, and they will be joined by MCC staff and will communicate via emergency phones.

3.1.2 Training of Personnel

There is a training program which acquaints the trainee with all safety hazards in Hall B, with an emphasis on fire safety. The course is called the ‘Hall B Safety Walkthrough’ because it consists of actually walking through the hall to see the hazards and safety devices. This course is part of the Jefferson Lab staff training program, course number SAF 132. This course is required for anyone entering the hall without a constant escort. An additional requirement for fire alarm investigators is to complete a written test including a detailed walk-through tour of Hall B, and to undergo additional classroom training. Final approval to investigate fire alarms is at the option of the Hall B program manager.

3.1.3 Buddy System

Because of the number and variety of hazards, and because of the complicated layout of the area, a buddy system has been implemented for Hall B. Under this system, no one may enter the hall without having a clearly identified ‘buddy’. The two people involved are required to communicate at least every five minutes.

3.1.4 Maintenance Plan for Auxiliary Fire Safety Systems

There is a maintenance plan for the systems developed by Hall B staff related to fire safety[1]. The staff to carry out this maintenance plan are designated by the Hall B program manager.

3.2 Modes of Operations/Description of Facility Use

The Hall B facility has three modes of operation: data acquisition periods, maintenance periods, and public tours. The data acquisition periods are scheduled in conjuction with Halls A and C, and the accelerator; approximately 35 weeks of the year (67%) will be operation in this mode. Maintenance periods occupy the rest of the year, with public tours being occasional events which are organized in advance.

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[1] Currently under development.

3.2.1 Data Acquisition Periods

For most of the data acquisition periods, no personnel are present in Hall B because of the radiation in that area. This is enforced by Radiation Control Group procedures for sweeping the areas before introducing beam, and by the Personnel Safety System after the sweep is completed.

At times there are accesses to the hall under the conditions of ‘controlled access,’ meaning that the number and identity of the people in the hall is controlled by key access. The exact information as to who is in the hall at a given time is recorded in the Machine Control Center (MCC), and is also generally known by staff in the counting house.

3.2.2 Maintenance

During maintenance periods the hall is in ‘restricted’ access (there is no formal record kept of who is present). A number of restrictions apply to those who enter the hall; the current requirements are posted on the entrance doors. The type of restrictions include requirements for personal safety equipment to be worn, for mandatory training, and restrictions on types of activities. These requirements may change depending on conditions; typically they exclude smoking, eating or drinking; require hard hats, safety glasses, and steel-toed shoes; require Hall B safety orientation; and require Oxygen Deficiency Hazards (ODH) training. During maintenance periods, all major power supplies (for minitorus and main torus, tagging magnet, and pair spectrometer) are switched off to minimize risks and power consumption.

3.2.3 Public Tours

Public tours are coordinated through the director’s office and through Hall B management. There exists an Operational Safety Procedure (OSP) for tours which permits groups of up to 15 people to tour the hall when accompanied by one escort who is trained in Oxygen Deficiency Hazards. The members of the tour group are required by the OSP to wear hard hats and safety glasses.

4.0 Fire Protection Approach

W. Brooks

There are two fire protection issues for Hall B; protection of the experiment hall and support facilities, and protection of the experimental apparatus. Of these, the experiment hall and support facilities present no fire hazards which cannot be addressed by compliance with the applicable codes and standards. The experimental apparatus, however, presents a fire protection problem which is simply not addressed by conventional codes and standards. For example, use of riser-rated cables for vertical cable runs is not possible because of the technical requirements for high-frequency transmission in the cables. A second example is the requirement for having an absolute minimum of material between the target and the detectors; this is crucial to their operation, and this consideration has dominated the design of the spectrometer as a whole. This precludes, however, the use of sprinklers or fire barriers to protect the detectors, which introduces a problem in that at least one detector system (the time-of-flight counters) consists of a large mass of fuel which is in no sense self-extinguishing. The problem is compounded by several other factors, such as the large inventory of cable plastic which is distributed throughout the hall, the sensitivity to smoke and water damage of many of the detector and electronic components, and the one-of-a-kind nature of all of the detector systems. The impact of a major fire on the experimental facility would be large, both in terms of the dollar cost of replacing components and in terms of the delay to the experimental program.

Broadly speaking, there are two distinct types of fire scenarios for Hall B. The first is a smoldering cable fire occurring in one of the electronics areas; this is the most likely type of fire for Hall B. In this scenario the fire spreads relatively slowly because the cables are fire-rated, and the cable runs are horizontal (see “Fermilab Horizontal Cable Tray Fire Test Results” on page 83). The main damage in this case is due to production of smoke and to the extinguishing agent used to put out the fire. This type of fire is the most probable because it involves fuels in quantity which are constantly in the presence of credible ignition sources. The harmful effects of the smoke damage should not be underestimated; for electronic circuitry the damage is primarily due to the corrosive nature of the combustion products of burning PVC. A smoldering cable fire could also occur in one of the cable storage rooms, but this is much less likely since there are no credible ignition sources during remote operations.

The second type of fire scenario is the ‘runaway’ fire which spreads rapidly and which is limited in growth only by the available fuel supply. In Hall B, this scenario is less likely since the vulnerability to it is for those fuels which essentially do not have a credible ignition source during remote operation. This includes the vertical cable runs on the forward carriage, and the time-of-flight counters. For the vertical cable runs, the damage from this type of fire could include a very large amount of smoke generation and extensive damage from an extinguishing agent, in addition to radiant and convective heat damage of detectors and electronics nearby. For the time-of-flight counters, this type of fire would produce extensive smoke damage, damage from extinguishing agents, direct loss of detector components, and heat damage to other detector and magnet components. Compounding these problems is the lack of access to these detectors in the installed position, where a straight line-of-sight would not be available to allow spraying extinguishing agent directly on the fire.

In addition to these two basic fire scenarios, there are a number of other scenarios as detailed in “Specific Fire Scenarios - Hazard Analysis and Risk Estimates” on page 41.

The basic fire protection approach for Hall B includes the following elements:

- Fires will be detected in an incipient stage by redundant, position-sensitive early warning systems.
- Personnel in the counting house or in the hall will receive immediate notification of the problem, including specific information on the location of the fire or pre-fire.
- The predominant ignition sources (electrical) will be shut down and manual intervention initiated.
- Combustibles control (i.e. fire rated cable and proper housekeeping), fire barriers, and hazard specific fire suppression systems will control fire growth, allowing the smoke ejection systems to maintain tenable conditions.
- An efficient manual response will rapidly extinguish the fire.

Since conventional fire protection methodologies (sprinklers, multi-hour fire barriers, riser-rated cables, etc.) cannot be applied in several locations of the apparatus, a much higher emphasis has been placed on three elements of this approach: the redundant, position-sensitive early warning systems, the centralized notification system, and the rapid response capability. To a large extent this extra emphasis compensates for the lack of more conventional protection components. It is also appropriate to concentrate on very early-stage detection because of the high cost of any programmatic delays in the experimental operation of the detector. If the early warning systems can be made sufficiently sensitive and the response to them is sufficiently prompt, any fire can in principle be extinguished before it causes significant damage.

5.0 Life Safety/Emergency Egress

B. Manzlak

5.1 Occupancies

In normal data taking mode, no one is in the hall. During controlled accesses, no more than ten people can be in the hall at any time (there are ten access keys); typically only two to four people are in the hall during these times. While there is a large variation, for the purposes of estimating occupancy, about one hour out of 24 can be considered to be devoted to controlled access, by an average of three people.

During maintenance periods the hall occupancy varies greatly. During working hours, an average number may be estimated to be ten. After working hours, the number may be estimated to be one person. At peak times, there have been as many as 25 workers in the hall during working hours, for a few days. During public tours, there are typically 10-15 people in addition to workers, and there can be more.

In summary, taking into account the fraction of time the hall is in each operating mode (see “Modes of Operations/Description of Facility Use” on page 21), the average occupancy is estimated in Table 1.

TABLE 1. Occupancy estimates for Hall B.

Average Occupancy per 24-hour day	Average Occupancy per 8-hour business day	Typical Peak Occupancy	Maximum Peak Occupancy
6 people	4 people	15 people	25 people

5.2 Exits

There are three exits to Hall B. The personnel access labyrinth door is at the floor level of the hall on the east side of the building; the truck access tunnel is at the floor level on the southwest side of the building. The third exit is through the upstream beam penetration into the hall, and this is accessible from Level 1 of the space frame.

There are multiple exits from each Level of the platforms. In most cases there is a ‘normal’ exit and an ‘emergency’ exit, such as a vertical ladder. The exits are listed in Table 2.

TABLE 2. Exits from each elevated platform level in Hall B.

Location	**Number of 'Normal' Exits**	**Number of 'Emergency' Exits**	**Total Exits**	**Comments**
Forward Carriage, Level 1	**1**	**1(operating position)/0 (maintenance position)**	**2/1**	Rollup stairs for emergency exit.
Forward Carriage, Level 2	**1**	**1**	**2**	
Forward Carriage, Level 3	**0**	**2**	**2**	Little instrumentation, rarely accessed. Ladder access only.
North Carriage, Level 1	**1**	**1**	**2**	Little instrumentation, rarely accessed. Emergency ladder.
North Carriage, Level 2	**1**	**1**	**2**	Little instrumentation, rarely accessed. Emergency ladder.
South Carriage, Level 1	**0**	**2**	**2**	Both are rollup stairs.
South Carriage, Level 2	**0**	**1**	**1**	Little instrumentation, rarely accessed. Ladder access only.
Space Frame, Level 1	**2**	**1**	**3**	Most-accessed spot in hall. Emergency ladder.
Space Frame, Level 2	**1**	**1**	**2**	Emergency ladder.
Space Frame, Level 3	**1**	**1**	**2**	Emergency ladder.
Downstream Alcove	**1**	**1**	**2**	Rollup stairs for emergency exit.
Tagger Alcove	**1**	**1**	**2**	6 foot jump for emergency 'exit.' Rarely accessed.
Pie Tower Level 1	**1**	**1**	**2**	
Pie Tower Level 2	**1**	**0**	**1**	No instrumentation, no fuels.

5.3 Maximum Travel Distance

The maximum travel distance to get to a hall exit is approximately 160 feet. This distance assumes a worker is on the south end of Level 3 of the forward carriage and exits via either the truck ramp tunnel or the personnel access door. This number compares favorably with, for example, the NFPA 101 requirements for general industry (maximum of 200 feet, unsprinklered, or 250 feet, sprinklered) or for special purpose industry (300 and 400 feet, respectively)[1]. Since, however, the truck access tunnel does not qualify as a fully protected exit, this number effectively depends on which exit is chosen. See the comments on smoke escape hoods and protection of means of egress in the following sections.

5.4 Protection of Means of Egress

Of the three exits to the hall, two are to areas which are isolated by commercial smoke and fire barriers; the third, the truck ramp, is somewhat isolated if the rollup door is closed, and not isolated if it is open. Even if closed, the rollup door is not a rated fire barrier.

None of the exits from the platform Levels are protected from fire or smoke by a rated fire barrier. In case of a fire incident, there is effectively some smoke and convective heat protection in the early stages of the fire because the smoke is free to rise to the dome (as demonstrated by one historical small fire). The large volume of the hall provides a buffer not typical of the average apartment building or office space. If the exiting occupant is close to the point of the fire, of course, this effect does not offer any protection.

Normal exits are marked by exit signs.

5.5 Emergency Lighting

Emergency lighting has been installed on all platforms. These were tested by Jefferson Lab EH&S staff after installation, and are maintained by plant services on request.

5.6 Smoke Escape Masks

Because there are significant smoke and fire hazards in Hall B, and to partially compensate for the long maximum distance of travel and the unprotected truck access ramp, smoke escape masks have been installed in Hall B. These devices provide a minimum of 15 minutes of breathable air, with a much longer maximum time depending on severity of smoke conditions and degree of exertion of the user. They also provide protection to the head and neck of flash temperatures of up to 1200 degrees F for a duration of a few seconds. The particular brand of smoke mask used satisfies the European standard EN403 for ‘escape hoods’. (At the time of purchase there did not yet exist a North American standard for smoke masks.)

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[1] NFPA Fire Protection Handbook, Eighteenth Edition (1997) pg. 8-40.

The smoke masks have been mounted at the exits to each platform, and in addition they have been mounted at locations where egress is particularly constrained. To use them the wearer opens the box or pouch, removes the plugs from the filter (the plugs are attached to the box), pulls the mask over the head and pulls a strap to tighten the mask against the head. Glasses do not have to be removed; long hair should be pulled into the mask. Although the operation is simple, proper training in the use of these devices is needed.

6.0 Combustible Inventory

W. Brooks

By far the largest fuel supply in Hall B consists of the inventory of plastics. Most of the plastic is in the cable jacketing or dielectric, although a significant fraction is found in the detectors. An overall summary of the plastics and gas inventory is shown in Table 3.

TABLE 3. Total combustible inventory in Hall B.

Plastics	Gases
Cable materials: PVC 842 ft^3 polyethylene 324 ft^3 teflon 13 ft^3	**Target gas:** 46 ft^3 (room temperature, 1 bar) cryogenic H_2/D_2 target
Unprotected scintillator: 362 ft^3 "Protected" scintillator **(inside calorimeters):** 982 ft^3	Note: target gas as quoted is only contained in the hall in liquid form; in gaseous form only a small volume is in the hall (unless the cell ruptures)
Total flammable plastic: 2506 $ft^3 = (13.6)^3\ ft^3$	Total flammable gas: 46 ft^3 at 1 bar

The scintillator material for essentially all systems is polyvinyltoluene (PVT), with very small admixtures of other chemicals. Included in the scintillator inventory is a small fraction of acrylic, of which the light guides (which join the phototube to the scintillator) are fabricated. A breakdown of the plastics inventory as a function of location in Hall B is shown in Table 4.

TABLE 4. Plastics inventory as a function of location.

Location	**PVC (ft^3)**	**Poly-ethylene (ft^3)**	**Teflon (ft^3)**	**Enclosed Scintillator (ft^3)**	**Exposed Scintillator (ft^3)**	**Total Exposed Plastic (ft^3)**	**Total Plastic (ft^3)**
Forward Carriage, Level 0	443	198	0	214	25	666	880
Forward Carriage, Level 1	47	21	0	214	25	93	307
Forward Carriage, Level 2	67	29	0	214	25	121	335
North Carriage, Level 0	0.2	0.1	0	0	35	35	35
North Carriage, Level 1	0.2	0.1	0	0	35	35	35
North Carriage, 'Level 2'	0.2	0.1	0	0	35	35	35
South Carriage, Level 0	127	57	0	0	35	219	219
South Carriage, Level 1	25	11	0	170	35	71	241
South Carriage, 'Level 2'	10	4	0	170	35	49	219
Space Frame, Level 0	0	0	0	0	25	25	25
Space Frame, Level 1	35	0	9	0	25	69	69

TABLE 4. Plastics inventory as a function of location.

Location	PVC (ft^3)	Poly-ethylene (ft^3)	Teflon (ft^3)	Enclosed Scintillator (ft^3)	Exposed Scintillator (ft^3)	Total Exposed Plastic (ft^3)	Total Plastic (ft^3)
Space Frame, Level 2	34	0	1	0	25	60	60
Space Frame, Level 3	22	0	0	0	0	22	22
Torus Magnet Region (Drift Chambers)	23	0	3	0	0	26	26
Downstream Alcove	0	0	0	0	0	0	0
Tagger Alcove	8	4	0	0	2	14	14

6.1 Cable Insulation

6.1.1 Power Cables

In general, utility power cables are routed through metal conduit throughout the hall. A minimal number of individual cables are contained within a given conduit. Flexible power leads are used for many of the crate power supplies; these are typically kept short (< 10 feet). As a whole, utility power cable jacketing provides little fuel.

In the drift chamber systems, a fraction of the electronics is located directly on the chambers. This electronics is powered by 354 relatively long cables (~70 feet) distributed along the chambers and the space frame on Levels 1, 2, and 3. Each cable contains two conductors surrounded by a braided metal shield and an outer jacket. All plastic parts are PVC. These are referred to as the ‘drift chamber low-voltage cables.’

Another category of ‘power cables’ is what is referred to as ‘high voltage cables.’ (These are in no way power cables in the ordinary sense, since the typical power delivered through them ranges from 0.1 to 2 watts.) The high voltage cable associated with the drift chambers is a commercial multiconductor cable with 12 conductors individually insulated by a teflon jacket, surrounded by a braid shield and a PVC jacket. These are also distributed along the length of the drift chambers, and on Levels 1 and 2 of the space frame.

For the phototube-based detectors, the high voltage cable is a coaxial cable, RG-59 style, constructed of polyethylene and PVC. These cables are distributed on all three levels of all four platforms, but the largest number are located between the calorimeters and the carriages on which the calorimeters are mounted (forward carriage Levels 0, 1, and 2, and south carriage Level 1 and 2).

6.1.2 Signal Cables

Most of the cable volume in the hall is due to, broadly speaking, ‘signal’ cable.

For the phototube-based detectors there is one type of signal cable, referred to as ‘delay cable’, which accounts for the largest fraction of the plastics in the hall. This delay cable is associated with all of the phototube-based systems: all calorimeters, all time-of-flight scintillators, all Cerenkov counters, and the timing scintillators of the photon tagger. This delay cable is RG-213 type coaxial cable. There are 2211 individual cable assemblies, averaging 300 feet in length. They are distributed over all four carriages, but concentrated in Level 0 of the forward carriage and Level 0 of the south carriage.

Most of the phototube-based systems also use what is referred to as ‘trigger cable’; this is of the low-loss RG8 type (‘air-core’), with a PVC jacket and a semi-hollow polyethylene core. These are distributed over all four carriages, but are concentrated in the areas between the calorimeters and the carriages which support them.

For the drift chambers the cables there are 2208 signal cables which average 70 feet in length, and which are routed from the drift chambers to racks on Levels 1, 2, and 3 of the space frame. This cable has 17 twisted pairs with individual PVC jackets, surrounded by an overall shield, within an outer PVC jacket.

6.2 Scintillating Plastic

6.2.1 Time of Flight Scintillators

The time-of-flight scintillators are rectangular bars of BC408 scintillator material with acrylic lightguides at both ends. They are all 5 cm thick and range in length from approximately 30 cm to approximately 450 cm. In total there are nearly 300 of these detectors, arranged in a single layer completely enclosing the drift chambers and Cerenkov counters like a ‘skin’. The only barrier between the ‘fuel’ and the outside world is a thin layer of fire-retardant plastic (carbon impregnated mylar), 0.002” of aluminum foil and 0.005” of lead metal on the front face. Although it is not in direct contact with any ignition source (except perhaps the high voltage divider circuit, which is enclosed in a sealed container), there is a very large surface area exposed, and the basic scintillator material is quite flammable.

6.2.2 Calorimeters

There are two categories of calorimeters: the ‘forward angle’ calorimeters and the ‘large angle’ calorimeters. The former are triangular shaped assemblies mounted on the forward carriage in all six sectors, while the latter are rectangular assemblies mounted on the south carriage in two sectors only. Both types are of the lead-scintillator sandwich design, with steel-and-foam composite plates covering the large surface area sides. In addition to the scintillator plastic, the light guide structures and the phototube housings are also plastic, but are mostly enclosed within the metal of the aluminum light cover. The plastic inside could only be available as fuel to a fire which is large enough to decompose the epoxy binding of the composite front or back plates, or melt the 1.5” thick aluminum side walls, or if it got hot enough the plastic could perhaps melt and drip out the lowest point on each module. The plastic is interleaved with lead metal sheets which would additionally slow the heating process. For these reasons, the plastic in the calorimeters is only available as fuel in the event of a large fire in an advanced stage which occurs in close proximity to the modules, such as could perhaps only occur on Level 0 of the forward carriage.

6.3 Combustible Gas

6.3.1 Hydrogen

Hydrogen gas is only used in the endstation as a nuclear target. The volume of the cryogenic target hydrogen gas at STP is about 46 cubic feet, including the volume of supply lines. This is still a tiny amount of fuel compared to the cable plant, although a significant explosion potential exists under the proper circumstances.

6.4 Electronics Rooms Enclosures

Sheet metal is used to enclose a number of the electronics rooms to isolate the cooling air flow from the surrounding spaces.

6.5 Ordinary Combustibles

There are very few ordinary combustibles in the endstation. There is a minimum of furniture, paper, or wood. Materials of this type are minimized as a matter of housekeeping.

6.6 Other Combustibles

The chamber bodies and chamber-mounted electronics boards contain a negligible amount of flammable material. The printed circuit boards are constructed of FR-4, which is highly resistant to burning.

7.0 Potential Ignition Sources

A number of devices or activities could start a fire in Hall B. This section attempts to enumerate all possible ignition sources, and to identify all ignition modes of each ignition source. No systematic attempt is made to evaluate the credibility of a given source; the relative likelihood of these sources actually creating a fire is estimated in Section 8.0.

7.1 Electrical Power

Broadly speaking, there are at least four modes in which electrical devices in Hall B can be ignition sources. These are: inadequate connections, incorrect connections, sparks or flame from electrical or electronic components, or loss of cooling.

Inadequate connections which have higher resistance than the design value can generate more heat than the connector/cable combination is designed to manage. This can be characterized in terms of the power dissipated in the connection, written for resistive loads by the familiar equations $P = IV = I^2R = V^2/R$. For a given resistance, the power dissipated increases rapidly for increasing voltages and currents. In the situation of an improper connection, the resistance often increases with time as well, due to oxidation associated with elevated temperatures or humid conditions. The higher the voltages or currents involved in the connection, the greater the risk of overheating an inadequate connection. The problem is most severe when the junction resistance developed is small compared to the load resistance, for high-current loads. In this case the current and voltage are maintained at approximately their nominal value, but substantial power is being deposited at the junction; safeguards based on overcurrent and overvoltage protection are not activated.

Incorrect connections involve the element of human error more directly than the other ignition modes. It is more difficult to predict what possible incorrect connections could be made without some assumptions about the level of training, competence, and good will on the part of the person making the connection. The most straightforward example of incorrect connections is replacing a power fuse with one of an incorrect value unintentionally. Power leads which are unlabeled or poorly labelled and which can extend to more than one connecting point could be incorrectly connected. Miscommunication (between a technician and a supervisor, for example) and poor labelling could lead to an incorrect connection. An individual’s response to time pressures or sleep deprivation can also be implicated in making incorrect connections.

Sparks or flame from electronic components are often short-lived and low-energy; sparks in particular are unlikely to be able to ignite massive fuels directly. The main vulnerability to sparks or flame from components is to low-mass materials with low ignition temperatures such as paper or small cables. These materials, when ignited, can then propagate the flame to more massive fuels.

Loss of cooling of electrical or electronic components can result from breakage or blockage of cooling water lines, failure or blockage of HVAC systems, or clogged cooling fan air filters.

7.1.1 Drift Chamber On-board Electronics

M. Mestayer

The drift chambers have two kinds of boards mounted directly on the chambers: high voltage translation boards (HVTB's) which distribute the high voltage to the wires, and signal translation boards (STB's) which route signal pulses from the wires to single inline package (SIP) amplifiers. The STB components are resistors, high-voltage capacitors, regulators and SIPs. Both boards have small areas at high electrical potential (-1000 to +2000 VDC). Low voltage power to the STB's is transported via individually fused wires.

One ignition mode for this source is deposition of power in an inappropriate spot. The power for the Region III drift chamber is typically 1.25 A at 7.5 VDC. The fuses are set at 2 A. This leaves 7.5 V, .75 A (5.6 W) ”extra” power which could be dissipated at inappropriate places on the board, such as bad connections or in shorted SIP's. (As a general rule, the fuses are set 20% over the measured maximum current and rounded up to the next commercially available fuse.)

A second ignition mode arises if a fuse is accidentally replaced with one of a larger value, and a failure occurs in a component which deposits power in a flammable material. The maximum power available from the power supply is 50 A at 8 VDC, or 400 watts. However, the internal trip circuit would have to fail (or be set incorrectly) in order for this much power to be available (see Section 1, “Internal and External Protection of DC Low Voltage Supplies,” on page 58) in addition to both a component failure and incorrect fuses in both the supply and return lines.

All of this electronics is located in an inerted atmosphere, making it a relatively implausible ignition source.

7.1.2 High Current Fast Electronics

M. Mestayer

The largest concentration of high-current electronics is associated with the drift chamber system. The drift chamber electronics (rack-mounted) is comprised of 11 FASTBUS and 31 VXI crates which have high power dissipation. These (and other miscellaneous modules) are located in 5 rooms on the space frame. The total power dissipation in such fast electronics crates is anticipated to be about 200 kW. For these devices, the units which supply power to a given crate are located within the crate. Many of the racks used to house these supplies are closed and interlocked.

There are a number of other crates distributed throughout the hall which service the other detector systems. These include FASTBUS, VME, VXI, CAMAC, and NIM crates. In general, the heat from the high-current supplies is ejected into the electronics rooms by fans; the rooms themselves are air conditioned. All of these supplies are commercially manufactured, although a few include custom features.

A typical ignition scenario involves dissipation of power in unintended locations such as at cable junctions or in under-sized cables; with most of these devices the normal current draw is large compared to what is required to generate enough heat for a fire, so overcurrent protection or fusing may not prevent a problem from arising. Another ignition mode for these is overheating due to cooling failure, such as blocked or inoperative cooling fans. A third ignition mode involves internal component failure resulting in sparks or flames coming from within the metal chassis of the supply, which subsequently ignite nearby combustibles. A fourth ignition mode arises if there are any power cables which are poorly labelled and which are long enough to connect to the wrong location. Typically these supplies are adjacent to many cables as well as temporary transient combustibles such as notebooks. Because there are so many of these supplies, all in close proximity to several types of fuels, this is one of the most probable ignition sources in Hall B for remote operation.

7.1.3 High Current Magnet Power Supplies

There are five large, high-current magnet power supplies in Hall B. These include the torus supply (3,861 A through a superconducting load), the minitorus/pair spectrometer supply (10,000 A at 40 VDC), the photon tagger magnet supply (2,400 A at 70 VDC), and a pair of dual-use supplies (each 8,000 A at 40 VDC) which power either the Møller polarimeter magnets or the photon beamline sweeping magnets. In addition to these, for polarized target experiments there will be a polarized target magnet supply (500A at 10 VDC).

All of these devices are commercially manufactured. Three of the larger supplies are located on Level 0 of the space frame, that is, on the hall floor and not adjacent to much fuel. The other two are on space frame Level 1, also relatively remote from combustibles. For all of these supplies the housing is made of metal, and any penetrations through them are minimal. Therefore, it is essentially impossible for flames or sparks to be ejected directly from the chassis.

The primary ignition mode for these devices involves depositing power at unintended locations such as cable connections or in undersized conductors, or in a shorted magnet coil. An additional consideration is that the current from these supplies travels through long conductors which are routed between the supply chassis and the load. While the voltage is fairly low, it is clearly possible to involve these leads in a mechanical accident which results in a short circuit, in which case sparks and splattered molten metal would be likely to result. A third ignition mode for the non-superconducting magnets could result from a loss of cooling water. A fourth ignition mode is for sparks or flames to be emitted from apertures in the power supply chassis, which is unlikely as noted above. A fifth ignition mode is for cables to be long enough and poorly labelled so that they could be connected to the wrong location. In a system such as the minitorus leads, if one pair of the flexible cables were interchanged by accident, tested briefly, and then remote operations were to proceed, the mis-cabling might not be detected, and remote operations would begin even though one lead is carrying several times its rated current. (In general these leads are so massive that it is only possible to connect them one way.)

There are only a few of these supplies, and they are expensive, highly engineered devices which have many safety features. Nonetheless, as ignition sources the overall system must be considered (supply + extended power leads + load). These supplies must be considered as significant potential ignition sources both in remote running conditions and while the hall is occupied, if they are left on. This is particularly true in that some of the loads are reconnected frequently, and the power leads travel through locations where many activities take place.

7.1.4 Miscellaneous Power Supplies and Instrumentation

While the high-current supplies and their respective loads offer the largest current sources, even a small power supply can start a fire, and these supplies and their leads and loads may receive less safety engineering attention. An example is the rastering magnet power supply. This device provides 10 A to the rastering magnets, and it is not a commercially produced supply. Other examples include power supplies for drift chambers and for photomultiplier tube high voltage, and the low voltage power supplies for the drift chambers. For some of these devices the possibility of accidental mis-cabling is much greater. In an environment where outside users contribute significantly to the hall instrumentation, there is always the possibility that some small, ‘temporary’ device is configured in a way which is significantly less fire-safe than the highly engineered ones.

7.1.5 Photomultiplier Tube Bases

Of the several thousand photomultiplier tube bases in Hall B, there are only a few distinct electrical and mechanical designs. The list of different designs includes: forward calorimeter, forward time-of-flight, Cerenkov counter, large angle calorimeter, large angle time-of-flight, tagger energy, tagger timing. In any photomultiplier base the typical current draw ranges from a fraction of a milliampere to two milliamperes. The maximum power deposited is approximately 5 watts, and the typical power deposit is approximately 1 watt.

Because the bases contains high voltage components, they are fitted with protective housings. Generally these housings are completely enclosed and are made of metal or thick plastic to prevent accidental shocks. In order to burn, the power available has to be deposited in a small flammable component which ignites, and the flame has to spread to other flammable components; the power supply must also not trip off. If the fuel of the first ignited component runs out, or the available oxygen runs out, the flame is extinguished. The ignited internal components must then ignite or burn through the massive or metallic housing of the base in order for the fire to spread. If the housing is made of plastic, there must be enough heat available to raise its surface temperature to the ignition point. In the case of the time-of-flight bases, for example the housing is made of thick plastic (unplasticised PVC, schedule 80) and a substantial amount of heat would be required to attain ignition temperatures on its inner surface.

While full ignition of a photomultiplier tube base may not be impossible, it is very unlikely because of the small available power, the limited amount of available fuel within the housing, and the massive or nonflammable housing of the base.

7.1.6 Drift Chamber Wires

M. Mestayer

Under normal circumstances the individual drift chamber wires carry minute amounts of current, therefore ohmic heating is negligible. In the case of a fault these wires could heat up to some extent, however, because of their mechanical fragility and electrical resistance, the wires cannot carry much current without breaking. (The most robust wires are the guard wires, which are also closest to the nylon gas bag.) Sparks due to high voltage, on the other hand, are likely to occur, since the chamber will operate at potentials of up to 2000 V relative to ground. Sense wire to field wire potential differences will be as high as 3000 V. Intense, prolonged arcing is unlikely due to the trip capability of the power supply and to the mechanical fragility of the wires. Since the wires are in an inerted environment, the sparks are unlikely to be a significant ignition source. In addition, the amount of energy contained in a given spark is limited by the high voltage power supply and by the capacitance in the system. The closest combustibles to the drift chamber wires are the gas bags and the plastic portion of the wire feedthrough (regions I and III only). Adjacent combustibles include the gas bag, which is made of aluminized nylon, and the feedthroughs, which are injection-molded plastic.

The power available from the high voltage supplies and delivered to these wires is current limited by a trip circuit (in distinction to the low voltage supplies). Under normal circumstances the power available cannot exceed 0.12 watts. Each output channel has its own separate high voltage ‘generator’ circuit, so it is extremely unlikely for multiple internal channels to contribute to a single external channel by a failure internal to the supply.

7.1.7 Static Electricity

M. Mestayer

Static electricity can produce low-energy sparks which can ignite flammable gas mixtures. In order to accumulate static electricity, an insulating surface in a dry environment is required. In the hall, the only flammable gas is inside the target, usually in liquid form. The beam pipe is a conducting material which completely surrounds the target. In the vicinity of the beamline area the only insulating surfaces are the drift chamber gas bags, which are metallized on one side. The insulating side is in contact with the ambient air in the hall which is maintained at 30-50% relative humidity, making it unlikely that any charge could accumulate. In the event of a simultaneous catastrophic failure of both the target cell and the beam pipe, the gas could come into contact with the bag. Although unlikely, there is a remote possibility of ignition from this source.

7.1.8 Other Electrical Appliances

There are many other electrical devices which may be operating in the hall at a given time. These may include soldering irons, computer terminals, oscilloscopes, extension cords, incandescent and fluorescent lights (both fixed and portable), and an assortment of other devices. These are all possible ignition sources; in highly protected facilities, it is often true that devices of this type initiate fires, since less safety engineering attention has been applied to their use compared to the fixed, high-value devices such as the high-current power supplies.

7.1.9 Lightning

B. Manzlak

Lightning strikes to the outside of the hall can in principle produce fire hazards in Hall B. In the unlikely event that something like this happened, a very substantial amount of power is available to be deposited in unplanned locations.

The ubiquitous feature of lightning is its unpredictability. While features such as the standard grounded lightning rods attached to the hall, the gas sheds, and the counting house may decrease the probability of lightning strike (by ‘defusing’ the local electric field), there is always a certain degree of non-deterministic behavior as to whether a strike will occur, and to which point it will choose to touch down.

The current may travel to the hall through the earth covering the building, through electrical conductors entering the building, through piping entering the building, and typically some current may go through several such paths, since the potential differences are very large. The obvious candidates for Hall B include the electrical power distribution and its associated ground network, and the gas system piping, which travels from elevated locations outside the hall directly into the hall through stainless steel tubing. While there is an intentional section of insulator pipe in this line to isolate it electrically, it is unlikely to guarantee breakover isolation from the potentials available from lightning. The current-carrying capacity of the electrical power distribution system is higher than that of the gas piping, and circuit breakers may provide some protection, depending on which conductor carries the current and on how large the currents are.

There is a ground grid within the floor of the hall to which the carriages are grounded by a high-capacity conductor. The metal frames of the carriages present an immense area of ground potential. This may help to distribute the charge from a lightning strike, depending on the route the lightning takes.

In any case, reasonable measures have been taken to avoid this intrinsically unlikely event, however, it cannot be ruled out as an impossible ignition source. The areas most subject to damage are the locations where electrical conductors come into the hall and points connected to them (hall perimeter and all carriages), and the drift chambers near space frame Level 1 (from the gas piping).

7.1.10 Switches

The light switches and other switches are enclosed in metal housings, from which it is remotely possible that sparks could be emitted. None of these switches are explosion-proof, so that internal sparks could ignite any flammable gases permeating the area when the switch is cycled.

7.2 Hot Work

B. Manzlak

Hot work is an important potential ignition source. It was historically the source of one small fire in Hall B during the construction phase, and while welding activity has decreased there will always be a continuing need for occasional welding or grinding in the area. The primary mode of ignition is through hot sparks which, unnoticed, ignite low-mass combustibles such as paper or thin plastic, and these proceed to ignite more massive combustibles. While direct ignition of cables or scintillator is possible in principle, the typical situation is that the spark does not provide enough heat to raise the surface temperature of these combustibles to the temperature needed for self-sustained burning. This temperature is, for example, in excess of 600 degrees C for sheet polyvinyl chloride (minimum hot plate ignition temperature)[1], the jacket material for almost all CLAS cables.

Other possible ignition modes include direct or radiant heating from the flame, or ignition of flammable gas mixtures, for which a single spark is sufficient. Under normal circumstances, however, there is are no welding, cutting, or burning activities in the hall while there is any hydrogen in the target; it is always pumped out before beginning any maintenance activities.

7.3 Electro-Mechanical Device Failure

J. O'Meara/WT

7.3.1 Pumps

All the vacuum pumps used in the CLAS are closed metal housing commercial pumps. There are no belt-driven pumps. Therefore, it is unlikely that these would be involved in starting a fire, although sparks could be thrown from the vent holes in a housing, or a circuit breaker could fail to trip when the motor seizes, causing the windings to overheat.

7.3.2 Motors

The HVAC fans are powered by commercial motors; there is at least one layer of metal housing surrounding the windings and brushes. Emission of sparks from the metal housing is possible but unlikely; there are sparks available during the normal operation of the motor inside its housing, such that flammable gas could be ignited.

7.4 Smoking

B. Manzlak

A no-smoking policy is in effect within Hall B and its truck ramp, as well as all other parts of the counting house building. If this policy is violated, it is possible that a lighted cigarette, or the open flame which lights it, could ignite a combustible or flammable gas. This is an unlikely situation, since the heat available from a cigarette is limited. However, in combination with transient, low-mass combustibles such as dry scrap paper or cardboard, this becomes a credible ignition source.

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[1] NFPA Fire Protection Handbook, Eighteenth Edition (1997), pg. 4-102.

7.5 Sparks

Mechanical accidents are capable of producing sparks. This potential ignition source produces sparks which may have a smaller energy than those produced by welding or grinding, but which have the accompanying characteristic of the element of surprise. This may lead to situations where there are distractions from any consequences of the production of the sparks, and there are no engineering or administrative controls. As in welding and grinding, the sparks are not likely to carry sufficient heat to ignite cables or scintillator directly, but can ignite paper or thin plastics present as transient trash.

8.0 Specific Fire Scenarios - Hazard Analysis and Risk Estimates

W. Brooks

In this section, possible fire scenarios are identified by examining combinations of ignition sources, fuels, and conditions which may lead to combustion. In addition to this hazard analysis, a qualitative risk estimate is performed[1]. ‘Risk’ is conventionally defined[2] as taking into account two factors: the probability of a scenario arising, and the severity of the losses if it actually arises. In this section, the occurrence *probability* for a given scenario is categorized into one of the following two classes:

- ***marginally possible*** - ignition from this source-fuel combination is very unlikely, but still remotely possible.
- ***possible*** - ignition from this source-fuel combination is clearly possible.

The *severity* of the scenario is categorized into one of the following two classes:

- ***moderate impact*** - a fire in this scenario is likely to have a moderate impact in terms of the target outcomes defined on page 9.
- ***severe impact*** - a fire in this scenario is likely to have a severe impact in terms of the target outcomes defined on page 9.

A categorization of the fire risk into three levels of ‘risk classes’ is given in Table 5.

TABLE 5. Definitions of risk classes in terms of scenario probability and scenario impact.

	marginally possible	**possible**
moderate impact	risk class 1	risk class 2
severe impact	risk class 2	risk class 3

A discussion of risk factors and possible growth modes of the fire follows the risk estimate for each scenario.

It should be recognized that fires are inherently a rare occurrence, and that the ‘ignition sources’ discussed are always safe devices under ‘normal’ circumstances. They become true ignition sources when component failure occurs, or other unusual conditions arise. In industrial accidents it is often true that ‘single failure’ accidents result in a safe condition when proper procedures are followed; the catastrophic accidents are usually those in which there were multiple component or procedural failures. The challenge in identifying and categorizing fire scenarios is to correctly assess the relative probability of single and multiple component failures which can lead to the ignition of a fuel, when these probabilities are intrinsically small.

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[1] A risk estimate or calculation is not classically a part of a Fire Hazards Analysis; however, since the goal of this analysis is to minimize overall risk in the categories listed in “Executive Summary” on page 9, it is appropriate to identify the relative probabilities of each fire scenario in order to ensure that the most likely fires are mitigated.

[2] “Fire Risk Analysis, ” John R. Hall, Jr., in NFPA Fire Protection Handbook, Eighteenth Edition (1997).

The combustible inventory has been identified in Section 6.0, and the ignition sources have been identified in Section 7.0.

8.1 Drift Chamber Low Voltage On-board Electronics Ignites Cables

Scenario: A connection on the on-board electronics develops resistance, depositing 10 watts of power into a small plastic part such as insulation on a small wire. The fuse rating is not exceeded, so it does not open. The plastic part attains its self-ignition temperature (typically 400-600 degrees C for plastics; see Appendix I: "Fire Characteristics of Hall B Fuels" on page 85) and develops a small flame which ignites other plastics in the area. Because this is in a completely inaccessible area, the fire grows without being extinguished.

Specific mitigations for this hazard include:
Drift Chamber Endplate Inerting (page 63)
Fire Rated Cables (page 51)

Probability: marginally possible. Severity: severe impact. Risk class: 2

Normal currents are low (~1-2 A); increased resistance would only decrease the current, so the full current allowed by the fuse is not available. Attaining 400-600 degrees C temperature is unlikely because of heat conducted away by the electrical conductor, but might be possible; if 1 watt were transferred to 1 g of plastic with no heat losses, a naive calculation using a typical heat capacity for plastics of 1 J/g^{o}C predicts 400 degrees is attained in 7 minutes. Heat losses, however, will occur through the air, local wires, and other plastics, increasing this time significantly. The main safeguard here is the inerting of the drift chamber endplate region, which would prevent any flame from occurring. Self-extinguishing cables (CL2 rating) could probably not be ignited by a single small flame, and would not propagate the fire if ignited. Besides the cables, there are essentially no flammable materials on these boards with the exception of a Molex brand connector, which could not be made to burn in informal ignition tests.

8.2 Drift Chamber Low-Voltage Power Ignites Cables at Disconnect

A connection develops resistance, depositing 5 watts of power into a small plastic junction connector located at the upstream end of the torus. The fuse rating is not exceeded, so it does not open. The plastic part attains its self-ignition temperature and develops a small flame which spreads to the cables nearby. Because of the large cable density in the area, part of which is in a vertical orientation, the fire grows rapidly.

Specific mitigations for this hazard include:
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)

Emergency Access (page 59)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Experiment Power Shutdown (page 64)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: marginally possible. Severity: moderate impact. Risk class: 1

Normal currents are low (~1-2 A); increased resistance would only decrease the current, so the full current allowed by the fuse is not available. Attaining 400-600 degrees C temperature is unlikely because of heat conducted away by the electrical conductor and other materials, but might be possible (see comments in previous scenario). Self-extinguishing cables (CL2 rating) could probably not be ignited by a single small flame, and would not propagate the fire significantly if ignited; linear heat sensors on these fuels would sound an alarm. Vertical runs of cable in this area are limited in length. The Sniffer system would be likely to see gases if the heat deposit to the plastic were large, and the VESDA system would see smoke products after ignition (and possibly before ignition also).

8.3 High Current Electronics Ignites Cables by Inadequate Connection

Scenario: In the case of an inadequate connection to the power cable or bus of the high-current fast electronics, dripping flaming cable insulation or other dislodged burning material may drop through the open floor grating or open area beneath the racks on all four carriages. (The current being produced by the supply may not be detected as excessive since these supplies normally draw large currents, and depending on where the heating occurs the over-temperature sensor may not activate.) This open floor area is dense in cables which are oriented both vertically and horizontally. These cables are configured both as thick cable bundles and individual small bundles spaced widely apart, so a wide range of potential propagation conditions are present. Once a sufficient number of cables ignite under the floor (the floor is an open grating), the fire can propagate along the cables to the detectors (and to the bulk cable delay rooms on the mobile carriages), propagating upward and horizontally via burning, and downward by dripping burning material down any vertical openings to spaces below.

A similar scenario occurs for loss of power supply cooling if there is a failure of the overtemperature protection. This scenario can also result from miscellaneous other smaller power supplies which have similar failure modes.

Specific mitigations for this hazard include:
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)

Emergency Access (page 59)
Experiment Power Shutdown (page 64)
Training of Employees and Users (page 51)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Internal and External Power Supply Protection Circuits (page 58)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: possible. Severity: moderate impact. Risk class: 2

Employee training on how to clean and attach the supply leads properly will reduce the likelihood of the condition arising. The prefire condition should be detected by VESDA and Sniffer. Fire rated cables and predominantly horizontal runs will slow fire growth; cables may self-extinguish at a small radius from the ignition point. The vertical cable runs within the rack or in front of the rack may, however, burn to completion before fire-fighters arrive if the fire is not detected in the incipient stage. Linear heat sensors may respond early depending on the diameter and location of the fire.

8.4 High Current Fast Electronics Ignites Cables by Sparking

Scenario: A component failure inside a crate power supply causes sparks or flames to be emitted from the chassis for a short time. Paper, cardboard, or small, easily ignited cables catch fire from the sparks or flames, and these materials burn longer and produce enough heat to ignite larger cables. The fire then propagates along all available cables.

A similar scenario can arise from one of the other miscellaneous smaller power supplies.

Specific mitigations for this hazard include:
Housekeeping (page 51)
Fire Safety Inspection Checklist for Hall B (page 92)
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Emergency Access (page 59)
Experiment Power Shutdown (page 64)
Training of Employees and Users (page 51)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Fire Department Pre-plans (page 61)

Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: possible. Severity: moderate impact. Risk class: 2

Housekeeping with respect to transient trash will reduce the likelihood of the condition arising. The fire condition should be detected by VESDA and Sniffer. Fire rated cables will slow fire growth; horizontal cables may self-extinguish at a small radius from the ignition point. Any vertical cable sections may, however, burn to completion before firefighters arrive if the fire is not detected in the incipient stage. Linear heat sensors on ignited vertical cables may respond early after initial flame occurs. Although most of these areas are remote from the time-of-flight detectors, the fire in an advanced stage could propagate via vertical cables to these detectors, which may not be self-extinguishing. While this is possible with any late-stage fire, there is a slightly greater vulnerability in this case in that sparks can ignite a fire several feet away from the crate, and the appearance of the flame occurs almost immediately. There may not be an incipient stage to such a fire; therefore, rapid response by firefighters is critical (and killing electrical power may not help). Fortunately, a key component to this scenario is controllable; if there is no transient trash under the fuel, the sparks are extremely unlikely to have enough energy to light any existing fuel directly. Momentary flames from the supply chassis are a more serious threat, but can also be avoided by routing small cables away from the chassis or by adding buffer space between the cables and the chassis.

8.5 Minitorus Magnet Supply Ignites Cables by Inadequate Connection

Scenario: After multiple reconnections and after the conducting surfaces have been handled frequently, the minitorus power leads acquire enough surface oxidation to produce an average resistance of 150 $\mu\Omega$. This is only a 3% change in the total load seen by the supply, so the software controls don’t identify it as a problem. However, at 6000 A (the nominal operating current) the power deposited in the junction reaches 5,400 watts in a small spot, and the water cooling flow (and to the heat conduction of the system) is no longer able to cool the junction. The cable jacket heats and burns, and ignites some of the many other cables nearby, providing some radiant and convective heating as well. Boiling in the cooling water lines exacerbates the heating problem. A runaway heating condition might result, where the resistance grows rapidly at the junction, resulting in escalating heat production producing sparks or an electrical explosion.

Specific mitigations for this hazard include:
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Linear Heat Sensor on Magnet Leads (page 58)
Emergency Access (page 59)
Experiment Power Shutdown (page 64)
Training of Employees and Users (page 51)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: possible. Severity: moderate impact. Risk class: 2

Employee training on how to clean and attach the power supply leads properly will reduce the likelihood of the condition arising. The prefire condition should be detected by VESDA and Sniffer. Linear heat detectors on the magnet leads would be likely to provide an early warning of the problem, before any flame breaks out. Fire rated cables will slow fire growth; horizontal cables may self-extinguish at a small radius from the ignition point. The vertical cable sections may, however, burn to completion before firefighters arrive if the fire is not detected in the incipient stage. Linear heat sensors on ignited vertical cables may respond early after initial flame occurs.

8.6 Pair Spectrometer Magnet Supply Ignites Cables by Sparks

Scenario: One of the aluminum welds in the pair spectrometer magnet high-current leads fails. These leads are approximately 150 feet long and they are made in sections joined together by approximately four dozen welds. The failure could be due to undetected mechanical damage (forklift backing into the unprotected leads), corrosion at the weld due to contaminants in the aluminum, or other problems. The weld area heats up, causing mechanical stresses, which cause further damage. The PVC tubing around the lead melts and sags away, exposing the conductor, or the electrical tape holding the tubing in place loses its strength and allows the tubing to fall away from the conductor. The damaged weld reaches a critical temperature and shorts out in a shower of aluminum sparks. If the short occurs behind the forward carriage when it is in the ‘maintenance’ position, the shower of sparks could easily reach any of the three levels of the forward carriage. Paper left in these areas ignites from the sparks, and the paper lights the cables. The cables accessible to this spot include the signal delay cables on Level 0, a huge supply of fuel.

Similar considerations would apply when considering the (upstream) Møller polarimeter magnets, which have extended welded aluminum leads passing by cable fuels.

Specific mitigations for this hazard include:
Housekeeping (page 51)
Linear Heat Sensor on Magnet Leads (page 58)
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Training of Employees and Users (page 51)

Other mitigations which may be relevant to this hazard include:

Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: marginally possible. Severity: moderate impact. Risk class: 1

Significant corrosion is unlikely since the corrosion properties of this water supply (the Low Conductivity Water, ‘LCW’) are monitored. Mechanical damage of the conductors is unlikely to be overlooked. The insulating cover on the conductors is mechanically robust and unlikely to come off. The aluminum conductors are sized for much larger current than is practically used. Prefire condition should be detected by linear heat detectors on magnet leads. Fire rated cables will slow fire growth; horizontal cables may self-extinguish at a small radius from the ignition point. The vertical cable sections, such as those on the back of Level 0 of the forward carriage, may burn to completion before firefighters arrive if the fire is not detected in the incipient stage. Linear heat sensors on ignited vertical cables may respond early after initial flame.

8.7 Photomultiplier Tube Base Ignites Time-of-Flight Detectors

Scenario: A fire due to electrical component failure occurs in a photomultiplier tube base attached to a time-of-flight counter near the bottom of one of the side carriages. The flames propagate to the plastic cover of the detector itself and ignite the scintillator material. The flames propagate across the surface of the detector plane, baking the outer support surface of the Region III drift chamber which then collapses and burns, exposing the inner two drift chambers to radiant heat and smoke damage.

Specific mitigations for this hazard include:
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Training of Employees and Users (page 51)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: marginally possible. Severity: severe impact. Risk class: 2

The photomultiplier tubes are a very unlikely ignition source (see page 36). When heated, both the PVC of the tube base and the Lucite light guide emit gases to which the Sniffer system is sensitive; the Sniffer tube at the apex of the spectrometer would be likely to detect a pre-fire condition. The linear heat sensors on the TOF light guides would be likely to give a signal before the flame got to the scintillator; both of these systems would be reported by the PLC system and the linear heat sensors would provide specific position information. The return air duct VESDA would give an elevated output at some stage of the fire as well. The degree of access to the fire depends strongly on the location of the problem and whether the carriage is in the operating or maintenance position; the access may be very simple if the fire is in an early stage on the bottom of the spectrometer, or totally inaccessible if the fire is, for instance, in the region between the large angle calorimeters with the carriage in the maintenance position.

8.8 Transient Electrical Device Ignites Cable

Scenario: A transient electrical device such as a soldering iron, portable halogen lighting, or damaged extension cord produces heat. The most likely location is in or near an electronics area. Transient combustibles such as paper come into contact with the heat. This could happen through direct carelessness of a person putting the two into close proximity, or the paper could be blown by a draft onto the hot object; strong drafts are produced, for instance, by the local cooling blowers. The transient combustible ignites and proceeds to ignite other fuels.

Specific mitigations for this hazard include:
Housekeeping (page 51)
Fire Safety Inspection Checklist for Hall B (page 92)
Training of Employees and Users (page 51)
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Emergency Access (page 59)

Other mitigations which may be relevant to this hazard include:
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Experiment Power Shutdown (page 64)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: possible. Severity: moderate impact. Risk class: 2

Housekeeping with respect to transient trash will reduce the likelihood of the condition arising. The fire condition should be detected by VESDA and Sniffer. Fire rated cables will slow fire growth; horizontal cables may self-extinguish at a small radius from the ignition point. Any vertical cable sections may, however, burn to completion before firefighters arrive if the fire is not detected in the incipient stage. Linear heat sensors on ignited vertical cables may respond early after initial flame occurs. Fortunately, a key component to this scenario is controllable; if there is no transient trash available, or if the temporary electrical device is not present or is de-energized, the scenario cannot arise.

8.9 Target Failure Causes Hydrogen Explosion by Sparks

Scenario: A sudden catastrophic failure of the vacuum pipe also ruptures the target cell (or vice versa), and hydrogen gas and (briefly) liquid fill the volume of the Region I drift chamber and its vicinity. The failure ruptures the drift chamber gas bag from flying pieces of the vacuum pipe, or from sudden overpressure, and a spark from the drift chamber wires ignites the hydrogen-air mixture, which explodes. The explosion destroys all three regions of drift chambers and starts fires in several locations including the TOF detectors.

Specific mitigations for this hazard include:
Safety Design Features of the Cryogenic Target (page 63)
Training of Employees and Users (page 51)
Fire Rated Cables (page 51)
Emergency Access (page 59)

Other mitigations which may be relevant to this hazard include:
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)
Closed Circuit TV System (page 58)
Fire Extinguishers (page 60)
Experiment Power Shutdown (page 64)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: marginally possible. Severity: severe impact. Risk class: 2

The pressures in the system at any given time are low, which makes it unlikely that both the gas cell and the beam pipe would rupture simultaneously. Engineering tests of components are performed before they are used; no new stresses are put on the system when the hydrogen is introduced. Beam pipe failure is likely to be an implosion (or a slow leak) and may not produce any flying parts which could damage the chamber. An explosion would not be directly detected by fire safety related systems, but any ensuing fires would. If the explosion were not audible in the counting house, it would be detected by various alarms from the hydrogen target monitoring system.

8.10 Welding or Grinding Ignites Cable or Scintillator by Sparks

Scenario: A welding or grinding activity produces sparks which ignite transient trash. The transient combustible ignites and proceeds to ignite other fuels. This can happen anywhere in the hall, including locations with no other ignition sources; examples include the cable storage rooms (Level 0 of forward carriage and south carriage) or the TOF scintillators.

Specific mitigations for this hazard include:

Hot Work Permit System (page 51)[1]
Housekeeping (page 51)
Fire Safety Inspection Checklist for Hall B (page 92)
Training of Employees and Users (page 51)
Fire Rated Cables (page 51)
PLC-Based Alarm Processor (page 53)
VESDA (page 55)
Hall B ‘Sniffer’ System (page 55)
Linear Heat Sensors on Fuels (page 57)

Other mitigations which may be relevant to this hazard include:
Fire Extinguishers (page 60)
Experiment Power Shutdown (page 64)
Fire Department Pre-plans (page 61)
Automatic Sprinklers in Space Frame and Front and Side Carriages (page 65)

Probability: possible. Severity: moderate impact. Risk class: 2

Risk estimate: credible. Housekeeping with respect to transient trash will reduce the likelihood of the condition arising. The fire condition should be detected by VESDA and Sniffer. Fire rated cables will slow fire growth; horizontal cables may self-extinguish at a small radius from the ignition point. Any vertical cable sections may, however, burn to completion before firefighters arrive if the fire is not detected in the incipient stage. Linear heat sensors on ignited vertical cables may respond early after initial flame occurs. If the TOF detectors are involved, a large amount of damage can occur if the situation is not identified in an early stage (see Section 8.7). Fortunately, a key component to this scenario is controllable; if there is no transient trash available, or if the required firewatch is attentive, the condition can be minimized or avoided altogether.

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[1] See also Appendix J: "Jefferson Lab Hot Work Program" on page 87

9.0 Hazard Mitigation

9.1 Administrative Controls

M. Mestayer

Several administrative controls effectively mitigate fire hazards as listed below.

9.1.1 Hot Work Permit System

Work which involves an open flame or produces sparks must be specifically authorized via a Fire Hazard Work Permit or Operational Safety Procedure. Fire Hazard Work Permits are valid for a specified time not exceeding 14 days.

Jefferson Lab has a hot work program as documented in the following EH&S manual sections:

Section 6122 - Welding, Cutting, and Grinding Safety.

Section 6122-T1 - Use of Fire Hazard Work Permit.

Section 6122-T2 - Welding Safety Practices.

These sections are included for reference in Appendix J: "Jefferson Lab Hot Work Program" on page 87.

9.1.2 Training of Employees and Users

Employees are trained in making proper electrical connections to high-current leads.

Employees and outside users are trained in housekeeping procedures, especially minimizing combustible trash.

Specialized training is given to those who are authorized to investigate a fire alarm, and to those who have operational leadership roles (see Appendix L: "Procedures for Responding to an Endstation Fire Alarm" on page 93).

9.2 Hazard Minimization

9.2.1 Housekeeping

B. Manzlak

The laboratory has a policy of keeping no more than 20 pounds of transient trash in any of the endstations, as documented in the EH&S manual in section 6910 - T5. This trash must be removed each day.

9.2.2 Fire Rated Cables

W. Brooks

Essentially all cables used in the CLAS have a fire rating. Whenever feasible, a higher rated cable was purchased over lower rated or unrated cables. An inventory of cable types and their fire ratings is given in Table 6.

TABLE 6. Cables used in the CLAS and their fire safety ratings.

Cable Type	Cable Model	Fire Rating
Drift chamber signal cable	17 pair round cable	CL2
Drift chamber high voltage cable	12 conductor round cable	CL2
Drift chamber low voltage cable	2 conductor	CL2
Phototube signal delay cable	RG-213 type co-ax	CL2X
Phototube trigger cable	Low-loss RG8 type co-ax	CL2
Phototube high voltage cable	RG-59 type co-ax	CL2
Miniature jumper (‘Lemo’) cables	RG-174 co-ax	VW-1
Jumper cables for trigger and signal delay	RG-58 type co-ax	CL2
Tagger high voltage	RG-59 type co-ax	[a]
Tagger signal	RG-58 type co-ax	[a]
Large angle calorimeter signal cable		‘Self-extinguishing’ (European-made)
Large angle calorimeter high voltage cable		‘Self-extinguishing’ (European-made)
Large angle calorimeter trigger cable		‘Self-extinguishing’ (European-made)

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[a] Some of these cables are rated CL2; others, purchased early in the project, are not marked with a fire rating.

9.2.3 Connector Design

M. Mestayer

The only connections carrying electrical power which are not commercially manufactured are for the drift chamber low voltage power. The power connections are distinct from the signal cable connections so signal and power cables cannot be interchanged. The power connectors are equipped with positive key interlocks to prevent erroneous connections.

9.2.4 Cable Routing

The most critical cable routing issue is to avoid small cables running near open apertures of any power supplies. This minimizes the hazard of flames emitted briefly from a power supply chassis igniting small cables, which then propagate the flame to larger fuels.

9.3 Monitor Status of Hazards

The hazards are monitored using highly sensitive, multiply redundant automatic systems which detect elevated temperatures, smoke, and gases related to overheated fuel. In addition to the automatic systems, remote visual verification of conditions in the endstation is available.

9.3.1 PLC-Based Alarm Processor

A programmable logic controller (PLC) monitors the status of all fire safety related hazard signals, makes alarm level assignments based on these inputs, and announces any alarms via annunciator boxes in the counting house.

The approach of using a PLC was chosen because of the very high degree of reliability and flexibility offered by these systems. The hardware and software components were chosen so that compatibility with the international standard for use of PLC's in safety systems could be achieved (IEC 1131), including the IEC compliant programming language "Structured Text". Increasing the number or type of inputs or outputs is a simple matter of adding modules; the control or monitoring points can be located anywhere a network cable can be placed, at distances of up to 6000 feet. Peer-to-peer device communication on the high-speed, dedicated network (~1 Mbyte/sec) allows near-instantaneous response to any alarm. The flexibility of having a user-accessible program means reconfiguring the system, including the alarm logic, can be easily performed. Implementing any changes requires only a few seconds of system down time for downloading the new control program into the CPU and restarting the controller. (As in any such system, validation procedures must test that the hardware and software are all functioning properly.)

The initial PLC configuration is indicated in Table 7.

TABLE 7. Initial PLC configuration for monitoring fire safety systems and related systems.

Monitored Inputs	Other Inputs	Control Outputs	Alarm Action Outputs	Notification Outputs
24 channels of linear heat sensors	Alarm acknowledge	32 solenoid valves for 16 sniffer channels	Autodialer calls 4 numbers for trouble, or 4 numbers for alarm	Counting house annunciator box - 16 channels (lights and audio alarm)
5 channels of VESDA analog signals	2 spare ADC channels		Power kill to hall electronics and utilities (optional)	Hall B annunciator box - 16 channels (lights and audio alarm)
Sniffer incipient gas detector concentration levels (unlimited number of locations, using sequential sampling)			5 spare high-current relays	Web page monitor of PLC parameters

The intention of the PLC-based system is to provide very early warning, therefore, the alarm levels will be set with the intention that the this system will respond well before the building fire alarm system. (The building fire alarm system is triggered by a high-level VESDA alarm, heat detection in the dome of the hall, or by a water-flow indication from a sprinkler head actuation.) The Hall B system produces ‘pre-alarms,’ and the building fire alarm system produces ‘alarms,’ the distinction being made in order to define who is in charge of the response (see Appendix L: "Procedures for Responding to an Endstation Fire Alarm" on page 93).

The basic function of the system is to alert workers in the hall or in the Hall B counting room of a pre-alarm condition as soon as it is identified, and give information on which system reported the problem, the location of the problem, and an estimate of how serious it is (see Table 8). The resulting actions can then be very efficiently focused on investigating the nature of the problem, such as by immediately entering the hall, or by looking at the closed circuit TV camera displays for signs of trouble. In addition to reporting to the counting house and the hall, an autodialer allows notification of up to four telephone numbers or pagers on an equipment trouble condition, or up to four (potentially different) telephone numbers or pagers on a warning or alarm condition.

The initial PLC alarm logic is shown in Table 8. Four levels are defined: Normal, Warning, Alarm, and Trouble. The numerical definitions of the individual settings may depend on conditions in the hall, and will be adjusted according to experience.

TABLE 8. Initial PLC alarm logic.

Normal	Warning	Alarm	Trouble
Normal linear heat sensor currents, AND	Any one linear heat sensor current higher than normal, OR	Any two simultaneous indications listed in ‘Warning’ column, OR	‘Broken wire’ indication from VESDA or linear heat sensor, OR
normal concentrations of hydrocarbons and CO in all areas, AND	Either hydrocarbon or CO slightly above normal concentration in any area, OR	Both hydrocarbons and CO above normal, OR	No update of gas concentrations within acceptable time window, OR
minimal smoke levels from all VESDA detectors	Smoke levels from VESDA slightly elevated	Hydrocarbons or CO well above normal, OR	Gas concentrations reported as negative (indicates background ratioing is wrong)
		Smoke levels from VESDA well above normal	

In case of power failure, the PLC and its annunciator boxes have a local backup power system (UPS) which will provide 15-30 minutes of additional operation. The system has been designed to have a minimum number of components, and the components have been selected with reliability in mind. For instance, all the bulbs on the annunciator panels are neon lamps with a 25,000 hour mean operating life; no relays or switches are wired between the PLC output modules and the indicator lights or audio alarms; each annunciator box has two audio alarms wired in parallel, so that if one fails the other still operates. Devices such as the linear heat sensors use a monitoring current, so that a broken wire results in a ‘trouble’ condition. Regular maintenance and testing of the system by Hall B staff will verify continued operation.

In the case that additional suppression systems are installed in Hall B, the PLC system could be used as part of the input decision as to whether to release an extinguishing agent (such as water mist).

9.3.2 VESDA

B. Manzlak/M. Willard

The Very Early Warning Smoke Detection Apparatus (VESDA) is part of the installed, approved, automatic fire detection system. It provides detection of a fire in its incipient stage. The VESDA sampling tube system includes extensive arrays of sampling tubes on each level of the forward carriage, the space frame and the north and south carriages. The system also continuously monitors the return air of the central air handler unit in the hall.

The system has an array of 15 dry contact outputs which are available for use. The ‘or’ of these is used to kill all Hall B electrical power at the same trip level that the building fire alarm system is activated.

The analog outputs of the VESDA system are monitored by the PLC from 0 to 5 volts, and are also monitored by the Hall B slow controls system. During normal operation the slow controls system plots these levels and additionally provides an audio and visual alarm, as well as archiving these voltages.

The system is configured in an approved way and is maintained by contract with a local vendor; this service is coordinated by the Jefferson Lab Fire Safety Engineer.

9.3.3 Hall B ‘Sniffer’ System

In addition to the commercial VESDA system, Hall B has developed a second incipient detection system referred to as the ‘Sniffer’ because it detects gases. This system is similar in spirit to a pioneering system developed at Fermilab[1]. It looks for gases which are emitted from flammables when they are heated, in principle finding the precursors to a fire before any flame has formed. This approach is partially redundant to the VESDA system, and partially complementary, in that some materials emit smoke when heated below the flame point, and others do not; for PVC cable jacketing, this property depends on the additives such as plasticizers and fire retarding chemicals, and so varies widely among cables which are otherwise similar.

In the Fermilab system, up to three gases are detected at the same time by point measurements, that is, each area monitored has three local detectors in it. In the Hall B system, a different approach has been taken. Here there is a single detector, and sequential sampling through long tubes is used. This approach has the disadvantage that one of the PVC signature gases (hydrogen chloride) is not readily detectable because it is deposited on the tubing wall in the presence of humidity and therefore doesn’t transport well. Another disadvantage is that there is a delay in the average time it takes to sample the gas in a given

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1. CEBAF Fire Safety Meeting Documentation, August 1993, from John Elias.

room; since the sampling is sequential, a problem could go undetected in one area until other areas have been sampled.

The advantages to this approach, however, are several. It permits the use of a single detector which can be located outside the radiation area, allowing servicing at any time and removing the concern for radiation-initiated problems. It is also possible to buy a higher-quality instrument as the detector, since only one (or one set) is required. A higher-sensitivity instrument requires less signal integration time, which means the measurement time at a given point can be short, reducing the average time delay of the overall system. Propagation delays for transporting the gas through long tubes can be minimized by using high pumping rates and large aperture tubing.

The gas detection instrument chosen for the Hall B system is a Fourier Transform Infrared Spectrometer (FTIR), a device which measures the absorption spectrum in the mid-infrared. Since the gases of interest all absorb in the infrared, this device is sensitive to all of these simultaneously. The minimum measurement time is 4 seconds; a 10 meter folded optical cavity is used to increase the sensitivity. For 1 ppm sensitivity, multiple measurements improve the error estimate.

With a system of this type it is possible to contemplate extracting ‘fingerprints’ of each combustible, that is, one can in principle identify *which* combustible is being heated, from its infrared absorption pattern. To fully exploit this option requires a systematic study of the effect of temperature, humidity, and other relevant variables, a pilot study of which has been performed at Jefferson Lab. In this study, all the cables in the hall were heated to approximately 180 degrees C and the gases measured. This was done both in a dry nitrogen environment and in air of normal humidity; the study was also performed with scintillator, lightguide, and PVC pipe, representative fuels in the hall.

Even in the absence of a fuel-specific identification, it is possible to identify gases at variance with the nominal hall background gas spectrum. Hydrocarbons are identified by a characteristic feature of stretching the C-H bond, which occurs in a relatively background-free region of the spectrum. Carbon monoxide can be quantitatively measured at the few ppm level. In addition, there are absorption peaks for many of the combustibles in background-free regions of the spectrum besides these well-defined components. An advantage peculiar to this approach is that the background spectrum can be taken as normal air in a fuel-free region of the hall; in this case a sensitive measurement of the deviations from normal air is possible. Even if, for example, a vehicle is operated occasionally in the hall, as long as the vehicle combustion products are uniformly diffused throughout the hall and change concentration slowly, they can be included in the background measurement. This feature recovers some of the specificity lost by not having the HCl signature gas.

In the Hall B system, the PLC controls the gas valves which select the area being sampled. The concentration of the gases found are transferred from the FTIR to the PLC using standard software over a dedicated network. The PLC evaluates the gas concentrations to determine if they are outside the acceptable range. The initial locations of the Sniffer tube inlets are indicated in Table 9.

TABLE 9. Initial locations of Sniffer tube inlets.

Space Frame, North Side	Space Frame, South Side	North Carriage	South Carriage	Forward Carriage	Other
Level 1	Level 1		Level 0	Level 0	Torus area
Level 2	Level 2		Level 1	Level 1	Top of large angle TOF
Level 3	Level 3			Level 2	Background location

9.3.4 Linear Heat Sensors on Fuels

W. Brooks

All cable trays and cable runs are to be outfitted with linear heat sensor wire, including the captured wire in-between the drift chambers. In addition, the ceilings of the electronics rooms and other locations are instrumented as needed. These heat sensors are the nominal 155° F type, and therefore respond at a temperature comparable to or slightly lower than the sprinklers.

The linear heat sensors report to the PLC (see “PLC-Based Alarm Processor” on page 53) so that fault information goes directly to the counting house staff and is incorporated into the position information reported by the PLC annunciators. The system is divided into 24 zones; a list of the zones is given in Table 10. Additional zones can be trivially added as needed. These zones are intentionally much smaller in area than the typical installation of this type of product. This was done in order to pinpoint the location of the problem in a way which does not rely on calibrations or calculations.

TABLE 10. Initial zoning of linear heat sensors.

Space Frame, North Side	Space Frame, South Side	North Carriage	South Carriage	Forward Carriage	Other
Level 0	Level 0 (tagger)	TOF cables	TOF cables	Level 0	Torus area
Level 1	Level 1	TOF light guides	Level 1	Level 1	Drift chamber endplates
Level 2	Level 2	spare	TOF light guides	Level 2	Magnet leads
Level 3	Level 3	spare	spare	Level 3	spare

A testing mechanism has been implemented by providing three-way switches in a junction box at the end of the wire in each zone. The three switch positions indicate 1) normal operating conditions, 2) the ‘broken wire’ configuration, 3) the ‘shorted’ configuration which imitates a fire condition. The testing procedure requires a technician to locate the zone, inspect the wire placement and condition in each zone, and to position the three-way switch in each of its positions; technicians at the locations of both annunciator boxes then verify by telephone that these report the correct location of the simulated problem, and report a simulated broken wire.

9.3.5 Linear Heat Sensor on Magnet Leads

Linear heat sensors are adapted to monitor the extended leads on the high-current magnet supplies.

9.3.6 Closed Circuit TV System

E. Smith

The Hall B Counting House is equipped with a closed circuit viewing system to monitor Hall B equipment areas. The experimental areas are viewed from the control console on a set of six monitors which can cycle through all the cameras or stop at a particular camera. This allows the operators to monitor important pieces of equipment, the operation of the experiment, and identify fires or pre-fire conditions should they develop. This system has been documented[1].

A total of approximately thirty cameras have been mounted in Hall B. One camera views the VESDA readout electronics (including a view of the bypass switches), seven cameras view the forward carriage instrument racks from both the north and south side, two cameras view the instrument racks on the side carriages, and fifteen cameras view locations on the space frame. In addition to these, there are a number of others which view the gas shed, faraday cup, tagger beam dump, access cage, as well as a number of spares for future use.

9.3.7 Temperature Monitoring of Large Magnets

The temperature of each of the large normal-conducting magnets is interlocked to its respective power supply by a series Klixon circuit. All of these magnets are water cooled.

9.3.8 Temperature and Water Flow Monitoring for Beamline Magnet Supplies

The cooling water flow for each of the large beamline magnet power supplies has an interlock to the supply power. The temperature of these supplies is also interlocked to the supply power.

9.3.9 Internal and External Power Supply Protection Circuits

M. Mestayer(PB)/A. Freyberger(beamline)

1. Internal and External Protection of DC Low Voltage Supplies

The DC low voltage supplies have two levels of protection. Each individual line is externally fused; both the supply and return line are individually fused, protecting against single fuse failure and other failure modes. The fuse values are chosen by measuring the actual current draw, then increasing this number by 20% and rounding up to the next avail-

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[1] CLAS NOTE 97-002, C. Martin.

able fuse value. The second level of protection is that the power supply internal trip circuit is set to 2 A greater than the normal current draw, which is approximately 16 A for the Region I chambers and 31 A for the Regions II and III. This also protects against fuse failure and various common mode failures.

2. Internal Protection of Crate Power Supplies

All crate supplies have overcurrent, overvoltage, and overtemperature protection. A network which monitors the status of these crates has been designed and partially implemented; this network provides notification to the counting house of the crate status. This information will eventually be included in the PLC-based notification system (see “Future Upgrades” on page 68).

3. Overcurrent Protection of Beamline Power Supplies

The Hall B experimental equipment extends beyond the CLAS detector and includes apparatus along the beamline both upstream and downstream of CLAS. Most notable of this equipment are large magnets and their associated power supplies. In order along the beam line these are the following magnet types: four Møller rasters, two Møller quads, 2 target rasters, tagger magnet, 2 sweeping magnets, 2 target rasters, mini-torus, and the pair-spectrometer. Not all of these magnets are operated simultaneously, and power supplies will be shared among the magnets.

All of these power supplies will be monitored and controlled remotely. The first line of defense against overcurrent will be the software control system which will shutdown the power supply if the read back current does not fall within some nominal range of the set current (usually 3-5%). However hardware interlocks to guard against overcurrent are also implemented in case of software failure or when the supply is operated in local mode. These hardware interlocks include overtemperature sensors on the magnets and internal interlocks in the power supply.

9.4 Rapid & Definitive Manual Response

9.4.1 Emergency Access

T. Hassler

1. Current Policies/Anticipated Delays

During data acquisition periods the current Jefferson Lab policy permits undelayed access by counting house personnel to Hall B, under emergency conditions. The access policy for fire alarms and pre-alarms is given in Appendix L: "Procedures for Responding to an Endstation Fire Alarm" on page 93. This includes response from the MCC as discussed in the Appendix.

Emergency access to Hall B is simplified relative to the other halls in that the level of persistent radiation is very small when the beam is turned off. From a radiological control point of view, exposure to residual radiation can be controlled by limiting access to parts of the upstream beamline, and to the beam dump (Faraday cup) area. The details of the control of these areas are given by Radiation Control Group policy.

If the pre-alarm panel has indicated a possible fire condition, the delays involved in getting counting house personnel into the hall include the time required to decide to make an entry, notify the crew chief, and run down the stairs to the hall. If the Hall B fire alarm has sounded, access to the hall is subject to more requirements, including training and authorization of individuals who may lead a two-man investigation (see Appendix L). If an actual fire is known to exist in the hall, no Jefferson Lab staff enter the hall, rather, information is gathered during the time the fire department drives to the site.

Rapid emergency access for firefighters is available according to laboratory policy. This includes a policy for emergency personnel entering oxygen deficiency hazard areas.

The transit time for firefighters to get to the site has been historically measured as approximately five minutes. The distances to the three local fire stations are 1.2, 1.8, and 3.8 miles.

Firefighters entering Hall B may be delayed by several actions which must take place first:

a)Shutting off the electron beam.

b)Unlocking and opening the secured gates and doors.

c)Exhausting smoke.

d)Donning SCBAs and fire fighting gear.

e)Hooking up fire hoses.

f)Reaching the area via the truck ramp or the labyrinth passageway.

2. Actual Hazards to Responding Personnel

The following hazards could potentially be present during a fire in Hall B: heat, flame, smoke, oxygen deficiency, radiation, radioactive particulate, exposed lead particles, cryogenic fluids, extreme cold, toxic gases, trip and fall hazards, high voltage, magnetic fields.

9.4.2 Fire Extinguishers

M. Willard

1. Hand-held Extinguishers

Hand held extinguishers as provided in the hall are typically the 10 lb. carbon dioxide extinguisher. The BC rated CO_2 extinguisher provides a clean agent that is not damaging to the equipment. They are located near the exits to each level of the four platforms.

2. Wheeled Extinguishers

Two wheeled Halon 1211 extinguishers are available on the floor level of the hall. The primary utility for these extinguishers is to put out fires which are out of reach, such as on the time-of-flight detectors mounted on a side carriage.

9.4.3 Dry Standpipes

M. Willard

Dry standpipes are provided in Hall B which require fire department hookup on the outside of the hall. (There are no wet standpipes with hose available.) The hookups are located near the counting house and are clearly labelled. These hookups are identified during fire department familiarization tours.

9.4.4 Fire Department Pre-plans

M. Willard

There is a single entry point to the site for the fire department, which is the Onnes road exit accessed by Jefferson Avenue. The guard at Post 2 directs the fire trucks from that point to the location of any fire alarm on the site. For the firefighters who will enter Hall B there is little chance for confusion in that the distance from Post 2 to the hall is only a few hundred feet and the Hall B truck ramp is visible from that point. If a water truck needs to get to the dry standpipes, however, the route taken is a more complicated one.

The paved area around the entrance to the truck ramp provides ample space for ground staging operations, even when a number of cars are parked in the area.

The ‘fire department phones’ report to the MCC building. The MCC crew chief and the battalion chief can use these to communicate with firefighters within the building. Additionally, cordless emergency phones are available at the top of the truck ramp and in the counting house. These have been tested to function throughout the hall and personnel access labyrinth.

The fire department access will be either through the truck access ramp or through the personnel access labyrinth. This decision is made by the battalion chief.

A fire hydrant is located adjacent to the opening of the Hall B truck access tunnel on the east side. This is the only hydrant which could practically service the hall without making use of the dry standpipes.

The truck access tunnel is a direct route into the hall. However, it is not a well-sheltered area in case of a large fire. The rollup door is not a fire-rated door, and if the smoke exhaust fans are turned on, both rollup doors must be open. The personnel accessway is a sheltered route into the hall, since it is separated from the hall by commercial fire barriers. In a small, early-stage fire, either location is well-sheltered from smoke or heat. In the targeted scenario of very early warning coupled with rapid fire department response, either entrance point is an acceptable area of refuge.

9.4.5 Fire Department Familiarization

M. Willard

The local fire departments visit the site on a regular basis for familiarization visits. These are organized by the emergency response coordinator, the Physics Division EH&S staff, and by the Jefferson Lab fire protection engineer. These typically occur quarterly.

9.4.6 TJNAF Staff Training

M. Willard

TJNAF staff are trained in general workplace fire safety training. ‘Hands on’ fire extinguisher training is required for “hot-work” workers, for all Hall B staff, and MCC operations staff. In addition, a number of Hall B outside users have received this training. Hall B staff, MCC staff and a number of users have also received training in the use of the two wheeled Halon 1211 extinguishers located on the floor level of the hall.

9.5 Passive Barriers

B. Manzlak

9.5.1 Accelerator Tunnel and Labyrinth Smoke and Fire Barriers

The passage of smoke or fire between the experimental hall and the accelerator tunnel is prevented by a commercial fire door and the thick cement wall used as a radiation shield. The same function is performed to isolate the hall and the personnel access labyrinth with a commercial fire door and professionally installed firestops in the cable tray in this area.

9.5.2 Non-Combustible Surfaces on Detector Components

E. Smith

The forward and large angle calorimeters have very substantial barriers which protect the scintillator material within. The sidewalls of the forward calorimeter, for instance, are 1.3” thick aluminum, while the front face is a 3” thick composite of stainless steel and structural foam.

The time-of-flight scintillators are protected on the back side with a composite backing structure similar in construction to the calorimeter box plate. The exposed side faces the target where any additional material will impact the physics program. There is, however, a layer of aluminum foil 0.002” thick which is wrapped around the scintillator, and there is a 0.005” thick layer of lead on the side facing the target. Therefore there is approximately a 0.007” thick metal layer on the face of these detectors which provides a significant measure of protection against sparks and a marginal amount of protection from small fires.

The two gaseous detectors, the drift chambers and the Cerenkov counters, are protected on two sides either by the magnet cryostats or aluminum walls. However, they each contain entrance and exit windows which must be thin in order to meet physics requirements.

9.5.3 Drift Chamber Endplate Inerting

The drift chamber endplates are inerted in all three regions. The primary reason for doing this is for improved technical performance (limiting high voltage currents), however, it also has the desirable effect of removing oxygen from the vicinity of the on-board electronics. As long as this condition is maintained, a fire in this location is not possible, a great advantage since there is essentially no access to these locations to extinguish a flame.

9.6 Safety Systems

9.6.1 Beam Shutdown

A. Freyberger

The output of the Hall B fire alarm system is monitored at the Machine Control Center (MCC). This monitor reports an alarm if fire is detected in Hall B. The alarm does not automatically shut off the electron beam to Hall B, however an operator in the MCC can, at the time of an alarm, shut down the Hall B beam line or even the entire accelerator. Other fire sensitive signals can also be made available to the MCC either through a direct line from the Hall B counting house to the MCC or through the slow controls system via ethernet.

It is possible to interlock the fire protection system into the accelerator fast shutdown system. This system takes as input a 24 VDC signal, and if this 24 V level transitions to ground the accelerator will be shut down. Hall B has requested that another level be created on the fast shutdown system that will terminate beam to Hall B alone and not shut down the entire accelerator. Such a hall specific shutdown system is more appropriate for an automated beam shutdown due to a fire alarm in the hall. This option will be taken advantage of at a future date.

Personnel entering the hall to investigate a fire alarm or pre-alarm are protected from beam exposure by the Personal Safety System (PSS). The PSS will not allow anyone to enter Hall B without first terminating the presence of the electron beam; it interlocks access doors with the electron injector to the accelerator using redundant systems. The PSS does not protect personnel from radiation exposure due to activated elements in the Hall. Due to the low beam current in Hall B it is expected that the activated elements will be limited to the beamline, especially the Faraday cup.

9.6.2 Safety Design Features of the Cryogenic Target

W. Brooks

A detailed description of this system and its associated safety features exists.[1] The cryotarget was constructed by a group at Centre d’Etudes de Saclay in France, in cooperation with Hall B engineering staff. This system was reviewed for safety by an external committee. The target is used both for photon and electron beam experiments. A brief summary is

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[1] “CLAS Cryotarget Safety Manual,” L. Murphy.

included here for completeness; reference to the original document should be made in the case of detailed questions.

All routine target operations are completely controlled by an industrial process controller (brand SEGELEC-GEFANUC). All pressures, temperatures, and levels are stored on a regular basis on hard disk and are histogrammed.

The cryogenic target is designed to operate with liquid hydrogen, deuterium, ^{3}He or ^{4}He. The operating parameters are different for these four liquids; for the flammable gases, the operating temperature is 20 K, and the pressure in the holding cell is 1.05 bar. The volume of the gas is 1600 liters for H_2 and 1700 liters for D_2, of which only 600 liters is within Hall B; the rest is contained in the storage system outside. In the Jefferson Lab Flammable Gas Standard categorization scheme, the outdoor storage area is at risk class 0.

A passive feature of the system in the case of target cell rupture is the large vacuum volume of the system. In the case of a target cell rupture the vacuum chamber pressure rises to less than 1 atmosphere (absolute pressure). In the event of a rupture of the vacuum system, the hydrogen warms up and is released back into the storage vessel by a pressure relief valve. Every electropneumatic valve in the system is protected by a relief valve.

9.6.3 Experiment Power Shutdown

B. Manzlak/J. O'Meara

1. Local

In each electronics area there is a power kill switch for the clean power and for the utility power. These are implemented using shunt-trip breakers. A testing program for these devices exists (see Appendix M: "Elements of Hall B Maintenance for Safety-related Systems" on page 96).

2. Global

In the counting house there is an array of kill switches which duplicate the function of the buttons in the hall. In addition there is a master kill switch which shuts down all of the electronics rooms, both the clean power and utility power. There is also a connection to the VESDA dry contact relays which automatically kills power if any of the VESDA circuits reach the same level that activates the building fire alarm system. The PLC can optionally also automatically kill power.

3. Magnets

At this time there are not power kill switches for the large magnet supplies. When operating in local mode these can be turned off with the normal switches on the power supply. When operating in remote mode these can be turned off using their software controls.

9.7 Smoke Exhaust System

B. Manzlak

There are two smoke exhaust systems: one for the Hall B truck ramp and one for the endstation itself. These are activated manually by push-buttons located at the top and the bottom of the truck access ramp, and in the personnel accessway.

9.8 Appropriate Suppression Systems

Protection systems are designed to ensure that a fire will be successfully controlled until such time that emergency response forces arrive to complete extinguishment. Since there are some fuels which cannot be protected by conventional suppression systems without compromising the functioning of the detector, the detection, notification, and response aspects of the overall scheme have been emphasized. Sprinkler systems have been provided for the fuels which are able to be protected by conventional systems.

9.8.1 Automatic Sprinklers in Space Frame and Front and Side Carriages

M. Willard

Automatic sprinklers have been installed by contract with qualified service personnel in all levels of all four platforms which have electronics or fuels. These are wet pipe sprinklers requiring only a fused or melted sprinkler head before the discharge of suppression water. This configuration minimizes the delays before automatic suppression can take place and relies on a minimal number of components. Given the relatively low initial energies of fires that can be expected with the electronics in the these areas, the effectiveness of the system is limited to preventing spread of fire in an advanced stage.

10.0 Conclusions

10.1 Facility is Safe to Operate

A set of fire scenarios based on identified fuels and possible ignition sources has been presented. A qualitative risk assessment has been made for each scenario. The level of risk is approximately the same for most of the identified scenarios; no one scenario presents significantly greater risks. In no case has it been found that a clearly possible fire scenario results in a severe loss (risk class 3). Operation of the facility with the mitigations given in this document may be undertaken with an acceptable level of risk. A summary of hazards and their risk classes is given in Table 11. The relevant mitigations are summarized in each individual scenario section.

TABLE 11. A summary of scenarios and risk classes.

Scenario	Risk Class
Section 8.1, “Drift Chamber Low Voltage On-board Electronics Ignites Cables,” on page 42	2
Section 8.2, “Drift Chamber Low-Voltage Power Ignites Cables at Disconnect,” on page 42	1
Section 8.3, “High Current Electronics Ignites Cables by Inadequate Connection,” on page 43	2
Section 8.4, “High Current Fast Electronics Ignites Cables by Sparking,” on page 44	2
Section 8.5, “Minitorus Magnet Supply Ignites Cables by Inadequate Connection,” on page 45	2
Section 8.6, “Pair Spectrometer Magnet Supply Ignites Cables by Sparks,” on page 46	1
Section 8.7, “Photomultiplier Tube Base Ignites Time-of-Flight Detectors,” on page 47	2
Section 8.8, “Transient Electrical Device Ignites Cable,” on page 48	2
Section 8.9, “Target Failure Causes Hydrogen Explosion by Sparks,” on page 49	2
Section 8.10, “Welding or Grinding Ignites Cable or Scintillator by Sparks,” on page 49	2

10.2 Level of Safety can be Improved

A number of improvements can be made to decrease the total fire risk. These are detailed in Appendix B: "Future Upgrades" on page 68. Most of these would provide only incremental improvement. A significant improvement, however, would be obtained by providing *automatic*, *early-stage*, *clean* fire suppression systems for each fuel. Although developing such a system is a multi-year research project, the total fire risk would be significantly smaller.

Appendix A - Loss Calculations

B. Manzlak,W. Brooks

Corporate risk management and insurance companies often use the following terms to describe loss expectancies[1].

The *Normal Loss Expectancy* (NLE): Loss expected with all existing protection systems in service and working.

The *Probable Maximum Loss* (PML): Loss expected with the primary automatic protection system out of service (typically this is the automatic sprinkler system).

The *Maximum Foreseeable Loss* (MFL): Loss expected with automatic protection out of service and a delay in manual fire-fighting efforts (i.e., delayed or no fire department response). Loss limitiation is primarily by passive means only (i.e., fire barrier walls, etc.).

The Department of Energy often uses the following terms to describe loss expectancies:

The *Maximum Credible Fire Loss* (MCFL): assumes that the fire protection systems function as designed, but ignores manual fire suppression efforts.

The *Maximum Possible Fire Loss* (MPFL) assumes there is no automatic or manual fire suppression. The only limitations on fire growth are the availability of fuel and combustion air, and legitimate fire barriers with a rating of 2 hours or greater.

Crude estimates for these quantities are indicated in the following table. Clean up and staff salaries during program delays are included.

TABLE 12. Estimates of risk profiles.

NLE	PML	MFL	MCFL	MPFL
$1,000-50,000	$1,000-50,000	$100,000-2M	$100,000-2M	$55M[a]

a. Includes significant foreign contributions.

It should be noted that some of the above numbers appear particularly severe because the present fire protection program relies heavily on an early manual response, which is focused on limiting the fire growth to the incipient stage.

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[1] NFPA Fire Protection Handbook, Eighteenth Edition (1997), page 11-116.

Appendix B - Future Upgrades

W. Brooks

Section 1: Improved Suppression Coverage

A decreased fire risk could be obtained by installing or improving automatic suppression systems in several locations. The areas which could benefit from this improvement include the time of flight counters, the back of the forward electromagnetic calorimeters, and the electronics areas in general. While the electronics areas are presently sprinklered, the sprinklers only activate in a late stage of the fire, after a significant amount of smoke and heat damage may have been done. The other two areas mentioned currently have no automatic suppression. Mist systems or inerting systems have been suggested for these applications, but no commercial system is available which would address all issues. A custom-engineered system could be developed which would decrease the overall fire risk.

In addition to adding new systems, improvements to the existing sprinkler coverage are possible, such as re-location of some sprinkler heads to obtain optimal coverage of fuels in their as-built configuration.

Section 2: Improved Fire Detection Capability

While the fire or pre-fire detection is a strong point of the existing program, there remains some room for improvement. A systematic study of the response of the Sniffer system to pre-fire gases could clearly produce higher sensitivity by identifying the individual gaseous components emitted from each fuel over a range of temperatures and heating conditions. A pilot study of this type verified that all Hall B fuels produce gases identified by the Sniffer detector at temperatures of 160-180 C. No investigation was performed for other temperature ranges. Further studies, in combination with use of software libraries of gas absorption characteristics (which are commercially available), would be likely to yield a threshold sensitivity to pre-fire gases exceeding that of the present approach by a factor of 2 to 5 or more. This is clearly a research project which would require one to two years to complete.

A second enhancement to the existing system would be to correlate information from the crate monitoring system into the PLC alarm decision-making process. The crate monitoring system (currently in prototype phase) will report the status of a large number of crates in the hall, including overvoltage, overcurrent, and overtemperature indications. The correlation of this information with small signals in the VESDA, Sniffer, or any linear heat detector, will provide helpful early notification of a fire or pre-fire condition, including very specific position information. This enhancement is definitely planned to be incorporated, and is a relatively simple extension to the existing system due to the flexibility of the PLC approach to alarm correlation and annunciation.

A third enhancement would be to mount a VESDA sampling tube routed up the wall and onto the dome. Historically, small fires have produced a smoke cloud bank which stratified at a certain height above the floor, near the polar crane. A vertically oriented sampling tube which extends all the way to the upper part of the dome would be very likely to intercept such a cloud bank early in its formation, and might ‘see’ a fire before the platform-mounted VESDA systems, depending on the fuel location.

Section 3: Improved Fire Barriers

A somewhat decreased fire risk would be obtained by improving fire barriers or fire stops in several locations. Enclosing the cable storage rooms with a fire-rated wall or even a marginally fire-resistant enclosure would protect these large fuel arrays. Designing fire-stops into all vertical cable runs, especially the long runs on the forward carriage and the south carriage, would be beneficial.

Fitting the time of flight counters with a thin, non-flammable cover is a possible improvement. In general, the amount of mass between the target and these detectors has been minimized at great effort; this stringent constraint has dominated the mechanical design features of all of the drift chambers, the Cerenkov counters, and the time of flight counters. However, it may be that a large fire safety benefit could be obtained by a thin, solid layer of non-flammable material, such as a 0.020” aluminum or copper sheet, at the cost of some performance degradation. It is a topic of study to decide whether this produces a significant fire safety improvement, and to understand which material has the minimal impact on the detector performance for a given useful thickness.

Enclosing the electronics rooms has been extensively discussed. A study of this issue might conclude that this would be beneficial, perhaps in a restricted number of locations. The positive aspects of enclosing the electronics areas include: sparks emitted from electronics could not reach the detector; sprinkler action would be enhanced within the room due to trapping of hot air by the walls; the Sniffer would have greater sensitivity to gases within the room; cooling of the electronics would be improved. The undesirable aspects of enclosing the rooms include: significantly restricted egress from some electronics areas; significantly decreased visibility across some platforms; ‘blinding’ the Sniffer and the VESDA to signals from any fuels outside the enclosures; extensive rework of the existing sprinklers to take the new walls into account.

Section 4: Improved Alarm Annunciation

The Hall B fire pre-alarm annunciator panels provide a significant amount of position information, however, with additional hardware an even more focused report on the position and nature of the alarm is possible. The ultimate system would display a diagram of the entire hall, with separate lights in each area to indicate which system at each location is reporting.

Another improvement of the alarm annunciation would be obtained by placing annunciator panels in the MCC and perhaps in the guard shack, along with procedures as to how to respond to various alarms.

Section 5: Miscellaneous Improvements

An implementation of labelled local and remote power kill buttons for the high current magnets (similar to those for the electronics rooms power) would be of benefit where possible.

A systematic effort to put software controls on PMT HV currents would make it even more unlikely that a PMT base becomes an ignition source.

A systematic effort to put stringent, load-dependent software controls on all of the high current magnet supplies would be of benefit. (this is already partially implemented)

A systematic method for limiting the current on high-current crate supplies to that which is known to be needed by the normally installed modules would be of benefit. (this is already partially implemented)

Appendix C - Programmatic Fire Protection Features

M. Willard

A complete Fire Protection Program exists and is described in the CEBAF/TJNAF Safety Manual, Chapter 6900. This document is available at many locations on the Jefferson Lab site and is also available for web browsing at http://www.cebaf.gov/ehs/manual/EHSbook-1.html.

The Jefferson Lab EH&S manual addresses fire safety in the following five sections:

6910 Fire Protection Program (June 1, 1996)

6920 Safe Egress (March 4, 1995)

6930 Fire Protection Systems (March 4, 1995)

6940 Portable Fire Extinguishers (March 4, 1995)

6950 Fire Safety Construction Requirements (March 4, 1995)

Excerpts from this manual which are relevant to Hall B fire safety are included in the following.

Section 1: Jefferson Lab EH&S Manual - Rev. 3.1 - 12 SEP 1997 --- 6910 Fire Protection Program (June 1, 1996)

Key Terms

Authority Having Jurisdiction (AHJ)

The decision-making authority for fire-protection systems, building features and suitability for occupancy with respect to fire safety as described in this program. Final AHJ responsibilities rest with the cognizant DOE Authority. The Jefferson Lab Plant Engineering Director provides the laboratory with direction for fire-protection based upon contractual commitments and applicable standards and codes, and serves as the on-site AHJ.

maximum possible fire loss (MPFL)

The total value of the structure and contents within a potential fire area. This assumes there is no automatic fire suppression or fire-fighting efforts.

maximum credible fire loss (MCFL)

Property and content damage from a fire assuming fire-suppression systems worked as designed.

NFPA

The National Fire Protection Association, the recognized standard-setting organization in the U.S. for fire and life safety.

Responsibilities

Everyone at Jefferson Lab

Take action to prevent and to correct problems. Plant Engineering accepts phoned-in reports (ext. 7400) from any laboratory or subcontractor employee regarding problems with fire protection systems.

Supervisors and managers

Line management is responsible to ensure buildings are used in a manner consistent with their design and intended occupancy.

EH&S staff and safety wardens

Jefferson Lab's EH&S professional staff and area safety wardens are required to monitor their areas for fire safety as part of their regular inspections and provide information about unresolved fire safety problems to the Fire Protection Engineer.

Security personnel

All fire protection systems at Jefferson Lab with alarm capabilities are monitored at a central master display panel located in the accelerator-site guard station. This panel is manned at all times by security personnel who have instructions on responding to alarm or system trouble conditions. Security conducts a roving patrol several time during each shift, and they are alert to incipient fire conditions.

Plant Engineering Director

The Plant Engineering Director (PED) has overall responsibility for the preparation, implementation, and maintenance of the FPP. The PED serves as the on-site authority having jurisdiction (AHJ) and makes decisions about fire-protection design, construction and maintenance in Jefferson Lab buildings in consultation with the Fire Protection Engineer.

Maintenance Services Manager

The Maintenance Services Manager reports to the PED and has operational responsibility for the FPP. This includes reviewing subcontract documents for fire-protection systems maintenance and modifications, and other quality-assurance activities. The Maintenance Services Manager also coordinates interdisciplinary work, including temporary system impairments involving the FPP, and drafts revisions to the FPP. The maintenance services manager is also the primary point of contact for fire protection issues with respect to external agencies.

Jefferson Lab Fire Protection Engineer

The Fire Protection Engineer (FPE) reports to the Maintenance Services Manager and is the in-house technical expert for Jefferson Lab's fire-protection systems and associated components. The FPE monitors the status of protection systems during normal operation, repair, and impairment, develops interim protection strategies and documents all changes to the systems, maintaining complete records on the systems. The FPE serves as the Subcontracting Officer's Technical Representative for all fire-protection system work, and prepares design specifications and other technical material for subcontracts involving the systems. The FPE serves as the initial internal point of contact for all facility fire-safety issues, acts as inter-divisional liaison, and provides technical assistance to the PED on all fire protection matters.

Newport News Fire Department

The City of Newport News Fire Department--by written agreement--provides fire brigade and other emergency-response services to Jefferson Lab. The closest station is Fire Station Number 6 which is 1.3 miles from the site, with normal response time of five minutes.

Section 2: Jefferson Lab EH&S Manual - Rev. 3.1 - 12 SEP 1997 --- Appendix 6910-T1 Building Fire-Protection Design (June 1, 1996)

Codes and standards

Jefferson Lab's facilities have been, and shall be, designed to incorporate contemporary fire-protection standards, while accommodating the unique features of the accelerator, experimental apparatus, and a variety of associated workplace environments. Principal design criteria include pertinent sections of the National Fire Protection Association Standards and the BOCA National Building Code. Other industry standards may apply, such as ANSI, UL, FM, OSHA and statutory authorities. A complete listing of sources for design and operational practices is listed in the "References" section of this appendix. The code of record is documented as part of archival records for each Jefferson Lab structure. The design-review process used by Plant Engineering is described in detail in its Quality Assurance Plan. This includes appropriate review by the FPE of a proposed project early in its design phase. Plant Engineering uses standard and customary design reviews of A&E design, such as reviews of the 30, 60, and 90-percent design documents. This review may be conducted on a less frequent basis, depending upon the size of the design project. Plant Engineering maintains all relevant files for each project, including design criteria and rationale. Design review shall also be done for projects performed by in-house staff, with peer reviews of each design.

Fire loss determination and reporting

Fire damage or loss

The maximum credible fire loss (MCFL) is an important basis to Jefferson Lab's fire-safety planning. The MCFL is normally taken to be the value of the property--building and contents--in the predicted fire area. It assumes that all installed fire protection systems functioned as designed. On occasion, a Fire Hazard Analysis (FHA) may provide justification for increasing or decreasing the MCFL from the apparent value.

Actual loss determination

Fire loss is considered to be the replacement cost of structures and contents--less any salvage value. Replacement costs must include any expenses for clean-up and decontamination, disruption to normal production, and other ancillary actions.

Loss Reporting

Actual fire losses shall be reported to DOE as described in Chapter 5300 Occurrence Reporting.

Chemical spills, which may occur as a consequence of fires, must be reported. See Appendix 6750-T1 Chemical/Material List of EHMs at Jefferson Lab.

Fire-safety features in buildings

Many of the codes and standards referenced in this program specify design features, construction methods, materials, and building accessories to reduce fire risk. Some of these can become impaired through neglect or improper modification. As such, they are elements of the Fire Protection Engineer's inspection activities described in Appendix 6910-T4 Fire Protection Program Assessment and Appraisal. They include, but are not limited to:

- Fire-resistive rating of walls and floors
- Fire-stopping of penetrations through walls and floors
- Fire dampers in ventilation ducts
- Emergency lighting
- Ventilation system shut-down in fires

- Smoke-removal systems
- Fire-resistance rating of doors and windows
- Door hardware

Fire protection systems selection

Fire protection systems (FPS) include two broad categories of equipment:

- Suppression systems
- Detection and alarm systems

Jefferson Lab uses both systems, often in tandem.

Suppression Systems Detection/Alarm Systems

- Hand-held fire extinguishers
- Early-warning fire detection systems
- Hydrant/water supply systems
- Building evacuation alarms
- Automatic sprinkler systems
- Deluge systems (for exhaust hoods and similar applications)

The thresholds for determining suitable systems are summarized in the table below. These thresholds are based upon widely accepted fire and casualty insurance industry criteria. In addition, Jefferson Lab shall use only equipment which is approved for its intended use by Underwriters' Laboratory and/or Factory Mutual.

TABLE 13. Thresholds for determining suitable systems

Maximum Possible Fire Loss (MPFL)	Maximum Credible Fire Loss (MCFL)	Fire Protection Systems Required
< $1,000,000	Human injury or death	Early-warning fire detection and/or audible alarms
>1,000,000	Unacceptable loss of vital structure or programs	Complete automatic fire suppression system: sprinklers
>50,000,000		Redundant protection: suppression and fire detection systems
>$150,000,000		Redundant protection: suppression and 3-hour rated barriers to limit MPFL to $150 million

In addition, all new structures over 5000 ft^2 shall have automatic suppression systems, regardless of MPFL. These system requirements are based upon the normal response time of the Newport News Fire Department.

System acceptance

Newly installed or modified systems shall be accepted only after performance testing as specified by NFPA standards. In addition, Jefferson Lab shall require complete documentation of systems, to include as-built drawings, operation and service manuals, diagnostic and test reports, and any other information as necessary to ensure a properly functioning system. New systems or additions to existing systems shall be incorporated promptly into the FPP inspection, testing, and preventive maintenance plan.

Fire protection water supply

The City of Newport News provides water for the Jefferson Lab site. There are three water-supply-line connections to the site:

- two on the Jefferson Avenue side main
- one on the Canon Boulevard side main

With the exception of the VARC Building/Trailer City area, the site hydrant and suppression systems can be fed from either the Canon or Jefferson mains. This supply redundancy provides an outstanding level of confidence in a continuous water supply for most of the site. The VARC/Trailer City area is served by the second Jefferson main tap only. Plant Engineering maintains the site water-distribution system and maintains an up-to-date drawing of the system: #91-U-8-0144-001. Testing, flushing, or special connections to the water supply system use back-flow prevention precautions as discussed in Chapter 6730 Water Quality Management.

Equivalencies and exemptions to codes or standards

Equivalencies

On occasion, literal compliance with a broad-based life-safety code or standard is not feasible. In such instances, Plant Engineering is responsible for developing an equivalent level of protection through an engineering analysis of the hazard and potential fire loss. In all cases, the objective of equivalencies is to ensure that design and construction methods are suitable for the intended occupancy of the structure, to protect occupants from fire by providing ample means of egress, to safeguard valuable property, and to minimize fire spread.

Exemptions

Code or standard exemptions are sought when their application to Jefferson Lab is inappropriate with respect to the facility purpose, or would offer insufficient additional protection for the cost required. Plant Engineering is responsible for documenting the conditions, costs and benefits (usually in the context of a Fire Hazard Analysis), and presenting the rationale for a proposed exemption. The proposed equivalency or exemption is submitted by the Plant Engineering Director to the Jefferson Lab Director's Council for institutional approval. The PED then submits the proposal to the DOE Site Office for review and transmittal to the cognizant DOE authority for final review and approval. Managers of work groups affected by an equivalency or exemption shall be provided information by the FPE that they need to adopt special procedures reflecting any limitations on space use, material selection, or restrictions on welding, cutting, and grinding. See Chapter 6122 Welding, Cutting, and Grinding Safety.

Section 3: Appendix 6910-T3 Fire Protection Aspects of Planning and Property Acquisition (June 1, 1996)

New facilities

Facility planning and property acquisition requirements are Plant Engineering functions. The objective is to anticipate the laboratory's needs in a timely manner, based upon direction from the Director's Council and specific information from the divisions involved. New facilities or major renovation of the existing physical plant necessitate a review of existing fire-protection systems and features within the affected area. Plant Engineering determines the need for new or enhanced protection based on code and contractual requirements, determines its costs, and provides this information as part of the overall planning information.

Existing facilities

In addition, needs for improvements in existing structures and systems may be identified through the FPP's continuous-improvement processes described in Appendix 6910-T4 Fire Protection Program Assessment and Appraisal. These are given a priority ranking for available funding. The major elements of this prioritization scheme are:

- Life-safety consequences
- The presence of critical process equipment
- Value of property at risk in terms of maximum credible fire loss (MCFL)
- Anticipated fire department response
- Damage recovery potential
- Environmental, health, and safety implications from a fire
- Emergency management planning considerations
- Security and public-safety considerations
- Natural disaster potential and implications

Fire hazard analysis

Jefferson Lab has unique, difficult-to-replace facilities and apparatus. Fire damage could cause severe operational disruption. The equipment in these areas is also very expensive. For these reasons, Jefferson Lab contracts for a rigorous Fire Hazard Analysis (FHA) of mission-essential areas. The main elements of the FHA are, for each functional area:

- description of construction
- fire protection features (fire-rated walls, automatic sprinklers, etc.)
- description of likely fire hazards based upon intended use
- fire-spread risk to adjacent structures
- life-safety considerations
- property and equipment value and potential loss from fire
- fire department response
- special environmental implications from a fire
- emergency planning
- deficiencies and recommendations

The FHA establishes a baseline of fire-safety information for a structure. Continuing engineering assessments keep the FHA valid. Plant Engineering maintains the official copy of the FHAs and is responsible for the coordination of corrective actions for FHA deficiencies. In addition, the documents are a basis for future design and planning for changes to the areas involved.

Section 4: Jefferson Lab EH&S Manual - Rev. 3.1 - 12 SEP 1997 --- 6920 Safe Egress (March 4, 1995)

Responsibilities

Everyone at Jefferson Lab

Know your

- Primary exit route
- At least one alternate exit route from your customary work location
- Muster point outside the building. (This is designated on evacuation diagrams posted in the building.)

Do not obstruct exits and egress routes. If you observe any obstruction, remove it, or report it to a supervisor promptly. Assist visitors and others who are unfamiliar with the evacuation route from a particular building If you have a visitor in the work area with impaired mobility, inform the appropriate supervisor Respond to all evacuation alarms or directions to evacuate as if they were life-threatening situations. If an alarm is identified in advance as a test, evacuation is not necessary.

Supervisors

Ensure that egress routes and exits are kept free of obstructions at all times. Ensure that normal and special work operations always make provisions for emergency egress. Ensure that new employees, subcontractor employees, and long-term visitors unfamiliar with a particular workplace are given the opportunity to familiarize themselves with egress routes and with muster (or assembly) points outside of the building, and that they know how to identify alarm/evacuation-alert signals. Ensure that provisions are made for any employee or visitor with impaired mobility. This may consist of physical assistance from a designated able-bodied employee or by ensuring the mobility-impaired person is led to a safe area to await emergency services rescue. Supervisors shall make the selection of these safe areas with the assistance of the Jefferson Lab Fire Protection Engineer and the local fire department. Ensure that changes to space-use in any particular work area do not impair safe egress. Consult with the landlord division EH&S staff as needed to evaluate potential changes to space use. (See Chapter 2220 Landlord and Tenant EH&S Responsibilities, which describes landlord/tenant relationships.)

Plant Engineering Manager

Ensure that safe egress is provided for all existing and proposed Jefferson Lab work environments and that routes and doors are suitably marked. Ensure that doors that are not part of an egress route, but could be mistaken for an exit, are labeled “Not an Exit.” Maintain all door hardware, handrails, stair treads, emergency lighting, and other vital egress systems to ensure safe evacuation from all buildings. Coordinate the production and installation of emergency evacuation diagrams for all Jefferson Lab buildings and underground areas as required by standards. These are to be revised as necessary to reflect wall and door relocations or other modifications.

Section 5: Jefferson Lab EH&S Manual - Rev. 3.1 - 12 SEP 1997 --- 6930 Fire Protection Systems (March 4, 1995)

Responsibilities

Everyone at Jefferson Lab

- Understand how to report a fire and what to do in the event a fire alarm sounds.
- Know how to activate any manually operated fire protection systems in your work area.
- Avoid damage to fire protection systems and report problems or damage promptly to your supervisor, safety warden, or Plant Engineering.

Supervisors

Ensure that work operations and space use do not impair or exceed the capability of the fire protection systems installed in the area. Consult with the division EH&S staff whenever you are unsure about the suitability of a work process in a particular environment. Implement the necessary modifications to work procedures whenever the fire protection system is being serviced or has reduced capability. Inform Plant Engineering of any pending work operation which may require temporary modifications or adjustments to fire protection systems. Appendix 6910-T1 Building Fire-Protection Design describes the temporary operational safety procedure (TOSP) for fire protection system impairment.

Fire Protection Engineer

Coordinate the selection and design of all Jefferson Lab fire protection systems. Systems must meet all applicable code and regulatory requirements, and must conform to Appendix 6910-T1 Building Fire-Protection Design. Ensure that fire protection equipment is inspected and tested as required by standards and manufacturer’s recommendations. Inspection intervals are described in the Appendix 6910-T1 Building Fire-Protection Design. Maintain records of all inspection and testing. Provide guidance to Jefferson Lab divisions on potential fire protection requirements and associated costs as part of space-use and modification planning. Select, install, and modify fire protection systems as required by the operational needs of the facility.

Appendix D - Sitewide Fire Protection Features

T. Hassler/M. Willard

Section 1: Newport News Fire Department

Jefferson Lab does not have a fire department or a fire brigade. Other than the employees who are trained to use a fire extinguisher, the Laboratory is fully dependent on the City of Newport News Fire Department for responding to and extinguishing a fire that has not been extinguished by automatic suppression systems.

The Newport News Fire Department has three fire stations in close proximity to Jefferson Lab. Fire station 6 is on Oyster Point Road and less than one mile from the nearest entrance to the Lab. Fire Station 6 is also headquarters for the Battalion Chief and is home base for the Peninsula HAZMAT Team. Fire Station 8 is located on J. Clyde Morris Boulevard and is about 2.5 miles from Jefferson Lab. Fire Station 10 is on Warwick Boulevard and is about 4 miles from Jefferson Lab.

The Newport News Fire Department has been very supportive of Jefferson Lab and has participated in annual fire exercises at the Lab. The Fire Department conducts an annual walk-through partial inspection of the Lab.

Further information is available on the Web at http://www.cebaf.gov/intralab/emergency/fire/.

Section 2: Sitewide Fire Alarm Reporting System

A sitewide fire alarm reporting system provides instant location information to the gate guard who relays the information by telephone and pager to designated staff.

Section 3: Water Supply

Water Supply tests in the area indicate available flows up to 1000 gal/minute is available, and is adequate for the hazard. Further information is available on the Web at http://www.cebaf.gov/intralab/emergency/fire/.

Appendix E - Outline of Hall B Safety Training Program

Classroom discussion:

Importance and relevance of safety, and special features of Hall B.

Smoke escape mask training.

In-hall orientation:

Visit 3 levels of space frame, 2 levels of forward carriage, 1 level of south clamshell, floor level of the hall.

Count the number of egresses from each area, including vertical ladders and contingencies due to carriages being in or out of position

Find the fire extinguishers in each area.

Find the fire alarm pull stations in each area.

Discuss egress routes out of the hall, and the need for daily identification of these due to changing equipment on the floor. Muster point at top of tunnel.

Discuss the cost of replacement and fragility of the drift chambers, TOF counters, and Cerenkov counter, including connectors and cables.

Note the danger of dropping items from elevated platforms, and the danger of falling from elevated platforms.

Note requirement for hard hats, safety shoes, and safety glasses for anyone in the hall.

Note location of flammables in hall: cable room of forward carriage and south clamshell, cable in subfloor of forward carriage and space frame, TOF bars.

Note location of fire hydrant outside Hall B.

Appendix F - Contract Requirements for TJNAF Fire Safety

The Thomas Jefferson National Accelerator Facility (Jefferson Lab) is managed by the Southeastern Universities Research Association (SURA). SURA is a contractor for the United States Department of Energy. Jefferson Lab is bound by contractual requirements to comply with a particular body of laws, regulations, and directives, including standards for Environment, Health, and Safety.

In a joint DOE/SURA effort, Jefferson Lab has undergone the process[1] of identifying those laws, regulations, and standards which constitute the minimal set of requirements for the operation of the laboratory. This set has been incorporated into the contract between SURA and the Department of Energy.

The “necessary” (required) standards identified by the committee which are related to fire safety are: 29 CFR 1910 Subparts E, H, I, K, L, S; 29 CFR 1910.38(b); 29 CFR 1910.103; 29 CFR 1910.252(a); and the Code of Virginia 15.1-291.1-11(Virginia Indoor Clean Air Act, concerning cigarette smoking).

These standards address the fire safety issues related to: fire prevention and protection, means of egress, electrical installations, hazardous materials, personal protective equipment, hydrogen fuels, and stationary engines in buildings.

The committee also identified “sufficient” standards, including NFPA standards, building codes, and portions of the Jefferson Lab EH&S manual. For complete documentation, refer to the document “Jefferson Laboratory Work Smart Standards Documentation.”

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[1] This process was formerly known as the “Necessary and Sufficient Standards” development process, now referred to as “Work Smart Standards.” The Jefferson Lab committee which carried out this work received the “Hammer Award” from U. S. vice-president Al Gore in 1997 for their efforts.

Appendix G - External Consultations

A series of consultants and reviewers have contributed in some measure to shaping the direction of the Hall B fire safety efforts.

Fire Safety Review #1: John Elias, Ph.D., Fermi National Accelerator Laboratory; Mark Dumais, P.E., Argonne National Laboratory; James Eckroth, P.E., Brookhaven National Laboratory.

Mark Dumais, P.E., Argonne National Laboratory, two-day consulting visit.

Bill Biscontini, National Sales Representative for Securiplex water mist systems, ond-day consulting visit.

Fire Safety Review #2: John Elias, Ph.D., Fermi National Accelerator Laboratory; Mark Dumais, P.E., Argonne National Laboratory; Timothy Tess, P.E., Argonne National Laboratory.

Jackie Holloway, NASA Safety and Occupational Health Specialist (retired), two-month consulting relationship.

Factory Mutual Research Corporation consultants: Paris Stavrianidis, Associate Director, Risk Methodologies (industrial risk assessment); Brenon Knaggs, Project Engineer (electronics-initiated fires); Dr. Soonil Nam, Ph.D., Senior Research Scientist (water mist systems); two-day consulting visit.

Fire Safety Review #3: John Elias, Ph.D., Fermi National Accelerator Laboratory; Mark Dumais, P.E., Argonne National Laboratory; Timothy Tess, P.E., Argonne National Laboratory.

Appendix H - Fermilab Horizontal Cable Tray Fire Test Results

Fermi National Accelerator Laboratory conducted a series of full scale horizontal cable tray fire tests in 1988. Because of the similarity of their test setup to the CLAS environment, their conclusions are quoted here in full[1].

1.High intensity fires with fast flame propagation by cable installations in Fermilab underground enclosures is highly improbable, if not impossible. Adequate sealing of penetrations to above ground support facilities is a necessity.

2.Automatic sprinkler systems in Fermilab underground enclosures would be of little benefit and would not be cost-effective due to the low heat release rate and very slow flame propagation, if any, in horizontal cable trays. Automatic sprinkler systems would be ineffective in minimizing potential smoke damage.

3.Early warning fire detection followed by manual fire fighting is the effective defense against underground enclosure fires. Fire detection might be accomplished in some cases by accelerator malfunction or by an appropriate and functional state-of-the-art smoke detection system. Linear type heat sensors in cable trays are not recommended.

4.In the Main Ring, Booster and New Muon Lab NMS fire tests, the cable tray fire self-extinguished almost immediately or within a few minutes after removal of the propane burner ignition source. Because of machine safety interlocks and time required for access into the enclosures, it is probable that a fire would have self-extinguished before the arrival of the fire fighters. Therefore, it is somewhat questionable whether automatic smoke detection systems would be justified in such areas.

5.Hardline coaxial cables are essentially signal and communication links, not directly associated with accelerator operation. In quantities to provide sufficient fuel loading and with ample oxygen supply, they do support horizontal flame propagation at a very slow rate of 1.7 inches/minute, which could go undetected for a considerable period of time. In such cases, a very early warning smoke detection system might be appropriate. An alternative could be the field application to cable bundles, of intumescent type cable coating at selected intervals to serve as a fire barrier and limit the extent of flame propagation. This proved to be very effective for both horizontal and vertical hardline cable runs.

6.The presence of an automatic sprinkler or fire detection system would not prevent a cable tray fire but rather would only limit the time for possible slow flame propagation before extinguishment. Property loss value would not be a major factor. Accelerator or experimental beam time would be lost in any case, with an estimated one person-week recovery time. During an operating period, such an outage would undoubtedly be also used to accomplish desired elective maintenance and development work.

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[1] Fermi National Accelerator Laboratory "Report on Full Scale Horizontal Cable Tray Fire Tests", 1988, pg. 15-17.

7.Automatic sprinkler spray nozzles mounted along each side of the Collider Detector Facility movable cableway would not be thermally activated in the event of a cable fire even if equipped with heat reflectors. They would be ineffective against a deep seated cable fire. The existing VESDA smoke detection system provides very early warning to the on-site Fire Department. Flame propagation would be extremely slow and with a very low heat release rate. Portable Halon extinguishment was proven to be most effective.

8.Existing Fermilab Fire Department response planning and fire fighting techniques were evaluated with the data from the cable tray fire test series and judged to be sound. Portable fire extinguishers are most effective for cable tray fires. Increased ventilation rates have little impact on horizontal flame propagation rates. Visibility is not a problem in ventilated tunnels even at an air velocity of as little as 20-50 fpm. However, smoke ejection equipment should be available for use in enclosures with little ventilation.

Note to the above The conclusion that linear heat sensors were not recommended in cable trays came from the following observations and reasoning found in the discussion of the fire test results:

"Thermocouple temperatures, both surface mounted and imbedded in the cable bundles, were recorded during the fire test. As indicated by the graphs included with the individual test reports, due to the low heat release rate and very slow flame propagation rate, automatic sprinklers if installed in the enclosures would be very slow to operate, if indeed they even operated. The very slow temperature rise of the imbedded thermocouples would indicate that linear heat detection installed in the cable trays might not be dependable or practical since there is every probability that they would become buried as additional cables were added to the trays."[1]

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[1] Fermi National Accelerator Laboratory "Report on Full Scale Horizontal Cable Tray Fire Tests", 1988, pg. 13.

Appendix I - Fire Characteristics of Hall B Fuels[1]

Nearly all of the fuel mass in Hall B is included in the following five plastics: PVC (polyvinyl chloride, with various additives, in cable jacketing and dielectrics), PVT (polyvinyl toluene, with various additives, making up essentially all scintillators), polyethylene (cable dielectric), Teflon (cable dielectrics), and Lucite (light guides).

Typical properties of plastics: carbon monoxide is generated rapidly from fires involving any of these plastics, and is usually the cause of smoke-related deaths from such fires. Figures for net heat of combustion given below assume complete burning (no CO produced) under standard conditions; less heat is generated for incomplete combustion. (For reference, the net heat of combustion of wood is 18-20 MJ/kg, and the net heat of combustion of gasoline is 44 MJ/kg.)

Section 1: PVC - Polyvinyl Chloride

This material has been extensively studied. When burning, most of the chlorine in the plastic is emitted in the form of hydrogen chloride gas, which is corrosive. Fire properties for plasticised PVC are largely determined by the plasticiser. Unplasticised PVC softens as it burns. Generally somewhat difficult to ignite. Heat capacity is 0.9-1.2 J/g^{o}C. Net heat of combustion is 16.9 MJ/kg. Minimum radiant flux for ignition is 21 kW/m^2. Energy required for ignition is 3320 kJ/m^2. Self-ignition temperature is 507 ^{o}C. Hydrogen chloride gas is evolved beginning at approximately 227 - 277 ^{o}C, for pure PVC; this temperature varies depending on which additives are present. Smoke particle/aerosol diameters are 0.3-0.6 μm for flaming fires and 0.8 - 1.4 μm for the pyrolysis stage.

Section 2: PVT - Polyvinyl Toluene

Not a commonly used plastic, and therefore not extensively studied. Ignites readily.

Section 3: Polyethylene

Marked in low, medium and high density formats; most in Hall B is high-density. Ignites readily. Heat capacity is 0.9-1.2 J/g^{o}C. Net heat of combustion is 43.1-43.4 MJ/kg. Minimum radiant flux for ignition is 19 kW/m^2. Energy required for ignition is 1500-5100 kJ/m^2. Self-ignition temperature is 488 ^{o}C (piloted ignition temperatures are much lower).

Section 4: Teflon

Several types in common use. Generally has a higher range of working temperatures (PTFE teflon can be used up to 260^{o}C). PTFE: Heat capacity is 1.02 J/g^{o}C. Net heat of

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[1] NFPA Fire Protection Handbook, Eighteenth Edition (1997), and the SFPE Handbook of Fire protection Engineering, Second Edition (1995), for most of the data in this section.

combustion is 5 MJ/kg. Minimum radiant flux for ignition is 43 kW/m^2. Energy required for ignition is 9000 kJ/m^2. Self-ignition temperature is 660 ^{o}C.

Section 5: Lucite

Chemical name is polymethylmethacrylate. Heat capacity is 1.44 J/g^{o}C. Net heat of combustion is 24.88 MJ/kg. Minimum radiant flux for ignition is 18 kW/m^2. Energy required for ignition is 1300-4200 kJ/m^2. Self-ignition temperature is 478 ^{o}C; piloted ignition temperature is 278 ^{o}C (varies with type). Smoke particle/aerosol diameters are 0.6 µm for flaming fires and 1.2 µm for the pyrolysis stage.

Section 6: Cables

Cable assemblies fabricated from several constituent materials (including copper braid) have fire properties which may be distinct from those of the isolated materials. In addition to the Fermilab tests described in Appendix H: "Fermilab Horizontal Cable Tray Fire Test Results" on page 83, there have been many controlled measurements of cable burning properties. Heat release rates of 300 - 600 kW/m^2 have been measured for PVC/polyethylene cables in cable trays at an irradiance of 60 kW/m^2. For Teflon cables, 98 kW/m^2 was measured at the same irradiance. These numbers illustrate the feasibility for an escalation to occur when multiple burning cables irradiate each other or are irradiated by other fuels such as transient trash.

Appendix J - Jefferson Lab Hot Work Program

Jefferson Lab EH&S Manual - Rev. 3.1 - 12 SEP 1997 --- 6122 Welding, Cutting, and Grinding Safety (November 28, 1993)

Introduction

Welding, cutting, and grinding of metal is a common part of Jefferson Lab fabrication and construction activities. Because of the high temperatures involved and the potential for fire and serious personal injury, care must be taken to ensure that work is performed safely.

- This chapter is primarily a guide for workers and supervisors who use welding, cutting, and grinding processes. It applies to all welding, hot cutting, and abrasive grinding on site by employees, users, temporary help, or subcontractors.
- Work which involves an open flame or produces sparks is specially restricted and must be specifically authorized via a Fire Hazard Work Permit or Operational Safety Procedure. The permitting process requires the supervisor of the work to inspect the area to ensure that preparations are complete and safe conditions exist.
- Fire Hazard Work Permits are valid for a specified time not exceeding 14 days. See Appendix 6122-T1 Use of Fire-Hazard Work Permits for more information.
- A permanent welding or cutting area may be established via an approved Operational Safety Procedure. See Chapter 3310 Standard Operating Procedures and Operational Safety Procedures for more information.

Hazard Avoidance

Experience

Approximately 6% of fires on industrial properties are caused by welding and cutting, primarily from sparks produced by portable equipment in areas not specifically designed or approved for such work.

- Electric arcs or oxy-fuel gas flames have rarely caused fire except where they have overheated combustibles in the vicinity of the work.
- At Jefferson Lab, weld spatter caused a minor fire in the North Linac Service Building in 1991.
- A Jefferson Lab employee received a significant “sunburn” from UV exposure while working near an arc welding area in 1993.

If you are not involved with welding and cutting, you can avoid hazards by following these precautions:

- Observe and follow warning signs.
- Do not bring combustibles into an area where welding, cutting or grinding occurs.
- When passing through a fabrication work area, be aware that welding may be in progress, and stay on marked walkways.

Arc welding produces an intense bright light which can quickly cause eye damage and “sunburn”.

- When you are in an area with arc welding in progress, do not look at the arc or its reflection off of shiny surfaces.
- If you encounter exposure to a welding arc, correct the situation with the welder, supervisor, and area safety warden.

Responsibilities

Worker

- Do not operate welding, cutting, or brazing equipment without specific authorization by your supervisor.
- Follow all guidance in this chapter and any authorizing Fire Hazard Work Permit or Operational Safety Procedure.
- Take the initiative to work safely.

Fire watch

- Remain present and undistracted during hot work operations.
- Be alert for any condition which could lead to a fire.
- Guard passersby from welding hazards.
- Interrupt the work when a hazardous condition develops, and deal with the situation appropriately.
- Remain on the scene for at least thirty minutes after completion of hot work to detect and report a fire resulting from stored heat.

Supervisor or inspector

Supervisors are responsible for authorizing and ensuring safe welding, or cutting, and grinding operations:

- Physically inspect the area before work begins.
- Ensure that personnel involved are appropriately trained.
- Ensure that the area is appropriately configured and made firesafe.
- Recognize and address potential complications such as environmental or radiological conditions or the effect of operations on other nearby activities.
- Coordinate fire hazards with the area Safety Warden and Building Manager (if applicable.)

Qualifications

Welder

Only personnel who have been properly instructed and qualified by their supervisor may operate welding and cutting equipment at Jefferson Lab.

Fire watch

A fire watch must be trained in the use of the available fire extinguishers and familiar with:

- All exit routes from the building.
- Use of the building fire alarm system (closest pull station).
- Emergency procedures in the event of fire (911 calls, for example).

Refer to the Fire Safety Chapters 6900 for additional information.

Program Summary

Fuel-gas welding and cutting and spark-producing cutting and grinding are restricted activities on the Jefferson Lab site. These activities are permitted only in areas that have been made firesafe.

- Open flame and spark-producing work is authorized only by a current Fire Hazard Work Permit or an Operational Safety Procedure for a specific area.
- Fire Hazard Work Permits are valid for a specified time not exceeding 14 days. See Appendix 6122-T1 Use of Fire-Hazard Work Permits for more information.
- A permanent work area for fire-hazardous operations may be established via an approved Operational Safety Procedure. See Chapter 3310 Standard Operating Procedures and Operational Safety Procedures for more information.
- The procedures in an authorizing OSP must be consistent with those required for a standard Fire Hazard Work Permit.

General Requirements

- Do not cut, weld, or grind inside a building if you have reason to suspect the sprinkler system (if present) is not working properly.
- Do not cut, or weld, in the presence of explosive atmospheres (gases, vapors, or dusts).
- Do not cut, weld, or grind on drums, barrels, tanks, or other containers until they have been thoroughly cleaned and declared free of flammable or combustible materials and gases.
- If the object to be worked cannot readily be moved to a routine welding area, move all combustible material in the vicinity to a safe place.
- If the object to be worked or cut cannot be moved and if all fire hazards cannot be removed, then protect the immovable fire hazards with appropriate guards and covers.
- Check cracks and holes in floors, walls, and ceilings to ensure that no combustible materials will be exposed to sparks should they pass through a crack or hole.
- Ensure that suitable fire extinguishing equipment is available.
- If material capable of causing a Class D fire is present, ensure that the fire extinguishing equipment is suitable for that case.
- Ensure that appropriate shields or welding curtains are in place to protect passersby and nearby workers.
- If in doubt about the safety of a new welding, cutting, or grinding area, inform Plant Services (Extension 7400). Plant Services will inspect the area and assist you in addressing fire hazards and the adequacy of the fire alarm system. They may also need to make temporary adjustments to fire detection systems.
- Do not cut, weld, or grind material which is known or suspected to be radiologically activated. Treat such material in a manner consistent with the Jefferson Lab Radiation Safety Program summarized in 6310 Ionizing Radiation Protection and associated appendices. You can call the Radiological Control staff at Extension 7236 for information, guidance, or assistance.

Inspection

The person responsible for authorizing the cutting and welding operation must physically inspect the area before work can begin.

Fire Watch

Whenever a Fire Hazard Work Permit is required for work, a fire watch must be designated if any of the following conditions exist:

- A significant amount of combustible material is closer than 35 ft (10.7 m) to the point of operations.
- A significant amount of combustible material is more than 35 ft (10.7 m) away, but could be easily ignited by sparks.
- Wall or floor openings within a 35-ft (10.7 m) radius expose combustible materials in adjacent areas, including concealed spaces in walls or floors.
- Combustible materials are adjacent to the opposite side of metal partitions, walls, ceilings, or roofs and could be ignited by conduction or radiation.

More than one fire watch may be required, depending on the situation.

Other safety concerns

- Welders and those performing similar work must wear appropriate personal protective equipment such as face shields, leather gloves, and leather aprons which are designed to prevent burns by protecting skin and clothing from welding slag, sparks, UV radiation, and radiant heat. For additional information, see Chapter 6620 Personal Protective Equipment.
- Welding, cutting, and grinding may present other safety hazards besides heat and fire. The glare of an arc can cause serious damage to eyes. Chapter 6650 Vision Protection discusses the use of special glasses, goggles, and shields to protect eyes from the glare of hot work. The Respiratory Protection Program found in Chapter 6630
- Respiratory Protection addresses protection from the hazards of breathing fumes and gases resulting from such activities.
- The Jefferson Lab Lockout/Tagout procedure, Chapter 6110 Lockout/Tagout, provides administrative controls which minimize the possibility of accidentally penetrating a pressurized fluid system or an electrical system while welding, cutting, or brazing.
- Welding, cutting, or grinding in a confined space presents additional hazards which must be addressed in a confined-space entry procedure. Refer to 6160 Confined Space Entry.

More detailed guidance is given in Appendix 6122-T2 Welding Safety Practices for the following:

- Oxygen-Fuel Gas Welding and Cutting
- Arc Welding and Cutting
- Resistance Welding

Appendix 6122-T1 Use of Fire-Hazard Work Permits (November 28, 1993)

Introduction

This appendix provides direction on the use of a Fire-Hazard Work Permit at Jefferson Lab. Work activities which employ an open flame or produce sparks are restricted and require specific written authorization by means of Fire-Hazard Work Permits or Operational Safety Procedures (OSPs).

A Fire-Hazard Work Permit

- is issued by the supervisor of the work, or, in the case of subcontracted activities, the Jefferson Lab inspector or COTR of the work,
- is valid for a specific duration, not exceeding 14 days,
- is required for all fuel-gas welding, cutting, and brazing activities as well as spark-producing grinding and cutting operations unless these activities are covered by an approved Operational Safety Procedure.

Exception: pedestal and stationary grinders mounted in permanent machine shop areas do not require a permit.

Below is the Fire-Hazard Work Permit form. (not reproduced here)

Appendix 6122-T2 Welding Safety Practices (November 28, 1993)

Oxygen-Fuel Gas Welding and Cutting

Arc Welding and Cutting

Resistance Welding

General Precautions

- Sweep floors clear of combustible material. If the floor itself is combustible, cover it with noncombustible material, such as sand, or wet it down. In the latter case, welders must be protected from possible shock by such means as standing on fire resistant, non-conducting mats.
- Do not cut or weld in sprinkled buildings when the sprinkler system is impaired.
- Do not cut or weld in the presence of explosive atmospheres (gases, vapors, or dusts).
- Do not cut or weld on drums, barrels, tanks, or other containers until they have been thoroughly cleaned and declared free of flammable or combustible materials and gases.
- Use appropriate protective clothing such as face shields, leather gloves, and leather aprons which are designed to prevent burns by protecting skin and clothing from welding slag, sparks, and radiative heat. Face shields must have the appropriate opacity for the type of weld being performed.
- Avoid polyester or nylon clothing; cotton or cotton blend fabric is preferred.

Appendix K - Fire Safety Inspection Checklist for Hall B

All inspections should be documented in writing, including date and identity of inspectors.

Section 1: Electronics rooms inspections:

- Cables on top of crates or adjacent to penetrations in crate chassis - re-route.
- Any transient trash removed. Any remaining temporary combustibles relocated away from stationary combustibles such as cables. Cover temporary combustibles with a non-combustible surface when feasible, as a spark guard.
- Remove any transient ignition sources such as soldering irons, temporary lighting, or extension cords.
- Inspect labels on electrical power kill switches; repair as needed.
- Inspect placement of linear heat sensor on fuels; modify as needed. Sensor line should be on top of fuels. Termination boxes should be visually intact.
- Inspect filters on power supply cooling fans for cleanness. Clean or replace as needed.
- Inspect Sniffer filters; replace as necessary

Section 2: Smoke Masks

- Count and inspect smoke escape masks at each station. Replace any which appear to be opened or missing.

Section 3: Magnet Lead Junction Inspection

Section 4: Crate Power Supply Lead Junction Inspection

Appendix L - Procedures for Responding to an Endstation Fire Alarm

Section 1: Full Alarms and Pre-alarms

The endstations may be equipped with systems which give pre-alarm warnings, such as low-level VESDA dry contact outputs or a locally-built incipient fire detection system. The pre-alarm condition is treated differently from the full building fire alarm, as follows.

Section 2: Pre-alarms

Authority: Response to a pre-alarm is entirely under the control and jurisdiction of the counting house/endstation staff, although MCC staff may receive automatic notification and may participate in the response.

Personnel: Staff who may respond to pre-alarms are to be designated by the endstation management.

Procedures: Procedures for pre-alarm response are to be specified by endstation management and may include the MCC and guard services as well as counting house/endstation staff.

Section 3: Full Fire Alarms

Authority: If the building fire alarm is activated in any way, the MCC crew chief is in charge of the response to the alarm. There is a crew chief on duty 24/365; the on-duty crew chief always has a cellular phone, and is almost always stationed on-site.

Personnel: The staff who may investigate fire alarms in the endstation include:

1. MCC operations staff
2. A counting house shift worker who has been authorized by the endstation management, and one assistant, on a voluntary basis
3. The area safety warden (if authorized by endstation management) and one assistant, on a voluntary basis
4. The guard staff

Procedures: When an endstation fire alarm sounds:

1. 911 is called, by any combination of the counting house staff, crew chief, and the guard.
2. No staff will enter the endstation if any of the following is true:

- Smoke or flames have been seen
- Any two automatic UL-approved systems indicate a fire
- A pull station has been activated

3. If none of the conditions in (2) is true, then the action depends on the conditions in the endstation:

A) Beam is being delivered to the endstation when the fire alarm sounds.

The shift leader contacts the crew chief and informs him/her of any intent to investigate the alarm. The first responders are one authorized member of the counting house staff, and one assistant, on a voluntary basis. If available, a third person will be dispatched to MCC to enhance communications with the crew chief, who is in charge. The authorized responders will take the emergency portable phone along on the investigation, to communicate with the crew chief. These two responders must not become separated during the course of the investigation.

MCC operations staff will be dispatched to join the investigation. They will bring an emergency portable phone along on the investigation, to communicate with the crew chief and counting house responders. When they arrive in the endstation, they will join the counting house responders in investigating the alarm.

When the fire fighters arrive, the investigators terminate their activities. They are available as information sources to the crew chief and the battalion chief. The JLAB emergency portable phones will be made available to the firefighters as needed.

B) Workers are in the endstation when the alarm sounds.

The workers evacuate the hall and proceed to the muster point, noting any smoke or fire as they exit.

If a shift leader is on duty, he/she informs the crew chief of the intention to investigate, and the response proceeds as in (A).

If the area safety warden or alternate is available, he/she informs the crew chief of the intent to investigate, and responds to the alarm with one other person, on a voluntary basis. MCC operations staff will be dispatched to join the investigation. The safety warden and the MCC operations staff will remain in contact with the crew chief via the portable emergency phones.

In rare cases both a counting house shift worker and a safety warden might respond; the crew chief may elect to limit the number of people who enter the hall.

C) No one is in the counting house or the hall when the alarm sounds.

In this case there is presumably no shift leader. The area safety warden and one other person may respond on a voluntary basis, after contacting the crew chief. MCC operations staff will be dispatched to join the investigation. The safety warden and the MCC operations staff will remain in contact with the crew chief via the portable emergency phones.

D) No one is in the MCC when the alarm sounds.

In this case the crew chief coordinates the response in conjunction with the roving guard and the guard stationed at post 2 (“guard shack”).

Appendix M - Elements of Hall B Maintenance for Safety-related Systems

- testing of emergency lights
- testing of power kill switches
- cycling of circuitbreakers
- linear heat sensor test procedure
- sniffer test procedure
- sniffer filter replacement
- vesda test procedure