INVESTIGATION REPORT OF THE FIRE IN THE WIDE BAND LABORATORY AT FERMI NATIONAL ACCELERATOR LABORATORY BATAVIA, ILLINOIS OCTOBER 3, 1987

U.S. DEPARTMENT OF ENERGY

Chicago Operations Office

INVESTIGATION

OF THE

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TABLE OF CONTENTS

I. SCOPE

On October 3, 1987, a fire occurred in the Wide Band Laboratory at Fermi National Accelerator Laboratory (FNAL). It resulted in a property loss of approximately one million dollars, a programmatic delay of several weeks to the continuation of the experiment, and possibly a permanent effect on the research capabilities of the experiment.

As a result of this fire, an investigation committee was appointed (see Appendix A) by the Chicago Operations Office of the U. S. Department of Energy (DOE). The Committee was asked to determine the technical elements in the sequence of events leading to the fire and to evaluate the management systems which should have or could have prevented the occurrence (e.g., the safety or hazard review system or the quality assurance program for safety).

In developing the information contained in this report, the Committee visited the scene of the fire on numerous occasions, interviewed FNAL and E687 personnel, and conducted and/or requested several tests or inspections of equipment related to the fire. The Committee followed the guidance of DOE Order 5484.1 and the DOE Accident Investigation Manual in the conduct of the investigation and preparation of the report.

Concurrent with this investigation, FNAL conducted an internal investigation to determine the cause of the fire and formulate recommendations on design of experimental and fire protection systems. Many of the activities (e.g., component tests and inspections) were performed concurrently with the FNAL Committee, when appropriate, to avoid duplication of effort. The FNAL Committee also contributed by making arrangements for many of the tests and for certain consultant services. The DOE Committee acknowledges and appreciates this cooperation.

II. SUMMARY

On October 3, 1987, at approximately 1:45 a.m., a fire was discovered in the Wide Band Laboratory at the Department of Energy's Fermi National Accelerator Laboratory. At the time, experimenters were in the process of checking out a portion of a detector system. The fire involved four particle detectors: the hadron calorimeter (HC), inner electromagnetic calorimeter (IEC), HxV hodoscope (HxV), and the P4 proportional wire chamber (P4). The cost of the facility and equipment damage, including recovery and cleanup costs, was approximately one million dollars.

An accident investigation committee was formed by DOE-Chicago Operations Office. The Committee concluded that the probable cause of the accident was the misalignment of a ribbon cable connector in the "dynode sum box" of the IEC. This misalignment caused an overcurrent condition in the ribbon cable, which caused the cable to heat and subsequently ignite. The fire in the dynode sum box spread to several cable runs and to the IEC, HxV, and P4 detectors. Five ceiling sprinklers operated; although unable to extinguish the fire, they did prevent it from spreading further. The smoke produced by this fire contained lead (from the IEC) and other contaminants, which required special considerations during recovery.

The Committee determined that that were shortcomings in certain management and physical systems. For example, some attention needs to be devoted to expanding safety reviews of experimental equipment and developing criteria for selection and installation of electrical cables. The overall emergency response was adequate; however, some improvements are warranted in the placement of fire detection equipment and in certain fire fighting systems and procedures. Other findings were identified and specific judgments of needs have been developed.

III. FACTS

A. Site Description

Fermi National Accelerator Laboratory (FNAL) is operated by Universities Research Association, Inc., a consortium of 56 major research-oriented universities under contract with the Department of Energy (DOE). The Laboratory is located on 6,800 acres east of Batavia, Illinois, and conducts high energy physics research. Protons can be accelerated to energies approaching 1000 GeV (one GeV equals one thousand million electron volts) and transported to any of several beam lines (see Figure 1). There are several facilities, such as the Wide Band Laboratory, where experiments are set up for high energy physics research. The Wide Band Laboratory (see Figure 2) is located downstream of the extracted proton beam line. It consists of a) an experimental hall where the beam is delivered and particle detectors are located, and b) a service building containing support systems and "counting rooms" for analyzing and recording data.

The experimental hall is a 50 x 227 ft building constructed of insulated sheet metal walls on unprotected steel beam above grade and reinforced concrete below grade. The roof is a single membrane roof cover over a isocyanurate insulation on a steel deck on steel beams (FM Type I and UL Class A). The floor elevation is approximately 20 ft below grade. (The floor area is sometimes referred to as "the pit".) The distance from the floor to the roof deck is 48.5 ft. There is a catwalk at grade level around the entire interior perimeter. The entire building is served by a gridded hydraulically designed sprinkler system with a design density of 0.16 gpm/ft^2 over the hydraulically most remote 1500 ft^2. The automatic sprinklers are upright Viking Micromatic Model M (thermosensitive glass bulb type) rated at 155°F, and are mounted 1.5 ft below the roof deck. Immediately south of the building and below grade is a beam tunnel, in which the beam is transported from upstream enclosures.

The service building is a 52 x 177 ft one story building located 25 ft east of the experimental hall. It is constructed of insulated metal panels with a roof similar to that of the experimental hall. It is separated into five areas: counting rooms for E687 and E683, a technical area, pump room, and power supply room. Two 12 x 13 ft gas storage rooms ("gas sheds") are located on the east side of the building. They are constructed of hollow concrete block with explosion relief panels in the east walls. The building is provided with automatic sprinkler protection, smoke detection, and automatic halon extinguishing systems.

Between the two buildings is a double labyrinth which allows access between the experimental hall and both counting rooms.

There are also several penetrations for power lines, signal cables, gas lines, etc.

B. Experimental Information

1. Scientific Overview

Experiment E687, "High Energy Photoproduction of States Containing Heavy Quarks and Other Rare Phenomena", is designed to investigate photoproduction of physical states which contain charm and bottom quarks. (To the best of present knowledge, there are six quarks - up, down, strange, charm, bottom, and top.)

The experiment begins at upstream locations where, by means of a multistep process, an 800 GeV proton beam is used to make a high energy electron beam, which is directed toward the Wide Band Laboratory. When this electron beam passes through strips of lead, a high energy photon beam is produced. This beam has a large energy spread, hence the terminology "wide band". The electrons are then swept by a magnet into a beam dump and no longer participate in the experiment. Photons with energies up to approximately 500 GeV proceed to a beryllium target in which charm-anticharm and bottom-antibottom quark pairs are produced by interaction of the photons with the quarks/gluons bound in the nuclei which make up the target. From this production vertex, the reaction products emerge and the detection process begins. Because E687 is a fixed target experiment, all reaction products and their decay products are confined to a relatively narrow cone pointed in the direction of the incident photons.

The objectives of E687 include a) identification and characterization of the particles emerging from the target, b) determination of the cross-sections (a cross-section is a measure of the probability that a specific process will occur) for production of charm-anticharm and bottom-antibottom quark pairs, and c) determination of the rates and sequences (or decay modes) through which these particles ultimately decay into more familiar particles (neutrons, protons, pi mesons, K mesons, muons, and electrons). A strong point of E687 is its ability to identify and analyze a broad spectrum of particles over an extended mass and energy range. E687 is designed to yield data on up to a million charm quark events, with several tens of thousands of charm events fully reconstructed.

2. Participants

E687 is being conducted by an international collaboration of approximately forty scientists from FNAL, University of

Colorado, Northwestern University, University of Illinois, Notre Dame University, University of Milan (Italy), and Frascati National Laboratory (Italy).

3. Functions of E687 Detectors

E687 employs a variety of detectors (see Figure 3) to identify reaction and decay products, measure their energies/momenta, and recognize significant occurrences (such as two or more muons from the production vertex). From such analysis, E687 scientists attempt to determine the sequence from quark-antiquark production to final decay and thus, as completely as possible, reconstruct each event. Immediately after the beryllium production target, silicon strip detectors identify and locate the production of the charm-anticharm and bottom-antibottom states and their decay into "particles" which are to be further studied. Magnets 1 and 2 and wire chambers P0 through P4 bend and track electrically charged reaction and decay products through magnetic fields and thus measure their momenta. Gas Cerenkov counters C1, C2, and C3 are used to identify charged particles (e.g., distinguish pi mesons from K mesons and protons) and to assist in the reconstruction of certain events involving electrically neutral particles which decay into charged particles. The OEC (outer electromagnetic calorimeter) and IEC (inner electromagnetic calorimeter) identify photons, neutral pi mesons, and electrons and determine the energy carried by these reaction/decay products. HxV (horizontal x vertical) is a scintillator hodoscope array which responds rapidly to alert the experiment that something of interest has happened. The HxV signal and other components of E687's master gate logic decide electronically whether the electrical signals from all the other E687 detectors are to be recorded or discarded. The hadron calorimeter (HC) and uranium calorimeter (UC) measure the energy carried by hadronic reaction/decay products such as protons, pi mesons, and K mesons and assist in differentiating them from electrons and muons. Finally, scintillators (MU1 and MU2) adjacent to Muon Filters 1 and 2 detect those high energy electrically charged particles which have traversed all other elements of the E687 system; with few exceptions these particles are muons.

In all cases, the electrical signals produced in the various E687 detectors are transmitted by cable to analysis and recording instruments situated in the (E687) counting room. Some of these signals are amplified or otherwise processed before going to the counting room.

4. Detectors Involved in Fire

The fire principally involved the P4, HxV, IEC, and HC detectors. Under DOE contract DE-AC02-76CH03000, FNAL was responsible for fabrication of P4 and HxV. The University of Colorado, under contracts DE-AC02-81ER40025 and DE-AC02-86ER40253, built the IEC. (FNAL was responsible for construction of the IEC's supporting steel superstructure.) Northwestern University, working under DE-AC02-76ER02289, constructed the HC. Portions of these detectors in their pre-fire configurations are visible in Figures 4, 5, and 6.

P4 is a proportional wire chamber having an active area of 60 x 90 inch. The wires cross the chamber and are attached to circuit boards in the perimeter frame. The chamber is protected by a metal screen and mylar windows on both sides, and is filled with a 65% argon/35% ethane mixture. The gas mixture is delivered via copper tubing from cylinders stored in a gas shed. Flow and pressure instrumentation is provided in the counting room. When a charged particle crosses P4, an electrical signal is produced which is proportional to the amount of ionization produced by the passing particle. By identifying which wires had current, the path of the passing charged particle can be determined.

E687 personnel had experienced minor problems with temperature control of electronic components in P4 and certain other detectors. This heating affected the electronic balance of the detector circuits and in some cases led to improper output. To alleviate this, four large blower fans had been placed on the experimental hall floor. One of these was due west approximately 20 ft and directed at P4.

HxV is a criss-crossed network of NE 102 polyvinyltouluene plastic scintillators (twenty-four 8 x 32 x 0.25 inch scintillators in the horizontal direction; sixteen 8 x 48 x 0.25 inch scintillators in the vertical direction). When a charged particle passes through the scintillator, it produces flashes of light. For each scintillator section, the light is channeled by multiple internal reflections into a photomultiplier tube (PMT), which converts the light into electrical signals. The first element of a PMT is a sensitive surface which emits electrons when struck by light. These electrons are then accelerated by electric fields onto a series of electrodes (called dynodes). At each dynode, the number of electrons participating in the process is increased or "multiplied". The last electrode in a PMT is called the anode. The electrical signal or pulse at the anode is the PMT's final output; however, electrical signals may also be taken at any intermediate dynode. The

PMT's electric fields are created by application of high voltage (typically 2000 V (volts) for HxV and 1200 to 1300 V for the IEC). Proper distribution of high voltage is done by a series of resistors in the base into which the PMT is inserted. In E687, high voltage was provided by LeCroy Model 1440 High Voltage Power Supplies. E687 uses eight such units which are referred to as MF1, MF2, ..., MF8 (MF stands for mainframe).

The IEC contains planes of scintillator strips (largest is 0.3 x 3.2 x 145 cm) and side-by-side lead sheets (precision rolled calcified lead, each 90 by 24 inch). (See Appendix B.) Individual scintillator planes have their strips in horizontal or vertical configurations; these are alternated to provide position and trajectory information. The scintillator strips function as described above for HxV. When a high energy photon or electron traverses the IEC's lead sheets, it produces cascaded showers of electrons and positrons which are detected by the IEC's scintillators. These scintillators are serviced by 626 PMTs. High voltage is provided by MF6, MF7, and MF8. The scintillating material is a plastic consisting of approximately 96% polymethyl methacrylate (PMMA). The IEC is constructed in three modules. The first module (facing the incoming beam) contains 16 scintillator planes, the next two, 36 each. Between the modules are 45° arrays of "tiebreaker" scintillator planes to maximize trajectory definition. The entire IEC assembly contains approximately 2500 lbs of scintillator and 9000 lbs of lead. It is supported by an aluminum framework, which hangs from trolleys on a steel support structure. The entire assembly can be moved out of the beam line for setup or maintenance.

For gain calibration and monitoring, each of the IEC's PMTs employs an americium alpha source (nominally 50 nCi) imbedded in a small "button" of scintillator material affixed to the face of the PMT. As the alphas stop in the scintillator, they produce flashes of light to be processed by the PMT. To provide an appropriate gate signal (an electrical signal which notifies the experiment's analysis electronics that a signal to be processed is coming), an electrical signal from the dynode just prior to the anode is transmitted to the IEC's "dynode sum box"; the PMT's anode signal is the signal to be processed.

The dynode sum box is a multiple chassis system located on the west side of the HC (see Figure 5). All IEC dynode signal cables plug into the exterior panels; the signals are initially summed and amplified by 28 amplifier circuit boards located inside chassis boxes mounted on the side panels. Output from the amplifiers is fed into discriminator boards located in the center of the sum box.

These connections are made with 34-wire ribbon cables which have foam padding for electronic noise suppression. Of the twenty-eight ribbon cables, half are 20 inches long and half are 40 inches. Four power supplies (located just north of the sum box) provide power and bias voltages to the discriminator and amplifier boards. The highest output power supply is a Lambda Model LXS-8-06 (6 V; 70 A (amps) at 40°C and 56 A at 71°C). The final output of the sum box is seven groups of gate signals which are routed to the counting room. For proper system function, each gate signal must precede its associated anode signal by a small but well-defined period of time.

The HC consists of twenty-eight 120 by 82 by 1.75 inch iron plates interspersed with planes of extruded aluminum proportional detector tubes (see Appendix C). The working principle of these tubes is very similar to that of the P4 counters described above; however, their geometry differs significantly. HC proportional counters use a 50% argon/50% ethane mixture. It is delivered from the same gas shed as for P4, through monitoring instruments in the counting room. At the HC there are inlet and exhaust manifolds and flow meters. Monitor tubes are provided near the inlet and exhaust manifolds; these are sensitive to changes in composition, temperature, pressure, and impurities in the gas. Located on top of the HC are its preamplifier circuit boards inside chassis boxes. There are three vertical bundles of cables on the east and west sides which feed into these boxes.

Clearly visible in Figures 4, 5, and 6 is the great amount of RG-58 high voltage and signal cabling used for these detectors. This cable is coaxial; there is a polyethylene filling between the center wire and the braided shield, with a polyvinyl chloride (PVC) outer jacket. For the IEC, a consistent color scheme is followed: red - high voltage, black - anode signal, and green - dynode signal. Much of the cabling is routed through horizontal and vertical cable trays. There are also several vertical bundles hanging freely, i.e., not confined to a cable tray or conduit.

C. Description of the Accident

Shortly before 0100, October 3, the experimental hall was in an open access mode. (It is closed and interlocked during beam-on data taking; however, the accelerator was not operating at the time of the fire.) Scientist A was examining gate logic for the IEC PMTs. This involved observing the arrival of the anode pulses relative to the gates created by the dynode sum box and determining corrections needed to assure proper gating of the anode pulses.

At this time, Scientist A was examining the gate logic associated with a selected subset of PMTs driven by MF6. This involved first going to the dynode sum box (in the experimental hall) and disconnecting certain cables. These include selected dynode signal cables (green RG-58) connected to the exterior panels of the sum box and internal ribbon cables. Disconnecting all but a few cables is a normal procedure employed to isolate selected channels and to simplify gate timing measurements. (In this case, the cables of interest were on the foreground right lower section of the sum box.) (See Figure 5.) Next, he went to the counting room to observe the affected gates (on an oscilloscope) and make appropriate measurements. He then returned to the dynode sum box, reconnected the cables, and went back to the counting room.

Shortly after 0100, he started to examine pulses from PMTs driven by MF7. He noticed that there were "weak or nonexistent" signals coming from these PMTs. Upon investigation, he observed that MF7 was enabled (input power was on, and the unit was ready or "enabled" to receive computer commands) but that the high voltage output was not on. At 0111 (indicated by the computer log) he turned on the high voltage by entering a command on the computer which controls MF7. After this, he observed the anode pulses from MF7 driven PMTs.

Scientist A then resumed his examination of the gate logic associated with MF7 driven PMTs. He observed that gate pulses were being satisfactorily provided by the dynode sum box, but some adjustment in the relative timing of the anode and gate signals was necessary. At about 0115-0120, he went into the pit to disconnect the appropriate dynode and ribbon cables, which were on the foreground right upper section of the dynode sum box. He then proceeded to leave the area and go upstairs to observe the gating signals. As he was walking by the west side of the HC, he noticed an odor which he later described as "sour milk". He continued upstairs to pursue his gate timing examinations.

Scientist A first examined anode pulses and found them satisfactory, indicating proper function of MF7 and its associated PMTs. He then attempted to examine the gates (which should have been coming) from the dynode sum box but observed none. He searched all modules (electronically) and found no gates. He then began to examine various systems in an effort to identify the problem.

During this time (about 0145) Scientist B left the counting room and entered the experimental hall through the southeast labyrinth (see Figure 2). He had been inspecting the experimental area periodically because of a power trip on the west wall outlets experienced a few hours earlier. As he entered the west hallway of the labyrinth, he noticed white smoke and a glow coming from the experimental hall. He proceeded to the east catwalk and observed fire around the southwest corner of the HC. It appeared to him that the overhead lights were out. He returned to the counting room and shouted that there was a "fire in the pit". At this point, Scientist C called the Research Division (RD) Operation Center and then the Laboratory emergency number (3131). Scientist B then went to inform Scientists A and D of the fire. Scientists A, B, and D reentered the pit and observed increased smoke density (breathing was now difficult) and flames visible near the west side of the HC. They returned to the counting room, and all four went outside.

Security personnel arrived at 0150. Scientists B and C entered the gas shed to shut off the gas supplies to the HC and the wire chambers. Scientists C and D then reentered the counting room with a Security guard and shut off high voltage to the wire chambers and the HC. (It was noticed that the HC power supplies had tripped off). Scientists A and B shut off the remaining gas supplies in the gas shed. All four scientists then left the scene while emergency response personnel began their activities (discussed in III.D. below).

After the fire was extinguished and the situation stabilized, the first assessment of the damage was made. (See Figures 7-13.)

The front module of the IEC was totally destroyed. Most of the PMTs from the second module were burned off the top, bottom, and west sides and had fallen into the debris. The third module was damaged similarly to the second one (with some top PMTs remaining), but was still hanging, supported by its east hanger and by aluminum framework on the bottom. The upstream section of the aluminum framework was nearly totally destroyed. The downstream section had its west beams burned off, with some distortion to the remainder. There was also some distortion of the steel support structure.

The HxV counter was nearly totally destroyed. The P4 chamber was severely damaged on its downstream side (and was eventually determined to be non-recoverable). The HC was burned on its south and west sides, resulting in extensive damage to the first two detector planes, and to several of the west interior aluminum proportional tubes. All the HC preamplifier cable on the west side was destroyed, along with the inlet gas system (manifold, connections, and flow meters). Some of the preamplifier boards (on top of the HC) were also damaged. Most of the ribbon cables, multi-wire connectors, and circuit boards in the dynode sum box were destroyed. MF7 was heavily damaged by fire and distorted by the weight of burning cables that had fallen on it. Several auxiliary items were affected (circuit, boards, conduit, connectors, etc). The C3 Cerenkov counter appeared to be only slightly damaged.

Most of the cabling near these detectors was destroyed. Virtually all of the vertical cable runs were consumed. The vertical cable tray (near the northwest corner of the IEC) had warped and fallen into the debris.

The dense smoke created during the fire resulted in heavy soot deposits on the interior surfaces of the building. There was also some heat discoloration of the ceiling over the fire area. Sprinkler discharge water had collected on the floor; deposition of combustion products in this water resulted in contamination of soil when this water was pumped out (see III.E. below). There was no smoke or heat damage inside the service building, due to effective sealing in the cable penetrations and the closing mechanisms on the east labyrinth fire doors.

D. Emergency Response

The emergency response was initiated by a phone call from Scientist C. He had originally called the RD Operation Center but was told to call the Communications Center using the 3131 emergency line. At 0148, the Communications Operator (CO) issued an all-channel page tone and then verbally informed emergency response personnel of the fire. A Security officer responded to the Wide Band Laboratory and confirmed the fire report at 0150. Another Officer arrived at 0152 and observed smoke coming from the building.

Five members of the FFD were on duty that night, a shift captain and four fire fighters. The shift lieutenant was off duty that day and one fire fighter was acting as the shift lieutenant. At 0150 the entire shift responded with two engines and a squad vehicle and arrived at 0153.

When the first Security officer had arrived, the E687 scientists were securing gas supplies as discussed in III.C. above. He accompanied them to the counting room, where they shut down certain power supplies. The scientists were then directed to evacuate the area. Two operators from RD Site Operations had also arrived by this time. One of their actions was to go into the power supply room and shut off power to the magnets in the beam line. As the FFD arrived, the fire alarm for the building was activated by operation of a sprinkler water flow alarm. (This alarm was announced by the CO at 0154.) The CO called the Emergency Coordinator (at home) at 0157 to inform him of the fire. At 0200 the FFD shift captain asked the CO to request an engine from the Batavia Fire Department (BFD), under the mutual assistance plan. The CO relayed this request to the Tri-Com dispatch, and the BFD engine arrived at 0217.

Throughout the emergency response, communication between the FFD and the CO was through the use of hand-held radios. Numerous malfunctions were experienced with these radios during the night. Also, the radios are not provided with the capability to operate on the "fire scene" frequency, which is used by the mutual assistance fire departments.

The shift captain, two fire fighters, and one RD operator attempted to gain access to the experimental hall. The fire fighters in turnout equipment (bunker coat, helmet, gloves, boots, etc.) and the operator in street clothes entered the southeast labyrinth. All these personnel were using self-contained breathing apparatus (SCBA). (The operator was certified for use of SCBA equipment.) They immediately encountered heavy black smoke. They continued about 20 ft into the labyrinth (see Figure 2) and could feel the heat of the fire. The smoke was so thick that hand-held lights could only be seen when held to the face plate of the SCBA mask. At this point they decided to withdraw.

One of the FFD engines had proceeded to the north end of the building to hook up to the sprinkler system fire department connection. The fire fighter assigned to this task had to don his SCBA due to the amount of smoke being emitted from an exhaust louver located immediately over the fire department connection. This task was completed at 0211.

FFD firemen and an RD operator proceeded to the north side of the building where a standard personnel door and large overhead rollup door are located. The fire fighters entered the building after the north personnel door was pried open since the key was not readily available. Inside this door, the smoke and heat appeared to be as intense as at the counting room entry maze. The rollup door was opened and the PVC strips (used to reduce heating losses when the door was open) were secured to the sides of the door frame.

The smoke emanating at this time was still black and heavy. The RD operator and one fire fighter then proceeded to open all other doors in the exterior wall of the experimental hall to further ventilate the building. The CO again called the Emergency Coordinator, who indicated he would respond to the fire scene. The CO later began to call personnel on the Wide Band Laboratory emergency notification list.

The scientists who were initially in the building discussed locations of equipment with emergency personnel. They noticed that a car normally used by the Italian E687 scientists was still located in the parking area east of the building. They went to the Operation Center, where they made several telephone calls in an attempt to locate an Italian scientist who was in the experimental hall earlier that evening. Several calls were also made to other E687 personnel to inform them of the fire.

After the rollup door was opened the FFD attempted to gain access to the fire from the north side of the building. Inside this doorway, equipment racks stored there made maneuvering difficult due to the poor visibility. The entry was made with two charged 1-1/2 inch fire hoses. Since there was some concern that the UC might be involved in the fire, a radiation safety technician was stationed to monitor the fire fighters as they exited the building.

The CO called the FFD Chief (at home) who requested that all off duty FFD fire fighters be called back (0226). At this time the BFD Chief requested his department to send a rescue squad vehicle and the Assistant Chief to the scene. As with other mutual assistance responses, arrangements were made for escort by FNAL Security.

The FFD fire fighters attempted another entry from the rollup door to assess what experimental equipment was involved in the still active fire. They proceeded on the west catwalk as far as the first building support column but were forced back because of the thick smoke and heat. On this entry (as with all other entries) they advanced a 1-1/2 inch hose and had another standing by at the rollup door. The FFD requested that Operations send someone familiar with the beam line as soon as possible to further assist in their attempt to understand if the fire involved the UC. The Emergency Coordinator arrived at about 0230 and took charge of the activities.

At 0233 the FFD requested that the electrical power be shut off. The CO contacted the duty electrician, who arrived at the fire scene at 0239 and proceeded to shut off electrical panels located in the electrical room at the south end of the service building. He was then instructed to shut off all power to the experimental hall, which was accomplished at 0249.

The FFD made another entry to determine which equipment was involved in the fire. This time they crawled along the west catwalk for about 75 ft until they ran into an obstacle, which later proved to be a ladder cage. They withdrew at this point. The visibility was still very poor.

The BFD ladder truck arrived at about 0245 and was positioned at the north end of the building. One FFD fire fighter and several BFD fire fighters attempted without success to ventilate the roof by opening an access hatch at the southwest area of the roof. Due to the weather conditions the roof was very slippery due to a frost coating. The fire fighters then began to cut two holes in the hatch which would allow smoke and hot gases to escape. This effort was hampered by roofing insulation material which gummed up the saw as it cut through. The cutting task proceeded slowly and required the use of five saw blades. It was completed at about 0330.

While the roof was being ventilated, the West Chicago Fire Department air cascade vehicle arrived at the fire scene and was used to recharge breathing air bottles. At 0300 the FFD Chief arrived on the site. He noticed heavy white smoke emanating from the north rollup door as well as the other open doors. The roof ventilation had not yet been completed when he arrived.

At 0317 the Marywood Fire Department was requested to occupy the FFD fire station to provide coverage for additional fire calls. (They arrived at about 0330.) FFD off duty fire fighters began to respond to the fire station to provide additional staffing. The BFD Chief also requested additional manpower, which arrived at 0340.

RD operators and E687 scientists reported to the north rollup door with an equipment layout of the facility, to assist the FFD in determining exactly what was involved in the fire. The FFD was also informed of the missing Italian scientist. The visibility within the experimental hall had improved somewhat but the source of the fire could not be determined from the outside. Fire fighters made another entry along the west catwalk, counting building columns as they passed them to determine the location of the fire. By comparison with the equipment layout, they were able to identify the approximate location of the fire. They withdrew and discussed this information with the scientists and RD operators, who then indicated that the UC was probably not involved.

At 0346 a smoke detector alarm was received from a residence in the FNAL "village" area. A Security officer was dispatched to investigate this alarm. The officer stood by until an off shift fire fighter (who was responding to the call back) arrived, investigated the alarm, and cleared it.

The fire fighters had now ascertained that the fire was located in the area of the IEC and HC, but did not involve the UC. Visibility was steadily improving due to the smoke and heat vent cut in the roof. Another entry was made to review the location of the fire. This entry included an RD operator, who was wearing SCBA and street clothes.

At 0358, the FFD attempted to extinguish the fire from the west catwalk but was unable to do so due to material shielding the active fire from the hose stream. They decided to attack the fire from the floor. One FFD crew advanced a 1-1/2 inch hose along the west catwalk to a point opposite the fire and then dropped the hose to the floor below. A BFD crew proceeded down the north stairs where a 1-1/2 inch hose was dropped and advanced. The two forces met in the area of the remaining fire where the BFD crew extinguished it. The sprinklers, which had been operating continuously, were then disabled. An RD operator called the Operation Center at 0425 and reported that the fire had been extinguished.

The FFD fire fighters began a personnel search of the experimental hall since the Italian scientist had still not been located. It was suggested that if someone had been in the building they may have attempted to extinguish the fire by using a hand fire extinguisher and become overcome by fumes. The fire extinguishers located in the experimental hall were inspected; all were present and none had been operated. The building electrical power was restored after the duty electrician had opened circuit breakers in the experimental area (to limit the power distribution). When power was restored (0545) the building lights operated, as well as the large fans on the experimental hall floor. A second search of the hall was conducted, including the beam tunnel, in an effort to assure that no personnel were in this area. It was not until 0600 that the Italian scientist was finally located; he had been off site during the fire.

The mutual assistance fire departments returned to their stations. The FFD Chief requested that a photographer report to the site to begin initial photographs of the accident scene. The FFD Deputy Chief roped off an area around the fire scene inside the hall. Control of the fire scene was turned over to RD at 0526.

E. Recovery

Power was restored to the building at about 0545. (Power was restricted from systems suspected of being damaged.) About 5 inches of water had accumulated on the floor due to sprinkler operation with the sump pumps inoperative (the power had been off). Five sprinkler heads (located at ceiling level) had activated (see IV.G.). The drains were cleared and the sump pumps restarted. Contamination surveys and sampling were initiated. The entire building was secured to control personnel entry. However, prior to this, there was at least one uncontrolled personnel entry without proper protective equipment. Security personnel were posted to maintain access control.

On Monday, October 5, more controlled entries were made. Electrical panels and distributions were inspected in detail. The status of the overhead cranes was evaluated. (Some problems due to soot contamination of electrical supply buses were observed; these were corrected later.) Contamination surveys were continued, which eventually included radiological (americium sources) and non-radiological (lead and organics) contaminants both inside the building and in the surrounding environment. One spot of slight americium contamination near the debris pile was identified and cleaned up. The soot deposited throughout the building contained low levels of lead.

However, there was no significant personnel contamination from any of these materials. Experimental equipment was inspected to determine needs for cleanup or corrective actions. A control perimeter had been established around the immediate area of fire location.

On October 5, the Committee conducted its initial inspections and discussions with personnel responsible for operational and experimental control of the area. This included the FNAL Mechanical Engineer associated with E687, the RD Safety Engineer, and one of the E687 co-spokesmen. Decisions were reached on areas and equipment to be controlled, items to be removed for cleanup or testing, personnel allowed to enter the experimental hall, protective clothing requirements, etc. In this and in all subsequent activities, these personnel and other Laboratory and experimental staff were very helpful in controlling the site, cooperating with the Committee, and rendering valuable assistance and advice. This contributed greatly to the recovery and investigation activities.

During the remainder of the week of October 5-9, the Committee primarily conducted interviews of personnel (discussed below). The fire scene was not disturbed; however, some cleanup activities were conducted outside this area, including inspection and cleaning of certain E687 equipment. Also during this week the open sprinkler heads were replaced and the system to be in good working order. The UC was inspected; no significant damage was observed. Overall, it appears that the beam line setup can be reestablished, with the exception of the IEC. Options include leaving this space vacant, inserting an array of lead to simulate the previous effect on the beam, or partial or total rebuilding of an IEC. The last option would require funding of about a half million dollars and would take about a year to complete.

During the week of October 19-23, the interior of the building (outside the immediate fire area) was extensively cleaned by a subcontractor. This cleaning included floors, walls, the ceiling, and other surfaces. The immediate fire location was cleaned by FNAL personnel. After these activities, there was no longer a continuing need for protective clothing. Overall the building is now in fairly good shape and shows little evidence of the fire.

The burned debris contains both americium (from the IEC's PMTs) and lead (from the modules) contamination. It is classified as mixed waste and will be disposed of accordingly. Also, the wires inside P4 contain beryllium; these will also require special precautions for disposal. The water collected during the building cleanup (about 7000 gallons) has been saved for proper disposal by a commercial service.

F. Management Systems and Services

Safety at FNAL is considered a line management responsibility. RD is the line organization responsible for operations at the Wide Band Laboratory, including the experiments performed there. The RD Safety Group is responsible for assuring that all RD facilities and operations conform to FNAL and RD safety policies and standards. The Group consists of a staff of safety professionals who cover all areas of safety and certain aspects of fire protection. They perform regular reviews and inspections within RD. The RD safety organization and program are documented in the RD Safety Manual.

In addition to the line safety activities of RD, there is an overview function carried out by the Safety Section. This organization is independent of FNAL operating units; it is responsible for developing policy and conducting reviews, audits, etc. of safety and fire protection activities throughout FNAL. Its organization and program are documented in the FNAL Safety Manual.

For design of fire protection systems, RD utilizes the services of a fire protection engineer who is part of the Business Services Section. FFD provides fire prevention inspections, fire alarm testing, fire fighting, and administration of the cutting and welding permit program. These activities are all subject to review by the Safety Section's fire protection engineer.

FFD staffing during normal daytime hours consists of the Chief, Deputy Chief, Fire Inspector, and shift personnel. Each shift normally consists of a captain, a lieutenant, and four fire fighters. The minimum off-hours shift staffing level is five personnel. If necessary, off-duty fire fighters are assigned on overtime to maintain this level.

FNAL has mutual fire protection assistance contracts with six surrounding fire districts (Aurora, North Aurora, Marywood, Batavia, Warrenville, and West Chicago). The shift captain has the authority to request assistance from any of these districts through the agreements. Requests are normally made through the FNAL Communications Center.

G. Environmental Considerations

1. Water and Soil

The chief environmental concerns were the presence of lead and organics resulting from the fire. Some of this contamination came in contact with sprinkler discharge water. The experimental hall has floor sumps (with pumps in each) at the northwest and southwest corners of the building. When the fire was extinguished, the sump pumps were not working (since the power had been turned off earlier) and there was about 5 inches of water on the floor. When building power was restored, the sump pumps were turned on and water was pumped out through the discharge pipes at the northwest and southwest corners of the building onto the ground. An initial sample of water was taken from the puddle at the northwest corner and showed a lead concentration of 2.1 mg/L. A later sample was taken from the puddle outside the southwest corner and showed a lead concentration of 0.4 mg/L. (The first sample is considered more representative since it was taken during actual discharge.) However, none of this water was discharged to a waterway, ditch, or to offsite; therefore, discharge limits to general use water do not apply.

The area which contained the contaminated water has been clearly identified. Soil samples taken in this area show gross concentrations up to 218 ppm of lead; the normal level in the general area is 20-25 ppm. No americium was detected. The remaining question is whether the soil qualifies as hazardous waste under 40 CFR 261.3. If the material exhibits the characteristic of EP (extraction procedure) toxicity as defined in 40 CFR 261.24 (i.e., if the extract from the sample contains greater than 5.0 mg/L of lead), then the soil must be transferred to an approved hazardous waste disposal site. The soil samples mentioned above were tested under the EP toxicity criteria for lead and exhibited no greater than 0.1 mg/L.

Samples taken for lead were also submitted for organic analysis. The results, which indicated the presence of trace amounts of organics, were invalidated when it was discovered that the samples had been taken and stored according to the procedures for lead only, not organics. With respect to organics, weather and soil conditions are not suitable for representative subsurface sampling at this time. At the earliest opportunity, the area will be sampled again and analyzed for organics. If indicated, appropriate remedial action will be taken.

2. Air

The wind at the time of the fire was out of the northwest. The site boundary to the southeast is approximately two miles away. A preliminary plume diffusion model calculation assuming a 250 g lead release showed a site boundary concentration for lead of 0.2 ug/m^3. For this calculation, it was assumed that the discharge took place over 120 minutes. (The actual time was probably closer to 40 minutes.)

The Environmental Protection Agency AIRDOS model was applied, taking into consideration smoke exit temperature, stack height, plume rise, and an estimated release (based on actual sampling after the fire) of approximately 450 g of lead. The concentration at the site boundary was approximated at 436 pg/m^3, time weighted averaged over one calendar quarter.

The State occupational standard for lead is 50 ug/m^3; the ambient air quality standard (applicable to the general public) is 1.5 ug/m^3, time weighted averaged over one calendar quarter. Accordingly, the potential releases from the fire were well within the acceptable limit. Moreover it can confidently be stated that no adverse environmental impact resulted off site from the fire. The same statements can be applied to the FNAL "village" area, which contains residential housing for long-term experimenters and their families. (This area is actually on site but is considered "off site" for environmental purposes.) It is close to the site boundary, and the majority of the smoke plume from the fire passed to the south.

Certain personnel who had been involved with the fire were sampled for possible uptake of lead or americium. No personnel were observed to have levels in excess of the normal ranges.

IV. ANALYSIS

A. Accident Site Evaluation

Due to the extensive damage caused by the fire, the Committee retained two consultants to assist in these evaluations. One is from a DOE national laboratory and has conducted research on cable fires and fire development; the other is a local fire marshall who has conducted many fire investigations to determine their origins. The fire scene had been extensively photographed immediately after the fire to document the location of equipment which was present at the time of the fire. The Committee, with the two consultants, began their evaluations with a brief tour of the site and discussion of the prefire conditions. Information on the materials used for construction of the detectors as well as gas and cable systems was made available. It was necessary to conduct an extensive disassembly of the debris pile in an attempt to determine the origin of the fire. Activities were videotaped and significant items were photographed to document the conditions of any evidence which might be disturbed.

C3 was rolled aside since it had apparently only suffered water damage from sprinkler and hand hose discharge. P4 was removed using the overhead crane. It had significant damage on the downstream face, but little upstream. This supported a theory that the fire (and its source) had occurred only downstream of this detector. It had been originally thought that the damage to P4 could easily be repaired by rewiring and installing new mylar windows and gaskets. However, after removal and disassembly, the main circuit boards were observed to be extensively damaged, which will necessitate a major refabrication effort. An interesting observation was that in spite of the damage to HxV (immediately downstream of P4) the ribbon cables from the P4 preamplifier boards were hardly damaged (see Figure 14).

The HxV detector was nearly totally destroyed. Almost all of the plastic scintillator material was consumed. The burn pattern was "U" shaped with slightly more damage on the west side than the east (see Figure 15). The downstream side was completely charred while the upstream side still had some intumescent paint undamaged. This reinforced the theory that the fire and source were further downstream. The remnants of HxV were removed in two pieces to gain access to the IEC, which suffered the bulk of the fire damage.

The third module of the IEC was partially resting on a downstream aluminum frame member and hanging from its east hanger (see Figures 16 and 17). Since it was estimated to weigh about 2 tons, great care was taken not to disturb it without adequate preparation. It was lifted out using the overhead crane and innovative rigging. The damage was found to be extensive on the west and bottom sides, with most of the PMTs and scintillator light guides burned off. The top received somewhat less severe damage. The east side of this module was undamaged and still had most of its PMTs and cables intact. (See Figure 18.) Thus, there was comparatively little fire on the east side of this module. A partial disassembly indicated that the majority of the internal scintillator material had remained unburned, apparently protected from heat by the lead sheets.

The east half of the downstream tiebreaker was hanging from the aluminum support structure. It was removed and examined. A damage pattern similar to that of the third module was observed.

The steel support structure which supported the IEC and P4 was then removed to allow access to the remaining portions of the IEC. Some distortion of these members was observed, indicating exposure to intense heat. With the support structure removed, the IEC's second module (which had fallen into the debris pile) was removed and examined. This module was somewhat more damaged than the third module. The damage was also along the west, bottom and top, with more damage along the west and bottom. The east side PMTs were still attached and appeared to be only slightly damaged. As with the third module, the damage to the internal scintillator material was minimal. The upstream tiebreaker was then removed. It was extensively damaged with only some of its the aluminum sheeting remaining.

The only remaining portion of the first module was the east row of PMTs. The remainder of this module was completely destroyed with nothing but melted lead and the charred remains of the PMMA, PMTs, and bases in the rubble pile (see Figures 16 and 19).

The bulk of the remaining debris was removed using shovels and by hand. The personnel involved wore respirators and protective clothing. The debris was continually wet down to reduce the amount of dust generated when material was removed. As the cables were removed a "V" burn pattern was observed on the top southwest concrete block supporting the HC and on the west side of MF7 (see Figure 20). This pattern initially suggested that the fire originated in or near MF7. This unit (MF7) was then carefully removed from the cable debris and set aside for further analysis (see IV.B.1). The 220 V outlet box for MF7 was found and set aside for further examination. The bulk of the cable was removed. It was noted that the damage to the RG-58 cables on the west side was extensive with most of them completely destroyed; only the metallic portions remained.

When the cable remnants were removed, the remaining debris was a mixture of unburned PMMA, melted lead and aluminum, and the remnants of PMTs and bases. When the last remnants were being removed, a plastic alcohol bottle was discovered which had suffered little visible damage (in spite of the intense fire). The bottle still contained some alcohol, which is used to clean the surfaces of the PMTs when they are replaced. However, the evidence did not indicate that the alcohol contributed to the ignition or propagation of the fire.

The examination then focused on the cable trays attached to the west side of the HC, as well as the dynode sum box and its associated cables. The cables in the horizontal trays were extensively damaged (see Figures 21 and 22), but for the most part, not as severely as the vertical runs. The dynode sum box was also badly damaged and was removed for further examination (see IV.B.5.). Most of the cables on the north side of the sum box were undamaged, while most of those on the south side were burned. This also suggested a fire origin near MF7.

The conclusions drawn from this examination were that the bulk of the fire damage was attributed to combustion of the cable (especially where there were long vertical runs) and the PMMA in the IEC (especially the first module). The origin of the fire was probably not upstream of MF7. The amount of fuel that the cable and PMMA provided was too large for the overhead sprinklers to extinguish, but the sprinkler discharge did prevent the further spread of fire beyond the immediate fire area. If there had not been an active sprinkler system, there would have been extensive damage to the experimental hall and its contents (see G.1.).

B. <u>Component Inspections</u>

Certain components involved in the fire were removed for specific inspection and analysis. The Committee retained a forensic engineer with electronic fire experience to assist in certain of these inspections. The results are summarized below.

1. MF7 was disassembled and examined in detail. The forensic engineer and two manufacturer's representatives were present during the process. All modules and high voltage cards were inspected and photographed.

   Extensive damage was observed both outside (see Figure 23) and inside the unit. The examination indicated that the damage was caused by external heat and mechanical stress. No evidence of internal failure that would have implicated MF7 as a source of the fire was observed.

2. Four circuit breakers were removed from wall panel boxes for inspection. The affected circuits were the three 220 V,

20 A supplies to MF6, MF7, and MF8, and the 110 V, 20 A supply which powered the dynode sum box. The circuit breakers were analyzed by the forensic engineer using x-rays, current testing, and visual inspection. All breakers were in good working order with no evidence of internal damage. One apparently minor problem was observed: the 110 V breaker was in the closed position, in spite of the red "trip" flag showing.

3. The 16 A main switch/circuit breaker and the two varistor switches (one from each 30 V supply module) were removed from MF7 and similarly analyzed. No problems were observed with these items. The 16 A breaker was in the closed position (it had not tripped) even though it had been exposed to sufficient heat to melt the plastic.

4. The 220 V outlet box which supplied MF7, its supply wiring, and the female connector (used at the MF7 end of the line cord) was taken to Argonne National Laboratory (ANL) for analysis by their Materials and Components Technology Division's Failure Analysis Laboratory. No evidence was observed of significant pre-fire arcing which might have heated the outlet and/or wiring.

5. The dynode sum box was analyzed in detail. The central discriminator boards were badly burned with a damage pattern

radiating from the center (see Figure 24). There was a hole completely burned through both panels on the south side, with the exterior panel being burned more (larger hole) than the interior (see Figure 25). This damage was apparently due to burning dynode signal cables and large amounts of cable fallen from vertical runs. Most of the RG-58 cables on the south side were destroyed, while those on the north side were, for the most part, not burned below the level of the top of the panel. (See Figure 13.) All but a small portion of the foamed ribbon cable was destroyed. The amplifier circuit boards and their connectors exhibited varying degrees of destruction.

Each ribbon cable (which contains 34 wires) is connected to amplifier and discriminator boards using 34-pin connectors. The male connectors are mounted on the circuit boards and have protective "walls" on three of the four sides around the connecting pins (i.e. the pins are not fully shrouded). This connector is designed to be mounted on the side of a circuit board (with the pins flush with an edge) so that the board forms the fourth protective wall. In the dynode sum box they were mounted on the edges of the boards, thus exposing one side of the pins. Also, neither the male nor female connectors have alignment keys. As a result, the female connector can be misregistered such that only one row (i.e., 17 pins) is engaged. (This is demonstrated in Figures 26a and 26b.)

Most of the wires in each ribbon cable conducted signals which the sum box processed. (There is virtually no power carried by these signals.) However, certain wires distributed power from the Lambda and one other power supply to the amplifier boards. If a connector is misregistered as described above, 5 V input power from the Lambda would have shorted to ground through the amplifier board. Since there was no fusing or current limitation (at the circuit boards or at the power supplies), 10 to 50 amps could be flowing through wires rated at less than one amp.

Attention focused on the 34-pin connectors that were handled immediately prior to the fire (see Figure 27). One of the connectors appeared to have been misregistered (see Figure 28). No plastic was observed on one side of the male pins, suggesting that the female connector was not properly in place on this side. Three amplifier boards (with their connectors) were removed and analyzed by the forensic engineer using x-ray and visual observation. This analysis strengthened the suspicion that the one connector had been misregistered. This connector (and the board on which it was mounted) was taken to ANL for further analysis. External and cross-section inspections of the connector indicated that it was in fact misregistered prior to the fire. (See Figures 29a and 29b.)

C. Selected Tests

1. Burning Odor Tests

Shortly before the fire, Scientist A had smelled an odor which he described as "sour milk" as he was leaving the dynode sum box. Tests were performed in which several materials were separately burned in Scientist A's presence to see if any of the burning odors were similar to that which he had smelled earlier. The materials were those that could have been involved in the origin of the fire, and included RG-58 cable, a LeCroy line cord, bakelite (as used in the 220 V outlet), a polyester capacitor (as used in MF7), G-10 circuit board material, and a foamed ribbon cable (as used in the dynode sum box).

When testing the ribbon cable, the foam burned first and its odor did not seem similar to the "sour milk." However, when the insulation on the wires burned, he described the combined foam/insulation odor as a "definite possibility". The burning line cord insulation was also described as a possibility. However, the other odors were not similar.

2. Electrical Tests

The Committee was assisted by an FNAL electronic engineer for many electrical/electronic tests and analyses.

a) Electrical tests were conducted with a LeCroy Model 1440 power supply which was not involved in the fire. The unit was set to provide high voltage and its output was shorted in ways that simulated faults in a PMT base or high voltage cable. In each case, a sustained electrical arc could easily be created. However, in these tests, no heating, smoking, ignition, or even visible damage of cable insulator was observed. When directly shorted, as well as when arcing occurred, the power supply automatically reduced its voltage (as designed) so that its current output was limited.

b) Current at low voltage was applied to the same type of line cord as used for actual LeCroy units. (The LeCroy input is through a 16 A circuit breaker; the experimental hall's supply circuits for these units had 20 A breakers.) The line cord was shorted at one end for these tests. No emission of fumes or other evidence of burning was observed until 50 A was exceeded.

c) A LeCroy power supply was turned on to supply high voltage. The line cord plug was pulled in and out a few times; no arcing was observed. The plug was left barely connected for several minutes; no arcing or heating was observed.

3. Fire Tests of Specific Components

Tests were conducted on ribbon cable and circuit boards which were duplicates of the type used in the dynode sum box. Power was applied directly to intentionally shorted wires in isolated strips of ribbon cable, and to ribbon cable with typical sum box circuit boards attached. These boards were shorted in ways in which faults (e.g. misregistering of connectors) could plausibly have occurred prior to the fire on October 3. In this configuration (i.e., with the connector misregistered), and at voltages typically used in the sum box (approximately 5 V), emission of fumes was seen at 5 to 10 A within times varying between three and ten minutes. Actual flame (burning insulation) was observed at currents as low as 8 A.

4. Fire Test of Major System Mockup

Much of the analysis suggested that the fire originated in the dynode sum box, being propagated by cables on the side of the HC, and eventually to the IEC and other components. To examine this scenario in detail, a full scale fire test was conducted at the Lawrence Livermore National Laboratory (LLNL), under the direction of the fire research consultant who had assisted in inspections of the actual fire scene. The test involved a full scale mockup consisting of a) three horizontal cable trays mounted on a solid surface simulating the west side of the HC, b) several vertical cable runs (including a large vertical cable tray near where the IEC would be) and c) a simulation of the dynode sum box, with a methane gas flame system used to simulate the original fire. The cable trays were filled with a fraction of the RG-58 cables actually used in E687. Simulation of the burning foamed ribbon cable in the sum box was determined by first burning a sample of the cable and measuring time, temperature, and heat delivery rates. This information was then used to provide the proper methane delivery rate for the gas flame used in the test.

The test was initiated by first igniting the gas burner. The heat ignited the lower cable tray; the fire advanced to the second and then to the upper cable trays. The fire advanced rapidly in the vertical cable run immediately above the sum box location; this cable was eventually totally consumed. The fire advanced more slowly in the horizontal cable trays, but eventually did spread to the large vertical cable tray. Once this vertical cable began to burn, it spread rapidly to the top of the tray. After a short time, cables fell from the tray in bundles, spreading the fire to the lower portion of the tray (which had not been previously burning).

This test strongly supports a scenario in which the fire originates in the dynode sum box, spreads to the horizontal cable trays on the HC, then to the vertical cable tray and vertical bundles on the IEC; fallen burning cables then ignite other cables and lower portions of the IEC.

D. Interviews & Discussions

Many persons were formally interviewed in an effort to understand the accident and the events and conditions preceding it. In addition, many informal discussions were held for clarification of specific points. Formal interviews were tape recorded so that Committee members could review key elements of testimony. Certain discussions at the fire scene were video taped to provide visual and aural recall capability. The principal interviews and discussions involved the following groups:

- E687 Scientists - to understand conditions and events prior to and during the fire. They were also the major source of information for details concerning the experimental equipment.

- Safety personnel - for information on prior safety reviews and safety/environmental requirements during recovery.

- Operational support personnel - those familiar with the engineering aspects of E687, and RD personnel who responded to the fire.

- Emergency response personnel - to understand actions and decisions made during the emergency phase. This includes the Emergency Coordinator and FFD personnel.

Much of the information gained from interviews and discussions was used in analyzing the observations and developing probable scenarios. Pertinent statements are discussed (usually in narrative form) in the appropriate sections in this report.

E. Possible Scenarios

Potential fire sources in the area of the fire damage are the dynode sum box, the MF7 line cord and connectors, the PMT bases, a gas leak with an ignition source, and MF7 itself. Also, deliberate or inadvertent human intervention was considered.

1. Dynode Sum Box

A short in a circuit board could overload the ribbon cables to the point that the resultant overheating would ignite the insulation on the cables (including the foam). This could result from a fault in a circuit board or the misregistering of a ribbon cable connector with an amplifier board such that only one row of pins was engaged. When this occurs, the 5 V input power from the Lambda power supply is shorted to ground through the amplifier board, resulting in high current (there is no fusing or other current limitation) flowing through certain wires in the cable. Tests confirmed that such overloading would initiate combustion of the insulation and foam padding. Also, Scientist A identified the odor from burning ribbon cable (in post-fire tests) as "a definite possibility" for the "sour milk" odor noticed just prior to the fire. Upon post-fire inspection, one of the connectors which had been reconnected shortly before the fire did appear to have been misregistered.

2. MF7

A fault could occur inside MF7 resulting in an internal fire. There is sufficient fuel inside the unit (in circuit boards and components) to result in a fire hot enough to propagate to the outside of the unit, thereby igniting the high voltage cables. MF7 was initially suspect because of its obvious heat damage and its location at the base of a significant portion of the fire. Also, a "V" burn pattern was observed with the vertex near the unit. However, the disassembly and inspection of the internal components of MF7 and observation of fire patterns indicated that the damage to this unit was due to external forces. Thus it does not appear that MF7 is a cause of the fire. Also, anode signals from PMTs driven by MF7 were observed even up to the first report of the fire, indicating that MF7 was working properly at that time.

3. <u>MF7 Line Cord and Connectors</u>

The MF7 line cord (which carries about 2500 watts) could have poor contact where it connects to the power supply or where it connects to the outlet, resulting in overheating of the connector or cable with ignition resulting. (There have been problems in the past with loose connectors which have necessitated securing them with tie wraps.) Another possibility is an electrical short which could cause insulation or a connector to burn. Scientist A reported that the smell of this burning insulation was similar to the "sour milk" odor. However, the ANL and other inspections did not reveal any evidence to support this scenario. Also, a continuing short would imply failure of a building circuit breaker, but the one that served MF7 operated properly when tested.

4. Photomultiplier Tube Base

Arcing inside a PMT base could possibly provide the spark needed to ignite a fire. Tests confirmed that such an arc was very easy to produce. Only a slight counter rotation of two adjacent disks in the tube base resulted in a high voltage lead in close proximity to a ground connection, resulting in an arc. Tests show that this does not result in heating or ignition of insulation. However, it might ignite gas (see 5. below).

Another consideration is that such a short in a tube base could result in high voltage being applied to its dynode cable, resulting in a high voltage "spike" to an amplifier board in the the dynode sum box. This could then cause a failure on the board, resulting in a short circuit overloading the dynode cables as discussed above. However, this is considered improbable due to the input dynode protective circuit (at the sum box), which consists of a resistor/diode circuit to ground. Any input high voltage spikes should be dissipated before they could affect the amplifier board. Even if a high voltage short circuit did occur through a dynode cable, the main frame power supply is designed to reduce its output, as discussed above.

5. Gas Leaks

It is possible that flammable gas could leak in sufficient concentration to be a fuel if coupled with an ignition source. The HC circulated a gas mixture of 50% argon and 50% ethane through each of its 28 detector planes. P4 used a mixture of 65% argon and 35% ethane. The probability of gas accumulation in sufficient concentration to support ignition was considered low since large fans were used to circulate air and cool certain electronic components. One of the fans was directed at P4. Although there was no specific gas leak detection system, there was no indication on the gas instrumentation for the HC or P4 of a leak in these systems, nor was there personnel observation of a leak.

6. Human Intervention

The Committee pursued this possibility through interviews with personnel and inspection of the debris. The "V" pattern near MF7 suggested the possibility of an ignition source in this area. However, no evidence of foreign devices or accelerants was found. There was no indication of personnel dissension, pranks, or irrational behavior.

F. Management Systems and Services

The RD performs regular safety and fire protection reviews of facilities such as of the Wide Band Laboratory. However, these reviews seldom deal with research equipment which is unique to a particular experiment. In particular, RD reviews are not of the kind that would have recognized problems with E687 equipment, e.g., no limitation on power delivered to the dynode sum box, ease with which connectors can be misregistered, and proximity of LeCroy power supplies and the dynode sum box to long vertical cable runs. Such reviews are the responsibility of scientists participating in the experiment. Similarly, participating scientists are responsible for providing information on equipment to incoming experimenters (e.g. postdoctoral scientists and graduate students). In the case of the dynode sum box, it appears that personnel were working with a system which had inherent safety flaws that had not been fully identified. For example, some personnel who worked with the system were not aware that the ribbon cables carried power. These flaws probably would not have been identified by the existing safety review program.

RD personnel do conduct a Preliminary Safety Review prior to an experiment being set up. The Preliminary Safety Review for E687 was conducted on July 29, 1983. They also conduct periodic flammable gas and radiation safety reviews. In the case of E687, a flammable gas review was conducted on June 7, 1987. If an FNAL engineering standard dealing with current limitation had been available for implementation in a safety review process, this fire might have been prevented. It is recognized that implementation of such a standard would involve a significant effort. However, it would serve to reduce the risks inherent in electronic systems. The complexity of the situation is recognized; however, implementation of such a standard should be considered.

The FFD response was quick and effective. Response time (from receipt of the alarm to arrival at the scene) was approximately four minutes. Within the first several minutes at the scene, the shift captain assessed the situation and initiated the request for mutual assistance. The off-site parties who responded rendered valuable assistance in controlling and extinguishing the fire and in providing fire station coverage. Fire fighters exercised prudent judgment when they delayed their entries due to the heat and smoke. Also, when they were informed that the Italian scientist could not be located, it was rightly judged that an entry at that time would have only jeopardized the fire fighters' safety.

Some concerns have been raised over certain fire response procedures. The use of the RD operator in the initial entry without protective clothing (turnout equipment) was inappropriate since the fire conditions inside the experimental hall were not well known at that time. Later discussions indicated that there may have been a near "backdraft" condition. This occurs when there is improper ventilation during a fire, producing large amounts of carbon monoxide, thus creating a potential for explosion or rapid increase in the fire volume. If this had occurred while the RD operator was inside the experimental hall, he may have been seriously injured.

Another concern is the potential involvement of the UC in the fire. Discussions with the FFD indicated that there was some uncertainty over the methods and materials to be used in fighting a uranium fire. In view of the expanding use of uranium in FNAL experimental systems, this information needs to be understood by emergency response personnel (which might include mutual assistance parties from off site).

The hand-held radios used by the FFD experienced many malfunctions during the emergency response. This has been attributed to the design of the radio battery interface. The batteries are charged by removing them from the radios and inserting them into a charger. When reinserted into the radios, there is often poor contact with the battery packs due to the age and design of these units. Also, these radios use the FNAL Security frequency. They cannot accommodate both the Security and the mutual assistance "fire scene" frequencies because of the large separation between them.

RD keeps drawings of building electric distribution systems on file. However, in the case of the Wide Band Laboratory (as with many facilities), these drawings were only of a generic nature and did not indicate the details of power distribution, especially to the experimental equipment. RD personnel did develop, upon the Committee's request, detailed drawings as they pertained to equipment involved in the fire.

Building electrical power distribution can play a role in fire development. About an hour after this fire was first observed, the FFD requested that the building power be shut off. Apparently, this option was not considered earlier. Also, about 15 minutes elapsed from the time the duty electrician was first contacted to when he was able to respond and secure the power. It may be useful to have a more timely system for this procedure. It may also be appropriate to combine the building power shutoff procedure with that of the beam line magnet power (which was secured by the RD operators).

For over four hours, there was concern over the whereabouts of the Italian scientist, who was eventually located off site.

This poses the question of personnel accountability during emergency situations. Accountability at FNAL can be very difficult due to the nature of the activities and work areas. However, it would be appropriate to review this consideration to see if potential uncertainties can be reasonably reduced.

When the fire was finally extinguished and controls were being established, at least one person entered the experimental hall floor without protective equipment. At that time, the nature and extent of surface and airborne contamination (from combustion products and radioactive material) was not known. Appropriate protective equipment should have been worn until the area was found to be hazard free. It should be noted, however, that after certain initial recovery activities were completed, very effective controls were established.

Several environmental samples were taken to assess contamination in the sump discharge water and soil on the west side of the experimental hall. These were effective in determining lead concentrations. However, due to improper sampling/storage procedures, analyses for organics were not valid. These analyses should be performed as soon as weather conditions permit. It would also be appropriate to develop specific procedures for environmental sampling in the event of an unplanned release (e.g., as caused by a fire).

G. Physical Systems

Operation of the automatic sprinklers was delayed by the distance between the fire and the sprinklers (approximately 43 ft). A total of five heads operated during the fire (see Figure 30). The pattern indicates an apparent heat gradient toward the east; this may have been enhanced by the operating floor fan west of P4. The FFD maintained input pressure at 150 psig on the fire department connection, which resulted in a combined flow of 288 gpm from the operating sprinklers. Analysis has shown that this pressure and flow are adequate. The most effective height (above a fire) for sprinkler protection is approximately 7 ft. Distances above 10 ft significantly reduce the effectiveness of the sprinkler discharge. In this case, the large distance, along with the amount of combustible material available, not only delayed the sprinklers' operation but also limited their ability to extinguish the fire. However, they did serve to confine the fire and prevent major involvement of the second and third IEC modules. They also prevented involvement of the cables on the east side of the IEC and ribbon cables attached to P4. Given the amount of combustible material still available (about 2000 lbs of PMMA and hundreds of feet of cables), if the fire had spread uncontrolled the building structure would have failed, causing more extensive damage.

The fire has raised concerns over the selection of cables used in the experiment. Hundreds of feet of cable (mostly RG-58) was burned. It is evident that under similar conditions, the vertical cable runs burned more quickly and completely than the horizontal ones. Discussions indicate that certain other laboratories specify the use of insulating materials having a high degree of flame retardance in the RG-58 cable they procure. The use of such cables in E687 equipment may have reduced the loss. Also, certain modifications to cable installation (e.g., limiting the length of free vertical runs or providing fire barriers), if feasible, may have been helpful.

The experimental hall was not provided with any smoke detection systems. In addition, there was no local smoke or heat detection provided near the experimental equipment. The provision of such devices may have allowed earlier notification. This in turn would have allowed an earlier emergency response and reduced the loss significantly. FNAL had recognized this consideration as a result of a minor fire experienced earlier in another area. A study to improve local fire detection systems has been in progress.

The large amount of smoke and heat prevented fire fighters from directly attacking the fire for almost two hours. If the experimental hall had been constructed with provisions for smoke and heat venting, it would have given fire fighters a valuable option, eliminated the need to have fire fighters on the roof, and reduced the loss.

The fire fighter who charged the fire department connector to the sprinkler system had some difficulty because of smoke pouring out of a nearby exhaust louver. SCBA equipment was necessary to perform this task. If the fire department connector were located away from the louver, this operation would have been more safely and quickly performed.

V. CONCLUSIONS

A. Findings

The Committee evaluated information gathered from interviews, inspections, and tests discussed above. The most probable scenario is considered to be one involving the dynode sum box (see IV.E.1.). A 34-pin ribbon cable connector (associated with PMTs driven by MF6) was apparently misregistered when it was reconnected to its amplifier board such that only one row of pins was engaged. This resulted in a short circuit and overheating of certain wires in the ribbon cable. About 15 to 30 minutes later, the cable ignited; traces of smoke probably provided the observed "sour milk" odor.

The fire spread to all the other ribbon cables (total length approximately 70 ft) in the sum box. This destroyed the cables, the discriminator boards (in the center of the sum box), some of the 34-pin connectors, and consequently, the sum box's functional capability. This sequence corresponds with the observation immediately prior to discovery of the fire that there were no gate signals coming from the sum box. Proper gate signals had been observed approximately 15 minutes prior to observation of the "sour milk" odor.

Flames from the burning ribbon cables and discriminator boards ignited RG-58 cables in the cable tray immediately above the dynode sum box. Cables located near the outer panels of the sum box were ignited but probably did not burn at this time much lower than the top of the side panels. Most importantly, the fire spread along cables to the south and then upward from the sum box, igniting cable in vertical bundles and in a vertical cable tray. About this time, the fire was first discovered. It appeared (from the east catwalk) to be coming from the southwest corner of the HC, which is where this vertical cable tray is located.

The burning cables produced copious amounts of smoke and heat which rose to the ceiling and began to obscure the lights. Initial observers reported that the lights appeared to be off; however, this was probably an illusion due to the dense smoke. The building power was still on at this time. When power was eventually restored, the lights operated immediately, indicating that they had not tripped off. (There was no report that lighting circuit breakers had been reset.)

The burning cables in the vertical tray and in nearby ubiquitous bundles spread the fire to the PMMA light guides of the IEC through radiant heat and direct flame impingement. When the PMMA heated, it melted and fell to lower surfaces, and burned in a manner similar to a flammable liquid. This fire ignited the lower IEC light guides and cables. (Combustion may also have been enhanced by the floor fan blowing air in this area.) Also, the fire progressed along the west side of the HC (discussed below). About this time, the first sprinkler operated, activating the building alarm. Heat currents along the ceiling eventually activated four other sprinklers. Throughout the fire, personnel reported white "smoke"; this was probably steam which would have been created by sprinkler water falling on the fire.

As the fire progressed along the west side of the IEC, the top and bottom light guides began to burn. However, the PMMA inside the modules was protected by the lead and aluminum sheets, and there was little air inside to support combustion. However, when the fire reached the first module, at some point the aluminum panel supporting the bottom row of scintillator strips failed. This resulted in PMMA falling out the bottom, being exposed to air and fire, and thus greatly enhancing the fire. This heated and melted out the lead sheets and other PMMA, further increasing the fire intensity and eventually totally destroying the first module. The front tiebreaker was also extensively damaged.

As the first module burned, HxV ignited and burned readily. P4 was severely damaged by fire from the IEC and HxV and by impact of the second IEC module when it fell. However, P4 apparently shielded C3 from the fire. The fire was limited (probably by sprinkler discharge) such that it did not burn the circuit boards or ribbon cables on the sides of P4. Except for the first IEC module and HxV, there was relatively little burning on the east side of the detectors.

The intensity of the fire around the first IEC module heated the upstream aluminum support framework to failure at several points. Only a small portion of this section survived. The support structure over this module was severely damaged; even the steel I-beam was noticeably deformed. Other overhead support components were also affected. Five of the six module hangers failed, as did three of the four trolley supports. After the first module had fallen, the second module also fell (mostly intact), thereby partially shielding the burning first module from the sprinkler discharge and from the fire fighters' hose stream (when they were on the west catwalk). The downstream aluminum support framework was less damaged, but was severed (due to melting) from top to bottom on the west side. Several ancillary aluminum supports were damaged by failure of the framework and/or by adjacent burning cables.

At some point the vertical cable tray fell into the area near MF7. This and other falling cables contributed to a significant amount of combustion on and near MF7 and the southwest concrete blocks supporting the HC. This produced the damage to MF7 and its supply wiring and created the "V" pattern observed there. This also resulted in intense burning on the south side of the dynode sum box, consuming most of the RG-58 and burning a hole through both side panels of the sum box.

In addition to the IEC, the fire had also spread to the cable trays and vertical cables on the west side of the HC. The fire also destroyed the plastic gas inlet tubing and the flow meters. The fire was most intense around the vertical cable bundles, which accounts for the damage pattern of the internal detector tubes and the preamplifier boxes, and the gaps in the flow meter mounting panel.

The distance between the initial fire and the overhead sprinklers contributed to the fire's progress. By the time sufficient heat had accumulated to operate the sprinklers, the fire was too intense for the sprinkler discharge to extinguish it. However, the sprinklers (and configuration of the second and third modules) probably prevented the combustion of the other modules. They probably also prevented combustion of the cables on the east side of the IEC. If the fire had spread uncontrolled and consumed these combustible materials, building failure would have resulted.

The pertinent events prior to and during the fire are schematically summarized in the Causal Factors Sequence Chart. This is presented as Appendix E.

Several other specific findings are discussed in IV.F. and IV.G. These are summarized in the Judgments of Needs (see V.C.). The Committee believes that attention to these considerations will significantly reduce the probability of a similar recurrence at FNAL or any other laboratory using similar equipment.

B. Probable Causes

The immediate cause of the fire was probably the misregistered connector in the dynode sum box, which led to overloading and igniting the ribbon cable, given that there was no fusing or other current limitation on the affected power supply which would have prevented the overloading. This situation existed due to inherent flaws in the sum box and inadequate safety review.

The fire was allowed to propagate early in its development since there were no nearby fire/smoke detection systems. The sprinkler system did eventually operate, but this is near ceiling level (approximately 43 ft above the origin of the fire) and the fire was well established by that time.

Other contributing factors were the flammability of the cable and the scintillator material. Also, the long exposed vertical cable runs allowed the fire to propagate rapidly upward.

C. Judgments of Needs

1. There is a need for FNAL to strengthen its safety review process for experimental equipment and systems.

2. There is a need for FNAL to develop a policy for selection and installation of cables used in experimental systems, to limit the fire potential.

3. There is a need for FNAL to review its policy for fire detection and fire protection systems design (location, type, etc.) to assure that optimum protection of high value equipment has been provided.

4. There is a need for FNAL to evaluate operating facilities for provision of emergency smoke and heat venting.

5. There is a need for FNAL to develop an engineering standard to assure that electronic systems are provided with current limiting devices to prevent overcurrent conditions in conductors or other portions of the systems.

6. There is a need for FNAL to review its procedures for personnel accountability during emergency situations.

7. There is a need for FNAL to review its emergency plans to assure that personnel who enter a facility which is on fire are provided with proper protective clothing to prevent burns.

8. There is a need for FNAL to evaluate its current radio capabilities to assure reliable communication with all appropriate parties (FNAL and mutual assistance groups) during an emergency.

9. There is a need for FNAL to review the locations of sprinkler system fire department connections to assure that this emergency equipment can be easily accessed during a fire.

10. There is a need for FNAL to review its fire department's current procedures for fighting uranium fires to assure that the procedures are appropriate and that fire fighters are adequately trained in them.

11. There is a need for FNAL to review procedures for emergency power shutoff to assure timely action is taken when this is required.

12. There is a need for FNAL to assure that only personnel with appropriate personal protective equipment enter an emergency scene before it has been declared hazard free.

13. There is a need for FNAL to analyze the soil on the west side of the Wide Band Laboratory experimental hall, to determine the levels of organic contaminants. Based on the results, all appropriate remedial actions should be taken.

14. There is a need for FNAL to develop specific procedures for environmental sampling in the event of a fire or other occurrence which could cause an unplanned release. The procedures should include necessary protocols for handling and storage of samples prior to analysis.

VI. SIGNATURES OF INVESTIGATION COMMITTEE MEMBERS

The investigation was conducted and the report prepared by:

Justin T. Zamirowski, Chief
Industrial Safety and
Fire Protection Branch
Environment, Safety, and
Health Division
DOE-Chicago Operations Office
Chairman

Edward F. Bucki, General Engineer
Batavia Area Office
DOE-Chicago Operations Office
Member

James K. Farley, General Engineer
Construction, Environment, and
Safety Division
Office of Energy Research
DOE-Headquarters
Member

Paul M. Neeson, Health Physicist
Environment, Safety, and Health
Division
DOE-Chicago Operations Office
Member

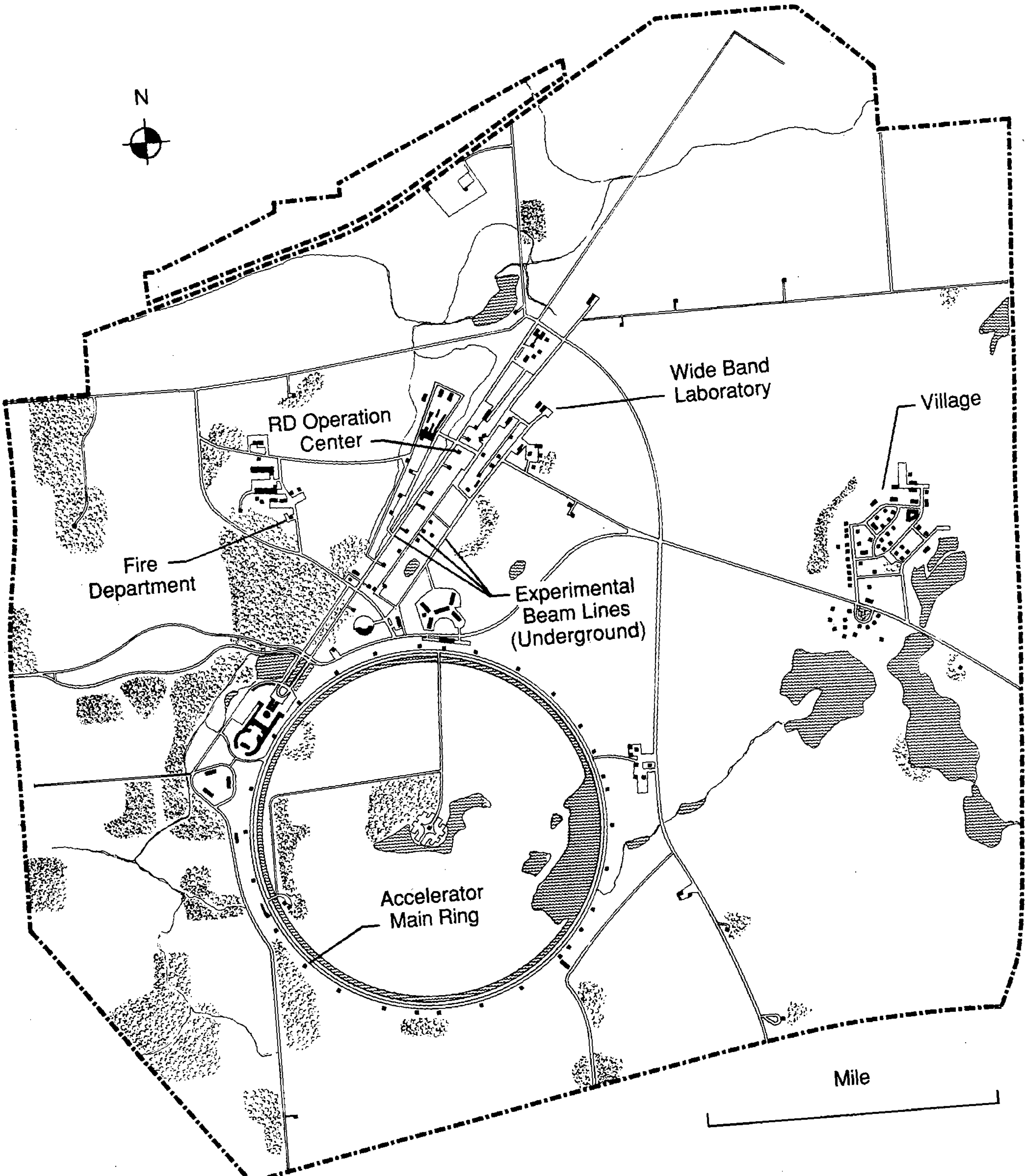


Figure 1. Fermi National Accelerator Laboratory Site Map.

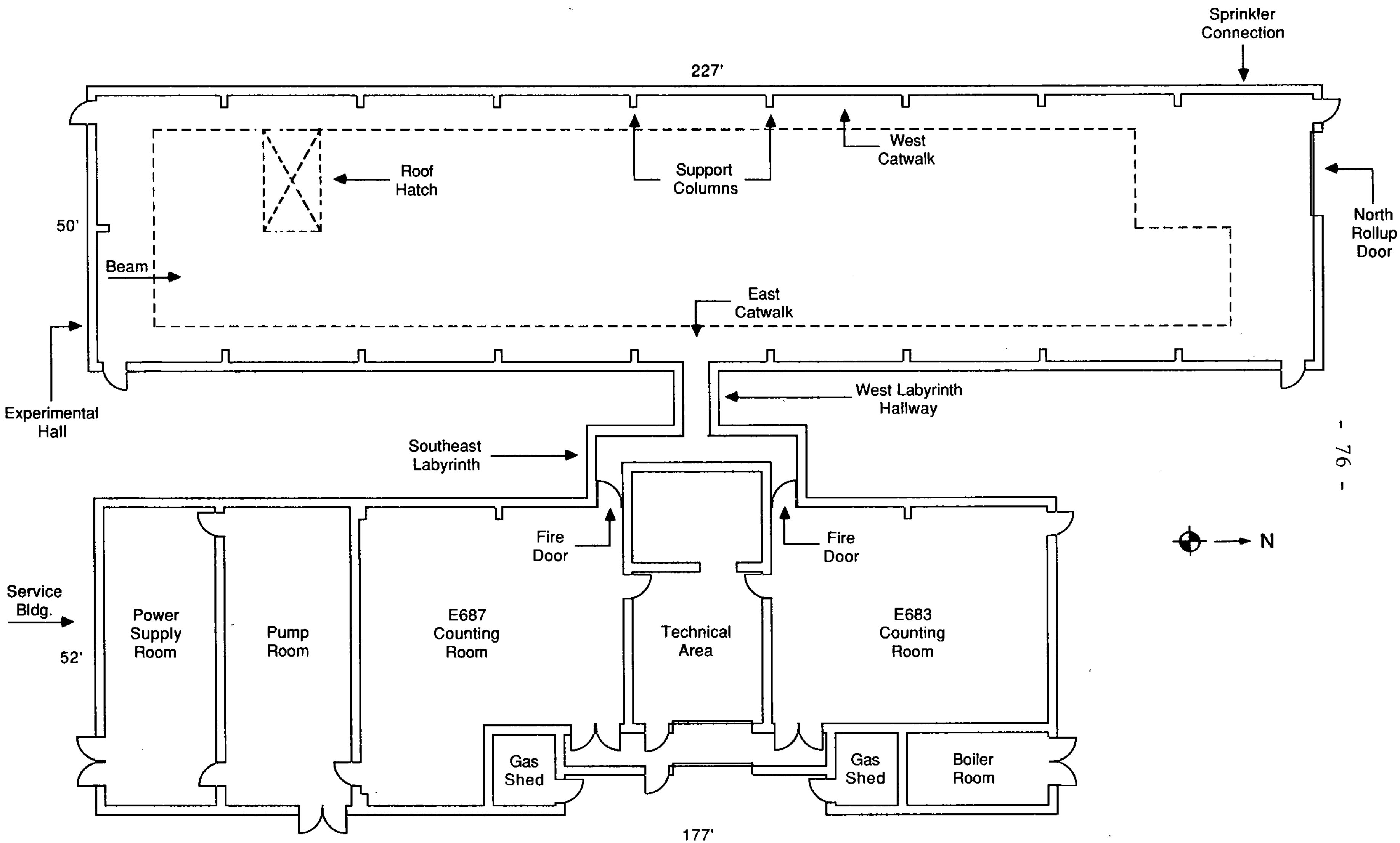
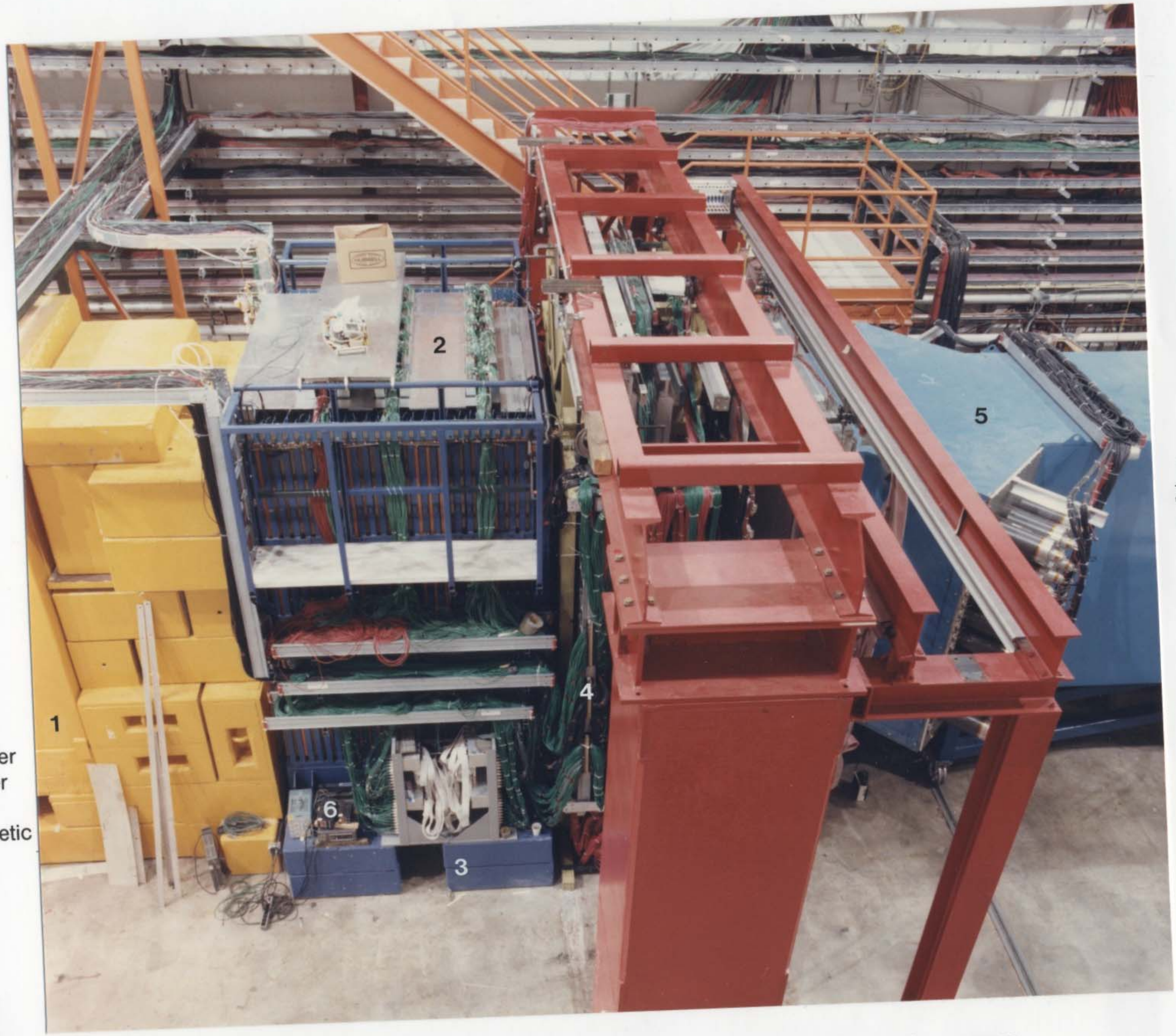


Figure 2. Wide Band Laboratory.



1. Uranium Calorimeter
2. Hadron Calorimeter
3. Dynode Sum Box
4. Inner Electromagnetic Calorimeter
5. Cerenkov Counter
6. Dynode Sum Box Power Supplies

Figure 4. Pre-fire condition, west side of E687 beam line. Note positions of UC, HC, dynode sum box, power supplies, and C3. IEC, HxV, and P4 are hidden by support structure.

1. Hadron Calorimeter
2. Dynode Sum Box
3. Inner Electromagnetic Calorimeter
4. Main Frame 7 Power Supply
5. HxV Detector
6. P4 Proportional Wire Chamber
7. Cerenkov Counter

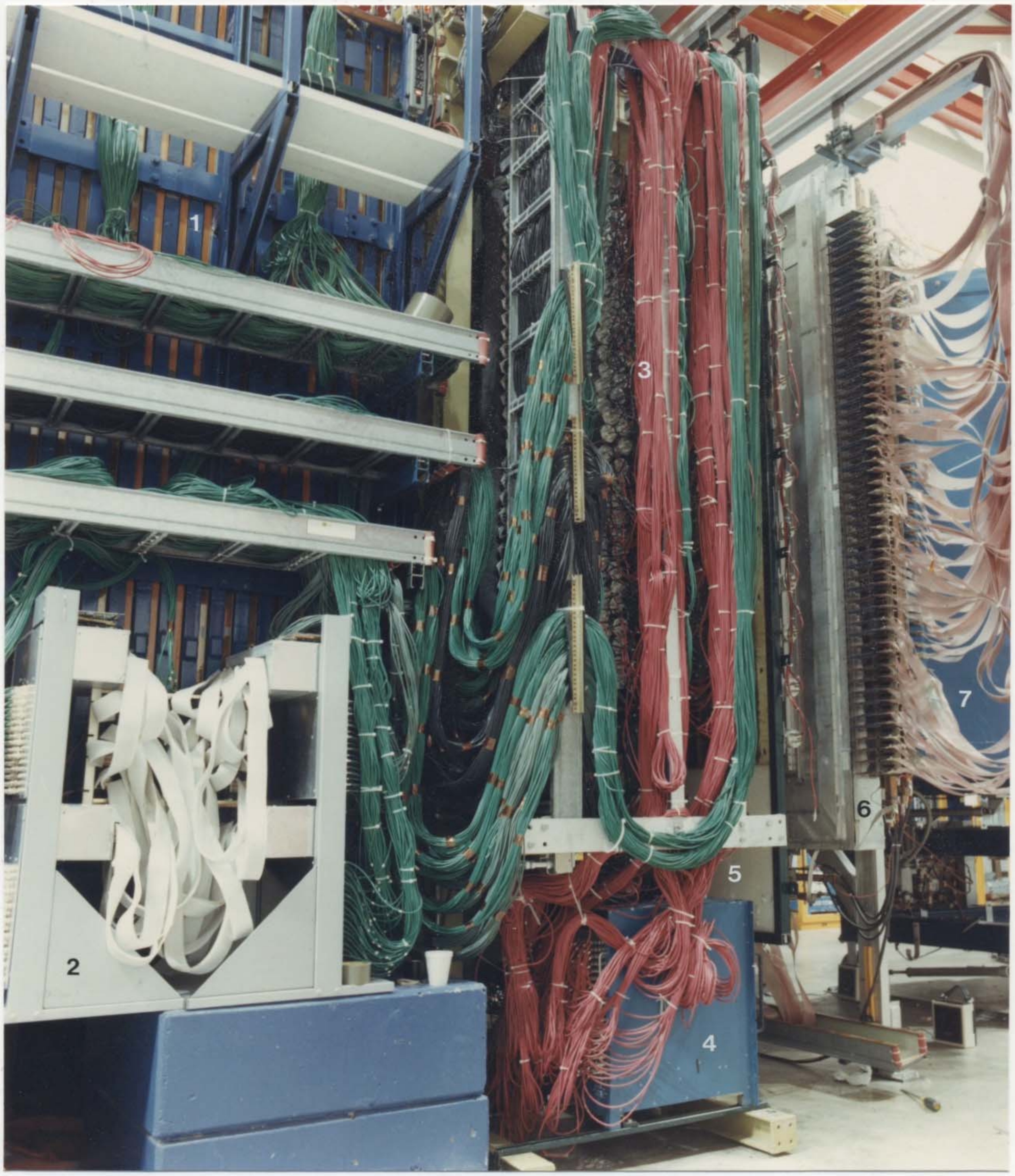


Figure 5. Pre-fire condition, west side of beam line looking southeast. Note HC, dynode sum box, IEC, HxV, P4, and C3. MF7 power supply is visible below IEC.

1. Uranium Calorimeter
2. Hadron Calorimeter
3. Dynode Sum Box
4. Inner Electromagnetic Calorimeter
5. Main Frame 7 Power Supply
6. HxV Detector
7. P4 Proportional Wire Chamber
8. Cerenkov Counter

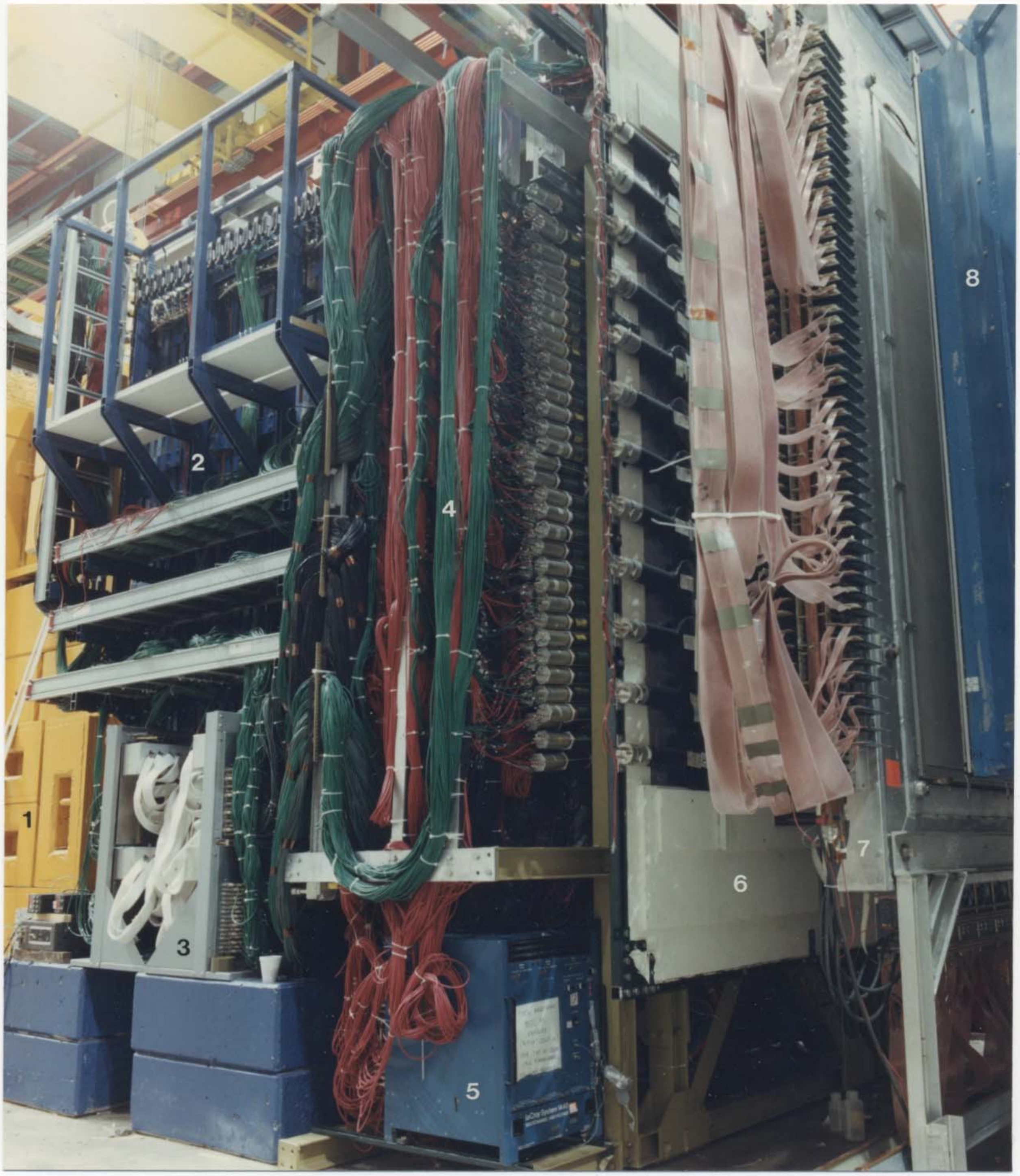


Figure 6. Pre-fire condition, west side of beam line, looking northeast. Note UC, HC, dynode sum box, IEC, HxV, P4, C3, and MF7.

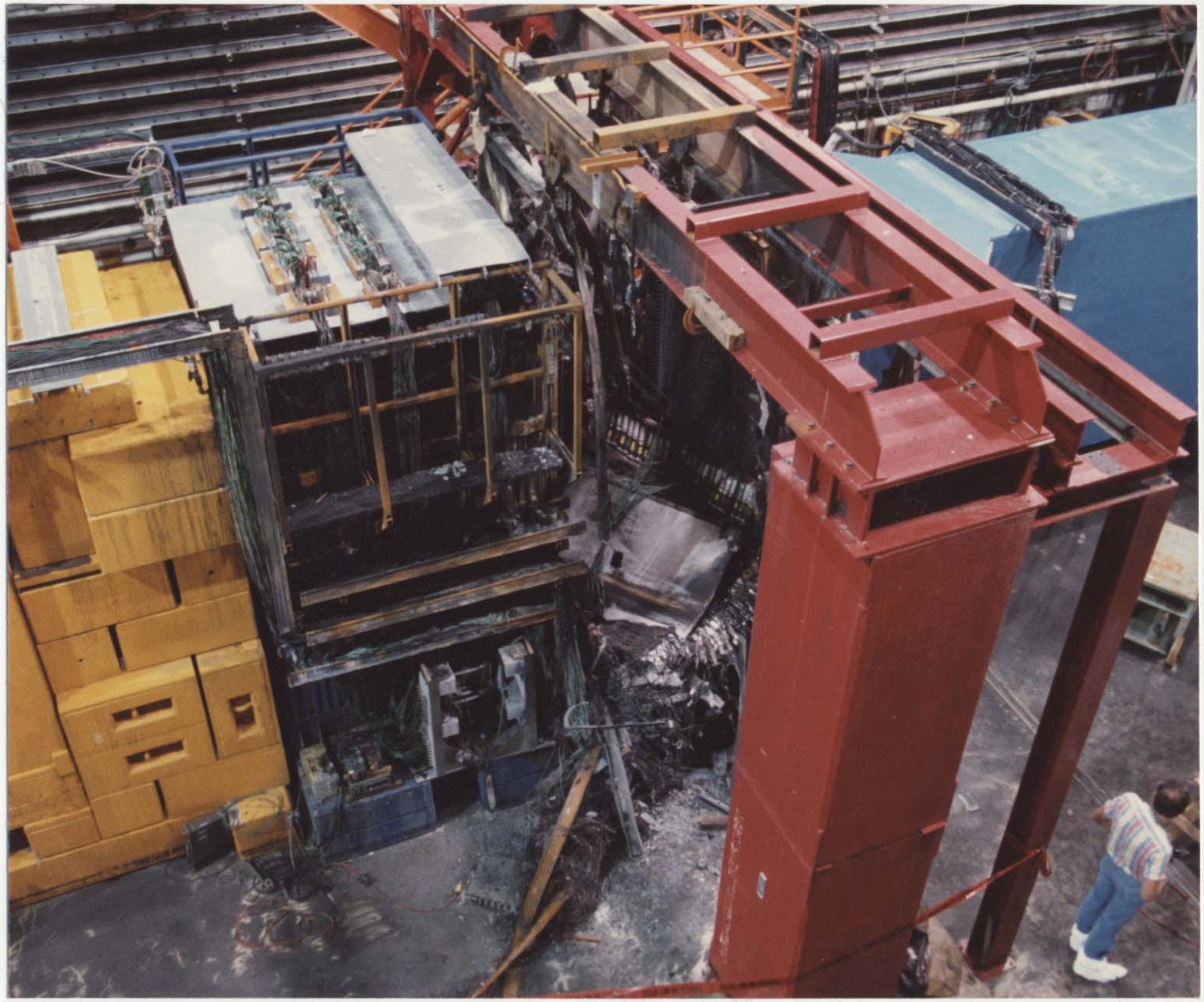


Figure 7. West side of beam line after fire.

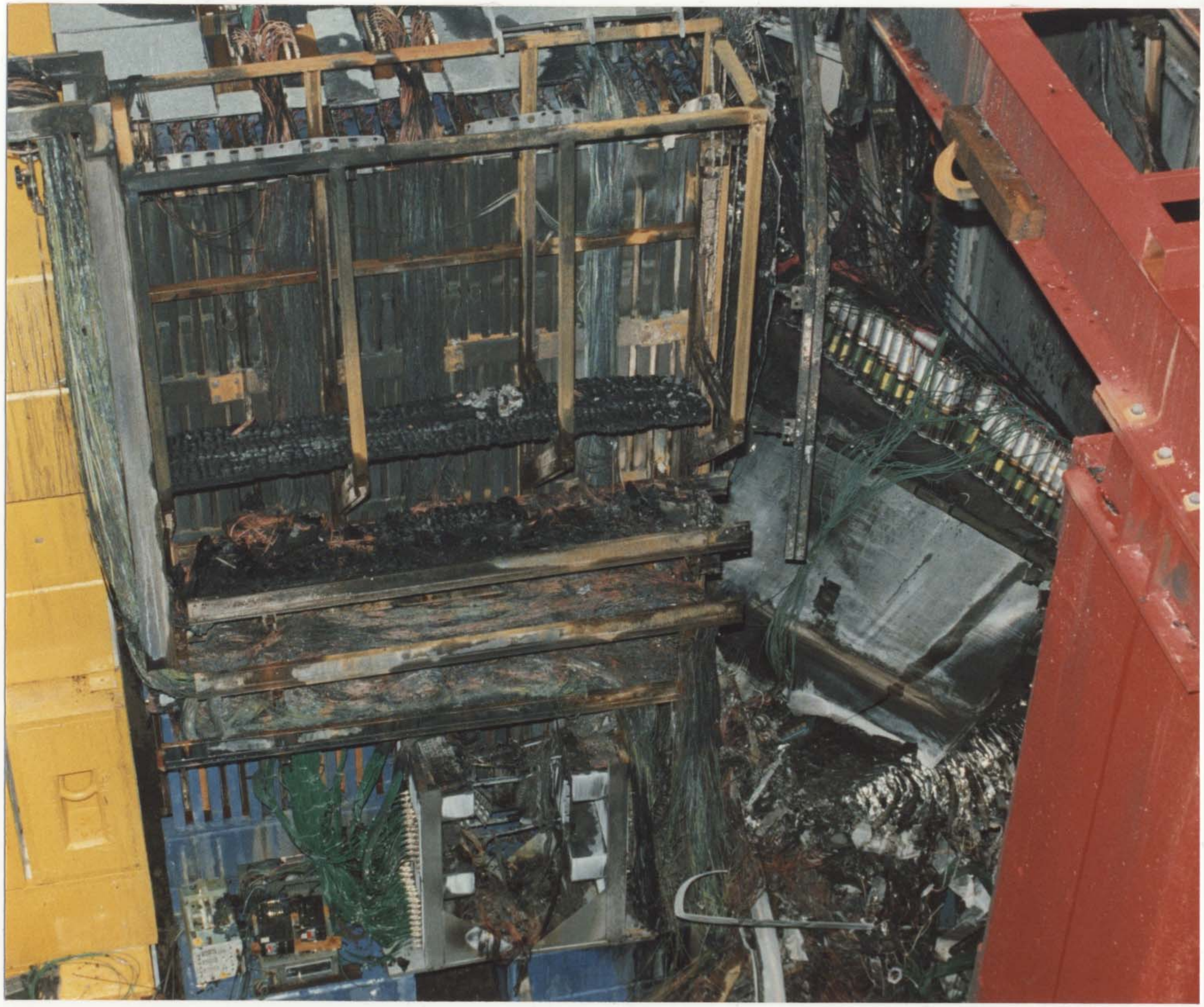


Figure 8. West side of beam line after fire. Note damage to HC, IEC, and dynode sum box.

Figure 9. West side of beam line after fire. Note damage to HC, IEC, and support structure, and undamaged ribbon cable on P4.

Figure 10. Damage to IEC and HxV. IEC third module and downstream tiebreaker are visible hanging from aluminum framework.

Figure 11. Damage to upper portion of IEC aluminum framework and support structure. Note remnants of HxV.

Figure 12. Damage to dynode sum box (with hole burnt through south panel) and IEC second module, remnants of west side of HxV, and damage to P4. Note minor damage to P4 ribbon cables.

Figure 13. Damage to west side of HC and dynode sum box. Note almost complete destruction of cables on right side of sum box and mostly intact cables on the left.

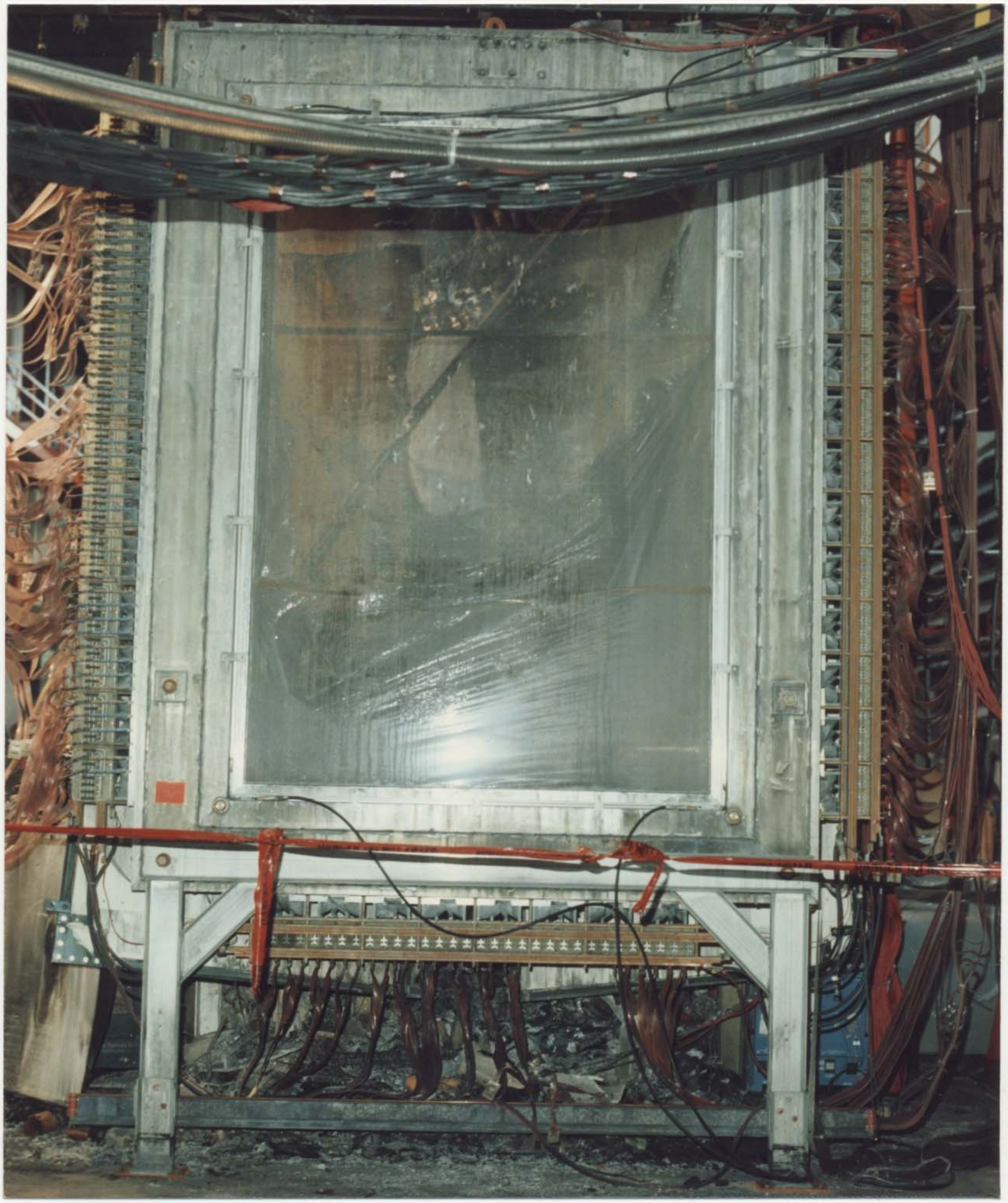


Figure 14. Upstream view of P4 after C3 was rolled aside. Note extensive damage to ribbon cable on bottom, but only minor damage to cables on west (left) and east sides.

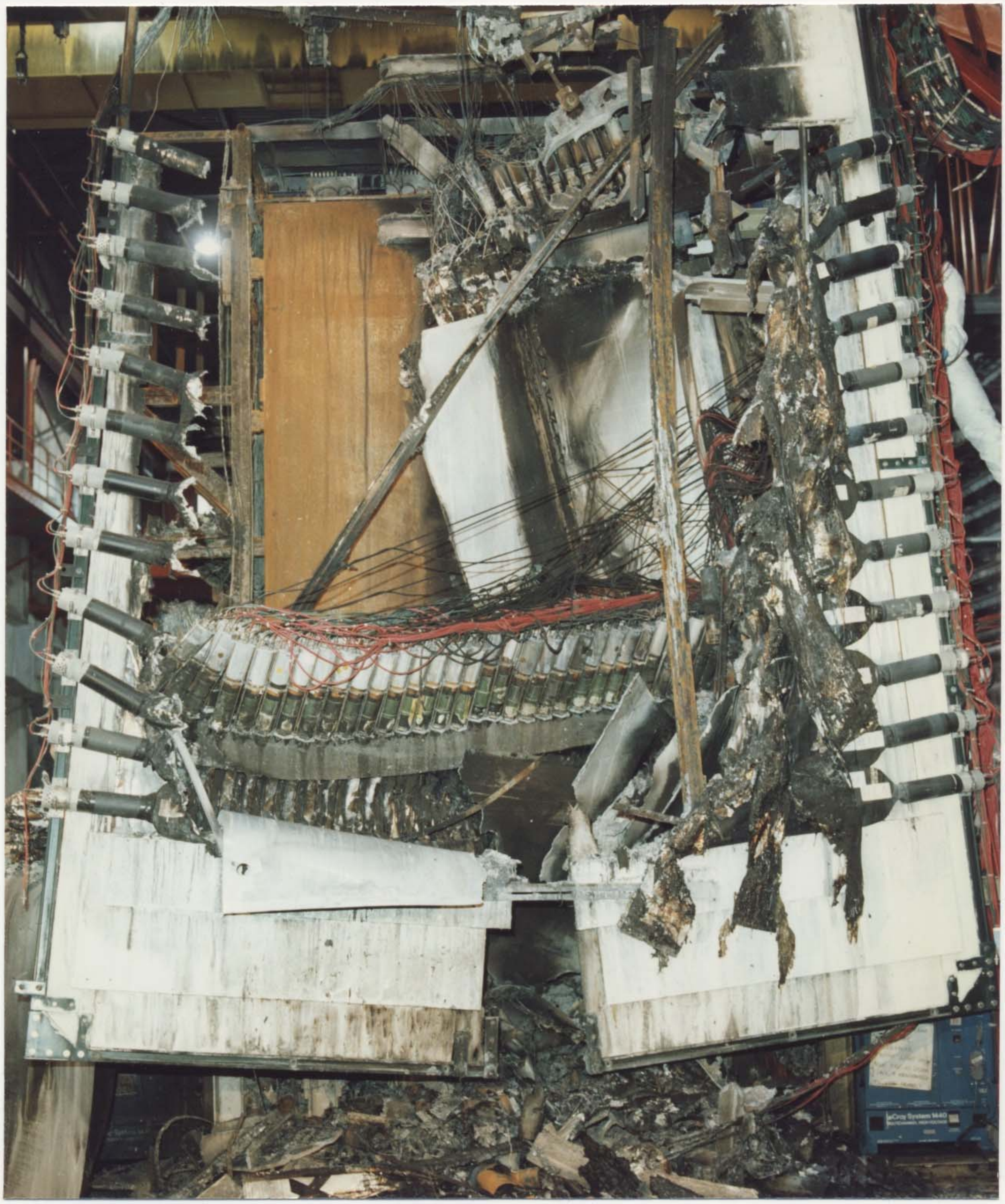


Figure 15. Upstream view of HxV with P4 removed. Damage on west side is only slightly more severe than on east side.

Figure 16. Upstream view of IEC with HxV removed. MF6 is clearly visible on lower right while MF7 is buried under rubble at lower left. Note undamaged cables along east side.

Figure 17. View of damage to IEC looking east prior to removal of HxV and P4. IEC third module is still hanging from aluminum framework and second module is in foreground.

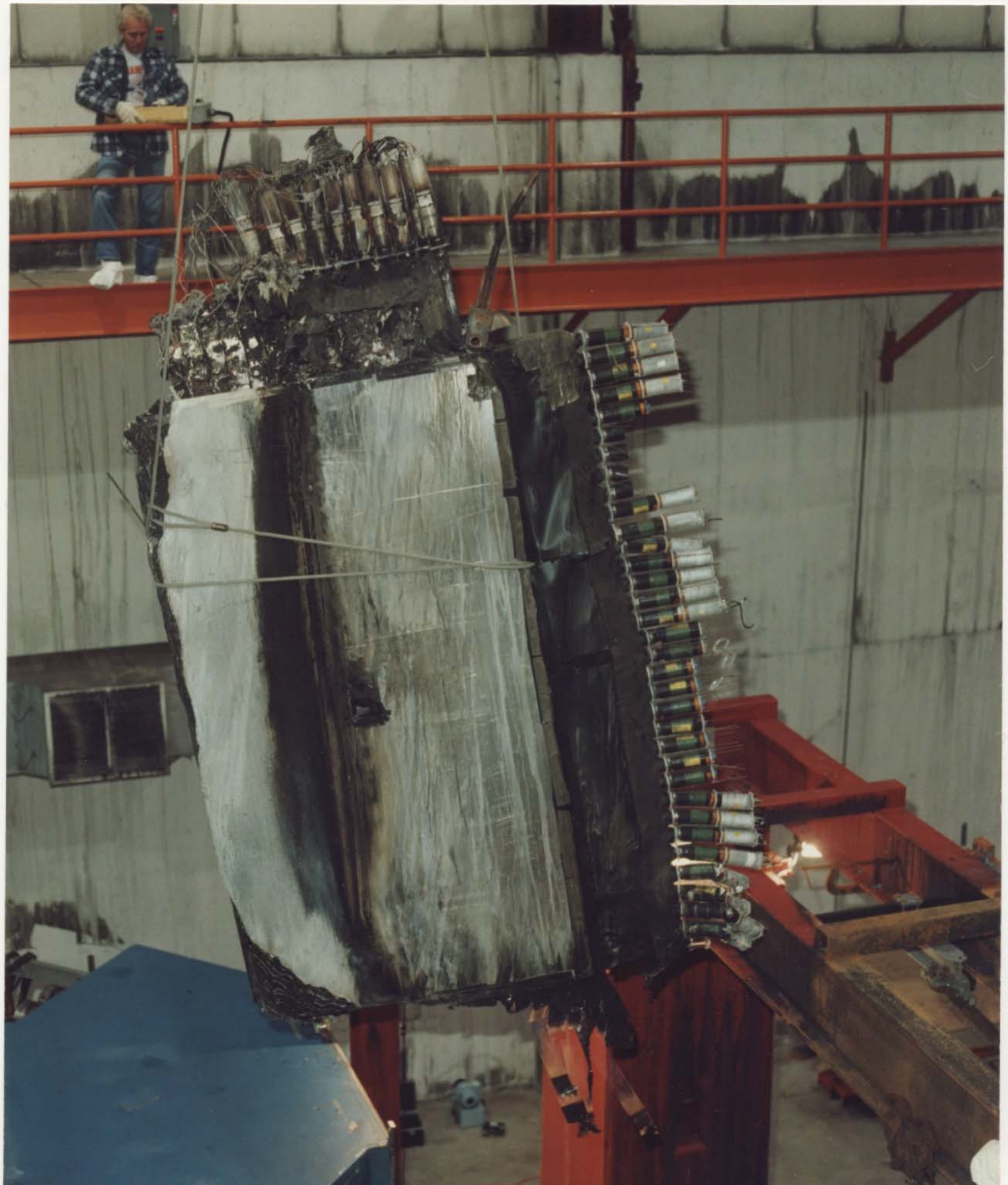


Figure 18. Upstream view of IEC third module after removal from fire scene. Note damage is greater on left (west) and bottom.

Figure 19. Rubble pile below the IEC containing damaged PMT parts, aluminum frame pieces, and burnt cables.

Figure 20. "V" pattern on southwest HC shielding block support and MF7 caused by burning cables.

Figure 21. Fire damage to west side of HC.

Figure 22. Fire damage to cables in trays on west side of HC.

Figure 23. Extensive fire damage to rear of MF7. The top has been mechanically damaged from weight of fallen cables.

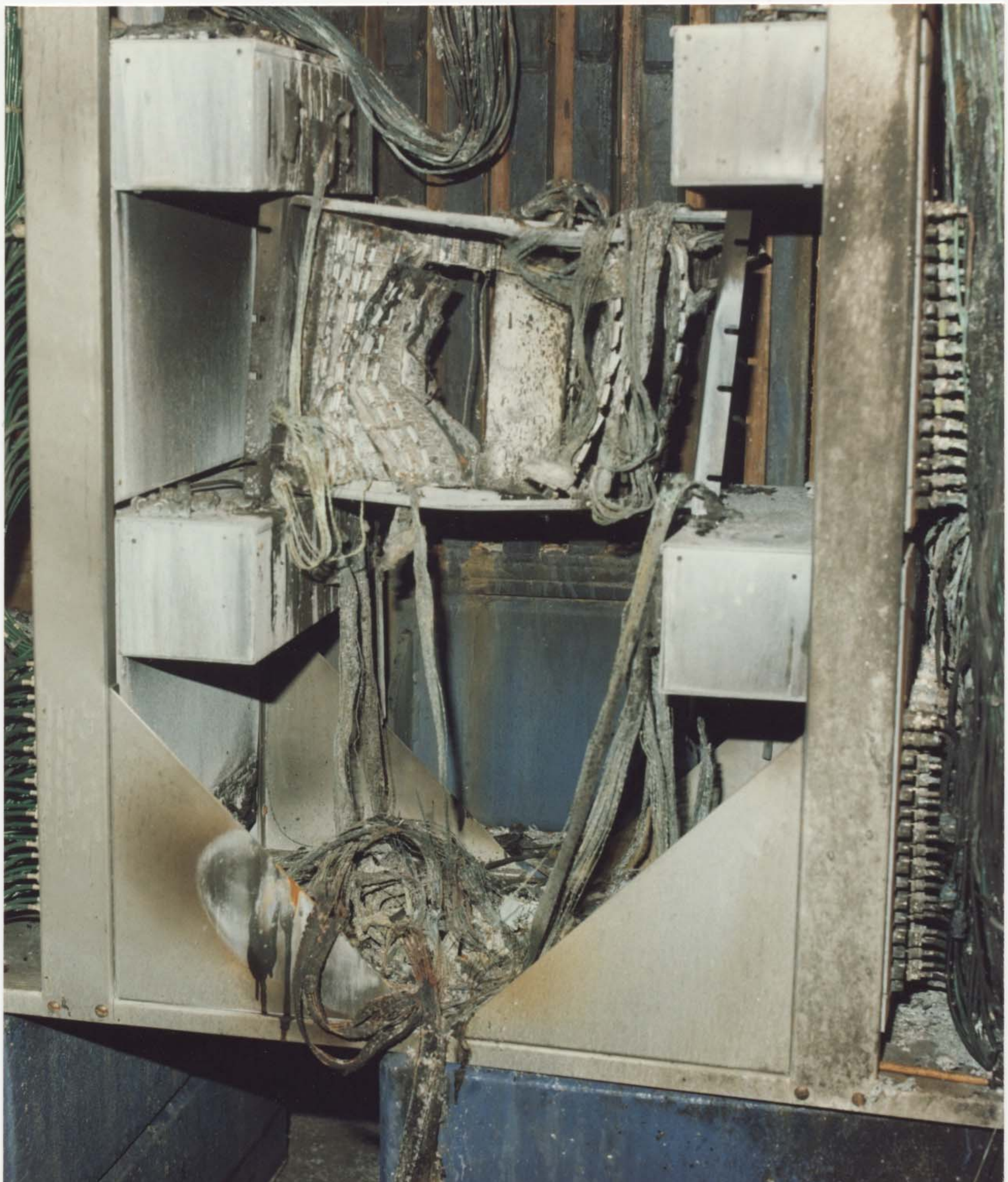


Figure 24. Fire damaged dynode sum box. Discriminator boards are in center of unit.

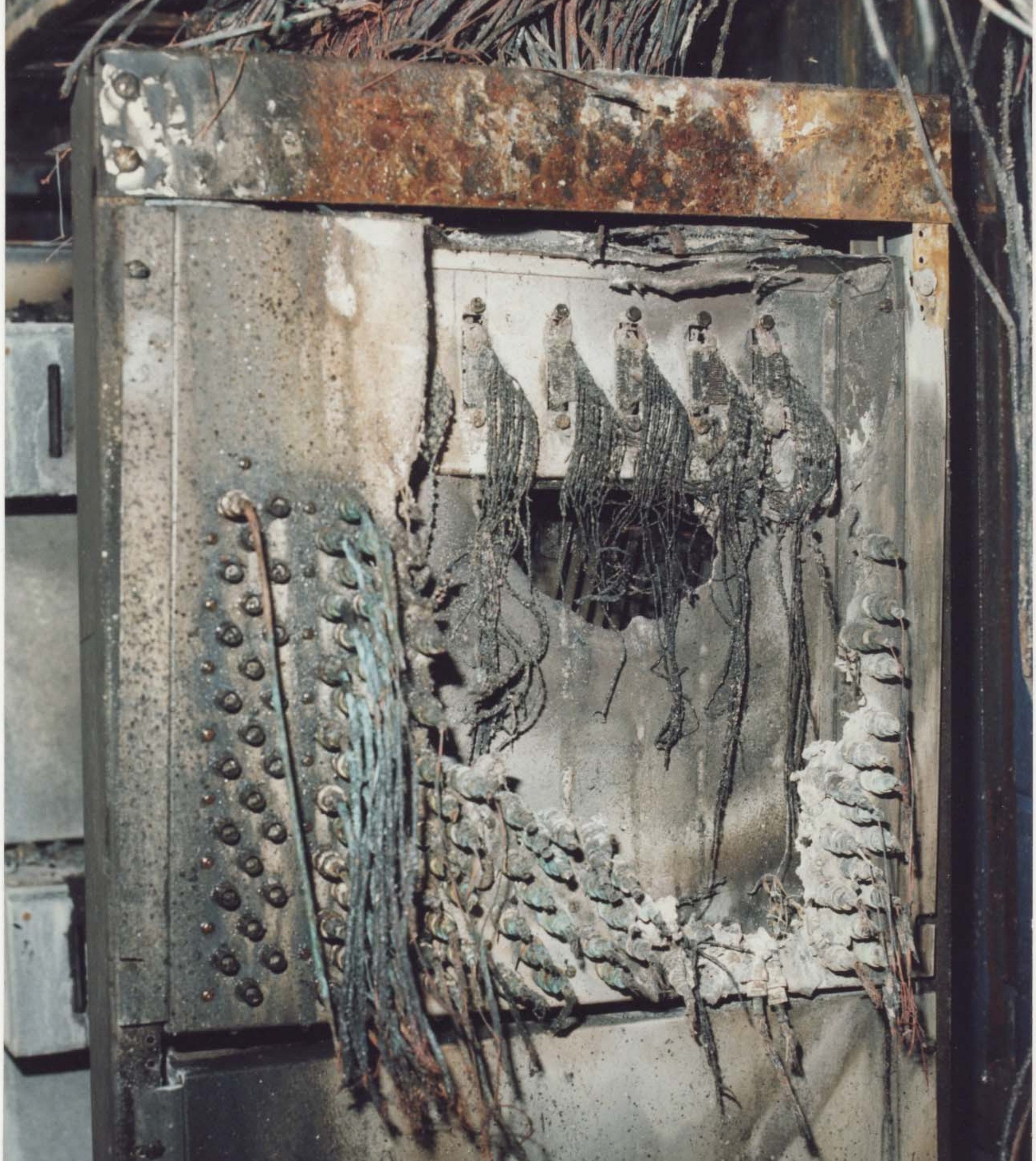


Figure 25. Upstream side of dynode sum box. Cable fire has melted exterior aluminum panel and a smaller portion of interior panel.

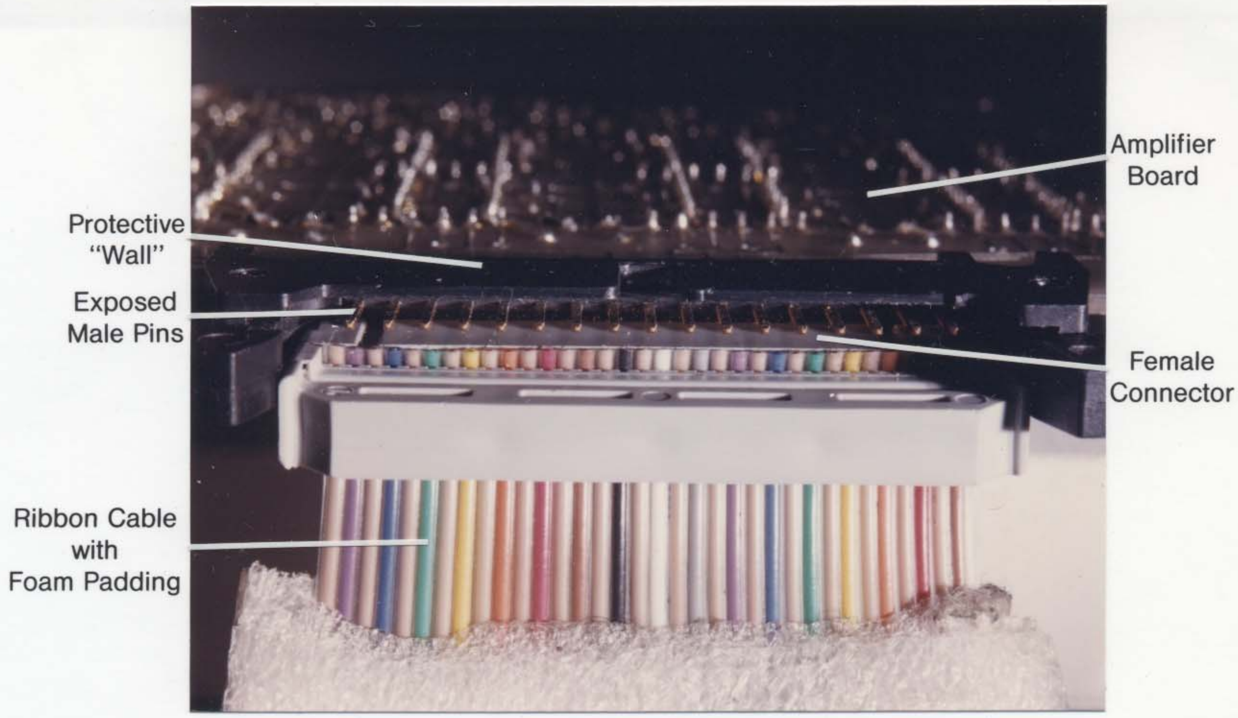


Figure 26a. Misregistered 34-pin connectors. Note row of exposed male pins. Cable and connectors are same type as those in dynode sum box.

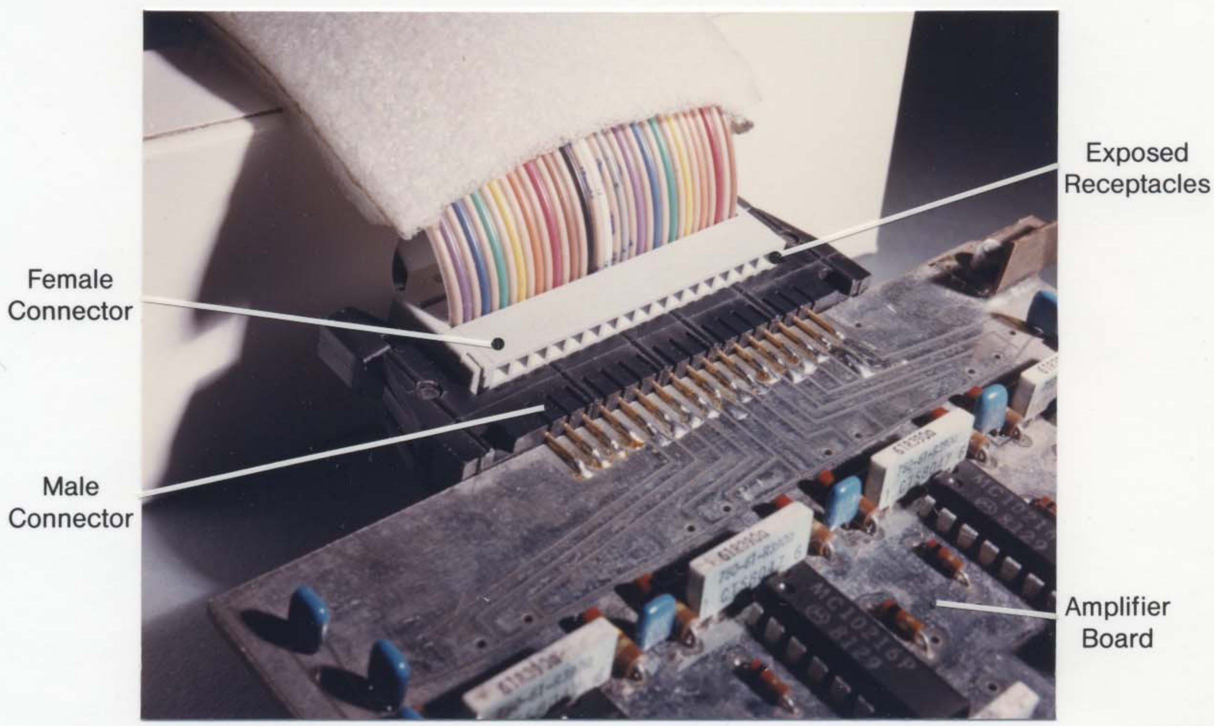


Fig. 26b. Misregistered 34-pin connectors. Note exposed female receptacles and absence of protective "wall" on male connector.

Figure 27. Interior of upstream side of dynode sum box. Connectors handled immediately prior to fire are on lower chassis box. Suspect connector is third from outside.

Figure 28. Closeup of suspect connector on lower upstream chassis box. Note lack of plastic on right side of pins.

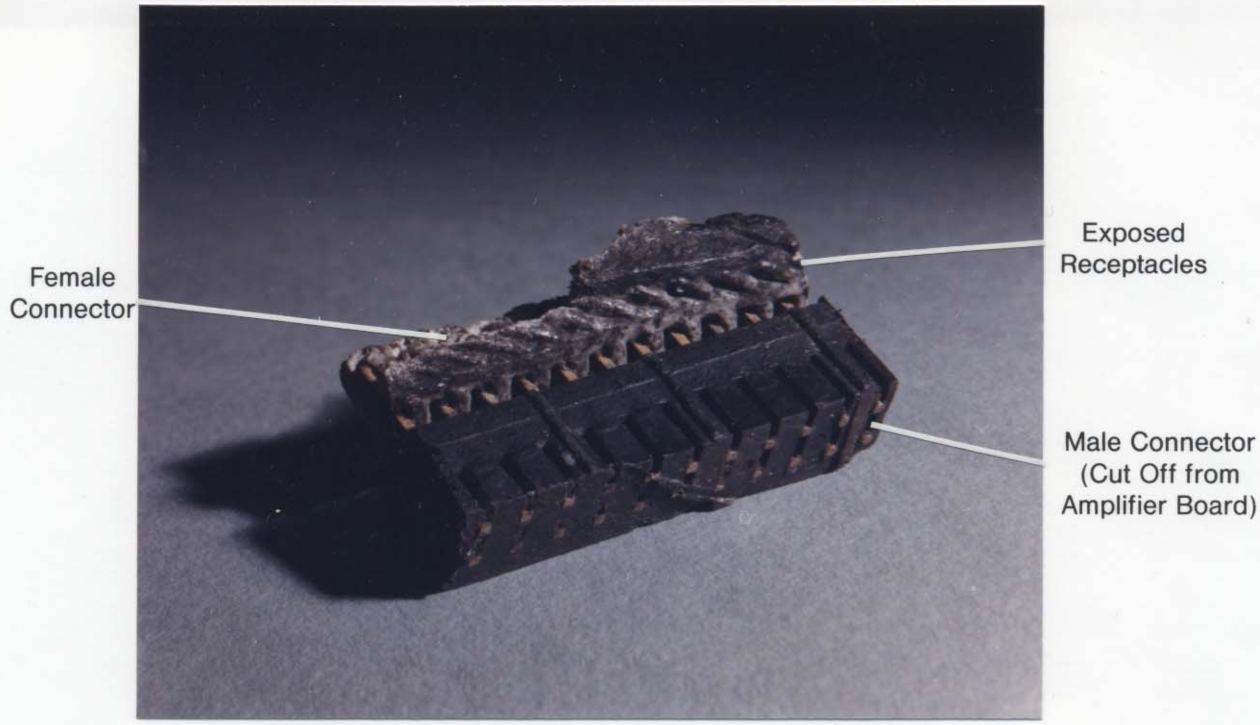


Figure 29a. External view, section of suspect 34-pin connectors. Note exposed row of female receptacles; deformed by partial melting of female connector.

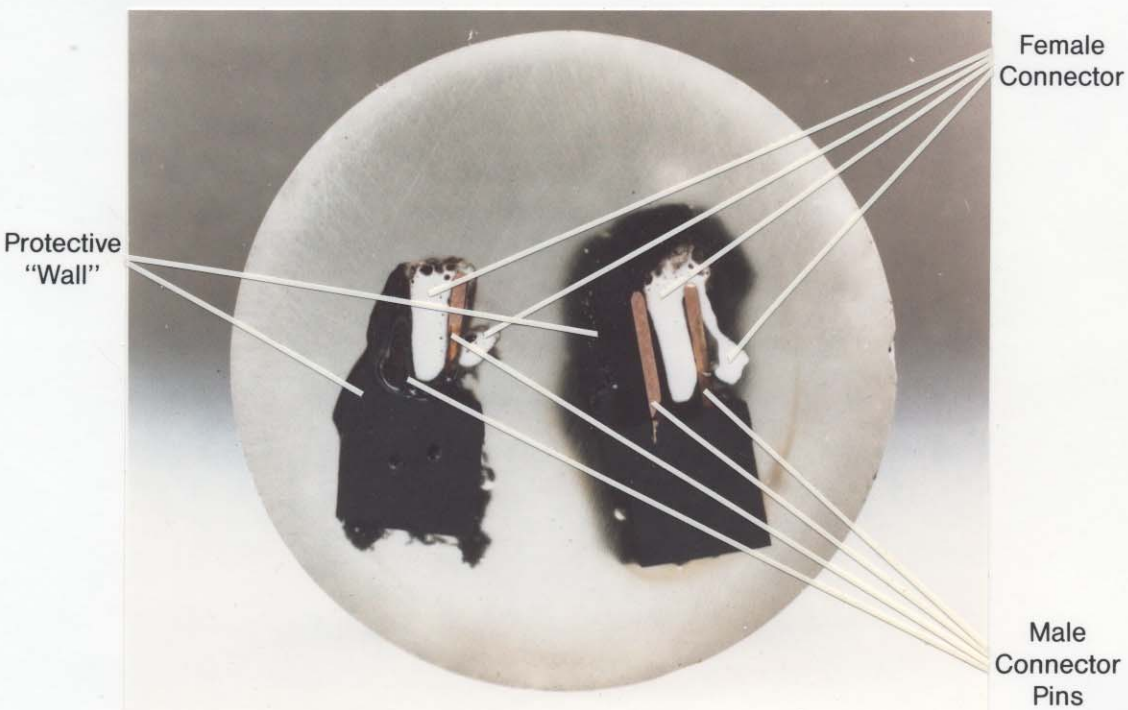


Fig. 29b. Cross-sectional views of suspect connectors. Note absence of gray plastic (female connector) on left side of pins.

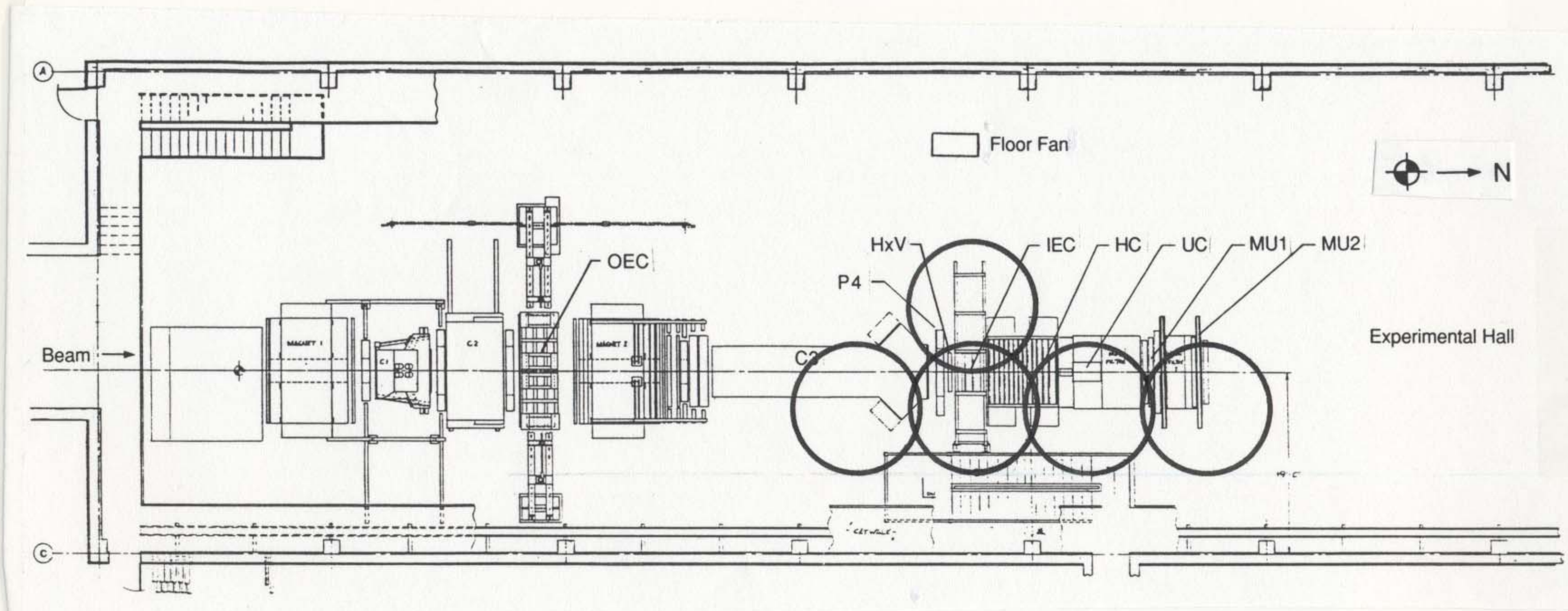


Figure 30. Discharge pattern for the five operated sprinklers in the experimental hall.

Department of Energy
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois 60439

October 5, 1987

Justin T. Zamirowski, Industrial Safety
and Fire Protection Engineer
Operational and Environmental Safety Division

SUBJECT: INVESTIGATION OF FIRE IN THE WIDE BAND HALL AT FERMILAB ON OCTOBER 3, 1987

You are hereby appointed as chairman of a committee to investigate the fire that took place at FERMILAB on October 3, 1987. The following additional personnel are appointed as members of the committee:

Ed Bucki, General Engineer, DOE-BAO
Paul Neeson, Health Physicist, DOE-OES
James Farley, General Engineer, DOE-HQ

In addition, the following persons are designated as technical advisers to the committee to be utilized as required and requested by the chairman.

Enloe Ritter, Technical Adviser, CH-TMD
Rebecca Boyd-Obarski, Legal Adviser, CH-OC

Should you require additional assistance or consultants, please contact me, and I will endeavor to provide you with these. You are delegated the authority to take those reasonable actions necessary to perform and complete this investigation in a timely manner. This includes the purchase of those services and products necessary (through authorized CH contracting officer[s]). The draft report shall be completed by November 8, 1987. Please keep me informed on a periodic basis of your progress on the investigation.

The activities of serving on the committee and the necessary secretarial help requested shall take precedence over all other activities until the investigation is completed.

The investigation and reporting are to be conducted in accordance with DOE Order 5484.1 insofar as circumstances associated with this subject permit. The report should, of course, fully cover and explain the technical elements of the causal sequence(s) of the occurrence. The report should also describe the management systems which should have, or could have, prevented the occurrence; e.g., the safety or hazard review system, the quality assurance program for safety (including the monitoring of actual operations). Appropriate recommendations for improvement of the management systems will be required.

Hilary J. Rauch
Manager

cc: A. Mravca, BAO
M. Samber, OC
J. Hunze, TMD
E. Temple, HQ
P. Neeson, OES
E. Bucki, BAO
J. Farley, HQ
R. Boyd-Obarski, OC
E. Ritter, TMD

APPENDIX B

INNER ELECTROMAGNETIC CALORIMETER DETAILED INFORMATION

The inner electromagnetic calorimeter basically consists of planes of scintillator sandwiched between sheets of lead. The scintillator consists of PMMA doped with napthalene (3%), and trace concentrations of wavelength shifting compounds. Parallel scintillator strips from different planes are externally formed and attached to light guides (see Figure B-1). Attached to the light guides are the PMTs (with americium sources on the faces), and in turn, the PMT bases. (See Figure B-2.) Figure B-3 is a sketch of a section of the first module (which contains 16 planes), showing the alternating scintillator and lead sheets.

Figure B-4 is a sketch of the front (upstream) view of the IEC. Each module has protective aluminum sheets on the front and back surfaces. A side view sketch is shown in Figure B-5. Tiebreaker detail has been omitted for clarity.

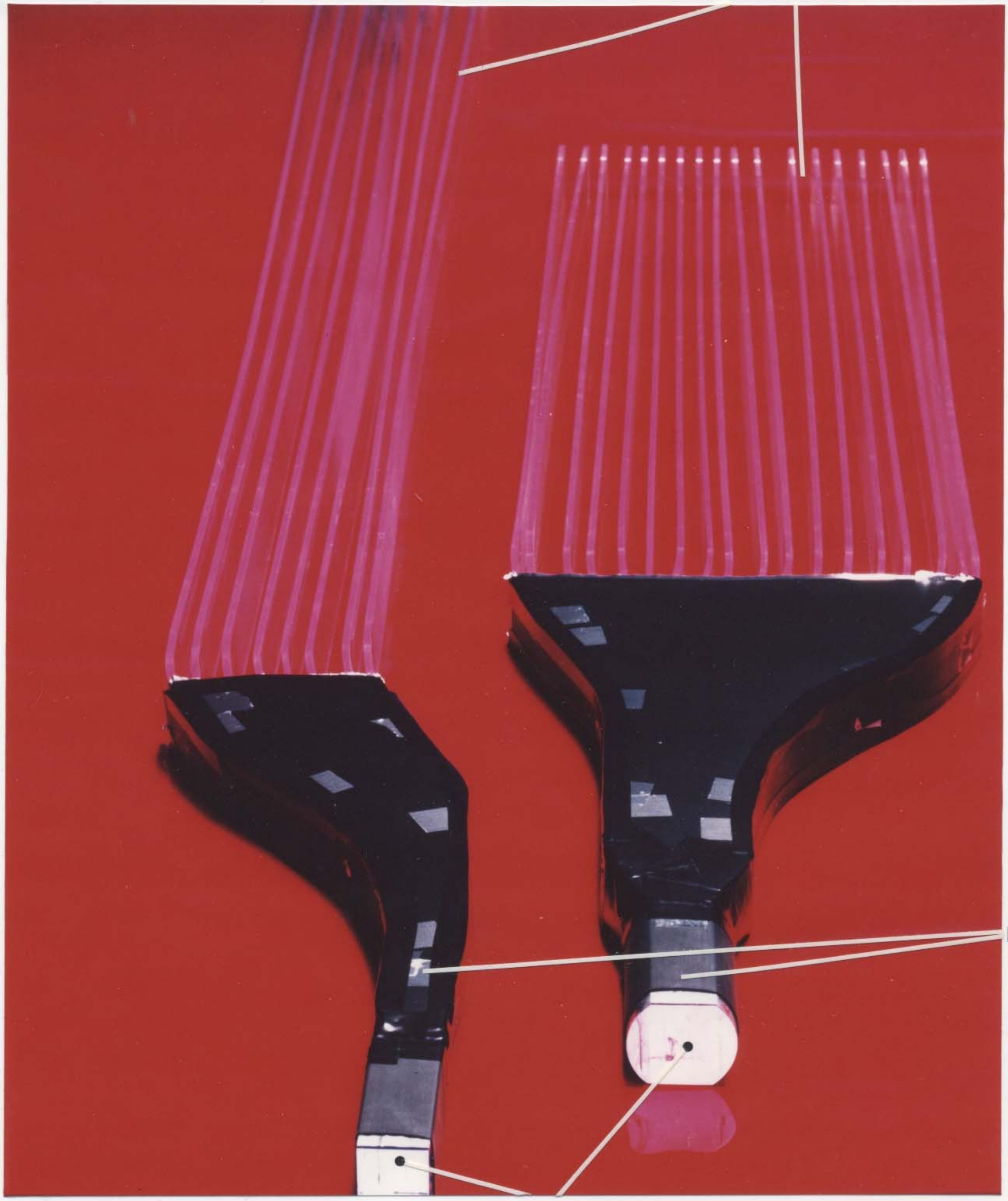


Fig. B-1. Typical IEC scintillator assemblies. Vertical assembly for first module is on left; horizontal assembly for second module on right.

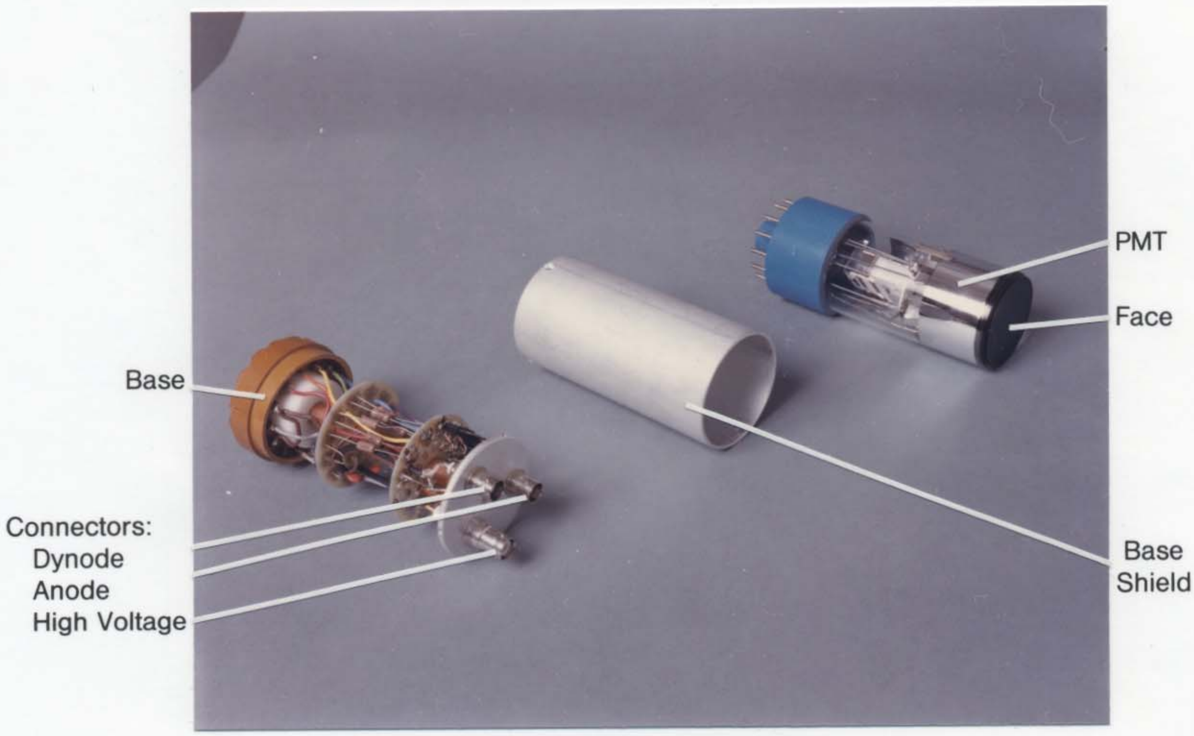


Fig. B-2. Photomultiplier tube and base of same types used in IEC. Shield has been removed from base to expose internal components.

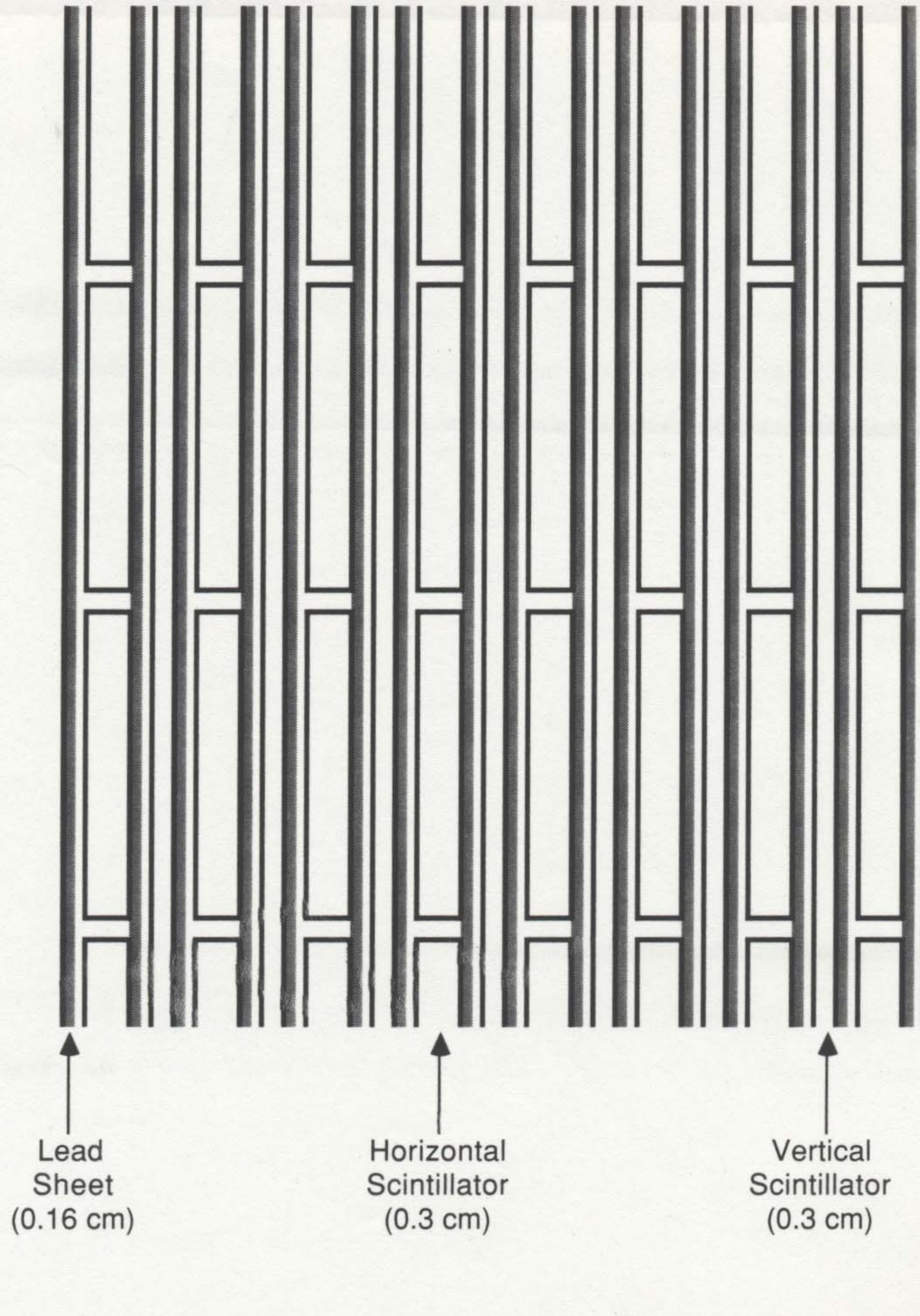


Figure B-3. Section of First Module (Side View).

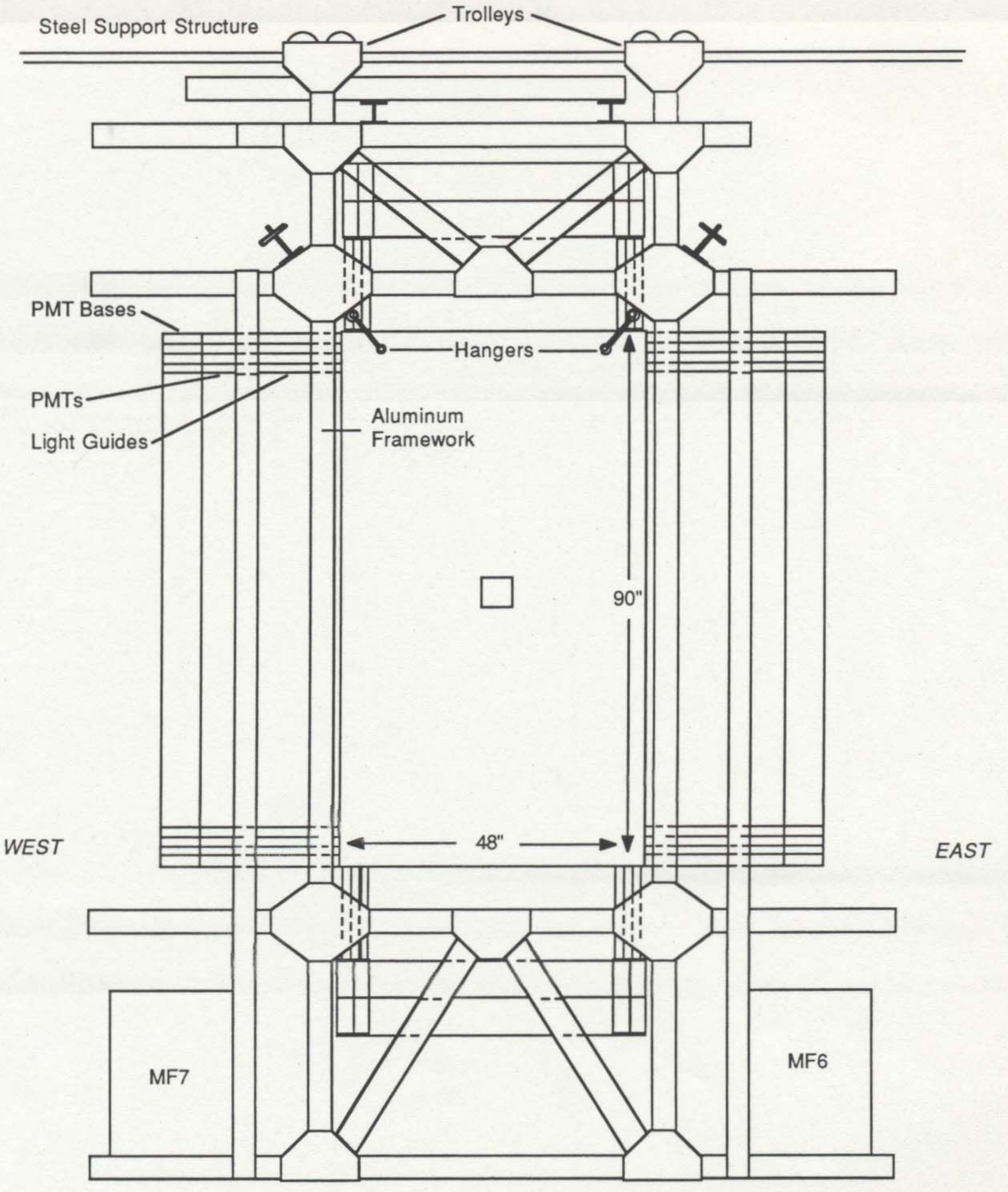


Figure B-4. Front (Upstream) View of IEC.

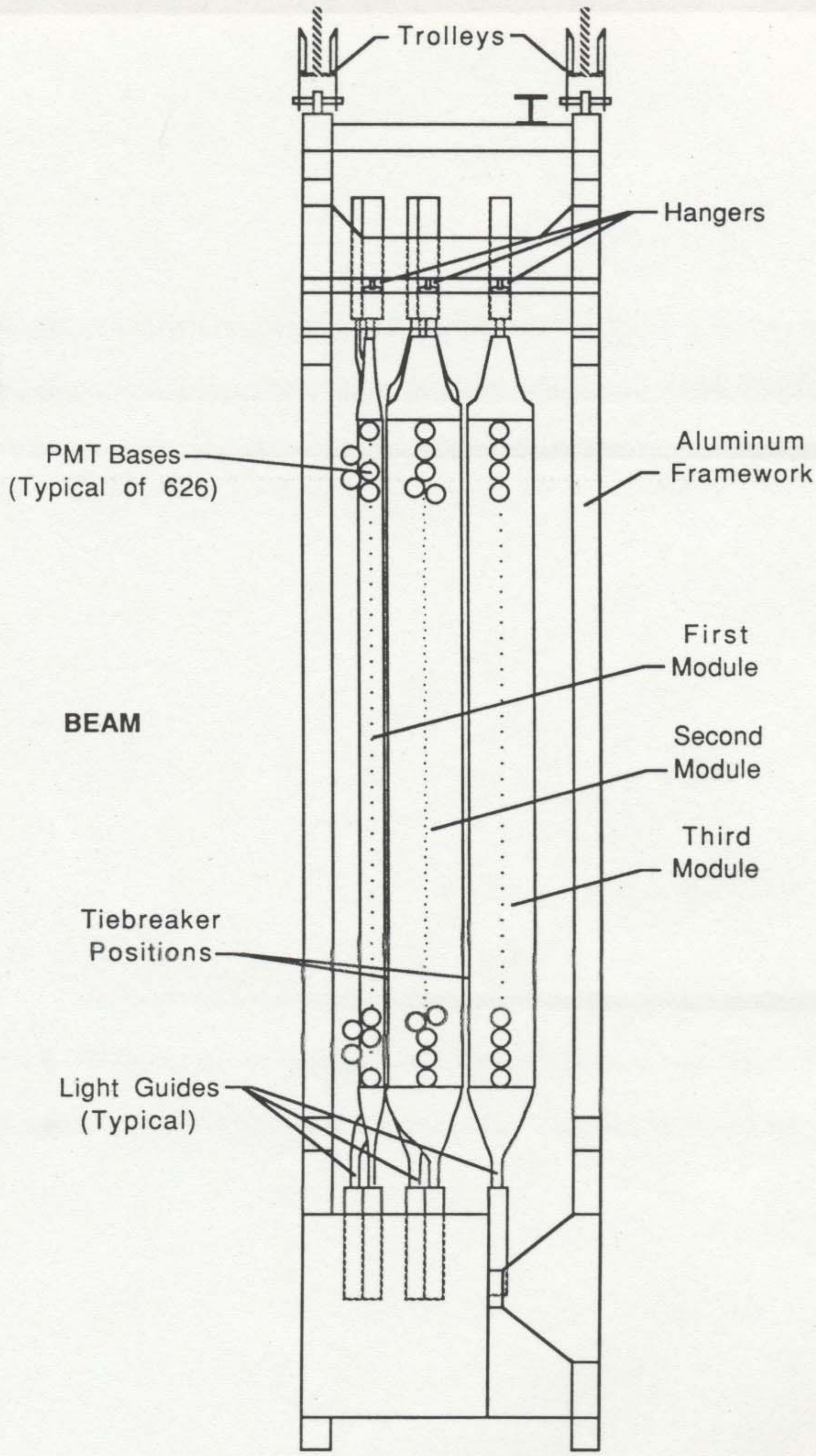


Figure B-5. Side View of IEC.

APPENDIX C

HADRON CALORIMETER DETAILED INFORMATION

The hadron calorimeter consists of iron plates interspersed with detector planes. The basic construction is shown in Figure C-1. The detectors consist of multiple layers, which include aluminum proportional Iarocci tubes, copper coated glasteel (a material similar to G-10), cardboard, and PVC.

Figure C-2 is a schematic sketch of the device and its support systems. Some details of the gas system are shown in Figure C-3.

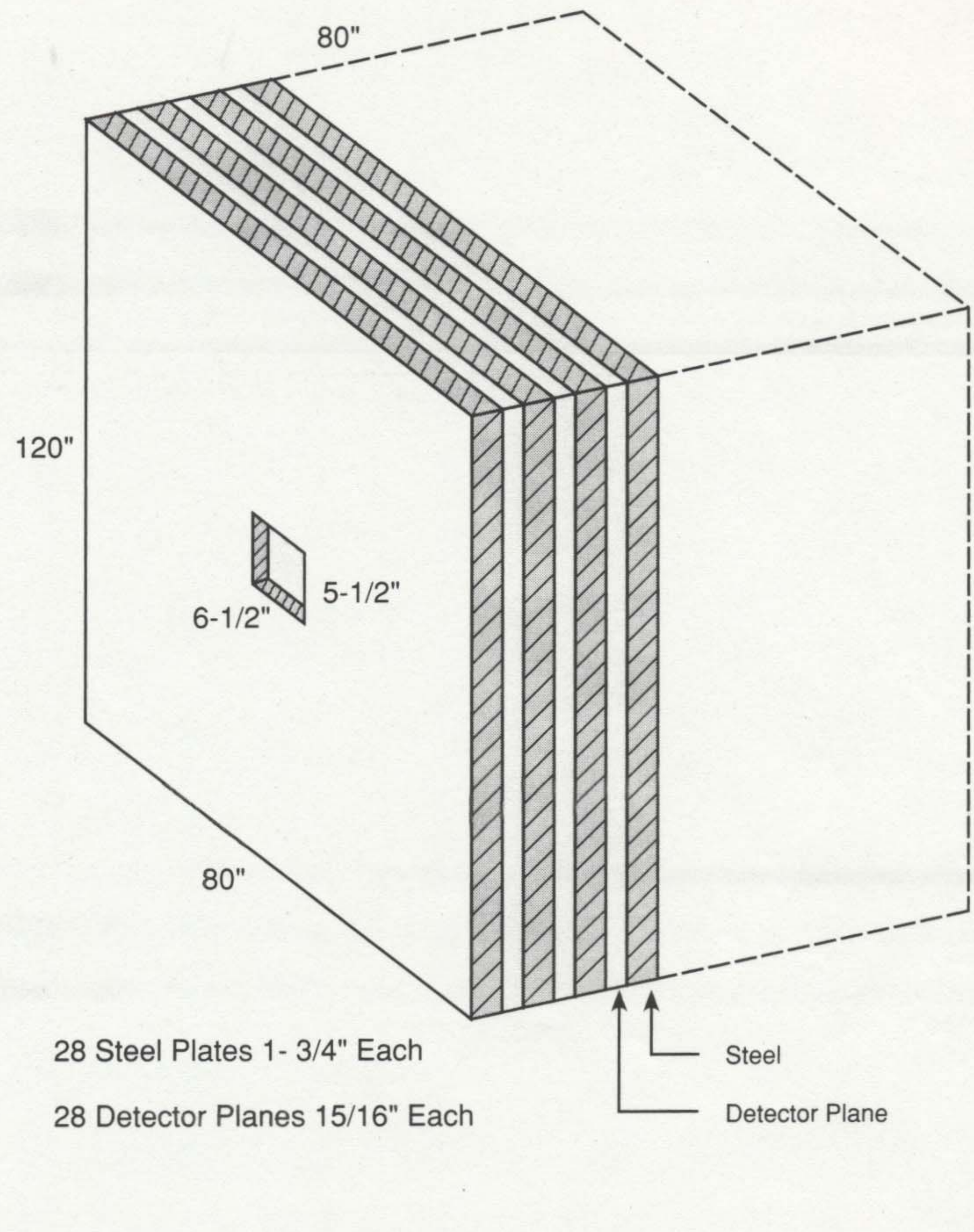


Figure C-1. Basic Construction of Hadron Calorimeter.

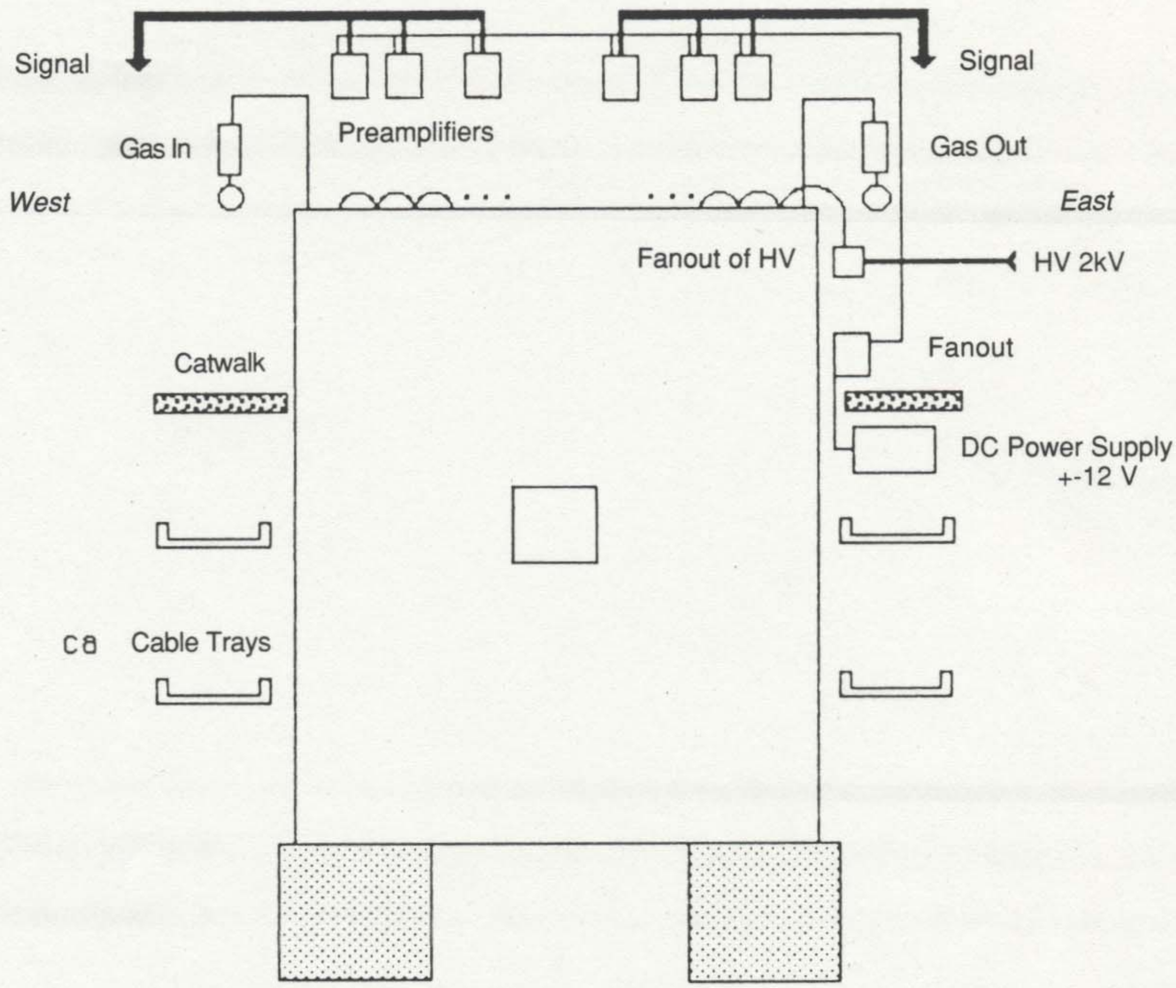


Figure C-2. Schematic of HC and Support Systems.

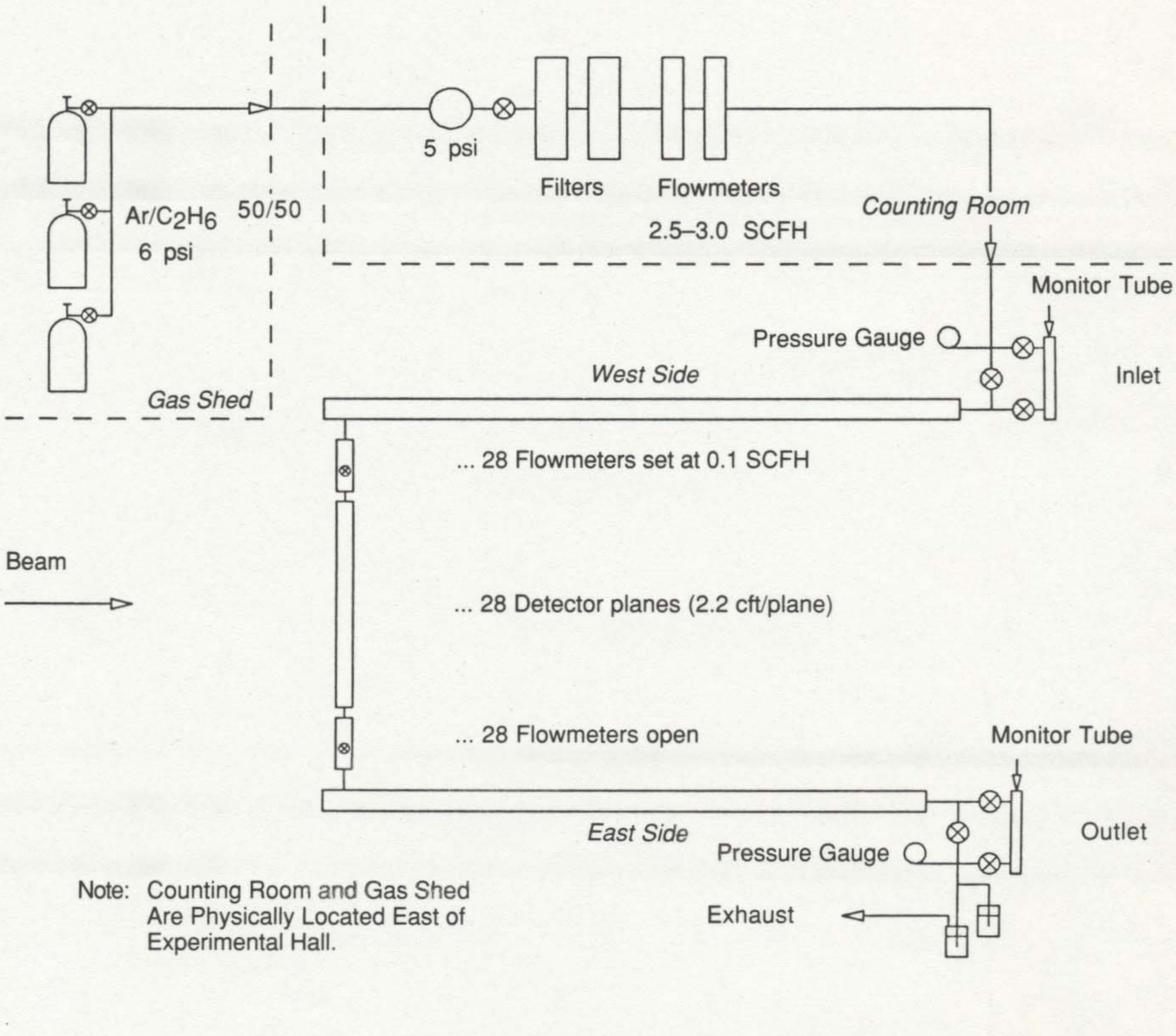
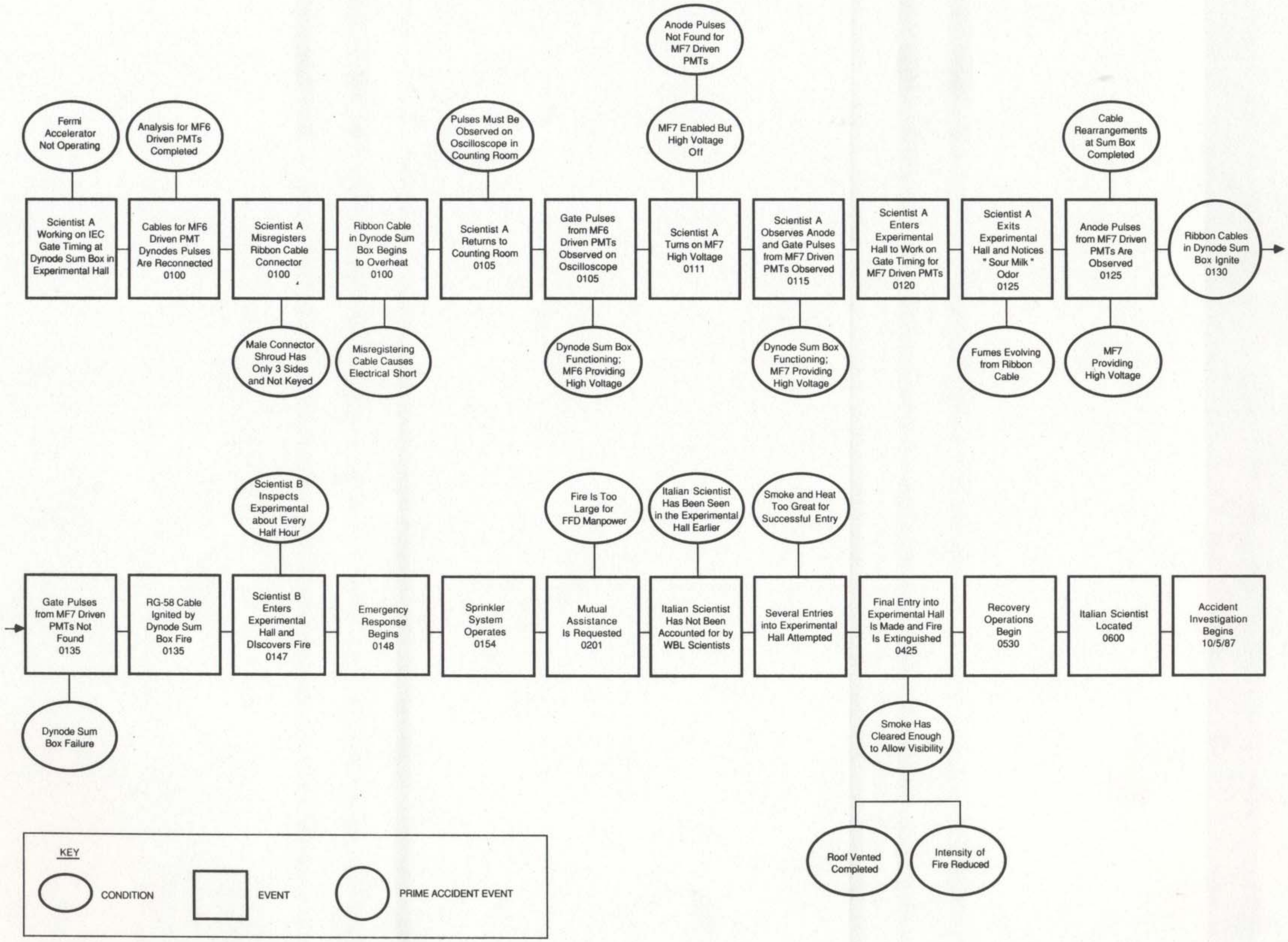


Figure C-3. HC Gas System.

APPENDIX D

CAUSAL FACTORS SEQUENCE CHART

Wide Band Laboratory Fire
Fermi National Accelerator Laboratory
October 3, 1987



Causal Factors Flow Chart.

APPENDIX E

ABBREVIATIONS USED IN THE REPORT

ANL	Argonne National Laboratory
BFD	Batavia Fire Department
C1-C3	Cerenkov Counters Nos. 1-3
CO	Communications Operator
DOE	U. S. Department of Energy
EP	Extraction Procedure
E683	FNAL Experiment No. 683
E687	FNAL Experiment No. 687
FFD	Fermi National Accelerator Laboratory Fire Department
FNAL	Fermi National Accelerator Laboratory
HC	Hadron Calorimeter
HxV	Horizontal x Vertical Hodoscope Detector
IEC	Inner Electromagnetic Calorimeter
LLNL	Lawrence Livermore National Laboratory
MF	Main Frame High Voltage Power Supply
MU1-MU2	Muon Detectors Nos. 1-2
OEC	Outer Electromagnetic Calorimeter
P0-P4	Proportional Wire Chambers Nos. 0-4
PMMA	Polymethyl Methacrylate
PMT	Photomultiplier Tube
PVC	Polyvinyl Chloride
RD	Research Division
SCBA	Self Contained Breathing Apparatus
UC	Uranium Calorimeter