A Report on Fermilab's Full-Scale Horizontal Cable-Tray Fire Tests

by William M. Riches

Preface

Fire is the lurking nemesis of any high-energy physics program. A costly, complex array of equipment that requires years of assembly, and that is situated in enclosed spaces, can be decimated in an instant by a fire. The time required to recover from such an incident could be devastating to a laboratory's mission.

At the urging of Fermilab Director Leon M. Lederman, and already in possession of a recommendation that all of the Lab's accelerator, beamline, and experimental enclosures be equipped with fire-suppression sprinkler systems, the Fermilab Safety Section conducted extensive tests of the most likely source of fire in an accelerator complex: the unassuming horizontal cable tray, where possible combustion raised the specter of a fire racing the length of an accelerator or an experimental hall.

What follows is a synopsis of the introduction to a lengthy analysis of Fermilab's cable-tray fire tests. This information has already been made available to the Department of Energy and other interested parties. Detailed descriptions of each fire test, including sketches of cable-tray configuration and contents, instrumentation, ventilation rates, Fermilab Fire Department observations, photographs, and graphs of thermocouple temperatures are available in a complete test report from the Fermilab Safety Section. - Larry Coulson
Head, Fermilab Safety Section

Introduction

In recent years, there has been much discussion throughout industry and various governmental and fire protection agencies relative to the flammability and fire propagation characteristics of electrical cables in open cable trays. It has been acknowledged that under actual fire conditions, in the presence of other combustibles, electrical cable insulation can contribute to combustible fire loading and toxicity of smoke generation. Considerable research has been conducted on vertical cable-tray fire propagation[†], mostly under small-scale laboratory conditions, but little was known about horizontal cable trays.

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Between July 1987 and June 1988, Fermilab initiated a program of full-scale, horizontal cable-tray fire tests, in the absence of other building combustible loading, to determine the flammability and rate of horizontal fire propagation in cable tray configurations and cable mixes typical of those existing in underground tunnel enclosures and support buildings at the Laboratory. The series of tests addressed the effects of ventilation rates and cable tray fill, fire-fighting techniques, and effectiveness and value of automatic sprinklers, smoke detection, and cable-coating fire barriers in detecting, controlling, or extinguishing a cable-tray fire.

Environment

The many miles of accelerator and beamline underground concrete tunnel enclosures contain beam pipe, electromagnets, water-cooled electrical bus, cooling-water piping, and electrical power, signal, and control cables installed in horizontal single and multiple stacked cable trays. Power supplies and electronic control equipment are located in adjacent above-ground support buildings and are connected to the tunnel equipment through sealed vertical pipe penetrations. Large, high-bay experiment halls located at the ends of the various beamlines, a mile or more downstream from the Switchyard, house large particle detector equipment and are connected by sealed horizontal pipe penetrations to adjacent electronic counting houses. In addition to the accelerator and beamline enclosures, the Antiproton Ring and Transport Line represents another two-thirds of a mile of underground enclosures containing equipment similar to that in the accelerator enclosures.

Fire Protection

Above-ground experimental halls, support buildings, and counting houses are protected with a combination of automatic sprinklers, Halon 1301 suppression systems, smoke detection, heat detection, portable fire extinguishers, hose cabinets, and exterior fire hydrants as appropriate. However, because of the non-combustible construction and mainly non-combustible contents in the underground enclosures, together with their enormous lengths, fire suppression systems are not provided in the underground enclosures. Due to radiation levels experienced in some portions of the enclosures, ionization or photoelectric smoke detectors are not practical or functional. The 24-hour/day on-site Fermilab Fire Department provides a four-minute response time to all accelerator and beamline locations upon fire alarm notification via a site-wide supervisory alarm system, FIRUS-88.

The Cable-Tray Fire-Test Program

The Laboratory conducted a physical survey of accelerator and beamline enclosures to establish typical cable-tray configurations and cable contents, including quantities and types of cables and their insulation. This survey resulted in a plan to conduct a total of five burn tests, complete with thermocouple instrumentation, videotape, and photography documentation, fire-fighter observations, and qualitative smoke analysis. Because of information gathered in the first five tests, the program was expanded to a total of 14 burn tests.

The simulations of cable-tray configurations included those found in the Main Ring, the Booster Tunnel, the NMO enclosure, the New Muon Lab NMS, and the Collider Detector at Fermilab's movable cableway.

Since the main purpose of this series of cable-tray fire tests was to determine the flammability of cable insulation, rate of horizontal flame propagation, and possible benefit of automatic fire suppression systems in typical Fermilab underground enclosures, no effort was made to measure the probability or ease of ignition of the cables. With no other combustibles present, it was assumed that ignition could occur due to an overheated magnet or an electrical short circuit in the cable tray. To this end, every effort was made to ignite the cable insulation, including increasing the propane burner intensity from 20 kW to 40 kW and extending the burner ignition time to more than 60 minutes during some tests. These tests, therefore, represented "worst case" conditions. In actual field conditions, it is highly unlikely that any probable ignition source would be sustained for the duration of time utilized in the tests. For the same reasons, smoke generation during the tests represented "worst case" conditions.

The Cable-Tray Fire-Test Facility

A fire-test facility was constructed utilizing 10-ft-long by 12-ft-diameter precast concrete Main Ring enclosure sections set on a concrete slab to form a 65-ft-long tunnel, exactly duplicating the Main Ring. Each end was enclosed with a plywood wall and door. Variable-volume fans were installed in a wall opening at the upstream end with inside horizontal plywood directional baffles to provide laminar air flow through the tunnel; adjustable louvers discharging into a smoke chimney were installed in the downstream wall. Floor-standing fans were also used to assist in controlling air velocity and laminar air flow. Since several of the early tests were conducted during winter weather, electric and propane heaters were used to maintain tunnel temperatures.

Single-, double-, or multiple-stacked 24-ft-long cable trays with various cable quantities and mixes were supported on unistrut along one wall near the center of the tunnel. An adjustable volume, 20-40 kW, 12-in.-diameter propane burner with a gravel diffuser was placed 6 inches below the cable tray to be burned. A total of 30 thermocouples were surface mounted and embedded in the cable bundles and connected to a data logger located in a van outside the tunnel. Thermocouple temperatures were recorded every 60 seconds during the course of the burn tests.

Pre-burn and post-burn photographs and a videotape camera inside the tunnel during each burn provided documentation for each test. Fermilab Fire Department observers with air packs and radio communication were located inside the tunnel during each test. Qualitative smoke monitoring equipment was installed at the exhaust louvers and chimney at the downstream end of the test enclosure.

An open-burning permit was obtained from the State of Illinois Environmental Protection Agency prior to the start of the test series. Burn residue was sampled, tested, and disposed of as hazardous waste where required. All tests were observed by representatives of the Department of Energy.

Fire-Test Results

The salient finding was that high-intensity fires with fast flame propagation in horizontal cable installations in Fermilab underground enclosures is highly improbable, if not impossible, in the presence of adequate sealing of penetrations to above-ground support facilities.

Specifically, ignition of the larger-sized power cables could not be achieved during any of the tests. PVC-insulated cables self-extinguished with a minimum of flame propagation. Twist'n'flat planar cables would not support combustion.

Only the polyethylene-insulated Hardline coaxial cables and the polyethylene-insulated flat-ribbon cable supported horizontal flame propagation with accompanying dripping of flaming insulation, but at an extremely slow propagation rate. In the case of the Hardline cable, this rate was a very slow 1.7 inches/minute, which could go undetected for a considerable period of time. In such cases, a very-early-warning smoke detection system might be appropriate. An alternative was presented by an intumescent-paint cable coating applied at selected intervals to the total cable bundle after the cables were placed in the tray. This proved to be a very effective fire barrier for both horizontal and vertical Hardline cable runs.

After 2.5-3 minutes of burner ignition to the Hardline cables, the out-gassing pressure build-ups inside the cable ruptured the aluminum casing causing a minor explosion, fireball, and heavy smoke generation. The subsequent horizontal flame propagation along the outer polyethylene jacket was of low intensity with only light smoke generation.

Although cables were placed in the trays in a rather random fashion with loose compaction as would be found in the field, it became apparent during the fire-test series that resistance to ignition and flame propagation increased with greater cable densities and compaction.

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

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

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

Automatic sprinkler systems in Fermilab underground enclosures would be of little benefit and would not be cost-effective due to the low heat-release rate and very slow flame propagation, if any, in horizontal cable trays. Automatic sprinkler systems would also be ineffective in minimizing potential smoke damage. The presence of an automatic sprinkler or fire detection system would not prevent a cable-tray fire, but rather would only limit the time for possible slow flame propagation before extinguishment. Property loss value would not be a major factor. Accelerator or experimental beam time would be lost in any case, with an estimated one person-week recovery time. During an operating period, such an outage could undoubtedly also be used to accomplish desired elective maintenance and development work.

Observations by Fermilab Fire Department personnel located in the fire test tunnel during each test indicated no problem in heat build up, no appreciable increase in flame propagation as a result of increased ventilation rates, and no serious visibility problems. Any flame propagation was very slow and easily contained by portable fire extinguishers. The greatest surprise was the violence of the short-lived Hardline cable explosions, but once finished, there was no problem in fire containment or extinguishment. The deep-seated fire and re-ignition in the CDF moveable cableway test was also a surprise to the Fire Department but represented no problem in containment or extinguishment due to its very slow propagation. Early detection was proven to be of much greater importance than the presence of automatic suppression systems.

† **Note:** It is important to emphasize that the results of these tests are not indicative of the fire-propagation characteristics of *vertical* cable trays, particularly where ducts are present. Please consult the pertinent literature for results of vertical cable-tray tests.