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EXPERIMENTS AND TARGET–GAS STORAGE AT THE CEA AT THE TIME OF THE JULY 5, 1965 ACCIDENT AND FIRE*

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INTRODUCTION

This paper is concerned with the experimental systems and the materials which contributed to the explosion and fire of July 5, 1965, at the Cambridge Electron Accelerator (CEA) [1].

The CEA is a 6-BeV electron synchrotron [2] located at Harvard University and is managed jointly by M.I.T. and Harvard. Used by scientists from several universities, it has been operating since 1961. Most of the particle detection apparatus and related equipment for experiments is located in a main experimental hall, 100 ft × 300 ft in plan dimensions, which can accommodate six electron-photon beams.

Figure 1 shows the various experiments in the hall at the time of the accident. Most experiments are located along beam paths and are separated from each other by 8-ft-high concrete radiation walls. Normally, the accelerator operates on a continuous basis, with periodic shut-downs for repairs. The support facilities, such as the machine shop, electronics, and cryogenics, are located adjacent to the experimental hall.

Experiments being carried out at this facility used liquid hydrogen for beam targets and hydrocarbon gases for particle analysis equipment. Other inflammables, such as oxyacetylene, oil, and liquefied petroleum gas, used in support equipment were located in the hall. The fuel sources in the hall that contributed significantly to the fire included: 500 liters of liquid hydrogen from a bubble chamber, 300 lb of propane stored in gas cylinders for use in Cerenkov counters, 20 lb of propane from a Cerenkov counter, two 100-lb LPG cylinders for an emergency power generator, and two oxyacetylene setups. Several other fuels that were present, including gaseous hydrogen, butane, and ethylene, did not burn.

EXPERIMENTAL ARRANGEMENT

Several experiments were in various stages of completion at the time of the accident. A brief description of each follows.

Photoproduction of Mesons (Beam 4)

This experiment was in the process of being assembled at the time of the fire. The

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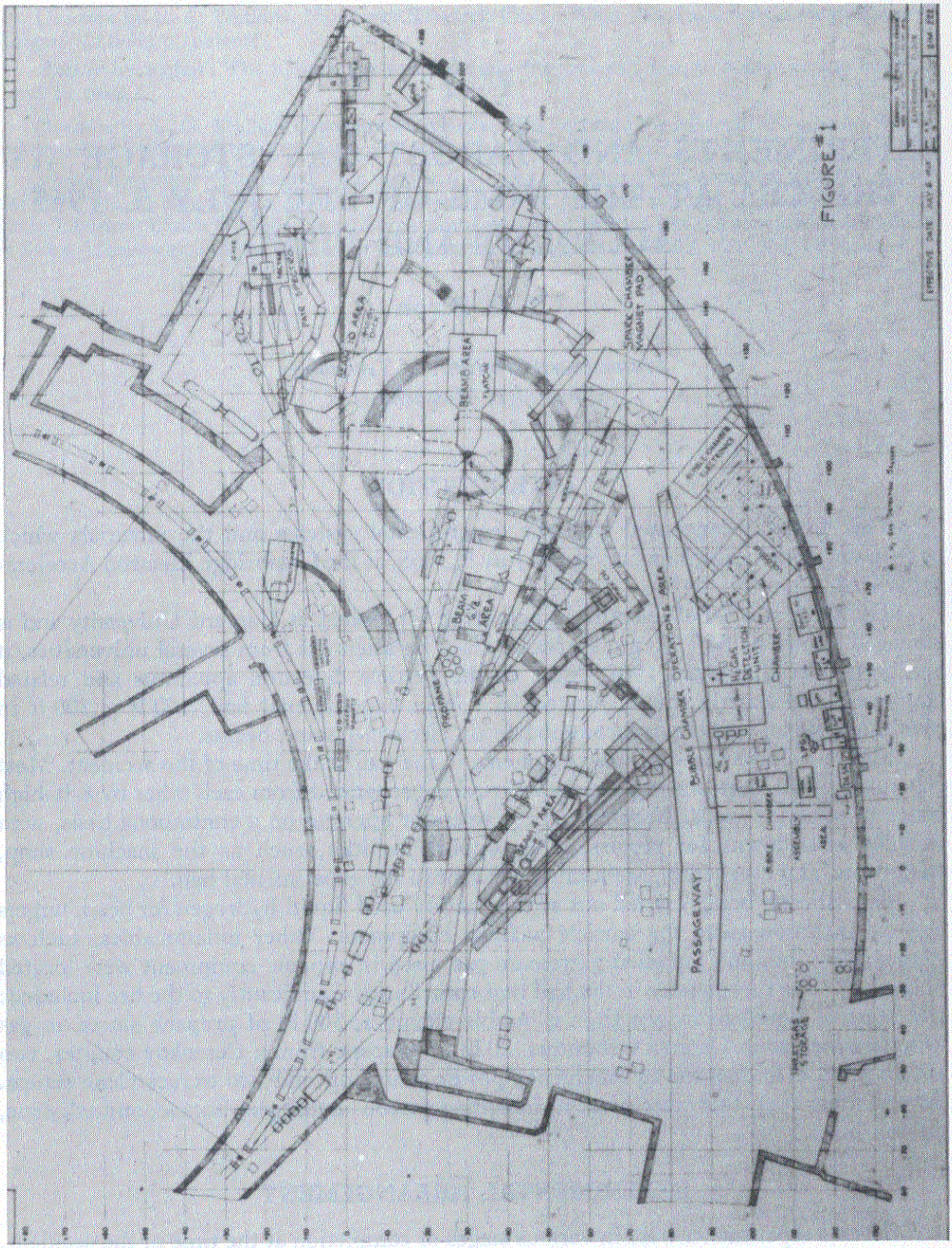

Fig. 1. Experimental floor.

equipment located in the area consisted of a one-liter liquid hydrogen target facility, a 1500-psi carbon dioxide Cerenkov counter, scintillation counters, beam transport magnets, and several CO_2 cylinders to be used in the counter. The hydrogen target and Cerenkov counter were empty, but a 200-scf hydrogen bottle was located at the control console.

Photoproduction of Mesons (Beam $6\frac{1}{2}$)

Equipment in this area included a hydrogen target facility, two 150-ft^3 propane Cerenkov counters, one 30-ft^3 ethylene Cerenkov counter, the beam transport system, six propane cylinders, and four ethylene cylinders.

The propane counters were 5-ft-long, 5-ft-diameter steel cylinders with a 12-in. flanged opening at one end that was sealed with three layers of 14-mil Mylar clamped between metal flanges. One of the two counters was active and it contained 20 lb of propane. The ethylene counter consisted of a 5-ft-long, 8-in.-diameter flanged pipe sealed by two thin stainless-steel diaphragms clamped at each end.

The hydrogen target had been removed prior to the fire but the control console located just outside the area had a 200-scf hydrogen cylinder secured to it.

Spark Chamber (Beam $6\frac{1}{2}$)

This group was located in the same area as the above-mentioned experiment. The equipment included a small spark chamber and the electronic equipment which was in operation at the time of the accident.

Bubble Chamber Equipment

The bubble chamber experimental complex, which included the chamber and magnet assembly, hydrogen purification equipment, refrigerator, film processor, auxiliary power generator, and associated support equipment, was located behind beams $4\frac{1}{2}$ and $6\frac{1}{2}$. The chamber was being filled with hydrogen for the first time. Approximately 500 liters of liquid hydrogen had been condensed in it.

Scattering Experiment. An electron–proton scattering experiment, including a hydrogen target facility, butane gas Cerenkov counter, beam transport and one cylinder of butane, was inactive at the time of the fire.

Photoproduction Mesons (Beam 10). This experiment was the prime beam user and was active at the time of the fire. Equipment included a full 1-liter target facility, Freon-gas Cerenkov counter, beamport transport system, and analysis equipment.

ARRANGEMENTS FOR FLAMMABLE GASES

Storage

All commercial gas bottles used at the CEA normally were stored in the hall. However, the hydrogen-gas supply trailer for the bubble chamber was located outside the hall in a fenced-off area. Since the bulk of the inflammable hydrocarbons were used by experimenters, these cylinders normally were stored within the confines of the respective experiment. The cylinders were secured to special stands provided by the laboratory. Experimenters were responsible for the control of these gases. For operation, each target facility required one 200-scf hydrogen cylinder, which normally was secured to the target control console.

Experimental Equipment

Special consideration was given to the design of experimental equipment containing flammable gases, particularly that containing liquid hydrogen. Emphasis was placed

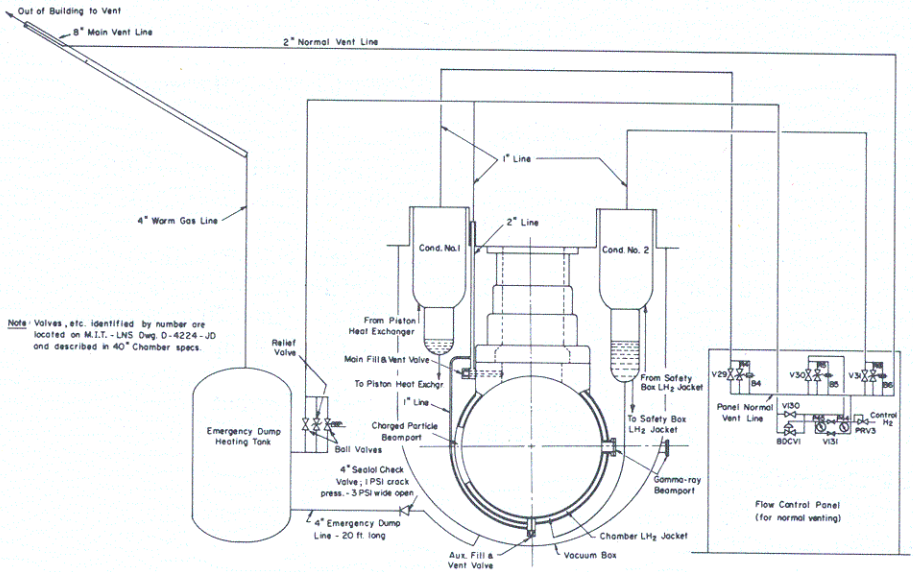

Fig. 2. Bubble chamber dumping and venting systems.

on the reduction of hydrogen quantity to a minimum. The laboratory designed and constructed a closed-cycle helium refrigerator for the bubble chamber system, a helium liquefier, and several hydrogen target facilities that were intended for utilization of the liquid helium from the aforementioned liquefier as a source of refrigeration. Target systems at other laboratories use liquid hydrogen as a source of refrigeration. These design considerations not only make it possible to reduce the overall inventory of liquid but eliminated the problems associated with liquid transfer and continuous venting of hydrogen. The maximum quantity of hydrogen tolerated in target systems never exceeded 2 liters; the maximum quantity of hydrogen associated with hydrogen-refrigerated 2-liter targets is approximately 45 liters.

Venting

There were three basic venting systems employed at the CEA for inflammables used with experiments. The main laboratory ventilation system, local exhaust systems associated with experiments, and a bubble-chamber venting system. The general philosophy was to provide maximum protection at all times. Eleven ceiling fans located on a platform along the inside wall of the experimental hall provided 215,000 cfm of air continuously into the one-million-ft^3 building. The flow of air from these fans is across the floor and upward to a continuous vent along the outer periphery of the entire ceiling. Some air was directed across the ceiling to eliminate pocketing of the lighter-than-air inflammables. All service areas in direct communication with the experimental hall were kept under positive pressure and provided additional air into the building.

Venting of inflammables from targets and Cerenkov counters was through several stacks to the outside. Exhaust fans connected to each vent provided a continuous flow of diluent to maintain the concentration below the flammable limits during normal and abnormal venting conditions. Collection manifolds (envelopes) around the lower areas of Cerenkov counters, containing heavy hydrocarbons, exhausted small leaks. Vent stacks

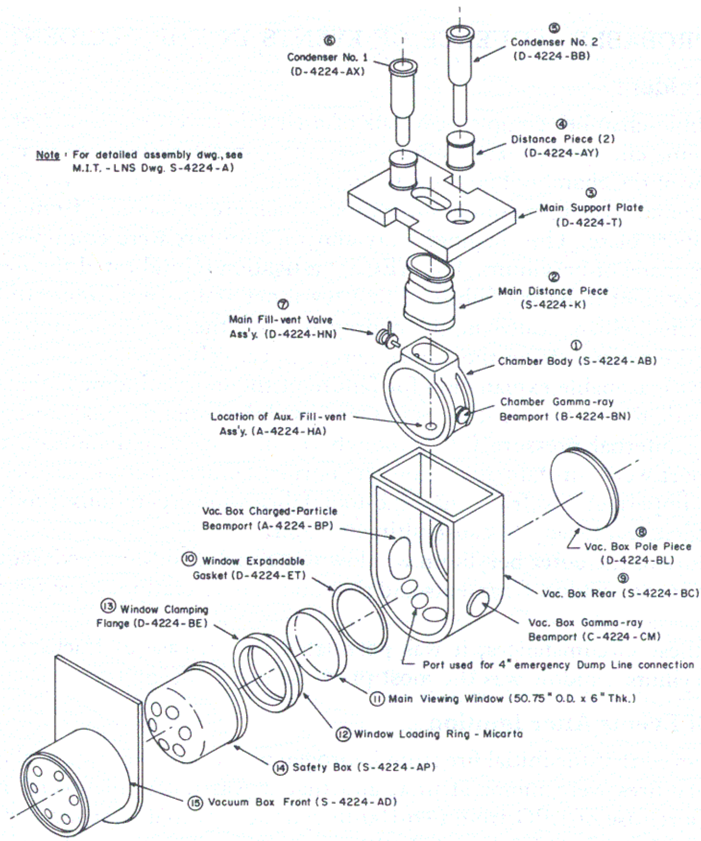

Fig. 3. General expanded view of 40-in. bubble chamber, showing order of assembly of major components exclusive of expansion system.

normally were extended several feet above the roof and were provided with special diffusers.

Several means of venting the bubble-chamber system were provided, as shown in Fig. 2. All dump and vent valves were connected to either a normal vent or an emergency vent. The normal vent line extended directly to the out-of-doors, and the emergency dump line was connected to an emergency dump tank. This vessel contained several tons of copper shot that would provide sufficient heat capacity and heat-transfer surface to warm the hydrogen prior to being dumped outside. The exhausting hydrogen was of sufficiently low density to ensure rapid diffusion in the air. A hydrogen-detection system monitored conditions in the bubble chamber area.

Ignition Source Controls

As a general rule, most of the electrical equipment in the hall was not of an explosion-proof design. Continuous ventilation was provided to dilute any leakage of inflammables below the flammable limit. A four-minute air change by the building ventilation system and local exhaust fans was the main line of ignition prevention. Some of the electrical equipment in the bubble-chamber complex, however, was explosion-proof.

PROBABLE SEQUENCE OF EVENTS IN THE ACCIDENT

Cause of Accident

The bubble-chamber complex consists of a chamber, refrigeration system, magnet, vacuum system, emergency vent system, and the control system. Figure 3 shows an exploded view of the chamber body, safety box, main viewing window, vacuum box, main distance piece and hydrogen condensors, all of which are suspended from and sealed to the main support plate. The chamber body and vacuum box were equipped with beamport windows made of beryllium. The AEC investigation [1] indicated the most probable cause of the accident to be the failure of first the inner and then the outer of these beryllium beamports, which sealed liquid hydrogen from the bubble-chamber insulating-vacuum and the vacuum from the atmosphere, respectively.

The most reasonable explanation for failure of the inner window is that it fractured in a brittle mode due to biaxial stresses induced by differential thermal contraction forces as well as by internal pressure [3]. Although calculations would indicate that stresses in the beamport were substantially below the normal failure levels, it has been suggested that surface imperfections from machine-tool fabrication operations produced stress-raisers of sufficient intensity to cause ultimate failure.

The failure of the outer beryllium window was concluded to be a consequence of the impact of the inner-window fragments and the sudden temperature shock from the hydrogen.

Under these circumstances, it was postulated that release of fracture energy from the outer beryllium window was the most probable source of ignition.

Sequence of Events After Ignition

It is believed that the initial fire from hydrogen in the chamber was of short duration, that secondary fires were minor at first, and that it was not until several minutes had elapsed that a release of LPG from two 100-lb cylinders caused a second explosion. This accelerated burning of roofing materials throughout the area—the Mylar window on the propane Cerenkov counter, weakened by heat from burning roofing, failed. About 20 min after the second explosion, the intense heat in the hall caused a pressure rise, followed by failure of the relief valves of the six propane cylinders in the Beam $6\frac{1}{2}$ area. Ignition of this gas caused an intense fire of long duration. The final stages of the fire involved the burning of large quantities of flammable roofing tar and insulation.

CONCLUSIONS

It is believed that a different system for storing flammable gases used in the Experimental Hall would have resulted in considerably less physical damage due to the accident. The bubble chamber, named as the site of the most probable cause, contained only about 15% by weight of all the gaseous fuels consumed in the fire; as pointed out earlier, this initial fire was thought to be of short duration.

Conscientious efforts were made by each group of experimenters to minimize the hazards associated with their equipment arrangements, and by the CEA to accommodate each group on the basis of its safety requirements. But, to a considerable extent, experiments were set up without concern for the hazards they might be subject to due to the presence of neighboring experiments. This clearly shows a need for integrated planning of equipment arrangements for all experiments sharing the floor of laboratories of this type.

More emphasis on the isolation of the Bubble Chamber-Magnet Assembly might have prevented the spread of fire. Isolation by totally enclosing the assembly in a structure of standard shield blocks, as is now done at some other laboratories, was not possible because of insufficient clearance under the building's overhead crane.

REFERENCES

1. "Summary Report Investigation of Explosion and Fire of Experimental Hall," TID—22594, Cambridge Electron Accelerator, Cambridge, Mass.
2. CEAL 1000, Cambridge Electron Accelerator, Cambridge, Mass.
3. "Investigation of Beryllium Windows from CEA Bubble Chamber," NYO—10742, Cambridge Electron Accelerator, Cambridge, Mass.

DISCUSSION

Question by W. Weleff, Aerojet-General Corporation: What is the safety factor used in the design for the beryllium components?

Answer by author: The calculated stress in the Be window due to the pressure and the mechanical interference was approximately 20,000 psi. The calculated stress due to the pressure only was of the order of magnitude of 8800 psi. The normal failure level of beryllium is approximately 55,000 psi for this condition. Most recent recommendations for designing with Be for pressure-vessel structures specify that the working stress levels be kept below 5000 psi.

Question by F. N. Olsen, Boeing Aircraft Company: Was the bubble chamber proof-tested (cold-shocked) at cryogenic temperatures prior to use?

Answer by author: All components that were constructed for the bubble chamber were individually tested prior to assembly. The entire assembly was then tested at liquid nitrogen temperature and at above-operating pressure.