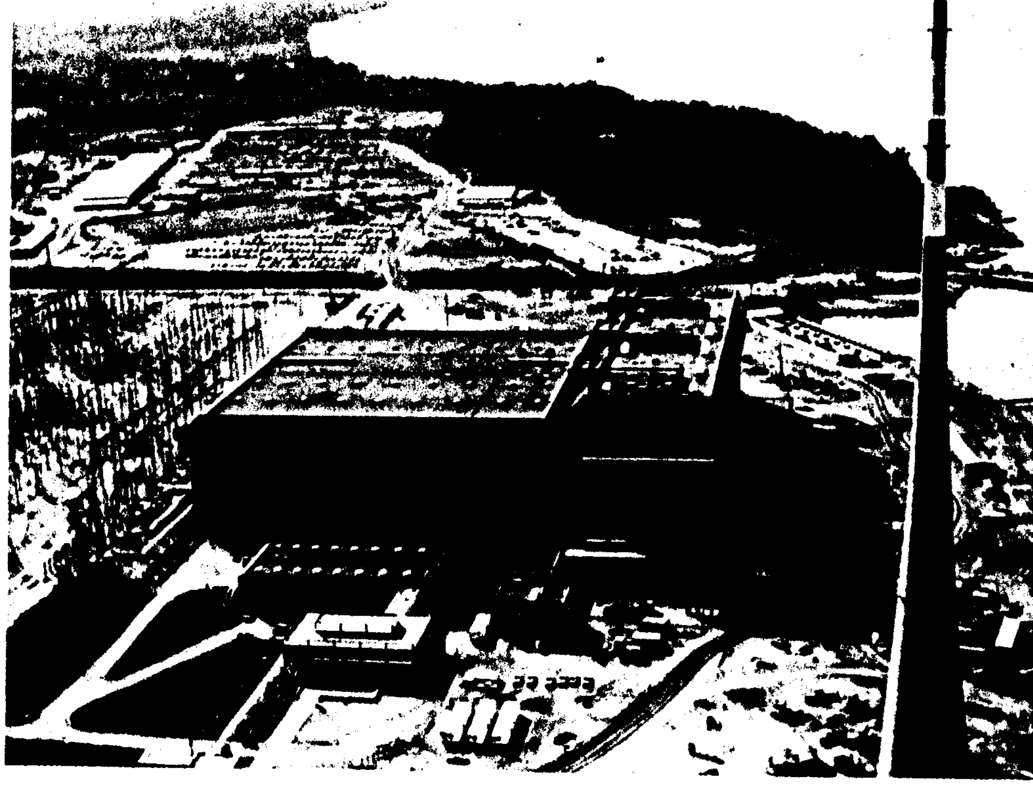
Cable Fire At Browns Ferry Nuclear Power Plant



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March 22, 1975 was the date of a major electrical cable system fire at the Browns Ferry Nuclear Power Plant of the Tennessee Valley Authority (TVA). The fire was accidentally started by an employee who was using a candle to check for air leaks through a fire wall penetration seal. The fire was not extinguished until seven hours after ignition and caused the shutdown of two nuclear generating units for over one year. Property damage at this self-insured facility is estimated at about $10 million, and the cost of replacement power was approximately $10 million per month. There was no release of radioactivity as a result of the fire.

The Browns Ferry Plant is situated along the Tennessee River near Decatur, Alabama. It is a three-unit plant utilizing three boiling water reactors (BWRs), each with an electrical capacity of 1,097 MW. Two units (1 and 2) were in commercial operation and the third unit was under construction, with completion expected in 1976.

The BWRs at Browns Ferry utilize a direct cycle concept, in which heat from nuclear fission is used to generate steam in the reactor core. The steam is used in a typical turbine/condenser cycle for the production of electric power, as shown in Figure 1. Each reactor is provided with control rods that are used to shutdown ("scram") the reactor, either upon receipt of a signal from the reactor protective circuitry or upon action by the operators. It should be pointed out that reactors are inherently unable to detonate like a nuclear weapon. However, it is important that residual or "decay" heat present in the reactor core following a scram be removed under all conceivable circumstances, even after a hypothetical major pipe rupture.

In order to insure removal of decay heat in these highly unlikely situations, numerous redundant emergency core cooling systems (ECCS) are provided to inject cooling water to the core. With regard to the nuclear consequences of this fire, the concern was not successful reactor shutdown, but rather, the continued ability to control reactor temperatures. If the ability of all the reactor core cooling systems to function had been impaired, then the possibility of core meltdown would have been of significant concern. However, although a number of core cooling systems were adversely affected by the fire, a significant number of these systems remained functional and were successfully used to maintain satisfactory reactor temperatures.

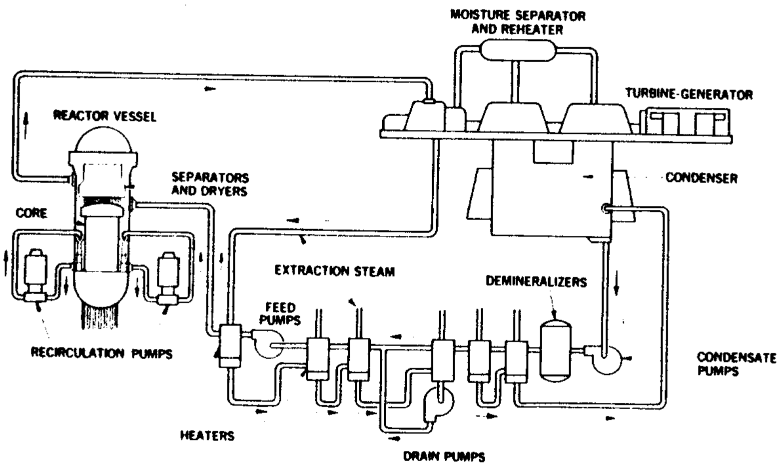


Figure 1. Direct cycle reactor power system. Steam generated in the reactor vessel is used directly to drive the turbine-generator.

At the outset, March 22 was a normal operating day. Units 1 and 2 were at 100 percent power and construction was proceeding on Unit 3 when the flame from the candle came into contact with polyurethane foam used in penetration seals between the Cable Spreading Room and the Reactor Building. The Cable Spreading Room is the distribution point where cables from the control board are routed to all areas of the plant. As shown in Figure 2, the reactor's primary containment has the shape of an inverted light bulb. The primary containment is located within the low leakage Reactor Building, which is maintained at a negative pressure to insure that air flow is inward. This precaution forces any potential contamination to remain inside. The start-up of Unit 3 would necessitate maintaining the third Reactor Building at a negative pressure, in addition to the other two units. The increase in total volume reduces the amount of air inleakage that can be tolerated while still maintaining the allowed pressure differential. As a consequence, penetrations that had been left open during cable-pulling evolutions on Units 1 and 2 now had to be sealed.

The penetrations between the Cable Spreading Room, directly beneath the Control Room, and the Unit 1 Reactor Building were being checked for leakage. The wall between the Cable Spreading Room and the Reactor Building is of 26-inch-thick reinforced concrete. Cable trays carrying control and instrumentation wiring

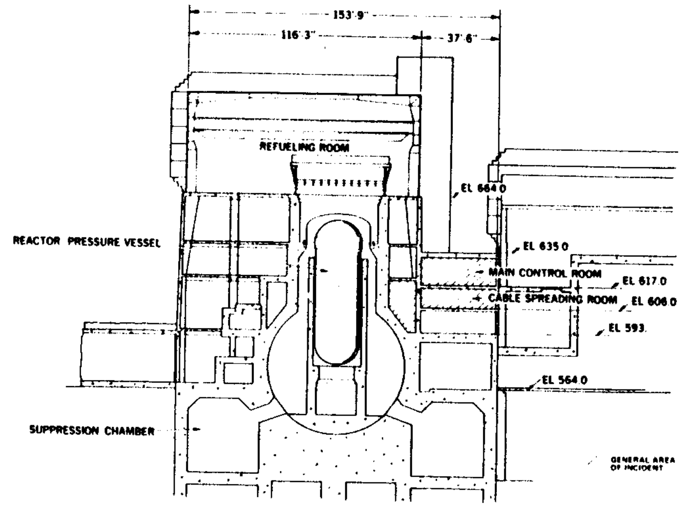


Figure 2. Reactor Building, Control Room, and Spreading Room.

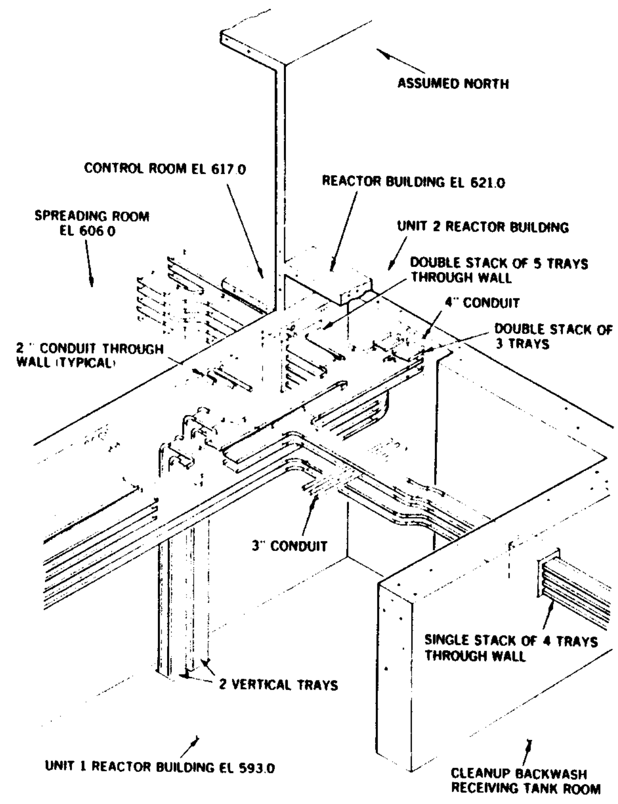


Figure 3. General area of the incident.

from the Cable Spreading Room to the Reactor Building butted up to either side of the wall (see Figure 3). Sleeves passed through a steel plate in the wall. To provide an air and fire seal in the sleeves, a polyurethane foam material was stuffed in around the cables. Foamed-in-place polyurethane was used to fill the sleeve; this was followed by application of a fire-retardant mass to cover the foam and provide a fire seal.

At the time of ignition, polyurethane foam sheeting had been stuffed in around the cables from the Cable

Spreading Room side of the wall. A candle was being used to check the efficiency of the blockage (the flickering of the flame would have revealed any leakage).

The fire started at approximately 12:20 pm when the flame from the candle was sucked into the penetration seal by the pressure differential, igniting the foam plastic sheeting. It should be noted that the actual seal was set back into the wall several inches, and was a difficult area to reach because of the congested cable trays. Immediate attempts to extinguish the flames by beating them out with a flashlight and smothering them with rags failed, and the first major fire in an operating nuclear power plant in the United States was under way.

FIRE CHRONOLOGY

Cable Spreading Room

12:30 pm. A portable carbon dioxide extinguisher was discharged onto the fire by an employee, and it appeared that the fire was out. However, after approximately one minute the fire reignited, and it was apparent that it had spread to the Reactor Building side of the wall. Two workers left the Cable Spreading Room at 12:30 to fight the fire in the Reactor Building. Additional carbon dioxide extinguishers were used by employees in the Cable Spreading Room during this period.

12:35 pm. One of the workers on his way to the Reactor Building stopped at a guard post manned by a Public Safety Service officer and informed the officer on duty that a fire was in progress in the Unit 1 Reactor Building. The worker then took a fire extinguisher from the guard post into the Reactor Building. The Public Safety officer immediately called the Control Room to report the fire. The Control Room received the first notification of fire at 12:35, nearly 15 minutes after the fire had started. The plant fire alarm was immediately sounded, and an announcement reporting a fire in the Reactor Building was made over the public address system. A short time later, the fire in the Cable Spreading Room was reported to the Control Room.

12:40 pm. The evacuation alarm was sounded in the Cable Spreading Room. A plant operator, after ensuring that all workers had been evacuated, attempted to manually discharge the fixed, total flooding, carbon dioxide system in the Cable Spreading Room. He was unable to discharge the carbon dioxide, as the initiating system had been de-energized because there were workers in the room. He then restored electrical power to the initiating system and discharged the carbon dioxide. Within a short time, the system was discharged again by another employee. An investigation showed that the fire was still burning on the Cable Spreading Room side of the wall. The ventilation system had not been shut off.

12:40 to 4:30 pm. The first organized fire fighting in the Cable Spreading Room began when an assistant shift engineer assumed charge of the plant fire brigade in this area. Fire fighting was continued, using portable carbon dioxide and dry chemical extinguishers. Access to the fire area was difficult because of the highly congested cable-tray system in the room. The carbon dioxide system was discharged a third time. The assistant shift engineer was relieved by an off-duty shift engineer, who took charge in the Cable Spreading Room at 3:00 pm. Fire fighting continued, and with the assistance of the Athens Fire Department, the fire in the Cable Spreading Room was suppressed by nearly continuous application of dry chemical and carbon dioxide extinguishing agents and declared out between 4:00 and 4:30 pm.

Reactor Building

12:35 pm. As fire-fighting efforts were being conducted in the Cable Spreading Room, fire-fighting operations under equally difficult conditions were being performed on the other side of the penetration in the Reactor Building. The workers who had left the Cable Spreading Room at 12:30 pm to fight the fire in the Reactor Building discovered that the fire was burning in the cable tray system, about 20 feet above the floor.

They obtained a ladder and discharged a dry chemical extinguisher on the fire. This knocked down the flames temporarily, but they flashed again. More carbon dioxide and dry chemical extinguishers were discharged on the fire, with little effect. An assistant shift engineer assumed charge of fire fighting in this area, and all construction workers were evacuated from the Reactor Building. Smoke was building up in the area, and breathing apparatus was requested and provided. Lack of visibility at this time drove all personnel away from the fire area.

1:10 pm. The assistant shift engineer in charge of the Reactor Building requested assistance from the Athens Fire Department at 1:10 pm. By 1:45, the Department's fire fighters had arrived at and entered the plant, and had been provided with routine film badges used to measure radiation exposure. The Athens Fire Chief made a survey of the fire, and by 2:00 pm recommended that water be used to extinguish the fire. However, the recommendation was not followed at that time.

1:30 to 4:30 pm. At approximately 1:30 pm, the lighting in the Reactor Building failed as a result of damaged cables. Between 2:30 and 3:00 pm, a guideline was provided and limited fire fighting was carried on, using portable carbon dioxide and dry chemical extinguishers. At this time, the fire was still confined to an area near the north wall. During this period, top priority was directed toward efforts to cool down the plant. Thus fire-fighting efforts were confined to extinguishing the fire in the Cable Spreading Room, in order to protect the Control Room above and prevent the loss of other vital equipment. The shift engineer, who had been directing fire-fighting activities in the Cable Spreading Room, took charge of activities in the Reactor Building at 4:30 pm.

4:30 to 6:00 pm. Limited fire fighting continued in the Reactor Building, and temporary lighting was provided shortly after 4:30 pm. Between 5:30 and 6:00 pm, the shift engineer readied a 1½-inch fire hose on the second level of the Reactor Building and made sure that water was available. The plant superintendent was reluctant to use water on the fire because he was afraid that the water would further degrade plant operations. The Athens Fire Chief again suggested that water be used to extinguish the fire. The shift engineer requested and received permission from the plant superintendent to use water to extinguish the fire.

7:00 to 7:30 pm. Not until some time between 7:00 and 7:20 pm was water discharged upon the fire, which had now been burning for seven hours. The nozzle on the 1½-inch plant hose was designed for use on electrical fires, and it was found that the water could reach only the lowest cable tray. The Fire Department attempted to use a nozzle from its apparatus, but the threads were not compatible. The nozzle came off when the hose line was pressurized. The original nozzle was reinstalled, and workers climbed up to the cable trays and discharged water directly onto the fire. The hose was wedged into position in the trays and left to discharge water onto the fire. At 7:30 pm, it was determined that the fire had been extinguished — seven hours and ten minutes after it had started.

Plant Operations

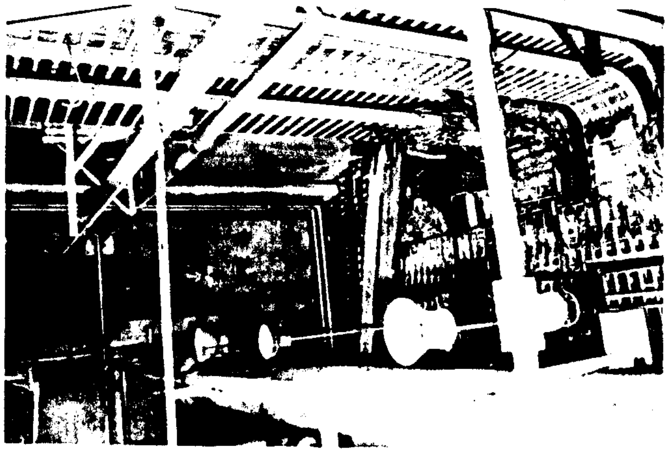
12:20 to 1:30 pm. From the time that the fire began in the Cable Spreading Room until 12:40 pm, the operators of the plant had maintained 100 percent power on both Units without any indication of operational problems. At 12:40 pm, alarms related to ECCS systems occurred on Unit 1 which were contrary to the observed status of the Unit. Between 12:45 and 12:48 pm, further unusual indications were observed on the Unit 1 control panels. At 12:51, the operator shut down Unit No. 1, while operations continued normally on Unit 2. By 1:00, abnormal indications had been received on Unit 2, and that reactor was also shut down. As the cable integrity deteriorated, plant safety systems were reverting to their designed fail-safe conditions, i.e., actuating ECCS systems, opening valves, etc. Since ECCS systems were not required for reactor cooling prior to about 1:03, when the main steam isolation valves failed to shut, the operator correctly secured the cooling pumps. Once the main steam isolation valves closed, the steam-driven feedwater pumps were lost and the reactor was isolated from its normal heat rejection system, the condenser. As a result of the cable fire, remote control of high-pressure and low-pressure water injection (ECCS) systems was now impossible for Unit 1, and alternate cooling means were necessary. Unit 2 was less affected by the fire, and high-pressure cooling water was still available. The decay heat stored in the cores caused pressures to rise on both units to the relief valve set points, where it stabilized. Eventually, the decision was made to depressurize Unit 2, using remote control of relief valves. Unit 2 was placed in its normal long-term, low-pressure cooling mode without any significant problem arising.

1:40 to 10:00 pm. Since Unit 1's high-pressure ECCS was inoperable, depressurization was begun at 1:40. Within about 20 minutes, the reactor was at a pressure low enough to allow cooling by the condensate booster pumps. During the depressurization — by remote actuation of relief valves — the water level in the reactor never went below four feet above the core. One final problem resulting from the fire affected the cooling of Unit 1. Between 6:30 and 9:50 pm, the remote control of relief valves was lost, causing the pressure to rise above the shutoff pressure of the booster pumps. However, the reactor vessel pressure and water transients were relatively slow. Adequate time was available to utilize other cooling methods if the relief valve control was not regained. By 9:50 pm, remote control of the valves had been restored.

In summary, the operational consequences of the fire were very complex and amply tested the "defense in depth" design philosophy of nuclear plants. Although numerous mechanical and electrical systems were rendered inoperable, the units were effectively shutdown and cooled, with some redundancy yet remaining. The fact that some of the redundant systems were lost because of a relatively localized fire raised valid and important questions as to the adequacy of cable separation criteria, fire protection systems, and fire prevention practices. It is important to state, however, that no radioactivity was released to the environment as a consequence of the fire. Contrary to some stated opinions, the Browns Ferry reactors did not hover at the brink of nuclear disaster.

Cable Tray Damage

The electrical cable system at the Browns Ferry Plant, as in any nuclear power plant, is an extensive system of instrumentation, control, and power cables. The cables were supported throughout the plant in open ladder-type cable trays that were tiered, with up to five trays



General view of fire damage in northeast corner of Reactor Building, showing extent of fire propagation downward in vertical trays.
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stacked above each other. The cable construction — insulation and jacket — consisted of the following materials:

Cable insulating materials: polyethylene, cross-linked polyethylene, high-density polyethylene, nylon-backed rubber tape, and an irradiated blend of polyolefins and polyethylene.

Cable jacket materials: Nylon, polyvinyl chloride, high-density polyethylene, polyvinyl, aluminum foil, chlorosulfated polyethylene, fiberglass-reinforced silicone tape, neoprene, and cross-linked polyethylene.

The wall penetration between the Cable Spreading Room and the Reactor Building was a 4-foot-by-4-foot opening through which the cables from ten 18-inch-wide-by-4-inch-high cable trays passed. The trays were arranged in two tiers of five trays each in the Cable Spreading Room. The trays terminated on each side of the penetration seal and did not pass completely through the wall. A steel plate was installed to fill the 4-foot-by-4-foot wall opening with rectangular, 5-inch-by-18-inch sleeves passing through the steel plate. The cables passed through these sleeves. Polyurethane foam sheeting was stuffed around the cables, and foamed-in-place polyurethane was applied to fill the remainder of the sleeve as an airtight seal. To provide a degree of fire protection, a fire-retardant mass was applied over the foam. A manual, total flooding, carbon dioxide system was provided in the Cable Spreading Room, but no fixed protection was provided for the cable trav runs in the Reactor Building.

The cable system in the Cable Spreading Room sustained severe damage for a distance of about three feet into the room from the penetration. Cable damage in the Reactor Building extended for about 20 feet outward and 40 feet parallel to the wall. In all, more than 1,600 cables in 26 cable trays were damaged in the fire. Of these cables, 482 were Unit 1 safety-related circuits, 22 were Unit 2 safety-related, and 114 were common to both Units. Aluminum conduits in the fire area were melted, and steel conduit was cracked. The only damage to piping systems was the failure of a soldered joint in an air supply line. Additional damage resulted from soot and smoke that contained corrosive deposits from the burning cable jackets and insulation. These deposits required an extensive cleanup, including disassembly of instruments and other equipment. The only permanent damage noted from corrosive deposits was confined to stainless-steel, thin-wall, instrument-tubing lines in or near the fire zone. There was no evidence of any damage resulting from water used for fire fighting.

DESIGN CHANGES RESULTING FROM THE FIRE

As the result of this fire, TVA (in cooperation with the Nuclear Regulatory Commission, the nuclear insurance pools, and other involved agencies) acted responsibly to carefully evaluate all aspects of this fire and extract lessons that can be utilized to prevent similar incidents at Browns Ferry and at other nuclear plants. The results of the evaluations are quite lengthy; however, a brief summary of major design changes is informative.

There will be modifications to Browns Ferry electrical systems that include selective relocation of conduits and rerouting of cables so that the effects of an electrical cable tray fire would be significantly reduced. Particularly important is the provision that such a fire will not affect more than one division of ECCS cables. Some supplemental techniques to be used include application of a listed flame-retardant cable coating of ⅛-inch thickness to exposed cable surfaces in areas of high cable density, and installation of firestops in certain cable trays where common mode failures could be caused by propagation of a cable tray fire.

The penetration design has been altered from the type involved in the fire. The sealant materials originally installed in existing penetrations will be removed, to the extent practicable, and will be replaced with a new sealant material. All new and repaired penetrations will be of a revised design that incorporates a silicone RTV® foam as sealant, and inorganic fiberboard as fire barriers.

The fire protection system will be augmented to provide increased ability to quickly terminate any future fires. A major change will be the installation of automatically actuated, fixed waterspray deluge systems. The deluge systems will be added in areas of high cable congestion, and will be initiated either by concurrent activation of both smoke and heat detector systems in the spray zone, or by local operator action. In addition, more throughout the plant.

A final design change of interest is the expansion of the plant's capability for recharging portable breathing apparatus. The modification provides for an air compressor and for purification equipment. The system will be able to charge 24 tanks an hour, in addition to a 1,200 standard cubic feet (scf) reservoir for immediate use.

CONCLUSIONS

The fire at Browns Ferry was important for three reasons, aside from the monetary loss. First, it showed that the "design in depth" philosophy of nuclear plants provides considerable margin to protect the public, even in the face of a severe, unplanned loss of redundant emergency systems, although the need for an in-depth review of separation criteria exists. Second, the use of water on cable fires was reaffirmed, since the use of water at an early stage in this fire would have extinguished it quickly and kept it from spreading to areas not already affected. The water would also have washed the corrosive vapors from the area and limited the extent of necessary cleanup. Third, the fire confirmed the fact that emphasis at a nuclear power plant must also be placed on the more conventional hazards, such as fire. The "defense in depth" theory present in nuclear design should also be made applicable to plant fire protection systems to ensure that fires will not affect the public. The lessons learned from this unfortunate incident provide insight into methods of enhancing the level of nuclear safety in an industry that has thus far maintained an unsurpassed safety record.

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