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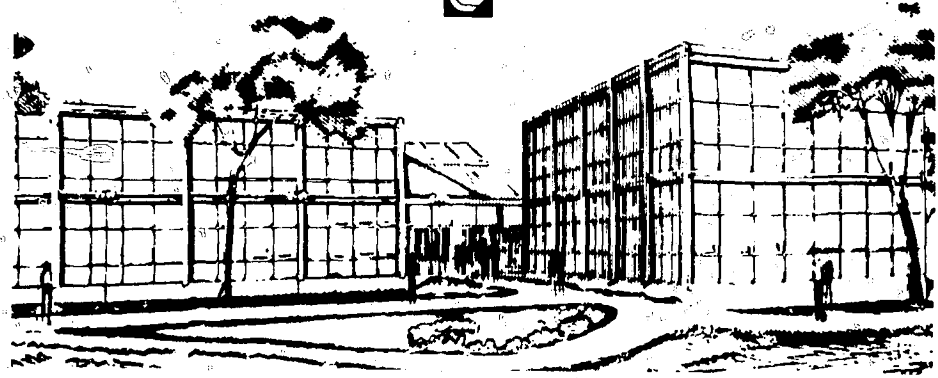

OPERATOR/INSTRUMENTATION INTERACTIONS DURING THE THREE MILE ISLAND INCIDENT

by

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Summary

This paper presents a discussion of the operator/instrumentation interactions which had an effect on the course of the incident at the Three Mile Island-2 Nuclear Power Plant. In the paper a brief review of the sequence of occurrences at TMI-2 over the first 16 hours of the incident is given with particular emphasis on operator/instrumentation interactions. A breakdown of the six major items that seemed to have contributed to the characteristics of the incident is then given and also an outline of some of the currently proposed operator/instrumentation improvements. The six major items involve water level indication in the reactor, electromatic relief valve operation, auxiliary feedwater flow indication, containment isolation, extended range instrumentation, and computer readout.

Introduction

On March 28, 1979, at 0400, a feedwater trip occurred at the Three Mile Island-2 (TMI-2) Nuclear Power Plant near Harrisburg, Pennsylvania[1,2,3,4]. During the next 16 hours substantial damage was done to the reactor core, and although there was no significant injury to the public, the accident seriously damaged the reactor and has had a profound impact on the future of nuclear power in this country. I plan on reviewing a number of the operator/instrumentation interactions which contributed to the course of this incident with the view that improvements are and will be made to prevent similar occurrences at nuclear power plants in the future. The incident itself was caused by operator, design, and equipment failures and I will be stressing the operator/instrumentation aspects of the incident.

Before reviewing the course of the incident, some history on the TMI-2 Nuclear Power Plant is needed. TMI-2 is a Babcock and Wilcox Company designed pressurized water reactor (PWR). It normally produces 905 MWe which is fed into the grid of the Metropolitan Edison Company, the electric utility servicing that area of Pennsylvania. TMI-2 first went critical in March of 1978 and achieved operational status in December 1978. Prior to March 28, the reactor had experienced five feedwater trips without damage. Such trips are considered a normal transient event from which the reactor is designed to recover without any damage. At the time of the incident, TMI-2 was running at 97% of full power with conditions normal.

The Babcock and Wilcox Company (B&W) is one of the three manufacturers of pressurized water reactors in this country. One of the distinguishing characteristics of B&W reactors is their use of once through steam generators (OTSG) of which TMI-2 had two. This type of steam generator has less of a feedwater inventory and thus boils dry more rapidly if feedwater flow is cut off.

Like other PWR's, TMI-2 has no boiling in the reactor core. The reactor coolant system (RCS) is comprised of two closed loops through which water is pumped up through the reactor core to pick up the heat from the fission process. This heat is transported from the core through hot legs to each OTSG where it is transferred to a working fluid circulating in a second pair of loops. The working fluid drives a conventional turbine-condenser system. After giving up its heat in the OTSG's the reactor coolant is returned to the core through two cold legs by two reactor coolants pumps per loop. Figure 1 is a schematic of this process.

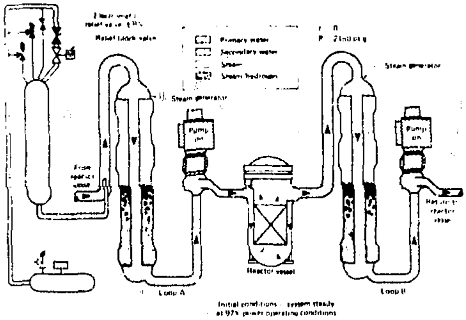

Figure 1. TMI-2 Configuration

High pressure and low pressure redundant backup cooling systems are provided to take care of the decay heat from the fission process should a loss of coolant accident occur. A large loss of coolant accident is the design basis accident for this type of reactor.

During normal operation the reactor heat is removed via the steam generators to the turbine-condenser system. When that system is not able to operate the reactor is tripped and the decay heat is either removed by natural or forced circulation. At all times, the reactor coolant must be kept above saturated conditions to preclude over heating of the tubes (cladding) that retain the uranium dioxide fuel pellets. The cladding is made of zirconium which, when heated above 2200°F, will react with the water to generate hydrogen. Forced cooling with liquid is required to keep this cladding from over heating even after shutdown of the fission process. It was the reaction of water with the zirconium clad that lead to the hydrogen generation at TMI-2.

Review of Incident

The incident started with a feedwater trip. Subsequently, it took the operating crew 16 hours to achieve a stable condition. Hydrogen evolution became a major concern and it was several days before the major danger was over. Several more weeks went by before natural circulation conditions were achieved and reactor cleanup is still underway. I will be concentrating in this paper on events which occurred during

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the first 16 hours. This is when the core damage occurred.

First 2.5 Hours

The trip of the feedwater pumps caused the turbine to trip resulting in a pressure rise in the reactor coolant system (RCS). This pressure rise caused the electromatic relief valve (ERV) on top of the pressurizer to open releasing steam to the Reactor Coolant Drain Tank (RCDT). This set of occurrences is expected to occur following a feedwater trip.

Following the opening of the ERV the reactor tripped causing the pressure to drop in the RCS. When the pressure dropped below the ERV set point, the valve did not close. This was an equipment failure. More than two hours passed before the operator noticed that the ERV was stuck open, in effect, creating a small loss of coolant accioent during that time period. Failure of the operator to detect the open ERV was an operator/instrumentation failure. The console demand signal indicated that the ERV was closed and a history of past leakage lead the operator to disregard the high temperature readings in the ERV tail pipe. These, among other things, were the cause of the slow response of the operator to the failure of the ERV.

Following the reactor trip, the auxiliary feedwater pumps automatically turned on but, unknown to the operator, the flow was blocked by closed valves on the pump discharge lines. The auxiliary feedwater system is the backup system that supplies water to the steam side of the OTSG's given a loss of main feedwater and without auxiliary feedwater flow the steam generators boiled dry in a few minutes. Lights on the console indicated that these valves were closed, but this was not noted for eight minutes.

With the ERV stuck open, there was a rapid insurge into the pressurizer leading the operators to think that the reactor coolant system was full. Operator training procedures emphasize the fact that the pressurizer should not be allowed to go solid or overpressurization of the RCS might result. For this reason, the operators disregarded the low RCS pressure and relied on the pressurizer level to indicate that the RCS was full of water. Low pressure in the RCS caused actuation of the high pressure back-up cooling system but injection was terminated because the level readings on the pressurizer indicated that the RCS was full. The operators had been trained to stop injection from this system as soon as possible following such a transient to prevent sodium hydroxide injection into the RCS. Indeed such a NaOH injection had happened previously in a similar transient at TMI-2.

At eight minutes into the incident, the operators discovered the closed auxiliary feedwater valves and opened them commencing flow into the steam generators. At 15 minutes into the incident, the RCDT ruptured because of the collected discharge from the stuck open ERV. This caused an increase in containment pressure. The operators, however, believed this pressure increase was caused by a broken steam generator tube assumed to have been ruptured by the sudden addition of cold auxiliary feedwater flow to the steam generator.

For the next hour or so the reactor coolant inventory continued to be dissipated through the open ERV until cavitation conditions necessitated the tripping of the reactor coolant pumps. At two hours and 20 minutes into the incident, the open ERV was discovered and it's block valve closed. At that time, substantial fractions of the core were uncovered and the zirconium clad was over heated and evolving hydrogen. The operating staff, however, still believed that the core was covered and it would be many hours before they discovered that it had been uncovered.

Efforts to Establish Stable Conditions

For the next 14 hours, the operating staff attempted to establish either forced or natural circulation cooling, finally, establishing forced circulation through one loop. During this period, a hydrogen explosion occurred in the containment resulting in a 28 psig pressure spike and actuation of the containment spray system. The hydrogen explosion was not recognized by the operating staff as such at the time. They thought that the core sprays came on because of electrical problems or ERV operation. Failure to note that there was a large inventory of hydrogen in the reactor and the containment made the stablization of the transient more protracted.

During this period, several other operator/instrumentation problems can be noted. The containment sump pump automatically came on several hours into the incident and transferred radioactive water from the containment floor to the auxiliary building. Also there were difficulties in obtaining samples of RCS water and this lead to the contamination and evacuation of the emergency control center which had been set up near the control room. This sampling difficulty and the high background radiation levels from the released noble gases prevented the operating crew from making an early identification of the types and quantities of the fission products which had been released.

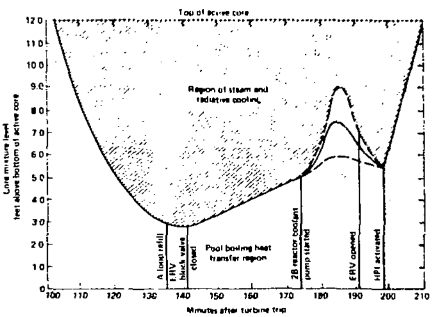

Figure 2. Core Mixture Level

A review of the water level in the reactor core is given in Fig. 2. As can be seen, the level continued to decrease for two hours until the ERV block valve was closed. The high pressure injection system makeup into the reactor then caused the reactor water level to rise. A reactor coolant pump was started at approximately 175 min. after the incident started. Saturated conditions prevented the continued operation of this pump but it delivered a surge of water into the core which is believed to have caused a certain amount of damage. As can be seen, the core was uncovered for a considerable length of time.

Operator/Instrumentation Problems

In Table 1, we have listed six major operator/instrumentation interaction problems. We will now discuss each of these individually.

Table 1

1. Reactor coolant system water level indication
2. Electromatic relief valve status indication
3. Auxiliary feedwater flow indication
4. Containment isolation
5. Computer readout speed
6. Narrow range instrumentation
   - Fuel temperatures
   - Coolant temperatures
   - Radiation level and composition

. The pressurizer level indicator did not give a direct measure of the water level in the reactor pressure vessel. During the TMI-2 incident, loop seals formed in the low points of the piping and prevented liquid in the RCS from seeking its own level. A reactor vessel pressure only a few psi above the pressurizer pressure was sufficient to keep the pressurizer full. The operators mistakingly believed that a full pressurizer meant that the core was covered when indeed it wasn't. It is clear that either through direct or indirect measurements, better indications of core water level are needed.

Several proposed solutions have been suggested. As an initial attempt to provide a better indication of core water level existing plant instrumentation can be used to detect core-voiding, e.g. core exit thermocouples, cold and hot leg resistant temperature detectors (RTD), in-core and ex-core neutron detectors, and coolant saturation meters. The thermocouples and RTD'S would, along with pressure readings, give an indication of saturated conditions. The in-core and ex-core neutron detectors would give an indication of lowered water level by an increase in their counting rates. Additional assurance of at least an indirect water level indication would be gained by placing the existing pressurizer instrumentation on the emergency power buses to assure a reliable power supply. In the long term, new instrumentation could be used to provide a more direct indication of core voiding, e.g. differential pressure cells, ultrasonic sounding gages, and gamma or neutron void detectors.

. The TMI-2 operators failed to realize that the electromatic relief valve on the pressurizer was stuck open. The console demand signal indicated that the valve was closed and the temperature indicator in the valve tail pipes was not interpreted correctly because of the past history of valve leakage. More positive means of reading valve position is needed. A proposed solution is to provide a direct indicator of the valve stem position.

. On most PWR's there is no direct indication of auxiliary feedwater flow. At TMI-2, the auxiliary feedwater discharge valves were left in a closed position in violation of technical specifications. Valve indicator lights did not alert the operators to the fact that the auxiliary feedwater was not flowing to the steam generators. A maintenance tab obscurred one light. The steam generators were allowed to boil dry and feedwater was not reintroduced for 8 minutes. Posed solutions to this problem are to provide flow indicating devices on the discharge side of the pumps so that there is a positive indication of flow. In addition, of course, operating procedures are being changed so that the discharge valves are not closed concurrently during normal maintenance.

. In spite of the release of radioactivity into the containment it did not isolate until 4 1/2 hours after the start of the incident. During this time, radioactive effluent was pumped to the auxiliary building. The TMI-2 containment isolates on a pressure rise within the containment of a few psi. This may be a sufficient enough parameter for timely containment isolation if you have a large loss of coolant accident, but for smaller loss of coolant accidents the pressure rise will be too small or slow to cause isolation in time to prevent releases. Proposed solutions are to provide a diversity in parameters sensed, e.g. safety injection signal, high radiation level.

. Another problem at TMI-2 occurred when the building containment isolation system was reset. The valves that had been initially opened were automatically reopened by the reset signal. A proposed solution would be to redesign the reset logic so that it leaves the valves in the closed state following reset.

. At TMI-2, the radioactive effluent was pumped from inside to outside the containment automatically. Operators of nuclear plants are now reevaluating systems that go outside the containment. Those that are not needed to assure safe shutdown of the plant will be automatically isolated.

. The computers provided in the control rooms at most nuclear power plants are for information purposes and to record various instrument readings at particular times. The computer at TMI-2 was hopelessly overloaded because of the many alarm points reached during the incident. The alarm status printer was running 1 1/2 hours behind time 2 3/4 hours after the incident started. In addition, because of low scanning frequencies, sequences of events were displayed in an erroneous manner. The computer was thus not only behind time, but it was giving the operators incorrect information. A proposed solution would be to dedicate a computer to assist the operator during accident situations. An alternative, of course, would be to upgrade the existing computers.

. During the TMI-2 incident, many of the temperature and radiation instruments went off scale. It will be necessary to provide instrumentation with extended ranges and shielded in such a manner that accurate readings can be provided to the operators under accident conditions.

Other instrumentation improvements are being and will be proposed. Typical are such things as hydrogen concentration meters, containment pressure instrumentation, and containment water level instrumentation. We have only attempted to address some of the more major concerns. As thinking turns towards the accident type situations, further improvements will result.

Conclusions

A number of conclusions can be reached when reviewing the history of the TMI-2 accident. A few that have become apparent are:

- Operator training and instrumentation were not sufficient to provide the operator with enough information to properly diagnose the incident.
- Failure of the operator/instrumentation interface was a major contributor to the resulting core damage.

- Improvements in operator/instrumentation interactions to specifically address accident situations are required.

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