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FROM: Report of the Advisory Panel to the Governor [Edward King] and Cabinet Task Force on Nuclear Safety Following the Accident at the Three Mile Island Nuclear Power Station, R. Wilson, G. Rathjens and S. Wiltshire (January 1980).

## Appendix I. The Three Mile Island Accident

To determine which state actions are now appropriate it is useful to follow in some detail the course of events between 4 a.m. on Wednesday, March 28, 1979 and the following Sunday, April 1, 1979. There are several voluminous reports on this, and we condense from these a simplified account. This summary is intended not to replace these more comprehensive and, therefore, more accurate accounts, but to place in clear language the problems as they arose so that the reader of this report can see the perspective of the recommendations.

Three Mile Island is 20 miles south of Harrisburg in the middle of the Susquehanna River. Two nuclear power plants are located there, Three Mile Island 1 and Three Mile Island 2. The nuclear steam generating systems were in each case designed by Babcock and Wilcox Co. The reactors are pressurized water reactors and the relevant parts are shown in a simplified diagram in figure 1.

The nuclear reactor core consists of about 30,000 fuel rods - about 1/2 inch in diameter and 16 feet long; each rod is a tube of zirconium alloy (zircalloy) filled with many ceramic pellets of uranium oxide, 1/2 inch in length. During operation nuclear fission takes place within the fuel rods, releasing energy within them. The zircalloy tubes are filled with helium under pressure and sealed to contain the radioactivity. The whole is surrounded by water. Neutrons from the nuclear fission escape from their tubes, are slowed down by collision with the water, and the slow neutrons reenter the tubes where most start a new fission in new uranium nuclei.

The fuel rods heat up as a result of the nuclear reactions producing a total power of 2772 megawatts maximum and water flowing around the rods is heated by them to 600° F; the water is pressurized to 2155 pounds per square inch (psi) (150 atmospheres) to prevent boiling. The water is pumped to a heat exchanger, called a once through steam generator (OTSG) where much of the heat in the water is removed. The water then passes back to the bottom of the reactor vessel. There are two such reactor cooling loops, each with 2 pumps. All of this is inside a concrete containment vessel designed to contain any radioactivity that would be released if the barriers of the zircalloy fuel rod and the reactor cooling system were to break.

Steam is produced in the steam generators, where the water is at a lower pressure of 900 psi, and passed to the turbine, where it is used to generate electricity. The steam is condensed back to water in the condenser, and flows through the condensate pumps and the feedwater pumps back to the steam generator. These two "secondary" loops pass through a penetration in the containment vessel to the turbine room.

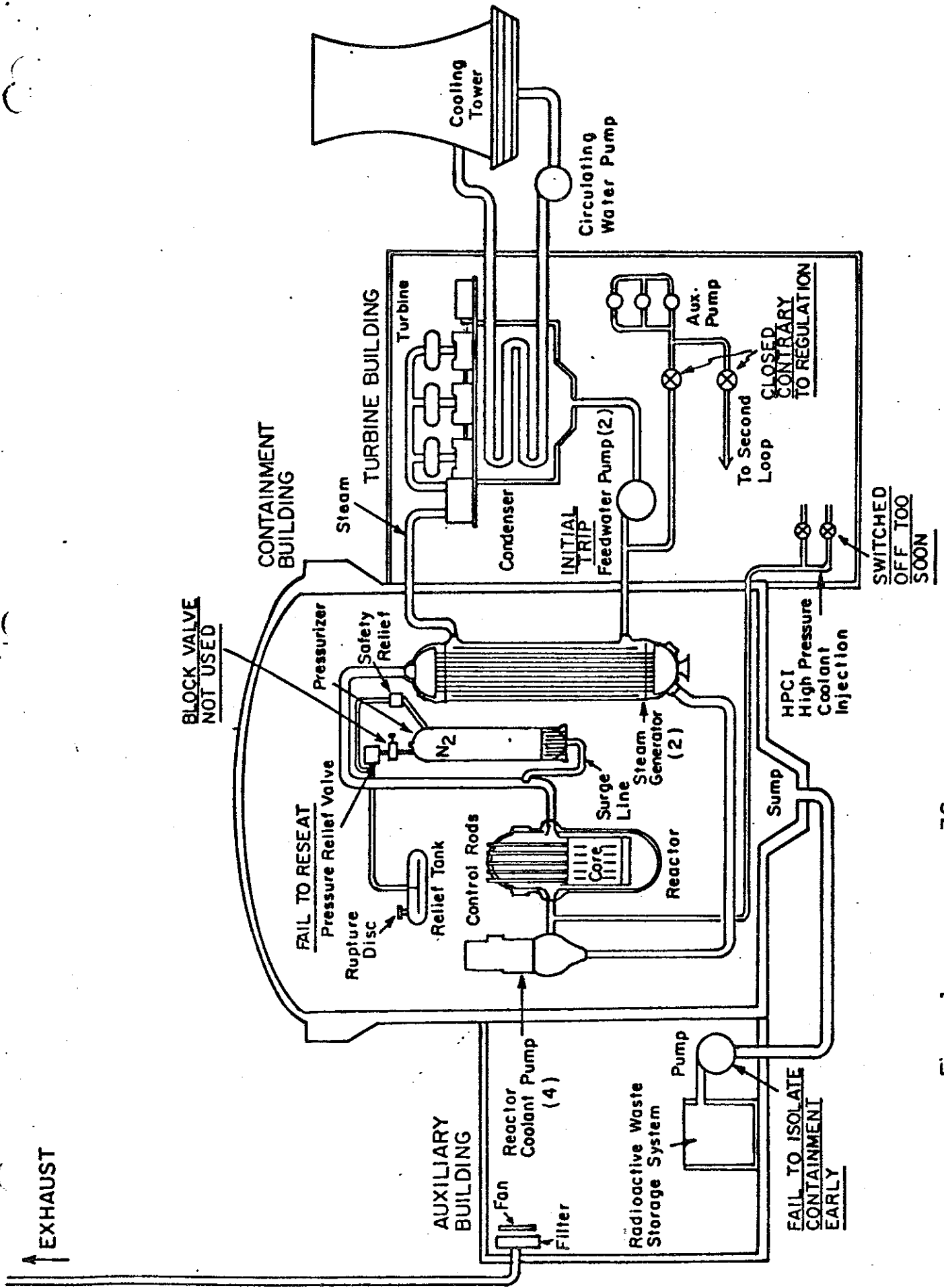


Figure 1 page 36

Various safety systems exist to insure that the radioactivity always stays within the fuel rods; this is done by ensuring that the generated heat is always removed and the fuel does not crack or melt. To shutdown the nuclear reaction (SCRAM the reactor) boron shutdown rods can be rapidly inserted into the reactor core; this can happen either manually or automatically.

Although the nuclear reaction can be (and was at Three Mile Island) shut down in less than a second, the radioactive fission products continue to provide some heat (decay heat). Immediately after shutdown this is almost 8% of full power or 200 megawatts at Three Mile Island.

If the main feedwater pumps fail, there are 3 auxiliary pumps to provide water to the steam generators. Two are electrically controlled, and one is operated by the steam turbine. If the reactor pressure gets too high, there are pressure relief valves; one can be controlled from outside the containment (electromagnetically operated relief valve EMOV) and two others which cannot be operated from outside the containment vessel are set at a slightly higher pressure in case the first fails to operate.

If the water in the reactor evaporates so that cooling slows down, a number of emergency core cooling devices exist to put water back in the core. This water is borated to ensure that the nuclear reaction ceases.

On March 28, 1979, just before 4:00 a.m., Unit No. 2 at Three Mile Island was operating at 97% of full power, under automatic control and had been for three weeks. Three of the operating crew of 4, the shift foreman and two operators, were engaged in transferring resin from a condensate polisher tank to a regeneration tank, and produced a block in the transfer line.

Probably as a result of action to clear the resin blockage, the plant suffered a total loss of feedwater, which automatically triggered a turbine trip, (i.e. a switch off of the turbine) at 04:00 and 37 seconds. All emergency feedwater pumps started, as they were supposed to do and this starting was noticed by the operator. The reactor continued to operate at full power, and since the heat was no longer being taken away as rapidly as normal, the reactor operating temperature and pressure rose. So far, the response to the transient was as anticipated.

The subsequent behavior can be seen most readily by examination of several figures and tables. In Figure 2 are the outputs of several strip chart recorders during the first 10 minutes after the transient. In figure 3 these and other recorders are shown over a period of 16 hours, and both figures show times of crucial events.

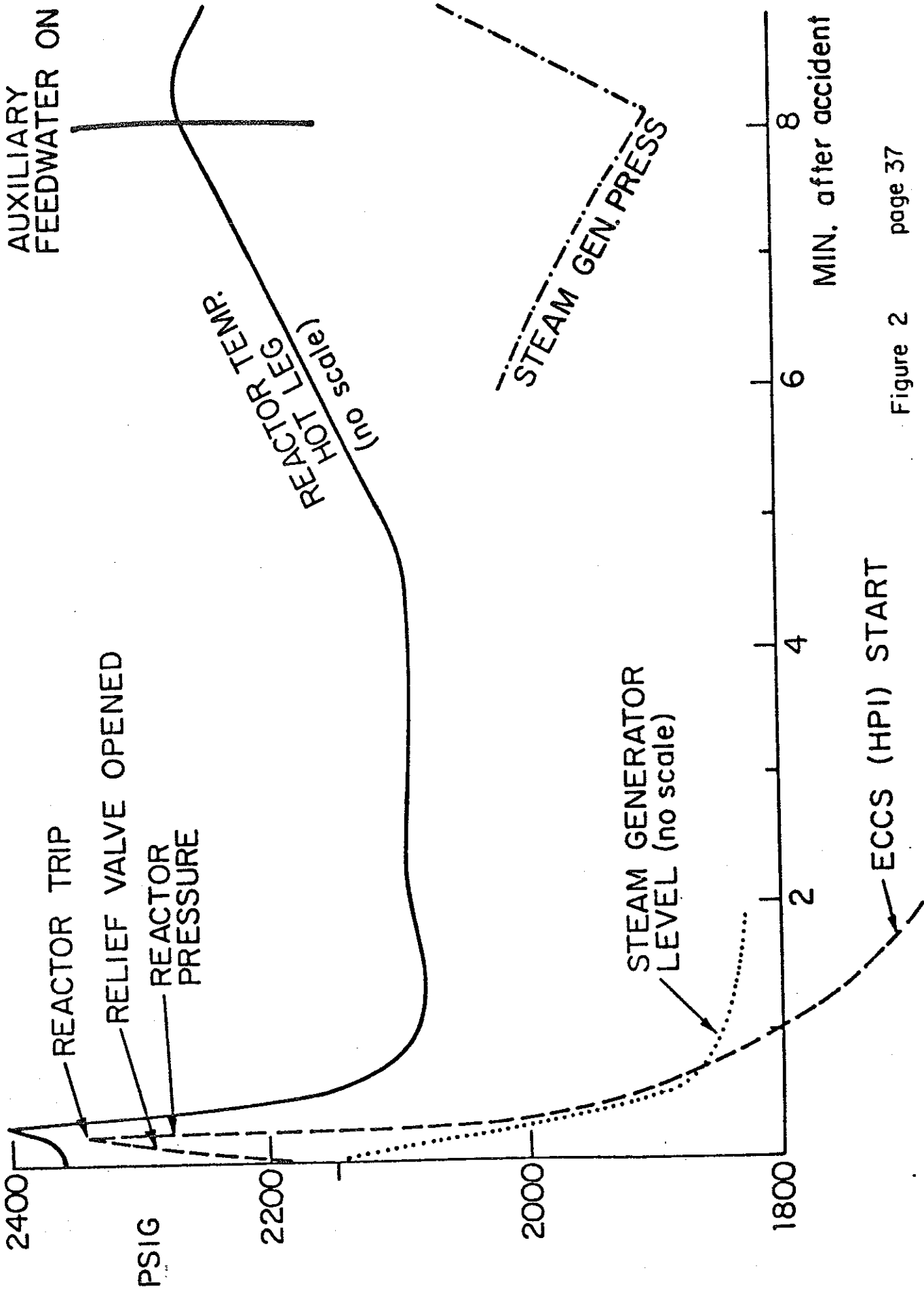


Figure 2 page 37

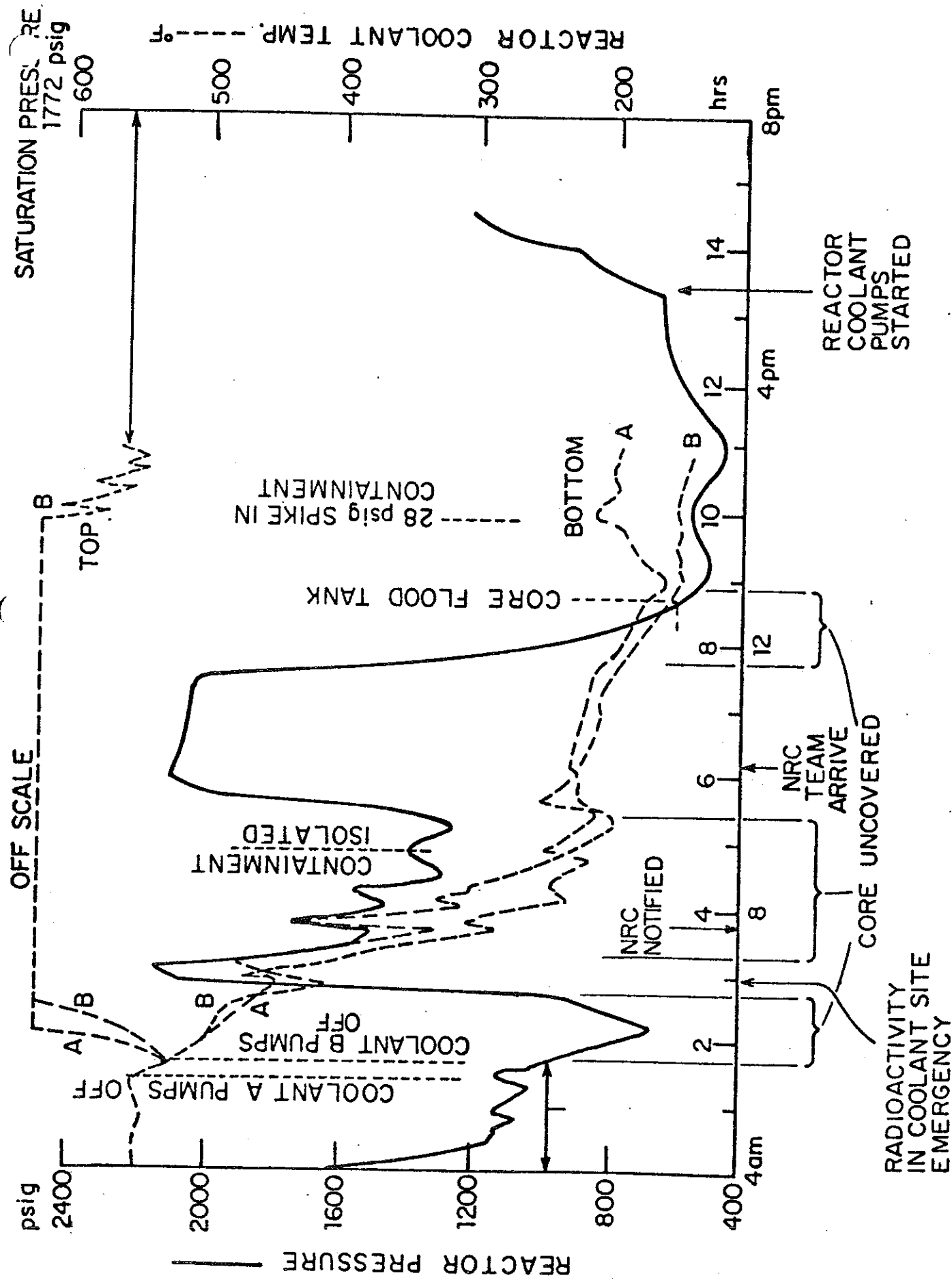


Figure 3 page 37

Approximately 8 seconds after the accident, the electromagnetically operated pressure relief valve (EMOV) opened, at a set point of 2255 psi to relieve the pressure. The reactor system pressure continued to rise, until the set point of 2300 psi was reached when the reactor tripped according to design and the control rods were injected, stopping the nuclear reaction.

We pause and note some problems that had developed. For safety, it would have been desirable (and possible) to have the reactor trip in the event of feedwater interruption. Were this the case, in many incidents the relief valve would not need to operate (although in this particular incident it would have).

After the reactor tripped, reactor system temperature fell; the pressure fell as steam was vented through the relief valve. The relief valve was supposed to close again as the pressure fell to 2100 psi (13 seconds after the accident) but it failed to do so. This failure was unnoticed by the operating crew, because falling temperature also leads to a drop in pressure (although a slower drop).

The reactor pressure continued to fall and when it reached 1600 psi (after 2 minutes) emergency pumps (high pressure core injection or HPCI) started to inject more water into the reactor. If this had been allowed to continue the reactor would be intact--and probably operating--today.

Unfortunately the operators were watching another indicator--the pressurizer level. The pressurizer is a small tank, normally half filled with reactor water, and covered by pressurized nitrogen gas. This gas enables the system to cope with small volume changes without large pressure changes. The operators are trained not to allow the pressurizer to be completely filled with water for this normally indicates that no gas is present. Control of the reactor is difficult in that case. (This is referred to as a "solid" plant.) The pressurizer began to indicate a high level of water, because of a combination of release of gas from it through the relief valve and formation of steam voids elsewhere in the reactor system. These steam voids formed because the pressure became low enough for the water to boil. The operators mistakenly thought that the reactor system had too much water and made the terrible mistake of turning off the emergency pumps which add water to the system; these pumps were turned on and off throughout the day, actions which showed a complete lack of understanding of the status of the reactor. It appears that this lack of understanding has been widespread throughout the nuclear industry. Naval reactor operators also are taught to follow the pressurizer level.

At 8 minutes into the accident, an operator noticed that the steam generators were dry of water on the secondary side, although the auxiliary feedwater pumps had been seen to start. The operator found that these pumps had been isolated from the system by closed

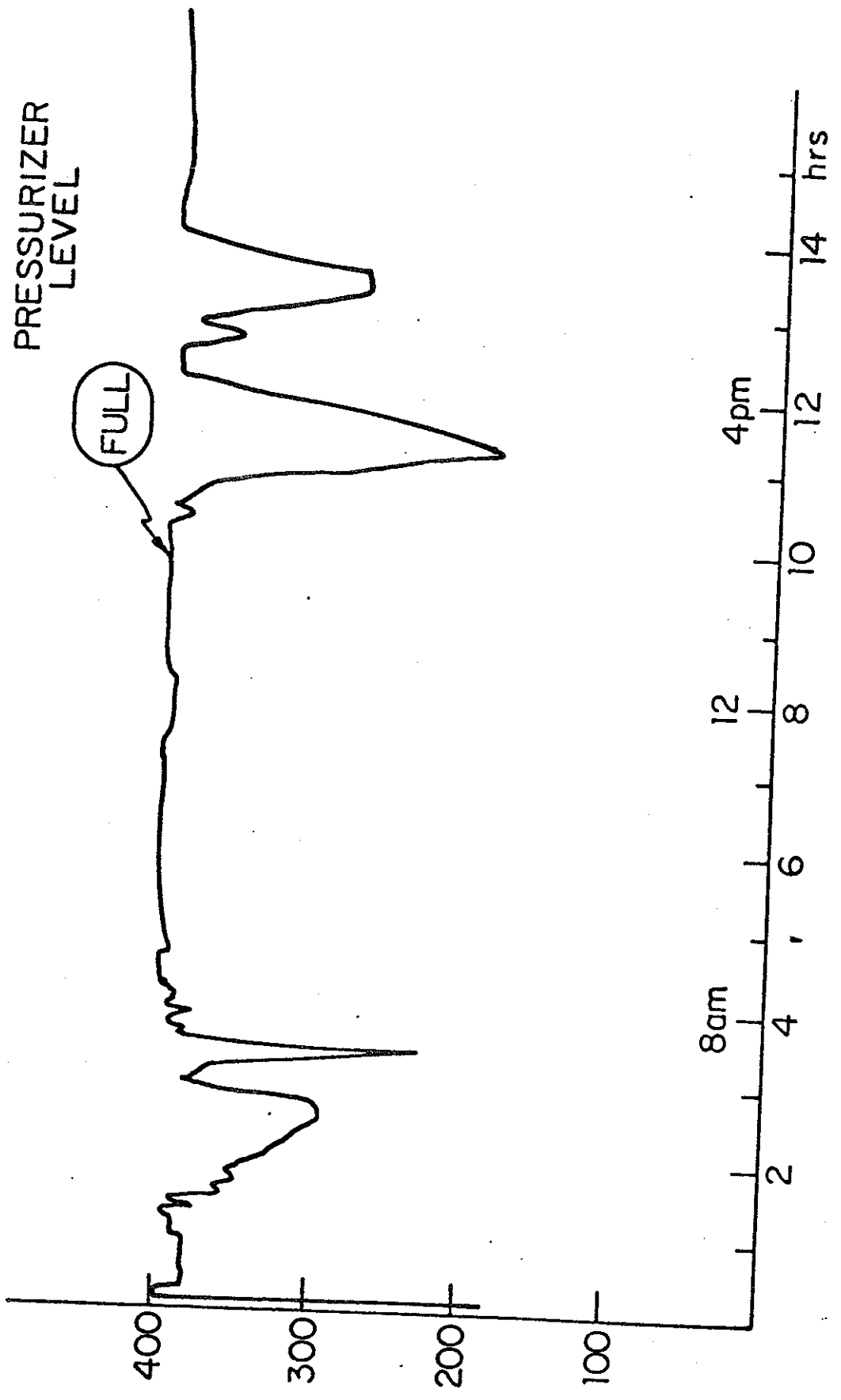


Figure 4 page 38

block valves, and the operator opened these valves. It still appears to be unclear why these valves were closed, and how long they had been closed. Although it was initially thought that this was a major contributor to the accident, it contributed nothing directly except added confusion. It misled the operators into false actions in the first minutes of the accident.

The reactor system temperature and pressure appeared to stabilize between 4:20 A.M. and 5:14 A.M.; this is because the water was boiling and the steam was going out of the relief valve. The reactor system was by this time rapidly filling with steam and emptying of water, and the circulating pumps were pumping a steam/water mixture.

This steam/water mixture was still adequate to maintain adequate cooling of the fuel rods, but the coolant pumps are not designed to pump steam and began to be noisy (cavitation). The operators turned off the pumps, one set at 5:14 a.m. and the other at 5:41 a.m., expecting that natural circulation would occur. Natural circulation would indeed have occurred if the reactor system had been filled with (subcooled) water. But since it was filled with a boiling water/steam mixture the decision led to a disaster. The water settled to the bottom and the steam rose to the top, making circulation impossible. Only the bottom 2 feet of the core was covered with water and the top part of the core was cooled only by steam.

Immediately after the pumps were turned off, the thermocouples measuring temperature in the coolant loops showed that the core was uncovered but the operators did not interpret them correctly. The temperature of the hot leg (top) went off scale, the temperature rising to a point that at that pressure could only indicate that the thermocouple was in pure steam, and the cold leg cooled down showing that circulation had stopped.

The operators had created serious problems, although they still did not know what the problems were or how they had created them. For about 1 hour--5:40 to 6:40 a.m.--the top of the core was uncovered and undercooled. Subsequent detailed calculations show that the temperature in the top of the core rose to 2000°F. At this temperature two phenomena occurred; the steam interacted chemically with the zirconium fuel rod claddings, oxidizing the claddings and releasing hydrogen:



The fuel rods, by then brittle, cracked open and released the gaseous fission products (xenon, krypton, and iodine) to the reactor coolant water whence some left via the relief valve to the containment vessel and some to the outside environment through leaks in the primary coolant system. Rising radiation levels were observed as early as 5:20 a.m., a site emergency declared at 6:35 a.m. and a general emergency at 7:24 a.m.

a probability of 1/10 has been estimated.

4. All the radioactivity will not be released even if the containment is violated. Particularly critical are the chemical elements iodine, tellurium and cesium; if released they interact chemically in the body whereas xenon does not. Filters and plate out mechanisms kept the iodine release low at Three Mile Island, but in a serious accident these filters might be overloaded; they were in fact not as effective as they should have been at Three Mile Island because they had become saturated in previous use.

## Acceptability of Accidents and Their Consequences

The panel made no attempt to decide whether one particular accident is publicly acceptable or unacceptable. The Kemeny Commission made a point that the present level of safety--which includes the accident at Three Mile Island, must be improved.

"To prevent nuclear accidents as serious as Three Mile Island fundamental changes will be necessary in the organization, procedures and practices--and above all in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions are typical of the nuclear industry."

It also note (P. 32 paragraph 16) that implicit among the calculations in the Rasmussen Report is an estimate of frequency of accidents similar in size to Three Mile Island. This frequency is one in several hundred reactor operating years. We have now had nearly 500 reactor operating years and one accident of this magnitude. Although the accident at Three Mile Island was not predicted by Rasmussen it was not in itself contrary to the probability estimates therein. Since Rasmussen and colleagues, and many of those who have read and understood the report, believe the results, if correct, were acceptable, it seems to us that this assumption of the Kemeny report represents a significant departure from those past beliefs and needs examination. This is particularly true when we realize that the main public criticisms of nuclear reactor safety and Rasmussen's report in particular, have been based on a disbelief in the numbers--not declared statements that even if the low accident probability estimates are correct, reactors are still unacceptable. Discussion by individual critics and the public seem not to have considered adequately whether the results in Rasmussen's report would be acceptable if true. However the nuclear industry and the Nuclear Regulatory Commission proceeded as if it were.

Kemeny doesn't address this discrepancy.