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THE THREE MILE ISLAND ACCIDENT AND POST-ACCIDENT RECOVERY — WHAT DID WE LEARN?

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Slide 1 - TMI Photo

Before I inherited this photograph, it had been captioned "Cleaning problems at TMI--what has been learned?"

This topic is appropriate for us to think about tonight as we review the accident and the post-accident cleanup activities--and as we project on "what the effects are and will be on nuclear powered generation of electricity."

When the TMI accident occurred, nuclear-related installations from all over the country were called on for help---the reponse was tremendous, and a large number of experts from all disciplines were sent to the island.

Oak Ridge National Laboratory was called on to provide on-site help in the areas of health physics, analytical chemistry, process instrumentation, and waste management. It was in the area of waste management--that is, the control of the radioactive gases and liquids that were released from the ruptured fuel rods--that members of the Chem Tech Division were called on to provide.

The team was lead by Bob Brooksbank and, in the several weeks following the accident, included myself, Orlan Yarbro, Jim Snider, Frank Harrington, Les King, Bill Shannon, Dave Campbell, Fred Chattin, and Charlie Waddell.

Speaking for myself, at least, it was quite startling to be suddenly called on to help out in such a situation--at that time, I had never been inside a nuclear-powered generating station--with a reactor some 30 times more powerful than the High Flux Isotope Reactor with which I was familiar.

However, for the TMI personnel, the situation was equally strange--because the accident had created for them, in effect, a chemical processing plant with a need for handling large quantities of radioactive gases and liquids.

The facilities at TMI were dwarfed by 4 large cooling towers, 3 of which are shown in this photograph. Natural draft cooling towers like these have come to be associated, in general by the public, as being representative of nuclear power plants, and some even think that the water vapor often seen steaming from these towers is radioactive. This of course is not true, as I'll show you in just a moment. In fact, cooling towers like these are also used in large coal-fired plants.

Three Mile Island contains 2 power stations--the facilities of Unit 1 are shown in the lower part of the picture and Unit 2, in which the accident occurred, is at the top.

Each unit has its own reactor containment building, control room, auxiliary building, and turbine building. In addition, the long, thin building between the 2 reactors is a common fuel handling building, which contains deep water pools for handling and storing spent fuel assemblies.

Slide 2 - Characteristics of Unit 2

Three Mile Island is located in the Susquehanna River about 10 miles downstream from Harrisburg--the capital of Pennsylvania.

Both TMI units are pressurized water reactors. About half the reactors in the United States are of this type. PWRs are manufactured in this country by 3 companies--Westinghouse, Combustion Engineering, and Babcox and Wilcox. The TMI units were supplied by B&W.

Unit 2 is slightly larger than Unit 1 and operated at just under 3000 MW thermal power and produced just under 1000 MW of electricity (1000 MW is equivalent to 10 million 100-watt light bulbs). The 33% efficiency of electricity production is typical of large generating stations of all types.

One of the ~~storage~~ strange facts about Unit 2 is that it first achieved criticality exactly one year before the accident. It went into operation just 3 months before the accident. In a few ways, this was fortunate because the spent fuel pools were empty and were available after the accident for storage of contaminated water.

Slide 3 - Diagram of PWR

In general, pressurized water reactors are operated as illustrated here.

The reactor containment building houses the reactor vessel, the steam generators, and the primary water system.

The reactor vessel at TMI-2 contains about 80 tons of uranium fuel. There are, of course, several lines of containment for the fuel. First, the fuel pellets are encapsulated in zircaloy rods. The rods are contained by the reactor vessel and the vessel by the containment building.

Three circulating water systems are used.

The primary system transfers heat from the nuclear reaction to the secondary water in large heat exchangers that serve as steam generators. The secondary water is evaporated and the resulting steam drives the ~~steam~~ turbine that generates the electricity. The excess steam is condensed in another exchanger in which the excess heat is transferred to the third water system. It is this water which is then air-cooled in the large cooling towers.

Slide 4 - B&W Reactor

This diagram shows realistically the layout of the B&W type of PWR that is used at Three Mile Island. Four large reactor coolant pumps are used to circulate the primary water through the reactor vessel to the top of two steam generators. The hot water entering the generator is at ~600 °F and the water leaving is at ~550 °F.

The pressure in this closed loop system is normally kept at ~2200 psi. Pressure control is maintained by means of a "pressurizer tank" which is connected to one of the hot legs. This tank is kept partly filled with water and partly filled with steam vapor, which provides a compressible cushion in the system. The steam bubble in the pressurizer and thus the pressure within the entire system is regulated by means of electric heaters in the lower part of the tank and by cold water spray nozzles in the top. In addition, a pressure relief valve is located at the top of the pressurizer tank.

In PWRs, the nuclear chain reaction is controlled by 2 means--water chemistry and control rods. The water chemistry--that is, controlling the concentration of boron in the primary water--is used to regulate the reactivity during operation; whereas, the control rods are primarily used as safety devices to enable an instantaneous shutdown if an emergency should occur.

Boron, of course, is a strong neutron absorber or poison, so that by increasing its concentration in the water, the reactivity is decreased. When the fuel is new, the boron concentration is usually about 2000 ppm and as the fuel is burned out and becomes less reactive, the boron concentration is decreased to maintain the desired reactivity. The boron concentration in the water is regulated by replacing part of the water in the circulating system, removing the desired amount of boron by means of ion exchanges, which are located in the auxiliary building, and then returning the water to the system. Since the accident occurred at TMI-2 when the fuel was fairly new, the boron content was still relatively high--about 2000 ppm.

The control rods are built of a metal such as cadmium that is also a strong neutron absorber. These rods are automatically controlled to raise or lower them into the vessel, inserting them in-between the fuel rods to "turn-off" the nuclear chain reaction. Therefore, when any safety system senses an emergency, it causes the control rods to drop into the reactor and shut-down or "scram" the reaction.

Slide 5 - Decay Heat Table

Now, when the chain reaction is stopped, the heat evolution does not immediately stop, as shown here. This decay heat itself remains intense for several days following the shutdown and, therefore, sufficient cooling must be available.

In the TMI-2 accident, the safety systems scrammed the reactor at about 4 AM on March 28, 1979, and it was the decay heat that was not adequately removed, leading to rupture of the fuel rods about 2-3 hours later.

Slide 6 - Diagram of the Accident

The accident was caused by a series of mechanical failures and human judgment errors.

It began in secondary water system.

The condensate in that system is normally passed through ion exchange columns for on-line purification.

They had been having trouble with resin fines causing plugging of the cleanup system and had been attempting to blow out the plugs with a mixture of air and water.

The air being used was instrument air; this, of course, is considered a violation of safety practices in chemical plants, but in the reactor station, most of the safety systems were concentrated in the reactor operation.

The instrument air became wet and caused the automatic valves in the system to close, thus stopping secondary water flow to the steam generator and removing the heat sink for the reactor.

A by-pass line around the ion exchange system was available, but it contained a manual valve which had been left in the closed position.

The primary water system began to overheat and pressurize, causing the relief valve to open. However, when the pressure decreased, the relief valve did not reclose, and this was not recognized by the operators for over 2 hours.

The operators interpreted their instruments to say that the pressurizer tank was full--a condition that they had been trained to prevent.

When the emergency core cooling water came on, they turned it off.

This allowed the water level in the reactor vessel to drop below the fuel rods, which then overheated causing the zircaloy cladding to react with the hot steam and rupture, thus causing radioactive gases and water-soluble materials to be released.

Slide 7 - Radionuclide Releases

Looking now at the radionuclides that were released--

About 60% of the gases Kr and Xe were released from the fuel and into the containment bldg.--about 10% was released through the Aux Bldg. to the atmosphere.

The Xe in the containment building decayed within ~2 months, but the Kr was eventually vented under controlled conditions.

Fortunately the uranium fuel and most of the fission products are not dissolved in the primary water which is maintained at a pH of >7.

About 50% of the iodine and cesium were released and dissolved in the water.

Iodine is a relatively volatile material and for the purpose of reactor licensing, the NRC assumes that 25% of the ^{131}I will be released from the water.

A recent study, made because of the TMI accident findings, has shown that iodine is present mostly in the iodide state and as such is essentially non-volatile.

Slide 8 - 2nd Photo

The situation after the accident was--

The Unit 2 containment building had about 250,000 gal of contaminated water, and in-leakage was continuing at several thousand gal/day.

During the first 2 months, the leak rate was reduced to about 100 gal/day but not before ~600,000 gal accumulated in the building---~8 ft deep.

The Auxiliary Building was also highly contaminated and about 250,000 gal of less-contaminated water had been collected in the tanks and on the floor of that building.

There was special concern about the release of radioiodine, particularly when the charcoal traps in the off-gas system were found to be degraded and inefficient.

Considerable effort and expense was put forth to replace the 360 charcoal traps and to install a completely new charcoal trap system on the roof of the Auxiliary Building.

The control room and the fuel handling and turbine buildings were not contaminated.

Slide 9 - Decay Chart

This chart shows that many of the radionuclides--particularly the ^{133}Xe and ^{131}I--are sufficiently shoft-lived so that if they are contained for several months, as they were at TMI, they will decay to insignificant levels.

This leaves, then, as the primary radioactive contaminants ^{134}Cs, ^{137}Cs, ^{89}Sr, and ^{90}Sr.

The chart also illustrates that rapid cleanup activities following an accident are not really practical.

Slide 10 - Contaminated Water

Three bodies of contaminated water were generated--all contained as the primary chemical impurities, boron and sodium.

In all, these chemical impurities constituted some 40 tons of sodium borate and boric acid. These impurities had a significant impact on the choice of processing methods used for decontamination.

The radioactive contaminants totalled almost 1/2 million curies. This can be compared to a total of 60,000 Ci that had been generated during normal operations at all PWR sites beween 1960 and 1977.

The Primary and Containment Bldg. waters were considered to be "high activity level", and the process for cleanup was developed here at Oak Ridge and at Savannah River under the guidance of a special Technical Advisory Group.

The Auxiliary Bldg. water was considered to be "intermediate activity level" and was processed by means of conventional water purification ion exchange methods.

Slide 11 - Processes Considered

In considering the various processes for concentrating the radioactivity and decontaminating the water, several schemes that involved clarification of the water by filtration followed by either ion exchange, evaporation, or combinations of both were considered and were compared on the basis of the volume of wastes that would be generated and on the relative operating difficulties that would be encountered.

Most of you are familiar with conventional organic ion exchange resins--they have a hydrocarbon base and functional groups such as sulfonic acids or amines.

These are the types of ion exchangers used to clean up the lightly contaminated waters in normal operations at power stations.

By using both an anion exchange resin and a cation exchange resin, total demineralization of the water is obtained.

If this type system were used, as in the first flowsheet, the amount of resin used would be large because of the large amount of sodium borate in the water.

- also, the amount of resin needed would be large because it would be necessary to keep the concentration of radioactivity small, in order to avoid resin degradation from the absorbed radionuclides.

- in flowsheet 2, the resin degradation could be lessened if the radioactivity was eluted with sulfuric acid, but the acid containing the radioactivity would have to be evaporated. In nuclear power stations, evaporators are of the forced-circulation type and require frequent maintenance. This would be difficult when the evaporator contained large amounts of radioactivity.

- in flowsheet 3 – direct evaporation--the same maintenance problems would exist plus the concentrate would contain all of the sodium borate.

- in flowsheet 4 – an inorganic ion exchanger--an alumino silicate clay called zeolite--would be used to absorb the bulk of the radioactivity, and this material would not be degraded by the absorbed radiation. Here, an evaporator would be used to finish the decontamination and the concentrate would again contain all of the sodium borate; but, in this case, the concentrate would be low-activity level waste.

- in the last flowsheet, the zeolite would be used to absorb the bulk of the radioactivity, and organic ion exchangers would then be used to complete the decontamination.

It is this last flowsheet that was selected for concentration of the radioactive materials and decontamination of the high-activity water at TMI.

Slide 12 - SDS Flowsheet

After evaluating many types of ion exchangers in small column tests and recommending that zeolites be used, a processing system was designed by Allied General Nuclear Services and was built and installed by the Chem Nuclear Company.

The system was installed in the spent fuel handling pools at TMI so that the pool water could be used for shielding. The system was called the "Submerged Demineralizer System", although the system did not really demineralize the water.

After development, we evaluated the flowsheet at ORNL using 64 L of actual containment building water and small columns only 1/100,000 the size of the real columns. Joe Knauer and Lew Byrd did most of the experimental work but were aided by many others. We found that there were solids on the bottom of the building and recommended that the water be decanted into the processing system; therefore, they designed a floating pump which was called the "sump sucker."

We recommended the proper type of filter for clarification and made improvements of the zeolites used in the ion exchangers so that all of the water could be processed while generating only about 600 gal of high-level waste. This represented a concentration factor of over 1000 from the contaminated water.

And finally, we found that a special technique could be used to make the polishing decontamination effective without having to totally demineralize the water.

Slide 13 - Status of Cleanup

The current status of cleanup at TMI is shown here.

Decontamination of the large volume of containment sump water was completed about 2 months ago, and preparations are now being made for decontaminating the primary water system.

After that, the relatively large job of removing the damaged fuel can be started.

When that is completed, the surfaces in the Reactor Containment Building will be decontaminated where possible.

Things Learned

Accidents can happen in nuclear power plants--more probably will occur.

At TMI, the safety systems worked well--no one was hurt, and if the systems had not been overridden, probably no releases of activity would have occurred.

More attention must be paid to proper training. Since the accident, much effort has been devoted to this.

Operators must be taught never to turn the emergency cooling water off--similar accidents have occurred before and after TMI, and because the water was left on, no fuel rupture occurred.

Radioiodine control may not be as much of a problem as originally thought.

Effects on Nuclear Power

Public opinion was raised against nuclear power but ~~have~~ mostly subsided now.

More restrictions have been applied--causing more downtime (less operating efficiency) and longer approval times (and higher costs) for new reactors.

In the long run, the application of nuclear power will depend on our energy needs.

In other countries, new reactors are still being bought.

The market for nuclear reactors may eventually return in the U.S.

FACILITY DATA, TMI UNIT 2

(From NUREG-0020)

Location: 10 miles southeast of Harrisburg, Pa.

Type of Reactor: Pressurized Water Reactor

Licensed Thermal Power: 2772 MWt

Design Electrical Rating: 906 MWe (net)

Date of Initial Criticality: 3/28/78

Date of Commercial Operation: 12/30/78

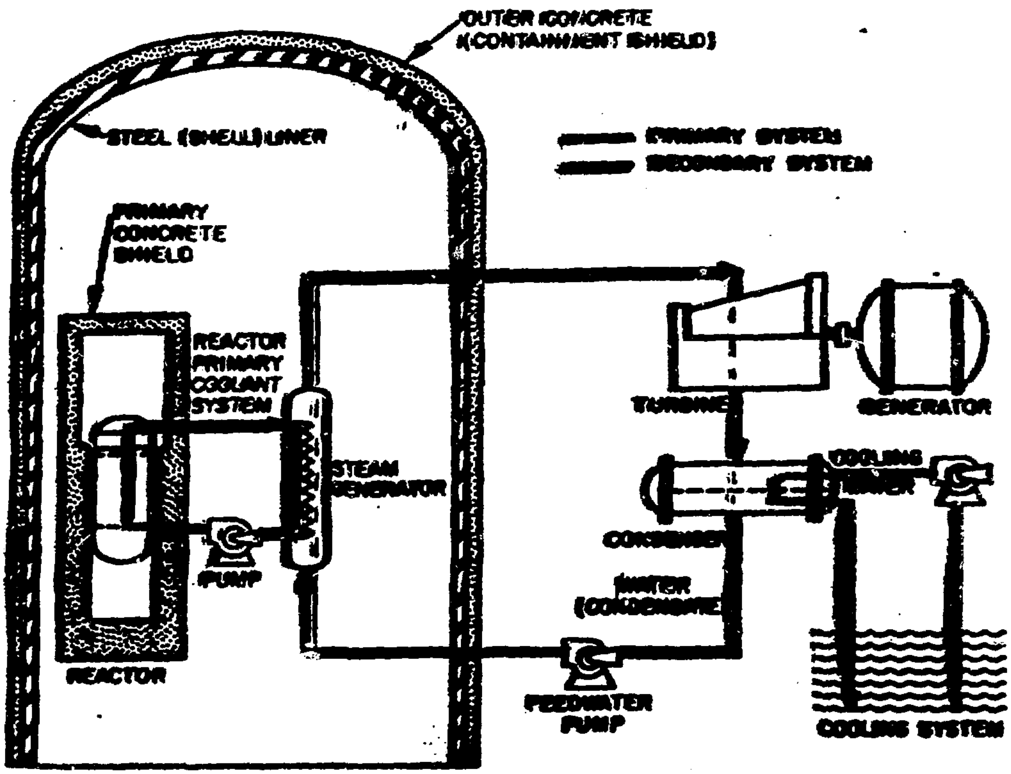


Figure 6-1. SCHEMATIC PRESSURIZED-WATER REACTOR POWER PLANT.
The primary reactor system is enclosed in a steel-lined concrete containment building. Steam generated within the building flows to the turbine-generator system (outside the building), after which it is condensed and returned to the steam generator. (Figure reproduced from ERDA-1541.)

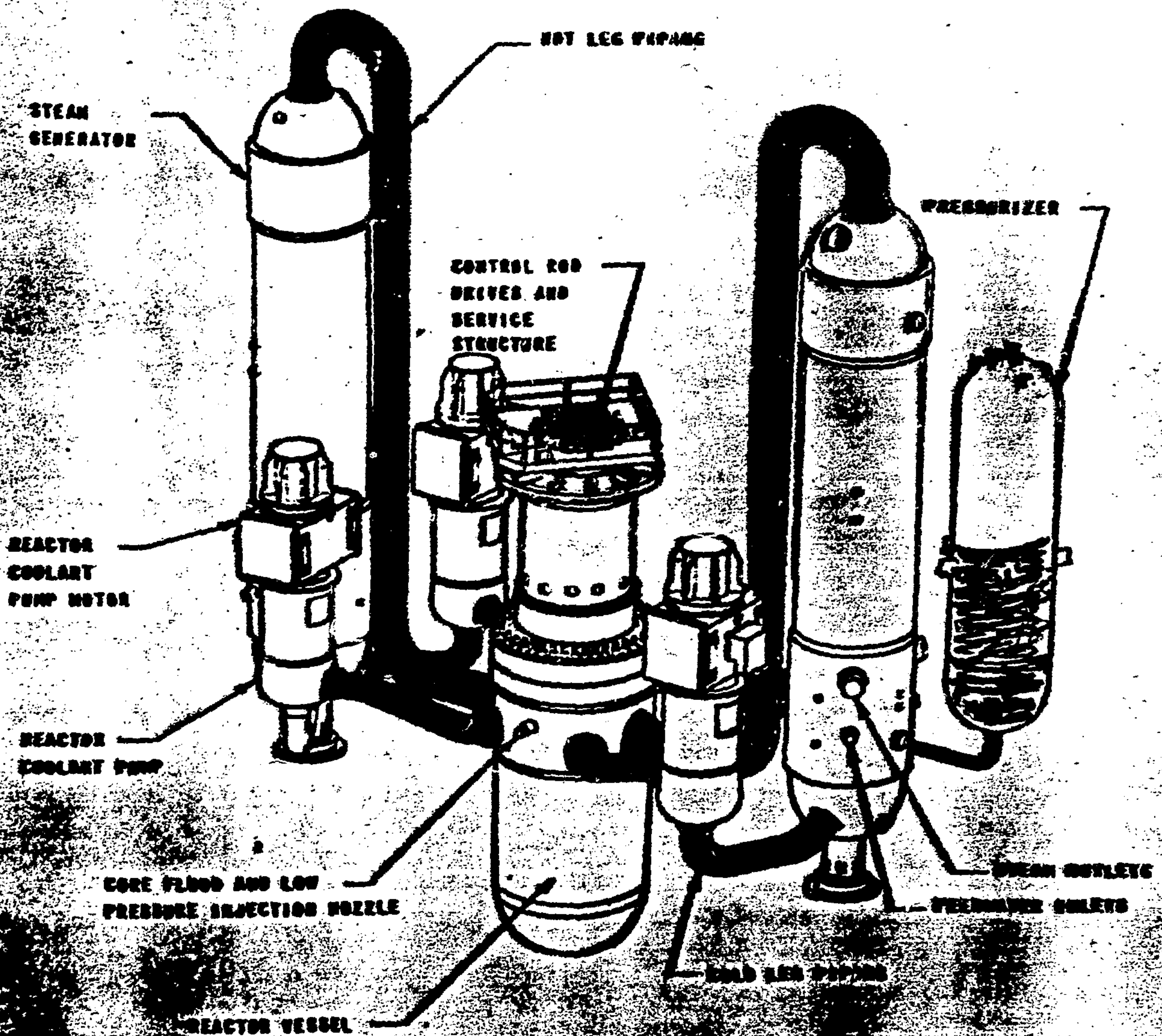
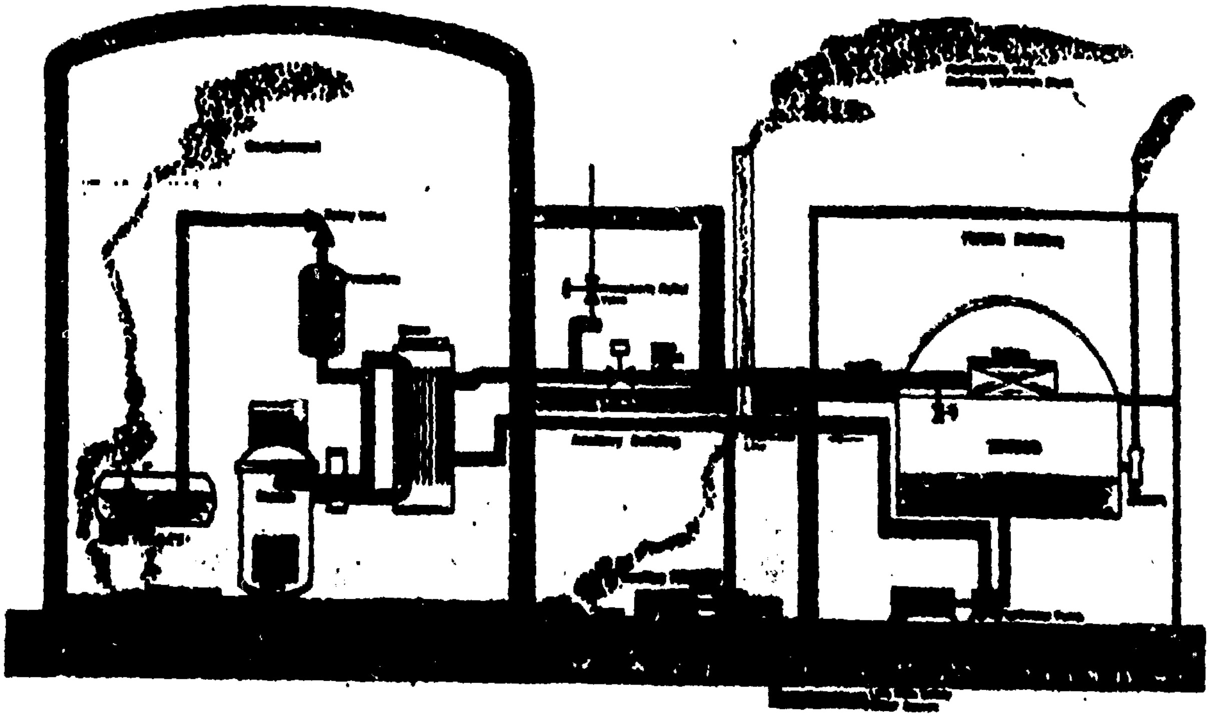


Figure 5-6. ALTERNATIVE ARRANGEMENT FOR A PWR PRIMARY SYSTEM.
This PWR system has two outlet nozzles, each leading to a steam generator. The outlet of each generator is connected with two coolant pumps, each of which is connected with an inlet nozzle at the reactor vessel. These steam generators use vertical tubes, rather than the U-tube design of figure 5-5. (Figure courtesy of Babcock & Wilcox Co.)

Time After Shutdown ("Scram")	Heat Generation Rate: TMI "Best Estimate"	Heat Generation Rate: "Design", Max. LWR Burnup
0	2700 MWt	100%
2 seconds	300-500 MWt	10-20%
2 minutes	100 MWt	4.0%
1 hour	36 MWt	1.5%
5 hours	22 MWt	1.0%
1 day	13 MWt	0.6%
1 week	5 MWt	0.3%
1 month	2 MWt	0.15%
3 months	1 MWt	0.08%
1 year	0.3 MWt	0.03%

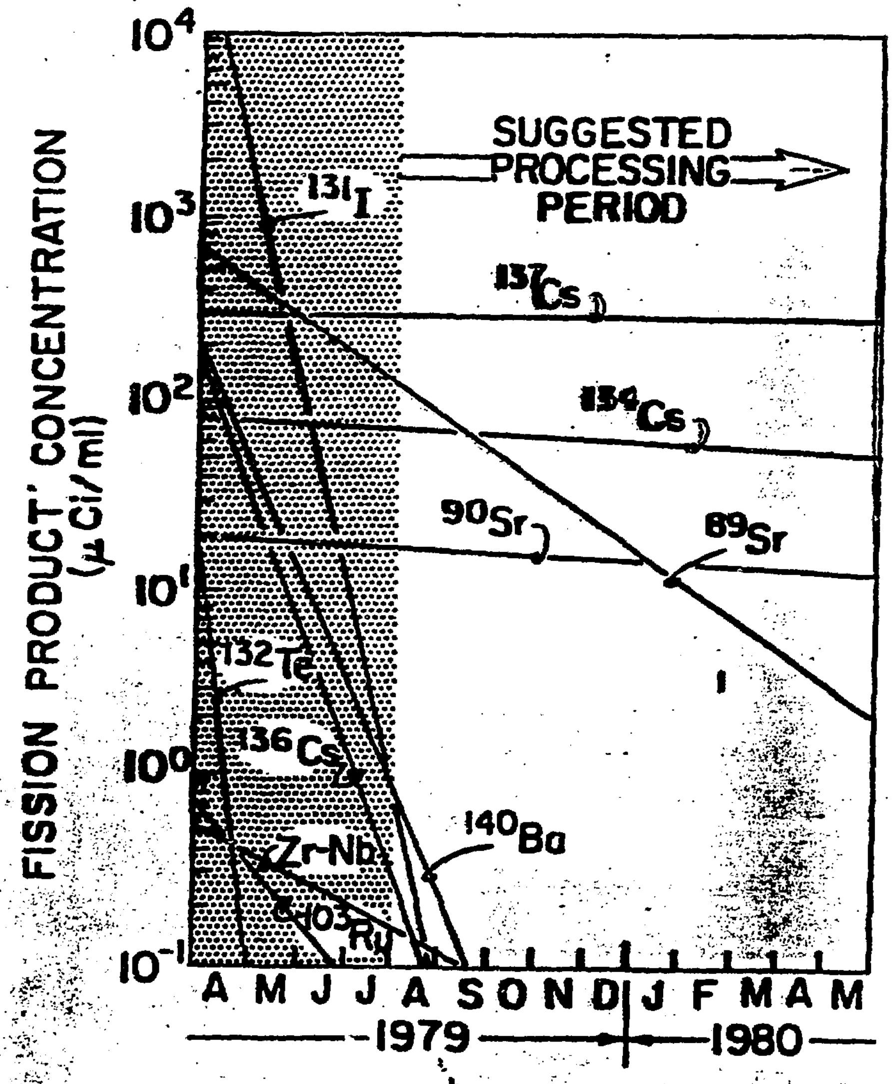
Simplified PWR Showing Three Mile Island Release Paths



RADIONUCLIDE INVENTORIES AND RELEASES AT THREE MILE ISLAND

Radionuclides	Inventory (MCi)	Amount Released: From Fuel	To Building	To Atmosphere
Kr-85	0.096	~60%	~60%	~10%
Xe-133	140	~60%	~60%	~10%
I-131	65	~50%	0.007%	0.00002%
Cs-137	0.85	~50%		0
Sr-90	0.77	<0.01%		0
Ba-140	140	0.2%		0

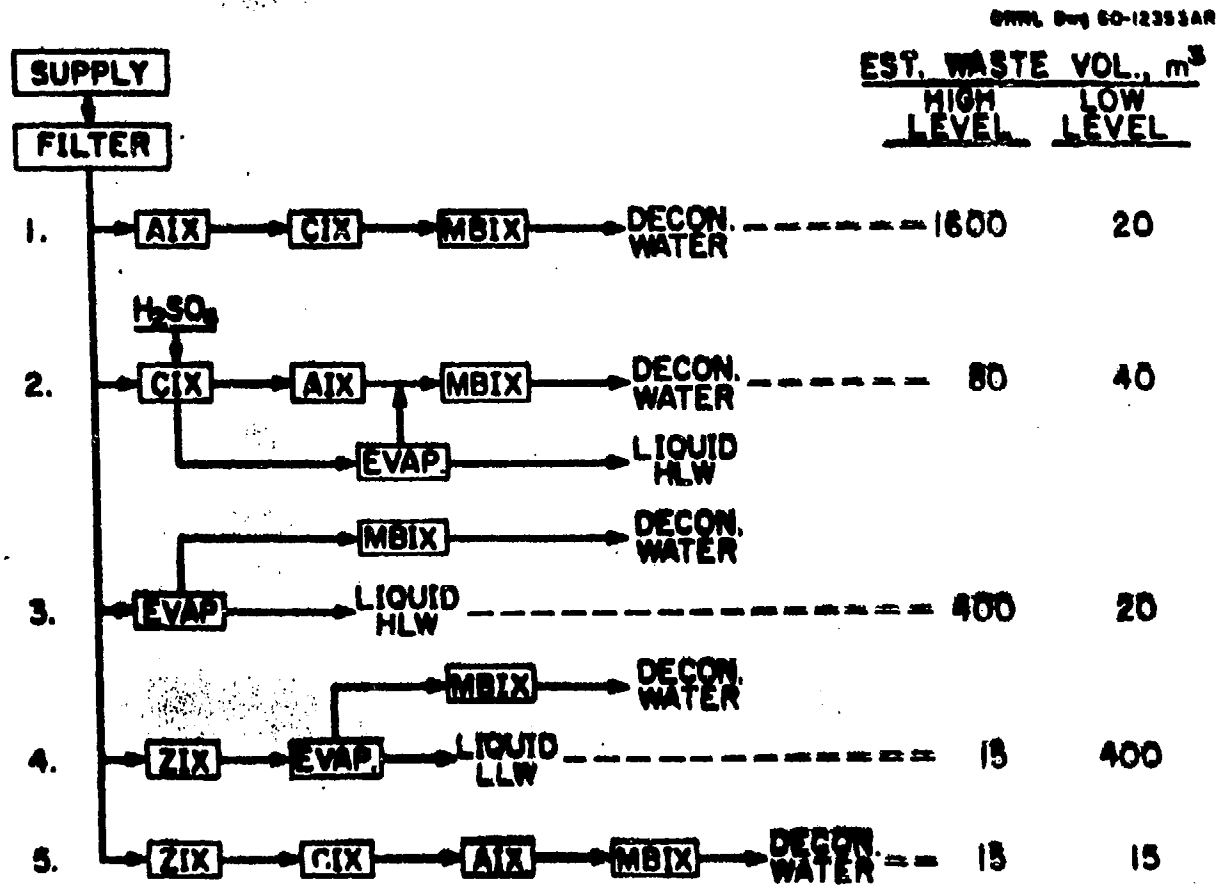
ORNL Dwg 79-13239R1



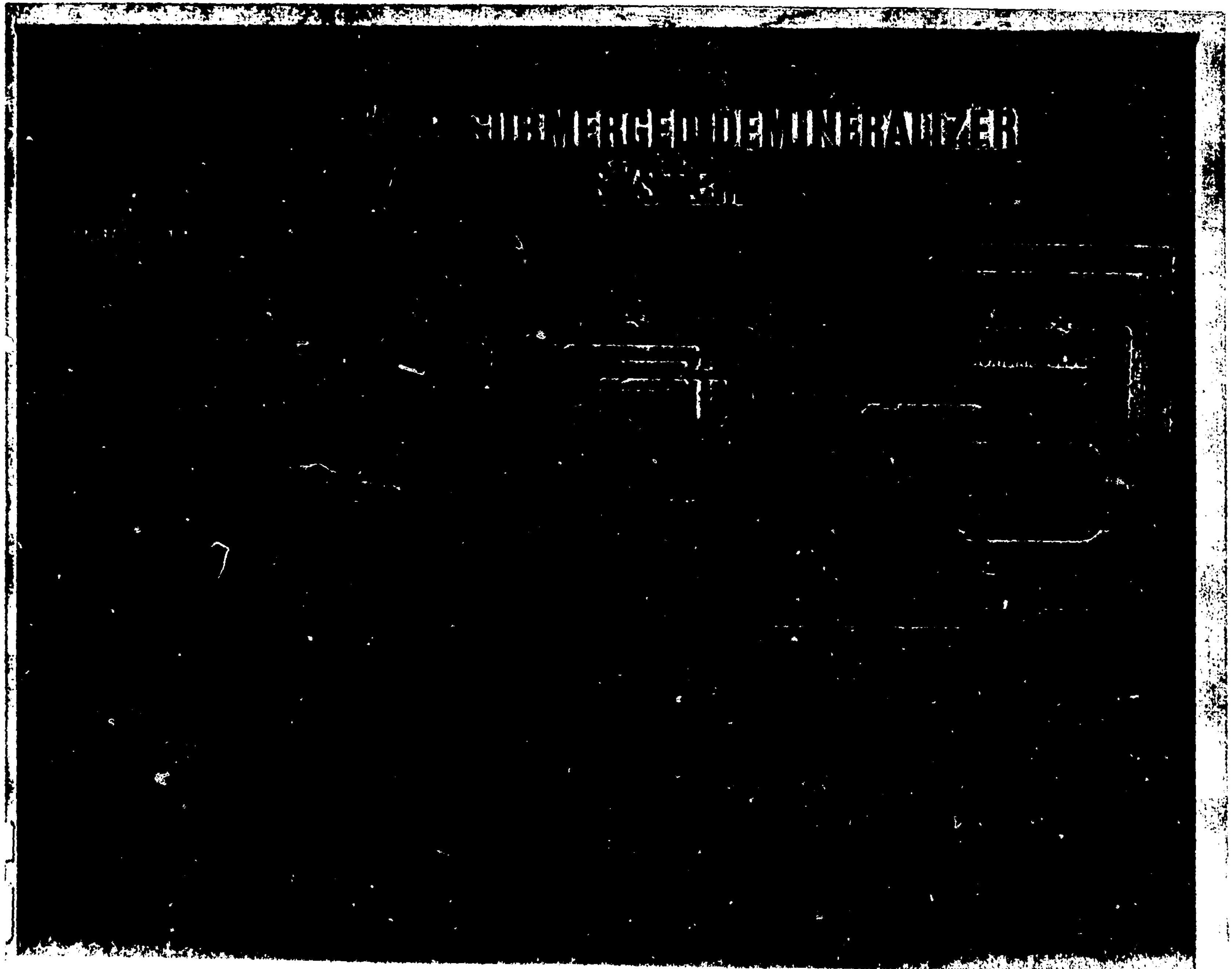
FISSION PRODUCT DECAY
IN THE TMI-2 PRIMARY LOOP

COMPOSITION OF CONTAMINATED WATER

	Aux Bldg. Water	Containment Bldg. Water	Primary Water
Volume	300,000 gal	650,000 gal	90,000 gal
Boron Conc.	300 ppm	2,000 ppm	3,870 ppm
Sodium Conc.	250 ppm	1,200 ppm	1,400 ppm
Cs-134, 137	35,000 Ci	400,000 Ci	8,000 Ci
Sr-90	~1,200 Ci	12,000 Ci	8,000 Ci



FLOWSHEETS CONSIDERED


SUBMERGED DEMINERALIZER

STATUS OF CLEANUP

Completed:

- Venting of ^{85}Kr
- Decontamination of Aux. Building Water
- Decontamination of Aux. Building Surfaces
- Decontamination of CB Sump Water

Planned:

- Decontamination of RCS Water
- Removal of Damaged Fuel
- Decontamination of Reactor Containment Building