

REACTOR CONTAINMENT AND REACTOR SAFETY IN THE UNITED STATES

Conc.

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Workshop on PWR Reactor Safety

Rio de Janeiro, Brazil

August 11-12, 1986

A second early effect of containment came with the development of criteria for selection and approval of sites for nuclear plants. These criteria defined an exclusion area, a low population zone, and a population center distance. The definition of these was made in terms of the effect of leakage from the containment after an accident is assumed to have taken place, and the effects of radiation on the surrounding population. Figure 5 states the principal aspects of the site criteria developed for the United States. They are still in effect. The site criteria were further amplified in a companion document called TID-14844, which illustrated how the calculations were to be made in applying the criteria.

The existence of containment also guided early reactor safety research. Dynamic experiments leading to destruction of small research-type reactors through reactivity transients ensured that these types of accident could not lead to destruction of properly designed containment structures. Much of the safety research prior to about 1970 was intended to clarify how fission products might be released from damaged reactor fuel, and the subsequent chemical reactions and dispersal mechanisms.

In 1967, some new questions arose, which led to forming a committee under the Chairmanship of the late William Ergen, of the Oak Ridge National Laboratory. The problem considered was a newly developed uncertainty as to ability of the reactor's primary vessel and afterward the containment structure itself to remain intact if a severe accident led to melting of the reactor core. The major conclusion of the Ergen Committee's report was that the emergency core

cooling systems of water reactors must work dependably after a hypothetical accident. If they do not work, the containment might fail through successive melt-through of the reactor vessel and the basement of the reactor. This was the so-called China Syndrome.

The Ergen Committee's conclusions altered earlier views of the role of containment performance in hypothetical accidents. For the first time technical questions arose as to the assured integrity of containment. The new importance of ECCS led to new research programs. Later in a bruising public hearing, a thorough review was made of the features of emergency core cooling that would ensure avoidance of severe core damage if an accident began. A new set of requirements was subsequently established on how performance of ECCS systems was to be evaluated. These new ECCS criteria are shown in Figure 6. The research program was further changed and strengthened, to lead eventually to satisfaction that the ECCS requirements were not only sound but were also very conservative. Assurance was developed that the probability of severe reactor core damage after a large pipe break would be low.

In 1975 a sequel to WASH-740 was issued. This was WASH-1400, the Reactor Safety Study, often called the Rasmussen Report. It succeeded where WASH-740 had failed, in providing estimates of the probability of severe accidents and the probability that public injury of various kinds would follow. These estimates were possible because detailed designs were now available for nuclear plants that had been built, so that calculations of failure rates could be made.

WASH-1400 identified five ways by which the integrity of a containment structure might be threatened. These are shown in Figure 7. The China Syndrome, or basement melt-through, is the last of these, and WASH-1400 found that the consequences of this type of failure would not be very serious. The other four failure modes were found to be more important, for it was concluded that they could lead to more serious effects.

The report dealt with two nuclear plants, the boiling water reactor plant called Peachbottom 2, and the pressurized water reactor plant called Surry.

Three general conclusions were drawn. It was found that a severe accident is more likely than had previously been believed. But the effects of such accidents would be much lower on the average than had previously been believed. Therefore the total risk was much lower than was earlier thought to be the case.

The next important event from the standpoint of containment and its role in reactor safety was the accident to the Three Mile Island nuclear plant, which showed how important containment really is. Figure 8 is a table of fission product inventory at TMI at the time of the accident, and release data for noble gases, halogens, and other fission products. It is impressive how well the containment building actually achieved its purpose, in reducing the release of fission products and in protecting the public.

This brings the topic of expected containment performance almost up to the present. Following recognition of the implications of fission product

release after Three Mile Island, a determined effort was started to reevaluate the analysis of containment integrity in WASH-1400, to find out if the estimates of failure probability can be improved, and if the changes to plants as a result of the Three Mile Island accident have improved matters.

Six basic types of containment structure are used in the United States. Figure 9 shows the type of large dry containments used for most PWR's. Figure 10 shows the type of subatmospheric pressure containment used for some PWR's, and Figure 11 is the type of ice condenser containment used with some other PWR's. Figures 12, 13, 14 are respectively the Mark I, II, and III containments for boiling water reactors. The Nuclear Regulatory Commission is engaged in an intense program to reevaluate the risk attached to six nuclear plants in the United States, one with each type of containment. The results of the study have been scheduled for this year, but this schedule has been too optimistic, and some delay is likely.

Some of the issues that have arisen in the review that is underway are listed in Figure 15. Direct heating is the term applied to sudden transfer of heat to the containment atmosphere when the molten core is assumed to be ejected into the building atmosphere as a fine spray. The probability and consequence of this form of rapid heating and pressurization of the containment atmosphere constitute one of the more controversial areas of safety analysis at this time. Event V is a means of containment bypass through failure of the connection between certain high pressure and low pressure systems.

The interaction between a molten mass of reactor core and the concrete floor on which it might fall after melting its way through the reactor vessel is difficult to describe, and a number of important effects could follow. This subject is becoming better understood but it was one of the principal points of contention at the time of an American Physical Society review about a year ago.

The WASH-1400 study assumed that if a nuclear accident took place, the population downwind would be evacuated. This may not be the best strategy for individuals beyond about two to three miles. Alternate plans involving sheltering or some optimum combination of sheltering and evacuation are being considered. A well thought-out emergency plan can substantially reduce consequences of an accident if one occurred.

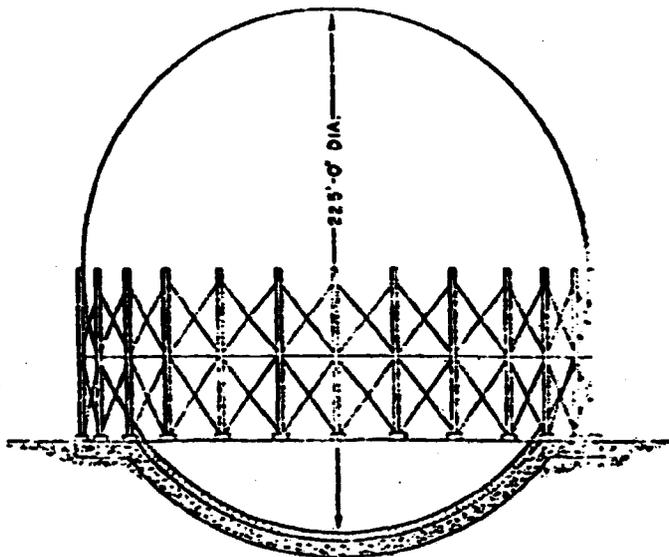
Figure 16 lists some of the tentative conclusions of the studies underway.

- If failure of a containment were delayed by a few hours, the consequences would be greatly reduced because of settling of radioactive aerosols.
- Steam explosions in the reactor vessel are unlikely to threaten integrity of the containment.
- Core-concrete interaction can mobilize the more inert fission products.

- Direct heating is still an issue.
- Some types of containment building may need some modifications, to meet guidelines.

I summarize the preceding as follows. The importance of tight, strong containments has been recognized from the start of the American nuclear power program. Factors affecting the integrity of containment structures have been submitted to intense scrutiny over the years, and confidence in the ability to ensure intactness has grown. But final certainty has not yet been achieved.

FIGURE 1



WEST MILTON CONTAINMENT VESSEL

FIGURE 2

WEST HILTON SPHERE

VOLUME 6,000,000 FT³ (170,000 M³)

DIAMETER 225 FT (68.6 M)

PRESSURE 15 PSI (1 BAR)

LEAK RATE 0.2%/DAY AT PRESSURE

STEEL , 2.5 CM THICK

WASH-740

"THE PROBABILITY OF OCCURRENCE OF PUBLICLY HAZARDOUS ACCIDENTS IN NUCLEAR POWER PLANTS IS EXCEEDINGLY LOW."

LETHALITY	0 - 3,400
INJURY	0 - 43,000
LAND	50 - 400,000 KM ²
COST	\$5x10 ⁵ - 7x10 ⁹

PRICE-ANDERSON ACT

LIABILITY INSURANCE

MAXIMUM \$500,000,000 PER ACCIDENT

FEE OF \$30/YEAR FOR EACH THERMAL MEGAWATT

REACTOR SITE CRITERIA

EXCLUSION AREA

LOW POPULATION ZONE

POPULATION CENTER DISTANCE

GUIDELINE DOSES 25 REM WHOLE BODY
 300 REM THYROID

TID-14844

ECCS CRITERIA

PEAK CLADDING TEMPERATURE < 2200°F (1200°C)

MAXIMUM CLADDING OXIDATION 17%

MAXIMUM HYDROGEN < 1%

COOLABLE GEOMETRY

LONG TERM COOLING.

WASH-1400

CONTAINMENT FAILURE MODES

STEAM EXPLOSION

INADEQUATE ISOLATION

HYDROGEN BURNING

OVERPRESSURE

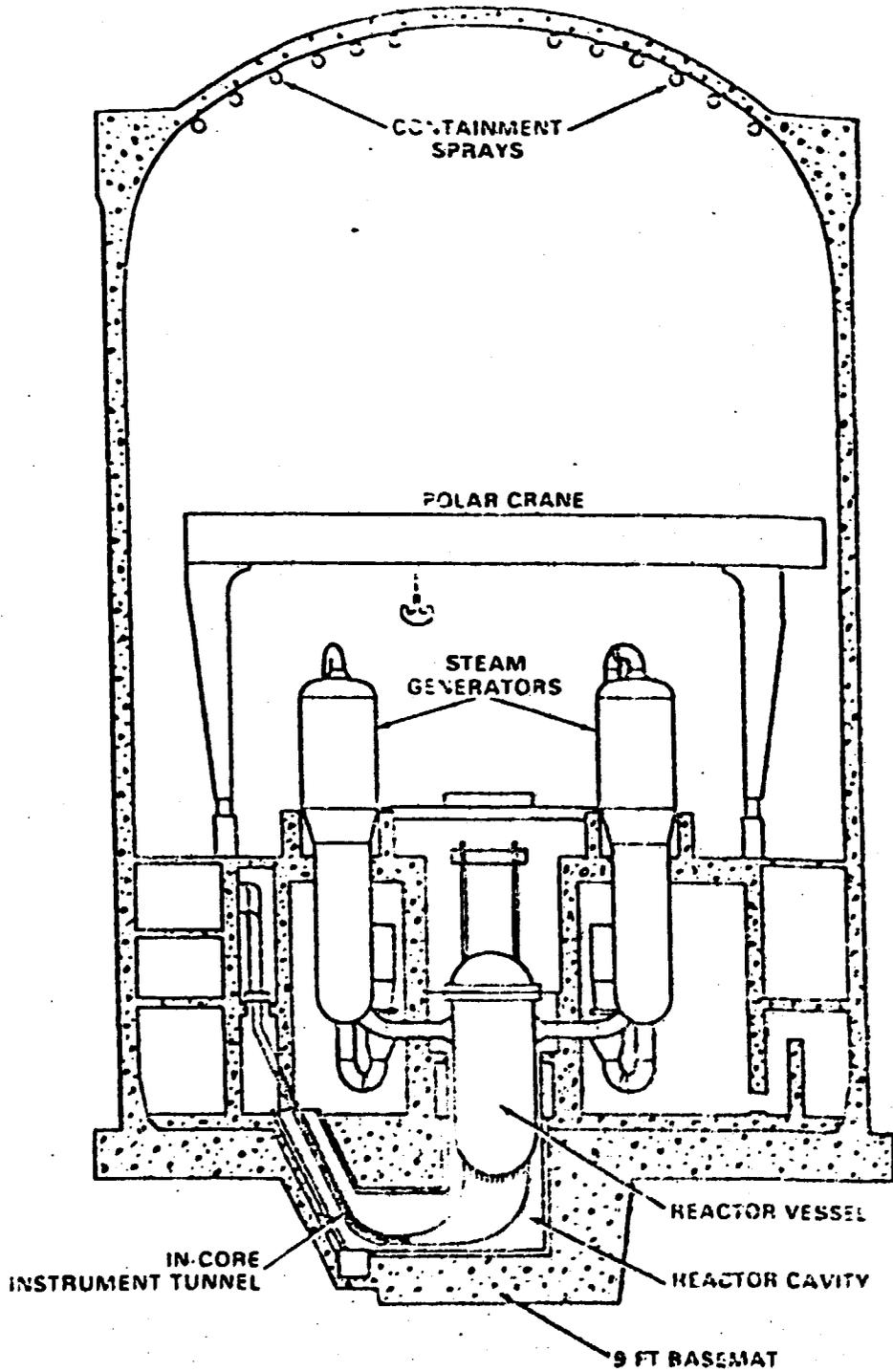
BASEMAT MELT THROUGH

FIGURE 8

TMI RELEASES

	INVENTORY	RELEASE	FRACTION
NOBLE GASES	$> 10^8$ Ci	$\approx 10^7$ Ci	10%
HALOGENS	10^9 Ci	17 Ci	10^{-8}
OTHER	$> 10^9$ Ci	0	0

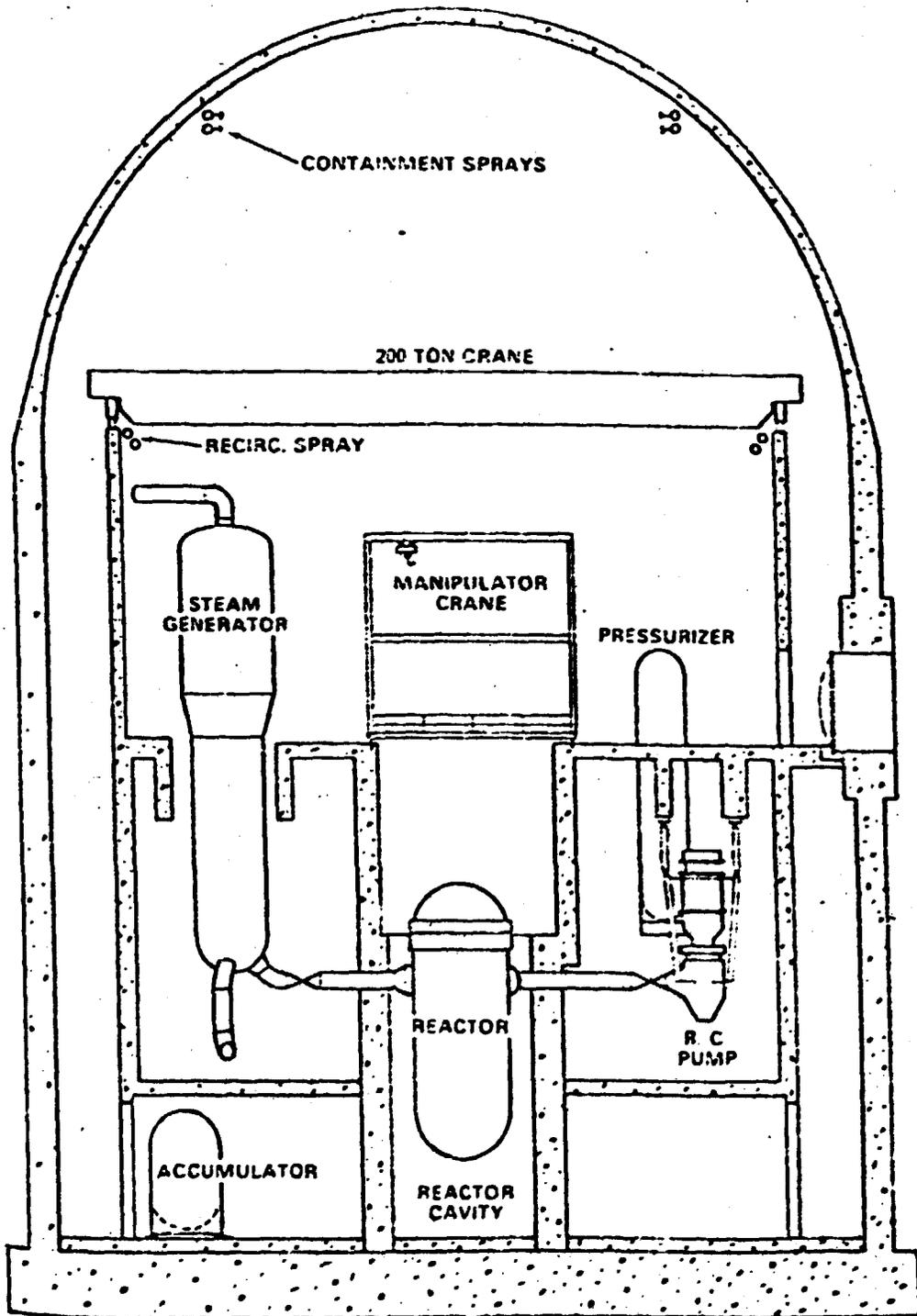
LARGE DRY CONTAINMENT (ZION)



SCHMATIC OF THE CONTAINMENT DESIGN
FOR THE ZION PLANT

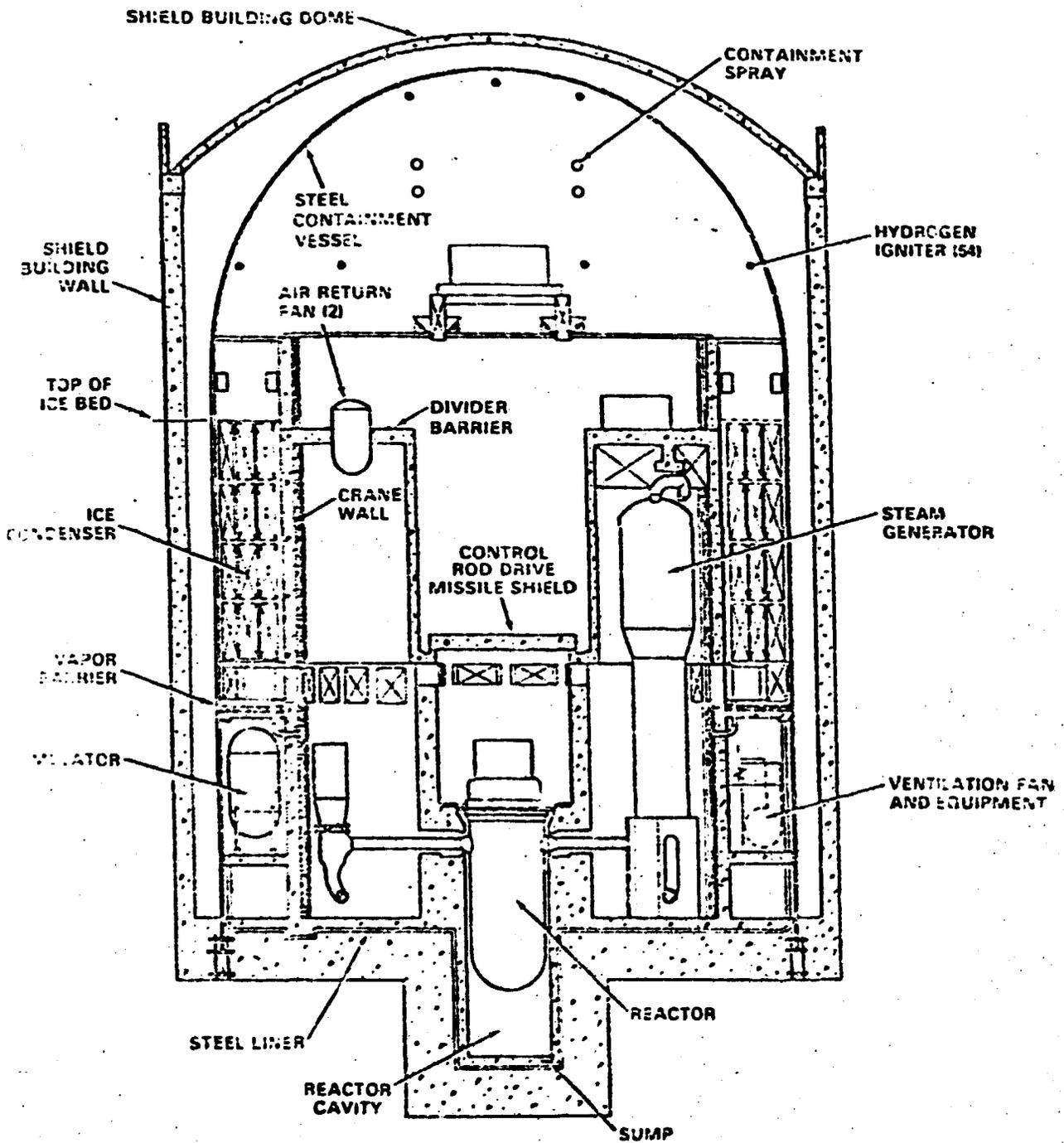
FIGURE 10

SUBATMOSPHERIC CONTAINMENT (SURRY)



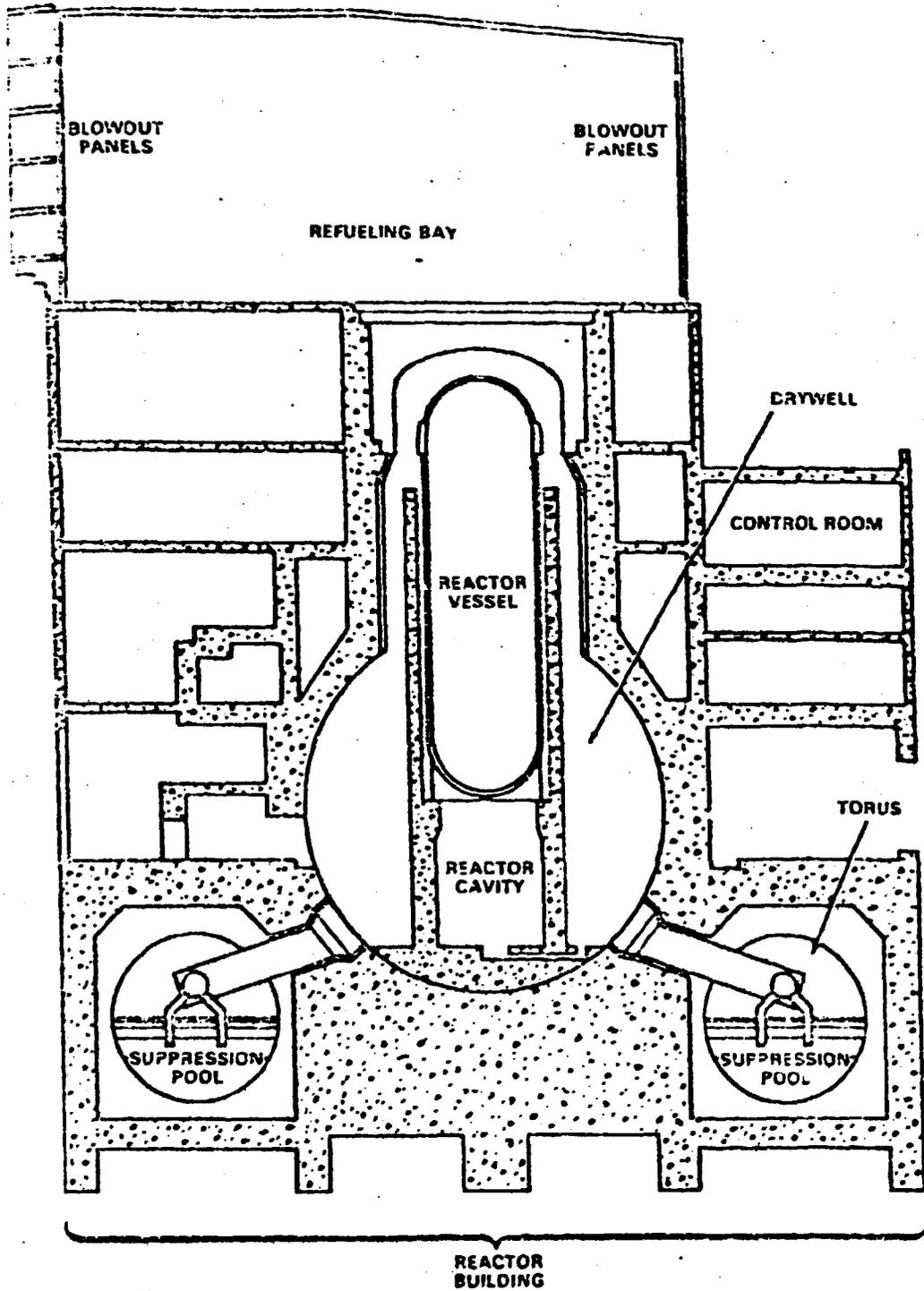
SCHMATIC OF THE CONTAINMENT DESIGN
FOR THE SURRY PLANT

ICE CONDENSER CONTAINMENT (SEQUOYAH)

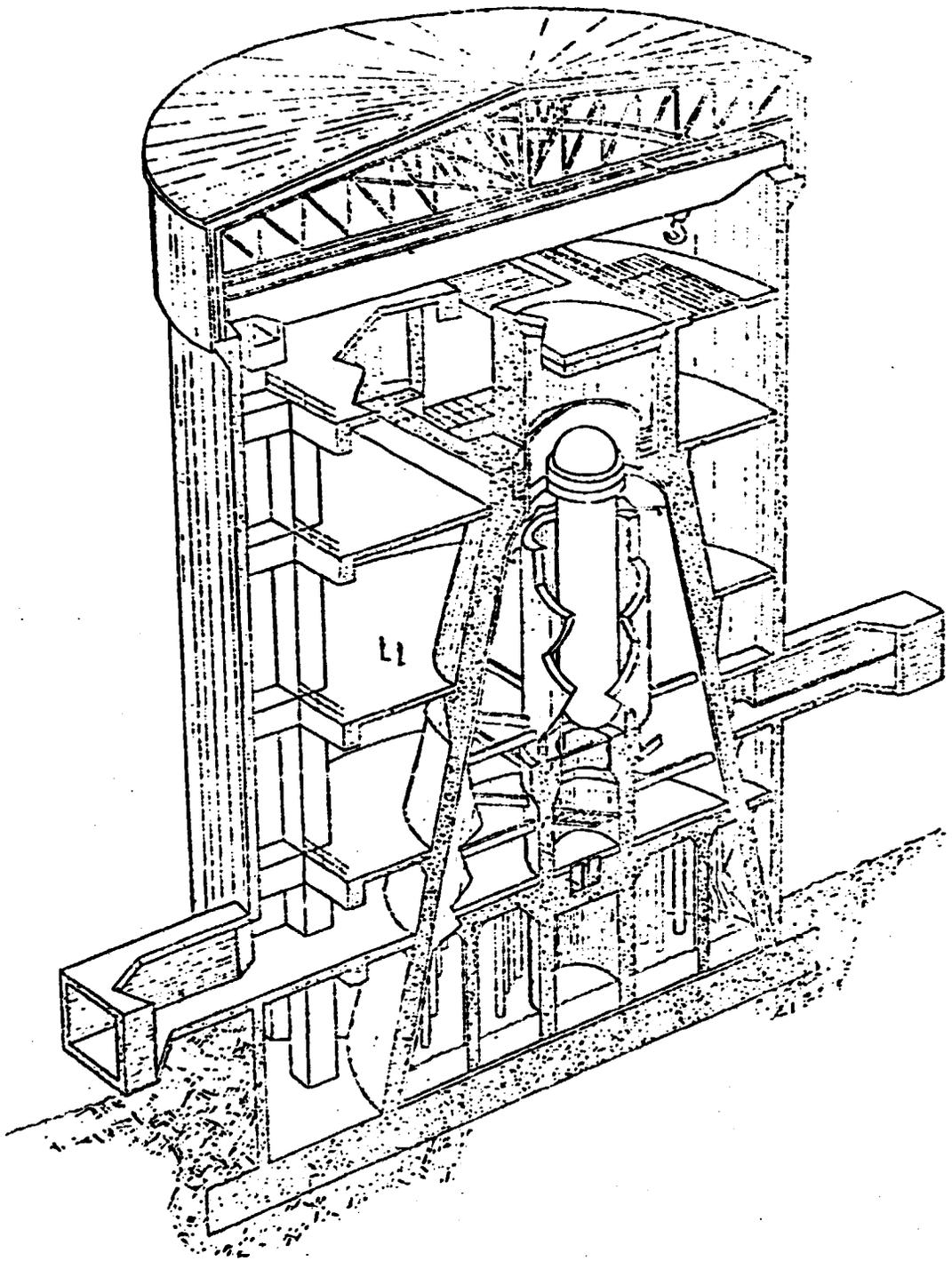


SCHMATIC OF THE CONTAINMENT DESIGN
FOR THE SEQUOYAH PLANT

MARK I CONTAINMENT (Peach Bottom)



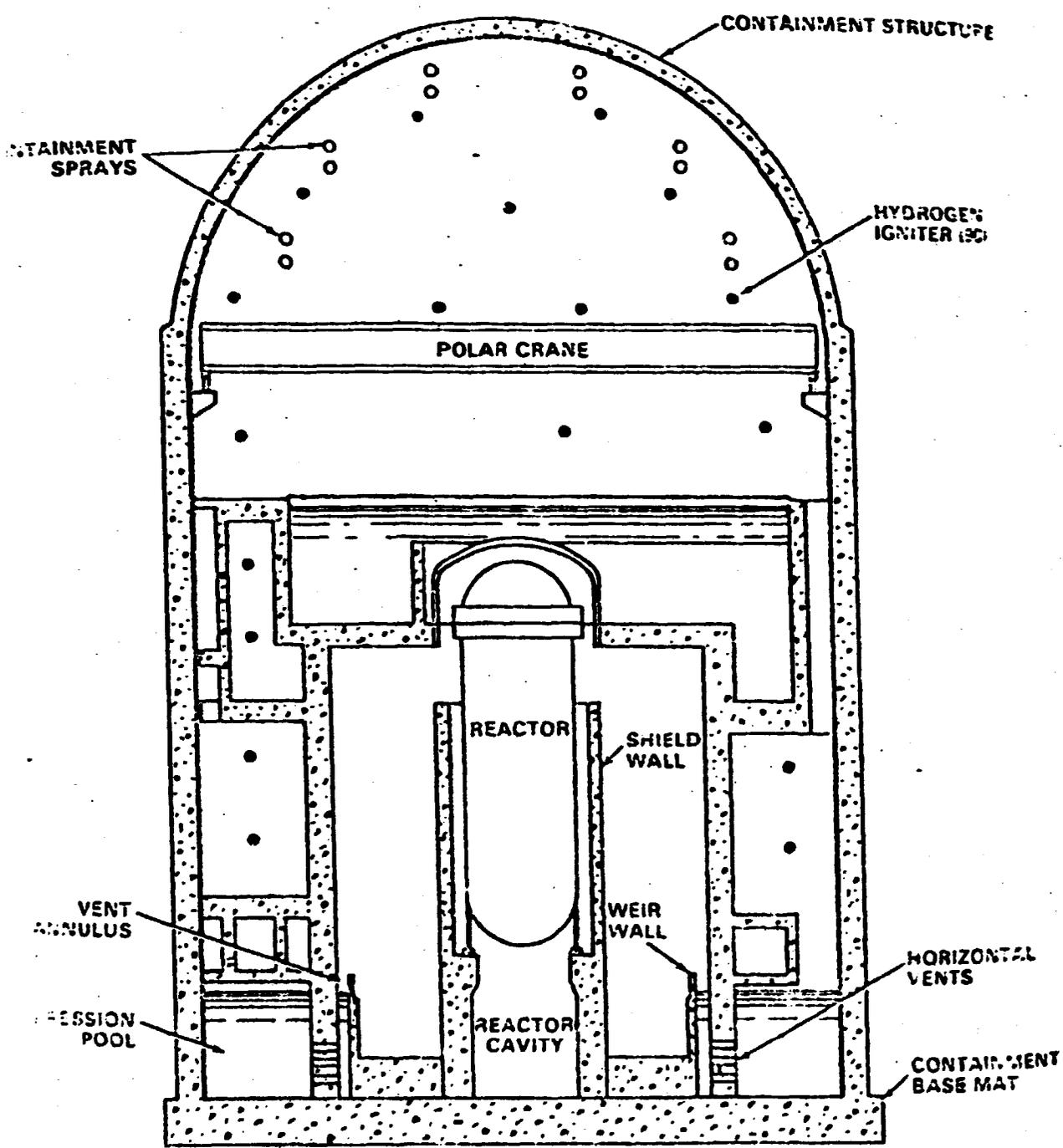
SCHEMATIC OF THE CONTAINMENT DESIGN
FOR THE PEACH BOTTOM PLANT



COMPOSITE SUPPRESSION CONTAINMENT FOR
SHOREHAM NUCLEAR POWER STATION, UNIT 1.

BROOKHAVEN NATIONAL LABORATORY 
ASSOCIATED UNIVERSITIES, INC. 

MARK III CONTAINMENT (GRAND GULF)



SCHMATIC OF THE CONTAINMENT DESIGN
FOR THE GRAND GULF PLANT

ISSUES

DIRECT HEATING

EVENT V

CORE-CONCRETE INTERACTION

EMERGENCY RESPONSE

TENTATIVE CONCLUSIONS

IMPORTANCE OF EARLY FAILURE

STEAM EXPLOSION

CORE-CONCRETE INTERACTION

DIRECT HEATING

NEED FOR SOME FIXES

The subject of containment has been of central importance in reactor safety in the United States since the start. The first major protection requirement for a nuclear facility after the Second World War was the Westinghouse Sphero, a containment building around the Submarine Intermediate Reactor test facility, near Schenectady, New York. This is shown in Figure 1. It is a very large structure by modern scale, about four times the volume of the large dry containments about present Pressurized Water Reactors. The principal specifications are shown in Figure 2.

This requirement for containment of large reactors set a precedent. All primary systems of commercial water reactors since have been fully contained in tight, strong buildings, except for the turbine-generator of boiling water reactors. This exception is specially taken care of by quick-acting isolation valves in the main steam lines and the return lines of BWR's.

The existence of containment had several important effects from the beginning. It strongly affected the analysis in the well-known report WASH-740, which was the basis for initial Congressional structuring of the Price-Anderson insurance legislation. In part because of the assumed requirement of containment, WASH-740 developed the conclusion that a severe accident to a nuclear plant that led to injuring the public would be extremely unlikely. The large values of damage to the public which this report calculated might occur in some cases could only appear if containment were to fail during or after an accident. The principal conclusions of WASH-740 are shown in Figure 3. The principal provisions of the Price-Anderson indemnity legislation that was subsequently passed are shown in Figure 4.