5B JUSTIFICATION OF STRUCTURAL
PROOF TEST-PRESSURES

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APPENDIX 5B

JUSTIFICATION OF STRUCTURAL PROOF TEST-PRESSURES

The basic purpose of a structural proof-test is to substantiate that the structure can, in fact, carry the load for which it is designed. By subjecting the structure to some degree of over-pressure, the test can show that the vessel has that degree of margin over design pressure and would not be at incipient failure as might be the case if it were only tested at design pressure. Most previous steel and reinforced concrete containment vessels and a number of the European prestressed concrete reactor vessels have been tested to 115 percent of design pressure.

As a minimum, the overpressure test must at least allow for the accuracy of the pressure instruments. At a maximum it must not endanger or damage the vessel (by reducing the reserve capacity of concrete in tension or creating permanent deformation in the vessel) by encroaching too close to the actual factored loads for which the vessel is designed. Since the over-all structural integrity of the vessel depends primarily on the integrity of the tendons, it is appropriate to test the vessel to at least that pressure which creates a stress in the tendons equivalent to the stress at design conditions due to dead load, pressure, and temperature. The stress in the tendons at design (accident) conditions will be approximately 64 percent of the ultimate strength. It is felt that a test pressure of 110 percent of design pressure would adequately demonstrate the over-all structural integrity of this vessel. However, in order to conform to past practices, it has been decided to proof-test the vessel at 115 percent of design pressure. At this pressure the stress in the liner is low and there is no concern that it will develop a crack during the proof test.

The safety margin of the prestressed vessel at test, compared to ultimate, can be compared to a steel vessel by reviewing safety margins on various types of stresses and the significance of the stresses in the failure mode of the respective vessels.

The prestressed vessel relies upon the tensile strength of the tendons for its ultimate strength. The secondary stresses of the vessel are isolated from the tendons. At ultimate capacity of the vessel, the secondary stresses and the thermal stresses have been relieved by local cracking of the concrete and the tendons are subjected to internal pressure and dead load only. Dead load stresses are insignificant and tend to reduce the tendon stresses.

The engineered margin of safety for ultimate structural integrity of a steel containment vessel should be based on the ultimate stress as related to stress at test pressure for various combinations of stresses. The margin of safety for steel containment is as follows.

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FACTOR OF SAFETY TO ULTIMATE FOR A STEEL CONTAINMENT VESSEL
(Based on ASME Boiler and Pressure Vessel Code, Section III)

Type of Stress	Stress at Test (1.25 x allowable, S_m)	Margin of Safety
Membrane	21,900	3.2
Membrane plus Bending	32,800	2.13
Membrane plus Bending plus Secondary	65,600	0.92

The prestressed containment vessel has various material elements contributing to the structural integrity of the vessel. The margin of safety at test pressure of the tendons, which are the most critical elements of the structure, is 1.60. This margin of safety for the prestressed containment is lower than that of a steel containment when it is based on a comparison of membrane stresses. However, the margin of safety of 3.2 shown for membrane stress in a steel vessel neglects the effect of secondary and thermal stresses and their ability to propagate failure. Since the membrane integrity at ultimate strength is controlled by the secondary stress concentrations, the margin of safety for this case forms a more reasonable basis for comparison with the prestressed vessel. Certainly the margin of safety at ultimate failure is larger than 0.92 and must lie between 0.92 and 2.13, depending on the significance of the secondary stresses. An exact value for this margin of safety would be virtually impossible to evaluate.

Based on the above, the margin of safety of a steel vessel and a prestressed vessel at ultimate capacity to test pressure are roughly comparable.

The prestressed containment is a ligament type vessel where the failure of a single ligament would result in a load redistribution to adjacent ligaments. This type of gradual progressive failure of isolated ligaments gives ample warning of distress during tests rather than a possible sudden catastrophic failure of a biaxially stressed steel membrane.

The selected test pressure cannot be considered as proof of tendon strength, but rather the safe design of the other important components, mainly the concrete and, to some limited extent, the liner plate. There is no other significant similarity between the test pressure and the design pressure. The design pressure is not considered to act before thermal stresses have been developed in the concrete shell. The uneven temperature in the shell produces compressive stresses in the inside and tensile stresses in the outside fibers. The test pressure produces tension across the whole concrete section, but still does not exceed the compressive stresses developed by the prestressing, even at any section where the design load would cause tension stresses. However, some tension stresses will exist at test pressure. In places where only the factored load causes tension, the design load will not. Therefore, further increase of the test pressure is not advisable.

In the case of accident, the liner plate will be under high compressive stresses, and the design pressure will only decrease the compressive stresses, but, unlike the test pressure, not cause any tension stresses. The high compressive stresses in the liner plate result from the prestressing and thermal

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conditions, and this most likely worst condition cannot be reproduced without heating up the inside of the vessel to the accident temperature while the outside ambient temperature also happens to coincide with the design conditions.

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