

Containment Design of a Simplified Boiling Water Reactor (SBWR) Plant

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1. INTRODUCTION

The SBWR has earned the praise and endorsement of government, the nuclear industry and utilities. It is being developed as a standardized 600 MWe Advanced Light Water Reactor for the 1990's for a generic site. The design concept of the SBWR is based on simplicity and passive features to enhance safety and reliability, improve performance and increase economic viability.

For SBWR, under a postulated loss of coolant event (LOCA), the suppression pool absorbs the blowdown energy, the reactor pressure vessel is depressurized with depressurization valves, the gravity-driven cooling system (GDCCS) floods the reactor and the isolation condenser (I.C.) removes decay heat. Use of these and other passive systems allow the elimination of safety grade emergency diesel generators, core cooling pumps and heat removal pumps thus simplifying plant design and reducing plant costs.

Due to the use of passive containment cooling, the SBWR has features that are different from those of existing designs. The I.C.'s that remove decay heat by natural convection and evaporation are in pools which are located on top of the drywell. To maintain long term cooling and water coverage of the reactor core, the suppression pool (SP) is elevated to such a level that water can flow by gravity from the SP to the reactor after a LOCA.

The main objective of the study described herein is to demonstrate the structural design feasibility of this containment for the pressure and temperature responses associated with the passive systems adopted for the SBWR. Another goal is to study whether a 30-month construction schedule can be achieved.

2. GENERAL DESCRIPTION OF THE CONTAINMENT AND REACTOR BUILDING

Nuclear island (NI) structures consist of the reinforced concrete containment vessel (RCCV) of 31.5^m ID and the three rectangular boxes of the reactor building (RB) supported on a common basemat of 66.3^m x 66.3^m with interconnected slabs at various elevations as shown in Figure 1. The structures are primarily of reinforced concrete construction up to the operating floor with a steel superstructure.

The RCCV consists of the reactor pressure vessel (RPV) pedestal, SP floor slab, the cylindrical containment wall and the drywell top slab.

The drywell top slab supports the IC pools and service pool. The IC pool girders on the drywell top slab provide strength to resist containment pressure loads. The top slab has a large opening ($\phi = 9.4^m$) in the middle for the drywell head and four openings ($\phi = 3.2^m$) for the I.C.'s. The vent wall structure and the diaphragm floor slab are steel structures filled with concrete.

The RPV pedestal supports the reactor vessel, reactor shield wall, vent wall structure and the suppression pool. It is also a part of containment pressure boundary.

3. DESIGN CRITERIA

The containment structure is designed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Div. 2, Subsection cc, 1989 edition (Ref. 1).

The containment temperature and pressure conditions for normal, testing and LOCA conditions considered in the study are shown in Table 1. Pool hydrodynamic loads and the corresponding containment pressures are also considered. Temperatures greater than 150°F are postulated to last a longer period of time after a LOCA or postulated severe accident conditions in the SBWR. Degradation of material properties is expected and, therefore, temperature dependent material properties are considered in the analysis and design.

4. SEISMIC ANALYSES AND DESIGN

The seismic analyses for this feasibility study were performed with lumped mass model as shown in Figure 2. A range of soils was considered in terms of shear wave velocity (v_s). Evaluated soils include soft soil with $v_s = 300^m/s$, $500^m/s$, intermediate soil with $v_s = 1000^m/s$ and hard soil with $v_s = 1500^m/s$ and $3000^m/s$. Two sets of input motion were used. One based on a peak horizontal ground acceleration of 0.3g (SSE) with a response spectrum per US NRC Reg. Guide 1.60. The other based on Japanese MITI Standardization program for LWR in Japan with S_1 (near) = 267 gal, S_1 (far) = 286 gal, S_2 (near) = 369 gal and S_2 (far) = 407 gal. In addition, a parametric seismic analysis was performed for various idealized site conditions as presented in Ref. 3. For the RCCV cylinder at basemat level, seismic shear used for feasibility evaluation is 34,600 tons and the overturning moment is 1.02×10^6 ton-meters.

5. STRUCTURAL ASSESSMENT

5.1 RCCV Walls

The reactor building and the containment were analyzed by finite element methods using plate and shell elements. The concrete cracking effects were evaluated by successive iterations.

The evaluation results demonstrate that the RCCV wall of 2.0 meter thickness can be adequately reinforced to resist the loads discussed. The RCCV, as designed for LOCA conditions, can withstand a severe accident pressure of at least two times the design pressure value together with associated temperature. Similar conclusions were reached in Ref. 2 for a slightly larger SBWR Containment but with somewhat different configuration.

5.2. Drywell Top Slab

The drywell top slab is supported along its periphery by the containment wall. It is further strengthened by integration with pool girders and other internal walls. The top slab is a part of the SBWR containment boundary. Both sides of the slab are lined with a steel liner plate.

The top slab was analyzed by a finite element model as shown in Figure 3. The details of analysis and results are presented in Ref. 4. The results show that the design is feasible with the specified number of large openings in the slab.

5.3 RPV Pedestal

In the present design, the RPV pedestal forms part of the containment pressure boundary. It was decided to adopt reinforced concrete pedestal with liner plate on the inner face acting as leak tight boundary. This was judged to be more desirable than a steel-concrete composite pedestal, based on consideration of applicable design codes, severe accident conditions and construction requirements including modularization. Figure 4 shows the pedestal design based on these considerations.

5.4 IC Pool Girders

In the present layout of the SBWR, the RCCV is integrated with the R/B by R/B floor slabs at various elevations and by the IC pool girders on the top. These reinforced concrete girders are located such that the clear distance between their supports at the RCCV and the inner box of the RB is only about 4 meters.

For the evaluation, a finite element model was prepared, and analysis performed using STARDYNE computer code. In a series of iterations, the stiffness of highly stressed elements were reduced to allow for redistribution of forces and particularly to evaluate the acceptability of the resulting stresses.

The study results showed that for the present configuration with integrated RCCV/Reactor Building/IC Pool Girders, the structural design is feasible. Even though large shear stresses are induced in the pool girders due to the thermal growth of the RCCV due to LOCA thermal loads based on the initial elastic analysis, the thermal stresses are significantly reduced after accounting for relaxation due to cracking of concrete.

5.5 Floor Slabs

The reactor building has floor slabs at various heights. Integration of the RCCV with the R/B is advantageous from seismic design considerations. However, when the design for LOCA pressure and temperature and construction are considered, integration of all floor slabs with the RCCV is not desirable. To optimize the structural responses it was decided that the two structures be integrated only at:

- o Suppression pool bottom floor slab level.
- o Suppression pool top slab level.
- o RCCV top slab level.
- o Operating floor.

It was decided not to integrate the remaining floors of the RB with the RCCV. A separation gap has been provided between these slabs and the RCCV wall, with appropriate detail for the required leak tightness against flooding, fire, etc. This will prevent containment pressure and thermal loads from being transmitted to these floor slabs, thus making their design more economical. Also, in absence of floor integration with the RCCV, the construction of RCCV can be expedited.

5.6 RCCV Internal Structures

The vent wall structure is made up of two concentric steel cylinders with vertical stiffeners in-between. There are 8 vent pipes that are equally spaced between stiffeners. The remaining spaces are filled with concrete. This type of construction lends itself well to modularization and off-site prefabrication. The design is feasible with 30mm thick steel plate.

Diaphragm floor slab is a steel structure consisting of continuous top and bottom plates with circumferential stiffeners and radial vertical web plates in between. This lends itself to modular construction and provides for easy anchorage of GDGS pool steel framing and the pipe support structure in the drywell.

5.7 Reactor Shield Wall

The reactor shield wall (SW) is made of a circular cylindrical shell of 6 inch thick steel plate. The thickness of the SW is based on shielding requirements. For the SW design, the major loads are the seismic loads, the annular pressurization (AP) and jet loads which result from a postulated pipe break in the annulus region between the RPV and the SW. The stress calculations show that the design of steel SW is feasible.

6. MODULARIZATION AND CONSTRUCTION SCHEDULE:

To achieve a short construction schedule of the project (30 months from first structural concrete to fuel load), it is important that prefabrication and modularization be adopted to the maximum possible extent. Larger sized modules offer potentially greater savings than smaller modules. Large modules are created from shop fabricated sub-units that are assembled onsite but out-of-hole thus making modularization more efficient.

It is proposed to use a heavy-lift crane such as the Lampson's Transi-Lift with about 1000 tons capacity for the large structural modules. Figure 1 shows some of the major modules for the SBWR NI structures, the heaviest one being the vent wall structure with the RPV support, weighing about 900 tons.

Most of the rebar for walls and slabs can be pre-assembled with the form work or with liner in large modules and lifted in place. For the top slab rebar assembly together with the liner can be prefabricated as a single module weighing about 700 tons. Composite structure equipment modules will be used where advantageous.

Studies based on the application of large scale modularization and assuming a 70-hour work week (rolling 4 x 10's), indicate that a 30 month construction schedule from start of first structural concrete pour to the fuel load may be feasible for the nth of a kind. However, it is recognized that it will take somewhat longer duration for construction of the first few units.

7. CONCLUSION

RCCV design based on ASME Section III, Div. 2 is feasible for the SBWR integrated configuration reinforced concrete pedestal subjected to the specified LOCA pressure, temperature, and seismic loads including long term high temperature effects associated with the SBWR passive safety system..

Design feasibility of the top slab with a number of large openings is demonstrated.

Studies show by using large scale prefabrication and modularization, and based on use of 1000 ton crane with rolling 4 x 10's a 30-month construction schedule from start of structural concrete to the fuel load should be achievable for the nth of a kind.

8. REFERENCES

- (1) ASME, Boiler and Pressure Vessel Code, Section III, Div. 2, Subsection cc, 1989.
- (2) Sawhney, P. S. G. L. Barnes, N. B. Duchon, P. F. Gou, "Integrated Reactor Building/Containment Design of a Simplified Boiling Water Reactor (SBWR) Plant:", 10th SMIRT 1989 p.p. 61-66.
- (3) Olivieri, M., G. Viti, M. Fiorese, M. F. Moholkar, P. F. Gou, "SBWR-RCCV Top Slab Design by Analysis", 11th SMIRT 1991, H12-3.
- (4) Olivieri, M. E. Traversone, G. Viti, "SBWR-Nuclear Island Parametric Seismic Analysis" 11th SMIRT 1991.

TABLE I PRESSURE AND TEMPERATURE LOADS

Condition	Pressure (psig)		Temperature (°F)	
	Drywell	Wetwell	Drywell	Wetwell
Test (1)	63.3	63.3	60	60
Test (2)	63.3	34.6	60	60
Normal	2.0	2.0	135	95
LOCA (72 Hours)	55	55	340	220

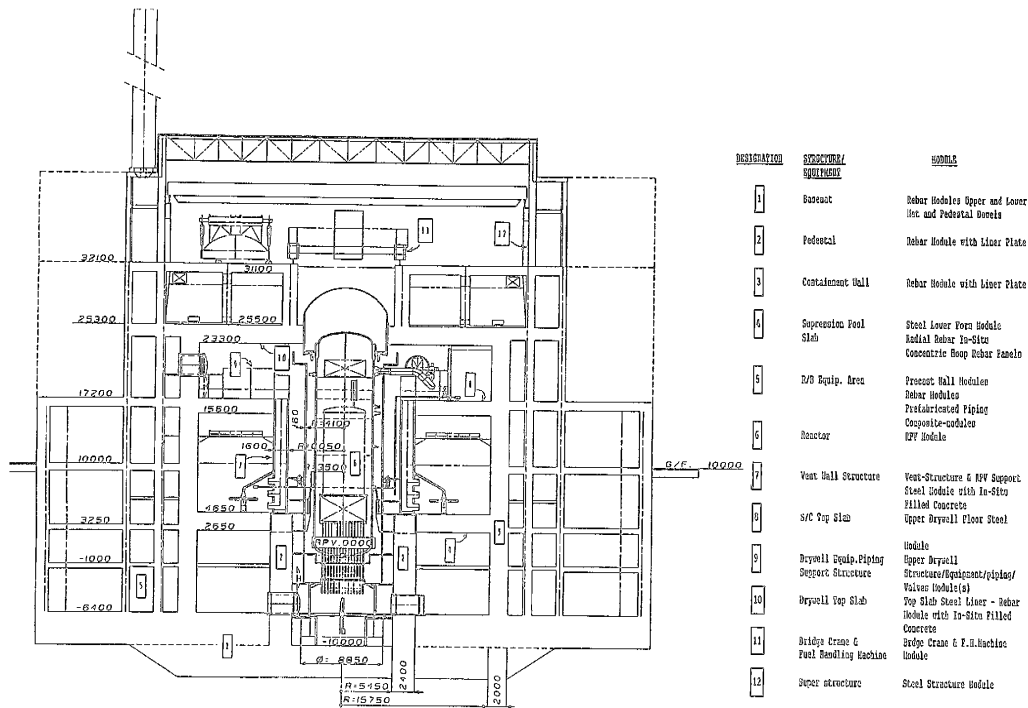


FIG. 1 A TYPICAL SECTION OF SBWR PLANT

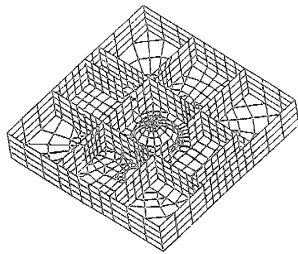


FIG. 3 FINITE ELEMENT MODEL FOR DRYWELL TOP SLAB

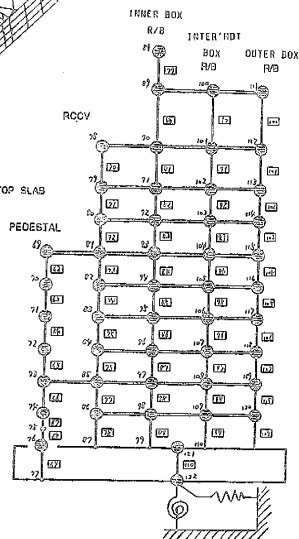


FIG. 2 LUMPED MASS MODEL FOR SEISMIC ANALYSES

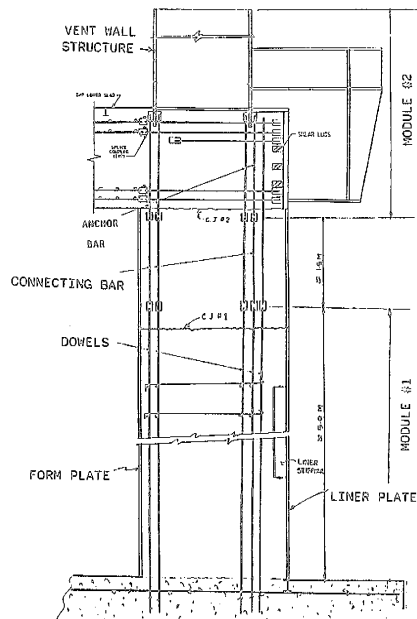


FIG. 4 PEDESTAL DESIGN