STUDY ON A 1200 MWE SIMPLIFIED LWR DESIGN

Ryokichi Yamazaki, Mototaka Yoshimura, Hiroaki Tabata
The Japan Atomic Power Company, Japan

ABSTRACT

In 1988, the Japan Atomic Power Company (JAPC) and the Japanese Utilities started two series of studies to modify AP600 and SBWR and accommodate them to the Japanese requirements. We call these plants Simplified Light Water Reactors. In a joint effort to keep nuclear power as an attractive energy option for the future, JAPC has studied to confirm the feasibility of a large sized Simplified Pressurized Water Reactor (SPWR) and Simplified Boiling Water Reactor (JSBWR) in cooperation with the Japanese Utilities and the vendors. Both concepts appear to be feasible though the design and development of some major components are required. The summary results of 1000 MWe Simplified LWRs were reported at the last PBNC meeting in Japan. Since then, the feasibility study of power uprating and alternative system design were proceeded to improve economics. In this paper, the feasibility of 1200 MWe plant, safety features in comparison with the current plant, reduced manpower required at an annual outage, and reduction of plant capital cost are discussed, including:

- Rationalization of main components such as PCCS pool size reduction by SIPOWER application, elimination of DPVs by adopting accumulators, and reduction of reactor building volume.
- Scoping safety analyses including small break LOCA, non-small break LOCA and containment analyses to determine feasibility of the uprated design.
- Nuclear island building layout, equipment general arrangement and associated seismic evaluation
- Comparison of plant capital cost, safety and required manpower for operation and maintenance with those of current ones.

The overall conclusion are that 1200MWe passive plants, both SPWR and JSBWR, compare favorably to conventional plants.

INTRODUCTION

The main aim of Simplified LWR development lies in the attempt to minimize accident probability by reducing the human workload required for plant operation and maintenance (a lesson learned from the Three Mile Island accident) and, in particular, to focus on reducing human error in the event of an emergency. To reduce human error, the measures may be taken through automation of both plant equipment and systems. However, ensuring the reliability of the automated equipment and systems requires multiplex design considerations. This involves a complicated system with a resultant increase of human workload in both operation and maintenance.

The simplified LWR adopts a totally passive safety system that operates on natural forces, such as gravity and natural circulation. The design is primarily concerned with the reduction of human workload during both operation and maintenance by simplifying multiplex system components. In addition, it is intended that the non-safety system will also be simplified to the extent allowable to maintain both reliability and plant operability, thus further lightening the human workload for operation and maintenance.

In terms of economy, the Simplified LWR should remain equivalent or superior to current plant with same electrical output, either by reducing the total number of components or by converting several safety system equipment into non-safety system equipment, as a result of passive safety features.

Furthermore in response to the current escalating demand for nuclear plant economy, a feasibility study to pursue the possibility of further uprates with a consistent SPWR/JSBWR concept has been conducted through review of safety and human workload in the sequential order of 670 MWe, 1000 MWe, 1200 MWe Simplified LWR units. The SPWR and JSBWR bird's eye views are shown in Figure 1 and Figure 2.

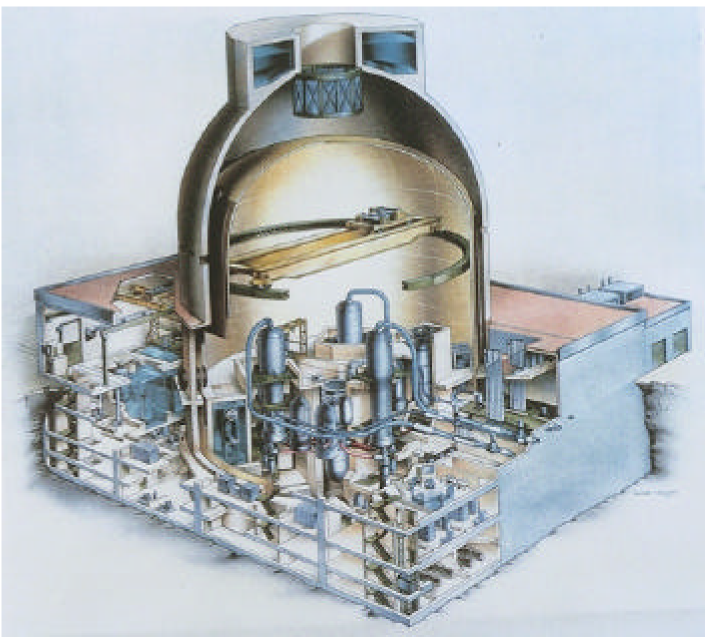

Figure 1: SPWR bird's eye view

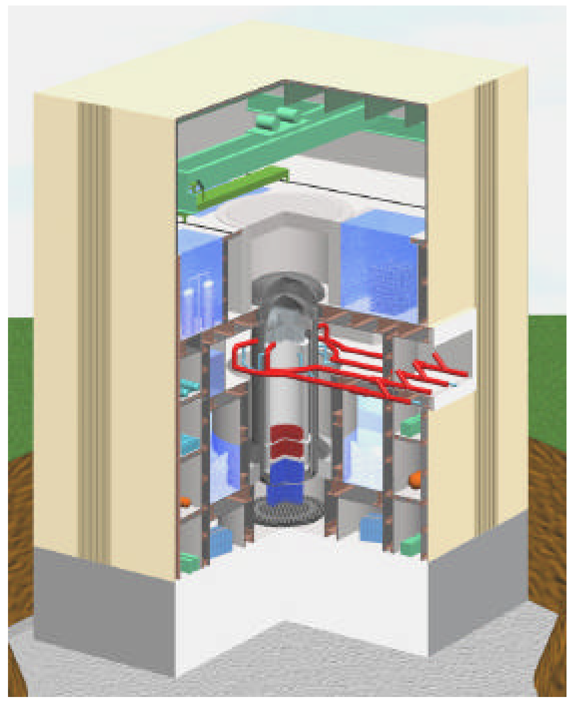

Figure 2: JSBWR bird's eye view

SIMPLIFIED LWR STUDY PROGRAM STATUS

SPWR

Plant design concept

Based on AP-600, a further review was made to look at the possibility of power uprate. The SPWR plant concept is shown in Figure-3. As a result of safety analyses and aseismic analyses, technological feasibility was confirmed for the development of large scale ratings in the order of 1000 MWe, 1200 MWe (3-loop) and 1300 MWe (4-loop).

In the 1200 MWe (3-loop) case, adopting a 14 ft fuel length (12 ft fuel in the current plant) satisfies the core feasibility. The CV is 48 m diameter by 65 m high and the R/B footprint layout is 83 m by 63 m.

In the 1300 MWe (4-loop) case, however, layout of the CV internal coolant piping requires the containment vessel to swell out larger than that of the 1500 MWe APWR. In terms of economy, it is considered that a realistic limit of optimum output should be set at about 1200 MWe or less. Even at a 1200 MWe rating (3-

loop), some future technical issues remain, such as assuring adequate earthquake resistance for a large steam generator and the development of a larger canned pump for the primary system.

Plant simplification

Since the current safety systems such as the component cooling sea water system, can be converted into non-safety systems with the introduction of the passive safety system, it is expected that plant system components will be significantly simplified; for instance, a decreased number of trains, etc.

Also, with fewer primary system components there is potential for the reactor building footprint to be reduced by 40% or so, compared with that of a current plant. The R/B footprint comparison between SPWR and current PWR are shown in Figure 4.

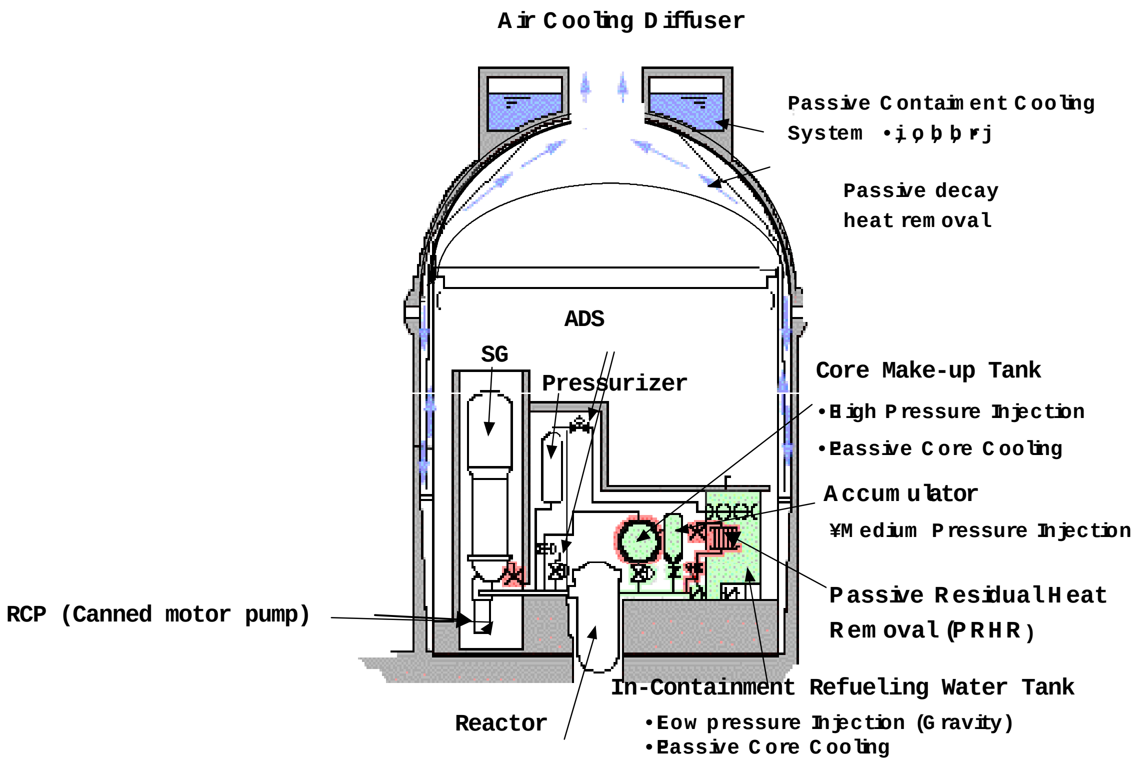

Figure 3: SPWR plant concept

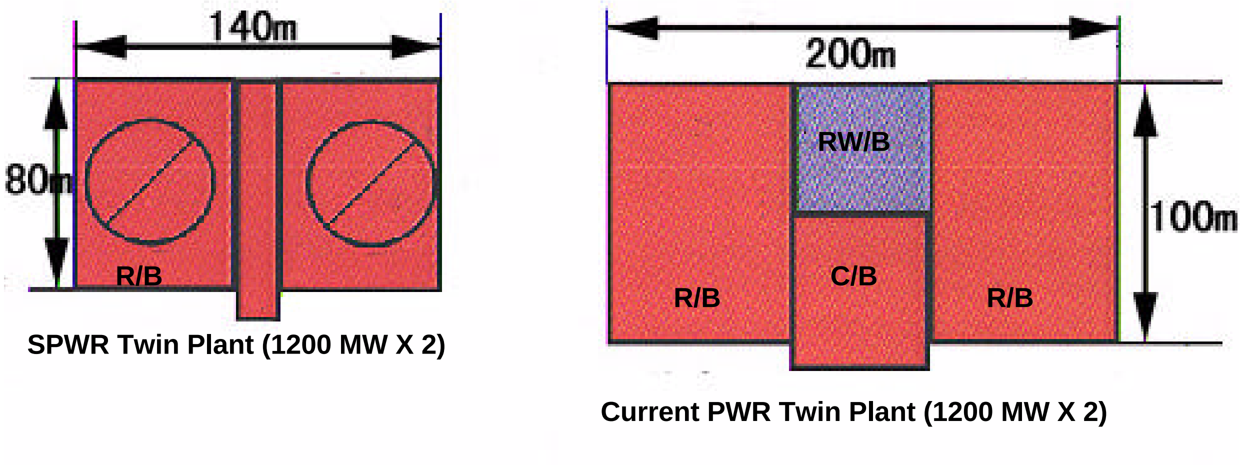

Figure 4: The R/B footprint comparison between SPWR and current plant

Safety

It is expected that with the passive safety system complicated operating practices, otherwise required in the past, will no longer be necessary in the event of a LOCA or SGTR, and three days "walkaway" period will be secured. So far, the major analyses have been performed for plants rated at 1300 MWe or less. In all cases, the results satisfy plants safety requirements.

Operability and Maintenance

Since the walkaway safety concept is incorporated into the design conditions, it is most likely that the total number of items to be monitored during an accident will be reduced as there will be no need for safety-related operational action by the plant personnel.

As for the plant maintenance, it can also be assumed that the plant outage workload for the primary system could be reduced by about 35% compared to the actual outage workload at JAPC Tsuruga Power station Unit-2 (4-loop), mainly because of the reduced numbers of equipment and simplified system components. The outage man-hour evaluation comparison between Tsuruga-2 and SPWR is shown in Figure 5.

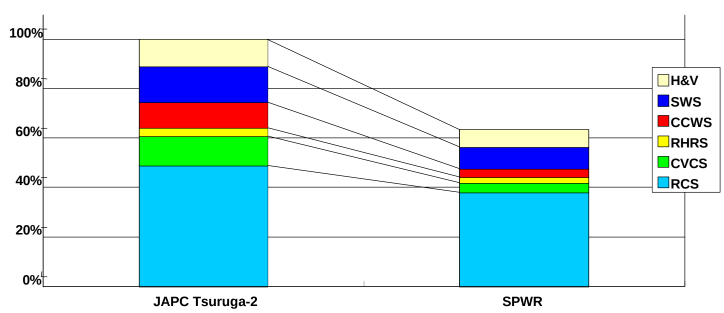

Figure 5: Outage Man-hour Comparison

JSBWR

Plant design concept

The possibility of power uprate was reviewed based on the U.S. SBWR plant design concept. The JSBWR plant concept is shown in Figure 6.

The technological feasibility was confirmed by the safety and aseismic analyses on the SBWR in sequential order from 600 MWe to 1300 MWe. However, with application of the natural circulation core, the JSBWR fuel length is reduced to 9 ft in order to enhance core flow. It is thought that the realistic output limit should be optimized at 1200 MWe or less, taking into account the increased number of fuel assemblies (i.e. 1132 bundles for 1200 MWe JSBWR compared with 872 bundles for 1356 MWe ABWR). It must also be considered that even at the 1200 MWe class output, other technical problems associated with a longer RPV and the increased number of bundles remain for the future study.

Plant simplification

Use of a natural circulation system eliminates external recirculation pumps and also the control and power supply systems associated with the pumps. A passive safety system is expected to be more simplified than the current safety system.

Furthermore, by converting the safety system components, such as the standby power generation sources and auxiliary cooling system, into the non-safety system, it is estimated that the reactor building footprint can be reduced by 30% compared with current plant. The R/B footprint comparison between JSBWR and current BWR is shown in Figure 7.

The Passive Containment Cooling System (PCCS) removes the decay heat by the boiling of PCC/IC (Passive Containment Cooling/Isolation Condenser) pool water. About 6000 tonnes of water is needed on the operating floor. In order to reduce the pool capacity, one option is to use a pool makeup system that supplies water from a tank outside of the reactor building by using the steam injector. The steam injector(S/I) is a simple, compact and passive pump which is driven by supersonic steam jet condensation.

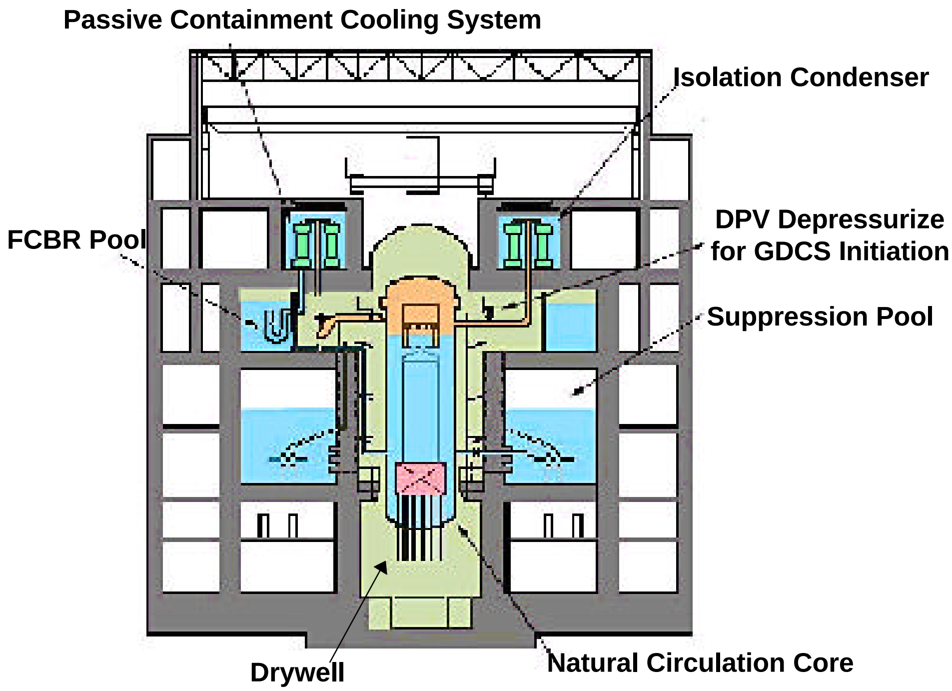

Figure 6: JSBWR plant concept

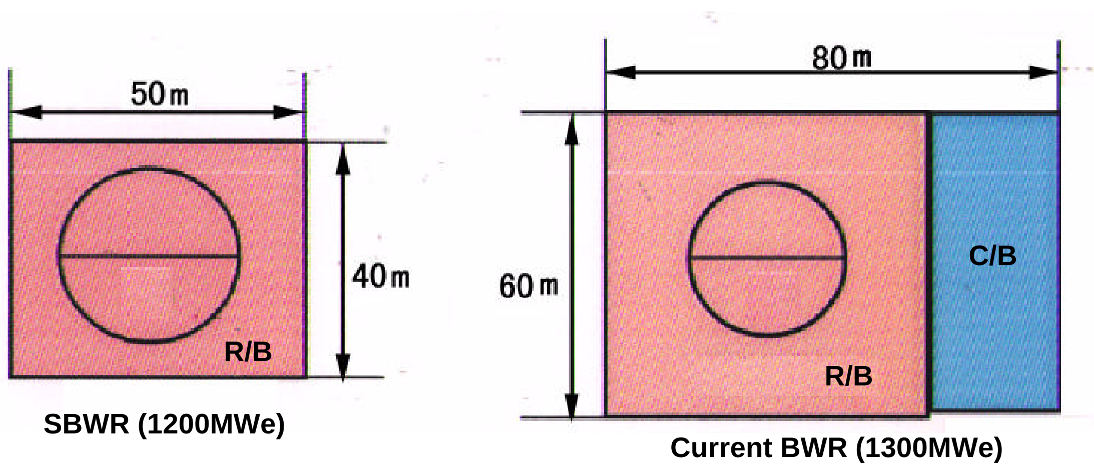

Figure 7: The R/B footprint comparison between JSBWR and current plant

The one example of S/I application is shown in Figure 8. The steam, generated from the PCC pool following a LOCA, is supplied to the S/I and the S/I supplies water from a tank on the ground to the PCC pool. By using this system the pool volume and area requirements can be reduced.

The pool area can be reduced by 30%. Furthermore, a feasibility study has been conducted on a S/I driven system for low pressure core injection system for JSBWR. The S/I system could discharge water at 0.6 MPa by the time the GDCS started operation. The system simplified the core injection system using the 8 DPVs.

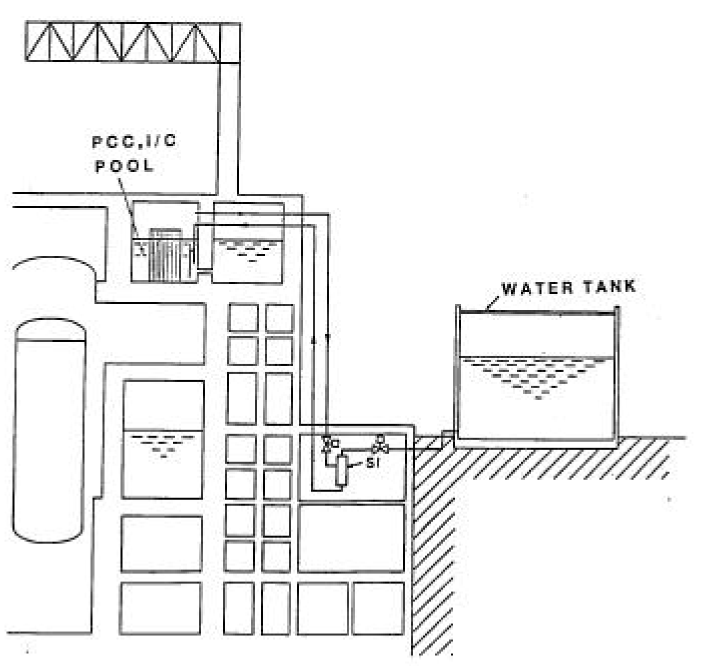

Figure 8: The S/I application to JSBWR

SAFETY

It is expected that with the passive safety system, complicated operating practices, otherwise required in the past, will no longer be necessary, and three days "walkaway" period will be secured after an accident. So far, major safety analyses have been conducted for all plants rated at 1300 MWe or less. In all cases, it was deemed the results could satisfy the plant's requirements.

OPERABILITY AND MAINTENANCE

Since the walkaway safety concept is incorporated into the design conditions, it is likely that the total number of monitoring items during plant shutdown will be reduced, as there will be no need for safety-related operational action by plant personnel. As for maintenance, it is also estimated that simplification of the safety system will reduce the workload required during annual plant outage by about 20%. The outage man-hour evaluation comparison between current BWR and JSBWR is shown in Figure 9.

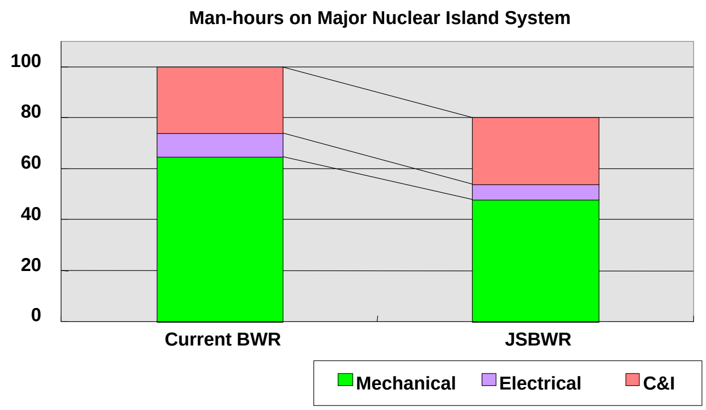

Figure 9: JSBWR Outage Man-hour Evaluation

MODULE CONSTRUCTION USING THE HULL STRUCTURE

The Reinforced concrete (RC) Reactor Building (R/B) construction cost is one of the major parts of the plant cost, because of the complicated interface installation work required at site for the reinforcing work, the mold installation, the concrete work and the mold removal.

By introducing a modular steel structure construction method for the R/B, similar in idea to ship construction, it is possible to shop-fabricate modules therefore reducing the amount of site work required and hence shorten the construction period. We call this type of building a “steel structure building”. The strength member is composed of the steel plate with ribs (girder and stiffener).

We estimate that by adopting this type of construction method for both R/B and containment vessel, the period from rock test to turn over is 27 months. This compares with a construction period of 48 months for RC R/B.

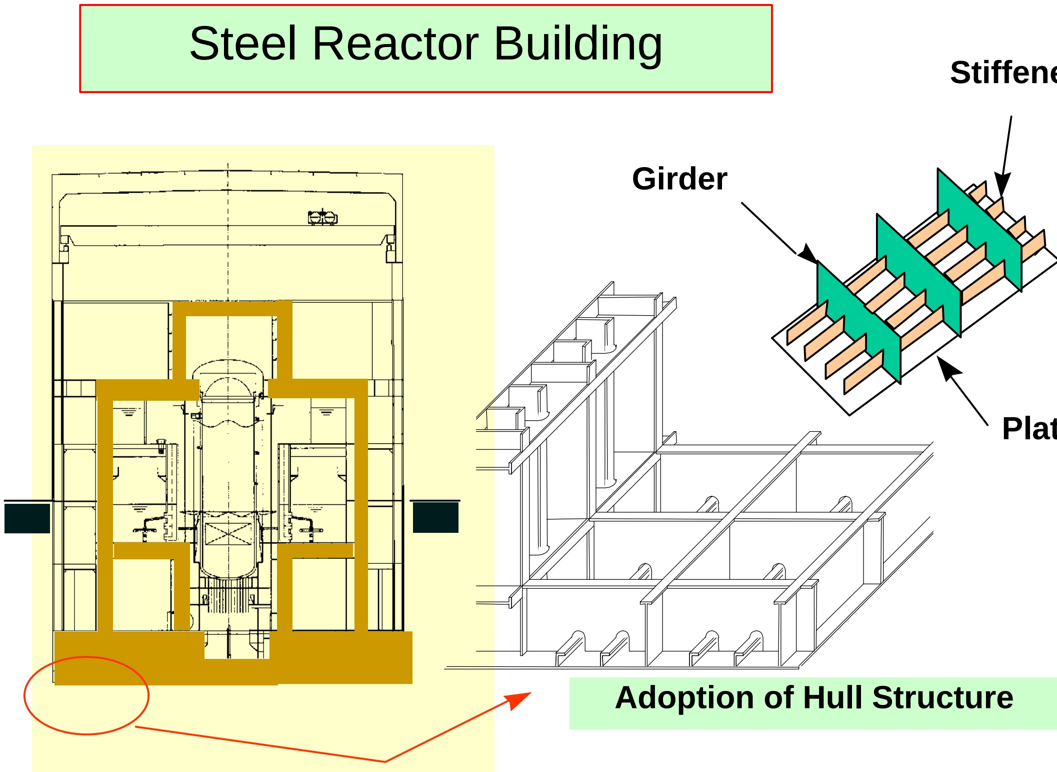

Figure 10 : Hull structure adoption to JSBWR plant

We have studied the earthquake resistance behavior of this R/B by the mass and beam model. The steel R/B mass is about 2/3 of the RC R/B mass. Thus the steel R/B overturning moment is greatly improved compared with the RC R/B.

ADDRESSING FUTURE ISSUES

Taking a long term future perspective on LWR, it can be expected that the simplified BWR/PWR will pose a typically representative global concept of the future light water reactor with a very accessible safety concept by applying the passive safety features by virtue of available natural force and will help to mitigate human workload in plant operation and maintenance. It can also be expected that passive technology itself will be incorporated into any future light water reactor.

Thus far, following an overall evaluation from past research results, the SBWR/SPWR has already proved its technical feasibility, with an encouraging prospect for the future. However, as already mentioned, some technical issues remain for the future study, such as verifying the earthquake resistance of the steam generator and the development of a large canned motor pump for SPWR, and the necessary extension of the pressure vessel with application of a natural circulation core system and increased fuel assemblies for the SBWR. In addition, a study must be made to improve plant economy as well as technologies, to meet electric industry demand for higher economy of nuclear power generation.