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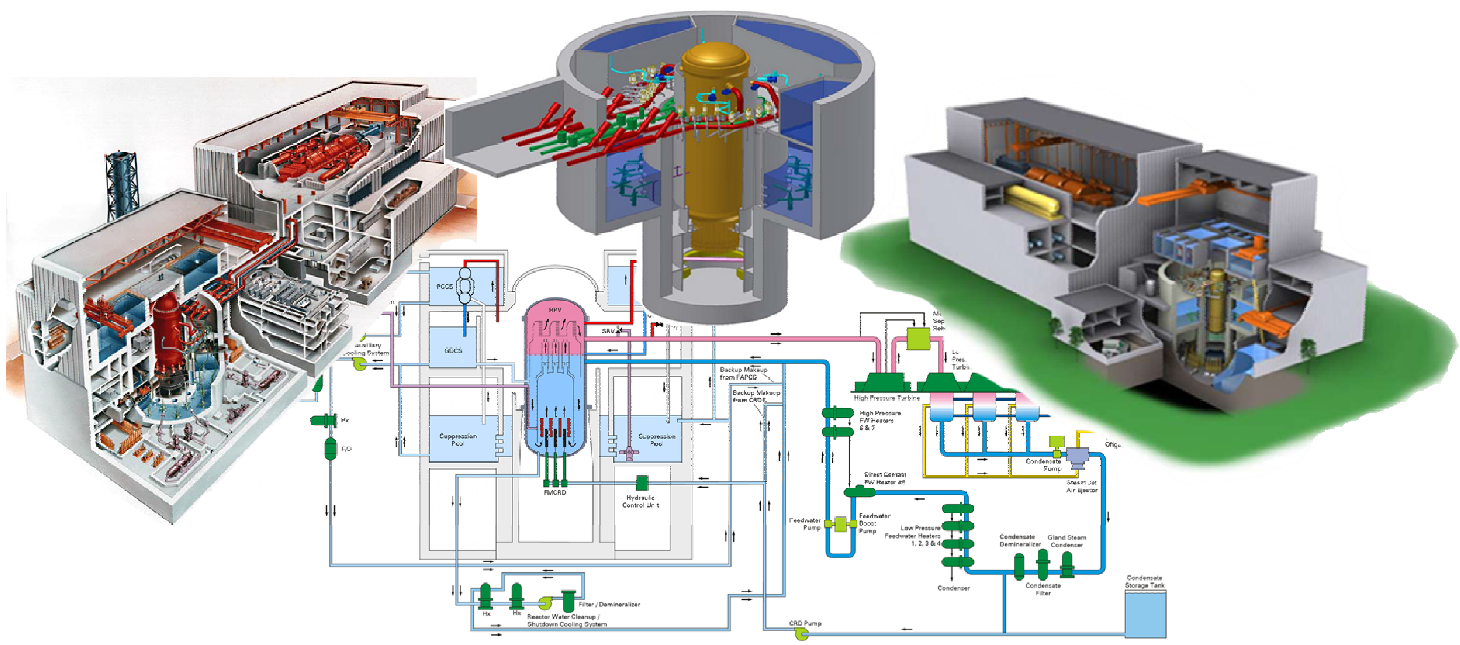

Part II

Introduction to Reactor Technology - BWR

Chapter 13.0, ESBWR Plant Overview

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HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.

The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.

The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, “First of the Next Generation,” GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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Table of Contents

Table of Contents 13-1
List of Tables 13-1
List of Figures 13-1
3.0 ESBWR Plant Overview 13-2
13.1 ESBWR Program Goals 13-2
13.2 Summary of the ESBWR Key Features 13-2
13.2.1 Design Philosophy 13-4
13.2.2 Improvements to Operation and Maintenance 13-4

List of Tables

Table 13.0-1, Comparison of Key ESBWR Features to previous BWRs 13-3

List of Figures

Figure 13.0-1, Cutaway of the ESBWR 13-8
Figure 13.0-2, ESBWR Major Systems 13-9
Figure 13.0-3, ESBWR Reactor Pressure Vessel and Internals 13-10
Figure 13.0-4, EWBWR Reactor Pressure Vessel and Internals 13-11
Figure 13.0-5, ABWR (Lungmen) Main Control Room Panel 13-12

3.0 ESBWR Plant Overview

13.1 ESBWR Program Goals

The ESBWR builds on the Advanced Boiling Water Reactor (ABWR) technology and construction programs, as well as the Simplified Boiling Water Reactor (SBWR) development program. The key design objectives for the ABWR were established during its development program. The key goals, all of which were achieved, are as follows:

- design life of 60 years
- plant availability factor of 87% or greater
- less than one unplanned scram per year
- 18 to 24-month refueling interval
- operating personnel radiation exposure limit <1 Sv/year (100 rem)
- reduced calculated core damage frequency by at least a factor of 10 over previous BWRs (goal <10-6/yr)
- radwaste generation less than that of the 10% best operating BWRs
- 48-month construction schedule

20% reduction in capital cost ($/kWh) vs. previous 1100 MWe class BWRs.

To these objectives, the following additional goals were established for ESBWR.

- All Essential Safeguards Features (ESF) shall be passive, eliminating the need for safety grade diesel generators.
- Following design basis events, no operator action shall be required for 72 hours.
- Built with a 36-month construction schedule.
- ESBWR cost advantage over competing baseload electrical generating technologies.

13.2 Summary of the ESBWR Key Features

A cutaway rendering of the ESBWR plant (Figure 13.0-1) illustrates the general configuration of the plant for a single unit site in the U.S. Shown in the foreground are the Reactor and Fuel Buildings, and in the background is the Turbine Building. In front of the Reactor Building is the Control Building. A comparison of key features of the ESBWR to previous models is shown in Table 13.0-1.

Table 13.0-1, Comparison of Key ESBWR Features to previous BWRs

Feature	BWR/6	ABWR	ESBWR
Recirculation System	Two external loop Recirc system with jet pumps inside RPV	Vessel-mounted reactor internal pumps	Natural circulation
Control Rod Drives	Locking piston CRDs	Fine-motion CRDs	Fine-motion CRDs
ECCS	2-division ECCS plus HPCS	3-division ECCS	4-division, passive, gravity-driven
Reactor Vessel	Welded plate	Extensive use of forged rings	Extensive use of forged rings
Primary Containment	Mark III - large, low pressure, not inerted	Compact, inerted	Compact, inerted
Isolation Makeup Water	RCIC	RCIC	Isolation condensers, passive
Shutdown Heat Removal	2-division RHR	3-division RHR	Non-safety system combined with RWCU
Containment Heat Removal	2-division RHR	3-division RHR	Passive
Emergency AC	3 safety-grade D/G	3 safety-grade D/G	2 non-safety D/G
Alternate shutdown	2 SLC pumps	2 SLC pumps	2 SLC accumulators
Control & Instrumentation	Analog, hardwired, single channel	Digital, multiplexed, fiber optics, multiple channel	Digital, multiplexed, fiber optics, multiple channel
In-core Monitor Calibration	TIP system	A-TIP system	Gamma thermometers
Control Room	System-based	Operator task-based	Operator task-based
Severe Accident Mitigation	Plant modification / Backfit	Inerting, drywell flooding, containment venting	Inerting, drywell flooding, core catcher

An artist's rendering of the major systems and how they are interconnected is shown in Figure 13.0-2. This shows the reactor, ECCS, containment, turbine equipment and the key auxiliary mechanical systems.

13.2.1 Design Philosophy

Recognizing the desire for simplification of the typically complex safety systems with attendant cost, quality assurance requirements and technical specifications, the ESBWR has adopted passive safety systems, together with a natural circulation primary system.

By shortening the active fuel length, adding an approximately 9 meter tall chimney above the core and lengthening the reactor vessel, the ESBWR eliminated the recirculation system, relying completely on natural circulation for core flow (Figure 13.0-3). High pressure inventory control and heat removal is accomplished with the use of isolation condensers if the reactor becomes isolated from the normal heat sink.

The reactor can also be depressurized rapidly to allow multiple sources of non-safety systems to provide makeup. However, the ultimate safety features are passive, both for core flooding as well as for containment heat removal.

Response to anticipated transients without scram (ATWS) is improved by the adoption of fine-motion control rod drives (FMCRDs), which allow reactor shutdown either by hydraulic or electric insertion. In addition, the need for rapid operator action to mitigate an ATWS is avoided by automation of emergency procedures such as feedwater runback and passive Standby Liquid Control System (SLCS) injection from borated water stored in pressurized accumulators.

Calculated core damage frequency for the ESBWR (~3E-8) is reduced by more than a factor of fifty relative to the BWR/6 (~1E-6) and five relative to the ABWR (~1E-7). Furthermore, the ESBWR also improved the capability to mitigate severe accidents, even though such events are extremely unlikely. Through nitrogen inerting, containment integrity threats from hydrogen detonation were eliminated. Sufficient spreading area in the lower drywell, together with a drywell flooding system and a core catcher located under the Reactor Pressure Vessel (RPV) provide further assurance against containment basemat attack. Manual connections make it possible to use onsite or offsite water systems to maintain core cooling. The result of this design effort is that in the event of a severe accident, the whole body dose consequence at the calculated site boundary is low.

13.2.2 Improvements to Operation and Maintenance

With the goal of simplifying the utility's burden of operation and maintenance (O&M) tasks, the design of every ESBWR electrical and mechanical system, as well as the layout of equipment in the plant, is focused on improved O&M. The reactor vessel lower sections are made of forged rings rather than welded plates. This eliminates 30% of the welds from the core beltline region, for which periodic in-service inspection is required.

The FMCRDs permit a number of simplifications. First, scram discharge piping and scram discharge volumes (SDVs) were eliminated, since the hydraulic scram water is discharged into the reactor vessel. By supporting the drives directly from the core plate, shootout steel located below the reactor vessel to mitigate the rod ejection accident was eliminated. The number of

hydraulic control units (HCUs) was reduced by connecting two drives to each HCU, as was done on the ABWR. The number of rods per gang was increased up to 26 rods, reducing reactor startup times. Finally, since there are no organic seals, only two or three drives will be inspected per outage, rather than the 30 specified in most current plants.

Responses to transients and accidents are first attempted by non-safety makeup systems, together with the isolation condensers. At high pressure, the CRD pumps of the Control Rod Drive system can add water directly to the RPV via a feedwater line. Postulated loss of coolant accidents (LOCA) are mitigated by automated reactor pressure blowdown followed by passive gravity-driven ECCS (GDCS) which has sufficient water stored in the containment to completely flood the lower drywell and the reactor to 1 meter (3 feet) above the top of fuel. Residual decay heat is removed from the containment passively via heat exchangers located directly above and outside the containment boundary.

By combining the reactor water cleanup function with shutdown heat removal, simplification was achieved in the reduction of equipment. A side benefit is that decay heat removal after shutdown can be accomplished at high pressure.

Lessons learned from operating experience were applied to the selection of ESBWR materials. Stainless steel materials which are qualified as resistant to Intergranular stress corrosion cracking (IGSCC) were used. In areas of high neutron flux, materials were also specially selected for resistance to irradiation-assisted stress corrosion cracking (IASCC). Hydrogen Water Chemistry (HWC) is recommended for normal operation to further mitigate any potential for stress corrosion cracking.

The use of material producing radioactive cobalt was minimized. The main condenser uses titanium tubing at seawater sites and stainless steel tubing for cooling tower or cooling lake sites. The use of stainless steel in applications that currently use carbon steel was expanded. Depleted Zinc Oxide injection to the feedwater system is recommended to further control radiation buildup. These materials choices reduce plant-wide radiation levels and radwaste and will accommodate more stringent water chemistry requirements.

Also contributing to good reactor water chemistry is the increase of the Reactor Water Cleanup/ Shutdown Cooling System (RWCU/SDC) capacity to approximately two percent of feedwater flow.

The ESBWR Reactor Building (including containment) was configured to simplify and reduce the Operating and Maintenance burden. Figure 13.0-4 illustrates some of the key design features of the ESBWR containment. In-containment elevated water tanks (GDCS) plus a raised suppression pool provide the means to passively provide ECCS, if necessary, and enssure core coverage for all design basis events. Natural convection heat exchangers located outside and just above the containment provide passive heat removal. The containment itself is a reinforced concrete containment vessel (RCCV).

Within the containment itself, no equipment requires servicing during plant operation and the amount of equipment that requires maintenance during outages is significantly reduced. The containment is significantly smaller than that of the preceding BWR/6, but about the same size as ABWR. However, primarily due to the elimination of the recirculation system, there is actually more room to conduct maintenance operations. To simplify maintenance and surveillance during scheduled outages, permanently installed monorails and platforms permit 360° access, and both the upper and lower drywells have separate personnel and equipment hatches. To simplify FMCRD maintenance, a rotating platform is permanently installed in the lower drywell, and semi-automated equipment was specially designed to remove and install that equipment. The wetwell area is compact and isolated from the rest of containment, thus minimizing the chance for suppression pool contamination with foreign material.

A new Reactor Building design surrounds the containment. Its volume (including containment) is about 30% less than that of the BWR/6 and requires substantially lower construction quantities. Its layout is integrated with the containment, providing 360° access with servicing areas located as close as practical to the equipment requiring regular service. Clean and contaminated zones are well defined and kept separate by limited controlled access. The fuel pool is sized to store at least ten years of spent fuel plus a full core.

Controls and instrumentation enhancements incorporate digital technologies with automated, and self-diagnostic features. The use of multiplexing and fiber optic cable has eliminated 1.3 million feet of cabling. Within the safety systems, the adoption of a two-out-of-four trip logic and the fiber optic data links have significantly reduced the number of required nuclear boiler safety system related transmitters. In addition, a three-channel controller architecture was adopted for the primary process control systems to provide system failure tolerance and on-line repair capability. These new C&I features were first added in ABWR.

A number of improvements were made to the Neutron Monitoring System (NMS). Fixed wide-range neutron detectors have replaced retractable source and intermediate range monitors. In addition, an automatic, period-based protection system replaced the manual range switches used during startup. The Traversing Incore Probe (TIP) calibration system has been replaced by fixed Gamma Thermometers (GT).

The man-machine interface was significantly improved and simplified for the ESBWR using advanced technologies such as large, flat-panel displays, touch-screen CRTs and function-oriented keyboards. The number of alarm tiles was reduced by almost a factor of ten. Many operating processes and procedures are automated, with the control room operator performing a confirmatory function. Figure 13.0-5 illustrates a main control room for the ABWR, which uses similar technology.

The plant features discussed above, while simplifying the operator's burden, have an ancillary benefit of increased failure tolerance and/or reduced error rates. Studies show that less than one unplanned scram per year will be experienced with the ESBWR. Increased system

redundancies will also permit on-line maintenance. Thus, both forced outages and planned maintenance outages will be significantly reduced.

The ESBWR combines advanced facility design features and administrative procedures designed to keep the occupational radiation exposure to personnel as low as reasonably achievable (ALARA). During the design phase, layout, shielding, ventilation and monitoring instrument designs were integrated with traffic, security and access control. Operating plant results were continuously integrated during the design phase. Clean and controlled access areas are separated.

Reduction in the plant personnel radiation exposure was achieved by (1) minimizing the necessity for and amount of personnel time spent in radiation areas and (2) minimizing radiation levels in routinely occupied plant areas in the vicinity of plant equipment expected to require personnel attention.

Changes in the materials will lead to a significant reduction in the quantity of radwaste generated through radioactive corrosion products. In addition, the condensate treatment system was improved to include both pre-filtration and deep bed demineralizers without regeneration which reduce liquid and solid radwaste input. Extensive use of mobile radwaste technology is used in the ESBWR radwaste system design. This also contributes to minimizing radiation exposure to operating personnel.

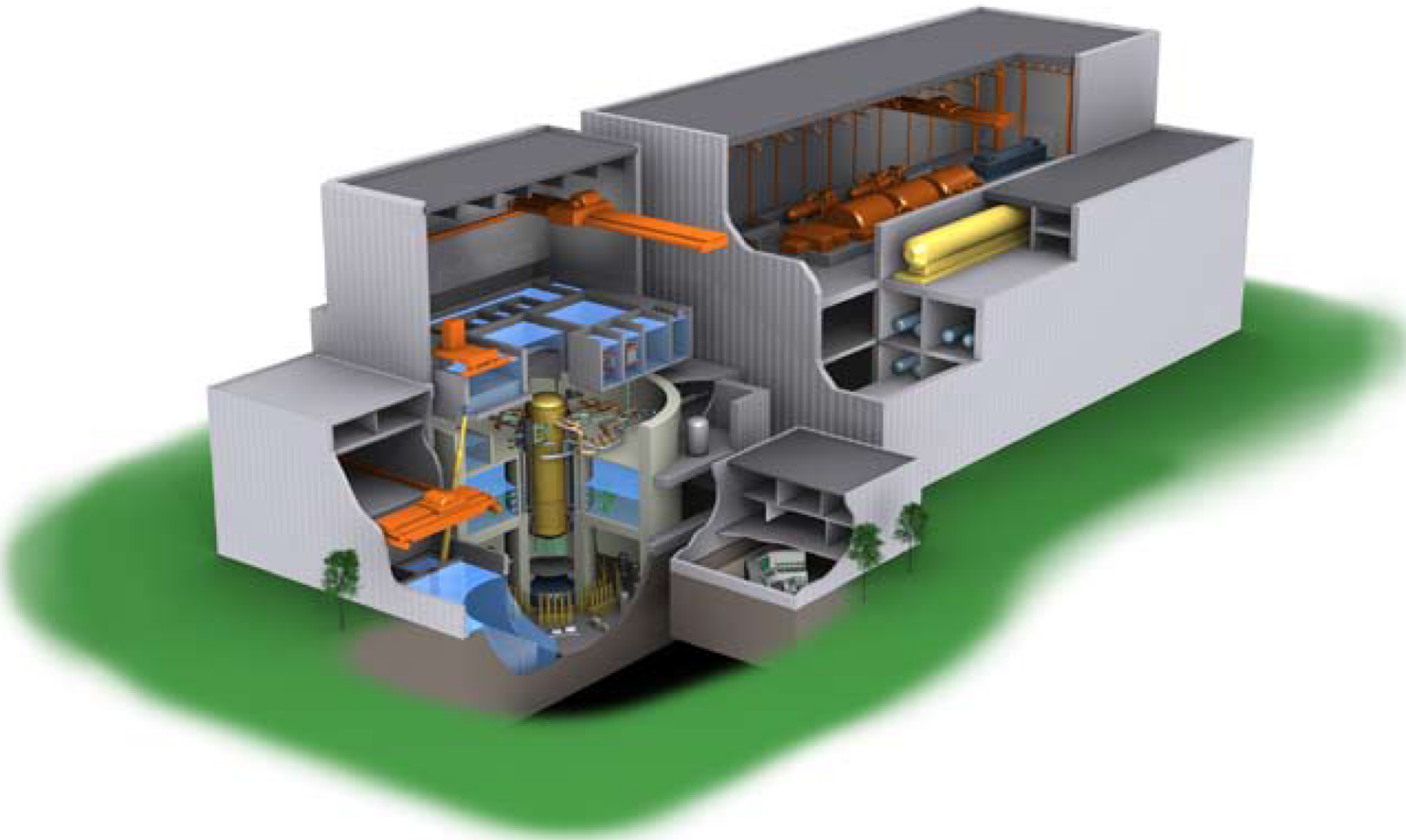

Figure 13.0-1, Cutaway of the ESBWR

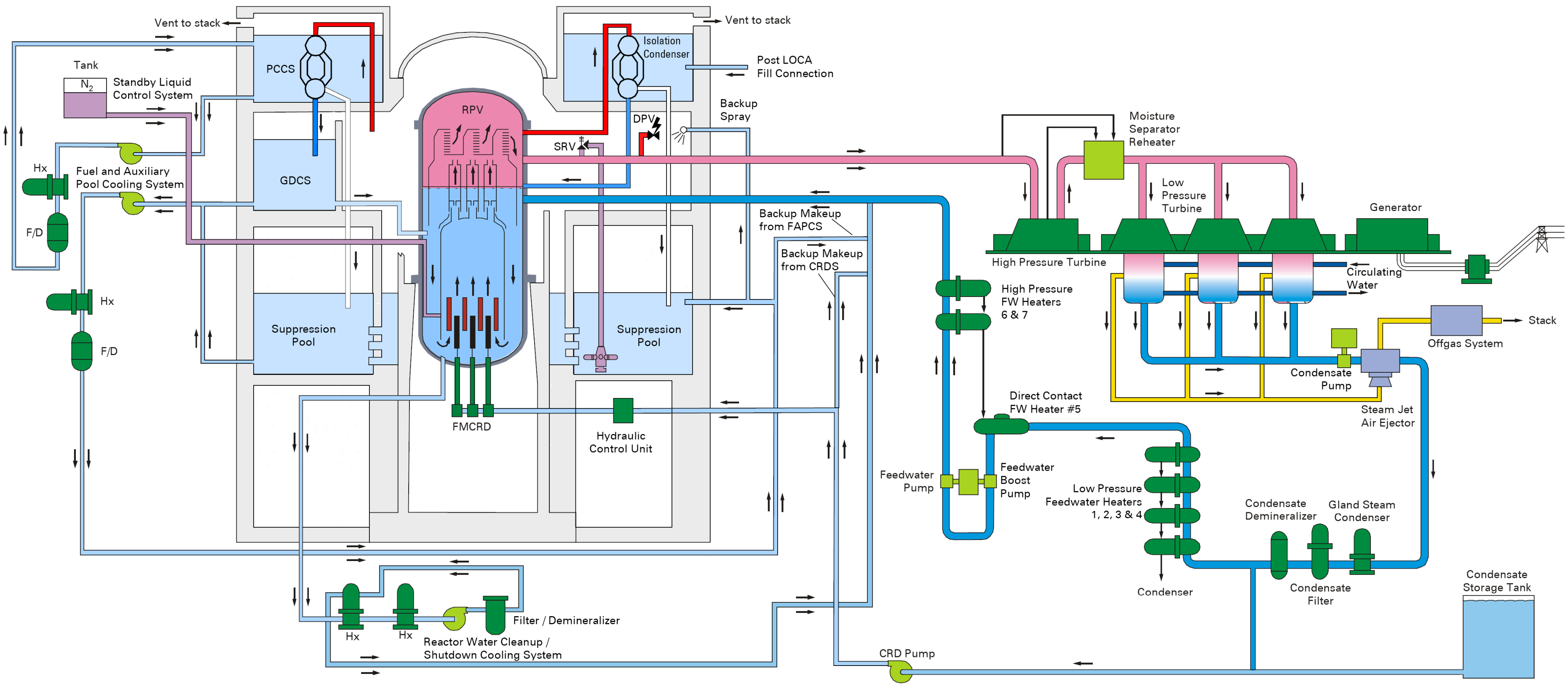

Figure 13.0-2, ESBWR Major Systems

Figure 13.0-3, ESBWR Reactor Pressure Vessel and Internals

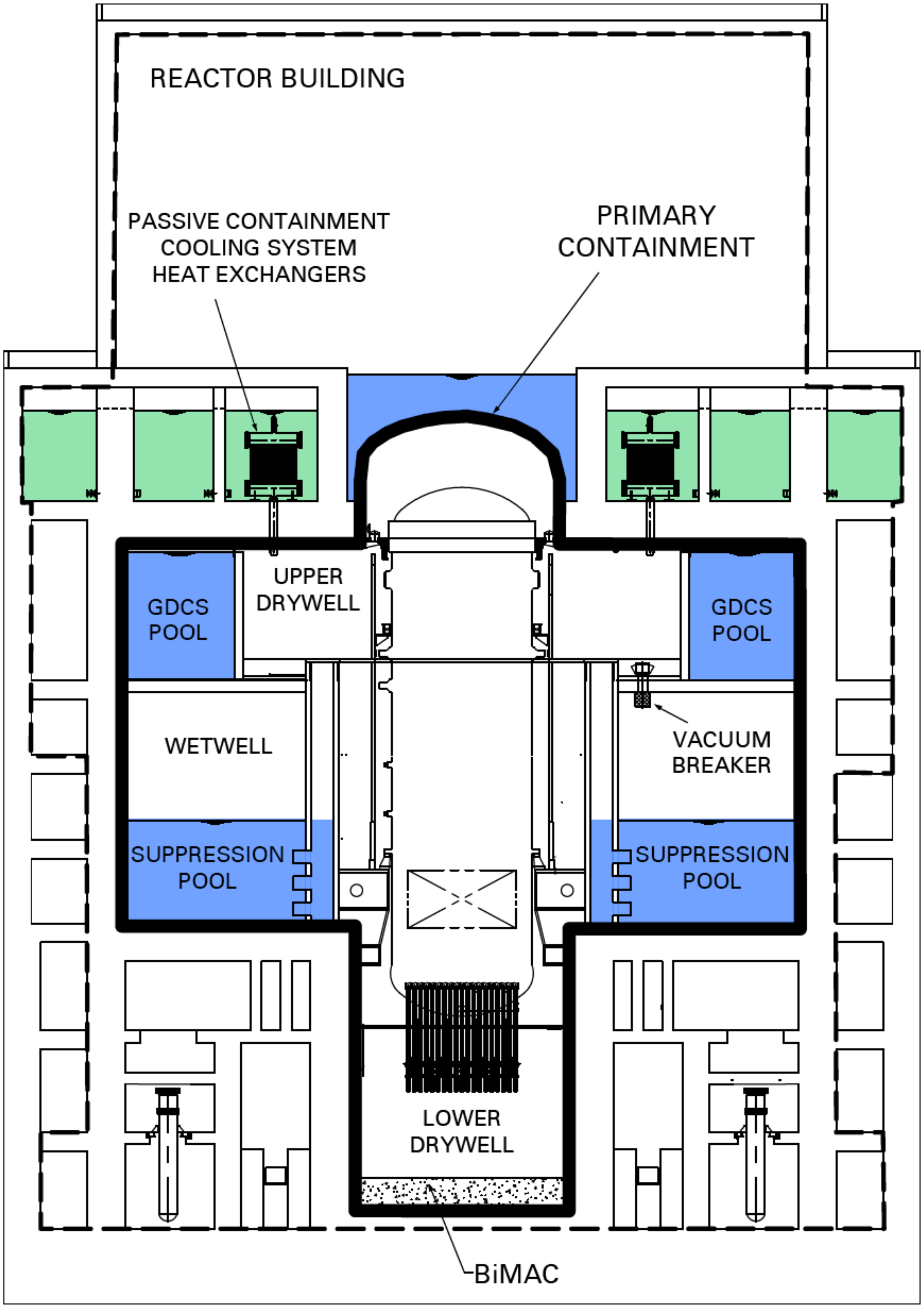

Figure 13.0-4, EWBWR Reactor Pressure Vessel and Internals

Figure 13.0-5, ABWR (Lungmen) Main Control Room Panel