GE Hitachi's ABWR and ESBWR: safer, simpler, smarter

OECD/NEA Workshop on innovations in water-cooled reactor technologies

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GE Hitachi’s new reactor portfolio

**Operational Gen III active safety technology**
- NRC certified design
- Lowest core damage frequency of any Generation III reactor
- Extensive operational experience since 1996
- Licensed in US, Taiwan, Japan
- First concrete to first fuel ... 39 to 45 months

**Evolutionary Gen III+ passive safety technology**
- NRC certified design
- Lowest core damage frequency of any reactor ... safest design
- Passive cooling for >7 days w/o AC power or operator action
- Lowest projected operations, maintenance, and staffing costs
- 25% fewer pumps, valves and motors than active safety plants

**Revolutionary Gen IV sodium cooled technology**
- Ultimate used fuel solution
- Passive air-cooling w/no operator or mechanical actions needed
- Ultimate answer to the used fuel dilemma - reduce nuclear waste to ~300-year radiotoxicity while generating new electricity
- Also solution for Pu disposition

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1. Claims based on the U.S. DOE commissioned ‘Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs’ and an ESBWR staffing study performed by a leading independent firm
2. To reach the same level of radiotoxicity as natural uranium
GEH new nuclear plant development

- Borax BWR test facility
- Worldwide BWR fleet
- K6/K7 – First ABWRs
- ESBWR

1950’s 1980’s 2000’s

Lessons learned … customer input … new features … testing … studies … detailed design

- EBR
- US sodium reactor experience
- SEFOR, Fermi I, Seawolf, FFTF
- EBR-II

- PRISM

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BWRs are simpler, safer, easier to operate

PRA of Core Damage Frequency

U.S. PWRs
2 E-5 (avg.)
U.S. BWRs
8 E-6 (avg.)
APR1400
2 E-6
APWR
1.2 E-6
EPR
2.8 E-7
AP1000
2.4 E-7
ABWR
1.6 E-7
ESBWR
1.7 E-8

References: Plant licensing DCDs and publically available information
Note: PRA of CDF is represented in at-power internal events (per year)
Note: NSSS diagrams are for visualization purposes only
Best-in-class SBO response

Responses needed to prevent core damage during extended loss of all AC power

- Gen II, EPR
  - DECAY HEAT
  - 30 MIN.
  - 24 HRS.

- VVER AES-2006
  - 24 HRS.

- ABWR
  - 30 MIN.
  - ~36 HRS.*

- AP1000
  - 72 HRS.

- ESBWR
  - >7 days

• Gen III+ passive plants allow for a much longer coping time
• Decay heat level impacts urgency

*ABWR DCD credits water addition at 8 HRS.
References: AP1000: US DCD Rev. 18 Section 8.5.2.1; EPR: US DCD Rev. 1 Section 8.4; VVER AES-2006: Stuk Preliminary Safety Assessment
ABWR features and improvements

ECCS - 3 Division Active Emergency Core Cooling System

Steam-driven RCIC pump

FMCRDs (Fine Motion Control Rod Drives)

RIPs (Reactor Internal Pumps)

From Condensate Storage

TO FUEL POOL

Containment

RPV

Core

HPCF

LPF

FROM FUEL POOL

Steam-driven RCIC pump

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The only Gen III Reactor with operating experience ... +25 years

Operational

- Kashiwazaki-Kariwa 6
  - COD 1996
- Kashiwazaki-Kariwa 7
  - COD 1997
- Hamaoka-5
  - COD 2005
- Shika-2
  - COD 2006

Under Construction

- Ohma 1
  - 38% complete
- Shimane 3
  - 94% complete
- Lungmen 1&2
  - 94% complete
  - Pre-op testing

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ESBWR significant attributes

**Safer**
- Safest reactor design available ... lowest CDF
- Passive accident response with no AC power or operator action
- Hands-free 72-hour design basis accident response
- Passively cools for 7+ days following SBO ... >2x better than AP1000

**Simpler**
- 25% fewer safety-related components than active plants ... 11 fewer systems than ABWR
- Simpler to operate and maintain ... fewer plant transients and online surveillances

**Smarter**
- 1520 MWe with 20% fewer staff and lowest projected O&M cost per MWe
- No steam generators to replace
- Dominion & DTE selected ESBWR ... NRC certification Oct 2014
**ABWR to ESBWR evolution: Nuclear Island**

1. Standby Liquid Control System – **simplified** design
2. Fuel and Aux Pool Cooling – **equivalent** designs
3. Suppression Pool Cooling & Cleanup System – **equivalent** capability
4. Residual Heat Removal System – **equivalent** for shutdown cooling
5. Reactor Water Cleanup System – **equivalent** designs
6. Hydraulic Control Unit – **equivalent** design
7. High Pressure Core Flooder – **replaced** by HP CRD makeup
8. Reactor Core Isolation Cooling – **replaced** by Isolation Condenser
9. Residual Heat Removal Containment Spray – **replaced** by PCCS
10. Safety Relief Valves – **Diversified** by Depressurization Valves

*Systems are Equivalent or Simplified*
ESBWR passive safety systems

No AC power or operator action required!

Passive Containment Cooling System: Passively transfers decay heat out of containment, sending water to GDCS pools.

Suppression Pool: Provides heat sink for initial LOCA depressurization.

Automatic Depressurization System: Passively depressurizes the reactor and keeps it depressurized following a LOCA.

Isolation Condenser System: Closed-loop cooling system transferring reactor decay heat to atmosphere; activates automatically if DC power is lost.

Gravity Driven Cooling System: Passively injects water into the reactor via gravity in case of LOCA.

Standby Liquid Control System: Passively injects borated water into the reactor for backup shutdown capability.

BiMAC core catcher: Passively cooled core catcher.
ESBWR modularization – based on ABWR
ESBWR reduces dose

- Shielding minimizes N-16 operating radiation
- N-16 is not an issue during maintenance ...
  decays @ $T_{1/2} 7.1$ seconds

ESBWR dose reduction vs GEN II

- Simplified design/less maintenance
  - No recirculation or ECCS pumps/pipes
- Cobalt containing material reduced 50+%
- Improved Reactor Water Cleanup
- Greater remote maintenance/inspection

Source: U.S. NRC; Hitachi GE
ESBWR requires reduced staffing

Comparison of Projected Gen III/III+ Nuclear Plant Staffing Requirements

ESBWR requires significantly fewer plant personnel than any other Generation III/III+ design

Source: An ESBWR staffing study performed by a leading independent firm
Reduced equipment and maintenance

ESBWR doesn’t require:
- Steam generators, pressurizer, reactor coolant pumps, primary loop piping
- PWR heat exchange surfaces (steam generators) wear out over 20-30 years ... 1/3 of ESBWR’s heat exchange surfaces (fuel) are replaced every outage (~2 years)

Extra components impact:
- Manufacturing
- Installation
- O&M
- Decommissioning

Everything in one vessel
ESBWR offers substantial O&M improvements

**Passive safety & simplified design**

- 25% fewer safety-related components
- 11 systems eliminated – others combined or simplified
- Lowest O&M costs of any Generation III+ technology*
- 50+% more fuel bundles exchanged in same outage time

**Easier to maintain**

- Hands-free 72-hour design basis accident response; 7+ day SBO
- Lowest staffing requirements ...
- 20% lower staffing per MWe*
- Fully digital I&C
- Fewer plant transients
- Fewer online technical specification surveillances

* Claims based on the U.S. DOE commissioned ‘Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs’ and an ESBWR staffing study performed by a leading independent firm
In conclusion …

• GE Hitachi has been bringing innovation to nuclear for 60 years

• Portfolio includes the two safest light water reactor designs in the world
  o 4 ABWRs built on time and budget … only GEN III reactors with operating experience
  o ESBWR recently certified by US NRC … provides >7 day passive cooling

• Focused on simpler, safer and smarter reactor designs to meet the global demands for nuclear power.
Back-up information
The Advanced Boiling Water Reactor

- Reactor Pressure Vessel
- Steam Dryer
- Steam Separator
- BWR Fuel Assembly
  - 90 fuel rods encased in a ‘channel’
  - 2 water rods
  - Part-length rods
  - Burnable absorbers
- Reactor Internal Pumps (ABWR)
- Control Rod Blades
- Control Rod Drives

550° F / 288° C
99.9% Steam

420° F / 216° C
ESBWR overview

1. Reactor Pressure Vessel
2. Fine Motion Control Rod Drives
3. Main Steam Isolation Valves
4. Safety/Relief Valves (SRVs)
5. SRV Quenchers
6. Depressurization Valves
7. Lower Drywell Equipment Platform
8. BMAC Core Catcher
9. Horizontal Vents
10. Suppression Pool
11. Gravity Driven Cooling System
12. Hydraulic Control Units
14. RMGU/SDCI Heat Exchangers
15. Containment Vessel
16. Isolation Condensers
17. Passive Containment Cooling System
18. Moisture Separators
20. Refueling Machine
21. Reactor Building
22. Inclined Fuel Transfer Machine
23. Fuel Building
24. Fuel Transfer Machine
25. Spent Fuel Storage Pool
26. Control Building
27. Main Control Room
28. Main Steam Lines
29. Feedwater Lines
30. Steam Tunnel
31. Standby Liquid Control System Accumulator
32. Turbine Building
33. Turbine-Generator
34. Moisture Separator Reheater
35. Feedwater Heaters
36. Direct Contact Feedwater Heater and Tank
ESBWR Parameters

- Core Thermal Power Output: 4500 MWe
- Plant Net Electrical Output\(^{(1)}\): 1530 MWe
- Reactor Operating Pressure: 7.17 MPa (1040 psia)
- Feedwater Temperature\(^{(2)}\): 216°C (420°F)
- RPV
  - Diameter: 7.1 meters (23.3 feet)
  - Height: 27.6 meters (90.5 feet)
- Reactor Recirculation: Natural Circulation
- Fuel: 1132 fuel bundles, shortened length of 3m
- Average power density: 54.3 kW/liter
- Control blades: 269 Fine Motion Control Rod Drives (FMC RDs)

\(^{(1)}\) Typical (site dependent)
\(^{(2)}\) Nominal Rated Operation
Fuel bundle ... evolutionary product development

GE14

~30,000 produced
Introduced in 1998

GNF2 Advantage™

~8,300 produced
to date

GNF2e

Shorter, otherwise same as rest of fleet

... optimized for the ESBWR

Same as GNF2 Advantage™ ... only shorter

• 10x10 same pitch & diameters (rods/pellets)
• 14 partial length rods
• 2 single piece water rods, same diameters
• 8 Inconel spacers
• DefenderTM Lower Tie Plate
• No finger springs
4 Separate divisions with 3 independent platforms

Each modular division features unique operation, vendor, and wiring & power:
1. RTIF Reactor Trip
2. Safety Systems
3. Independent Control Platform

Digital backup to the safety system with redundant and reverse SCRAMs

Based on IEEE Std 603
Criteria for Safety Systems for Nuclear Power Generating Stations