Advanced Design of Mitsubishi PWR Plant for Nuclear Renaissance

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Etsuro SAJI
General Manager, Reactor Core Engineering Department
Mitsubishi Heavy Industries, Ltd.
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1. Nuclear Renaissance
2. Mitsubishi PWR Nuclear Power Plant
3. Advanced design of APWR
4. Line-up of Mitsubishi PWR
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Nuclear Renaissance

- The importance of nuclear power plant (NPP) has been understood with increasing attentions.

- Energy security
- Environmental issues

And also the economical advantage of NPP has been widely recognized through their enhanced safe and reliable operation in recent years.
New NPP Construction Plan in the World

**France**: New construction plan
**UK**: Changes to construction promotion
**Russia**: Nuclear power development promotion
**Lithuania, Kazakhstan, Bulgaria**: New construction demand

**Saudi Arabia, Kuwait, UAE, Bahrain, Qatar, Oman**: New construction demand

**South Africa, Egypt, Turkey**: New construction demand

**China**: 30GW more nuclear capacity by 2020
**South Korea**: 8 units construction by 2015
**India**: 14 units construction by 2012
**Indonesia, Vietnam, Thailand**: New construction demand

**Brazil, Mexico, Argentina**: New construction demand

**USA**: Sees 30 units construction by 2020
**Canada**: New plan coming out

**Russia**: Nuclear power development promotion
**Lithuania, Kazakhstan, Bulgaria**: New construction demand
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Mitsubishi Experiences of PWR in Japan

Contribution to All of the 26 Japanese PWR Plants

- From First PWR Power Plant Mihama 1u in 1970 to the 21st Century’s Latest APWRs
- New Build or Replacement Projects Continued Constantly even in the 80-90’s “Nuclear Stagnation” in USA and Europe
- Developed Our Own Technologies throughout Long History to Our Core Competence

23 PWRs in operation
- Tomari-3 under Commissioning
- Tsuruga -3/4 APWRs under Licensing

OHI P/S
MIHAMA P/S
TOMARI P/S
GENKAI P/S
IKATA P/S
TSURUGA P/S
Manufacturing and Construction
3D CAD Systems

- Integrated database is also used for manufacturing and construction.

Integrated Database
Manufacturing

- Major Components (RV, SG, RCP, Internal, CRDM, PZR, Turbine etc) are in our hands.
- Works and Machines have been updated/enlarged and are prepared for the global deployment.

Super-large combined machine tool “Super Miller”

- High-Accuracy, High-Quality Processing in Upright Installation Position
Construction

- Reduction of on-site work volume and construction period

- Rational designs like
  - Internal Structures Using SC (-Left)
     (Steel Plate Reinforced Concrete)
  - Large Prefabricated Blocks (-Right)

- Tools for efficient construction like Super-large-capacity cranes
  - On-site welding of Containment and Formation

- Ability for comprehensive coordination of civil & installation work

Brilliant Successes
(1st Concrete to Fuel Loading)

- 2 loop : 34.5 months
- 3 loop : 37.5 months
- 4 loop : 40.0 months
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APWR : Tsuruga 3/4

- Application for Reactor Establishment License: March, 2004
- Commercial Operation
  - Unit 3: March, 2016
  - Unit 4: March, 2017

[Table]

<table>
<thead>
<tr>
<th></th>
<th>Tsuruga Units 3 and 4</th>
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<tbody>
<tr>
<td>Utility</td>
<td>Japan Atomic Power Company</td>
</tr>
<tr>
<td>Output of Thermal Power</td>
<td>4,451 MWt</td>
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<tr>
<td>Output of Electric Power</td>
<td>1,538 MWe</td>
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<tr>
<td>Reactor</td>
<td>Mitsubishi 4 Loop PWR</td>
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<tr>
<td>Fuel</td>
<td>Low Enriched UO₂ 17×17–12ft</td>
</tr>
<tr>
<td>Condenser Cooling</td>
<td>Sea Water</td>
</tr>
<tr>
<td>Layout</td>
<td>Twin Unit</td>
</tr>
<tr>
<td>Commercial Operation</td>
<td>Planned in 2016</td>
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<tr>
<td>Cycle</td>
<td>60 Hz</td>
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</tbody>
</table>

(From web-site of the Japan Atomic Power Company)
Features and Advanced Technologies of APWR

Attractive Economics
- Large capacity (RV, SG, TG)
- Construction cost reduction (compact layout, simplified systems and component)
- Improved neutron economy (radial reflector)
- Improved plant availability

Enhanced Safety
- 4 Mechanical systems of engineered safety features
- Advanced Accumulator
- Refueling water storage pit installed in containment vessel

Enhanced Reliability
- Improved core internals
- Improved steam generator

Operation & Maintenance
- Advanced control room
- All digital I&C

Enhancement safety features
- Reactor
- Steam generator
- I & C
- Turbine Generator

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Attractive Economics of APWR

Simple & Efficient Design
- Safety Systems
  - reduction component number & capacity, efficient layout
- Digital I&C System
  - compact control board, reduction of cables
- Plate type heat exchangers
- Utilization of Enriched $^{10}$B

Construction
- SC structure
  - employ SC widely for in-containment structure

Cost reduction

Compact layout of R/B

Reduction of primary build volume 20%

Current PWR

APWR

80%

100%

50%

Current 4loop PWR

APWR

(volume (m³)) / power (kWe)
Enhanced Safety of APWR - ECCS Configuration -

System Configuration

4 train; DVI*1 design for SIP
→ Independent and Redundant
→ Simplified configuration
50%-capacity pumps

Advanced Accumulator
→ Prolonged injection term
Elimination of LHSIP

In-containment RWSP
→ CDF*2 can be reduced
1/10 of current 4-loop plant

* 1: Direct Vessel Injection
* 2: Core Damage Frequency

ACC: Advanced Accumulator
SIP: Safety Injection Pump
LHSIP: Low Head SIP
CSP: Containment Spray Pump
SH: Spray Header
RV: Reactor Vessel
RWSP: Refueling Water Storage Pit

Principle of Advanced Acc.
# Enhanced Reliability of APWR

- APWR Reactor Internals -

<table>
<thead>
<tr>
<th></th>
<th>APWR (Neutron Reflector)</th>
<th>Current 4 Loop (Baffle/Former)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image1" alt="APWR Diagram" /></td>
<td><img src="image2" alt="Current 4 Loop Diagram" /></td>
</tr>
<tr>
<td><strong>Number of Bolts</strong></td>
<td>approx. 50 (Out of Core Region)</td>
<td>approx. 2,000</td>
</tr>
<tr>
<td><strong>FCC</strong></td>
<td>approx. 1% Reduction</td>
<td>Base</td>
</tr>
<tr>
<td><strong>Neutron Exposure</strong></td>
<td>approx. 1/3 (w/o Neutron Pads)</td>
<td>Base</td>
</tr>
</tbody>
</table>

- Control rod drive mechanism
- Inlet nozzle
- Outlet nozzle
- Fuel assembly
- Reactor Internals
Operation and Maintenance of APWR

- Improved Operability by Digital I&C Systems -

Improvement on human-system interface and reliability

**Advanced Control Room**

- Large Display Panel
- Compact Operator Console
- Soft Operation

**All Digital I&C**

Easier maintenance enhanced by self-diagnosis and automatic test systems

Improved monitoring and operational performance by integrating controls and information display
APWR is GEN-Ⅲ+ Plant

Generations of Nuclear Energy

- GEN-I (Generation I)
  - Early Prototypes
    - Shippingport
    - Dresden
    - Magnox

- GEN-II (Generation II)
  - Commercial Power
    - PWRs
    - BWRs
    - CANDU

- GEN-III (Generation III)
  - Advanced LWRs
    - CANDU 6
    - System 80+
    - AP600

- GEN-III+ (Generation III+)
  - Evolutionary Designs
    - ABWR
    - ACR1000
    - AP1000
    - APWR
    - EPR
    - ESBWR

- GEN-IV+ (Generation IV+)
  - Revolutionary Designs
    - Safe
    - Sustainable
    - Economical
    - Proliferation Resistant and Physically Secure

Evolutionary Designs of APWR
- Internals with Neutron Reflector
- Advanced Accumulator (Passive Safety)
- Refueling Water Storage Pit in CV
- All Digital I&C
- Advanced Control Room
- SG with High Corrosion Resistance
- 3-D Design Turbine Blade
- etc

Tomari-3
Latest Construction Experience: Tomari 3

- Approval for Reactor Establishment License: July, 2003
- Commercial Operation: December, 2009

<table>
<thead>
<tr>
<th>Tomari Unit 3</th>
<th>Utility</th>
<th>Hokkaido Electric Power Co., Inc.</th>
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<tbody>
<tr>
<td>Output of Thermal Power</td>
<td>2,660 MWt</td>
<td></td>
</tr>
<tr>
<td>Output of Electric Power</td>
<td>912 MWe</td>
<td></td>
</tr>
<tr>
<td>Reactor</td>
<td>Mitsubishi 3 Loop PWR</td>
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<tr>
<td>Layout</td>
<td>Single Unit</td>
<td></td>
</tr>
<tr>
<td>Commercial Operation</td>
<td>December 2009</td>
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<td>Cycle</td>
<td>50 Hz</td>
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GIII+ Reactors Development

Development & Improvement of PWR Technology

Enhanced up to APWR

APWR Tsuruga-3/4 licensing process

US-APWR
US NRC Licensing

EU-APWR

ATMEAl
by ATMEA (Joint Venture)

AREVA

US Utilities

European Utilities

Global Utilities
US/EU-APWR : 1700MWe Gen-III+ PWR

The World Largest Class Output 1,700MWe Based on “Our Own” Technologies

- **Thermal Efficiency Max 37% (NET)** note,
- **Enhanced SG Heat Transfer Area** (91,500ft²/unit) with Triangular Lattice of SG Tubes,
- **High-Performance Steam-Water Separators** Generate High Quality Steam,
- **High Performance LP-Turbine System** with 70-inch Class Integral Shroud Blades.
- **14-ft Fuels** Creates Additional Thermal Margin, Making **24-Month Extended Cycle Operation** with keeping Fuel Economy.

(note) it’s depend on site condition
US/EU-APWR : 1700 MWe Gen-III+ PWR

- Safe, Reliable and Economical Plant

  - **Top Mounted ICIS Eliminating Penetrations at the RV Bottom,**
  - **Full 4-Train Safety Systems, with Best Mix of Passive and Active Systems Allowing On-Line Maintenance (OLM),**
  - **Full Digital I&C Technology with Japanese Domestic Experiences.**
  - **Due Consideration on Protection against Airplane Crash and Long-term Containment Integrity against Severe Accidents.**
ATMEA1: The mid-sized Gen-III+ PWR(1)

ATMEA1 is a midsize PWR developed by ATMEA which is a joint venture established by MHI and AREVA.

World Wide Compliance with Regulations and Utilities requirements

-The IAEA’s Fundamental Safety Principles Review has been completed
ATMEA1: The mid-sized Gen.-III+PWR(2)

Superior operation performance by reliable and proven technologies

- **Electrical output**: 1,100MWe (NET)
- **Thermal efficiency**: 37% (NET)
- **Plant availability**: more than 95%
- **Primary system**: 3-loop

- **3-train reliable active safety system with advanced accumulators and in-containment water storage**

- **Operation flexibility** (12 to 24-month operation cycle length, Load-follow and frequency control, MOX loading)
Conclusions

- MHI has abundant experiences to deliver total PWR plants and to render excellent services to secure highest reliability.

- MHI's successful performance of integrating and managing the projects owes to the fact that all major activities, such as conceptual design, engineering, manufacture of main components, construction, commissioning and maintenance, are made by own resources and technologies.

- These resources and technologies have been developed, maintained and enhanced through over 40 years continuous dedications for nuclear power plants and MHI is ready to contribute them through the application of Mitsubishi PWR in the world.