
Hitachi’s activity for transmutation system of long-lived radioactive waste

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Cooperate on SFR/Fuel cycle national projects
Investigate an option based on BWR experiences

- Sodium-cooled MA burner
  Advancing SFR performance
  Conducted as MEXT project

- BWR TRU burner
  Advancing BWR features
  Study on option for SFR

Flexible fuel cycle
Adaptive to various fuel cycles, debris management
Conducted as MEXT project

SFR: Sodium-cooled Fast Reactor
BWR: Boiling Water Reactor
MA: Minor Actinide
TRU: Transuranium element
MEXT: Ministry of Education, Culture, Sports, Science & Technology
3. MEXT Project for MA burner

Pursuing harmonization of efficient MA transmutation with enhanced safety characteristics

“Study on minor actinide transmutation using MONJU data”*

* This material includes 2013 results of the study entrusted to University of Fukui by MEXT.

- **University of Fukui**
  - Management

- **Univ. Fukui/Kyoto/Osaka**
  - Advanced analysis method

- **JAEA**
  - Related experimental data analysis, DB construction

- **JAEA/Hitachi-GE**
  - Advanced core design

- **Hitachi-GE**
  - Transient, Accident analysis
4. Advanced homogeneous MA core

Reduce absolute value of void reactivity by placing Na plenum* on the top of core

## 5. Core specification and performance

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output (electric/thermal)</td>
<td>MWe/MWt</td>
<td>750/1,765</td>
</tr>
<tr>
<td>Operation cycle</td>
<td>month</td>
<td>18.6</td>
</tr>
<tr>
<td>Number of batch (core/radial blanket)</td>
<td>-</td>
<td>6/6</td>
</tr>
<tr>
<td>Core height (inner/outer)</td>
<td>cm</td>
<td>60/90</td>
</tr>
<tr>
<td>Internal blanket height</td>
<td>cm</td>
<td>20</td>
</tr>
<tr>
<td>Na plenum height (inner/outer)</td>
<td>cm</td>
<td>40/30</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pu enrichment, MA content (inner/outer)*</td>
<td>wt%</td>
<td>27.4/24.8, 6.8/6.1</td>
</tr>
<tr>
<td>Burnup reactivity</td>
<td>%Δk/kk’</td>
<td>0.63</td>
</tr>
<tr>
<td>Breeding ratio</td>
<td>-</td>
<td>1.14</td>
</tr>
<tr>
<td>Maximum liner heat generation rate</td>
<td>W/cm</td>
<td>396</td>
</tr>
<tr>
<td>Discharged exposure (core/all)</td>
<td>GWd/t</td>
<td>149.3/78.9</td>
</tr>
<tr>
<td>MA transmutation amount</td>
<td>kg/GWe/y</td>
<td>103</td>
</tr>
<tr>
<td>MA transmutation rate</td>
<td>%/discharge</td>
<td>36</td>
</tr>
<tr>
<td>Void reactivity (EOEC)</td>
<td>$</td>
<td>3.6</td>
</tr>
<tr>
<td>Doppler coefficient (EOEC)</td>
<td>Tdk/dT</td>
<td>-5.0×10⁻³</td>
</tr>
</tbody>
</table>

EOEC: End of equilibrium cycle

* Suppose TRU isotopes from LWR’s spent fuel

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6. Safety analysis with effective void

Negative void reactivity under transient might slow event progress

Na density and reactivity coeff. axial distribution

⇒ Study to enhance MA transmutation and safety is in progress
7. Hitachi’s activity outline

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8. BWR feature for TRU burner

Advance BWR’s moderation controlling capability to burn not only fissile but also fertile

- Enhance moderation ▼
  - Burn fissile
- Suppress moderation ▼
  - Burn fertile
  - Breed Puf

**Coolant to fuel ratio**
- Large
- Small

**Volume ratio (coolant/fuel)**
- Conventional BWR
- Conventional PWR
- TRU burner

**Effective volume ratio**
- (coolant/fuel)

*Coolant void fraction is considered*
9. RBWR concept

Reduced moderation core is optimized for TRU burning. Safety system, BOP, etc. are almost same as conventional BWR.

Plant cut-away view

RBWR: Resource-renewable BWR

Conventional BWR fuel

RBWR fuel

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10. Core configuration

Y-type Control rods are inserted between fuel bundles

Pressure vessel

The number of
- fuel bundles: 720
- control rods: 223

Y-type control rod

Follower zone

Absorber zone

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11. TRU burner types

**Burn TRU from PWR/BWR**
- Burn TRU
- Keep TRU composition during cycles
- Discharge Reprocess

**Burn-out almost all TRU**
- Burn-out leaving a core

- PWR/BWR
- RBWR
- TRU

- Parallel use
- Time

- Depleted uranium
- Other RBWR
- Feed TRU
- Keep TRU composition before/after burn

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12. Selection of moderator to fuel ratio

Proper fissile breeding ratio to achieve TRU multi-recycling is obtained by adjusting coolant(moderator)/fuel.
13. Fuel concept for inherent safety

Void reactivity coefficient is kept negative by two fissile zone core with top/bottom neutron absorber zones

- TRU zone
- Depleted uranium
- Fuel assembly
- Control rod (Follower zone)
- Control rod (absorber zone)
- Channel box (not shown)
- Plenum zone: accumulates FP gas
- Upper neutron absorber zone: dumps excess neutron@transient
- Upper blanket zone
- Internal blanket zone
- Lower neutron absorber zone
Fission not only fissile TRUs but also fertile TRUs at the rate more than twice the rate of TRU production by BWR.
## 15. Core specification and performance

<table>
<thead>
<tr>
<th>Item</th>
<th>RBWR TRU burner</th>
<th>ABWR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For RBWR-TRU</td>
<td>For PWR/BWR-TRU</td>
</tr>
<tr>
<td>Electrical power (MWe)</td>
<td>1356</td>
<td>1356</td>
</tr>
<tr>
<td>Core height (mm)</td>
<td>993</td>
<td>1025</td>
</tr>
<tr>
<td>No. of fuel bundles</td>
<td>720</td>
<td>720</td>
</tr>
<tr>
<td>No. of fuel rods</td>
<td>397</td>
<td>397</td>
</tr>
<tr>
<td>Fuel rods diameter (mm)</td>
<td>7.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Fuel rod gap (mm)</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Coolant flow rate (kt/h)</td>
<td>38</td>
<td>24</td>
</tr>
<tr>
<td>Core exit quality (%)</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td>Void fraction (%)</td>
<td>42</td>
<td>56</td>
</tr>
<tr>
<td>Pressure drop (MPa)*</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>HM Inventory (t)</td>
<td>77</td>
<td>76</td>
</tr>
<tr>
<td>Puf/HM in TRU zone (w/o)</td>
<td>13.9</td>
<td>25</td>
</tr>
<tr>
<td>Burnup (GWd/t)</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>MLHGR (kW/ft)</td>
<td>14.4</td>
<td>14.4</td>
</tr>
<tr>
<td>MCPR</td>
<td>1.3</td>
<td>1.28</td>
</tr>
<tr>
<td>Void coef. ($\Delta k/k/%\text{void}$)</td>
<td>$-2 \times 10^{-4}$</td>
<td>$-4 \times 10^{-4}$</td>
</tr>
<tr>
<td>TRU production eff. (%)**</td>
<td>-51</td>
<td>-45</td>
</tr>
</tbody>
</table>

* Active core region  ** Net increase in TRUs divided by the total amount of fissioned actinides through the total fuel resident time in the core.
16. Hitachi’s activity outline

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17. FFCI concept

Recover only U and store TRUs as recycle material with FPs
Meet FBR and various cycle deployment flexibly

FFCI: Flexible Fuel Cycle Initiative

Standard system

LWR spent fuel

Recovery

FBR cycle

Recovered U

(Pu,MA,U)

FFCI system

LWR spent fuel

Fluorination

Recycle material

FBR cycle*

Recovered U

(Pu,FP,MA,U)

A: FBR introduced on schedule
B: Delay in FBR introduction
* Also applicable to RBWR, ADS cycles
18. FLUOREX concept

Compact and flexible hybrid process of uranium (U) separation with fluorination and solvent extraction

* FLUOREX : Hybrid Process of Fluoride Volatility and Solvent Extraction

Spent fuel (SF) → Decladding → Uranium fluorination → PuF₆ trap → Storage or re-enrichment

UF₆ purification → U/Pu/MA recovery → MA-MOX fuel fabrication

Fluoride → Oxide → High level waste

Easy to process

Fast separation
Compact facility

Applicable to LWR-FBR/RBWR cycle
Applicability of fluorination was confirmed with simulated and actual spent fuel (SF) experiments.

\[
\text{UO}_2(\text{solid}) + 3\text{F}_2(\text{gas}) \rightarrow \text{UF}_6(\text{gas}) + \text{O}_2(\text{gas})
\]

**Simulated SF test**

**Actual SF test**
20. Application to debris treatment

Decompose debris and separate U/Pu with compact facility
Flexibly respond to disposal, storage and reprocessing

Fuel Debris
Fuel: U, Pu, FP, MA
Clad: SUS, Zr, etc.
Control rod: SUS, B_4C
Sea water: Na, Cl, etc.
Concrete: Si, Ca, Al, etc.

Volatile Fluorides
(U, Pu, FP, B, C, Cl)

Oxide Conversion
Steam

Disposal
(Waste)
Vitirificat.

Impurities
U, Pu, etc.
Reprocessing

Off-gas Treat.

Reprocessing case
Long-term storage
Disposal case

* Easy accountancy

Fuel debris treatment process with fluorination method
Hitachi contributes reduction of radioactive wastes:

- Cooperates on national project through development of the advanced sodium-cooled MA burner reactor
- Investigate feasibility of the TRU burner as an option for sodium-cooled fast reactor based on the BWR experience
- Cooperates on national projects through development of reprocessing and fuel debris treatment technologies with fluorination
23. Na plenum concept
