Research and Development Program of HTGR Fuel in Japan

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Block Type HTGR

Pebble Type HTGR

Spherical fuel element
HTGR Fuel Development under HTTR Project

- Safety design criteria were settled.
- Inspection standard (items, methods, sampling rates) was established.
- The first- and second-loading fuels of the HTTR were fabricated by NFI Ltd. (≈2 ton of U) and achieved low as-fabricated failure fraction.
- HTTR operation data and post-irradiation test
- Burnup extension
- Safety related test (RIA condition)
- Advanced coating (ZrC-coated particle)
Fuel Fabrication

Uranyl nitrate solution

→

UO₂ particle

Buffer coating (C₂H₂+Ar)
IPyC coating (C₃H₆+Ar)
SiC coating (CH₃SiCl₃+H₂:MTS)
OPyC coating (C₃H₆+Ar)

→

TRISO coated particle

Graphite powder
Binder

→

Overcoat particle

→

Fuel compact

Optimize hot pressing

Fuel rod

Graphite sleeve

Fuel assembly

Graphite block
Burnable poison

Average through-coatings failure and SiC-failure fractions were $2 \times 10^{-6}$ and $8 \times 10^{-5}$
Fuel Performance
(Normal Operating Condition)

Very low fission gas release fraction
about $10^{-8}$ even at high temperature operation

Development of fission gas release model for high quality fuel.
Postirradiation Examination of the First Loading Fuel of the HTTR

- Fuel reloading in 2008
- Fuel rods will be transferred to JMTR Hot Laboratory
- Many tests will be carried out

Confirm fuel behavior under real-HTGR condition
Development for Future HTGR Fuels

- Available data
- JAERI irradiation data
- German fuel data
- US fuel data (HEU)
- VHTR
- GFR
- HTTR
- Fast neutron Fluence ($m^{-2}(E>29fJ)$)
- Burnup (%FIMA)

● Burnup extension
● Safety test (RIA condition)
● Advanced fuel development
Burnup Extension

- Irradiation Tests
  91F-1A capsule irradiation test by Japan Materials Testing Reactor (JMTR) of JAERI
  HRB-22 capsule irradiation test by High Flux Isotope Reactor (HFIR) of ORNL

- Post-irradiation Tests
  X-ray microradiography
  Ceramography
  SEM
  EPMA

- Analysis
  Fission Gas Release
  Failure Fraction
  Model development
The failure criterion under RIA condition could be determined as a function of time and temperature.

Results of previous research:
- Fuel failed by internal high pressure by UO₂ evaporation
- Reactivity insertion rate (msec.) was MUCH FASTER than HTGR condition

New experiments with slow pulses simulating HTGR RIA condition.
ZrC-Coated Fuel Development

**Limitation of SiC**
- cannot be used at higher temperatures than the currently designed HTGR
- corrosion by Pd (transuranium nuclides has larger yield)

- Fabrication by Bromide process
- Better irradiation performance than SiC-coated particles

Next research and development
- Optimization of deposition condition to fabricate stoichiometric ZrC by larger-scale coater.
- Advanced inspection method development for ZrC-coated particle.
- Investigation of ZrC grain/crystal growth behavior under high burnup.
ZrC-particle develop program

• Stoichiometry and density of ZrC are strongly influenced by CH₄ pyrolysis behavior
  – ZrC deposit temperature would be determined by CH₄ pyrolysis efficiency

• Advanced inspection method development
  – Treatment with plasma (oxidation by O₂, reduction by H₂, …)

• Irradiation test and post irradiation experiment of ZrC coated fuel particle
  – Capsule irradiation test with ZrC-coated “surrogate fuel” particles (collaboration with ORNL).
  – Develop failure model of the ZrC-coated fuel particle for fuel and safety design (collaboration with INL).
Conclusions

• Under the HTTR project, JAERI carries out research and development of HTGR fuels.
• Fabrication technology was established through the HTTR fuel fabrication.
• Fuel performance data have been accumulated through HTTR operation.
• Post-irradiation tests of HTTR fuel will confirm the superior characteristics of the TRISO-coated particles.
• For VHTR fuel, JAERI has concentrated research and development of burnup extension, failure mechanism under RIA condition and ZrC-coating technology.
• JAERI expects that these tests are carried out in cooperation with other countries.
APPENDIX
Normal operation criteria

- The **as-fabricated failure** fraction shall be less than design limit (0.2%).
- The coated fuel particles shall not fail systematically (**Pd-SiC interaction, kernel migration, internal pressure**).
- The additional failure fraction shall be less than design limit (0.2%) through the full service period.
- The fuel compact and graphite sleeve shall not contact each other to keep their mechanical integrity.
Anticipated transient criteria

The maximum fuel temperature shall not exceed 1600°C (the coating layers shall maintain intact below 1600°C).

Accident criteria

The fuel compacts shall be held in the graphite block and the support post shall keep enough strength to support the core (Sufficient cooling capacity for residual heat removal shall be maintained).
## Quality Control of HTGR Fuel

### Inspection standards
- Compulsory
- User’s requirement
- Vender’s QC

### Inspection methods

<table>
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<th>Item</th>
<th>Main purpose</th>
<th>Method</th>
<th>Sampling rate</th>
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<tr>
<td>Kernel diameter</td>
<td>Nuclear design</td>
<td>Optical particle size analysis</td>
<td>1 sample (100 kernels) / Kernel lot</td>
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<tr>
<td>Sphericity of kernel</td>
<td></td>
<td>X-ray radiography</td>
<td>3 samples (100 kernels / sample) / Kernel lot</td>
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<tr>
<td>Coating layer thickness</td>
<td>Irradiation performance</td>
<td>Polarization photometer</td>
<td>1 sample (50 particles) / Coating batch</td>
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<td>OPTAF</td>
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<td>Deconsolidation &amp; acid leaching</td>
<td>1 sample (5 particles) / enrichment</td>
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<td>Exposed uranium fraction of fuel compact</td>
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<td></td>
<td>2 compacts / Fuel compact lot</td>
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<tr>
<td>SiC-failure fraction</td>
<td></td>
<td>Burn &amp; acid leaching</td>
<td>3 compacts / Fuel compact lot</td>
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<tr>
<td>Dimensions of fuel compact</td>
<td>Thermal-hydraulic design</td>
<td>Micrometer</td>
<td>All fuel compacts</td>
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<tr>
<td>Number of fuel compacts in a fuel rod</td>
<td>Process control</td>
<td>Check of assembling record</td>
<td>All fuel rods</td>
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</tbody>
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### Sampling rate
- Small-scattering data
- Medium-scattering data
- Large-scattering data (statistical evaluation)
# Roadmap of the Program

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<th>2006</th>
<th>2007</th>
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<td><strong>Fabrication of ZrC-CFP</strong></td>
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<td>ZrC coating test with dummy particle</td>
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<td>ZrC coating test with UQ particle</td>
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<td>Replace ZrC coater</td>
<td>Characterization of ZrC coating layer</td>
<td>Design of commercial coater</td>
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<td>Development of inspection techniques for ZrC</td>
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<td>Irradiation test and PIE</td>
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<td>Transport of JAERI ZrC fuel particle</td>
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<td>Modeling and evaluation of ZrC fuel under irradiation</td>
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<td><strong>Fuel behavior under RIA</strong></td>
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<td>Investigation of irradiation</td>
<td>Pulse irradiation tests by NSRR</td>
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<td><strong>Development of Non-destructive Method for Graphite Components</strong></td>
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<td>Ultrasonic testing and micro-indentation technique</td>
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Fuels and Materials Irradiation Tests in the HTTR

Assembly irradiation at in-core region

Capsule irradiation at reflector region

Pebble type

Multi-hole type

HTTR

Weight Loading System
Standpipe Closure
Irradiation Standpipe

Reactor Pressure Vessel
Load Transmission Rod

Load Transmission Rod
Differential Transformer
Specimen

Electric Heater
Irradiation Unit