Research and Development Program of HTGR Fuel in Japan

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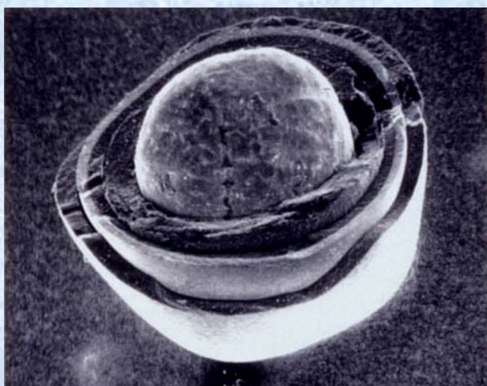
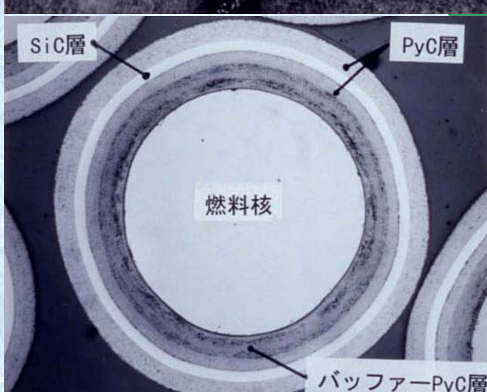




Block Type HTGR

Spherical fuel element

Pebble Type HTGR

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

↓

UO_2 particle

↓ **Buffer coating (C_2H_2+Ar)**
IPyC coating (C_3H_6+Ar)
SiC coating (CH_3SiCl_3+H_2:MTS)
OPyC coating (C_3H_6+Ar)

TRISO coated particle

Optimize fluidization
Continuous coating

↓ **Graphite powder**
Binder

Overcoat particle

Overcoat particle

↓ **Hot pressing**
Preheating
Heating

Fuel compact

Optimize hot pressing

↓ **Graphite sleeve**

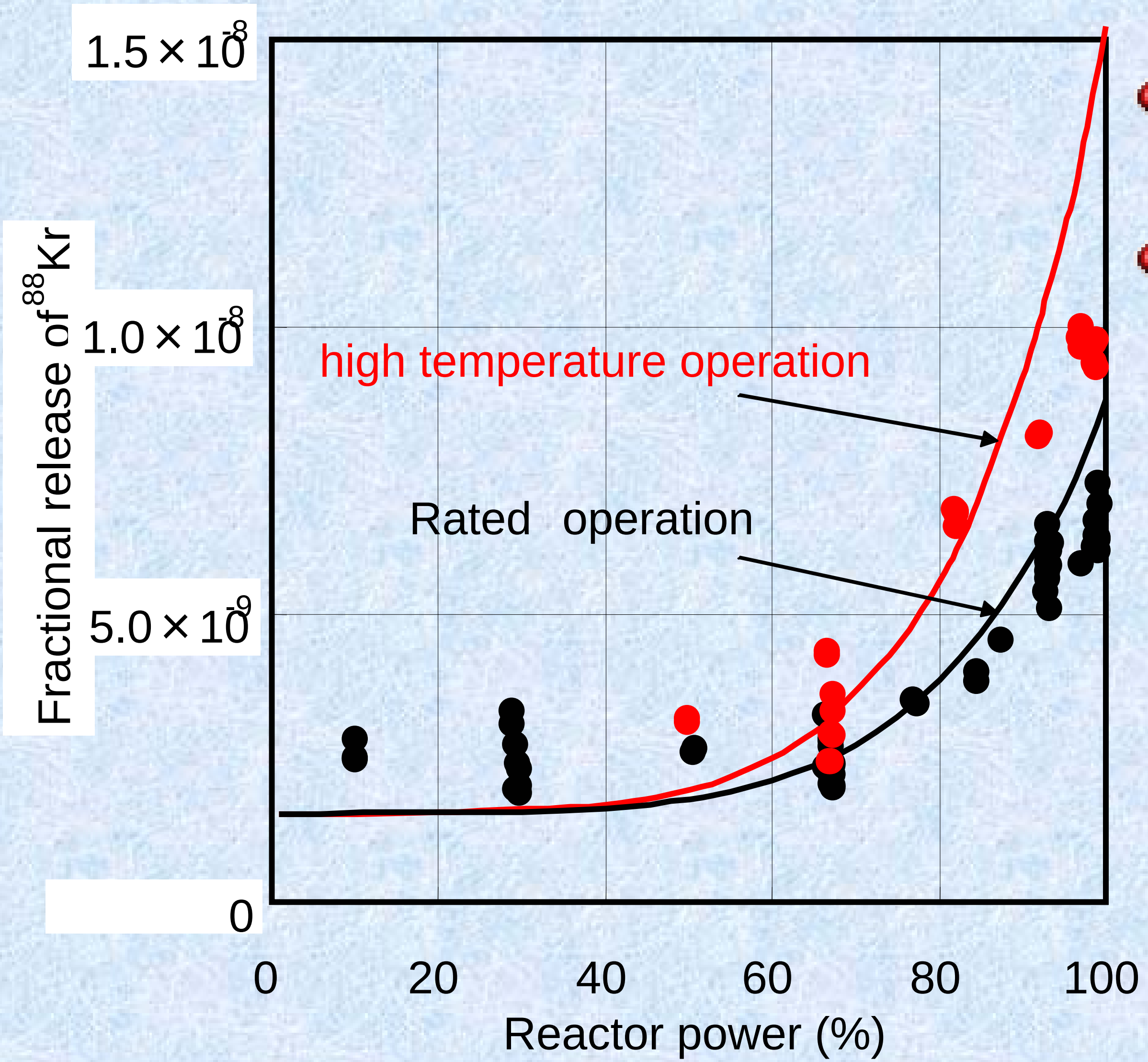
Fuel rod

↓ **Graphite block**
Burnable poison

Fuel assembly

Average through-coatings failure and SiC-failure fractions were 2×10^{-6} and 8×10^{-5}

Fuel Performance (Normal Operating Condition)

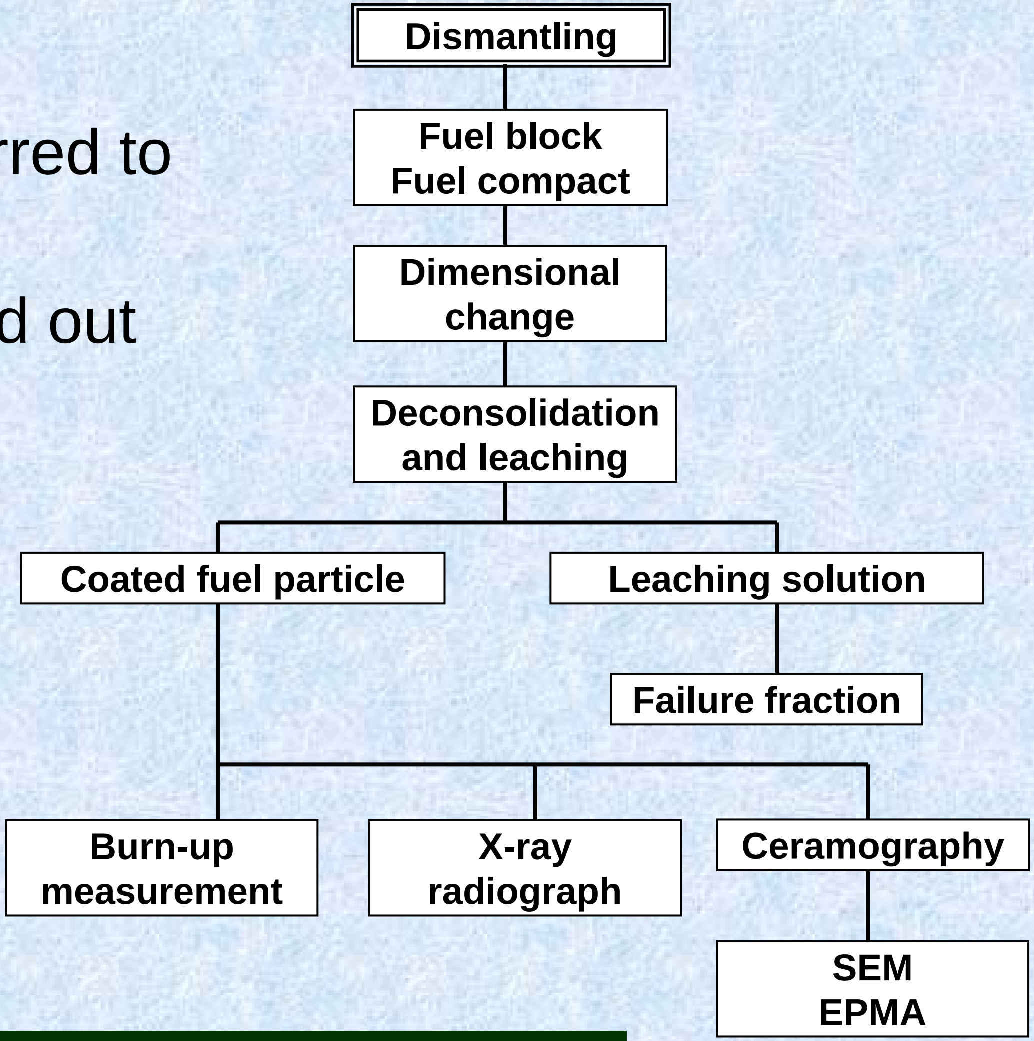


- Very low fission gas release fraction
- about 10^{-8} even at high temperature operation

Development of fission gas release model for high quality fuel.

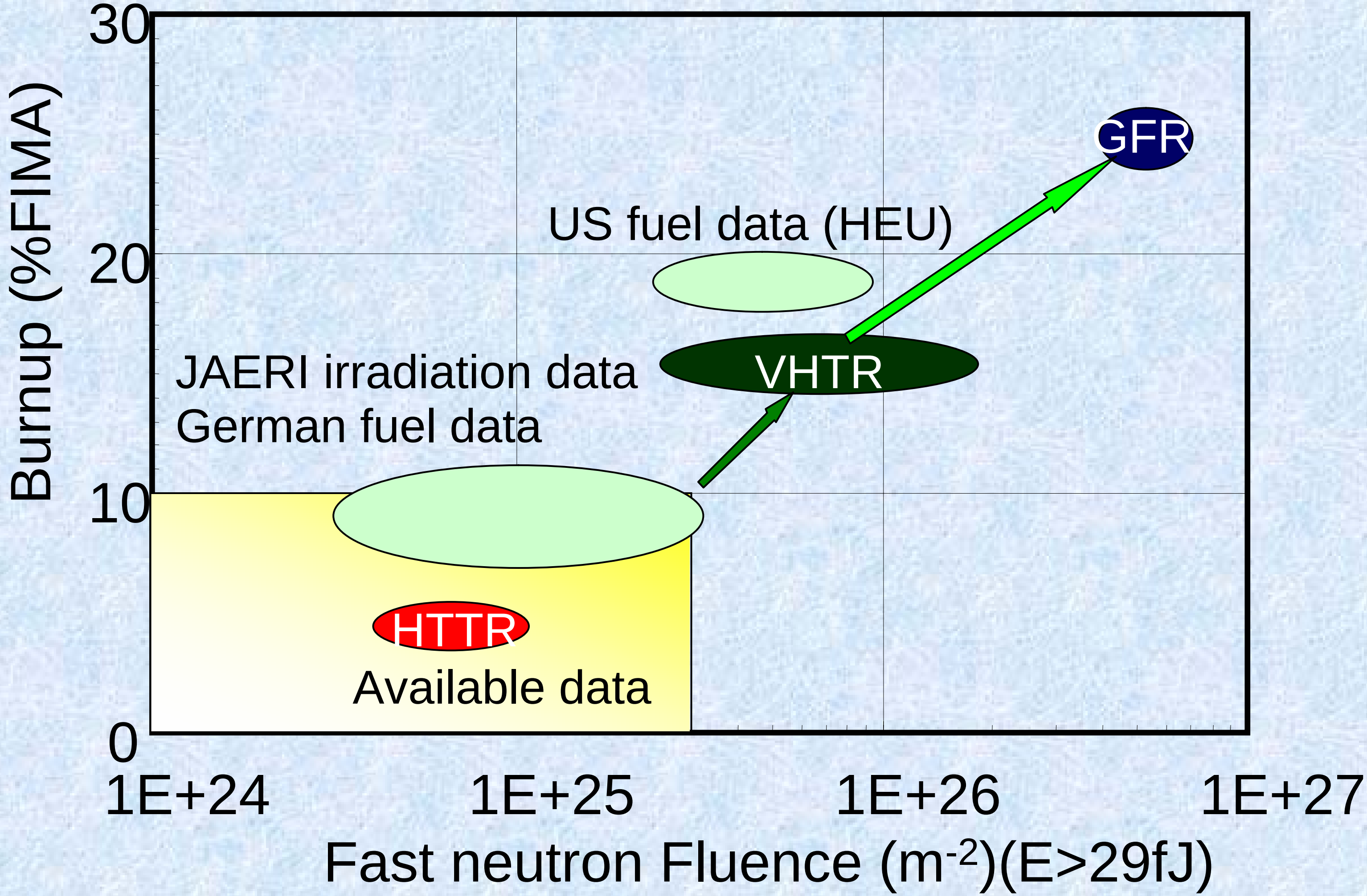
Postirradiation Examination of the First Loading Fuel of the HTTR

- 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



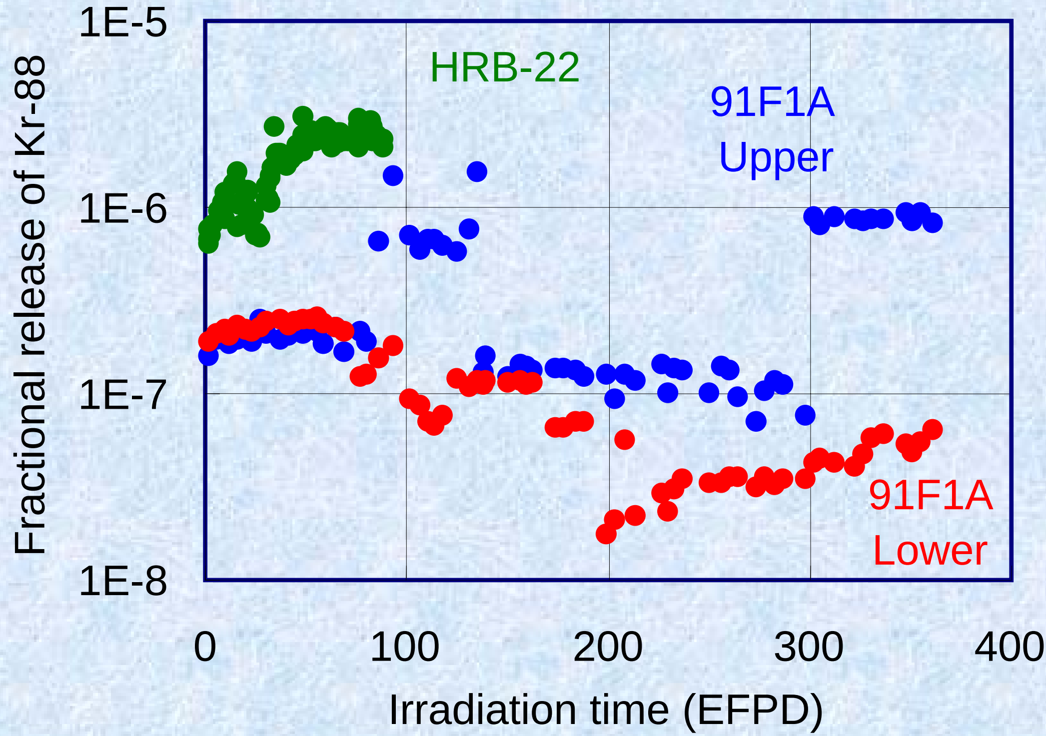
● Burnup extension ● Safety test (RIA condition) ● Advanced fuel development

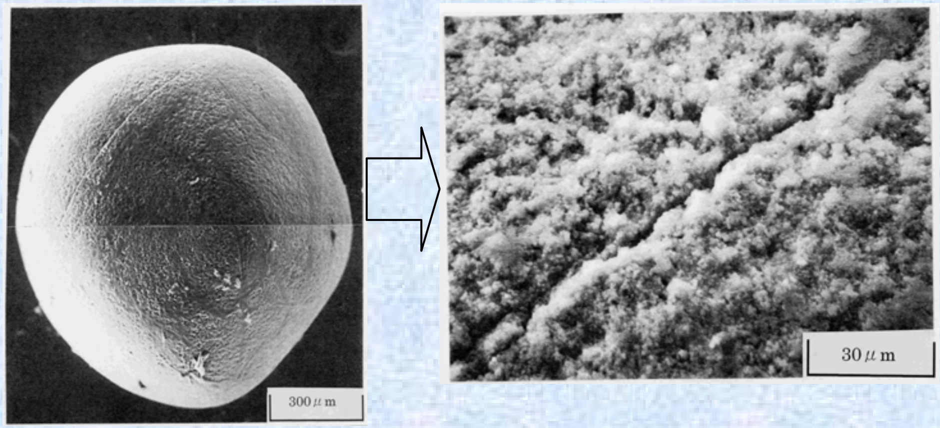
Burnup Extension

- 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
  Ceramograpy
  SEM
  EPMA

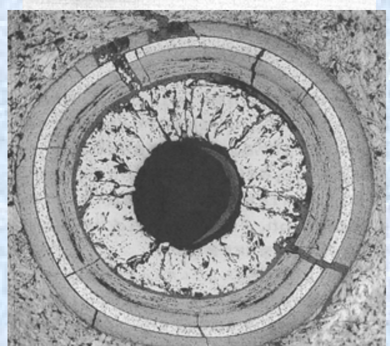
- Analysis
  Fission Gas Release
  Failure Fraction
  Model development





Pulse Irradiation Test for RIA Simulation

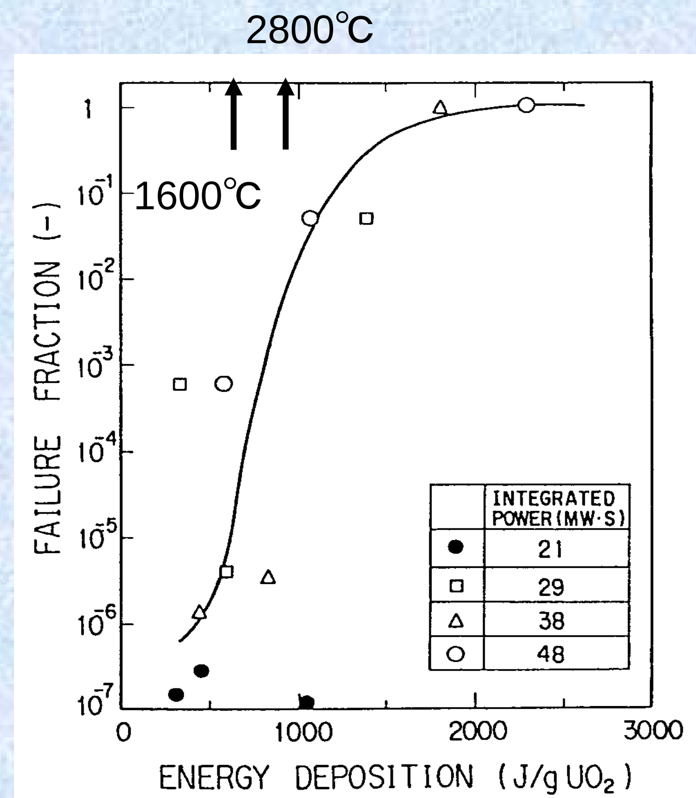
The failure criterion under RIA condition could be determined as a function of time and temperature



New experiments with slow pulses simulating HTGR RIA condition

Results of previous research

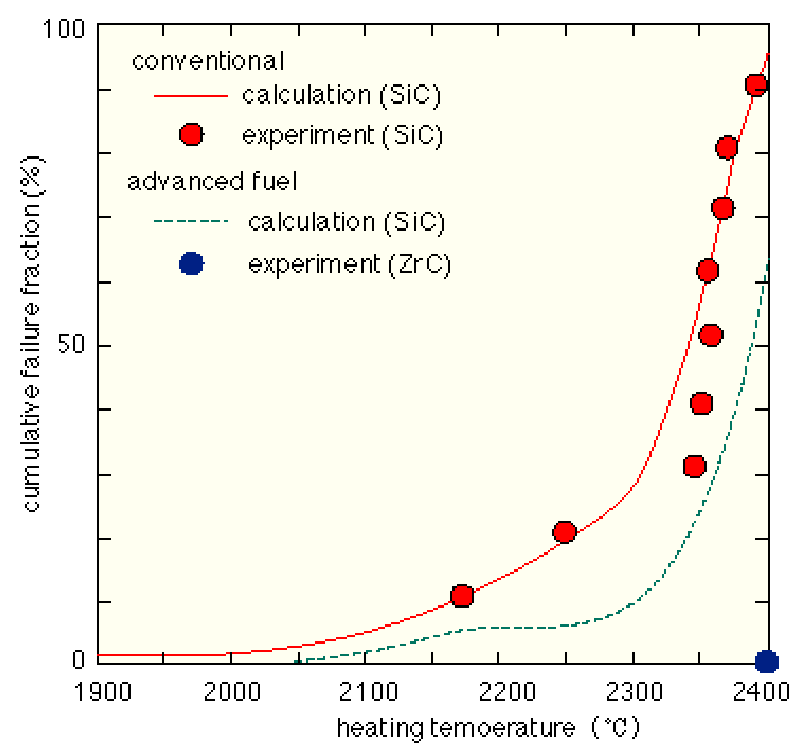
- Fuel failed by internal high pressure by UO_2 evapolation
- Reactivity insertion rate (msec.) was MUCH FASTER than HTGR condition



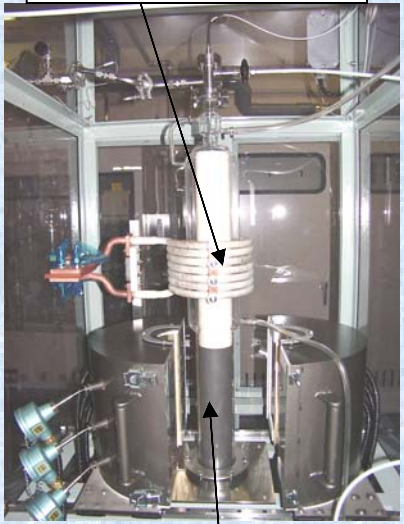
ZrC-Coated Fuel Development

Limitation of SiC

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



Upper furnace for ZrC deposition



Lower furnace for Zr-bromide production

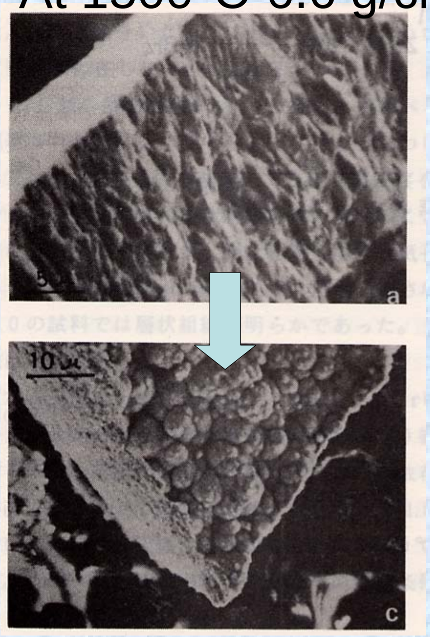
- Fabrication by Bromide process
- Better irradiation performance than SiC-coated particles

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

At 1500^{o}C 6.6 g/cm^3



At 1550^{o}C 6.1 g/cm^3

- Stoichiometry and density of ZrC are strongly influenced by CH_4 pyrolysis behavior
  - ZrC deposit temperature would be determined by CH_4 pyrolysis efficiency
- Advanced inspection method development
  - Treatment with plasma (oxidation by O_2 , reduction by H_2, …)
- 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^{o}C (the coating layers shall maintain intact below 1600^{o}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

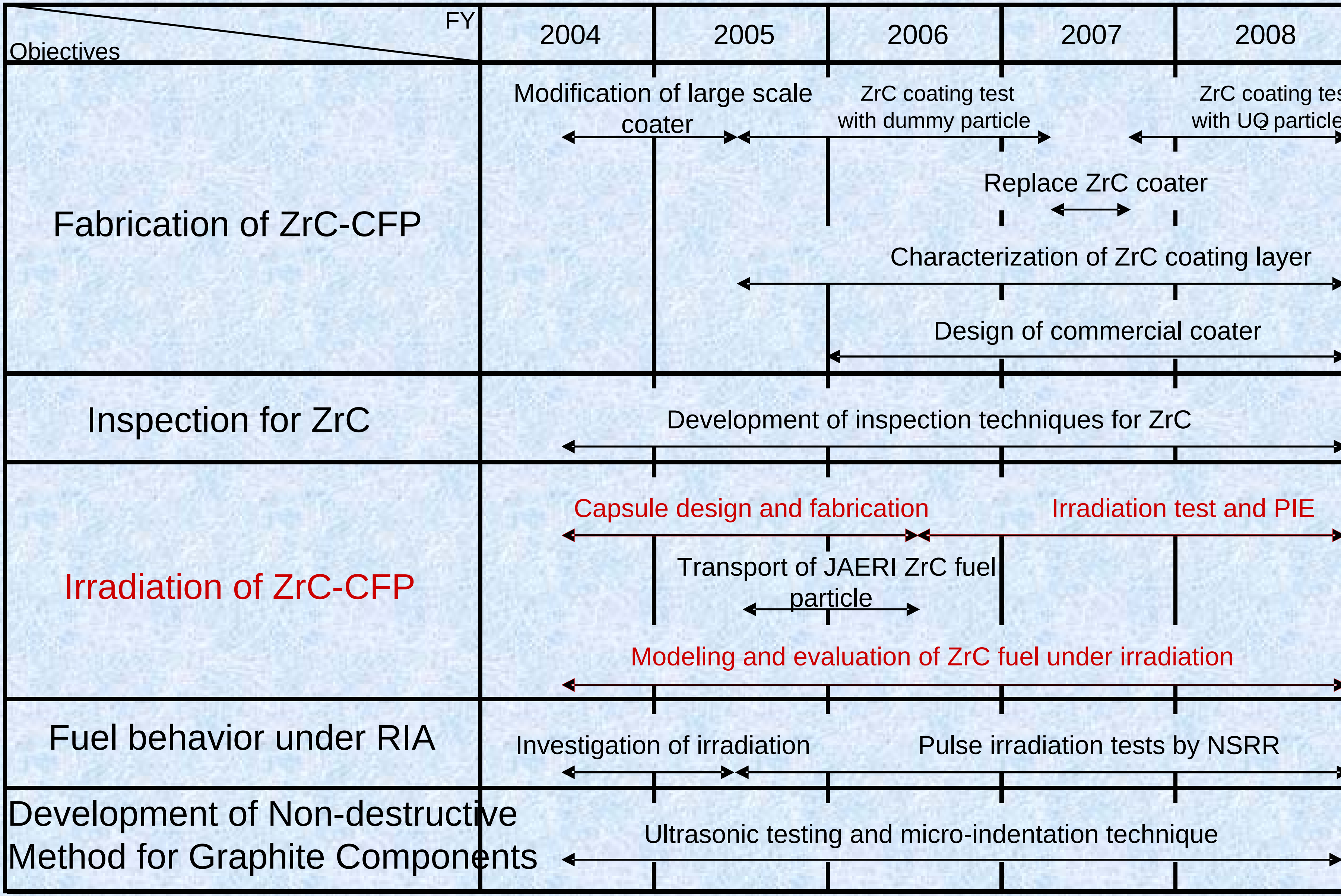
Inspection standards
- Compulsory
- User's requirement
- Vender's QC

Sampling rate
- Small-scattering data
- Medium-scattering data
- Large-scattering data (statistical evaluation)

Inspection methods

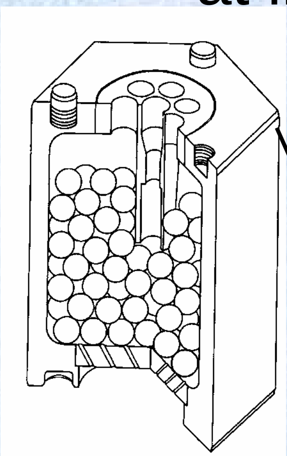
Item	Main purpose	Method	Sampling rate
Kernel diameter	Nuclear design	Optical particle size analysis	1 sample (100 kernels) / Kernel lot
Sphericity of kernel	Irradiation performance	Optical particle size analysis	3 samples (100 kernels / sample) / Kernel lot
Coating layer thickness	Irradiation performance	X-ray radiography	1 sample (50 particles) / Coating batch
OPTAF	Irradiation performance	Polarization photometer	1 sample (5 particles) / enrichment
Exposed uranium fraction of fuel compact	Irradiation performance	Deconsolidation & acid leaching	2 compacts / Fuel compact lot
SiC-failure fraction	Irradiation performance	Burn & acid leaching	3 compacts / Fuel compact lot
Dimensions of fuel compact	Thermal-hydraulic design	Micrometer	All fuel compacts
Number of fuel compacts in a fuel rod	Process control	Check of assembling record	All fuel rods

Roadmap of the Program

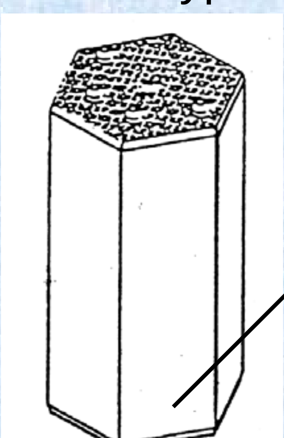


Fuels and Materials Irradiation Tests in the HTTR

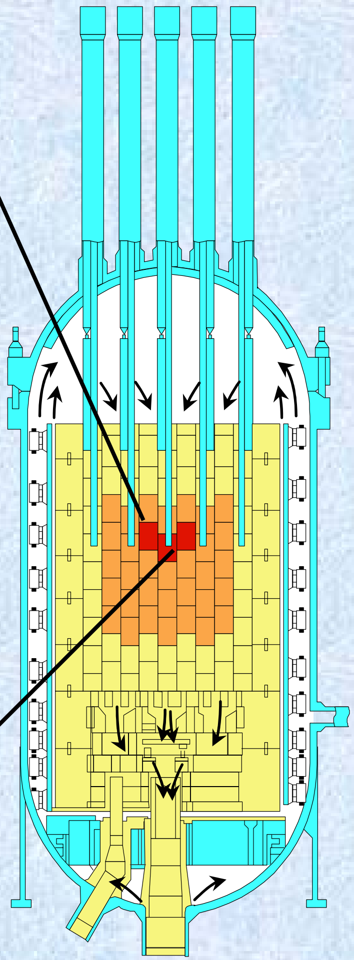
Assembly irradiation at in-core region



Pebble type



Multi-hole type



HTTR

Capsule irradiation at reflector region