# R&D of High Temperature Gas-Cooled Reactor Fuel (TRISO) in Japan

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This report was prepared based on various R&D information of HTGR fuel in Japan.

# Acknowledgement


- Dr. Kazuhiro Sawa, O-arai R&D center, JAEA
- Dr. Shoji Takada, O-arai R&D center, JAEA
  - HTGR history, roadmap, aims, R&D status
- Dr. Masao Owaki, Nuclear Fuel Industries, Ltd.
  - TRISO fabrication, feasibility study on TRISO utilization for LWRs

# History and Roadmap of HTGR Fuel R&Ds

**Objectives** To establish fundamental technologies for practical HTGR fuel

U3O8 powder

Vibration dropping external sol gel method

$UO_2$ kernel

Continuous coating

SiC-TRISO Coated fuel particl

Compaction technologies

Fuel compact

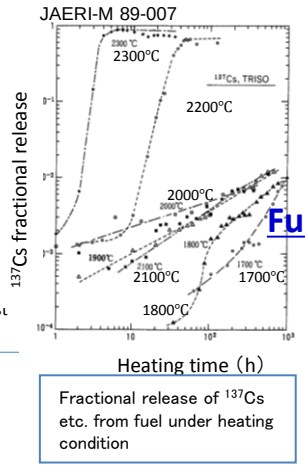
uel element
Fuel block

**Fabrication of SiC-TRISO**
JAEA's pamphlet

JAERI-M 89-007

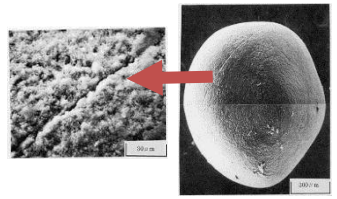
Post-irradiation heating test (～2400℃)

JAERI-M 89-007




Fractional release of $^{137}$Cs etc. from fuel under heating condition

**Fuel performance on FP retention**



**Fuel failure mechanism during irradiation**
Sawa, et al., Nucl. Technol.(2003)

**Practical HTGR**

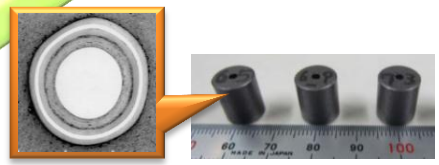
**Transfer technologies to industries**

**On-going R&Ds for practical HTGR**
(2000-2020)

Establish fundamental technologies

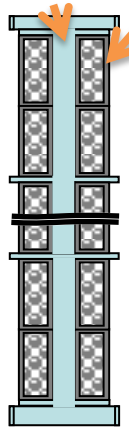
**On-going R&Ds for advanced HTGR**
(2014～2017)

**R&Ds for HTTR**
**(High Temp. Test Reactor)**
(1970-1999)



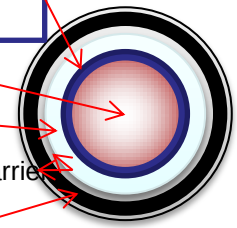
**Extended burnup SiC-TRISO**
Ueta, et al., HTR2014

**Fuel element for higher power density**
JAERI-M 89-007




**ZrC layer for getting free oxygen**

Kernel: $UO_2$ → **Pu-YSZ**
Low dense PyC: Buffer
High dense PyC: FP gas barrier
SiC: metallic FP barrier



**Pu-burn HTGR fuel**

**Oxidation-resistant fuel element**

# Establishment of Extended Burnup Fuel

## Objectives

*To demonstrate integrity of newly designed SiC-TRISO fuel to apply burn-up around 100GWd/t for VHTRs*

## Participants and Role

***JAEA** : Design of new SiC-TRISO fuel, Analysis, Evaluation*
***INP - Kazakhstan** : Irradiation by using WWR-K reactor*
***NFI** : Fuel fabrication, Supply fuel samples*

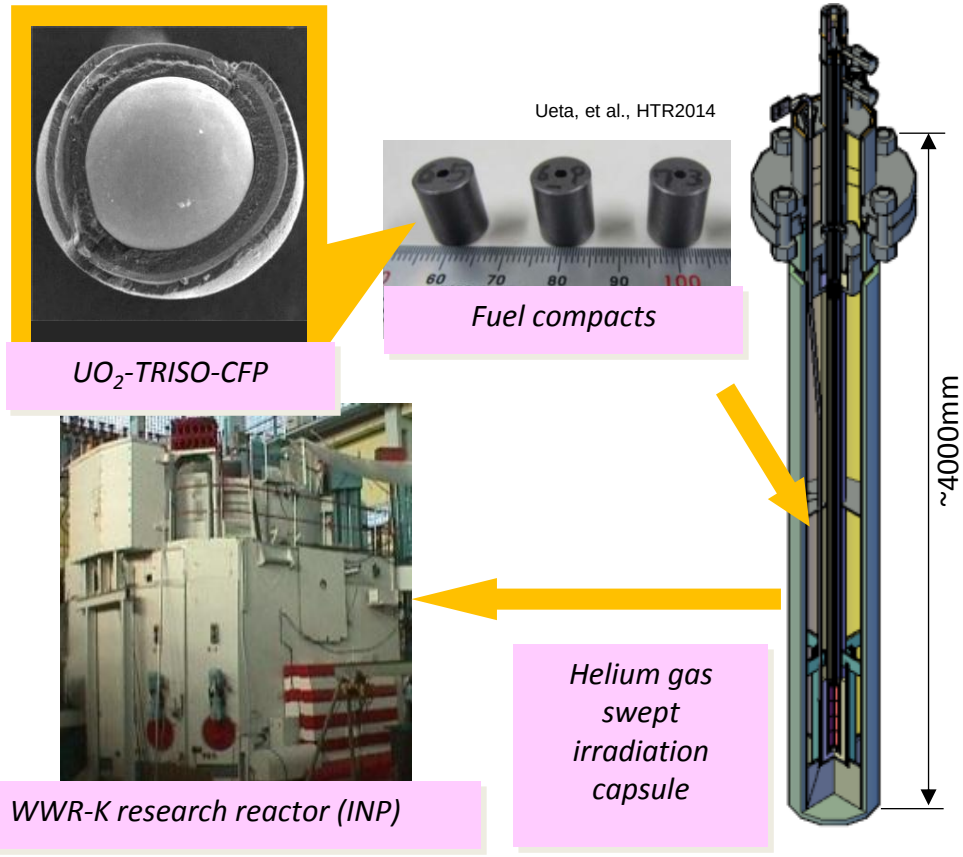
## R&D Items

*Evaluation of behaviour and effect during and after irradiation*

- *Integrity of SiC-TRISO fuel at 1050 °C*
  - *R/B of $^{88}Kr$*
  - *Fission gas ($^{85m}Kr$, $^{87}Kr$, $^{133}Xe$, $^{135}Xe$, $^{135m}Xe$, $^{138}Xe$, etc.) concentration*
- *Characterization of SiC-TRISO fuel by PIEs*
  - *Gamma spectroscopy, etc.*

## Present Status

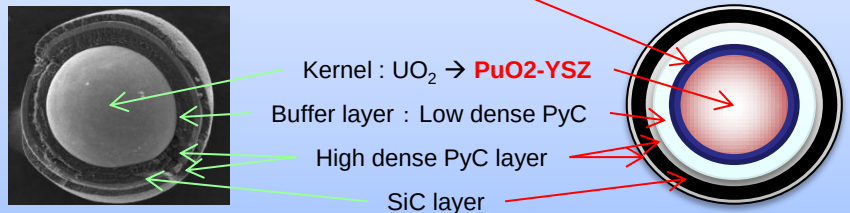
- *Irradiation test has been completed successfully in February 2015.*
- *Integrity of newly designed SiC-TRISO fuel around 100GWd/t has been confirmed.*
- *Post-irradiation examinations with the irradiated SiC-TRISO fuel are planned in 2015-16.*



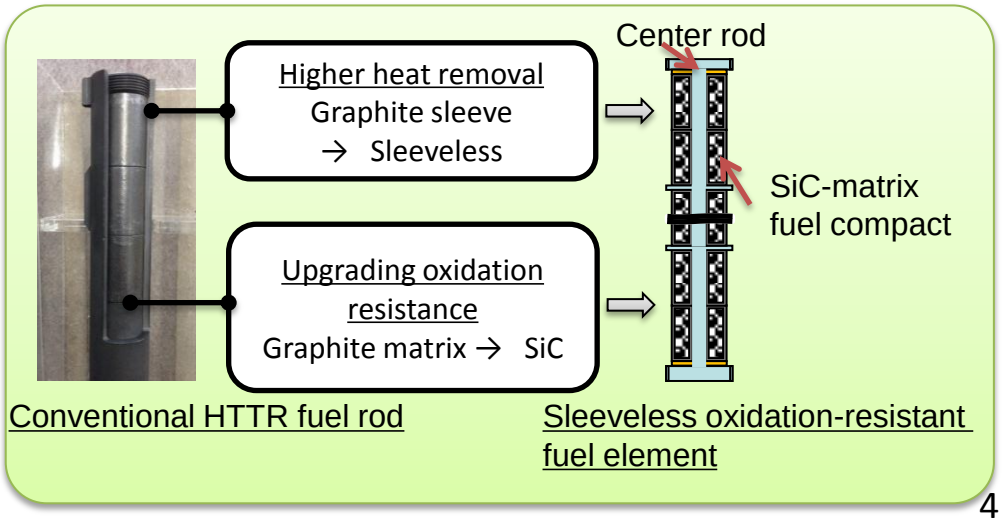
# Advanced fuel development

- **R&D on Security-Enhanced Safety Fuel for Clean Burn HTGR**
  - Objectives
    - Establish Pu-burn fuel technologies
  - R&D items on fuel fabrication technologies
    - (PuO2-surrogated) CeO2-YSZ kernel by sol-gel method
    - ZrC coating on YSZ kernel by bromide process
    - Continuous TRISO coating based on HTTR fuel technologies
  - Schedule (started in Oct. 2014)
    - 4 year project from 2014 to 2017
    - YSZ fabrication and ZrC coating in 2015 and 2016
    - TRISO coating on ZrC-coated YSZ in 2016 and 2017

**ZrC coating on PuO2-YSZ kernel as free $O_2$ getter to reduce 50% (max. in target) of internal gas pressure**



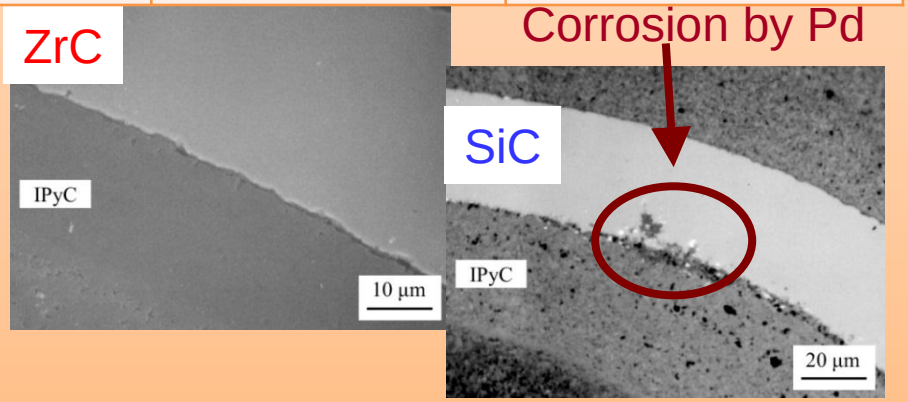

- **R&D on Sleeveless Oxidation-Resistant Fuel**
  - Objectives
    - Develop the advanced HTGR fuel performing higher heat removal than that of the conventional for decreasing the maximum fuel temperature during the normal operation
  - R&D items
    - Fabrication technologies by hot press with Si & C powders
    - New inspection methods based on HTTR fuel technologies
  - Schedule( started in Sep. 2014)
    - 3 year project from 2014 to 2016
    - Start fabrication of SiC-matrix dummy compact in 2015
    - Optimize fabrication and inspection conditions in 2016



# R&D on Security-Enhanced Safety Fuel for Clean Burn HTGR

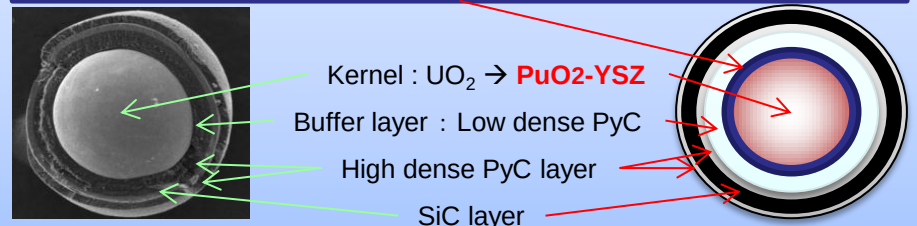
- Properties of ZrC
  - Higher refractoriness than SiC
  - High chemical stability against metal FPs
  - Needs good stoichiometry (C/Zr ratio = 1.0)
  - Works as O2 getter at high temperature

| | $ZrC_{1.0}$ | β-SiC |
|---|---|---|
| ° C | 2,850 (Eutectic point with C) | < 2,200 (Thermal decomposition) |
| $\sigma_a$ barn | 0.19(Zr) | 0.17(Si) |
| W/(m·K) | 40-50 | 30-70 |




Minato, et al., Global 2003

**ZrC coating on PuO2-YSZ kernel as free O2 getter to reduce 50% (max. in target) of internal gas pressure**

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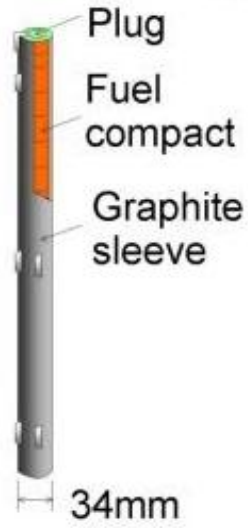
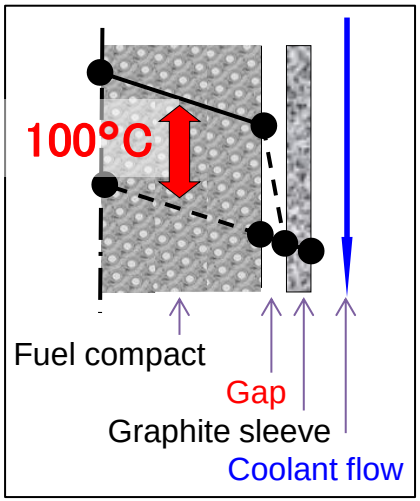
ZrC coater in JAEA

Ueta, et al., J. Nucl. Mater. (2008)

# R&D on Oxidation-Resistant Fuel Element

## HTTR fuel rod



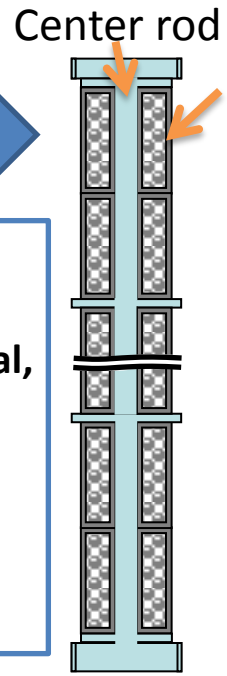



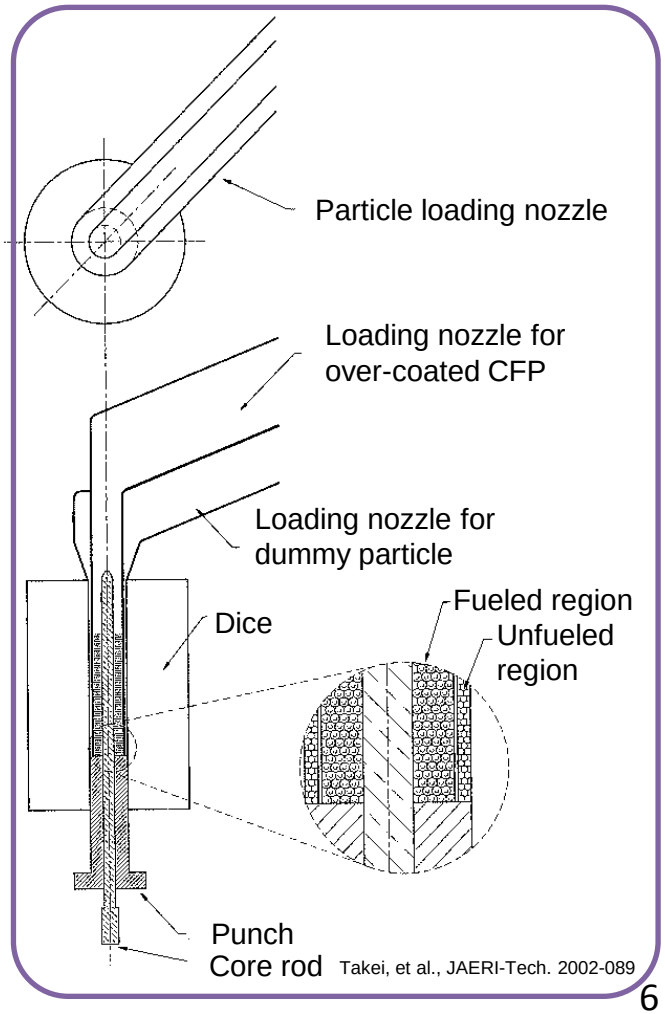

Cross section of fuel rod

**Remove gap by sleeveless structure**
**→ Upgrade heat removal, higher power density**

**SiC matrix**
**→ Upgrade oxidation resistance**

## Oxidation-resistant fuel element

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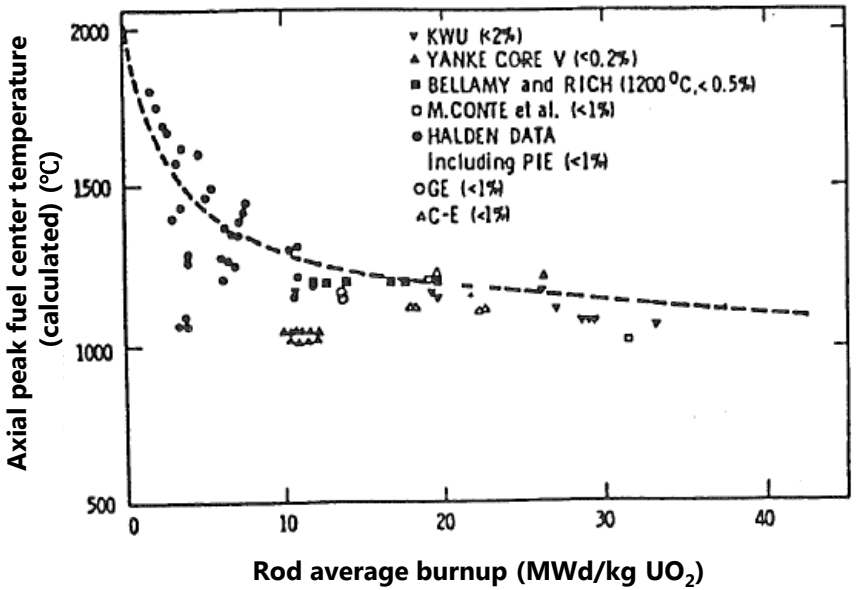
# Application of TRISO to LWRs, Background

- To develop Accident Tolerant Fuel (ATF) became a serious discussion after Fukushima Daiichi Nuclear Power Plant accident.
- Main objectives of ATF are:
  - ✓ to prevent or to minimize the release of radioactive species from fuel segments.
  - ✓ to increase the safety margin in severe accident by preventing core melt and by decreasing hydrogen generation.

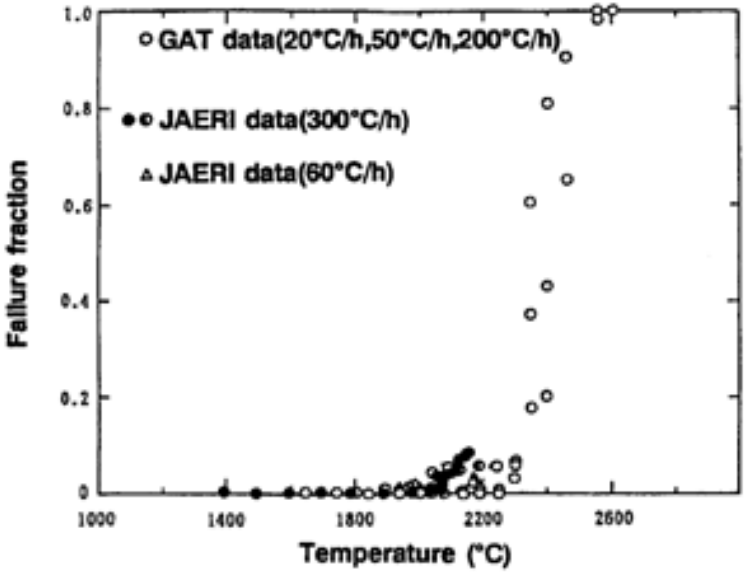
TRISO fuel has a superior capability for fission product retention based on fuel configuration (coated particle layers surrounding fuel kernel).

# Application of TRISO to LWRs, FP retention ability

## Fission product retention of TRISO:




**Threshold temperature of 1% FP gas release for $UO_2$ pellet [1]**




**FP gas release behavior of TRISO fuel [2]**

FP gas released remarkably at >1000℃ for $UO_2$ pellet.

FP gas retained inside in particles at <1800℃ for TRISO fuel.


[1] Vitanza et al, ANS Topical Meeting on LWR Fuel Performance, Portland, 1979.
[2] JAERI 1332, "Design of High Temperature Engineering Test Reactor (HTTR)", 1994.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# Application of TRISO to LWRs, Fabrication

Fabrication technology of TRISO is already established for HTGR.

- Fuel Kernel : Fabrication technology for $UO_2$ is established.
- Coated Particle : Thickness of coated layer is well controlled for $UO_2$ Kernel.
- Fuel Compact : Filling rate of particles in graphite matrix based compact is ca.30% for HTGR fuel.

Kernel Fabrication Equipment

CVD Coater Furnace

Fuel Compact Fabrication Equipment

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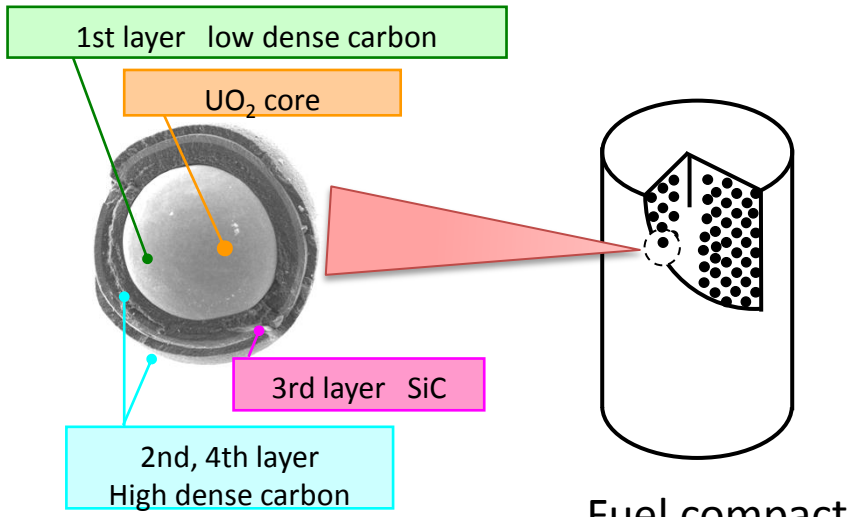
# Application of TRISO to LWRs, R&D issues

Study on compatibility of TRISO fuel to SiC cladding tube has launched:

- Evaluation of Technology Readiness Level
- Preparation of Attributes Guide and Identification of Metrics
- Databasing of UN or UC as Fuel Kernel for Modifying Fuel Performance Code
- Core design, etc.

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# Summary

- History and present status of HTGR fuel R&D in Japan introduced. The recent main R&D issues are extended high burn-up, security-enhanced safety, and oxidation resistance.
- Feasibility study on TRISO utilization as of LWR fuels ongoing in Japan, especially from aspect of good compatibility with SiC/SiC cladding.