KAERI

Workshop on Advanced Reactors With Innovative Fuels
ARWIF-2005

MATERIALS PROPERTIES AND FUEL PERFORMANCE OF THE DUPIC FUEL

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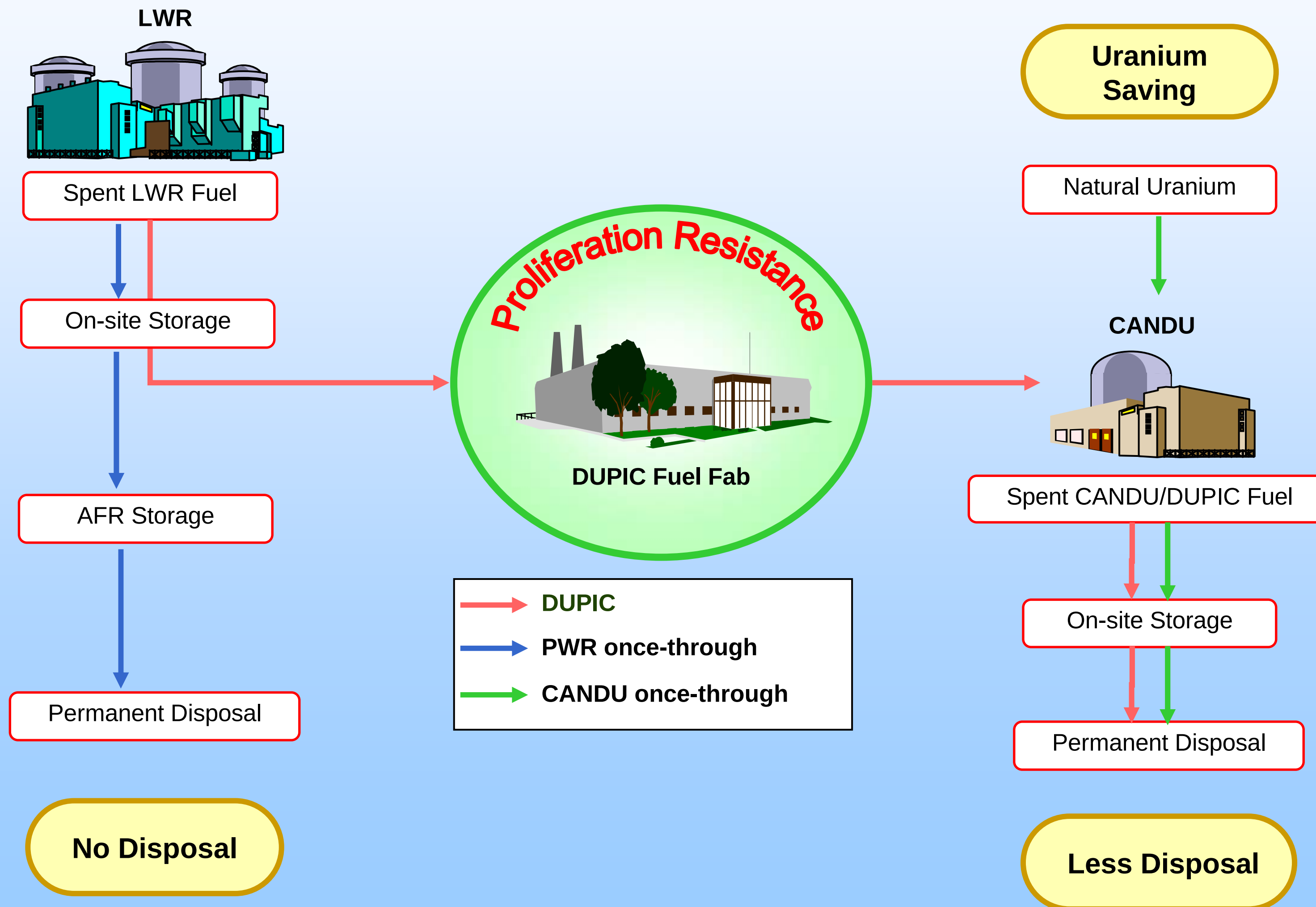
Contents

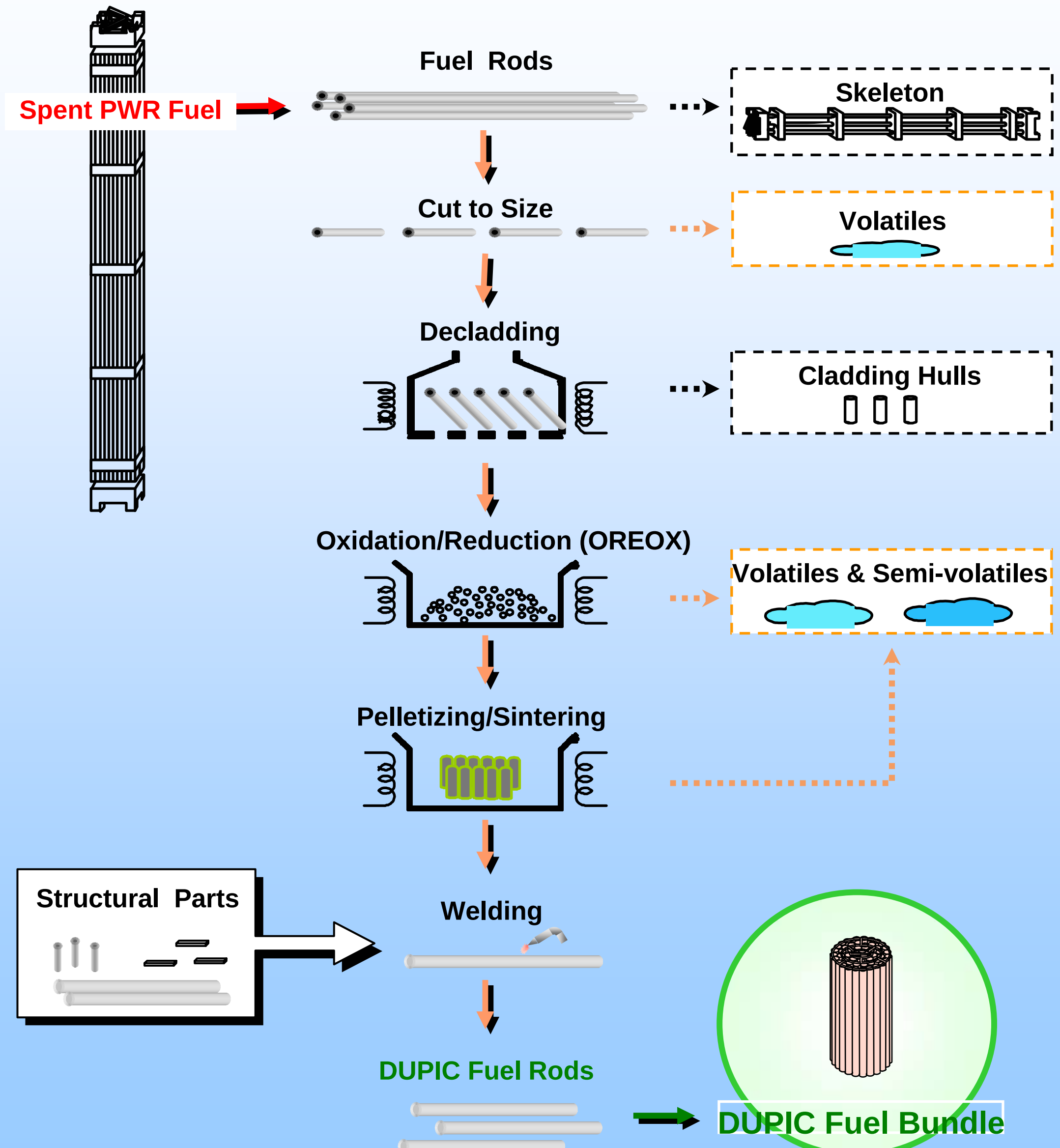
- Introduction to the DUPIC Fuel Cycle
- Material Properties of the DUPIC Fuel Pellet
- Performance Analysis of the DUPIC Fuel
- Irradiation Test of the DUPIC Fuel

Concept of DUPIC

*** DUPIC : Direct use of spent PWR fuel in CANDU reactors**



Fabrication Process of DUPIC



Technical Challenges

- Remote fabrication
- Remote handling
- Performance verification of the DUPIC fuel

Material Properties Characterization

- Simulated DUPIC fuel
  - Due to high radioactivity of spent fuel
  - Inactive isotope for fission product elements
- Thermal Properties
  - Thermal conductivity
  - Thermal expansion coefficient
- Mechanical Properties
  - Creep rate
  - Young’s modulus
- Diffusion Coefficient of Fission Gas (Xe)

Thermal Properties

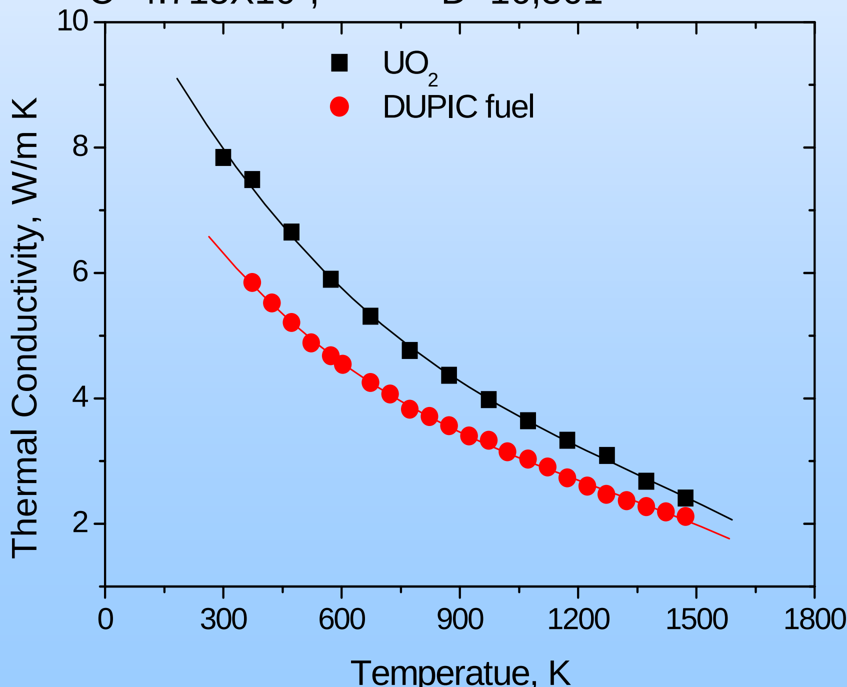
● Thermal Conductivity

Measured by Laser Flash Method

DUPIC < UO_2

$$K_{D0} = \frac{1}{A+BT} + \frac{C}{T^2}\exp\left(-\frac{D}{T}\right)$$

A=0.0944, B=2.027×10^{-4},
C=4.715×10^{9}, D=16,361

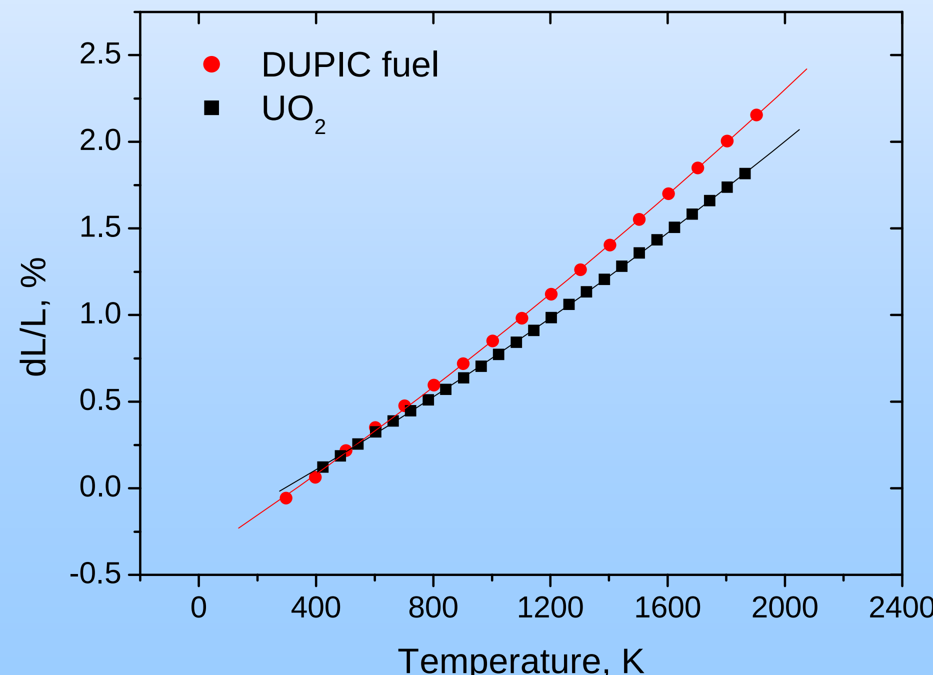


● Thermal Expansion

Measured by Dilatometer (DIL 402C)

DUPIC > UO_2

$$\Delta L / L_0, \% = -0.3854 + 1.130 \times 10^{-3}\,T + 1.095 \times 10^{-7}\,T^2$$



Mechanical Properties

- **Creep Rate**

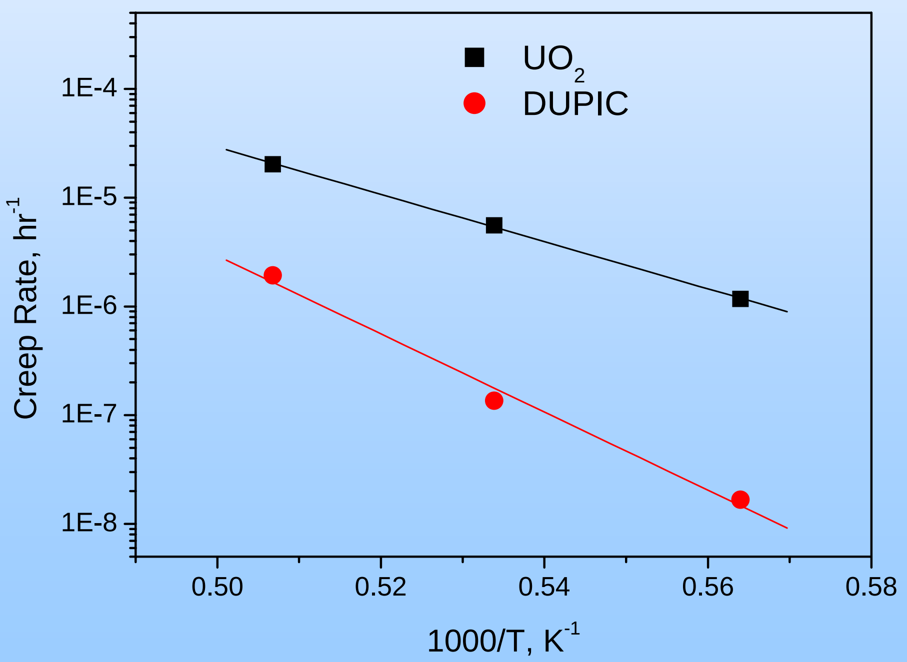
  Measured by Compressive Creep Test

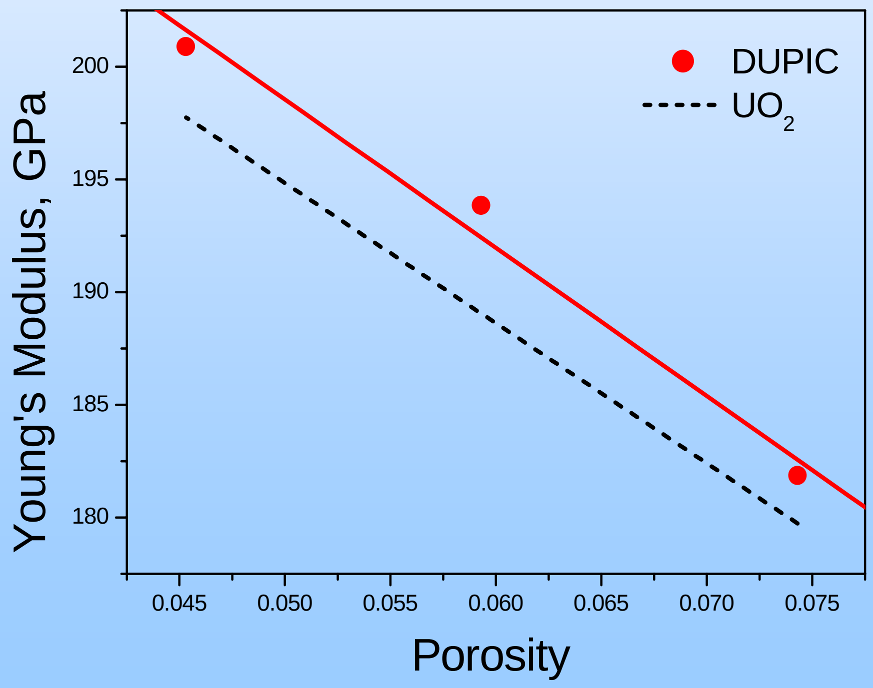
  DUPIC < UO_2

- **Young's Modulus**

  Measured by Resonance Ultrasound Spectroscopy

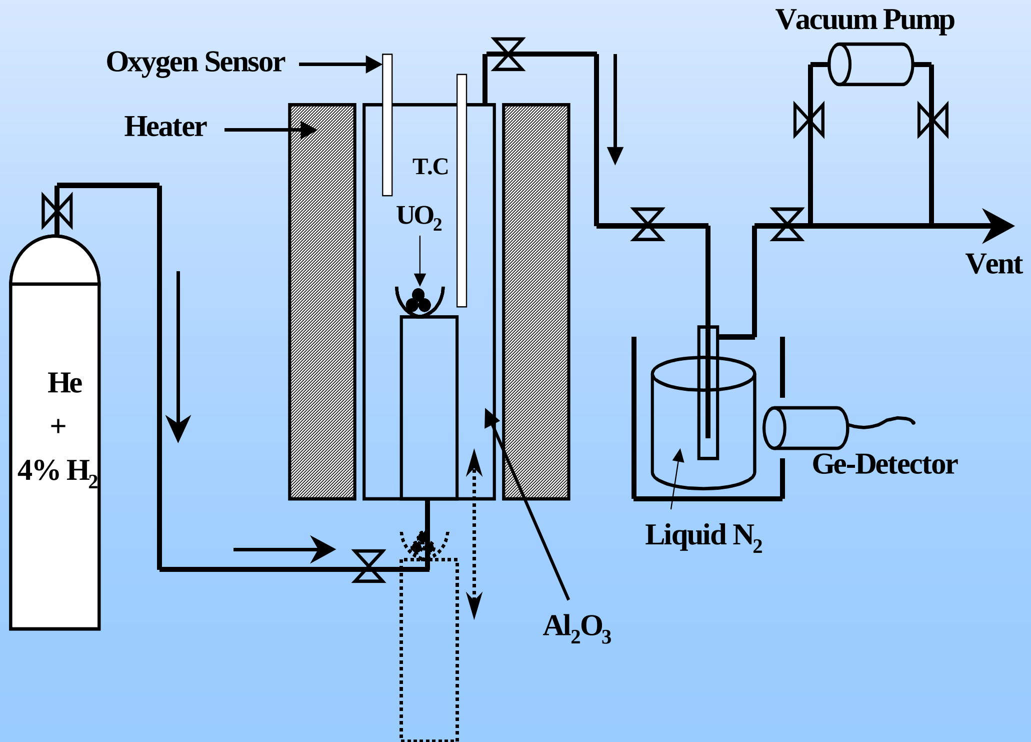
  DUPIC > UO_2

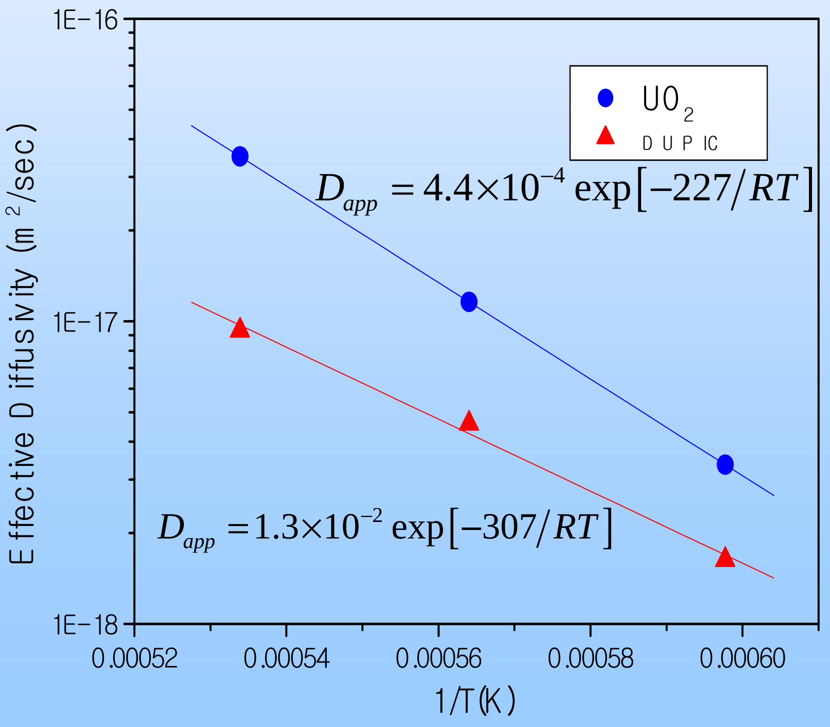




Fission Gas Diffusion Property

- Trace Irradiation in the HANARO reactor
  - Post-irradiation annealing : 1400 ~1600°C
  - Diffusion coefficient of Xe-133 : UO_2 > DUPIC
  - Cation vacancy concentration change by fission products (trivalent)

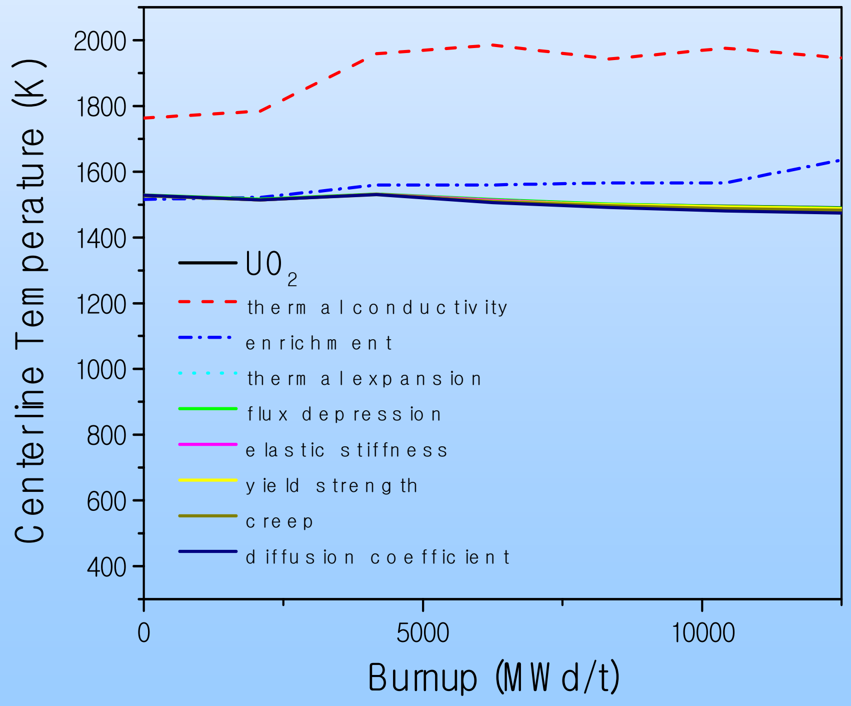




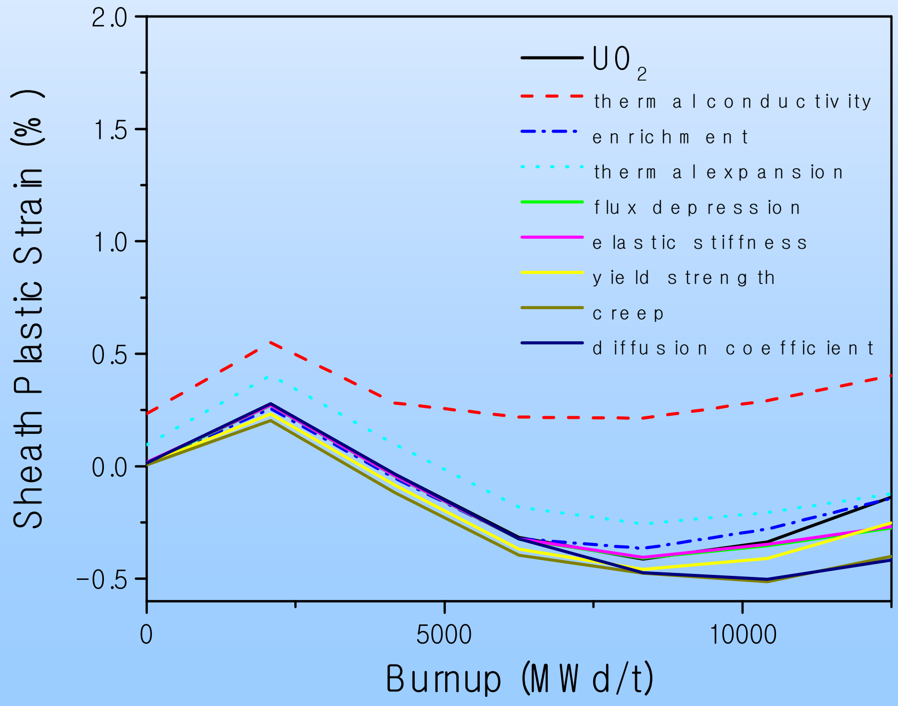
Basic Sensitivity Analysis

- Fuel Performance Code: ELESTRES (AECL)
- Modifying ELESTRES' material models for the DUPIC

Centerline Temperature

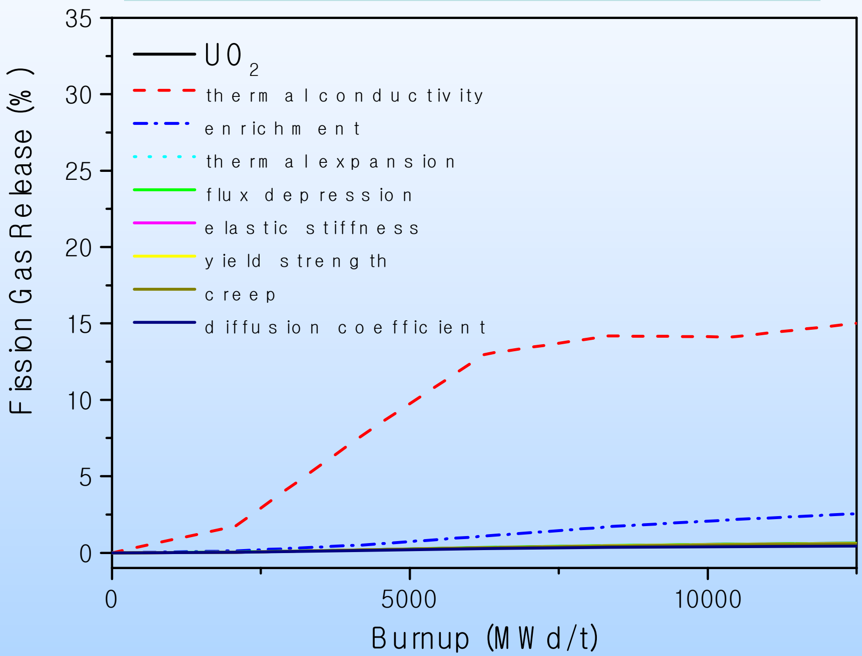


Sheath Plastic Strain

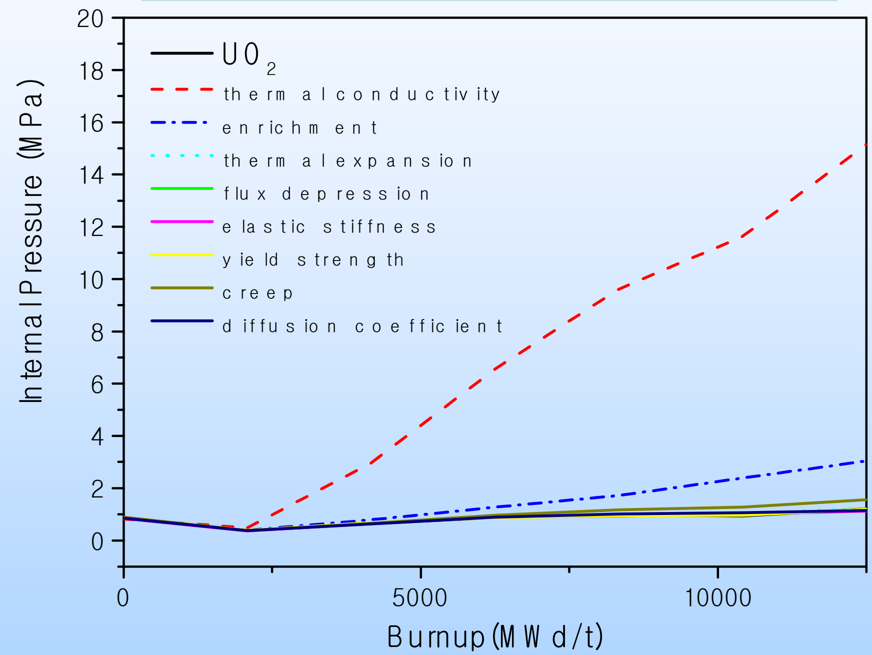


Basic Sensitivity Analysis

Fission Gas Release



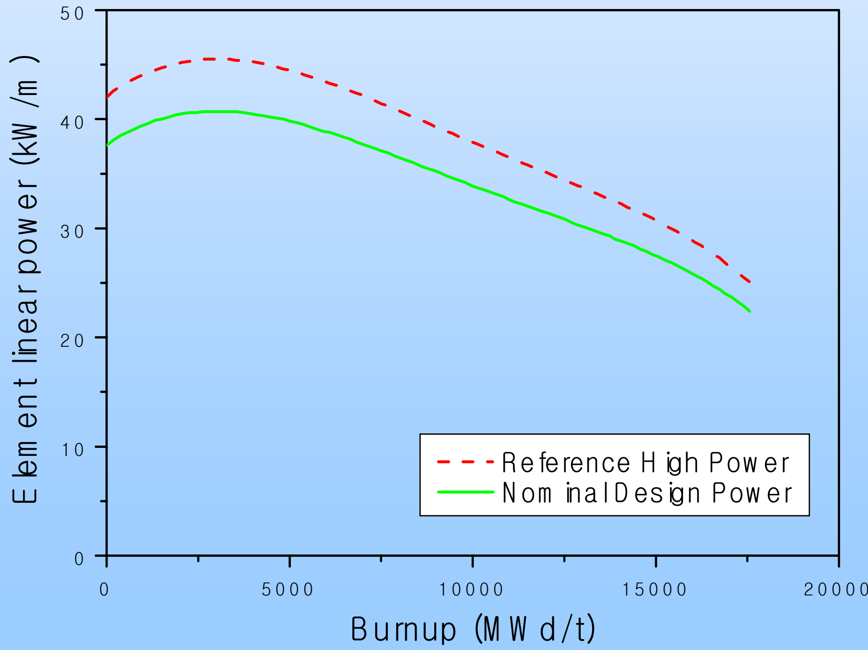
Internal Gas Pressure

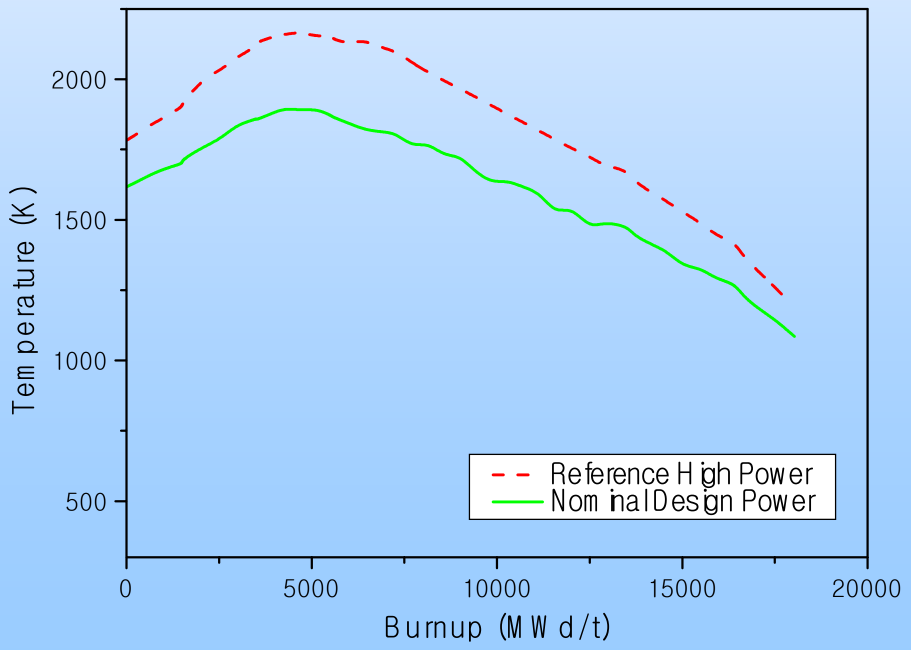


- The change of thermal conductivity influences most strongly on fuel performance of the DUPIC fuel.

Performance Analysis

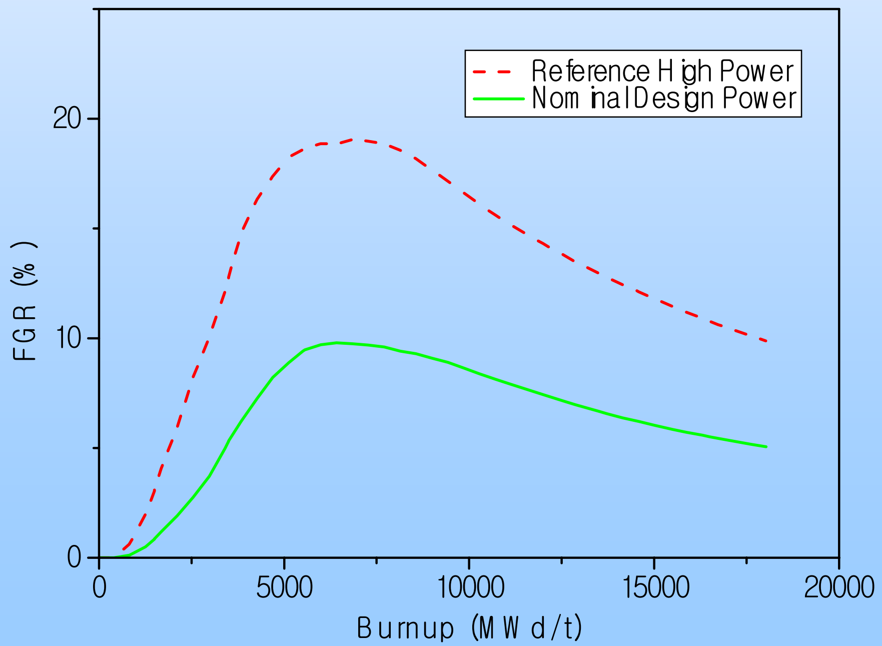
- Performance Evaluation by Calculated Power Envelop
  - Reference High Power Envelop
  - Nominal Design Power Envelop
- Higher Temperature than UO_2 but less than melting temp.
  - ~3000 K

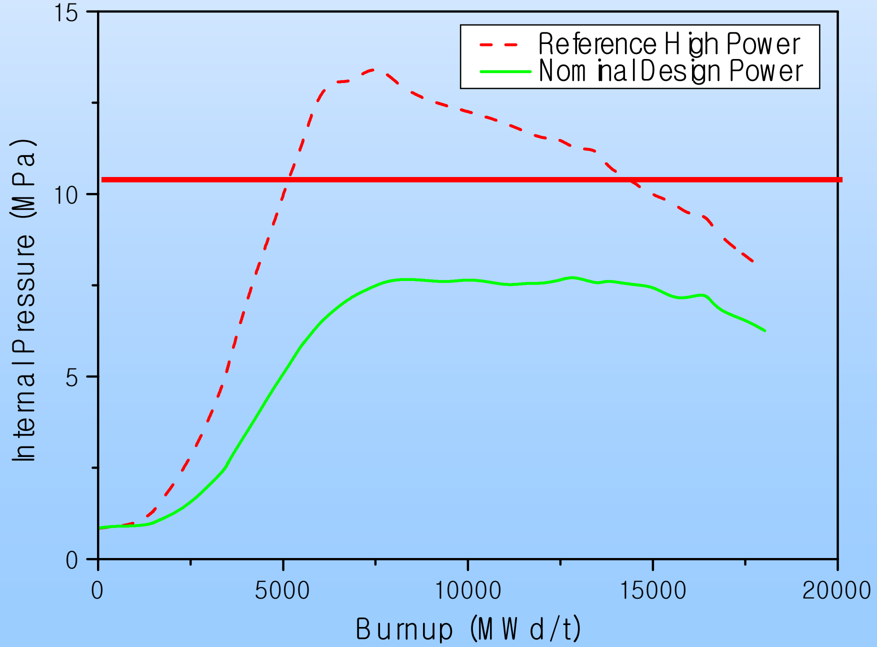




Performance Analysis

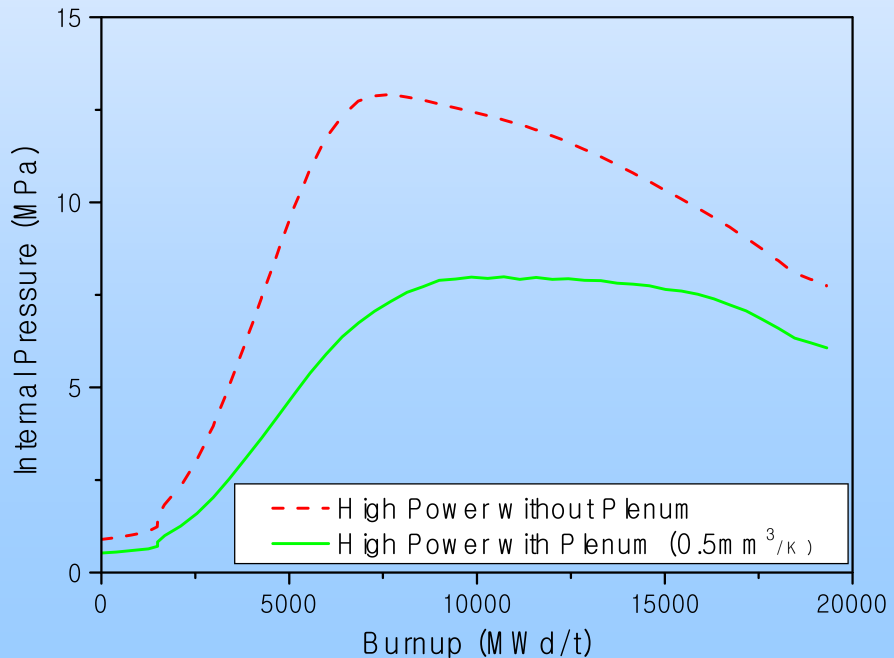
- Higher fission gas release:
  - Due to lower thermal conductivity and resulting higher temperature
  - Results in higher internal gas pressure than coolant pressure
  - Gap open and outward creep of clad
- Internal gas pressure should be reduced.

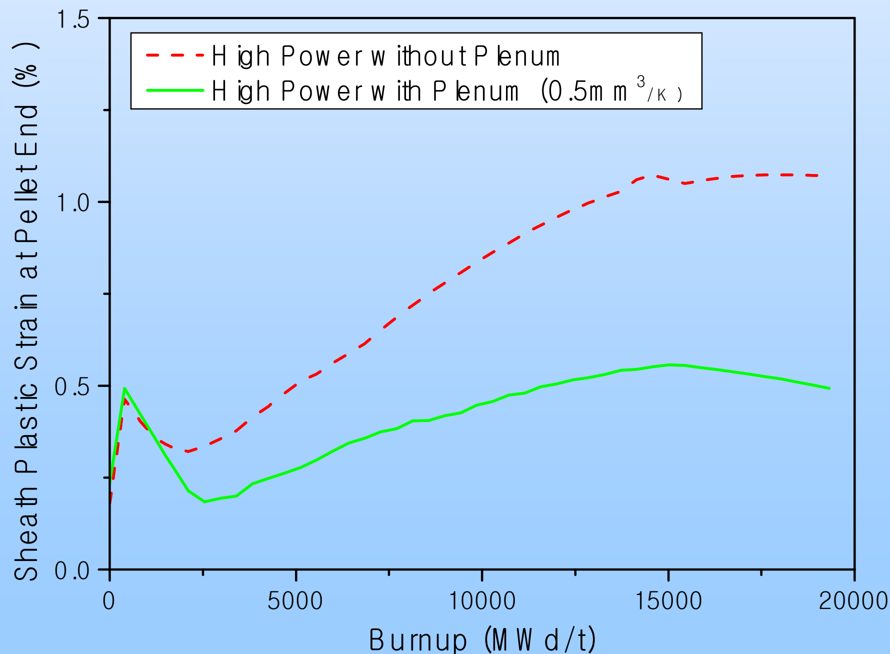




Internal Gas Pressure

- One way to reduce the internal gas pressure is to give more volume for fission gases.
  - Plenum
  - Radial gap
  - Axial gap





Orthogonal Array Design

- Assignment of the levels to the factors

level	gap clearance (μm)	pellet density (g/cm³)	grain size (μm)
1	40	10.30	5
2	80	10.45	15
3	120	10.60	25

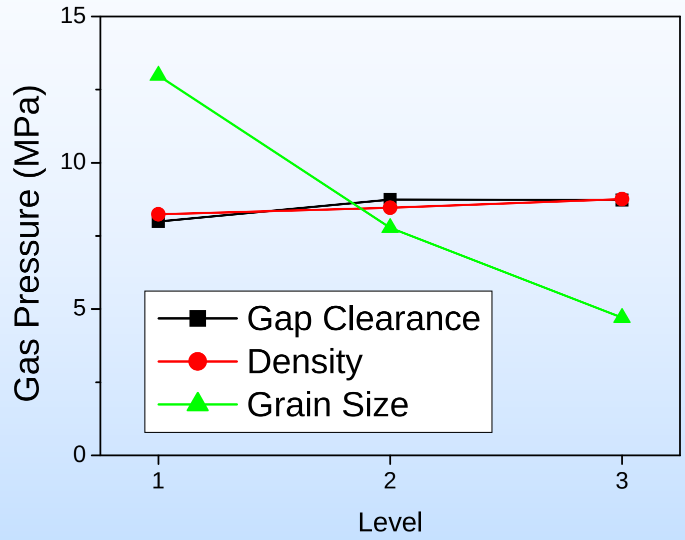
* within manufacturing spec.

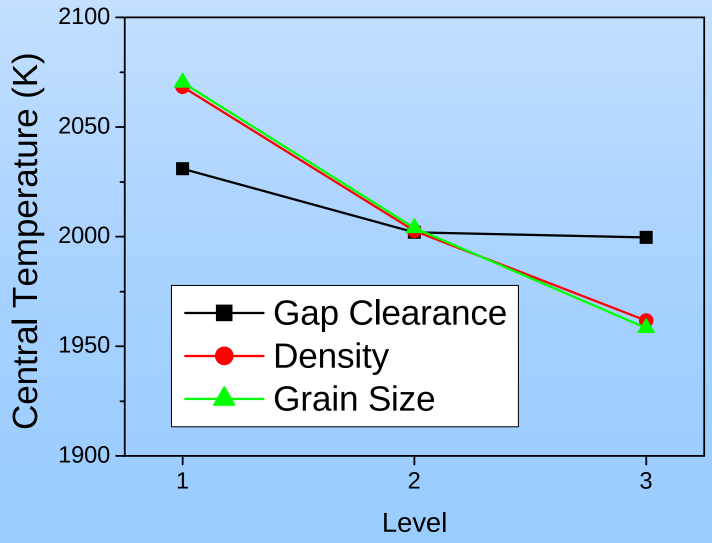
- 3 level OAD Table, $L_9(3^4)$

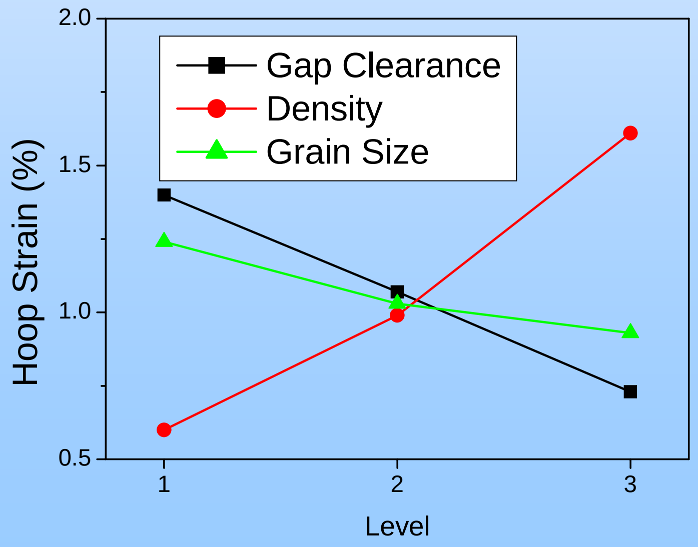
Run	factors			
	gap clearance	pellet density	error	grain size
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Level-average Response Graphs

- Safety Limiting Parameters
  - centerline temperature
  - Internal gas pressure
  - hoop strain
- gap & grain ↑, density ↓



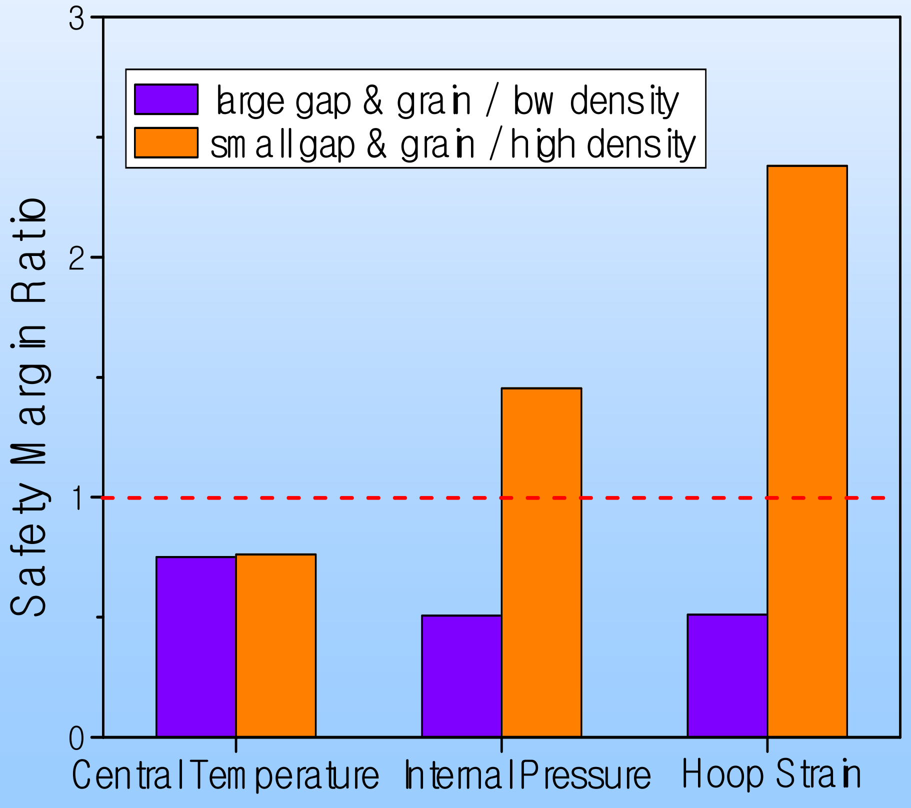




Safety Margin

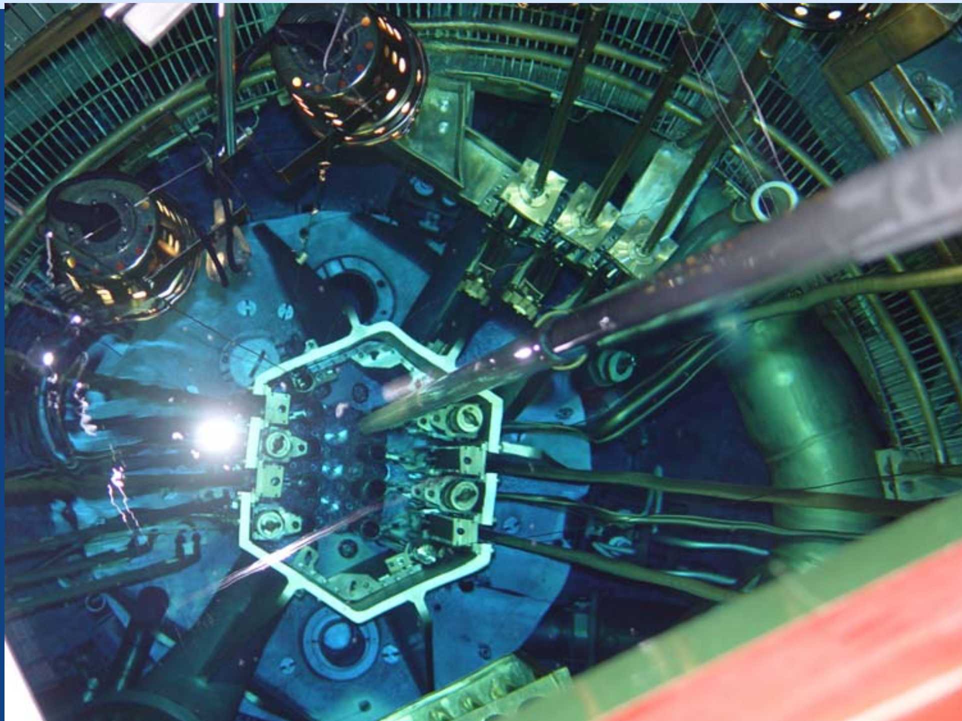
- Comparison of Fabrication Factors' Set
  - Large gap, large grain, low density
  - Small gap, small grain, high density

- Safety Margin Standards
  - Central temperature: melting temp.
  - Internal pressure: coolant pressure
  - Hoop strain: 1%



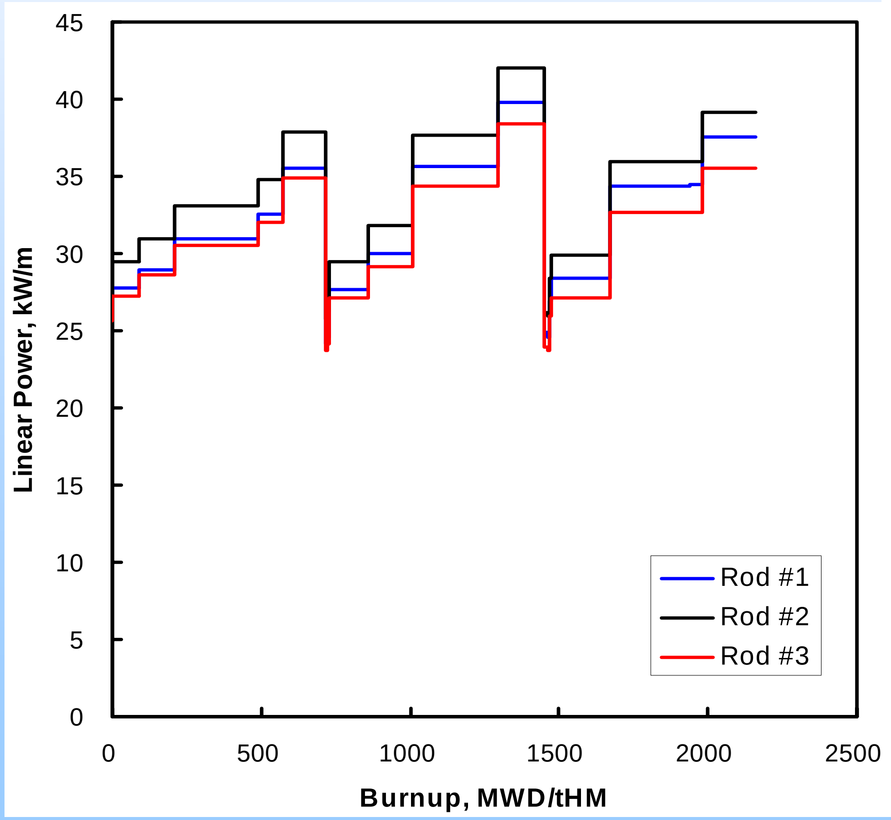
Irradiation Test of DUPIC Fuel

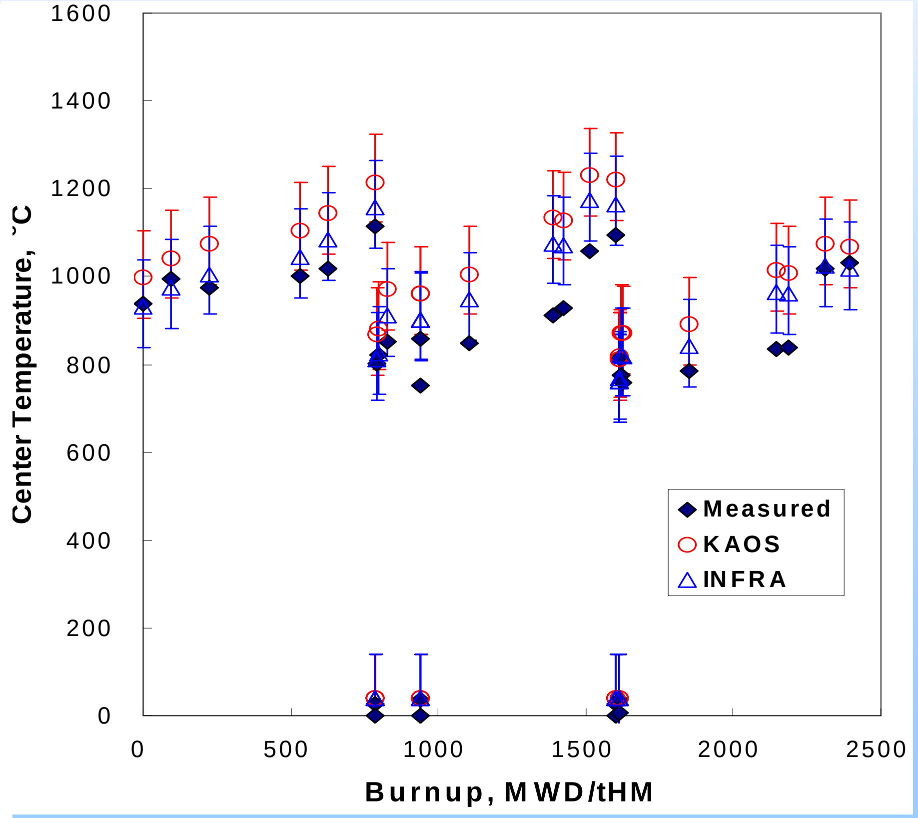
- Irradiation Test in HANARO Research Reactor (KAERI)
  - Spent Fuel: discharged from Gori-1 LWR at 27,300 MWd/tU
  - U-235: 1.06%, Pu: 0.51%
  - Linear power: ~38 kW/m
  - Discharge burnup : ~6,700 MWd/t
  - Instrumentation : temp. & SPND



Measured and Calculated Temperature

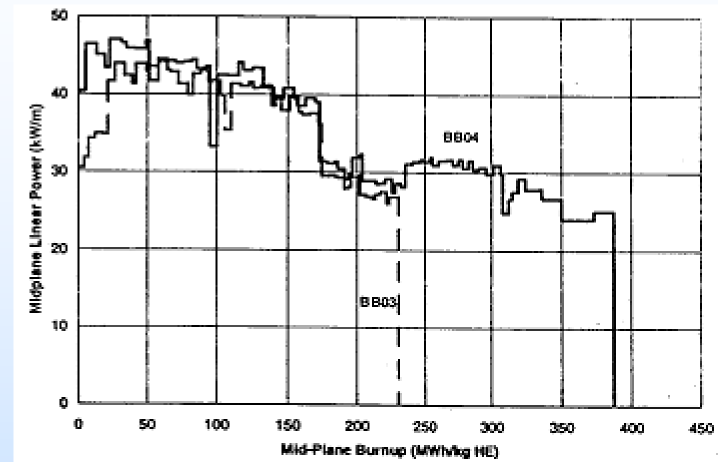
- Good agreement between measured centerline temperature and estimated one calculated by performance evaluation codes



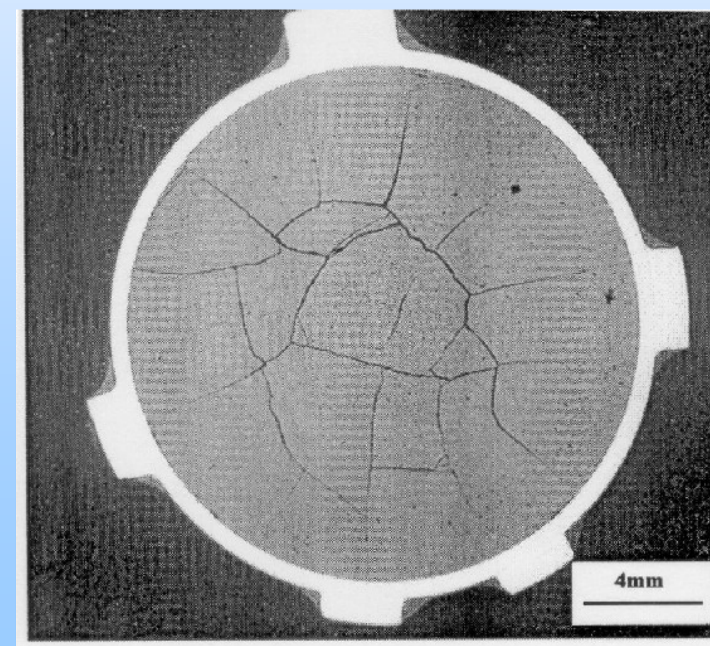


International Collaboration

- KOREA-CANADA-US-IAEA
  - 3 DUPIC Fuel Rod Fabrication (AECL)
  - Irradiation Test in the NRU Reactor
  - BB03: 2000. Sep. (10 MWd/kgHM)
  - BB04: 2001. Dec. (16 MWd/kgHM)
  - BB02: 2003. Dec. (21 MWd/kgHM)



Performance Para.	BB03	BB04
Midplane Burnup	10 MWd/kgHM	16 MWd/kgHM
Max. Power	~49 kW/m	~50 kW/m
Max. Ridge Height	0.021 mm	0.029 mm
Residual Sheath Strain (Pellet Interface)	0.2 % to 0.3 %	0.2 % to 0.6 %
Gas Volume	12.6 ml at STP	16.0 ml at STP



Conclusions

- The material properties of the DUPIC fuel pellet were measured to be used in the fuel performance code for the DUPIC fuel.

- The fuel performance of the DUPIC fuel shows that the DUPIC fuel requires adjustments of fabrication parameters to guarantee safety margin during the in-reactor operation.

- The irradiated DUPIC fuel shows good performance in agreement with estimation by performance evaluation codes using material properties for the DUPIC fuel.