NFK-MN-0908016

Technical Meeting on
'Advanced Fuel Pellet Materials and Fuel Rod Designs for Water Cooled Reactors'

Current Status of a Development Project on Erbia Credit Super High Burnup Fuel

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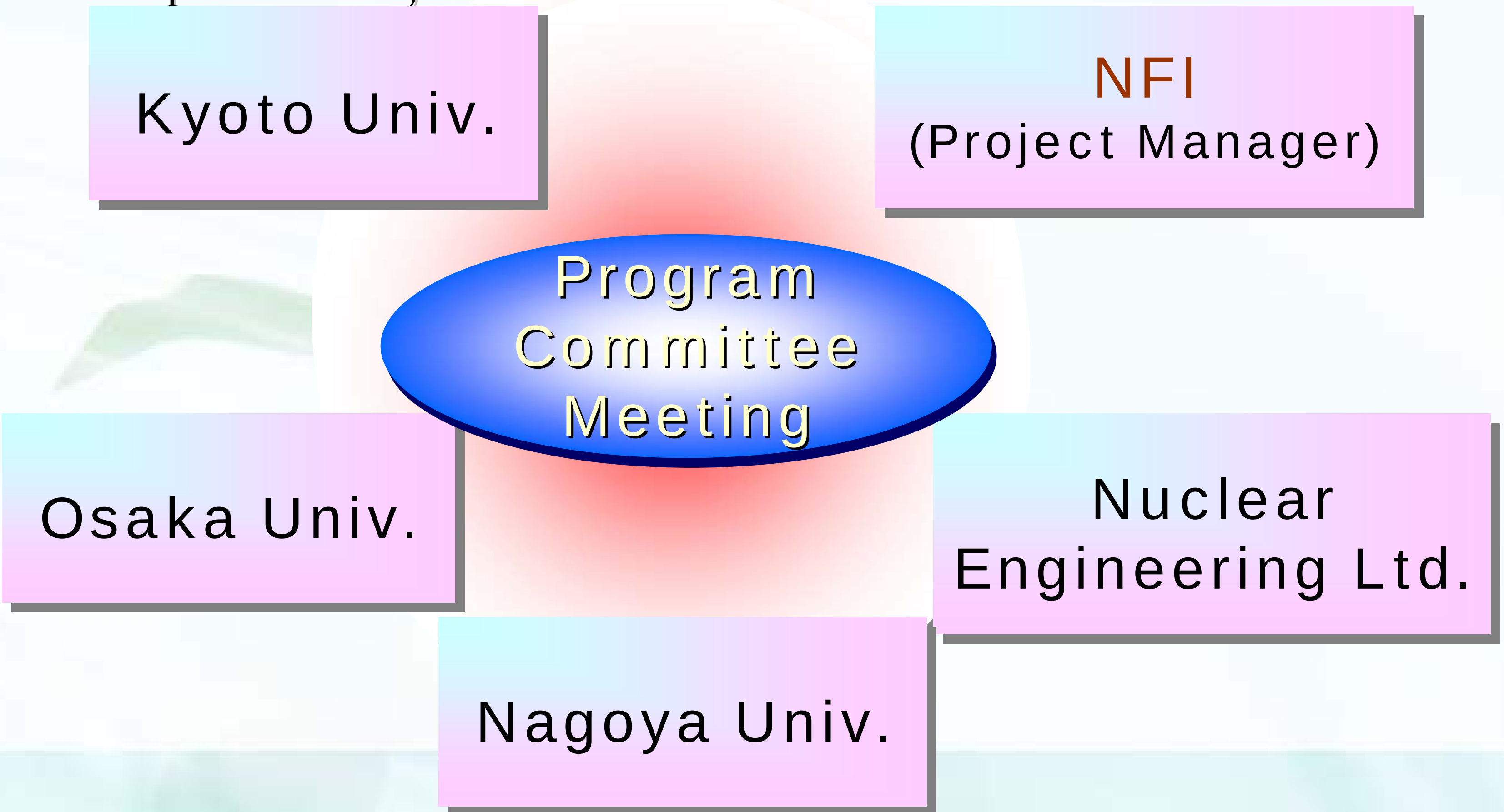
Nuclear Fuel Industries, Ltd.

23-26 November 2009 Villigen, Switzerland

Overview of the Project

- **Development Project**
  - Funded by Japanese government (METI) under framework of "Innovative and Viable Nuclear Energy Technology" (IVNET) Development Project



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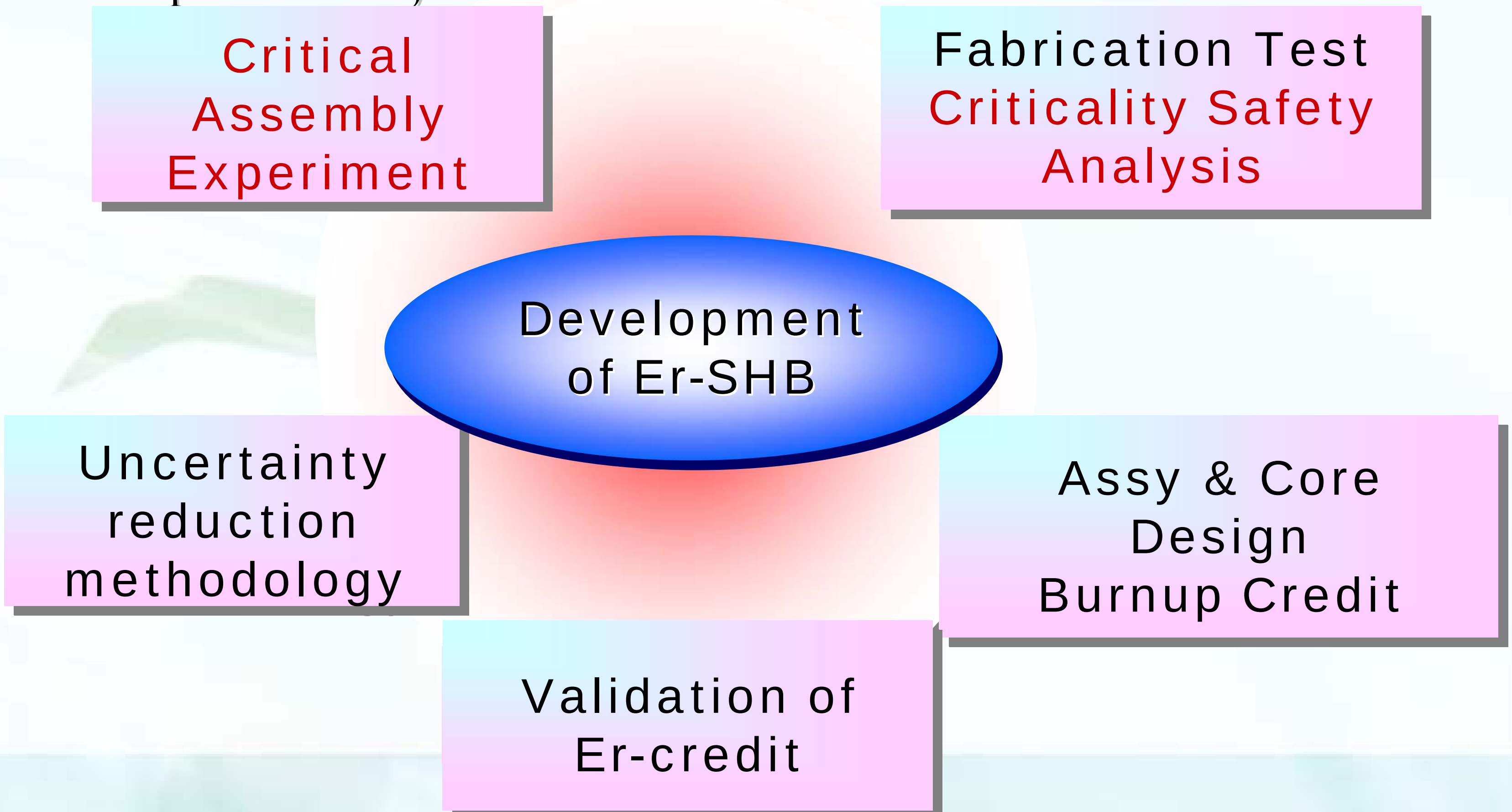


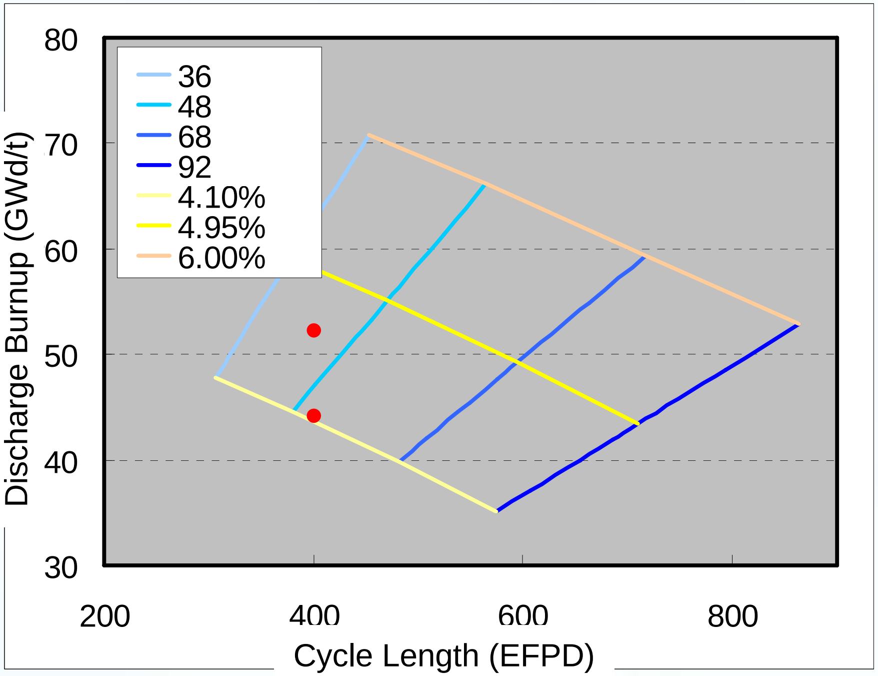
In this presentation…

- 1. Concept of Er-SHB fuel
- 2. Critical Assembly Experiments
- 3. Criticality Safety Analyses
- 4. Summary

1. Concept of Er-SHB fuel

Background

- **General needs**
  - In order to realize high burnup, longer cycle, higher power uprate, there is no doubt high enriched uranium fuel is one of the most reasonable option.



  - Actually in previous ANFM-III, some papers showed optimal enrichment will be 6-7wt% in PWR.

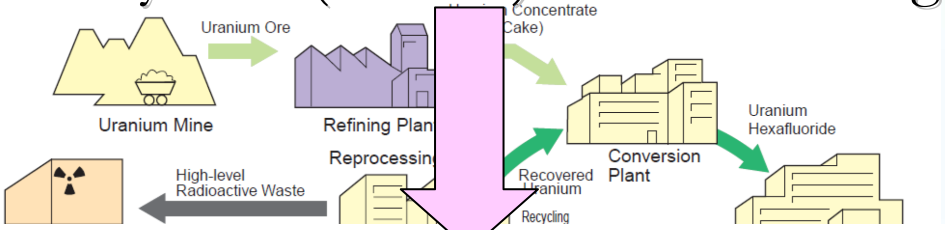
Background (2)

- **However, "The 5wt% Enrichment Barrier", which was mentioned in 1998, still remains.**
- **Main causes of this Barrier are;**
  - 1)Lack of critical experiments in the range of 5-10wt%
  - 2)The impact of plant safety of the fact that a "criticality accident" can occur above 5wt%.
  - 3)The impact of reduced subcritical limits
- **These matters prevent the merit of high enrichment**

How to Solve 5wt% Barrier

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

- **Er-Credit concept**
  - Add low content of Erbia (Er_2O_3) into all >5wt% UO_2 powder just after the re-conversion process
  - Enrichment of the fuel is still >5wt%, but its criticality becomes equivalent to <5wt% fuel
  - Fuel can be treated in the same manner of the conventional criticality safety limit (<5wt%) in the following processes

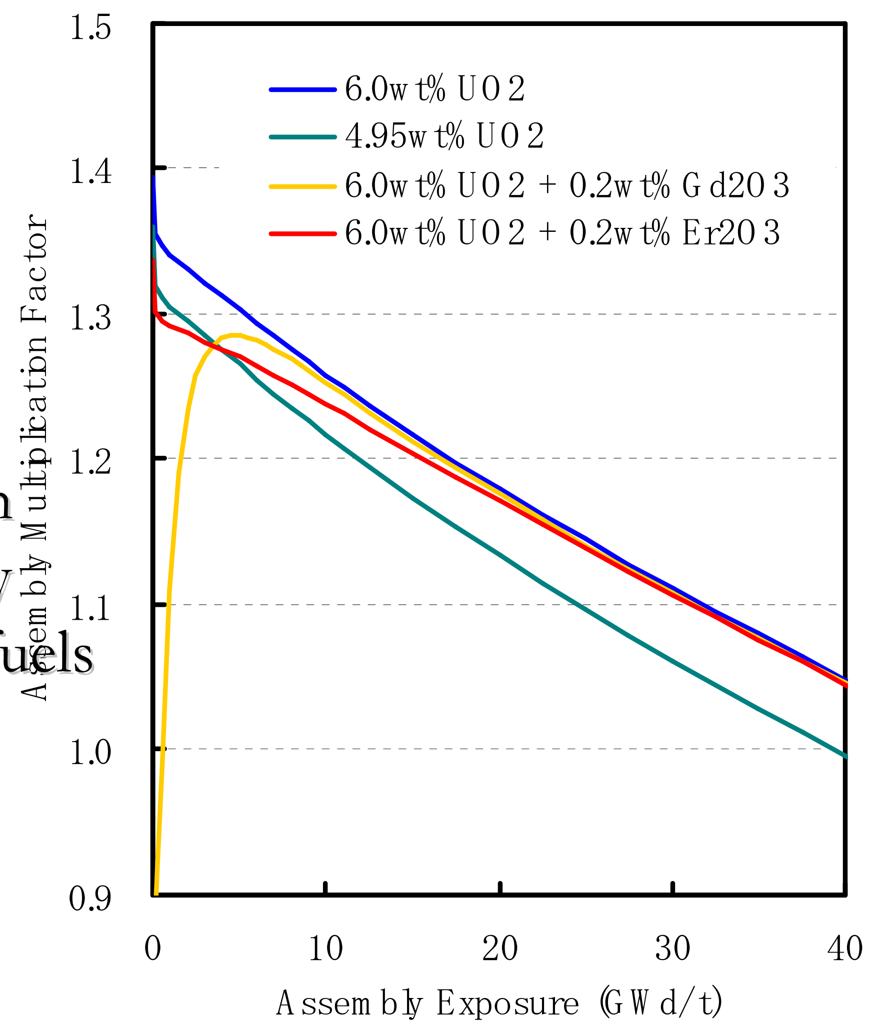


  - **Major modifications of fuel cycle infrastructure (caused by reactivity) will be eliminated**
  - **Efficiency of transport, storage, fabrication etc. will be improved**

Answer of FAQ (1)

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

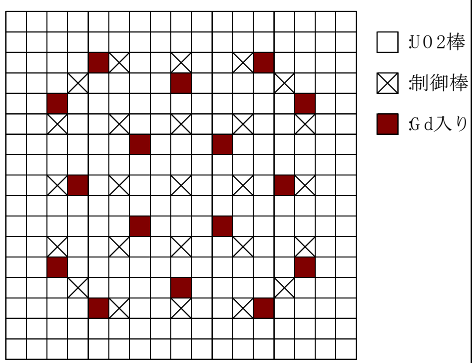
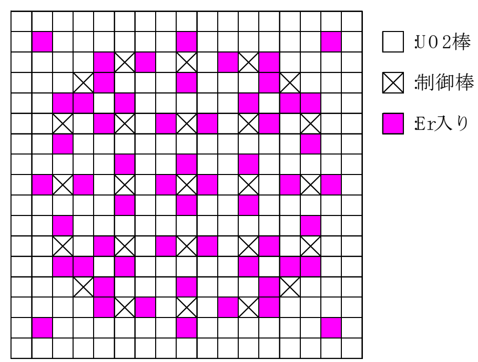
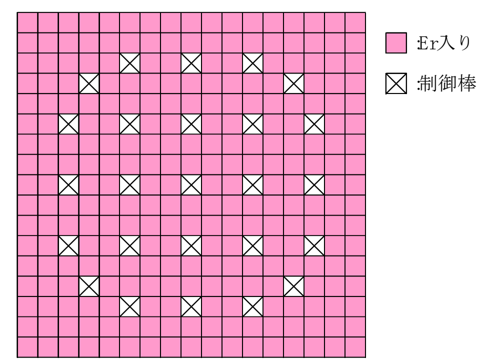
- **Why Erbia?**
  - Gd bearing fuel:
    - Reactivity change is too steep
    - Reactivity at BOL is too low to reach criticality
  - Er bearing fuel:
    - Reactivity change is smooth
    - Reactivity at BOL is slightly lower than that of current fuels (<5wt%)



Answer of FAQ (2)

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

What differs?

	Conventional Gd Fuel (Major LWR)	Conventional Er Fuel (CE-type, RBMK)	Er-SHB Fuel
Object	Improve Core property	Improve Core property	Whole Fuel Cycle
Effect	Suppress Power Peaking Negative Moderator Temp. Coef.	Suppress Power Peaking Negative Moderator Temp. Coef.	Suppress Power Peaking Negative Moderator Temp. Coef. ＋Criticality Safety
U Enr.	No greater than 5wt%	No greater than 5wt%	Greater than 5wt%
Poison Cont.	4～10wt%	2～3wt%	0.4～1wt%
Example of Assembly Layout			

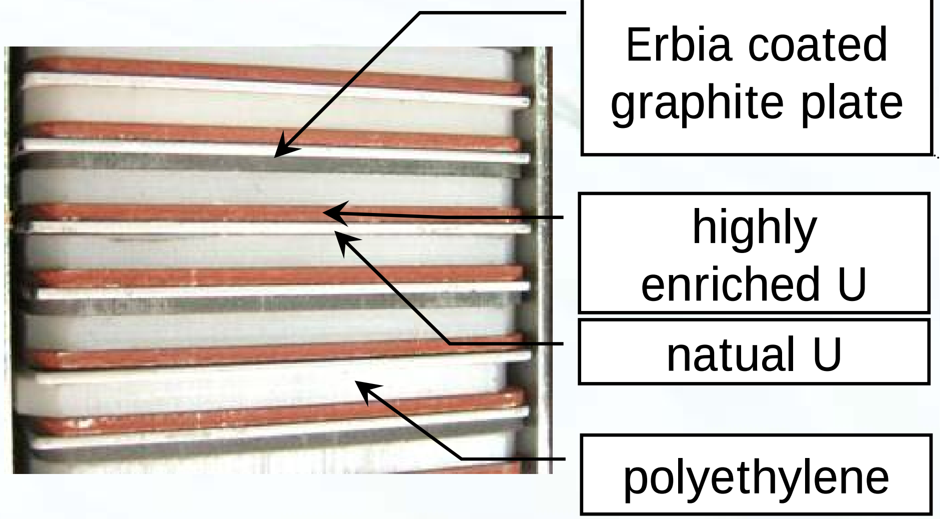
2. Critical Assembly Experiments

Kyoto University Critical Assembly

Outline of KUCA (1)

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

- Plate type fuel critical assembly
- Combination of material plates, various conditions of H/U ratio, average U235 enrichment and Er content can be simulated



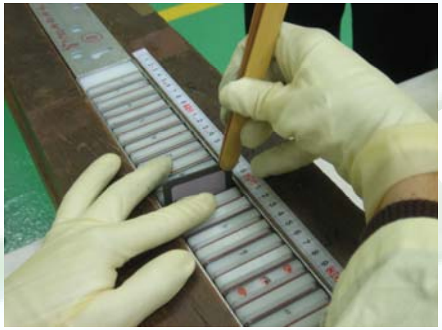
~0.3 g Er_2O_3 is coated on the engraved dish

Outline of KUCA (2)

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

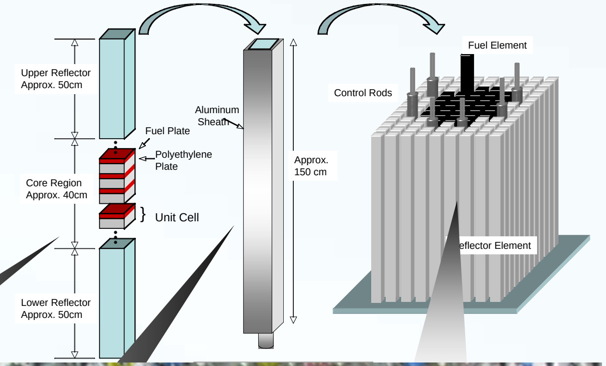
Fully Er-loaded Core at KUCA

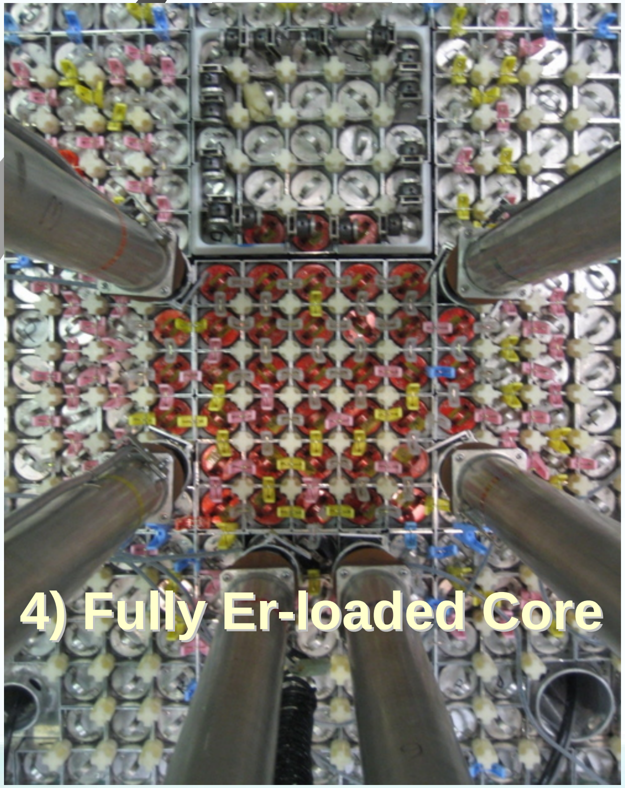
1) Erbia coated graphite plate (x1000)



2) Arranging plates into fuel elements

3) Loading fuel element to the core

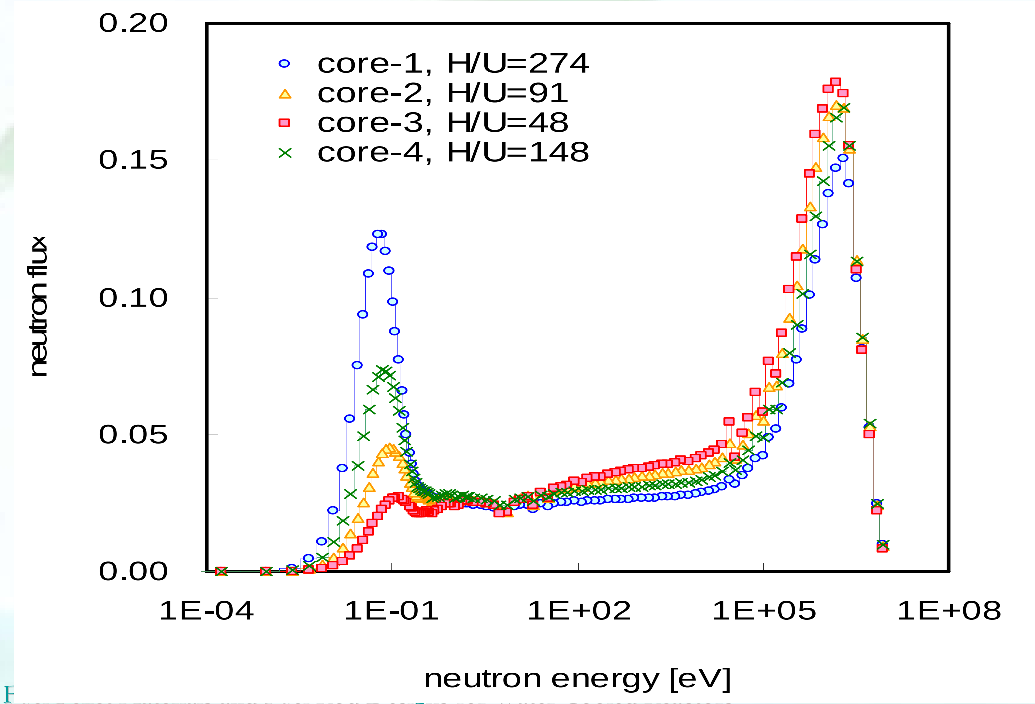




Series of Er loaded cores

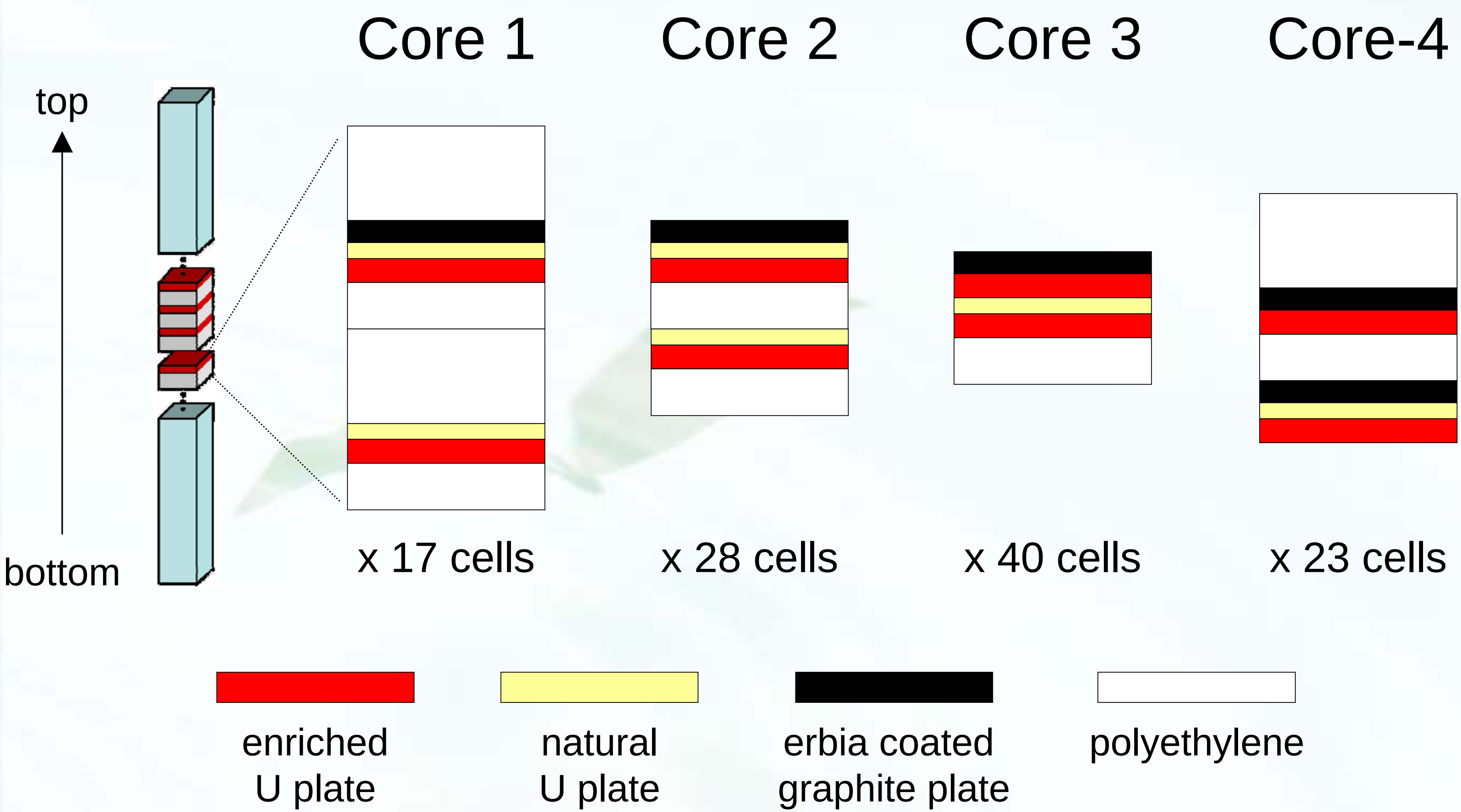
"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

Core	average U-235 [wt%]	H/U-235	Er content [wt%]
1	5.4	274	0.3
2	5.4	91	0.3
3	9.6	48	0.6
4	9.6	148	1.12



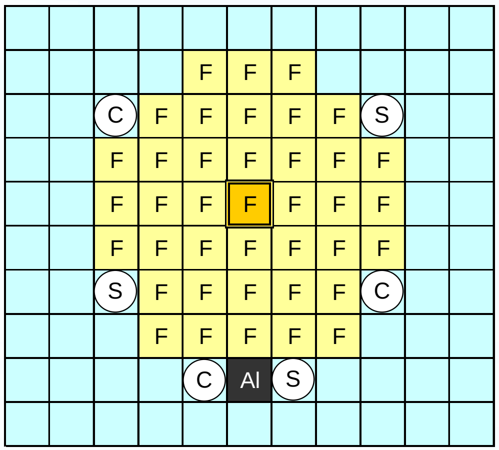
Unit fuel cell

"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

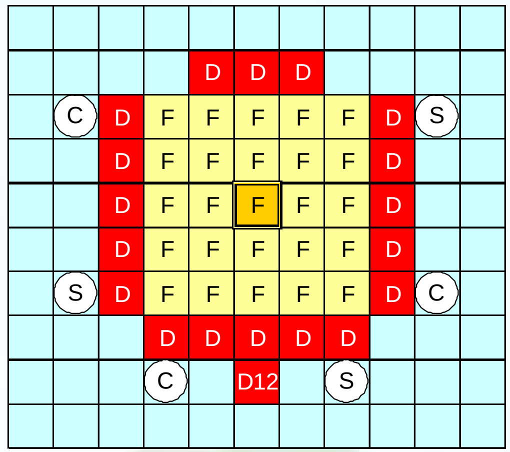


Core configuration

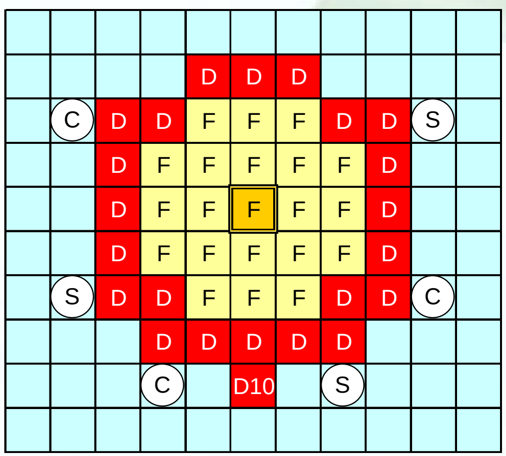
“The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel”



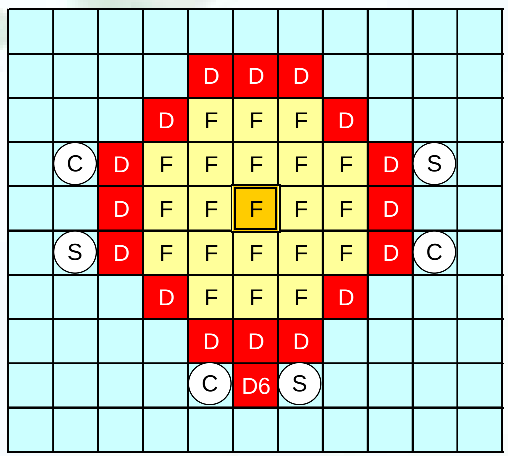
Core 1



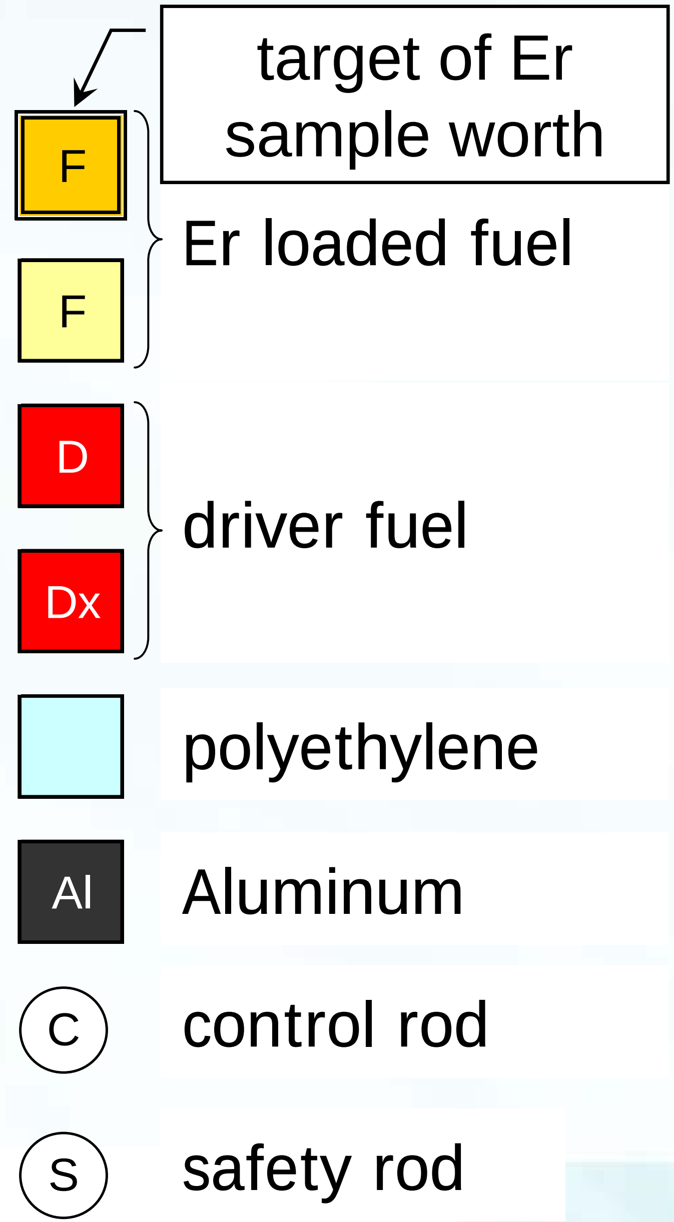
Core 2



Core 3



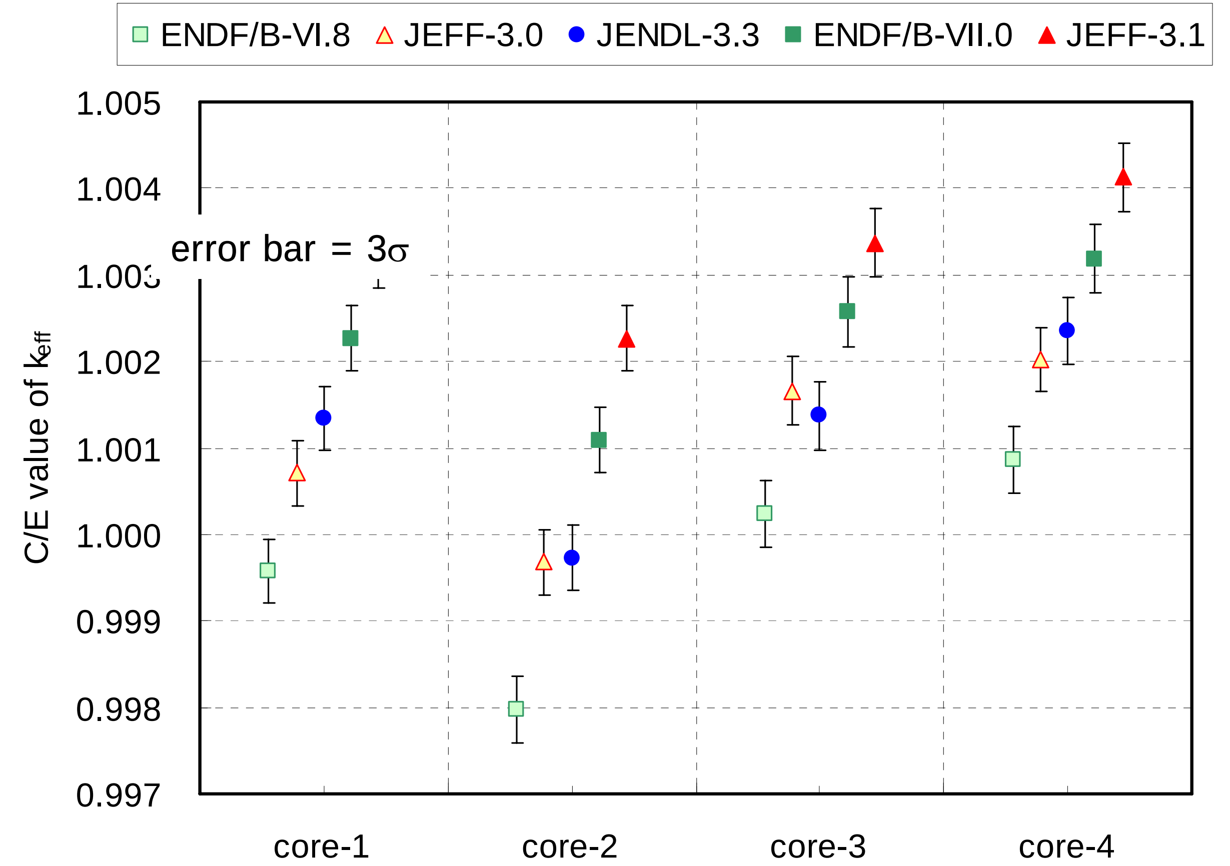
Core-4



Numerical Analysis

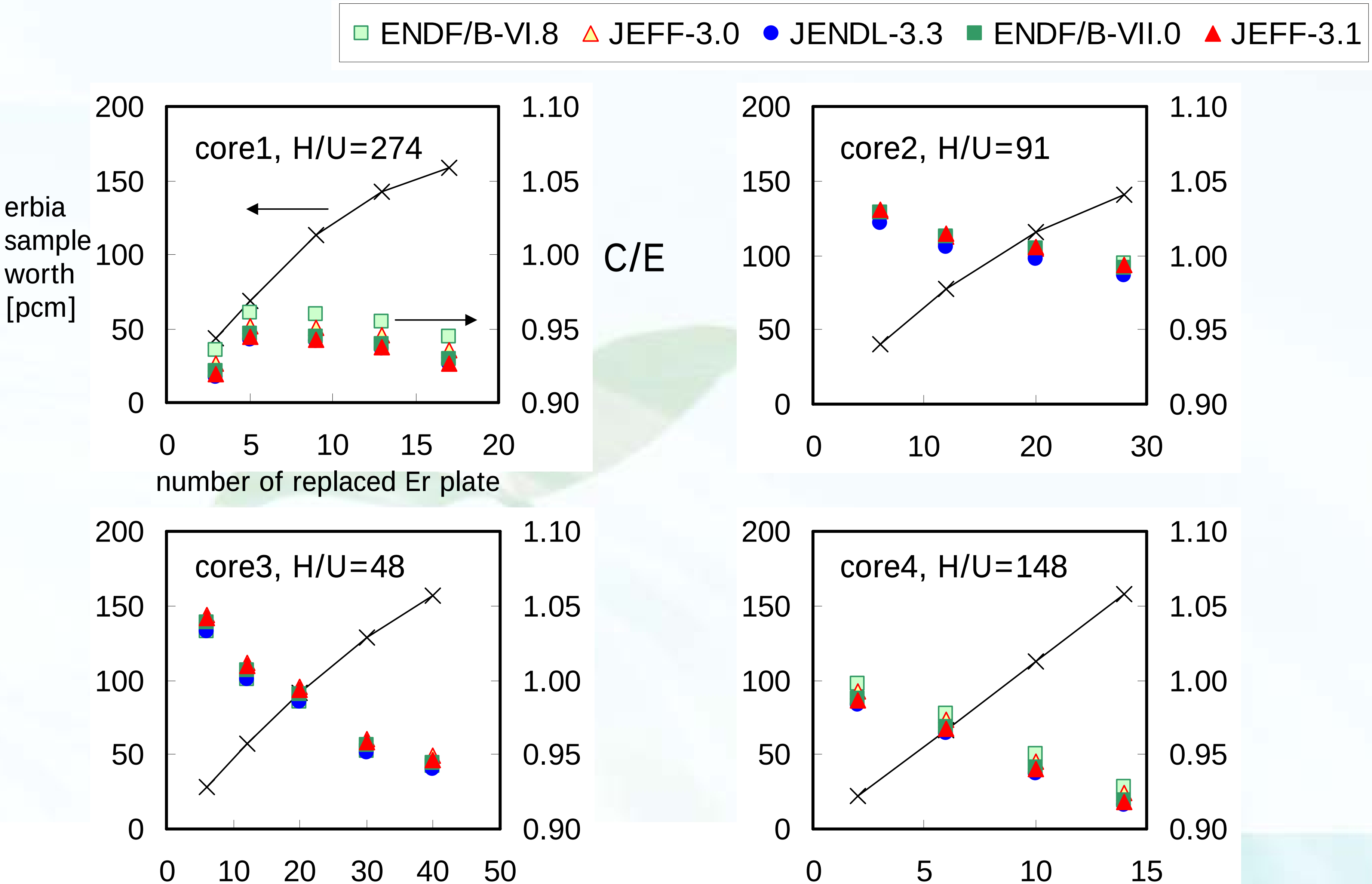
- **Criticality**
  - MVP
    - Continuous energy Monte Carlo method
    - 50M histories
    - JENDL-3.3, ENDF/B-VI.8 & VII.0, JEFF-3.0 & 3.1
- **Erbia sample worth**
  - SRAC2006/CITATON
    - Multigroup 3-D XYZ diffusion method
    - perturbation calculation
    - JENDL-3.3, ENDF/B-VI.8 & VII.0, JEFF-3.0 & 3.1
    - Macroscopic cross section of unit fuel cell is spatially homogenized, not heterogeneous

Criticality (Monte Carlo)



Core1	Core2	Core3	Core4
5.4wt%	5.4wt%	9.6wt%	9.6wt%
0.3wt%	0.3wt%	0.6wt%	1.12wt%
274	91	48	148

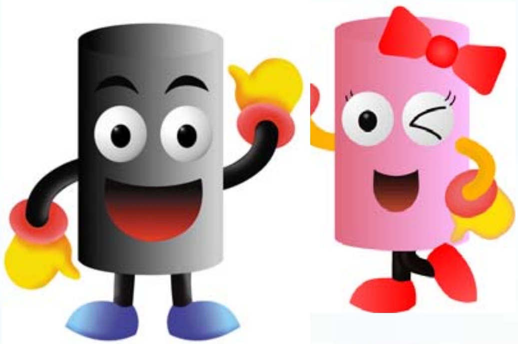
Er sample worth (Diffusion)

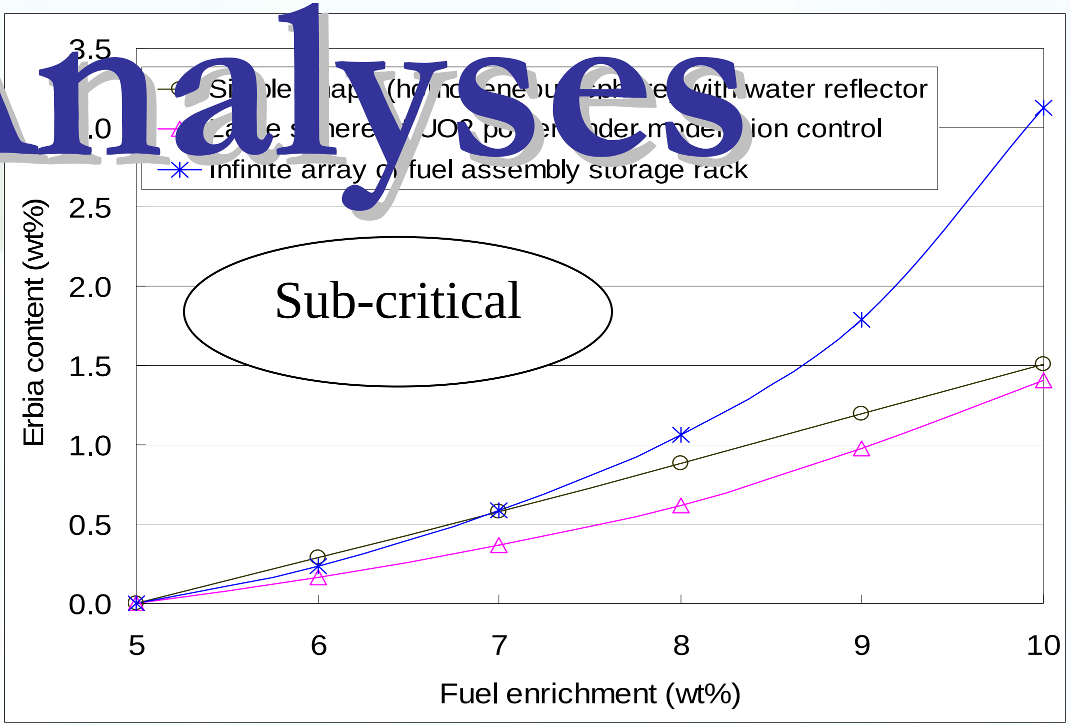


Summary of CA Exp.

- A series of fully Er-loaded core experiments are performed.
- These experiments appropriately cover the features of Er-SHB fuel.
- The comparison between measurement and analysis shows good agreement.
- These experimental data is efficient to validate neutronic analysis codes, which is used for criticality safety analysis of Er-SHB fuel.

3. Criticality Safety Analyses





ECOS diagram

Analyses Condition

- **Code and library**
  - KENO V.a, and 44GroupNDF5 in Scale 5
- **Configurations**
  - Simple shapes
  - Large sphere with moisture control
  - Fuel assemblies in storage rack
- **Calculated Results**
  - Erbia content vs uranium enrichment is determined as the ECOS (Erbia COntent for Sub-criticality judgment) diagram

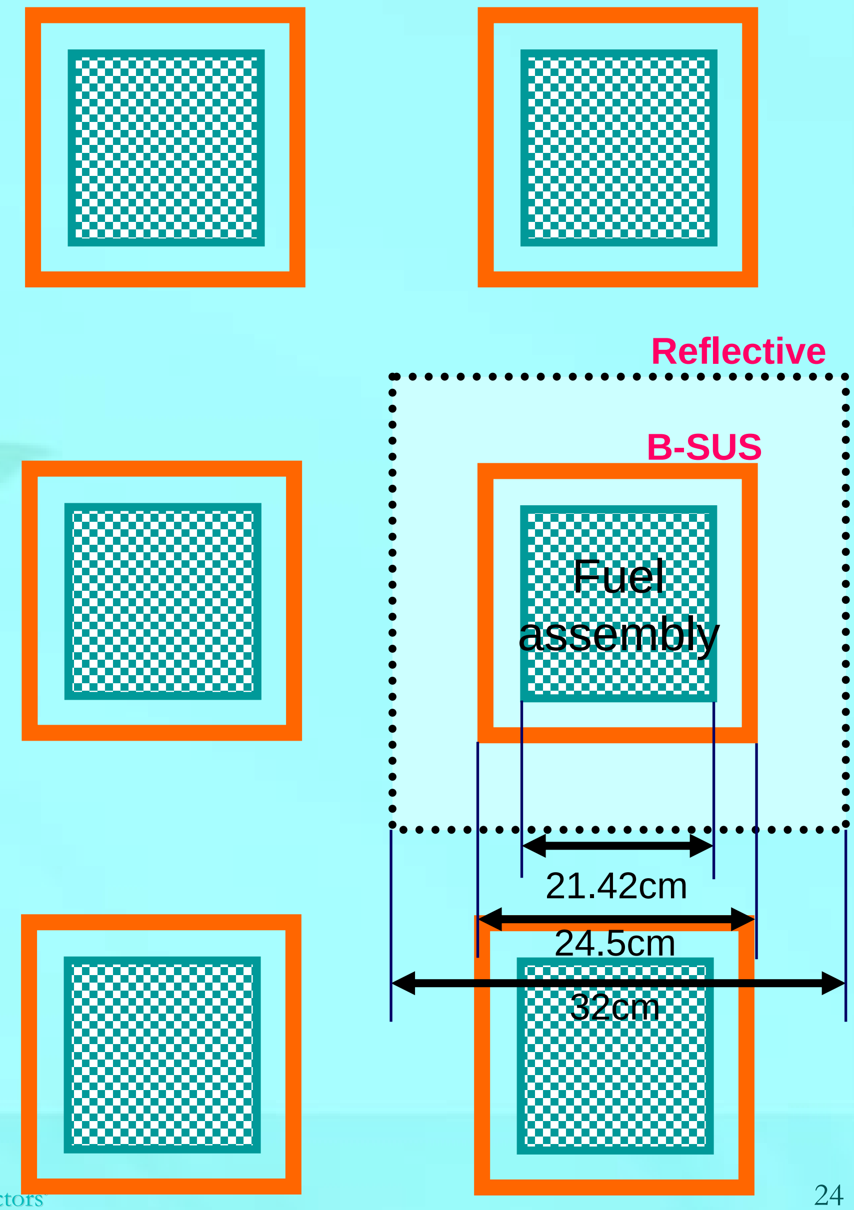
Configurations (1)

- **Simple shape**
  - 5wt%, w/o Erbia
    - Optimal condition is determined so that Keff equal to be subcriticality limit (=0.98)
  - >5wt%, w/ Erbia:
    - UO2/H2O ratio and Erbia content is surveyed to become same subcriticality (=0.98)
- **Large sphere with moisture control**
  - 5wt%, w/o Erbia:
    - Subcriticality is calculated in restricting condition
  - >5wt%, w/ Erbia:
    - Erbia content is surveyed to become same subcriticality

Configurations (2)

- **Fuel assemblies in storage rack**
  - Infinite repetition geometry of fuel storage rack
  - PWR 17x17 fuel assembly
  - Structural materials: B-SUS* surrounding fuels
  - Water density varied (0-100%)
  - 5wt%, w/o Erbia
    - Subcriticality is calculated in above condition
  - >5wt%, w/ Erbia
    - Erbia content is surveyed to become same subcriticality

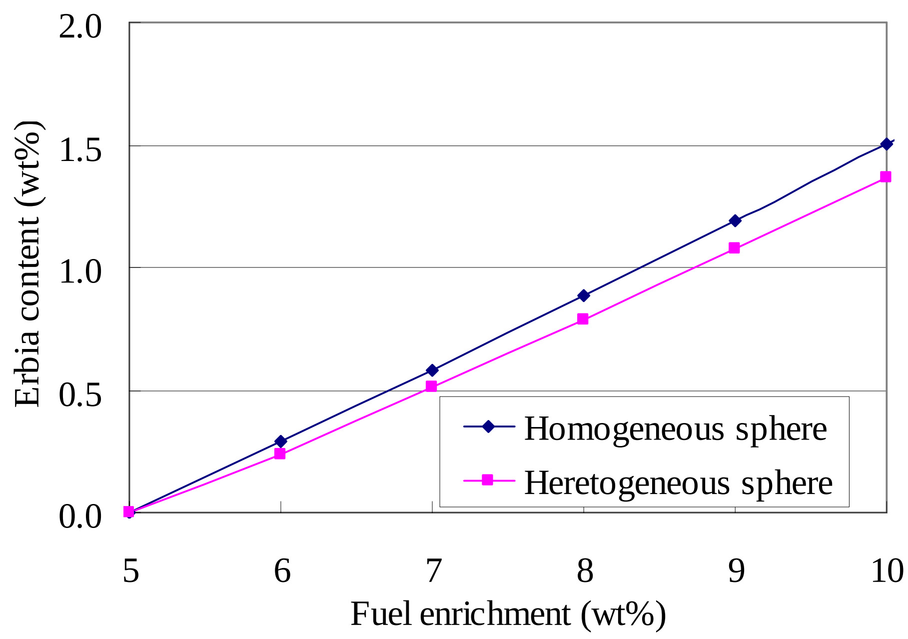
"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

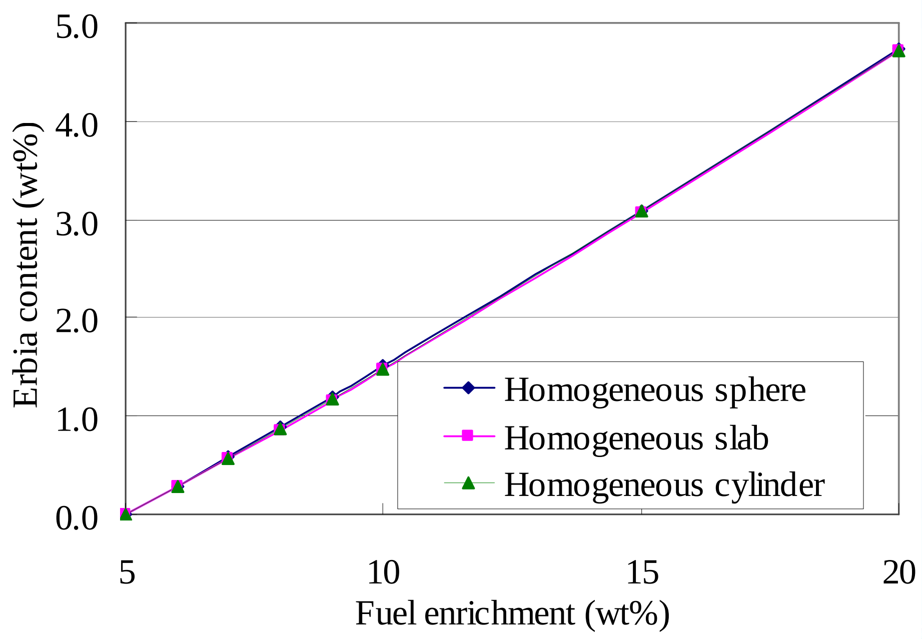


*B-SUS: Borated stainless steel
(Thickness of 1mm, 1wt% natural Boron)

Results (1)

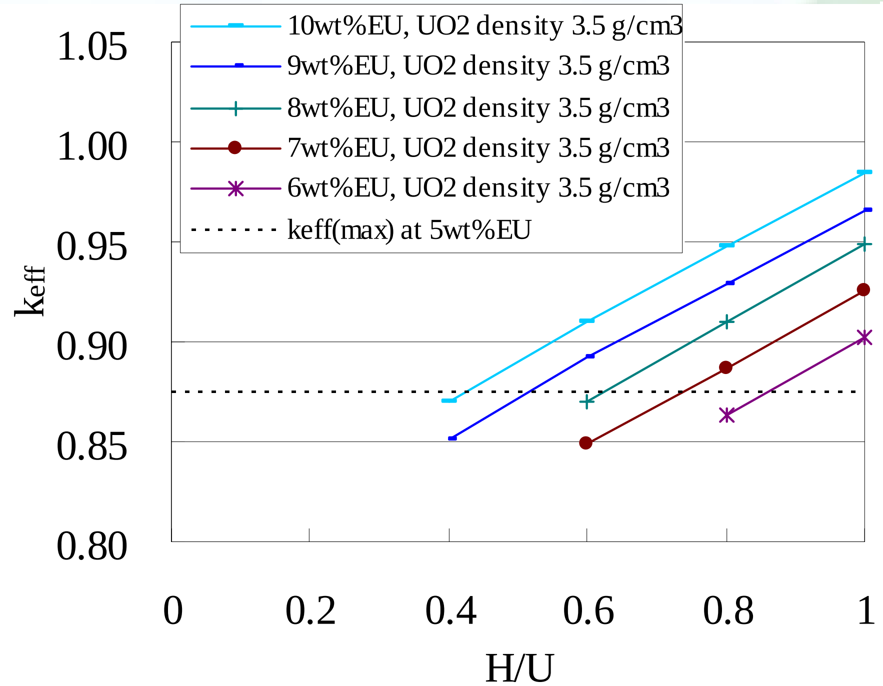
- **Simple shapes**
  - The erbia content is determined so that the keff is equivalent to the ones for enrichment of 5 wt% without erbia
  - Erbia cont. for Homo. is greater than Hetero.
  - Erbia cont. increases linearly with enrichment

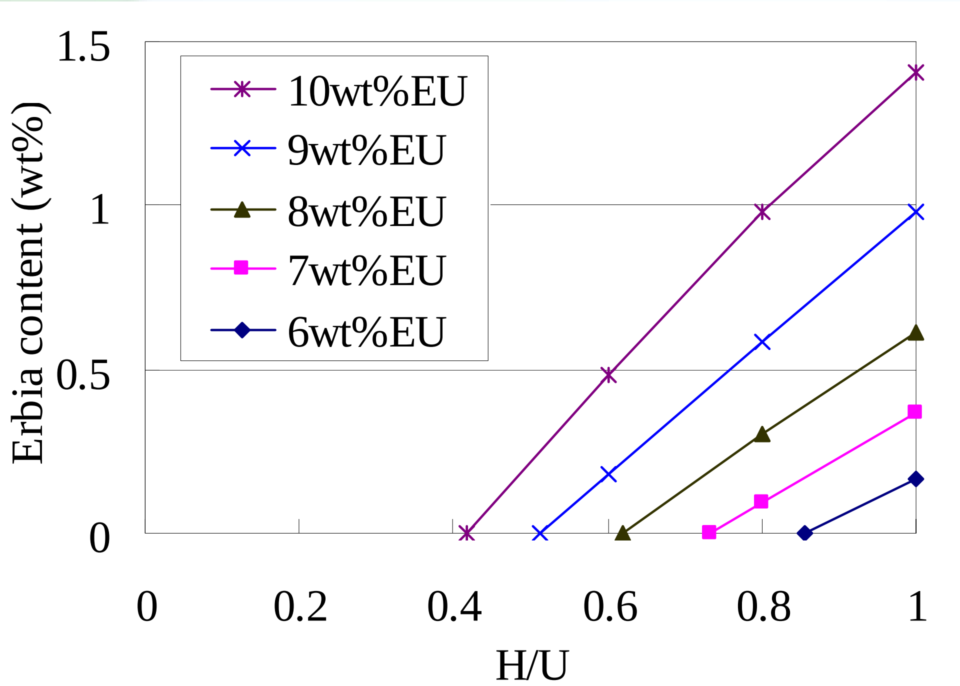




Results (2)

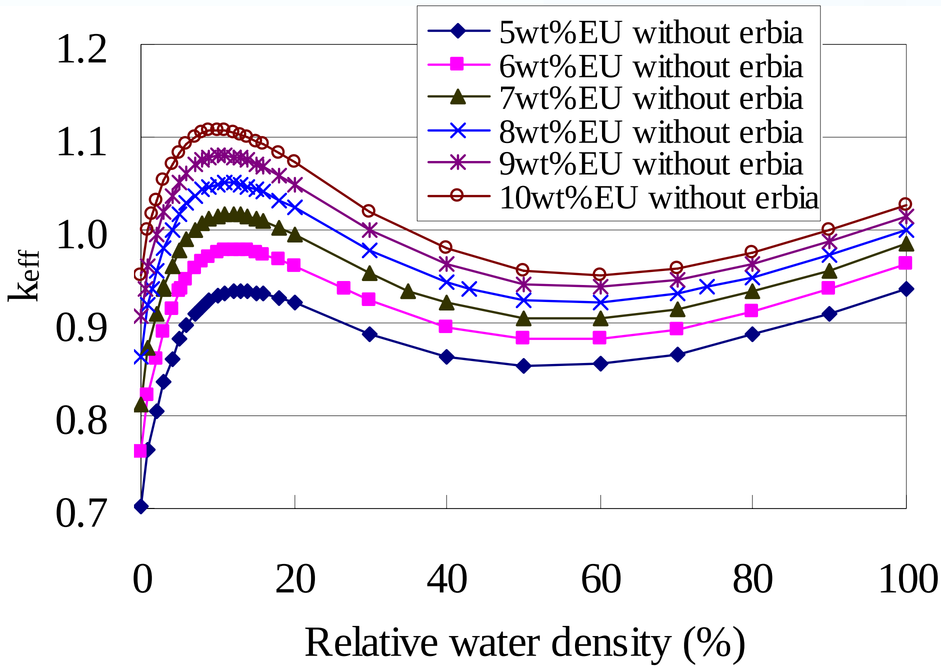
- **Large sphere with moisture control**
  - Keff increases with UO2 powder density and H/U in the ranges (UO2<3.5g/cc, H/U<1)
  - Erbia content to suppress the reactivity of >5wt% enrichment, increases with enrichment (UO2=3.5g/cc , H/U<1)

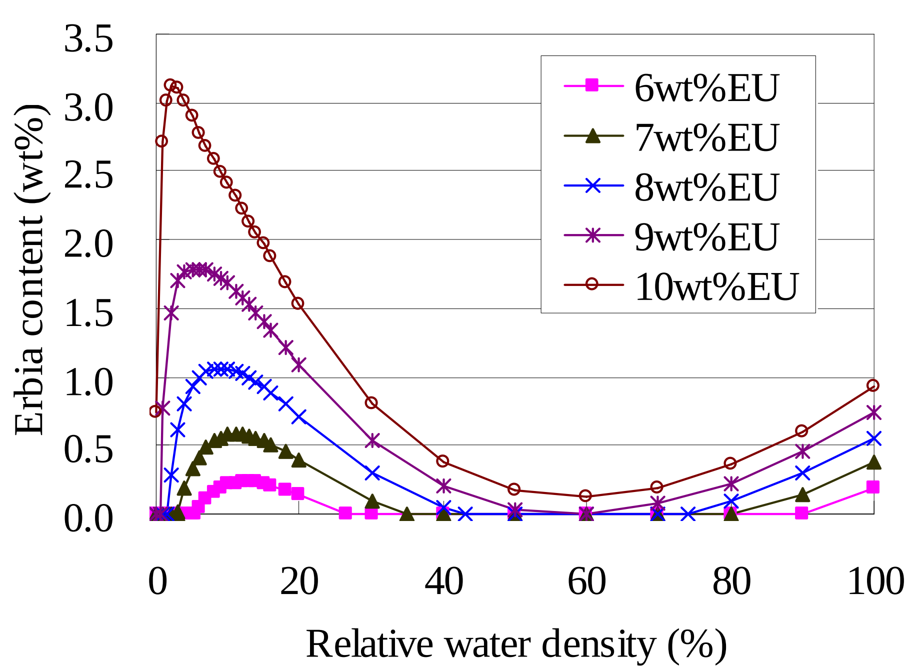




Results (3)

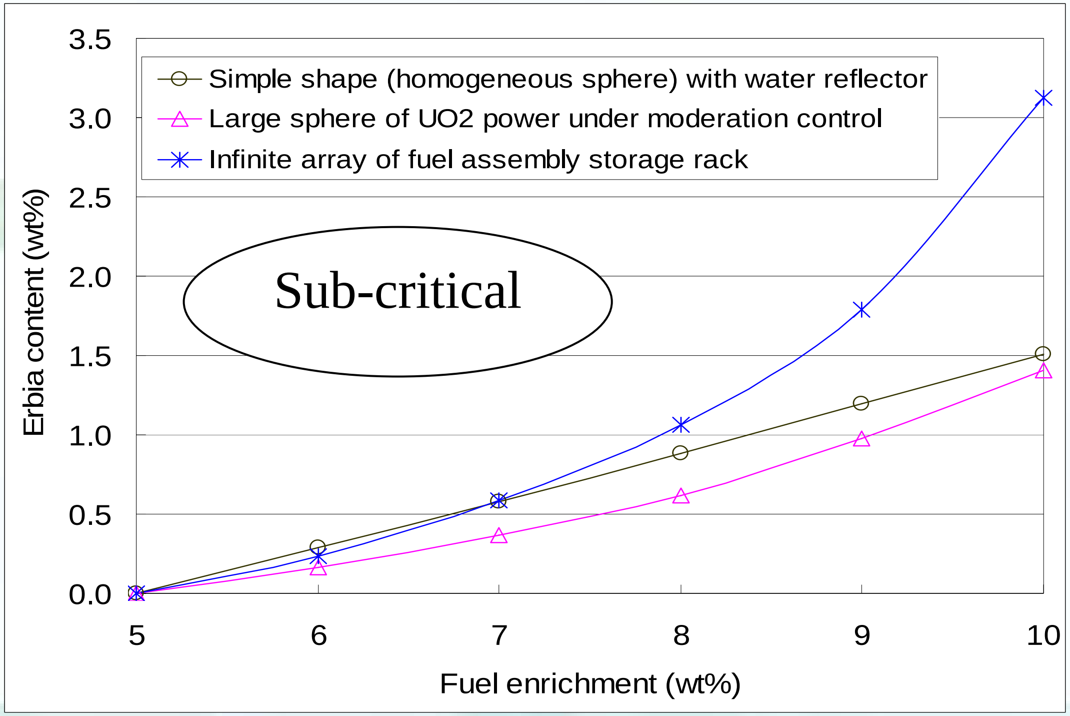
- **Fuel assemblies in Storage rack**
  - Reactivity peak at lower water density becomes more severe as enrichment becomes higher
  - According to this phenomena, required Erbia content becomes very large to suppress reactivity in hard spectrum condition





Results (4)

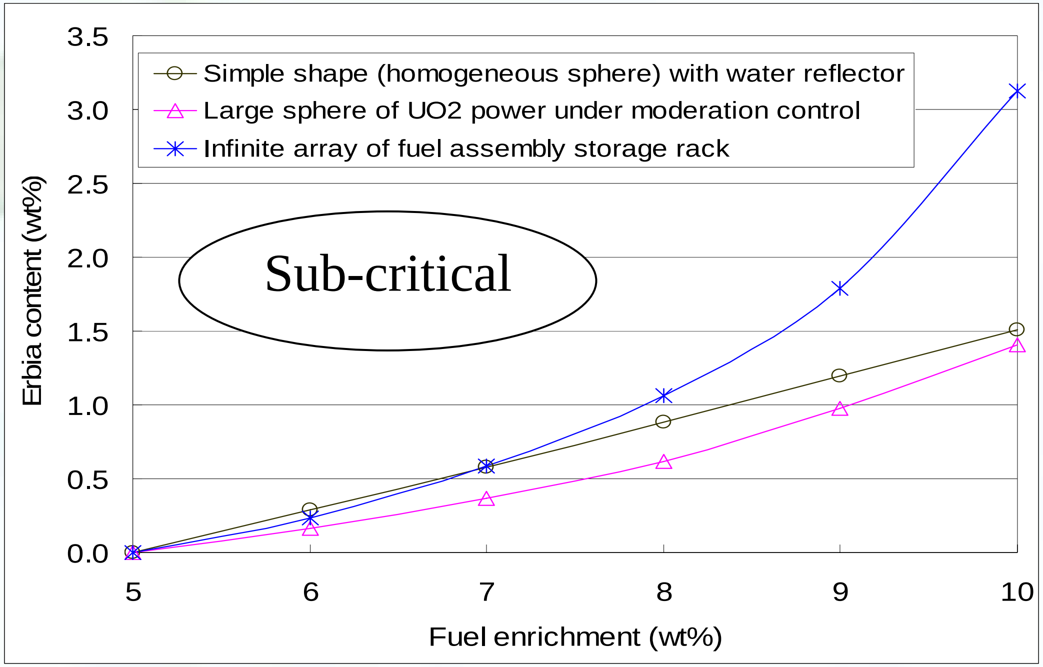
- **ECOS Diagram**
  - Er-content, needed to reduce its reactivity equivalent to 5wt% level, is determined
  - We named this diagram as "ECOS(=Erbia COntent for Sub-criticality judgment) Diagram"



Summary of CS Analyses

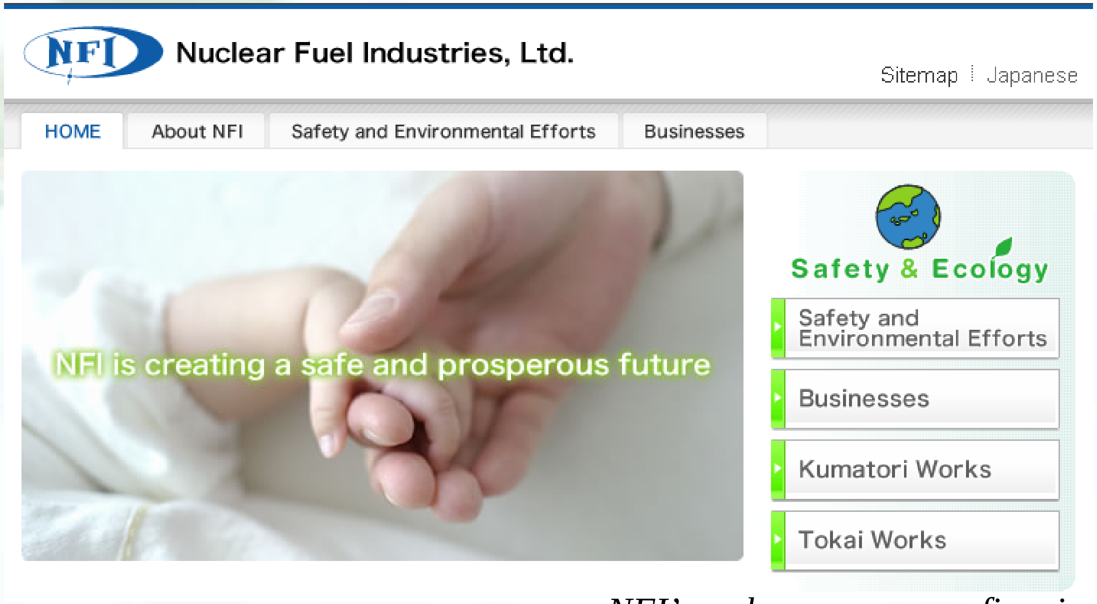
"The Outline of Development Project on Erbia Bearing Super-High-Burnup Fuel"

- Criticality safety analyses are performed with introducing the concept of Erbia Credit
- ECOS diagram is obtained in this study
- Note that ECOS diagram is non-linear depending on the specification of fabrication facilities



4. Summary

Miss Er-Pellet



NFI’s web page : www.nfi.co.jp

Summary

- Er-credit SHB fuel is an attractive candidate for breaking "the 5wt% enrichment barrier."
- Critical Experiments of fully Er loaded core and ECOS diagram are presented.
- From regulatory point of view, the validation of Er-credit should be discussed.
- Thank you for your attention;

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