Issues on Introduction of Th-Fuel to Actual Commercial Reactor

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Contents

Background

- **Motivations to introduce Th-fuel (Compared with U/Pu-fuel)**
  - **Abundance of Th resources**
    - ✓ **3~4 times more abundant than U**
  - **Low radiotoxicity waste**
  - **Higher proliferation-resistance**
    - ✓ **Strong gamma emission from U232 daughter**
    - ✓ **Incineration of civilian/weapon grade Pu**
  - **Higher conversion in thermal reactor**
  - **Better thermo-physical properties and chemical stability**
    - ✓ **Higher melting point, thermal conductivity**

Background

- **Challenges to establish closed Th cycle**
  - **Front and back end issues**
    - ✓ **Irradiated ThO2 and spent ThO2-based fuels are difficult to dissolve in HNO3 because of the inertness of ThO2**
    - ✓ **Remote refabrication technology is necessary due to the high gamma radiation associated with the short lived daughter products of U232**
    - ✓ **Development of 3 stream reprocessing technology is required for extraction U and Pu**

⇒ Once-through introduction seems to be appropriate for near-term target

Background

- **What is the most feasible scenario for using Th-fuels on a large scale ?**

  - **Building new reactors specialized to Th-fuels?**

    Maybe 20~30 years later or more …

  - **Using current commercial LWRs without any major modifications seems to be the most likely near-term introduction of Th-fuel.**

Objectives

- To **identify the issues** of Th-fuel introduction to **actual commercial reactors**

From the view point of

✓ **core and fuel design feasibility** to current reactors

✓ **safety analysis technology** for Th-fuel licensing

Knowledge of Th-fuel

- **About core and fuel design feasibility**
  - **Applicability to current core/fuel design**
    - ✓ Burnup reactivity trend
    - ✓ Feedback effect (Doppler, Moderator coefficients)
    - ✓ Control rod worth
    - ✓ Kinetics parameter (Delayed neutrons fraction)
    - ✓ Material properties
- **About safety analysis technology**
  - **Predictability of Th-fuel performance**
    - ✓ Code assessment
    - ✓ V&V data
  - **Data to determine design criteria**
    - ✓ PCI/PCMI performance data, etc…

Knowledge of Th-fuel

Applicability of Th-fuels to PWR core

- **Compared with current UO2 and MOX fuels**

- Benchmark is examined to reconfirm overview nuclear performance of Th-fuel -

Fuel type	Description
UO2 (base)	4.0wt% U235 enrichment UO2
U/Pu-MOX	0.3wt% U235 enrichment UO2, 8wt% RG-Pu
U-Th	20wt% U235 enrichment UO2, 76wt% ThO2
Pu-Th	9wt% RG-Pu, 91wt% ThO2

(*reference NUREG/CR 7176)

- ✓ Fuel compositions are designed to accomplish the equivalent fuel life (average discharge burnup ~48.5GWd/mt)
- ✓ Uniform pin-cell arrangement is assumed for 17x17 PWR assembly type to know the essential basic fuel characteristics

Knowledge of Th-fuel

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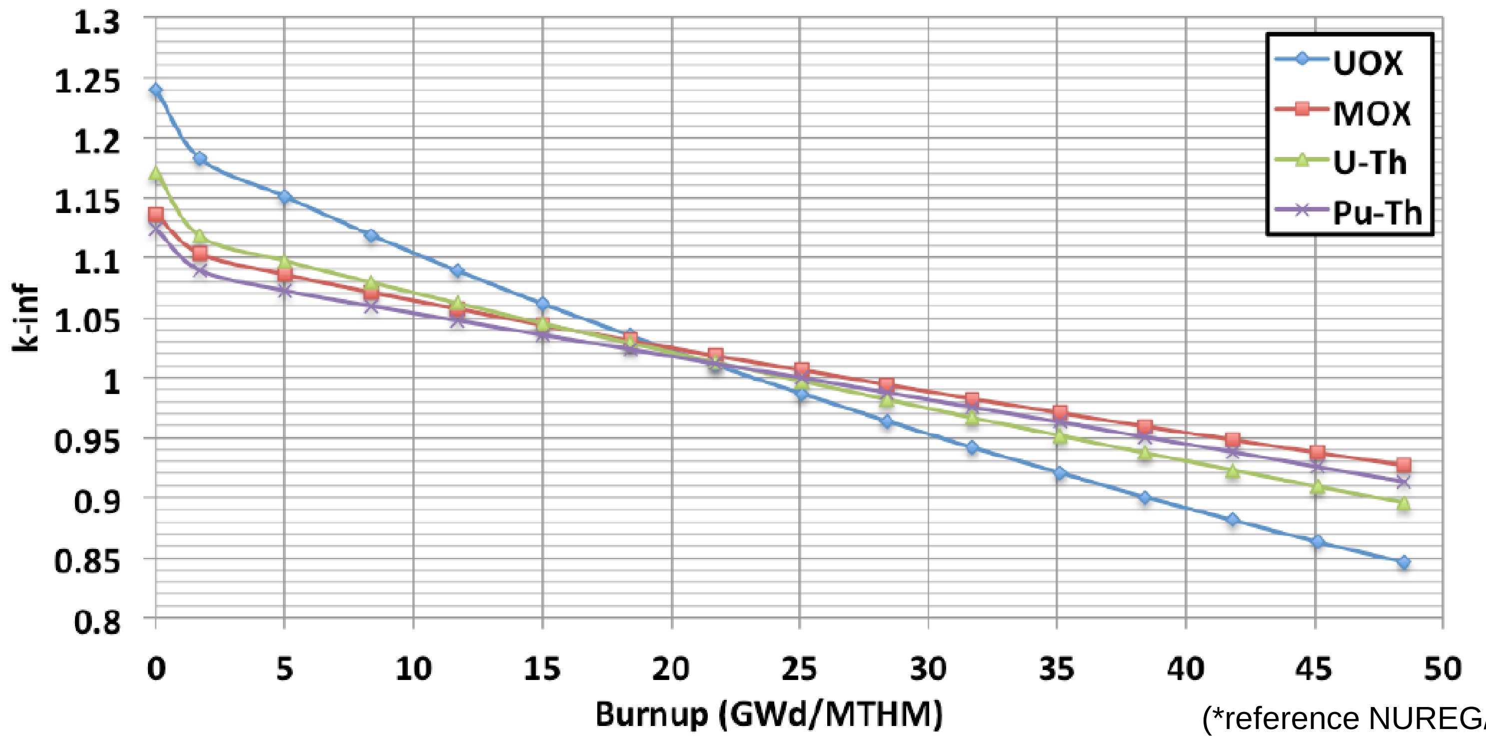
● Eigenvalue(k_inf) trend comparison



(*reference NUREG/CR 7176)

Higher conversion ratio of Th-fuel helps slowdown of Kinf degradation trend through burnup.

Kinf behavior is similar to that of U/Pu-MOX

Knowledge of Th-fuel

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Feedback effect (Doppler, Moderator coef. and Boron worth)

DTC (pcm/K)

Doppler Coef. (300-2400K) (pcm/K)				
	UOX	MOX	Pu-Th	U-Th
BOL	-1.74	-2.53	-3.03	-3.64
EOL	-3.02	-3.02	-3.71	-4.18

MTC (pcm/K)

Moderater Temp. Coef. (566-614K) (pcm/K)				
	UOX	MOX	Pu-Th	U-Th
BOL	-23.0	-50.0	-47.6	-31.7
EOL	-67.1	-75.4	-58.9	-50.9

Boron worth (pcm/ppm)

Boron Worth (0-2400K) (pcm/ppm)				
	UOX	MOX	Pu-Th	U-Th
BOL	-6.48	-2.60	-2.69	-5.81
EOL	-8.67	-3.64	-4.24	-7.68

(*reference NUREG/CR 7176)

Feedback coefficients of Th-fuels fall into almost the range of UO2 and MOX

Knowledge of Th-fuel

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● Control rod worth (B4C, AIC)

B4C

	Reactivity worth (%dk) @ assembly			
	UOX	MOX	Pu-Th	U-Th
BOL	40.2	26.0	28.7	41.2
EOL	54.8	33.5	37.6	51.0

AIC

	Reactivity worth (%dk) @ assembly			
	UOX	MOX	Pu-Th	U-Th
BOL	29.1	16.8	18.2	29.2
EOL	39.5	22.1	24.3	35.7

(*reference NUREG/CR 7176)

CRW of Th-fuel also falls into the range of UO2 and U/Pu-MOX

Knowledge of Th-fuel

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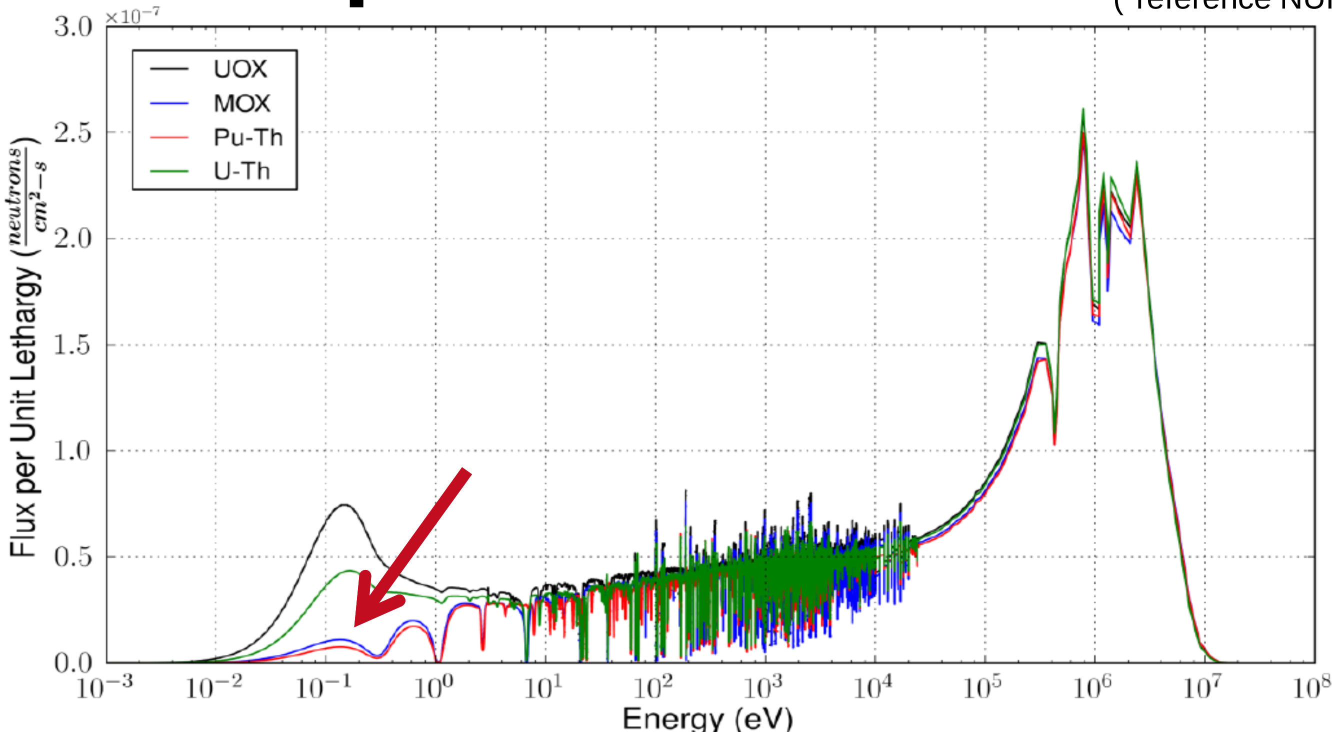
Neutron spectrum

(*reference NUREG/CR 7176)



Thermal neutron spectrum is more dominated by Pu rather than Th. Th-Pu fuel assemblies would require similar distributed arrangement like U/Pu-MOX fuel assemblies to reduce local power peaking caused by neighboring UO2 assemblies.

Knowledge of Th-fuel

Material properties

Property	UO2	PuO2	ThO2
Crystal structure	FCC	FCC	FCC
Melting point (K)	~3123	~2623	~3643
TD (g/cc) @298K	10.96	11.46	10.00
Thermal conductivity (W/mK) @773K @1773K	4.80 2.40	4.48 1.97	6.20 2.40
Coef. of thermal expansion (K^{-4}) @298-1223K	$10x10^{-6}$	$11.4x10^{-6}$	$9.67x10^{-6}$

(*reference IAEA TECDOC 1450)

Higher melting point and thermal conductivity would increase safety margins in terms of thermo-physical properties

But mixed with UO2/PuO2, thermal conductivity is not well-known?

Knowledge of Th-fuel

(Summary)

- **Applicability to current LWRs**
  - **Th-fuels (U-Th/Pu-Th) show almost the same or better performance compared with U/Pu-MOX**

    ⇒ Th-fuel introduction into current PWR seems no significant problem. (similar to U/Pu-MOX)

  - **Many studies on LWR Th-fuel utilization are considering FULL Th-fuel core**
    - ✓ **to avoid high local power peaking**
    - ✓ **to earn maximum U233 utilization**
  - **But most LWR cores introducing U/Pu-MOX limit its ratio up to 1/3 of the core**

    ⇒ Develop low local peaking design of Th-fuel?
    Enhance core capability to achieve full Th-fuel loading

Assessment of Safty Analysis

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About safety analysis technology

- **Predictability of Th-fuel performance**
  - ✓ **Code assessment**
  - ✓ **V&V data**
- **Data to determine design criteria**
  - ✓ **PCI/PCMI performance data, etc…**

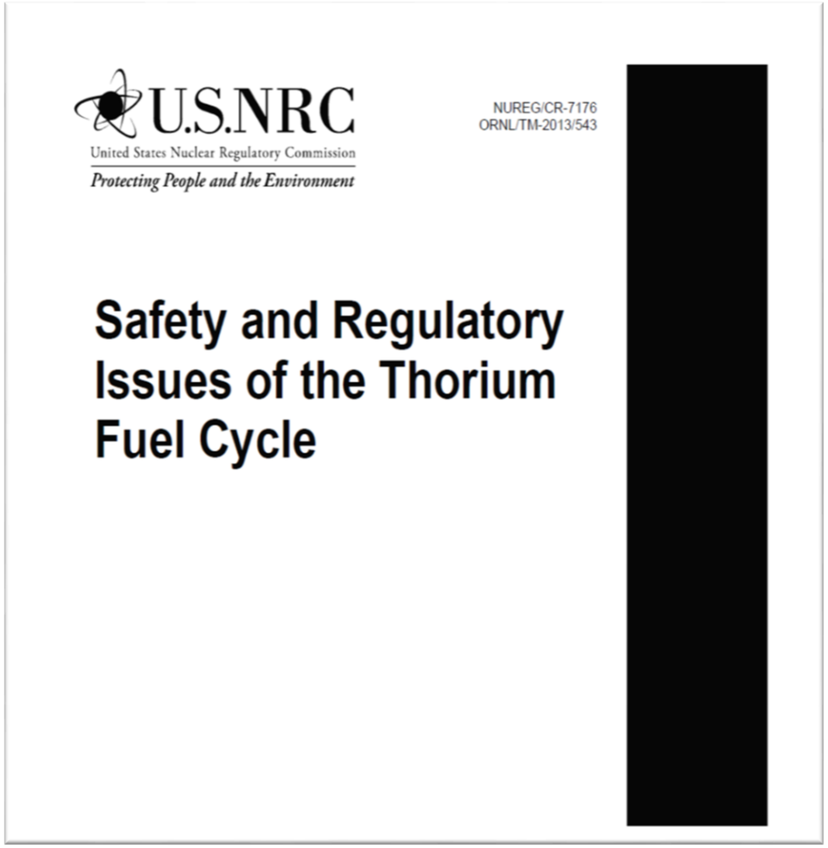
Lack of safety related experimental data might cause large disadvantage in use of Th-fuel.

- ✓ Large safety margin due to large uncertainties
- ✓ Result in very strict operating limitation

⇒ Assessment of current knowledge and technology of Th-fuel for licensing is very important to know what is not well-known and is needed in high priority.

Assessment of Safty Analysis

- **NUREG/CR-7176 "Safety and Regulatory Issues of the Thorium Fuel Cycle" was published in Feb. 2014**


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NUREG/CR-7176
ORNL/TM-2013/543

Safety and Regulatory Issues of the Thorium Fuel Cycle

To identify key knowledge gaps and technical issues that need to be addressed for the licensing of thorium fuel from the view point of NRC Standard Review Plan (SRP).

Assessment of Safty Analysis

- **Generation of PIRTs for Th-fuel**
  - ✓ To identify key knowledge gaps and technical issues. (Phenomena Identification and Ranking Tables)

- 1) Extracting relevant phenomena
  - ✓ Doppler, Delay neutron, etc.
- 2) Ranking importance
  - ✓ High/Middle/Low
- 3) Assessing level of current knowledge
  - ✓ Known/Patialy know/Unknown

→ **in order to determine what has high priority for research on each subject**

Assessment of Safty Analysis

- **PIRT for Th-fuel utilized in LWRs**
  - ✓ **Picked out the items categorized to High importance & Low/Partial knowledge**

Region	Phenomenon or Characteristic	Descriptions
Nuclear calculation	**Cross sections**	the relevance or impact of these uncertainties is not clearly known/understood due to **limited availability of relevant benchmark data**. Fig.
	Decay chain	Reasonably well known, although further analysis would be needed
	Fission yield	Reasonably well known, although less experiential knowledge
	Reactivity coefficients	Further study should be initiated when realistic fuel design information becomes available
	Control rod worth	Full-core calculations are needed to estimate the true control rod worth
	Fuel inventory	**There exists very little data** (destructive assay) to validate computational tools

Assessment of Safty Analysis

- **Prediction uncertainties (K_inf. benchmark results)**

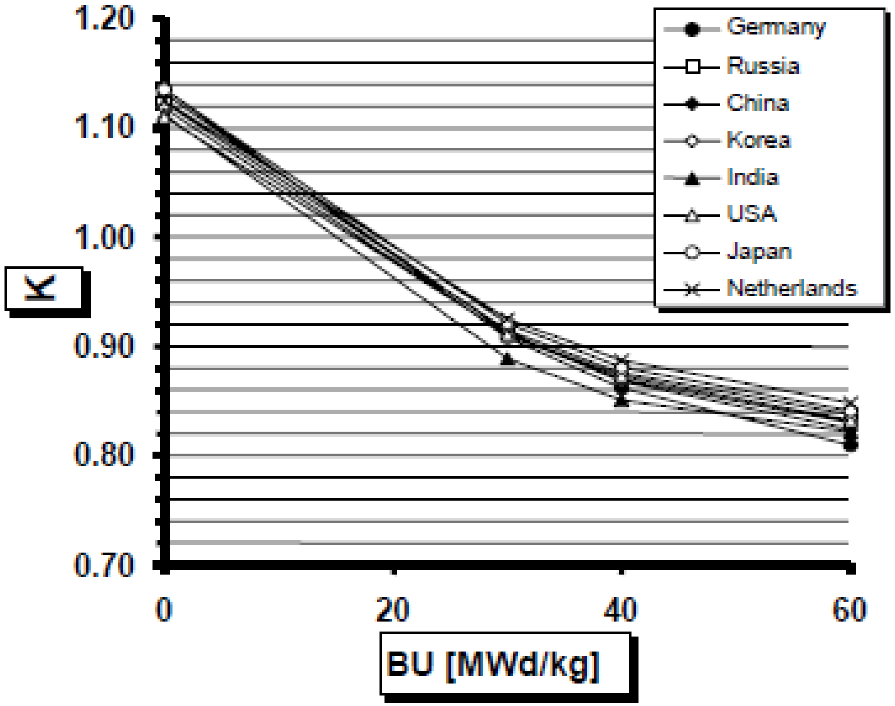


FIG. 2.2. Neutron multiplication vs. heavy metal burnup.

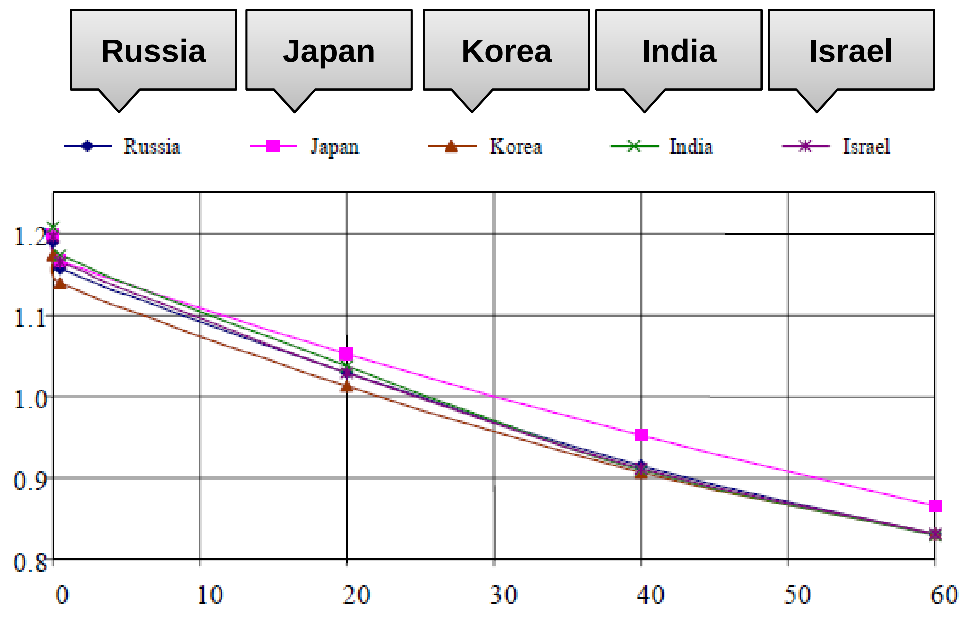


Fig. 2.9. k_{inf} as a function of burnup.

(*IAEA TECDOC 1394)

✓ Relatively large difference was observed

✓ More data would be necessary to reduce uncertainties to meet current design requirements

Assessment of Safty Analysis

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PIRT for Th-fuel utilized in LWRs (cont.)

Region	Phenomenon or Characteristic	Descriptions
Fuel property	**Fission gas release**	**Little is known** regarding the release of fission gases from mixed oxides of thorium
	Dimensional changes Swelling/Densification /Creep	**Little is known** regarding the irradiation-induced dimensional changes of mixed oxides of thorium
	Fuel/Clad interaction	Some **PCI** and **PCMI** fuel performance data for ThO2 exists, **more detailed data would be needed** for a specific fuel and reactor design
	Fuel bowing	**More detailed data would be needed** for a specific fuel and reactor design
	Fuel performance modeling	Fuel performance models (FRAPCON) would need to be developed for thorium fuel or mixed oxides of thorium. These models would **need to be validated against measured data, which do not currently exist**.

High priority data for licensing is identified.

Conclusions

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- ✓ **Th-fuel introduction into current PWR seems no significant problem** (from the view point of fuel properties)
  - ✓ But some studies reported that relatively high local power peaking was occurred when UO2 fuels are neighboring.
  - ✓ If full Th-fuel core concept is employed, there would be the same difficulties of Full MOX application to current LWR core.

- ✓ **When reprocessing option is considered in future, the mixed use of Th/U-233 and U/Pu cycles would cause some complexity in various aspects.**

Conclusions (cont.)

- ✓ **Recently US NRC published an assessment report of Th-fuel licensing to LWR.**

  (NUREG/CR-7176 Feb.2014)

  - ✓ **The report identifies key knowledge gaps and technical issues that need to be addressed for the Th-fuel licensing to LWRs, and also points out some issues on current status of limited knowledge for Th-fuel licensing.**
  - ✓ **Lack of safety related knowledge and experimental data might cause large disadvantage in use of Th-fuel.**

- ✓ **Utilizing these assessment results, it is expected that experiments and verifications required for Th-fuel introduction can be planned and carried out at maximum efficiency in limited resources.**

Thank you very much for your attention.

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