Design study of a small long life fast reactor core loaded with Pu without extracting MA

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Contents

1. Background

What is SMR?

– SMR: small and medium sized reactors

innovative SMRs is developed to meet the requirements of some special situations or supplying electricity for a small power grid .

Requirements of long life SMR?

– Long core life up to even more than 10 years;

– Small burnup reactivity loss;

fast reactor is preferred as larger conversion ratio makes small burnup reactivity loss.

– Enhanced non-proliferation capability.

using Pu as nuclear fuel in self-security is desired.

Representatives of long life SMR

– 4S and ENHS reactor

1. Background

Purpose of the work?

– To demonstrate the feasibility of utilizing *Pu without extracting MA (minor actinides)* as drive fuel for a long life SMR *(non-separation of MA and Pu to enhance fuel non-proliferation)*

- *Check the impact on core performance of introducing a small amount of MA into fuel*
- *Compare performance of the core using TRU from PWR with the core using pure Pu as fuel*
- *Check the enhanced non-proliferation of spent fuel when TRU is utilized as drive fuel*

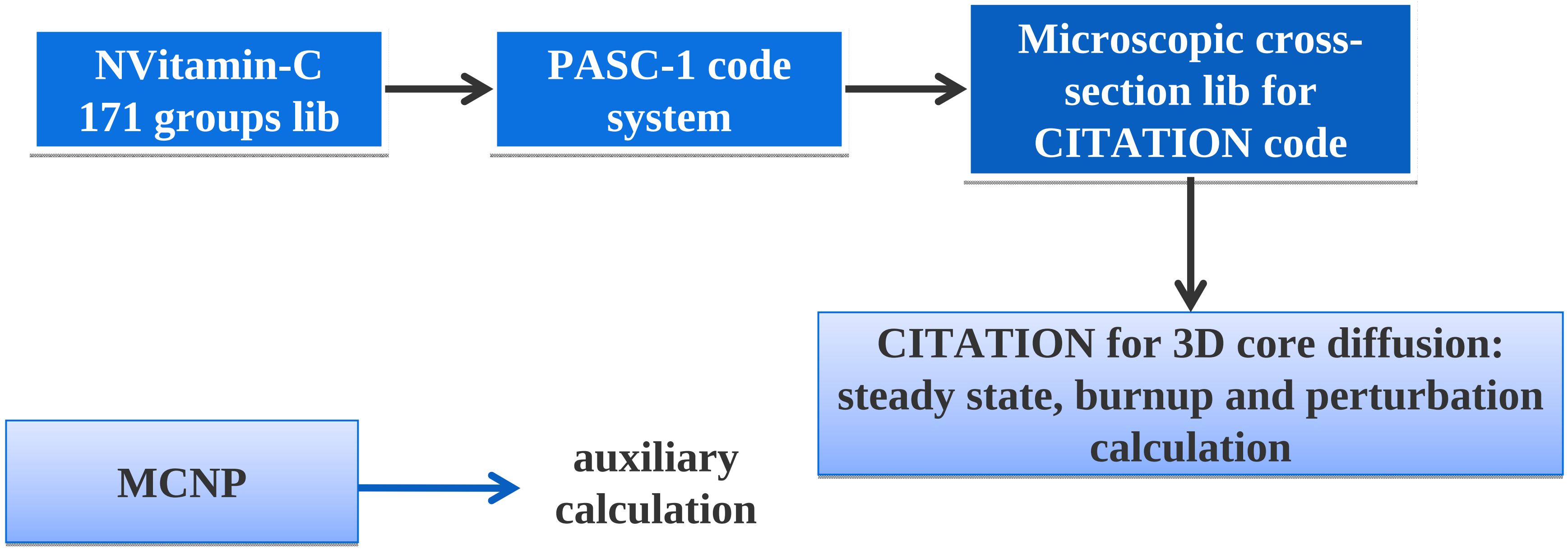
1. Background

Calculation tools(1/2):

— *N-Vitamin-C 171 groups lib (ENDF/B-VI, JEF-2, CENDL-2 and JENDL-3)*

— *PASC-1 system for few groups cross section processing*

— *CITATION and MCNP*

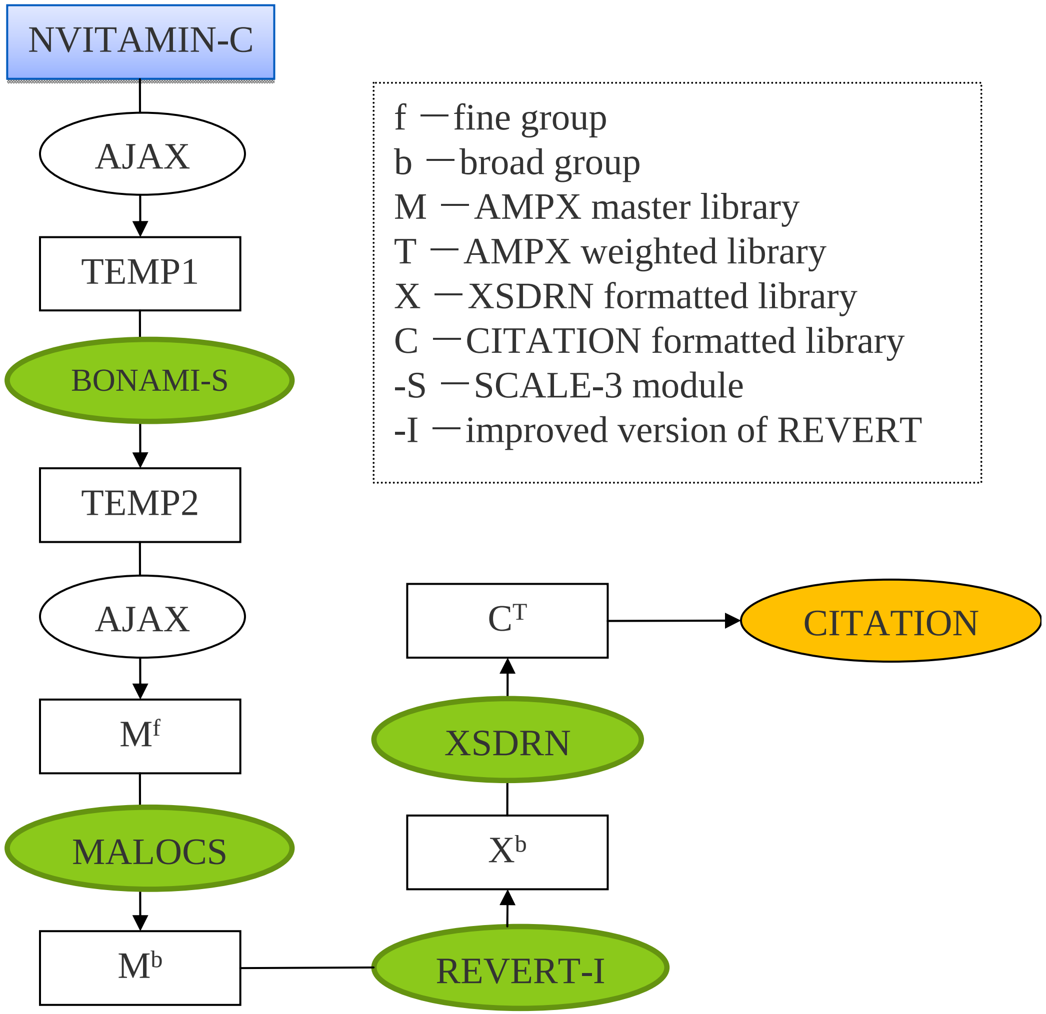


1. Background

Calculation tools(2/2):

– *PASC-1 code system: to collapse fine energy group to few group*

Flow chart of generation of few groups microscopic cross section lib



2. Core performance and results analysis

Basic core parameters(1/2)

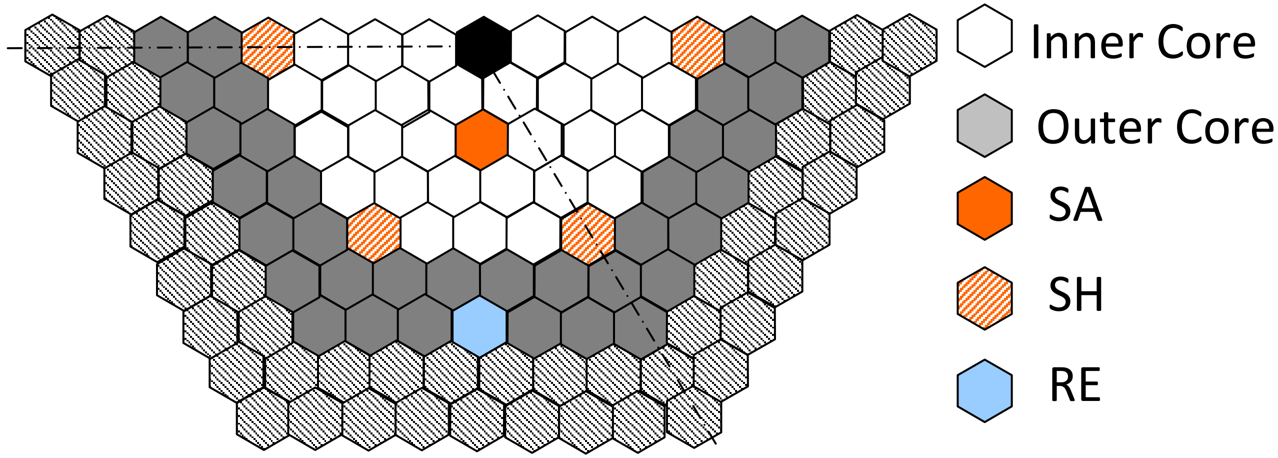
Parameter	Value
Thermal Power/MWt	300
Core dimensions e. q. Dia.×Height	189.181×80cm
FSA[a] width across flats/cm	16.6
Characteristics of FSA	
Number of fuel pins per FSA	217
Outer dia. of fuel pins/mm	10.0
P/D	1.1
Cladding thickness/mm	0.6
Fuel smear density	75%T.D.
Gas plenum/fuel volume ratio	1.0
FSA number: Inner/Outer	51/64

[a] FSA means fuel sub-assembly.

- *U-Pu-10Zr ternary alloy fuel with smear density 75%TD*
- *300MWt power*
- *Avg. specific power about 22W/gHM*
- *Initial mass loading: U ~11.056t, Pu ~1.79t*

2. Core performance and results analysis

Basic core parameters(2/2)



Radial configuration of core

– *2 enrichment zones*

2. Core performance and results analysis

Introduction of different cases in case study

Case	MA amt. wt%	Fuel composition wt%
A	-	10.2Pu-10Zr[a] ; 14.28Pu-10Zr[b]
MA added into fuel		
B	2.5	10.2Pu-2.5MA-10Zr ; 14.28Pu-2.5MA-10Zr
C	5.0	10.2Pu-5.0MA-10Zr ; 14.28Pu-5.0MA-10Zr
D	Non-sep.	10.2Pu-1.249MA-10Zr ; 14.28Pu-1.749MA-10Zr

[a] *Inner core. Natural uranium is used as supplement in all cases.*

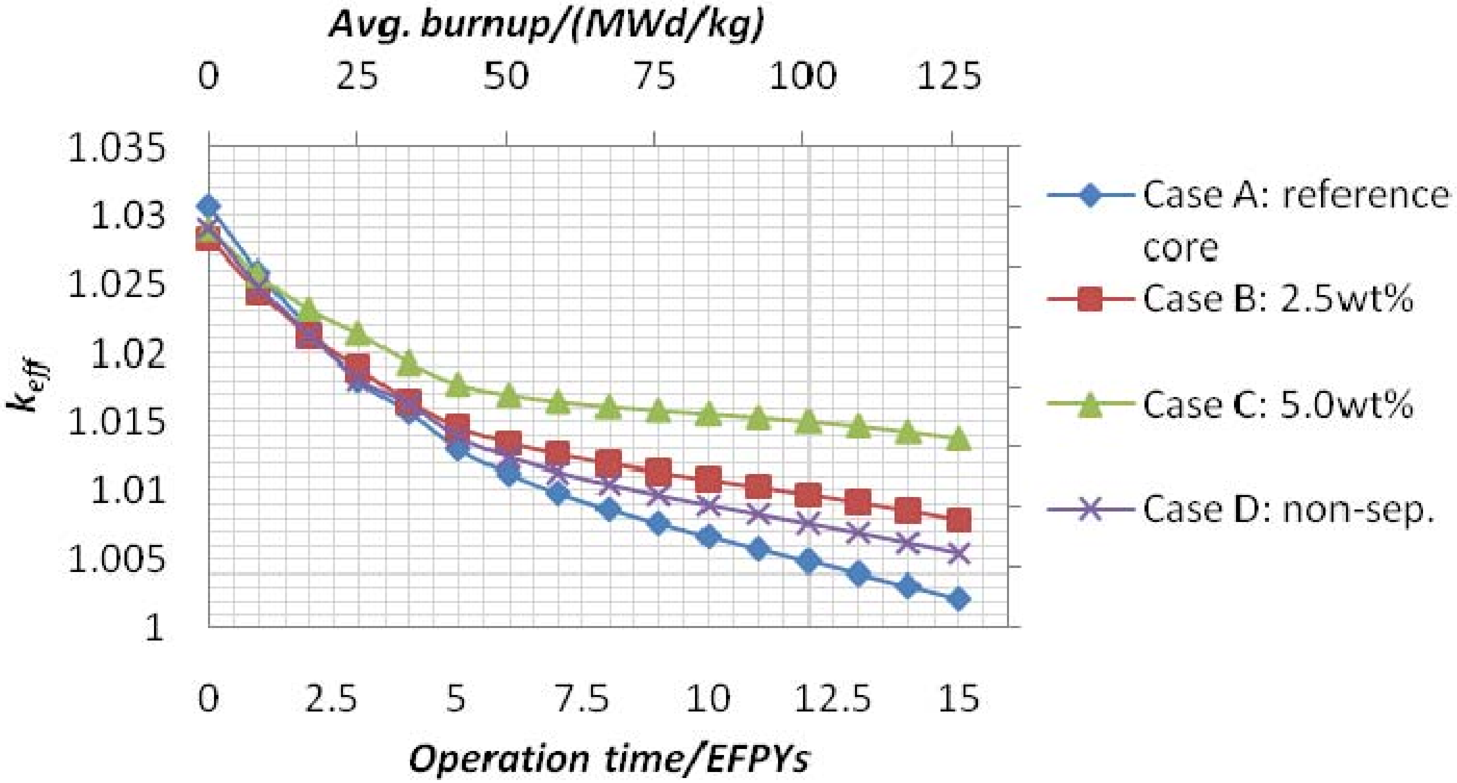
[b] *Outer core.*

– *3 kinds of core:*

- *case A → pure Pu as fuel, reference core*
- *case B&C → 2.5 and 5.0wt% MA addition into fuel*
- *case D → TRU (non-separation of MA and Pu) from PWR as fuel*

2. Core performance and results analysis

Burnup reactivity loss(1/2)



k_{eff} of different cases changes with fuel burnup

2. Core performance and results analysis

Burnup reactivity loss (2/2)

– *MA addition reduces △ρ $_{burnup}$ of core, the more MA the better*

- *better fission performance of MA capture offspring, like ^{238}Pu*

$$Np-237 \xrightarrow{(n,\gamma)} Np-238 \xrightarrow{\beta-,2.12d} Pu-238$$

$$Am-241 \xrightarrow{(n,\gamma)} Am-242 \xrightarrow{\beta-,16h} Cm-242 \xrightarrow{\alpha,163d} Pu-238$$

$$Am-243 \xrightarrow{(n,\gamma)} Am-244 \xrightarrow{\beta-,26m} Cm-244 \xrightarrow{(n,\gamma)} Cm-245$$

– *The core life time is limited to 9~10 EFPYs due to the irradiation damage effect, although from residual reactivity point of view the core can be operated for a longer time.*

- *assumption of limited neutron fluence is $4\times10^{23}/cm^2$*

Only from viewpoint of burnup reactivity swing, MA addition into fuel brings favorable consequence.

2. Core performance and results analysis

Kinetic parameters and reactivity feedback

$$\Delta\rho = K_D \frac{\ln T_2}{\ln T_1}$$

CASE	β_{eff} pcm	Λ 10^{-7}s	Dop. Effect K_D/pcm	Na void worth*a $
A	381.934	3.261	-435.2	3.408
B	359.158	2.821	-340.3	4.747
C	337.680	2.475	-268.4	6.178
D	368.221	2.992	-377.1	4.192

*a Assumption of voiding the whole core and core upper region in uniform is made.

– *with MA addition, β_{eff}, Λ and Doppler feedback will decrease, while Na void reactivity will increase*

– *Compared to β_{eff}, Doppler feedback and Na void reactivity is very sensitive to MA percentage in fuel*

– *Compared to core with pure Pu fuel, loading TRU (non-separation of MA and Pu) from PWR as a group will bring small impact on core performance*

- *mainly because of small MA percentage in TRU from PWR spent fuel*

2. Core performance and results analysis

Spent fuel characteristics of different cases(1/2)

BOL and EOL TRU composition of CASE A and D

Mass/kg	Case A (*Pure Pu as drive fuel*)		Case D (*Whole TRU as drive fuel*)	
	BOL	*EOL*	*BOL*	*EOL*
Pu	1790	1697	1790	1706
MA	0	43	219	185
MA/TRU	0	2.471%	10.901%	9.783%

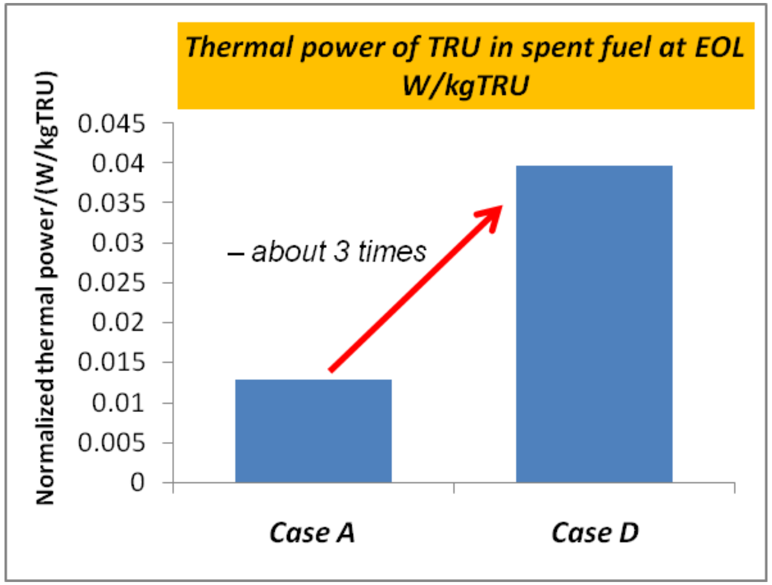
– *proliferation resistance of BOL initial loading fuel and EOL discharged fuel are both increased when TRU from PWR used as drive fuel*

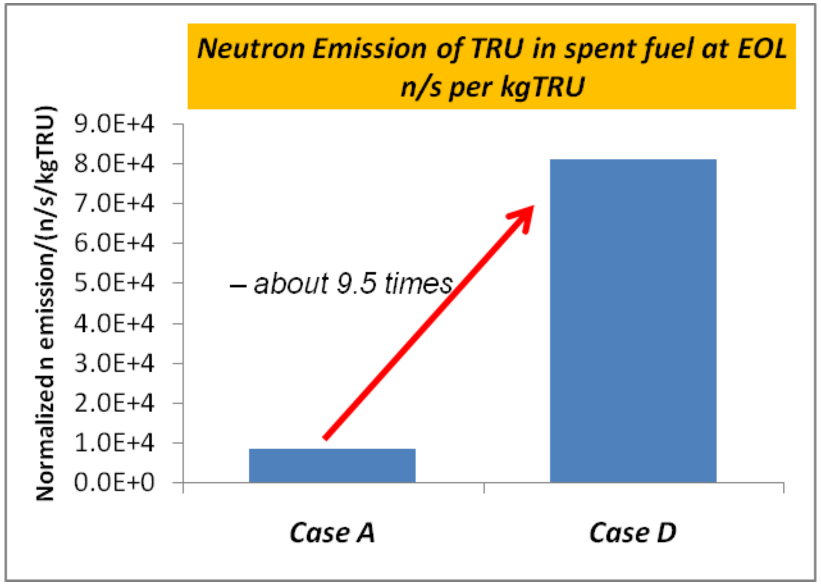
- *because high MA percentage in BOL fuel and EOL spent fuel*

– *additional benefit of loading TRU from PWR as a group is that considerable amount of MA is "burned", while in the reference core, MA inventory increases with the fuel burnup*

2. Core performance and results analysis

Spent fuel characteristics of different cases(2/2)





– *thermal power and, especially, neutron emission rate of TRU in spent fuel at BOL are both increased, which means enhanced non-proliferation capacity*

3. Summary

– **The work focused on design study of loading TRU from PWR as a group in a small long life SMR**

– **Along with MA addition into fuel, advantages including:**

- *reduced burnup reactivity swing;*
- *transmutation of considerable amount of MA;*
- *enhanced proliferation resistance*

while disadvantages are penalties on:

- *kinetic parameters;*
- *reactivity feedback performance(like Doppler feedback and Na void worth);*

– **Compared to the core with pure Pu as drive fuel, loading TRU from PWR without separation of MA and Pu will introduce small impact on core performance, while the benefit of significantly enhanced proliferation resistance can be obtained**

Thanks for your attention.