LMFBR Design and its Evolution: (2) Core Design of LMFBR

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Sodium-cooled core design studies are performed. MOX fuel core with axial blanket partial elimination subassembly due to safety consideration is studied. This type of core with high internal conversion ratio possesses capability of achieving 26 months of operation cycle length and 100GWd/t of burnup averaged over core and blanket, which are superior characteristics in view of reducing cost of power generation. Metal fuel core is also studied, and its higher breeding capability reveals a potential of better core performance such as longer operation cycle length for the same level of electricity generation, though core outlet temperature is limited to lower level due to steel cladding-metal fuel compatibility concerns. Another metal fuel core concept using single Pu enrichment and two radial regions with individual fuel pin diameters achieves 550°C of core outlet temperature identical to that of MOX fuel core, keeping operation cycle length comparable with that of MOX fuel core. This series of study results show that sodium-cooled MOX and metal fuel cores have a high flexibility in satisfying various needs including fuel cycle cost and breeding capability, depending on the stage of introducing commercialized fast reactor cycle system.

KEYWORDS: sodium-cooled reactor, core design, core thermal hydraulic, oxide fuel, metal fuel

I. Introduction

The advanced core for the next generation is considered to be a core with superior characteristics in safety, economics, resource utilization, environmental burden reduction, and proliferation resistance. Fast reactors are promising concepts to satisfy these demands with engineering consistency, since the fast neutron possesses essential neutronic superiority such as insignificant neutron capture cross section, high neutron yield per neutron absorbed, etc. Among the fast reactor concepts, the Mixed Oxide (MOX) core and the U-Pu-Zr base metal core are those of the most promising candidates of such advanced core of sodium cooled reactor concepts, due to the superior neutronic and thermal-hydraulic characteristics of sodium. Proven reliability of oxide fuel is another attractive feature of MOX fuel core. High content of heavy metal nuclide with appropriate irradiation experience of zirconium alloy metal fuel brings excellent neutronic performance including breeding capability and long operation cycle potential to the metal fuel core, while one of its major drawbacks is limiting feature of steel cladding temperature due to fuel cladding compatibility concerns.

Conceptual design studies of sodium cooled MOX fuel and metal fuel cores are performed to establish such advanced core concepts as a part of the Feasibility Study on Commercialized Fast Reactor Cycle System in Japan.[1)]

The present paper describes the sodium cooled MOX fuel core design studies of large scale and medium scale core concepts with a candidate subassembly idea taking the core safety into account. This is followed by the metal fuel core design study including efforts to achieve high core outlet temperature identical with the MOX fuel core.

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II. Core Design Consideration

In the Feasibility Study in Japan, advanced concepts of fast reactor and nuclear fuel cycle system are under development based on the five categories of target, such as ensuring safety, economic competitiveness, efficient utilization of resources, reduction in environmental burden, and enhancement of nuclear non-proliferation. In the case of the primary stage of sodium cooled reactor core design studies, major consideration is concentrated on the following four items.

- The target of core average burnup is 150GWd/t in discharge average.
- Coolant void reactivity in the core should be low enough to prevent the super-prompt criticality in the initiating phase of Core Disruptive Accident (CDA).
- Measures of early discharge of molten fuel should be considered in the core and fuel design to prevent the re-criticality in the transition phase of CDA.
- Core should have flexible breeding capability in a viewpoint of uranium resource utilization. The target of maximum breeding ratio is 1.2.

The burnup target aims at the reduction of fuel cycle cost due to the economical competitiveness requirement. The high burnup also contributes to reducing the fuel mass capacity requirement of fuel cycle facilities like reprocessing plants and fuel fabrication plants.

The second and third items are related to the safety consideration of hypothetical accidents and should be considered in the core and fuel design. In the present study, the following two kinds of preliminary design consideration are applied for MOX and metal fuel cores based on the accumulated experience of sodium cooled reactor core safety evaluation.

The first consideration is coolant void reactivity. The core designs of MOX fuel and metal fuel aim at coolant void reactivity of the core around or below 6$, 8$, respectively.

These are preliminary target values to avoid the excess positive reactivity insertion in the initiating phase of Unprotected Loss of Flow (ULOF) events. Future safety studies of MOX and metal fuel cores should investigate the limit values and their physical and mechanistic bases in detail.

The second consideration is fuel subassembly concept. The study here selects a subassembly with axial blanket partial elimination for MOX and metal fuel cores. [2] This feature may give a mechanism of early discharge of molten fuel form the core in case of CDAs. This is also an issue of future safety studies of MOX and metal fuel cores.

The fourth item, requirement of breeding capability is not only for the fuel breeding itself, but also for other requirements such as economical advantage, environmental burden reduction. A core with high breeding capability possesses characteristic of high internal conversion ratio. This leads to the following advantages by the flexible design management of the core concept.

- Breeding break even is achieved with less blankets. This offers more economical resource utilization due to the less blanket mass and cost.
- More neutrons are available for the environmental burden reduction such as long lived fission products transmutation, if a breeding break even core configuration is dedicated to the environmental burden reduction efforts.
- Longer reactor operation cycle duration is feasible due to the high internal conversion ratio and hence low burnup reactivity swing. This improves the rate of reactor operation and hence the unit cost of power generation.

Other items to be considered for an advanced core are,

- Capability of loading the low decontamination fuel as product of economical fuel recycle in economical and proliferation resistance viewpoints
- Capability of loading the fuel with a few percents of minor actinides (MA fuel) in uranium resource utilization and environmental burden reduction viewpoints, as well as limiting the core void reactivity within an acceptable level.

III. MOX Fuel Core Design Study

1. Large Scale Core

A large scale sodium-cooled MOX fuel core is one of the promising candidates of commercialized fast reactor core concepts from the viewpoint of reasonable unit cost of plant construction with rationalization of plant system.

(1) Core Design Conditions

The 1500MWe core design study is performed in viewpoints of core neutronic performance and thermal hydraulics. Major core design conditions are as follows:

- Core type : Homogeneous
- Core thermal output : 3570MWth
- Core outlet/inlet temperature : 550/395°C
- Fuel pin bundle pressure drop : 0.2MPa
- Fuel burnup (discharge average) : 150GWd/t
- Maximum diameter of envelope including the shielding region : 6.6m

These conditions correspond to the plant design conditions except for the fuel burnup, which is the primary target of the core design studies. The core type is selected considering of its proven reliability in accumulated experiences of construction and operation. The thermal output corresponds to 1500MWe of plant electricity output under the 550°C of core outlet temperature. The core outlet temperature of 550°C is the maximum acceptable temperature under the condition of cladding maximum temperature as 700°C with engineering uncertainties. The bundle pressure drop is as low as 0.2MPa and this contributes to the natural circulation capability of plant primary system for decay heat removal. Diameter of shielding region is derived from the reactor vessel dimensional design. Another target condition is core operation cycle length, which is selected to around 18 months to improve the rate of plant operation.

Another condition of core design is the isotopic composition of TRU and fission product content of as-fabricated fuel. The TRU isotopic composition indicated below corresponds to the composition of MOX fuel fast reactor core equilibrium cycle after the multi recycle of the core fuel, which is derived from core neutronic calculations of multiple recycle loading.

TRU isotopic composition (wt%) :
Pu238/239/240/241/242/ Np237/Am241/243/Cm244
=1.1/54.1/32.1/4.3/3.9/ 0.5/2.0/1.0/1.0

The fission product content of as-fabricated fuel corresponds to the low decontamination factor reprocessing application. In the core design study, the lowest decontamination factor is selected in the various aqueous and non-aqueous processes in the Feasibility Study in Japan. Based on such consideration, the as-fabricated fuel is assumed to contain 2 vol.% of fission products.

As regards the fuel pin design conditions, maximum fuel pin linear power and fuel smeared density are common value as 430W/cm and 82%TD, respectively. The low smeared density corresponds to the high target burnup as 150GWd/t of discharge average. This smeared density includes 2 vol.% of fission products, and then, the heavy metal content in the as-fabricated fuel is further lower corresponding to 2 vol.% of fission products content.

Cladding and sub-assembly duct materials are ODS(Oxide dispersion strengthened) martensitic steel [3] and PNC-FMS(ferritic/martensitic steel) [4] which withstand neutron dose of high burnup fuel. Ferritic/martensitic material is selected because of its dimensional stability up to high neutron dose. ODS martensitic steel is selected because of its excellent high temperature strength as well as its dimensional stability.

Under these common conditions as well as coolant void reactivity, the core is designed.

(2) Core Specifications and Characteristics

Table 1 shows the major core specifications and characteristics. **Figure 1** shows the core configuration. As shown in the core design results, the core studied here is feasible under the condition of 150GWd/t of discharge average burnup, around 18 months of operation cycle length, given shielding region diameter and bundle pressure drop. The results indicate that the core concept in Table 1 reveal reasonable achievement of target burnup and breeding capability in consistent with reactor safety consideration.

Table 1 Specifications and characteristics of 1500MWe MOX fuel core

Items	Values
Specifications	
Operation cycle length (EFPM)	18
Fuel reload batch (batches)	4
Core diameter (m)	4.9
Core column length (m)	0.8
Axial blanket length (top/bottom) (cm)	30/40
Fuel pin diameter (mm)	8.8
Fuel pins (pins/[S/A])	271
Fuel smeared density (%TD)	82
Fuel volume fraction (%) (100% dens.fuel)	36.2
Subassembly pitch (mm)	183.2
Characteristics	
Pu enrichment (Pu/HM) (%)	23.0*
Discharge burnup (GWd/t) averaged over core averaged over core + blanket	 148 63
Burnup reactivity swing (%?k/kk')	3.2
Breeding ratio (Core/Total) (--)	0.74/1.16
Core void reactivity ($)	5.8

* Average of inner and outer cores

2. Medium Scale Core

A medium scale sodium-cooled MOX fuel core is also one of the attractive concepts of commercialized fast reactor core in view of flexibility in increasing reactor vessel size within an acceptable level.

(1) Core Design Conditions

The 750MWe core design study is performed in viewpoints of core neutronic performance and thermal hydraulics. Major core design conditions are as follows:

- Core type : Homogeneous
- Core thermal output : 1785MWth
- Core outlet/inlet temperature : 550/395℃
- Fuel pin bundle pressure drop : 0.2MPa
- Fuel burnup (discharge average) : 150GWd/t
- Maximum diameter of envelope including the shielding region : 6m

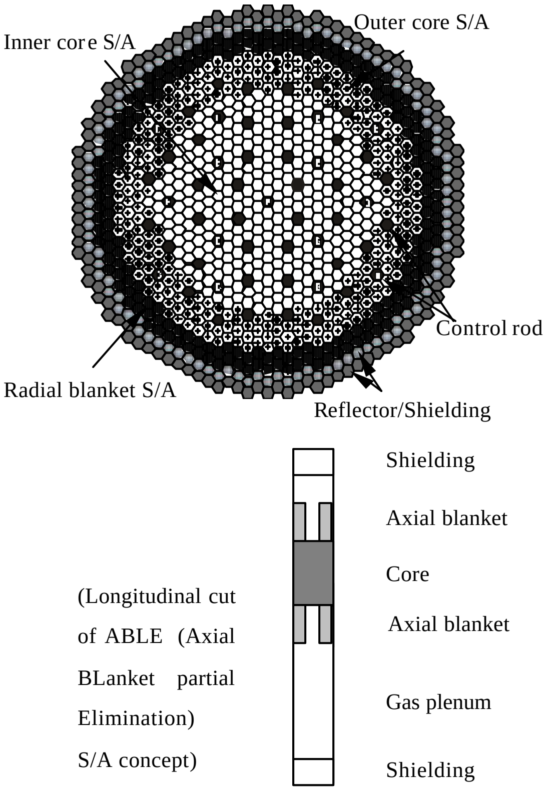

Fig. 1 Core configuration of 1500MWe MOX fuel core

These conditions are derived from the same viewpoints as those in the large scale core. The isotopic composition of TRU, fission product content of as-fabricated fuel, fuel pin design conditions, cladding and sub-assembly duct materials also correspond to the same ones as the large scale core.

The other conditions provided for the medium core design are as follows:

- Breeding ratio without radial blankets : Break even
- Minimum specific power density : 40kW/kg-MOX
- Maximum core column length : 1m

The first condition is derived from aim at reducing fuel cycle cost by achievement of high internal conversion ratio. A core with high internal conversion ratio has a potential to attain breeding break even without radial blankets, which lead to low fuel cycle cost. This design study is directed to large fuel pin diameter as one of the most effective ways of achieving high internal conversion ratio, though it may cause increase of core diameter which is disadvantageous in view of plant construction cost. A relation between the merit of low fuel cycle cost and demerit of high plant construction cost by means of large fuel pin diameter is discussed in the following section.

The second condition is required for preventing the super-prompt criticality in the initiating phase of CDA. This is based on the preliminary safety evaluation for ULOF initiating phase which shows that lower specific power density causes lower negative fuel discharge reactivity feedback as well as lower rate of Doppler reactivity. insertion.

The third condition is selected as a target for balance between limiting core void reactivity and keeping high internal conversion ratio.

(2) Core Specifications and Characteristics

Table 2 shows the major core specifications and characteristics. **Figure 2** shows the core configuration. As shown in Table 2, the core studied here is feasible under the condition of 150GWd/t of discharge average burnup, around 18 months of operation cycle length, given shielding region diameter, bundle pressure drop and specific power density. The core also reveals coolant void reactivity limited as low as 5.5$ with the core fuel column length of 1m, and break even breeding capability without radial blankets. Therefore, the core concept here has a potential for reasonable achievement of target burnup and breeding capability in consistent with reactor safety consideration.

Table 2 Specifications and characteristics of 750MWe MOX fuel core

Items	Values
Specifications	
Operation cycle length (EFPM)	26
Fuel reload batch (batches)	4
Core diameter (m)	3.7
Core column length (m)	1.0
Axial blanket length (top/bottom) (cm)	30/30
Fuel pin diameter (mm)	10.4
Fuel pins (pins/[S/A])	217
Fuel smeared density (%TD)	82
Fuel volume fraction (%) (100% dens.fuel)	37.6
Subassembly pitch (mm)	186.1
Characteristics	
Pu enrichment (Pu/HM) (%)	21.0*
Discharge burnup (GWd/t) averaged over core / averaged over core + blanket	149 / 101
Burnup reactivity swing (%?k/kk')	2.9
Breeding ratio (Core/Total) (--)	0.82/1.04
Core void reactivity ($)	5.5

* Average of inner and outer cores

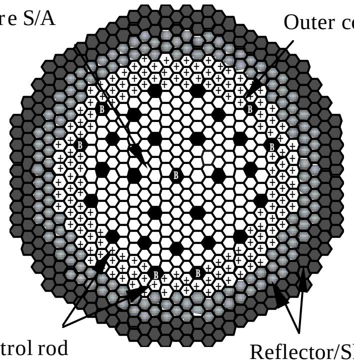

Fig. 2 Core configuration of 750MWe MOX fuel core

Some important characteristics should be discussed. The fuel pin diameter of around 10mm, which is larger than a conventional value, makes a contribution to high internal conversion ratio as 0.82 which attains break even breeding capability without radial blankets. This feature also indicates that the replacement of part of radial shielding assemblies with radial blankets can meet the requirement for higher breeding capability such as 1.2. In other words, the core studied here has flexibility to meet requirement for breeding capability with little influence on core and fuel specifications.

A potential of around 26 months of operation cycle length, which is quite longer than the target length, is achieved by the high internal conversion ratio. This feature is advantageous to improving operation rate and power cost.

As no radial blankets are loaded, as much as 100GWd/t of burnup averaged over core and blanket regions (hereinafter referred to as average burnup) is achieved, which is invaluable to improvement of fuel cycle cost. **Figure 3** is a schematic relation between average burnup and fuel cycle cost. The graph indicates that the fuel cycle cost is expected to be reduced by around 30 % if the average burnup is improved from 55GWd/t, one of the conventional values for a core with radial blanket, to 100GWd/t. On the other hand, a specification of large fuel pin diameter required for high internal conversion ratio may cause increase of core radial size, which will incur cost increase. Our rough sensitivity estimation shows that increase of core radial size has little impact on plant construction cost. Since each of fuel cycle cost and plant construction cost covers about one-third of total power cost according to our brief cost evaluation, the achievement of high internal conversion ratio by means of selection of large fuel pin diameter has a merit of reducing power cost.

III. Metal Fuel Core Design Study

1. Large Scale Core

Metal fuel has higher heavy metal content than MOX fuel. This indicates that a metal fuel core has a potential to reveal higher breeding capability and longer reactor operation cycle than a MOX fuel core. The former

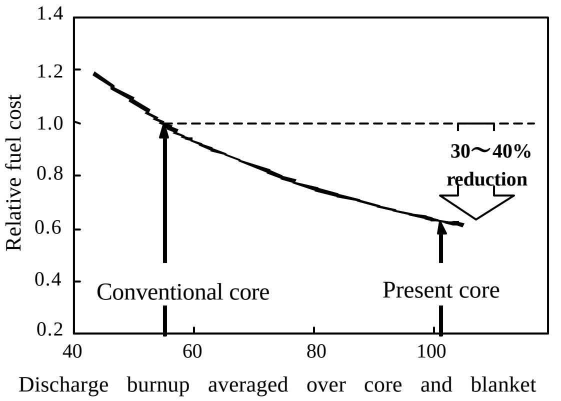

Fig. 3 Relationship between discharge burnup and fuel cost

may also need less blanket fuel inventory than the latter when both cores aim at the same level of breeding capability. Such a feature is advantageous to the metal fuel core from the viewpoints of fuel cycle cost and core dimension. The greater breeding capability also means that the metal fuel core has more flexibility to various needs for breeding capability in the fast reactor fuel cycle scenario, by adjusting the amount of blanket fuel load.

Here, the 1500MWe metal core design study is performed to show the above superiority to the MOX core with the same plant electricity output, in viewpoints of core neutronic performance and thermal hydraulics.

(1) Core Design Conditions

Major core design conditions are almost the same as those of the large scale MOX fuel core already described, except for the following items:

- Core thermal output : 3900MWth
- Core outlet/inlet temperature : 505/351°C

The core outlet temperature is limited to 505°C in this study, which is lower than that of the MOX fuel core by 45°C. This is derived from steel cladding-metal fuel compatibility, and the cladding inner surface maximum temperature is to be limited as 650°C to avoid the liquid phase formation in the fuel during steady state operation due to the inner-diffusion of elements (atoms) in the cladding and fuel.

The lower core outlet temperature leads to lower thermal efficiency of the plant and requires larger thermal output of the core. Thus, the thermal output is larger than that of the MOX fuel core by around 9%.

The isotopic composition of TRU, fission product content of as-fabricated fuel, dadding and sub-assembly duct materials correspond to the same ones as the large scale MOX fuel core. As regards the fuel pin design conditions, metal fuel irradiation behaviors give specific considerations. The cladding maximum temperature is 650°C discussed above. The fuel smeared density is 75%TD, which is standard specification of U-Pu-Zr base metal fuel, as possible appropriate value to achieve high burnup without severe FCMI (Fuel Cladding Mechanical Interaction). The fuel pin diameter is 8.5mm as the maximum allowable value in consideration of the earliest licensability of metal fuel pin design.

(2) Core Specifications and Characteristics

Table 3 shows the major core specifications and characteristics. **Figure 4** shows the core configuration.

As shown in Table 3, the core marked as "reference" reveals higher internal conversion ratio in the core fuel region than the large MOX fuel core. This brings the MOX fuel core to achievement of the same level of breeding capability as that of the large scale MOX fuel core with less axial blanket loads. This is an advantage for providing flexible breeding capability in accordance with the stage of utilizing fast reactor system.

Table 3 Specifications and characteristics of 1500MWe metal fuel core

Items	reference	longer cycle length
Specifications		
Operation cycle length (EFPM)	21	28
Fuel reload batch (batches)	4	3
Core diameter (m)	4.75	4.75
Core column length (m)	0.9	0.9
Axial blanket length (top/bottom) (cm)	40/5	40/5
Fuel pin diameter (mm)	8.5	8.5
Fuel pins (pins/[S/A])	271	271
Fuel smeared density (%TD)	75	75
Fuel volume fraction (%) (100% dens.fuel)	29.6	29.6
Subassembly pitch (mm)	187.2	187.2
Characteristics		
Pu enrichment(Pu/HM) (%)	15.5*	15.7*
Discharge burnup (GWd/t) averaged over core averaged over core + blanket	 150 72	 150 72
Burnup reactivity swing (%?k/kk')	2.1	3.1
Breeding ratio (Core/Total) (--)	0.84/1.17	0.84/1.15
Max. fast neutron fluence (E>0.1MeV) ($x10^{23}n/cm^2$)	7.4	7.7
Core void reactivity ($)	7.8	8.0

* Average of inner and outer cores

The greater internal conversion ratio also gives a superior feature of reactor operation cycle length, which is 3 months longer than that of the MOX fuel core in spite of smaller burnup reactivity swing in the metal fuel core. This property of metal fuel core indicate that the metal fuel core has a potential to reveal more attractive features for limiting core design impact on fuel cycle cost, though it has disadvantage of the core outlet temperature which is limited to lower value than MOX fuel core.

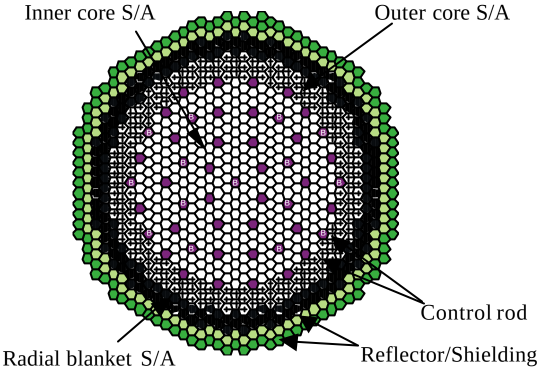

Fig. 4 Core configuration of 1500MWe metal fuel core

Table 3 shows higher fast neutron fluence than the value in Table 1. In this study, the value of fast neutron fluence in Table 3 is assumed to keep the core structure material from significant deformation, by considering reasonable evaluation of the structure material behaviors due to fast neutron irradiation. Future study on such behaviors should investigate the limit value of the fast neutron fluence.

The other case marked as "longer operation cycle length" is allowed to have the same level of burnup reactivity swing as that of the large scale MOX fuel core. Therefore, it reveals further long period of operation cycle, which is longer by about 50% than the MOX fuel core. This also gives advantage for limiting fuel cycle cost to the metal fuel core.

2. Challenge to Achieve High Core Outlet Temperature

Achievement of high core outlet temperature such as 550°C, which is identical to that of MOX fuel core in the current Feasibility Study in Japan, is a challenging issue for a metal fuel core design study, since steel cladding-metal fuel compatibility limits the inner surface maximum temperature as 650°C to avoid the liquid phase formation in the fuel described above. As it is inevitable for the core thermal-hydraulic design to give cladding hot spot temperature in the core higher than core outlet temperature, one should make design effort to reduce the diffrenece between the two temperatures.

The difference is sometimes discussed as Global Hot Channel Factor (GHCF) and Global Hot Spot Factor (GHSF) in the core. **Table 4** shows an example of GHCF expression. The hot channnel and hot spot in a core appear due to the mismatch of core power fraction/core flow rate fraction, core radial peakings of subassembly power and flow, radial power peaking in a fuel subassembly, sub-channel flow rate peaking of a fuek pin bundle, unavoidable engineering uncertainty and bulk coolant to cladding temperature rise in a fuel pin bundle sub-channel. Unavoidable engineering uncertainty is sometimes treated as Hot Spot Factor (HSF) in core thermal-hydraulic design. In usual core design, GHCF reaches 1.7 to 1.8 and temperature rise ratio between core inlet to cladding hot spot and core inlet to outlet becomes around 2 because of the temperature rise from bulk coolant to the cladding. Under such a situation, the maximum cladding inner surface temperature of a metal fuel pin will reach nearly 700°C if core design condition keeps 550°C of core outlet temperature with 395°C of core inlet temperature. Therefore, design effort should be made to reduce the GHCF to obtain 550°C of core outlet temperature with temperature limiting condition of maximum cladding inner surface temperature as 650°C.

In this section, a core design study is carried out to show a core concept which achieves core outlet temperature as high as that of MOX fuel core.

(1) Design Approach

The core design here aims at stable radial power distribution through core operation cycle and low radial power peaking to reduce GHCF. One of the core concepts which tried to achieve these features is the BREST-300 lead-cooled nitride fuel core with an idea of single Pu enrichment and radial 3 regions, in which fuel pin diameters take individual values[5), 6)]. The fuel pin diameter is larger starting from the outer core region with the same fuel pin pitch. The Pu enrichment defined by Pu/(U+Pu) is about 14wt% to maintain break-even criticality without blankets. Since the internal conversion ratio is about 1.0 with single Pu enrichment, the core can keep the radial power distribution stable during reactor operation period of time.

This kind of core concept was applied to a design study on sodium-cooled metal fuel core with 500MWe of plant electricity output[7)], in consideration of the same feature of high heavy metal content of metal fuel with that of nitride fuel. The study showed the achievement of 550°C of core outlet temperature with less than 1.7 of GHSF in comparison with about 1.9 of that of a conventional type of core. The improvement of radial power peaking as well as sub-channel flow rate peaking reduction due to grid spacer application contributes to the reduction of GHSF.

In this section, the similar core design study is tried to apply the idea of single Pu enrichment to the sodium-cooled metal fuel core with two fuel pin diameters as a more advenced specification in terms of lower impact on fuel fabrication.

(2) Core Design Conditions

Major core design conditions are almost the same as those of the medium scale MOX fuel core including core thermal output which corresponds to 750MW of plant electricity output, as well as core outlet/inlet temperature. The isotopic composition of TRU, fission product content of as-fabricated fuel, cladding and sub-assembly duct materials correspond to the same ones as the large scale MOX fuel core. As in the case of the large scale metal fuel core, the maximum cladding inner surface temperature, the fuel smeared density and the larger fuel pin diameter are 650°C,

Table 4 Cladding maximum temperature and GHCF expression

[Cladding maximum temperature]=T_{in}+GHCF·(T_{out}-T_{in})+?$T_{Na\text{-}clad}$

T_{in} : Core inlet temperature T_{out} : Core outlet temperature

GHCF : Global Hot Channel Factor (=1.7~1.8 in usual core design)= (P_c/W_c) · (F_c·F_b/F_w) ·f_w·HSF

P_c : Core power fraction W_c : Core flow rate fraction

F_c : Core radial power peaking factor (1.2~1.4)

F_b : Radial peaking factor of a fuel sub-assembly (1.0~1.2)

F_w : Sub-assembly flow rate peaking factor (1.1~1.2)

f_w : Sub-channel flow rate peaking in a fuel pin bundle (1.0~1.2)

HSF : Temperature Hot Spot Factor (around 1.2)

?$T_{Na\text{-}clad}$: Temperature difference between bulk Na and cladding surface

75%TD and 8.5mm, respectively.

(3) Core Specifications and Characteristics

Table 5 shows the major core specifications and characteristics. **Figure 5** shows the core configuration. As shown in Table 5, the internal conversion ratio of "reference" core is nearly 1.0 with no blankets, which is higher than that of the medium scale MOX fuel core in spite of smaller fuel pin diameters, due to its higher heavy metal content. This makes a contribution to achieving 24 months of reactor operation cycle length, which is over the target value of 18 months and comparable with that of the medium scale MOX fuel core.

The discharge burnup averaged over core and axial blanket regions is smaller than that of the medium scale MOX fuel core due to consideration of limit of fast neutron fluence. If the design is allowed to leave this limit out of consideration ("high burnup" core in Table 5), as in the case of the large scale metal fuel core, the burnup is around 130GWd/t, which is superior to that of the medium scale MOX fuel core.

The results of thermal-hydraulic design for the reference core are listed in **Table 6** to show the feasibility of achieving 550°C of core outlet temperature. The GHSF of cladding temperature is below 1.7 in the core studied here, whereas it is nearly 1.9 in a conventional metal fuel core.

Table 5 Specifications and characteristics of 750MWe metal fuel core

Items	reference	high burnup core
Specifications		
Operation cycle length (EFPM)	24	23
Fuel reload batch (batches)	4	6
Core diameter (m)	3.75	3.96
Core column length (m)	0.95	0.9
Axial blanket length (top/bottom) (cm)	0/0	15/0
Fuel pin diameter (Inner/outer) (mm)	8.0/8.5	7.8/8.3
Fuel pins (pins/[S/A])	271	271
Fuel smeared density (%TD)	75	75
Fuel volume fraction (%) (Inner/Outer:100% dens.fuel)	29.4/33.2	29.8/33.7
Subassembly pitch (mm)	176.8	171.1
Characteristics		
Pu enrichment(Pu/HM) (%)	12.2	12.9
Discharge burnup (GWd/t) averaged over core averaged over core + blanket	 88 --	 152 134
Burnup reactivity swing (%?k/kk')	0.52	1.23
Breeding ratio (Core/Total) (--)	1.03/1.03	0.94/1.03
Max. fast neutron fluence (E>0.1MeV) (x10^{23}n/cm^2)	5.3	8.4
Core void reactivity ($)	7.8	8.0

Table 6 Summary of core thermal-hydraulic design of metal fuel core

	The present study		Conventional	
	Inner	Outer	Inner	Outer
Core inlet/outlet temperature (°C)	395/550		420/540	
F_c*	1.38	1.23	1.37	1.33
F_b*	1.02	1.04	1.00	1.05
F_w*	1.20	1.16	1.18	1.18
f_w*	1.03	1.09	1.15	1.15
HSF*	1.21	1.21	1.21	1.21
GHCF*	1.54	1.54	1.64	1.64
Coolant hot spot temperature (°C)	633	634	617	617
Cladding hot spot temperature (°C)	648	648	645	650
GHSF	1.63	1.63	1.88	1.92

* See Table 4.

Figure 6 shows the low radial power peaking and remarkably small power swing during reactor operation cycle, and indicates a contribution to keeping the maximum cladding inner surface temperatures within the limit value, 650°C.

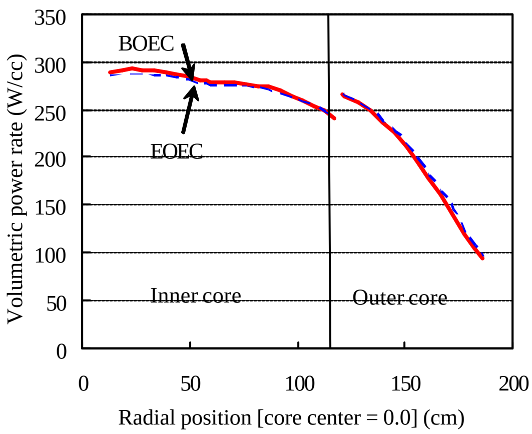

Fig. 6 Radial power profile of 750MWe single Pu enrichment type metal fuel core

IV. Conclusion

Sodium-cooled core design studies are performed. MOX fuel core with axial blanket partial elimination subassembly due to safety consideration is studied. A 750MWe MOX fuel core with high internal conversion ratio possesses capability of achieving 26 months of operation cycle length and 100GWd/t of burnup averaged over core and blanket, which are superior characteristics in view of reducing cost of power generation. Metal fuel core is also studied, and its higher breeding capability reveals a potential of better core performance such as longer operation cycle length for the same power generation level of 1500MWe, though core outlet temperature is limited to lower level due to steel cladding-metal fuel compatibility concerns. Another metal fuel core concept using single Pu enrichment and two radial regions with individual fuel pin diameters achieves 550°C of core outlet temperature identical to that of MOX fuel core, keeping operation cycle length comparable with that of MOX fuel core. This series of study results show that sodium-cooled MOX and metal fuel cores have a high flexibility in satisfying various needs including fuel cycle cost and breeding capability, depending on the stage of introducing commercialized fast reactor cycle system.

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This paper includes the outcome of collaborative study between Japan Nuclear Cycle Development Institute and The Japan Atomic Power Company (that is the representative of 9 electric utilities, Electric Power Development Company and JAPC) in the accordance with “the agreement about the development of a commercialized fast breeder reactor cycle system”.

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