International
Nuclear
Fuel
Cycle
Evaluation

INFCE

INFCE/DEP./WG.8/50

The Use of Medium Enriched Uranium Fuel for Research Reactors

Attention Microfiche User,

The original document from which this microfiche was made was found to contain some imperfection or imperfections that reduce full comprehension of some of the text despite the good technical quality of the microfiche itself. The imperfections may be:

- missing or illegible pages/figures
- wrong pagination
- poor overall printing quality, etc.

We normally refuse to microfiche such a document and request a replacement document (or pages) from the National INIS Centre concerned. However, our experience shows that many months pass before such documents are replaced. Sometimes the Centre is not able to supply a better copy or, in some cases, the pages that were supposed to be missing correspond to a wrong pagination only. We feel that it is better to proceed with distributing the microfiche made of these documents than to withhold them till the imperfections are removed. If the removals are subsequestly made then replacement microfiche can be issued. In line with this approach then, our specific practice for microfiching documents with imperfections is as follows:

1. A microfiche of an imperfect document will be marked with a special symbol (black circle) on the left of the title. This symbol will appear on all masters and copies of the document (1st fiche and trailer fiches) even if the imperfection is on one fiche of the report only.

2. If imperfection is not too general the reason will be specified on a sheet such as this, in the space below.

3. The microfiche will be considered as temporary, but sold at the normal price. Replacements, if they can be issued, will be available for purchase at the regular price.

4. A new document will be requested from the supplying Centre.

5. If the Centre can supply the necessary pages/document a new master fiche will be made to permit production of any replacement microfiche that may be requested.

The original document from which this microfiche has been prepared has these imperfections:

→ ☒ missing pages/figures numbered: Table 3 missing

☐ wrong pagination

☐ poor overall printing quality

☐ combinations of the above

☐ other

INIS Clearinghouse
IAEA
P. O. Box 100
A-1400, Vienna, Austria

INFCE/WG-8/JAPAN/DOC.10

THE USE OF MEDIUM ENRICHED URANIUM FUEL FOR RESEARCH REACTORS

JANUARY, 1979

JAPAN

I. Introduction

In the previous paper" Evaluation of Reseach Reactors " (INFCE/WG-8/JAPAN/DOC.4), described are the impacts on our research reactors and various R and D programs in the nuclear energy utilization due to use of less-than-highly-enriched (about 20 %) uranium fuel. There we have concluded that the use of 20 % enriched uranium fuel replacing the current 93 % enriched uranium fuel is not promising for our research reactors, because it reduces greatly the current performance of our reactors and thus results in the significant increase of fuel cycle cost and the fatal deceleration of various R and D programs, which are important for international collaborations.

The evaluation described in the present paper concerns the use of medium enriched uranium fuel for our research reactors. The underlying assumptions set up for the evaluation are as follows:

(1) At first, the use of alternative fuel should not affect, even to a small extent, research and development programs in nuclear energy utilization , which were described in the previous paper. Hence the use of lower enrichment fuel should not cause any reduction in reactor performances.

(2) The fuel cycle cost for operating research reactors with alternative fuel, excepting R and D cost for such fuel, should not increase beyond an acceptable limit.

(3) The use of alternative fuel should be satisfactory with respect to non-proliferation purposes, to the almost same degree as the use of 20 % enriched uranium fuel.

The alternative fuel must have a high reliability as before. If a sufficient time is available for development of high performance fuel, we could attain these goals. The present evaluation is based on this implicite optimistic assumption.

Every sensitive facility including any research reactor is under control of IAEA safeguards and Japanese government's safeguards. The latter system consists of physical protection, material control and materials accounting, which are defined properly according to Japanese social condition and international climate.

For the reprocessing of spent fuels from research reactor and re-enrichment of recovered uranium, we depend on oversea countries following the international or bilateral arrangement. Therefore, the only risk to proliferation arises from diversion of enriched uranium by non-state entity. If we could use 20 % enriched uranium for research reactors, the annual need of fresh fuels at any research reactor on fuel fabrication site would become less than a hundred kilograms, which is far below the critical mass of fully reflected sphere of 20 % enriched uranium metal. In the same sense, we could use medium enriched uranium fuels, if the inventory of fresh fuels at each reactor or fuel fabricator site does not increase extraordinarily compared with 20 %EU fuel. However, we should confirm thoroughly the performance of medium enriched uranium fuel before planning of fuel replacement. Because we believe firmly that any non-state entity in japan is not able to construct clandesteinly their own reprocessing or enriching facility in advance of the seizure of special nuclear material, the use of medium enriched uranium fuel is sufficient to suppress any incentive of non-state entity to divert research reactor fuel for production of nuclear explosives. The acquisition of sufficient amount of special nuclear material for nuclear explosives is impracticable even by re-enrichment of diverted material.

Taking the above consideration into account, the evaluation is made on the use of medium enriched uranium fuels for the Japan Research Reactor No.2 (JRR-2) and the Japan Material Testing Reactor (JMTR).

2. The case of JRR-2

Basic assumption

As described in the previous paper, JRR-2 serves for common use. Hence any alternative fuel should be designed to maintain the present performance of JRR-2 as far as possible. Especially, it is desirable that neutron flux, excess reactivity,thermo-hydraulic condition and operation mode remain unchanged. The present JRR-2 uses two types of fuel element, that is, the MTR type fuel element and the cylindrical type fuel element. Because the latter has a better nuclear performance, we adopt the cylindrical fuel element for the present evaluation, so that the reactor core consisting of only this type of fuel elements is considered, different from the present JRR-2 core.

The parameter range of fuel plate

In the present evaluation, we assume that fuel is fabricated as U-Al alloy or (UAl_x + Al) by powder metallurgical method. The fuel plate of the present JRR-2 core are fabricated by the picture frame method. Three fuel plates form a cylinder by support combs and the fuel element consists of 5 concentric cylinders with 3 mm windages by the rollswage method. The thickness of fuel meat and cladding is 0.51 mm and 0.38 mm respectively. U-235 content in a cylindrical fuel element is 195 g.

In order to find an appropriate lower limit of enrichment for alternative fuel, we change the thickness of fuel meat, and content of U-235 independently. The thickness of cladding, however is not changed, because it is related with the confinement capability of fission products, and a thin cladding will not be accepted by safety consideration. For the thickness of meat, we choose three cases; 0.51 mm, 0.76 mm and 1 mm. For the case 1 mm thickness, there might be a difficulty associated with the fabrication technique. For the U-235 content, we choose four cases; 195 g, 210 g, 230 g and 250 g. Table 1 shows the change of uranium loading density in each fuel meat due to the change of uranium enrichment which varies from 20% to 45%. Table 2 shows the range of fuel plate parameters, when the upper limit of uranium loading density is set to the same value as the maximum of the present JRR-2 fuel meat. The table shows that if the thickness of fuel meat could be doubled, 45% enriched uranium might be used as JRR-2 fuel. However because of thick fuel meat, the rate of rejected fuel plate will considerably increase in fabricating the curved plate for cylindrical fuel element. The reader will understand easily how the range of fuel plate parameters extends by the upper limit of uranium loading density. Table 3 shows the range of fuel plate parameters, when 40% uranium loading density is attained. The table shows 45% enriched uranium might be utilized for JRR-2, even the present meat thickness is maintained. The thermo-hydraulic characteristics will not be changed significantly, in the range of parameters considered here.

The nuclear characteristic

Reactor physics calculation has been made for several typical fuel parameters. Neutron flux is not changed so signigicantly. The maximum excess reactivity built in the present JRR-2 core is 15.5% $\Delta k/k$. The corresponding value of the effective multiplication factor is 1.17. In Table 4, the calculated effective multiplication factors are shown for several fuel parameters. The figures in the parenthesis are extrapolated from calculated results. The region surrounded by the bold frame shows the range of fuel parameters where k_{eff} exceeds 1.17. When we compare Table 4 with Table 3 we obtain the real range of fuel parameters. Considering the error involved in the present calculation and the flexibility of JRR-2 utilization, k_{eff} of about 1.19 is desirable. The range will become narrower than that defined by Table 3 and 4.

It can be seen from Table 1 and 4 that if maximum uranium loading density become 60%, then the range of allowerable fuel parameters will be extended. However, if lower limit of k_{eff} is set as 1.19, 30% enriched uranium is hardly used for JRR-2.

If the operation mode is not changed, the fuel inventory necessary to assure the steady reactor operation is not changed significantly. That is, 20 ~ 25 kg uranium (45% U-235) is required annually. The stock of fuel needed is about 10 ~ 12 kg (45% U-235), whereas fuel of the same anount is in the core. If the length of cylce could be increased using fuel element of higher U-235 content (250 g U-235/element), inventory of fuel may be decreased. However, in this case, this decrease does not seem so significant from non-proliferation consideration.

3. The case of JMTR

Basic assumption

JMTR is the only material testing reactor in Japan. Therefore the present performance of JMTR should be remained unchanged. Especially, mode of operation, number of fuel elements, number of loaded irradiation capsule, neutron flux should not be made worse. In the future, fuel production for DT burning fusion devices is anticipated by using JMTR. Hence we want to reserve flexibility for increasing U-235 content of fuel element. Also for the sake of operational flexibility, burnable poison fuel will be considered in the future.

The parameter range of fuel plate

JMTR uses modified ETR type fuel element. Different from JRR-2, we do not consider the cylindrical fuel element here. The parameters of the present JMTR fuel plate is the same as JRR-2. The present fuel element contains 279 g U-235. We consider here three cases; 320g U-235, 350g U-235 and 400g U-235 content. The first one is for replacement of the present fuel, the second one is for the production of fuel for fusion devices, and the last one is for the burnable poison fuel. The thickness of fuel cladding remains unchanged. However for the thickness of fuel meat, we consider four cases; 0.51mm(present), 0.60mm, 0.70mm and 0.80mm. Table 5 shows the change of uranium loading density in each fuel meat due to the change of uranium enrichment which is changed from 20% to 45%. The Table shows, if the maximum uranium loading density is 22% as same as the present JMTR fuel, we cannot use even 45% enriched uranium for JMTR.

Nuclear characteristic

If we fix uranium loading density and change uranium enrichment, we will have different U-235 content per fuel element. Table 6 gives the effective multiplication factors corresponding to enrichment.

JMTR is operated with the excess reactivity of 11.0% $\Delta k/k$, so that the lower limit of k_{eff} should be about 1.12. Table 6 shows 40% enriched uranium can be used for JMTR, when we adopt thicker fuel meat with uranium loading density of 35w/o. However we must consider thermo-hydraulic condition with this fuel. Table 6 shows also k_{eff} for 40 w/o uranium loading density. The 30% enriched uranium fuel is not acceptable for JMTR. When we could use 60 w/o uranium loading density, JMTR could be operated with 30% enriched uranium.

The fuel inventory is not changed significantly. The annual requirement of fuel will be in the range from 80 kg to 115kg(45% U-235). The stock of fuel needed is in the range from 30 kg to 45 kg(45% U-235), whereas fuel in the core is 15~22 kg.

Thermo-hydraulic consideration

To compensate increase of fuel meat thickness, there are two means. One is decreasing clad thickness and the other is to make narrower the cooling channel. The first one is undesirable due to risk of FP leakage. In case of JMTR, maximum fuel plate surface temperature is limited below 205°C, for preventing corrosion. By this reason, the hot spot factor is restricted below 3.92 for the present JMTR core. If we make the fuel plate thick, the upper limit of hot spot factor should be lowered, because the cooling channel becomes narrower. Fig. 1 shows the relation between the hot spot factor or the coolant velocity and the thickness of meat.

When the thickness of meat is 0.6mm, the limit of hot spot factor becomes 3.88. However, such hot spot factor upper limit does not cause any trouble for operating JMTR with almost same core configuration as the present core.

If we assume target uranium loading density as 45 w/o, then we can use enrichment about 40%. However we must be conservative considering uncertainty of calculated k_{eff}. We assume that this uncertainty will be reflected to the uranium loading density. So we must make allowances for the target uranium loading density.

Thus 40 w/o is set for maximum loading density attained by the near term R and D of fuel. Fuel plate parameters, which could be accepted, are indicated by the mark "○" in Table 5.

JMTR has the cooling system as described in the previous paper. The pumps are so designed that the nominal flow rate is 6000m^3/hr and the maximum flow rate is 6600m^3/hr. Under the condition of loading 60 irradiation capsules, which is the present JMTR utilization, we need the flow rate of 6000m^3/hr. With full load of irradiation capsule (100 capsules), we will need 6300m^3/hr that is considered as the actual maximum flow rate attained by this pump system.

On the other hand, when the thickness of meat is made thicker, we must increase the coolant flow rate in the core in order to maintain fuel plate surface temperature below the present upper limit 205°C. We will need the flow rate 6200m^3/hr for 0.7mm fuel meat thickness and 6300m^3/hr for 0.8mm fuel meat thickness, with load of 60 capsules.

Hence, if load of capsules is increased, for example to produce fusion reactor fuel, we might have to replace the pump with more powerful one, because exchange of the impeller is impossible for the present pump. The cost for this replacement is significant amount and we must shut down the operation during a rather longer period.

4. Conclusion

It was shown that 45% enriched uranium could be used for both for JRR-2 and JMTR under the condition that the technical basis for fabricating such fuel might be established.

However, considering uncertainties due to various factors, higher enrichment is favourable. It seems that, with respect to the proliferation resistance, there is no significant differences between medium and 20% enrichment.

It should be considered that in Japan we have only one fabricator of research reactor fuel. The specification of fabricated fuel plate there, is restricted only one set of parameters as used for JRR-2 and JMTR.

If there are two different specifications of fuel plate, availability of such small amount (20kg a year) of fuel is problematic. So we must standardize the specification of research reactor fuel plate. Considering adoptability for JMTR , which has much difficulty, we must choose 40 w/o loading density as the target of R and D for research reactor fuel. It is predicted by advocates for use of less-than-highly-enriched uranium fuel that 40 w/o uranium loading density can be reached by a near term, may be three years , R and D. However , it is not clear at present whether the fraction of rejected fuel could be decreased to the current degree. If the fraction is significantly large, cost of fuel fabrication will increase considerably, and such increase will not be accepted for Japanese research reactors.

In any case we must allocate a significant amount of money for R and D, and equipments for fuel fabrication.

Considering various impact due to use of lower enrichment fuel, it is better to be conservative for reduction of enrichment. It can be concluded that in Japan, the target lower limit of enrichment should be 45% and the target upper limit of uranium loading density should be 40 w/o.

If the fabrication technique is established and sufficient data is accumlated, we can start the fuel replacement plan for both reactors. perhaps the replacement will take 1~2 years including the time for obtaining the license from the government.

Table 1 Uranium loading density corresponding uranium enrichment(JRR-2)

Fuel plate (mm)	U-235 content (g/element)	Enrichment(%)				
		20	30	40	45	93
thickness of	195	39.56	29.73	23.81	21.56	
meat: 1	210	41.51	31.40	25.24	22.99	
thickness of	230	43.99	33.53	27.09	24.72	
clad: 0.38	250	46.30	35.56	28.81	26.38	
thickness of	195	47.40	36.54	29.73	27,19	
meat: 0.76 (0.03")	210	49.50	38.42	31.40	28.77	
thickness of	230	52.11	40.80	33.43	30.79	
clad: 0.38	250	54.53	43.05	35.56	32.71	
thickness of	195	59.11	47.40	39.56	36.54	
meat: 0.5 (0.02")	210	61.27	49.50	41.52	38.42	
thickness of	230	63.92	52.11	43.99	40.81	
clad: 0.38	250	66.32	54.53	46.30	43.05	
thickness of						
meat:						
thickness of						
clad:						

Table 2 Range of fuel plate parameters when maximum uranium loading density is 24%(JRR-2)

Fuel plate (mm)	U-235 content (g/element)	Enrichment(%)				
		20	30	40	45	93
thickness of meat: 1 (0.04") thickness of clad: 0.38	195			23.81	21.56	
	210				22.99	
	230					
	250					
thickness of meat: 0.76 (0.03") thickness of clad: 0.38						
thickness of meat: 0.51 thickness of clad: 0.38						
thickness of meat: thickness of clad:						

Table 4 Range or fuel parameters and k_{eff} (JRR-2)

Fuel plate (mm)	U-235 content. (g/element)	Enrichment(%)					fuel element type
		20	30	40	45	93	
thickness of meat: 1 thickness of clad: 0.38	195	1.132	1.152	1.166	1.171		S-1
	210 (220)	1.153					
	230						
	250	(1.166)	(1.186)				
thickness of meat: 0.76 thickness of clad: 0.38	195	(1.138)	(1.158)	(1.173)	1.179		S-2
	210				(1.184)		
	230				(1.20)		
	250				(1.212)		
thickness of meat: 0.51 thickness of clad: 0.38	195	(1.15)	(1.170)	(1.185)	1.192	1.231	S-3
	210					(1.250)	
	230					(1.274)	
	250					(1.300)	
thickness of meat: thickness of clad:							

Table 5 Uranium loading density(w/o) in fuel meat (JMTR)

Fuel plate (mm)	U-235 content (g/element)	Enrichment(%)				
		20	30	40	45	93
thickness of meat: 0.51 thickness of clad: 0.38	320	67	53	43	○40	
	350	70	56	46	42	
	400	73	60	49	46	
thickness of meat: 0.60 thickness of clad: 0.38	320	62	48	39	35	
	350	65	51	41	37	
	400	68	54	45	41	
thickness of meat: 0.70 thickness of clad: 0.38	320	58	44	35	32	
	350	61	47	37	34	
	400	65	50	41	37	
thickness of meat: 0.80 thickness of clad: 0.38	320	53	40	32	29	
	350	56	42	34	31	
	400	60	46	37	34	

Table 6 The effective multiplication factors (JMTR)

Fuel plate (mm)	uranium loading density (w/o)	Enrichment(%)				
		20	30	40	45	93
thickness of meat: 0.51 thickness of clad: 0.38	35	0.90	1.01	1.07	1.09	
	40	0.95	1.04	1.10	1.12	
	60	1.07	1.13	1.17	1.19	
thickness of meat: 0.60 thickness of clad: 0.38	35	0.94	1.04	1.10	1.12	
	40	0.98	1.07	1.12	1.14	
	60	1.09	1.15	1.18	1.19	
thickness of meat: 0.70 thickness of clad: 0.38	35	0.97	1.06	1.11	1.13	
	40	1.00	1.09	1.13	1.15	
	60	1.10	1.16	1.18	1.19	
thickness of meat: 0.80 thickness of clad: 0.38	35	1.01	1.09	1.14	1.16	
	40	1.04	1.11	1.16	1.17	
	60	1.12	1.17	1.19	1.20	

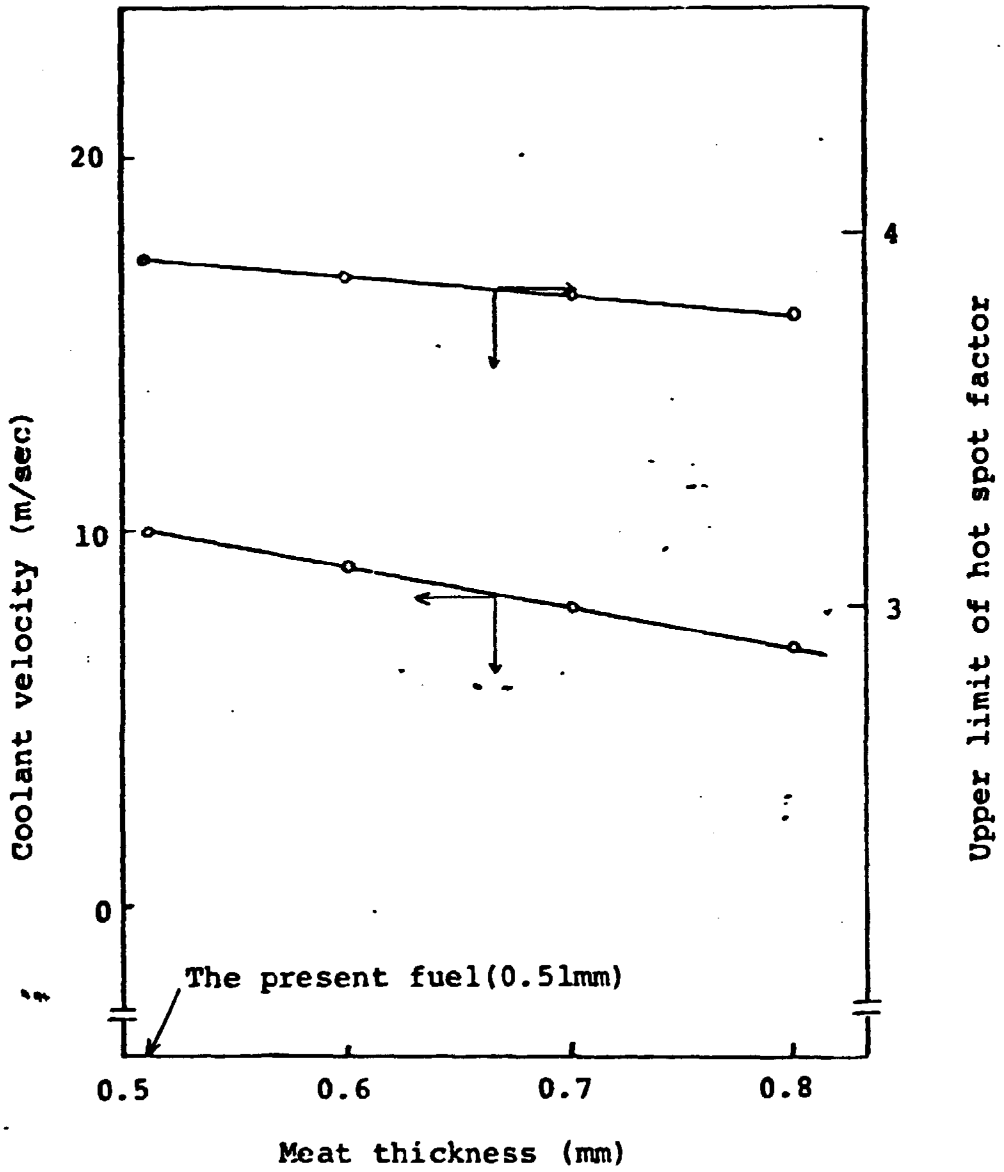

Fig. 1 The coolant velocity between fuel plate and the upper limit of hot spot factor VS the meat thickness (the core pressure difference is constant)

Summary INFCE/WG-8/JAPAN/DOC.10

"The use of medium enriched uranium fuel for research reactors"

The evaluation concerns the use of medium enriched uranium fuel for JRR-2 and JMTR. The underlying assumptions set up are: (1) The use of lower enrichment fuel should not cause any reduction in reactor performances. (2) The fuel cycle cost for operating research reactors with alternative fuel should not increase beyond an acceptable limit. (3) The use of alternative fuel should be satisfactory with respect to non-proliferation purposes.

In order to find an appropriate lower limit of enrichment for alternative fuel, we change the thickness of fuel meat, and content of U-235 independently. The thickness of cladding, however, is not changed, because it is related with the confinement capability of fission products, and a thin cladding will not be accepted by safety consideration.

We adopt the cylindrical fuel element for JRR-2 evaluation. For the thickness of meat, we choose three cases: 0.51mm,0.76mm and 1mm, although a difficulty associated with the fabrication technique for the last case. Reactor physics calculation has been made for several fuel parameters. Neutron flux is not changed so significantly. The maximum excess reactivity built in the present JRR-2 core is 15.5% $\Delta k/k$. The corresponding value of the effective multiplication factor is 1.17. Considering the error involved in the present calculation and the flexibility of JRR-2 utilization, keef of about 1.19 is desirable. From table 1 and 4, it can be seen that if the maximum uranium loading density becomes 60% and keff of 1.17 is sufficient for JRR-2, then 30% enrichment is allowed for JRR-2 fuel. However if the lower limit of keff is set as 1.19, 30% enriched uranium is hardly used for JRR-2. If the operation mode is not changed, the fuel invently necessary to assure the steady reactor operation is not changed significantly.

For JMTR, we use modified ETR type fuel elements. The present fuel element contains 279g U-235. We consider here three cases; 320g, 350g and 400g U-235, considering future utilization of JMTR. For the thickness of fuel meat we consider four cases; 0.51mm, 0.6mm, 0.7mm and 0.8mm. Reactor physics calculation shows that 40% enriched uranium can be used for JMTR, when we adopt thicker fuel meat with uranium loading density of 35w/o. However from thermo-hydraulic consideration this fuel is not acceptable for JMTR. If we assume target uranium loading density as 45w/o, then we can use enrichment about 40%. Considering uncertainties of calculated keff, 40w/o is set for the maximum loading density and 45% is considered as the lowest enrichment attained by the near term R and D of fuel.

Considering various impact due to use of lower enrichment fuel, it is better to be conservative for deduction of enrichment. It can be concluded that in Japan, the target lower limit of enrichment should be 45% and the terget upper limit of uranium loading density should be 40w/o.