Proceedings HTR2006:
3rd International Topical Meeting on High Temperature Reactor Technology
October 1-4, 2006, Johannesburg, South Africa

C00000050

A SCENARIO FOR THE DEPLOYMENT OF HTRs TYPE GTMHR USING REACTOR-GRADE PLUTONIUM

Lionel BOUCHER, Jean-Paul GROUILLER, Patrick BOURDOT, Jean Christophe KLEIN

CEA DEN/DER/SPRC, Bld 230, CE Cadarache, 13108 St Paul lez Durance, FRANCE

Tel. +33 4 42 25 66 43, Fax. 33 4 42 25 11 11, E-mail: lionel.boucher@cea.fr

Dominique GRENECHE

AREVA-NC/ DRD, Tour AREVA-F 92084 Paris la défense cedex

Tel + 33 1 47 96 79 92, Fax + 33 1 47 96 79 99, E-mail : dgreneche@cogema.fr

INTRODUCTION

The French nuclear park with an installed electricity power capability of 60 GWe produces about 11 to 12 metric tons of plutonium per year. With the La Hague plant, 850 metric tons of UOX spent fuel are currently reprocessed, which allow to recover around 8.5 tons of plutonium for the fabrication of 100 tons of MOX fuel at the MELOX plant. This MOX fuel is loaded in 20 PWRs (900 Mwe), using 30% MOX loading in the core.

In the coming years, one of the objectives of the French national utility EDF is to achieve a full equilibrium between plutonium produced in UOX fuels of its nuclear park and plutonium used in MOX fuels.

On the basis of this recycling strategy, and taking into account a possible development of HTRs, it is interesting to study what would be the performances of a nuclear park composed of LWRs and HTRs with regard to the plutonium management.

In this frame, a common program study between the CEA and AREVA-NC has been carried out, in order to assess the capability of a modular HTR (GTMHR type) to stabilize the total Plutonium inventory in the case of the French nuclear park.

The HTRs are fed out with fuel assemblies containing coated particles with Plutonium oxide. This concept of fuel allows, through a very high burnup and a high efficiency for the consumption of Plutonium.

2 PRESENTATION OF THE SCENARIO

2.1 Initial situation

The initial situation is the year 2010. In 2010, the Plutonium is monorecycled in the PWR with MOX fuel. The composition of the fuel in the nuclear park is 12% MOX and 88% UOX. The interim storage of spent fuel contains 1550 tons of MOX and 10600 tons of UOX. The total Plutonium inventory (reactors + fabrication plant + interim storages) is equal to 279 tons.

2.2 Main assumptions

The main assumption is that the production of electricity with nuclear energy in France will go on at the same level during the 21th century : 400 TWhe per year, corresponding to an installed capacity of 60 GWe. Consequently, two different strategies can be applied, taking into account the resources in natural Uranium :

<u>Scenario with HTR deployment</u> :

The resources in natural Uranium are sufficient to feed a nuclear park with LWR during the XXIth century. The deployment of the fast reactors can be delayed and the stabilization of the inventory in nuclear materials, and particularly Plutonium, becomes necessary. In this case, the deployment of HTR type GTMHR using fuel with Plutonium gives the possibility to stabilize the Plutonium inventory in the nuclear Park. This scenario is the object of the present paper.

<u>Alternative scenario : Fast reactor deployment</u> :

The decrease of the natural resources in natural Uranium will imply the deployment of the fast generation 4 reactors, to have a better use of Uranium 238. In this case, it is necessary to build a sufficient Plutonium stock pile for the deployment of the fast reactors. For instance, for a 60 GWe fast reactor park, the total Plutonium inventory needed is around 800 tons. For this scenario, the deployment of HTR with a high consumption of Plutonium is contradictory with the necessity to build a Plutonium stock pile for the fast reactors. This scenario has already been presented [1], [2].

2.3 Description of the scenario

In the scenario, we assume that the renewal of the current nuclear fleet will start in 2020, with EPR and also HTR. The HTR are deployed in 2025, at a pace of 2 GWe per year (7 HTR are deployed each year). At the same date, the mono recycling of Plutonium in the LWR is stopped, so as to keep Plutonium for the HTR. In 2031, the nuclear park is stabilized and the electricity production comes at 20% from the HTR and 80 % from the PWR (fed at 100% with Uranium dioxide fuel).

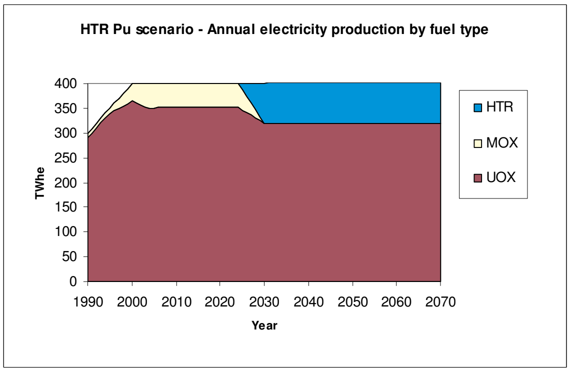

Fig. 1 : Annual electrical production

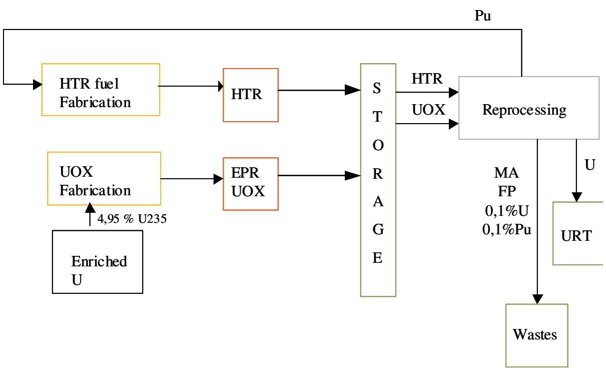

Fig. 2 : Nuclear Park after 2031

2.4 Neutronic assumptions of the HTR concept

The reactor core consists of 102 prismatic block-type fuel assemblies surrounded by internal and external graphite reflector. Standard/control fuel assembly contains 216/174 fuel compacts and 108 Helium channels (burnable poison are not considered here). The fuel is made of $PuO_{1.8}$ TRISO particles (ϕ_{fuel} = 200 µm, $\phi_{particle}$ = 630 µm) and different Plutonium isotopic compositions are considered. Thermal power is 600 MW.

The irradiation time for each HTR cycle has been fixed at 280 EFPD. To reach this objective, it is necessary to increase the total mass of heavy nuclides loaded in core when the Plutonium fuel contains low fissile nuclides (for example for high burn up PWR spent fuel). The particles content increases with the mass of heavy nuclides (HN) but must remains lower than 46%, assumed as the technological limit. In fact, the moderation ratio becomes rapidly too small to have a good neutronic balance even for poor fissile material, then the particle content cannot exceed 28%. The burnup of the fuel (in GWd/tHM) is given in the following table for 5 different plutonium fuel.

Fissil Plutonium %	Particle content	Mass Pu/reload (Kg)	burnup (GWd/tHM)
63.2	15.45%	275	810
55.07	19.66%	350	585
51.26	22.47%	400	450
49.98	23.41%	417	405
48.92	28.09%	500	315

Table 1 : fuel reload for the HTR

2.5 Reactor assumptions

The reactor assumptions are presented in the following table :

		PWR UOX	**PWR MOX**	**HTR**
Fuels				
Burnup	GWd/t HM	60	50	315<BU <810
Minimum cooling time	y	5	5	5
Fabrication time	y	2	2	2
Fresh fuel ^{235}U enrichment	%	4,95	0,25	0,25
Moderation ratio		2	2	Depends on the particle content
Cores				
Electrical nominal power	GWe	1,5	1,5	0,284
Efficiency	%	34	34	47
Production factor	%	76	76	76
Heavy metal masses	tons	128,9	128,9	0,825 < mass <1,500
Cycle length	FPED	410	410	280
Core management		1/4	1/4	1/3

Table 2 : Reactor assumptions

2.6 Processing assumptions

The processing of HTR spent fuel is necessary for two reasons :

1. The aim of the scenario is to stabilize the Plutonium inventory. For that purpose, it is necessary to process the HTR spent fuel to prevent the accumulation of the Plutonium contained in this spent fuel.
2. The Plutonium produced in the PWR is not sufficient to fed the HTR. Once the MOX spent fuel is processed, it is necessary to recover the Plutonium contained in the HTR spent fuel, in spite of its bad quality.

Thus, the processing priorities applied in the scenario are :

- Until 2025, only UOX spent fuel is processed
- From 2025 to the end of the study, UOX fuel is reprocessed, mixed with MOX fuel, and then with HTR spent fuel. The proportion between UOX and MOX fuel is 70% and 30%.

The processing capacity is adapted to the needs in Plutonium for the reactors

3 TOOL OF CALCULATION

The calculation of the scenario have been performed with the code COSI [3]. COSI is a software developed by the Nuclear Energy Direction at CEA, the French Atomic Energy Commission. This code simulates a pool of nuclear electricity generating plants with its associated fuel cycle facilities. It has been designed to study short, medium and long term options for the introduction of various types of nuclear reactors and for the usage of associated nuclear materials. It permits to study transition scenarios and gives due consideration to isotopic composition essentially of uranium, plutonium, minor actinides and some fission products.

The “COSI” code permits to explore different electronuclear scenarios involving :

- A pool of reactors : Pressurized Water Reactors (PWR), Sodium cooled Fast Reactors (SFR) , High Temperature Reactors (HTR), Gaz cooled Fast Reactors (GFR),
- The whole of the fuel facilities,
- The different types of fuels,

In COSI, the CESAR code [5] is used for the in-pile calculations. It solves a differential equation system that describes the fuel evolution in pile. The solving method is the RUNGE KUTTA method.

The COSI code uses cross sections generated after neutronic calculations performed with the APOLLO2 code [4] in a cylindrical geometry of the core, taking into account both fuel and reflectors zones. The code performs fuel management scheme, assuming that 1/3 of the core is reloaded with fresh assemblies after each cycle. Then 10 cycles are performed to reach equilibrium and to have the correct burn up of the discharged fuel assemblies.

4 RESULTS

4.1 Quality of the Plutonium

The quality of the Plutonium is the mass content of fissile isotopes :

$$Quality = \frac{Pu239 + Pu241}{\sum_{i=238}^{i=242} Pu_i}$$

The quality of the Plutonium in the fresh fuel is the results of the processing assumptions. The Plutonium used for the fresh fuel comes from a mix between :

- Plutonium coming from LWR spent fuel : UOX spent fuel and MOX spent fuel, with a high quality
- Plutonium coming from HTR spent fuel, with a low quality

For the HTR, we assume that the Pu quality of the fresh fuel cannot be lower than 49% corresponding to a particle content of 28% (§2.4).

However, to maintain this quality during the scenario, the needs in processing for UOX spent fuel is higher than the annual production. Thus, the quantity of UOX spent fuel available for processing decreases continuously and is equal to 0 in 2080. As a consequence, this scenario cannot be extended after 2080.

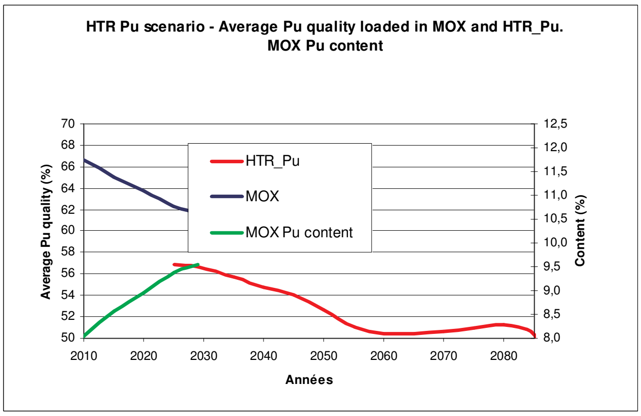

Fig.3 : Plutonium quality in the fresh fuel

4.2 Spent fuel interim storage

The spent interim storage contains the spent fuel unloaded from the reactors. For some calculation reasons, the values for HTR spent fuel represents only the actinides and fission products.

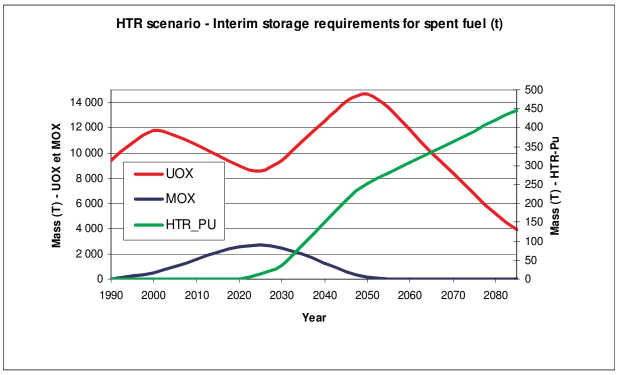

Fig.4 : Spent fuel interim storage

At the end of the scenario, all the MOX spent fuel has been processed and the amount of UOX spent fuel available for processing is equal to 0. The amount of HTR spent fuel increases rapidly. In order to keep a sufficient quality for the Plutonium, it is necessary to process more UOX spent fuel than it is produced in the reactors.

4.3 Plutonium inventory

The Plutonium inventory is the Plutonium contained in all the reactors, fabrication plants, processing plants, and interim storages. The results demonstrates the capacity of the HTR using Plutonium to decrease the Plutonium inventory in the park. The number of HTR necessary to decrease the Plutonium inventory is equal to 42.

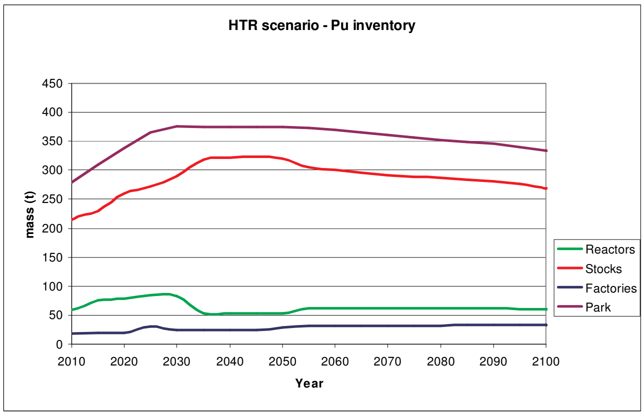

Fig. 5 : Plutonium inventory

4.4 Minor actinides in spent fuel and in the wastes

The following figure gives the minor actinides inventory in the spent fuel and in the waste.

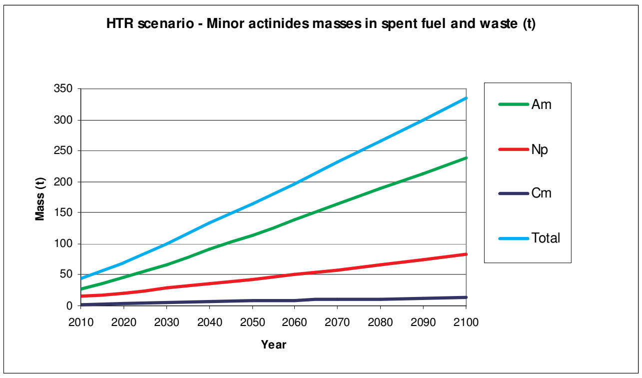

Fig. 6 : Minor actinides in the spent fuel and in the waste

The following table gives a comparison between the HTR scenario and two scenarios :

1) Open cycle scenario : This scenario assumes at equilibrium, that the nuclear electricity is produced at 100% by PWR with 100% UOX fuel. The burnup of the fuel is 60 GWd/t. The electricity production is the same as the HTR scenario :

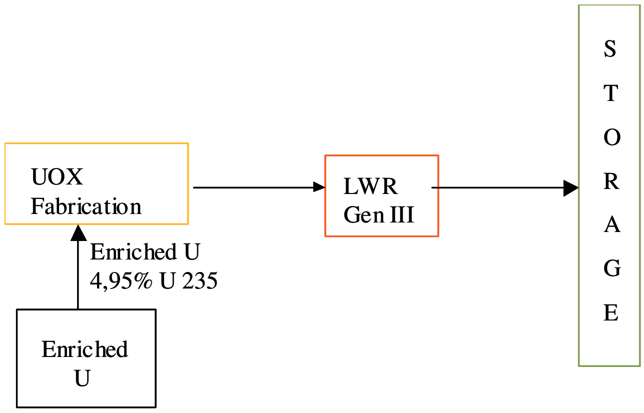

Fig. 7 : Open cycle

2) Monorecycling scenario : This scenario assumes at equilibrium, that the nuclear electricity is produced at 88% by PWR UOX fuel and 12% by PWR MOX fuel. The burnup of the UOX and MOX fuel is 60 GWd/t. The electricity production is the same as the HTR scenario :

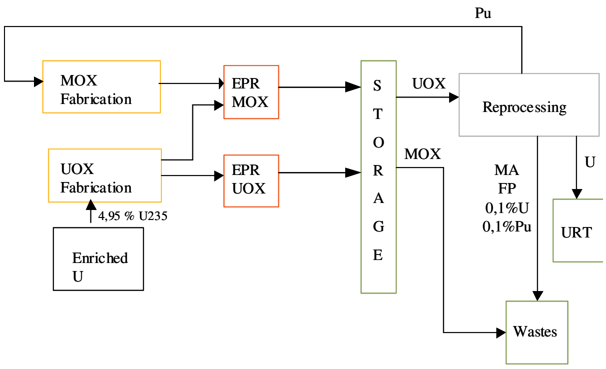

Fig. 8 : Monorecycling scenario

	Open cycle	Monorecycling of Pu in PWR	HTR scenario
Minor actinides inventory (tons)	Am = 135 t Np = 64 t Cm = 4 t Total = 203 t	Am = 151 t Np = 61 t Cm = 9 t Total = 221 t	Am = 164 t Np = 58.3 t Cm = 9.6 t Total = 231 t
Difference (%)	0	+8,8%	+13,8%

Table 3 : Minor actinides in spent fuel and in the waste (year 2070)

Compared to the open cycle, the monorecycling of the Plutonium in the PWR or in the HTR produces more minor actinides. However, this effect is partially counterbalanced by

- the production of Am241 through the decay of Pu 241 (T = 14,4 years)
- the decay of Cm 244 to Pu 240 (T = 18,1 years)

4.5 Natural Uranium needs

The following figure gives the annual and cumulated needs in natural Uranium.

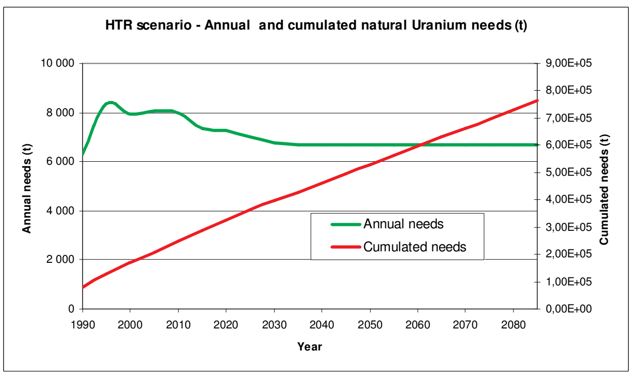

Fig. 9 : Natural Uranium needs

	Open cycle	Monorecycling of Pu in PWR	HTR scenario
Annual needs (tons)	8360	7350	6688
Difference (%)	-	-12%	-20%

Table 4 : Annual needs in Natural Uranium

The use of Plutonium in HTR occurs a decrease of natural Uranium needs, compared to open cycle scenario and mono recycling scenario.

5 CONCLUSIONS

A common program study between the CEA and AREVA-NC has been carried out, in order to assess the capability of a modular HTR (GTMHR type) to stabilize the total Plutonium inventory in the case of the French nuclear park.
This paper describes a scenario of a nuclear park with two types of reactors : PWR with UOX fuel and HTR with Plutonium fuel. In this scenario, HTR are introduced for the multirecycling of the Plutonium.

The mains results of this study are the following :

- HTR are able to reduce the Plutonium inventory. The Plutonium inventory remains lower than 400 tons compared to Generation IV scenarios : around 800 tons [1]. However, the number of HTR necessary for this purpose is very high : 42. It corresponds to an installed capacity of 12 GWe.
- The number of HTR to be deployed each year between 2025 and 2030 is 7. This aspect should lead to high investments during this period.
- Due to the multirecycling of the Plutonium, the amount of minor actinides in the spent fuel and in the waste increases., but this increase remains reasonable, compared to open cycle (+13,8%) and monorecycling scenario (+8,8%).
- The equilibrium is not reached : in spite of the processing of UOX fuel, the quality of the Plutonium in the HTR fuel decreases continuously. The scenario is not viable after 2080, due to a lack of UOX spent fuel for the processing. For this reason, HTR with Plutonium fuel can be considered as a transition solution for the management of the plutonium.

6 REFERENCES

[1] A synthesis of possible separation and transmutation scenarios studied in the frame of the French law for waste management
Jean Paul Grouiller and al. Proceedings of GLOBAL 2005. Tsukuba; Japan. Oct 9-13 2005

[2] Impact on nuclear waste production of different fuel cycle strategies
L. Boucher and al. Proceedings of ICONE 14. Miami; USA. July 17-20, 2006

[3] L. Boucher, J.P. Grouiller, COSI – A Simulation Software for a Pool of Reactors and Fuel Cycle Plants, ICONE-13, Beijing, China, May 16-20, 2005.

[4] R. Sanchez, A. Herbert, Z. Stankovsky, M. Coste, S. Loubiere, C Van Der Gucht and I. Zmijarevic, *« APOLLO2 Twelve Years Later »*, Mathematics and Computation, Reactor Physics and Environmental Analysis in Nuclear Applications - Madrid - (September 99)]

[5] JM.Vidal, J.P.Grouiller, CESAR, A code for nuclear fuel and waste characterisation
WM'06 conference, Tucson, USA, February 26 – March 02, 2006