ADVANCED OPTIONS FOR TRANSMUTATION STRATEGIES

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Abstract

Advanced options for transmutation strategies currently investigated in France are presented. Accelerator driven systems are the major item. In this field, the French National Initiative GEDEON is presented together with some relevant technical results, both in the experimental and in the scenario study fields.

Introduction

In the present paper, we will shortly recall that the motivation for hybrid system development at CEA and in France is related to the waste management optimisation by advanced options.

In this context, we will make a short presentation of the national programme ("Groupement de Recherche") GEDEON.

An example of the role of advanced options for transmutation will be given, in terms of possible scenarios, according to the "double strata" fuel cycle approach.

The physics of transmutation and role of ADS

Accelerator Driven Systems (ADS) can find a role in:

a) Energy production (widely discussed by C. Rubbia in the frame of the EA proposal).

b) Symbiosis with standard reactors (PWRs with UOX and MOX fuel, Fast Reactors with MOX fuel), in order to manage minor actinides (Np, Am, Cm) and selected Long Lived Fission Products (LLFP) in a separate "stratum" of the fuel cycle.

c) Symbiosis with standard reactors (PWRs with UOX fuel), in order to manage Pu, Minor actinides and LLFP.

These scenarios have been described in Reference [1], and the decisive role of fast neutron spectra has been underlined.

In the "transmutation" scenarios (b and c), when compared to the corresponding critical reactor, an ADS has the following features:

a) *Same* transmutation rates for actinides (since proportional to the power in the core).

b) Some extra-neutron availability to transmute LLFP (a neutron consuming process).

c) Subcriticality can allow to have a core with a very small fraction of delayed neutrons (case of the dedicated cores of scenario b), or a core with a significant reactivity loss/cycle (scenario c), possibly within a deterministic safety approach.

These arguments motivate the research in the field of ADS, and require further detailed intercomparison of critical and subcritical cores, to build-up a convincing case and a reasonable framework for future R and D.

The GEDEON Initiative

In order to co-ordinate several activities in the ADS domain, the "Groupement de Recherche" GEDEON has been created.

GEDEON is a meeting point for CEA and CNRS researchers, proposed by EDF in 1995, on ADS and thorium studies. Recently it has been extended to Framatome, and several other institutes and industries have applied to join it.

A network for basic research has been set up with no strong financial commitments but with more than 100 scientists involved.

Research programmes are discussed and, for some, carried out in common e.g.:

a) SATURNE programmes for spallation physics (ended in 1997).
b) Subcritical studies at MASURCA at CEA-Cadarache.
c) Material studies (in particular for lead alloys).

The motivation for setting up GEDEON can be summarised as follows:

a) The CEA is in charge of R&D in nuclear waste incineration and up to now carried it out mostly in the frame of critical reactors, with some exploratory studies in the ADS field.
b) The CNRS is traditionally not involved in such studies, but shares with CEA an expertise in nuclear and accelerator physics.
c) The EDF has a medium term policy with respect to spent fuels management and has an open scientific watching activity as far as new options for the back-end of the fuel cycle.
d) Finally, Framatome proposes his know how to be used in the framework of new reactor development (e.g. HTR), and in case a hybrid test reactor should be decided.

The focus of GEDEON is on following scientific issues:

- Spallation target physics
  - Neutron production from heavy targets.
  - Residues measurement (heat, radiotoxicity, corrosion).
  - Theoretical efforts to qualify intra- and inter-nuclear cascade codes.

- Nuclear data acquisition
  - Special cross sections, differential or integral (measurements at Geel LINAC, or irradiations in power reactors), for minor actinides, long-lived fission products, lead and bismuth.
  - Extending neutron cross-section libraries from 20 to 200 MeV.

- New material studies
  - Window : radiation damage in n and p fields.
  - Pb, Pb/Bi : corrosion, embrittlement, irradiation effects.

- Subcritical neutronics studies with the Masurca reactor at Cadarache (see Paragraph 4)

- Scenarios studies and system studies (demo experiment, targets etc.), including the assessment of the role of pyroprocesses (see Paragraph 5)

- IPHI project between CEA and CNRS for High Power Proton Accelerator development
  - An injector of 10 MeV × 100 mA (first stage) is presently considered.

Activities of GEDEON

The main activities of GEDEON have been devoted to experimental studies in the field of spallation physics, with experiments performed at the SATURNE accelerator (thin and thick targets; neutron production and double differential cross-section measurements for several materials and several proton energies) and at GSI-Darmstadt (inverse kinematics experiments for spallation residual measurement).

The MUSE experiments at MASURCA have been a major undertaking between CEA and CNRS, to investigate the neutronics of subcritical cores. Three experiments have been performed: MUSE-1 and 2 (References [2] and [3]), where a ^{252}Cf spontaneous fission neutron source was used, and MUSE-3 (see Figure 1) where a 14 MeV neutron generator was used to provide the external source, in pulsed and continuous mode.

The future configuration MUSE-4 (1999) will use a new accelerator (GENEPI, see Figure 2) developed at ISN-Grenoble, which will allow both neutrons from (d,t) and (d,d) reactions, with high neutron intensity (up to 10^{10} n/s) and sharp pulses (~ 1 μsec). This will enable to perform dynamic measurements of the reactivity, besides the measurement of the neutron source importance, core subcriticality, reaction rate distributions, etc.

Finally, in the frame of GEDEON, workshops are organised. Two of these workshops were organised in 1998:

- Role of pyrochemistry for advanced options in waste management.
- Nuclear data needs and experiments (for minor actinides, long-lived fission products, lead and bismuth).

Figure 1. **MUSE3 configuration (1998)**

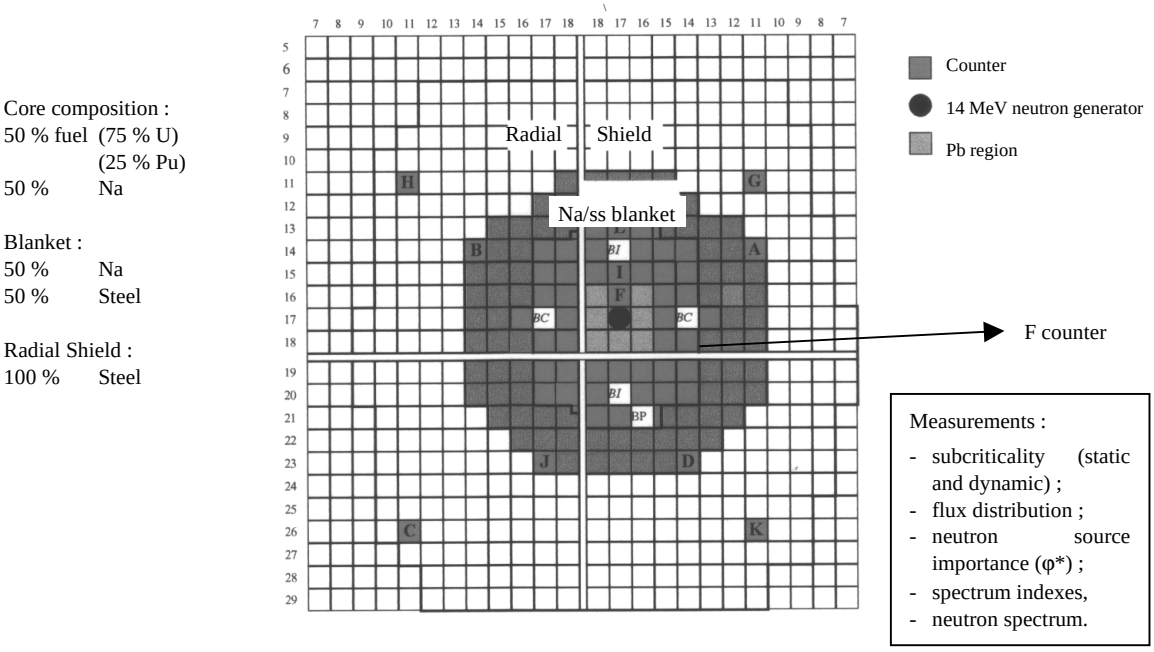
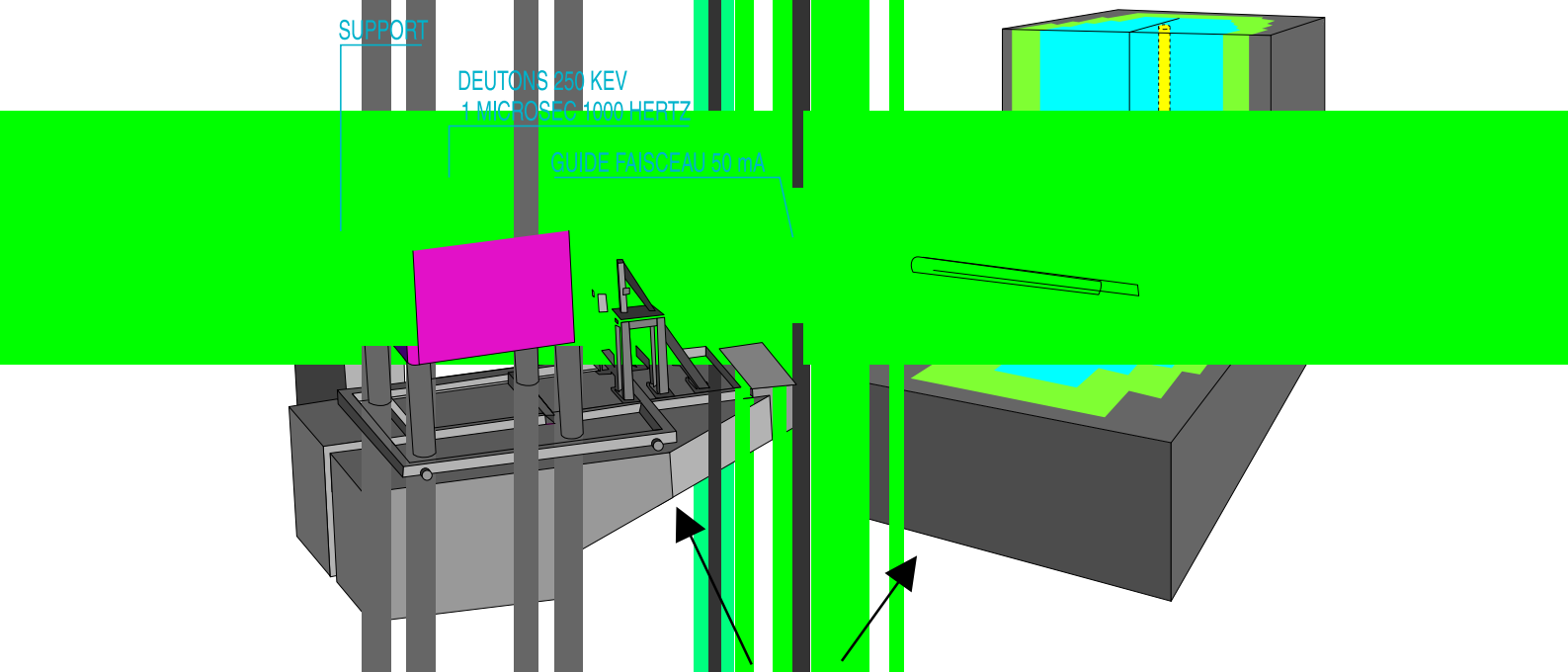


Figure 2. **...ny development: the G... P... ...ation developed at CNRS, ISN-Grenoble ...r neutron generation ...D, ... (D-D) reactions (early 1999)**

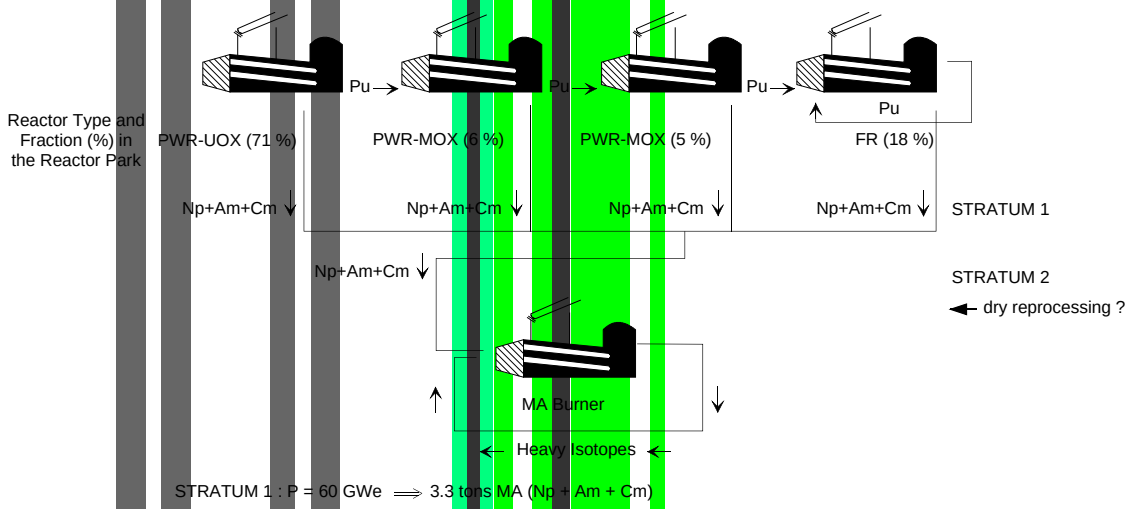


Scenario studies

The "double strata" approach, initially introduced at JAERI [4], has been developed in the frame of the studies described above. In Reference [5], a first quantitative assessment was given of the size of the separated stratum equipped with dedicated reactors, in terms of the share of the total power produced in the park.

The following scenario, with Np, Am, and Cm transmutation was obtained.

Figure 3. **Double strata fuel cycle**



This reactor park allows to reduce waste potential radiotoxicity by a factor of 100 with respect to a reactor park operated in open cycle and producing the same amount of energy.

The limit is due to the level of losses during reprocessing (here assumed to be 1% for all MA, and 0.1% for U and Pu). If dry reprocessing is used, a compact dedicated fuel cycle can be envisaged.

In order to specify the characteristics of the dedicated burner cores, critical and subcritical (ADS) dedicated cores have been specified in preliminary studies (Reference [6]). They have the following characteristics:

	Critical	**Subcritical (ADS)**
Power	130 MWt	130 MWt
Neutron spectrum	fast	fast
Coolant	Pb/Bi	Pb/Bi
Fuel	Pu + MA	Pu + MA
MA burning rate	- 78 kg/TWhe	-99 kg/TWhe
β_{eff}	~ 170 pcm	–
Target/beam	-	Pb/Bi target - Beam : E_p = 1 GeV - I_p = 1 mA (1.6 mA at EOC)

Versions of the same cores, but with gas cooling are under study.

If Long Lived Fission Products (LLFP) (^{129}I, ^{99}Tc) are introduced in “moderated flux” S/A at the periphery of the core (LSD concept see Figure 3), the following transmutation rates are obtained:

^{99}Tc -30 kg/TWhe
^{129}I -18 kg/TWhe

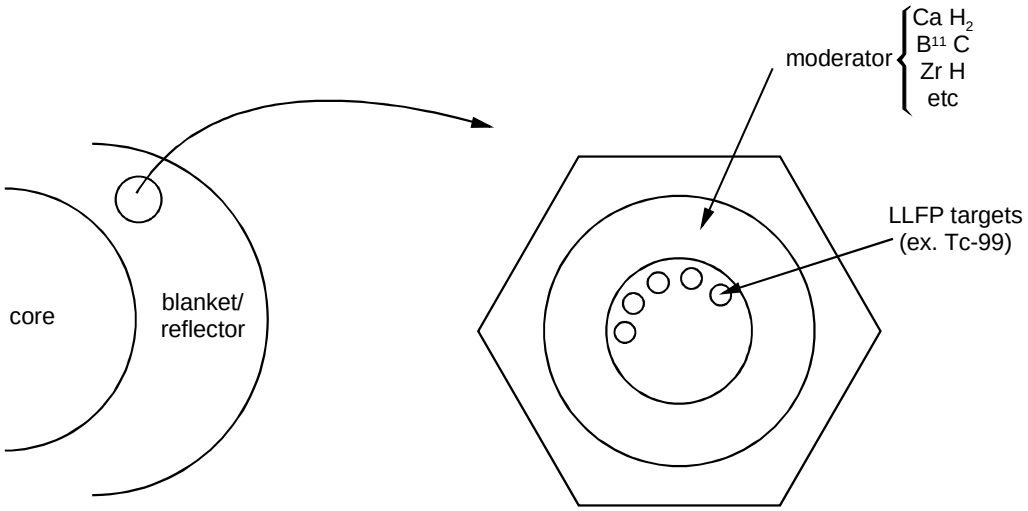
both for critical or subcritical (ADS) cores.

When these core are used, the following double strata scenario can be obtained:

- First fuel cycle stratum, with PWR (UOX) and both PWR (MOX) and CAPRA-type fast reactors to manage Pu.
- “Dedicated” second stratum, with the dedicated burners of Table I.

The characteristics of these scenarios (with critical or ADS in the second stratum) are given in Figures 4 and 5.

Example. **Reaction rate of ^{99}Tc**



Transmutation in a "moderated" S/A

The neutron surplus available leaking out of the core, is used in the blanket/reflector.

These neutrons are slowed down to the required energy ("spectrum tailoring") using moderator (not-absorbing) materials in the specific S/A.

Figure 3. **"Leakage with Slowing Down" (LSD) concept for LLFP transmutation**

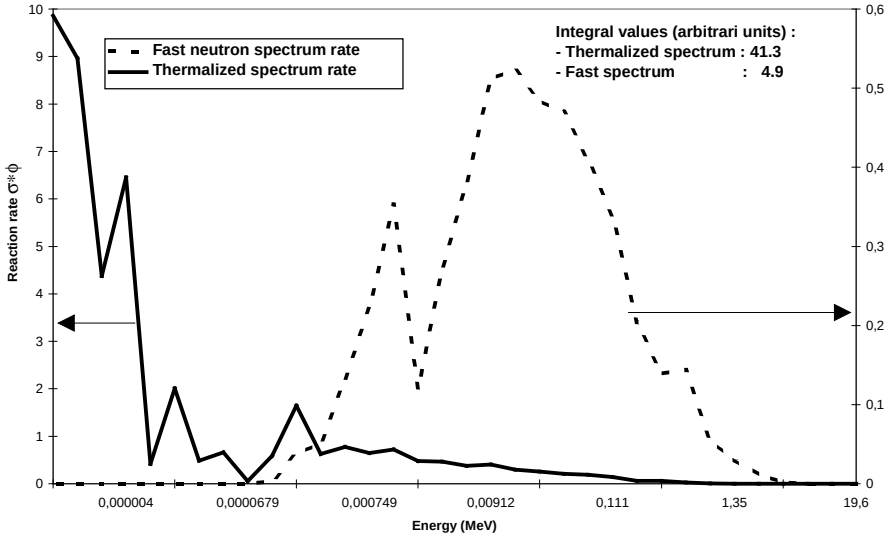


Figure 4

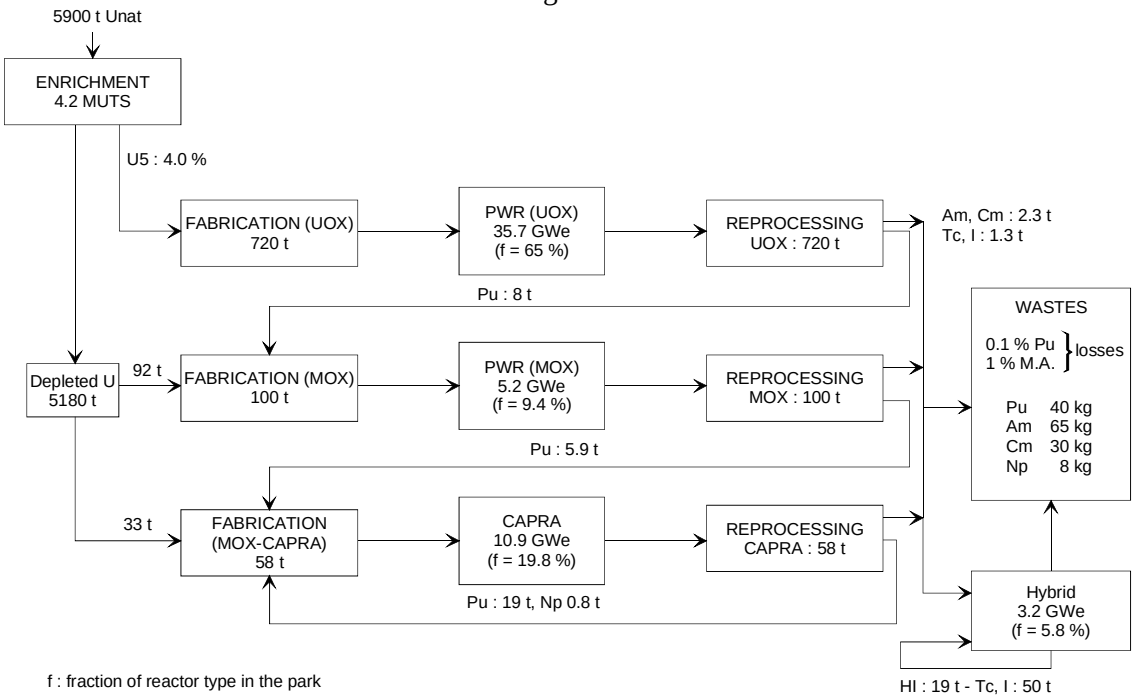
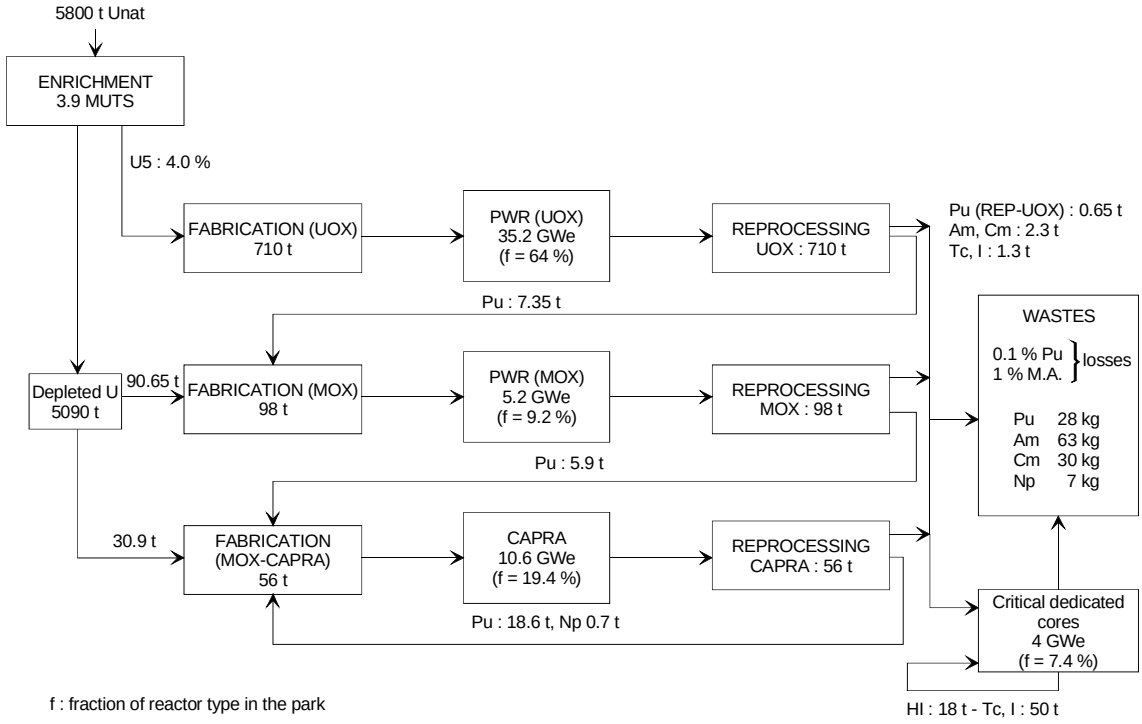


Figure 5



Conclusion

Advanced options for transmutation strategies are actively investigated in France. The ADS is a major field of R and D, at present performed mostly in the frame of the GEDEON initiative.

As far as CEA, these activities are part of the wider SPIN programme which is supported and co-financed by the industrial partners, EDF/Cogéma/Framatome, according to the 1991 Law on Waste management.

Finally, the construction of an eventual “demo” ADS of limited power and the performance of the associated R and D, is presently discussed by France together with Italy and Spain (technical group under the leadership of Prof. C. Rubbia).

A wider European initiative is expected in the very near future.

REFERENCES

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[4] T. Mukaiyama, ibidem.

[5] M. Salvatores *et al*., in *Long Lived Waste Transmutation and the Role of Accelerator Driven Systems*, *Nucl. Inst. Methods* A414 (1998) 5-20.

[6] M. Delpech *et al*., private communication.