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Journal of Nuclear Materials 274 (1999) 135–138

journal of nuclear materials

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Alternative versions of inert matrix fuel for the use of civil and weapons-grade plutonium in reactors

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Abstract

A fuel element approach that is an alternative to uranium–plutonium mixed oxide (MOX) fuel and inert matrix fuel is reviewed. It is designed to burn civil and weapons-grade plutonium in light water reactors (LWRs). The results of preliminary research reactor tests are given. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

According to assessments the weapons-grade plutonium stockpiles built up in the USA and the Russian Federation amount to 100 t in each country. Large amounts of civil plutonium have also been built up and the amounts are continuing to increase world-wide. Current estimates by IAEA indicate that presently ~110 t civil Pu is in storage and that by 2000 the stockpiles will increase to reach 150–170 t [1].

A useful way to dispose of weapons-grade and civil plutonium is to utilise it as nuclear reactor fuel. Currently, the only way of using civil plutonium is to fabricate a uranium–plutonium mixed oxide (MOX) fuel for utilisation in all types of thermal reactors. Under active development is the option involving a (uranium-free) inert matrix to burn plutonium.

Most of the interest in the inert matrix fuel initiative has been devoted to composites of ceramics and metals (cermet), to solid solutions of ceramics and also to composites of two ceramics types (cercer). All the strategies are based on microscopic scale concepts e.g. Refs. [2,3]. The concept investigated in this study is, however, based at the macroscale and at the fuel pin level.

2. Results and discussion

In our alternative to the MOX and inert-matrix fuel, we propose not a homogeneous but a heterogeneous distribution of plutonium material in a fuel element. The fissile material is then in the form of fuel mini-elements. Some advantages of the alternative approach can be pointed out:

- The fuel production process does not make use of the mixing of phases containing fissile, matrix or absorber materials. The mini-elements are loaded with Pu, or minor actinides e.g. Np, Am and Cm, or absorber containing materials in isolated production areas. Subsequently, depending on the purpose, a fuel rod is assembled from different mini-elements.
- Avoiding the use of pellets permit to have a non-cylindrical fuel element cladding instead of the traditional cylindrical one. The surface area for heat transfer is consequently increased, reducing the heat flux. The non-cylindrical shaped fuel element does not need any spacer grids.
- The requirements placed on the fuel composition are minimised which allows the immediate production of powders from weapons-grade Pu. In addition, elements can be filled with PuO_2 powder recovered from irradiated fuel rods of research or power reactors and from reactors of nuclear submarines and icebreakers.
- The suggested alternative could be well integrated within the existing infrastructure (reactors and fuel rod production) and should not require substantial capital expenses.

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PII: S0022-3115(99)00088-4

- The production process using phases from civil or weapons-grade plutonium for fuel mini-elements loading does not result in liquid waste arisings.
- The high reliability of the fuel elements should allow high burn-up of the fuel mini-element components to a degree when their disposal becomes less a problem with respect to the plutonium content.

Fig. 1 schematically shows cross-sections of the proposed fuel elements. In the fuel mini-elements shown in Fig. 1, the Pu containing component could be in the form of particles, granules or powders that may be prepared from oxides, intermetallics, alloys, carbides, nitrides, etc. In the described experiment the particle sizes were in the range of 100–300 μm. The fabrication of the fuel mini-elements capillaries were vibro-stacked with particles in special boxes at a depression of ~200 Pa.

Fig. 2(a) and (b) describes the particle manufacture processes for the fuel mini-elements. As can be seen from Fig. 2(b), the process flow sheet for the particle manufacture that is recommended for further developments has been significantly shortened. Other methods of granule manufacture may be suggested.

Regarding the use of the weapons-grade plutonium, it should be noted that admixtures or alloying elements do not interfere with the particle preparation technologies. Consequently, a refinement of weapons-grade plutonium is not required.

For preliminary reactor tests, two radically different versions of the fuel elements were manufactured, but in a shorten form (~200 mm). The aim of these tests was to preliminary investigate the concept and designs. Fig. 1(a) is an option of a cylindrical fuel element having the standard size cladding. The position of the fuel elements was adapted to the special design of the irradiation facility. Fig. 1(b) shows an option of a self-spaced fuel element clad in stainless steel. The reactor tests were carried out in the temperature ranges that are characteristic of pressurized water reactors (PWRs). The tests were implemented in the MIR loop at the Research Institute of Atomic Reactor (RIAR), Dimitrovgrad, Russia. The maximum temperature of the cladding surface was 623 K. The water pressure was in the range of 14.2–16.2 MPa. During some periods, the tests were carried on with surface boiling.

In the version ‘a’ of the fuel elements, E-110 (Zr–1% Nb) alloy tubes with 9.15 mm in diameter and 0.45 mm wall thickness, were used. Their outer diameter is standard for the VVER-1000. The tubes contained 7 fuel mini-elements 2.45–2.48 mm in diameter with different Zr alloy claddings 0.2 mm thick. UAl_3 particles (45% enrichment) served as fuel for the mini-elements. The porosity within the fuel mini-element was approximately 20%.

In the version ‘b’, the clads of the fuel elements were made of shaped stainless steel tubes, with a circumscribed diameter of 7.0 mm and a wall thickness of 0.2 mm. The tubes contained 4 fuel mini-elements, each 1.6 mm in diameter, the clads of which were 0.12 mm thick and made of stainless steel. Uranium dioxide particles (45% enrichment) served as fuel for the mini-elements. The porosity within the fuel mini-element was approximately 25%.

In both versions the space left free by the fuel mini-elements within the containing tubes was filled with a matrix material consisting of an aluminum alloy with silicon and nickel.

Preliminary reactor tests to confirm the feasibility of the concept have been completed. For the sake of comparison, Table 1 presents the parameters that were acquired during the irradiation.

The maximum design temperature in some areas of the matrix was 930 K in the dense arrangement of the

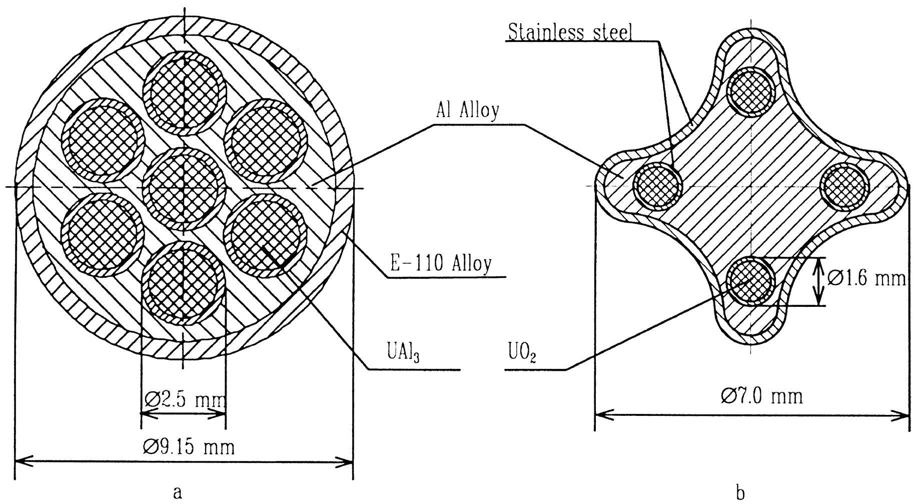

Fig. 1. Schematic cross-sections of the fuel elements.

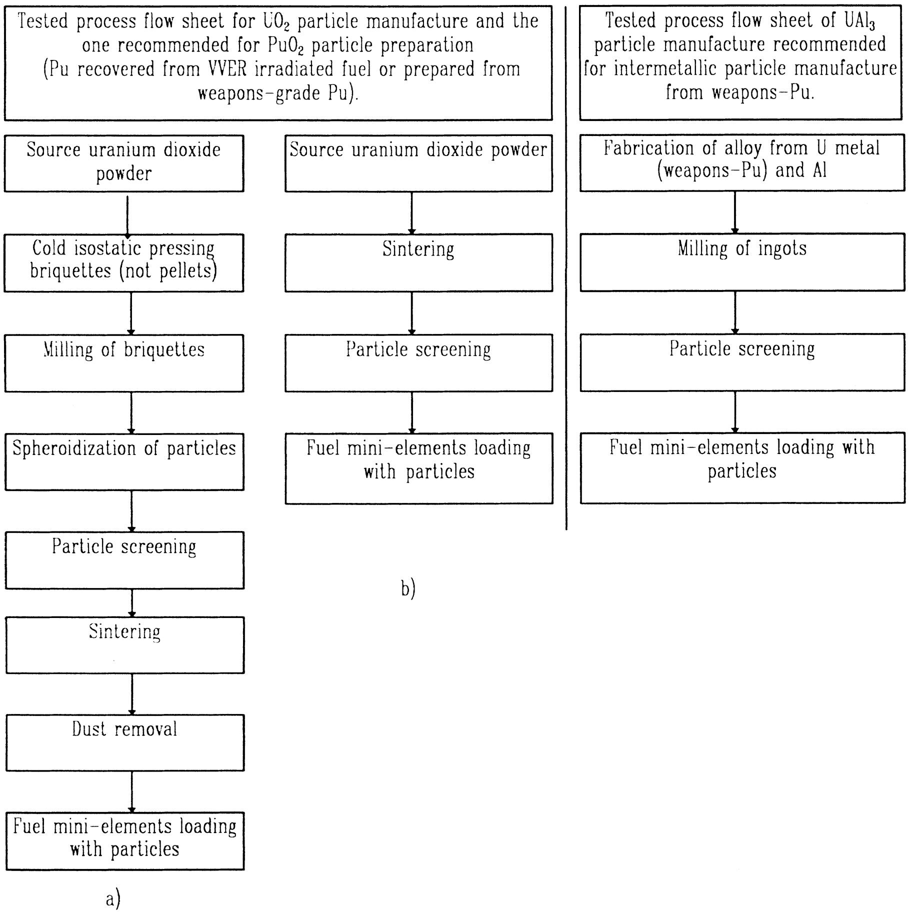

Fig. 2. Process flow sheet of the particle manufacture.

Table 1
Comparison of measured parameters in the achieved test with that for a VVER-1000

Parameter reported for 1 cm of fuel element	Fuel element of VVER-1000 at average reactor burn-up of 43 MW d (kg U)$^{-1}$	Fuel element of research reactor (Fig. 1(a))	Fuel element of research reactor (Fig. 1(b))
Burn-up (MW d)	0.16	0.13	0.06
Average heat rate (W)	183	236	185
Maximum heat rate (W)	448	442	431

fuel mini-elements (Fig. 1(a)) and 705 K in the loose one (Fig. 1(b)). The maximum design temperature on the fuel mini-element centres were 990 K (Fig. 1(a)) and 945 K (Fig. 1(b)).

The post-irradiation examinations showed the following results:

- All fuel elements retained their integrity.
- No changes were noted in the volume or dimensions of the fuel elements (the variations were within the measurement accuracy).
- The fuel mini-elements according to Fig. 1(a) had a porosity margin.
- In general, the macrostructure of the irradiated fuel element cross-sections is nearly the same as the initial one.

3. Conclusion and future prospects

The first irradiation tests on two suggested type of fuel elements in research reactor gave promising results. Comparative research reactor tests and post-irradiation examinations should be carried out using fuel elements containing fissile materials in quantities emulating the burn-up specified for light water reactors (LWRs) (upto

150 MW d (kg U)$^{-1}$). For this aim, the neutron physics of the fuel element has to be calculated. The respective plans and programmes have been worked out; however, their implementation is restricted on further interest.

Acknowledgements

Some sections of the work were implemented in the framework of ISTC Project 173-95. The authors are grateful to Nupec, Framatome, Belgonucleare and Ivo International for the support of Project 173-95.

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