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Metallic inert matrix fuel concept for minor actinides incineration to achieve ultra-high burn-up

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ABSTRACT

The advantages of using Inert Matrix Fuel (IMF) in a design of an isolated arrangement of fuel are considered, with emphasis on, low temperatures in the fuel center, achievement of high burn-ups, and an environment friendly process for the fuel element fabrication. Changes in the currently existing concept of IMF usage are suggested, involving novel IMF design in the nuclear fuel cycle.

1. Introduction

Inert Matrix Fuel (IMF) is considered as one of the options for the incineration of excess Pu and minor actinides (MA) in fast or thermal reactors [1,2]. IMF can be an advanced nuclear fuel form. It can potentially provide higher burn-up than current fuel form, making it a promising alterative for future generation of nuclear power reactors [3–7]. IMF is capable of reducing plutonium stockpiles (also of reactor-grade plutonium) more efficiently than MO_X fuel [7,8].

The use of IMF has economical benefits especially by obtaining ultra-high burn-ups. Currently, the existing versions of IMF based on pelletized fuel elements, particularly made of various ceramic materials- spinel, Yttria-stabilized zirconia (YSZ), Mg_2O, do not fully satisfy this requirement. They have no metallurgical bond between cladding and fuel form, which aside from raising the temperature in the center of a fuel element, degrades its serviceability, especially, in transients [2–5].

This investigation is to propose an IMF concept for achieving high burn-ups. [8–13].

Previous application of IMF or in other words – fuel on the basis of an inert matrix was considered as one of the options of recycling plutonium amount, particularly weapons grade, mostly in thermal reactors and utilization of its energy potential (Fig. 1 (a)) [1,9].

What has been changed in last years?

The long term development of nuclear power as a part of the world's future energy mix will require fast reactor technology with closed fuel cycle. Fast reactors are a versatile and flexible technology that promises to create or "breed" more fuel by converting nuclear "waste" into "fissile" material. Therefore, it does not make any sense now to incinerate fissile Pu in IMF designs. On the other hand increasing burn- up in thermal reactors and using MOX result in poor Pu composition in spent fuel as well as increase in the stockpile of MA needs incineration in FR (Fig. 1(b)).

2. Development and design

2.1. Methods and approaches

The main goal of investigations is to develop IMF design with a metallic matrix that makes it possible to achieve high burn-ups in FR. It should be produced by simple technology and comply with requirement for "Rock-fuel" (making direct geologic disposal of fuel feasible).

This can be achieved by replacing ceramics inert matrix of pelletized design by dispersion-type fuel element. A direct metallurgical bond between fuel and cladding provides conductivity while serving to protect against fuel-cladding interactions. Dispersion-type metallic IMF is an ideal separable system, allowing each component to be studied separately (i.e., actinide fuel, inert metallic matrix and cladding) (Fig. 2) [13–15].

Dispersion-type fuel elements with metal matrices that are distinct from the traditional pelletized fuel elements have a number of advantages. They exhibit a low temperature of a fuel center, high irradiation resistance and extended burn-ups [16].

2.2. IMF design and technology

One of the versions of dispersion- type IMF, which we are developing, is a fuel element having a heat conducting metal matrix and an isolated arrangement of PuO_2 in a fuel mini-element [16].

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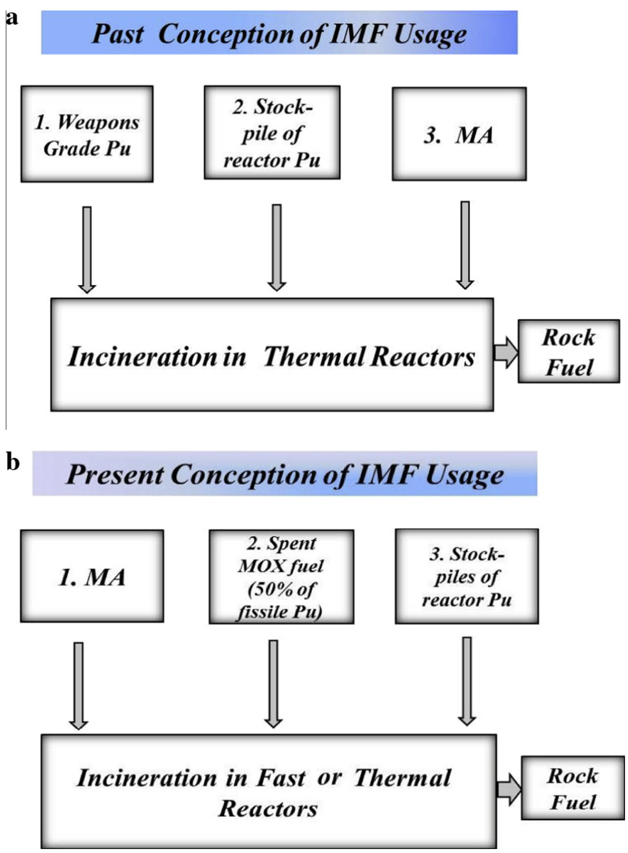

Fig. 1. Past (a), and present (b) conception of IMF usage.

The main distinction and advantage of such a fuel element consist in the fact that PuO_2 or MA oxide powder is separately arranged in fuel mini-elements that in turn are placed inside a fuel element (Fig. 3(a)). The space between fuel mini-elements and fuel cladding is filled with Zr matrix alloy using impregnation or capillary impregnation methods (Fig. 3(b)) [17,18]. Iron- based matrix alloys can also be implemented for FRs in this design (Fig. 3(c)).

The fuel mini-element is a thin-walled stainless steel or Zr alloy tube, 1.4–2.5 mm in diameter. It is filled with PuO_2 powder or granules (60–70% vol.), sealed and placed within a fuel element (Fig. 4).

Aside from PuO_2, also oxides of other actinides may be loaded into a fuel mini-element. Actinide oxides can be produced by pyrochemical method, and (Er, Y, Pu, Zr)O_{2-x} microspheres, prepared by internal gelation process (such as at Institute for Transuranium Elements (ITU) and Paul Scherrer Institute (PSI)) can also be implemented [2,9,19–21].

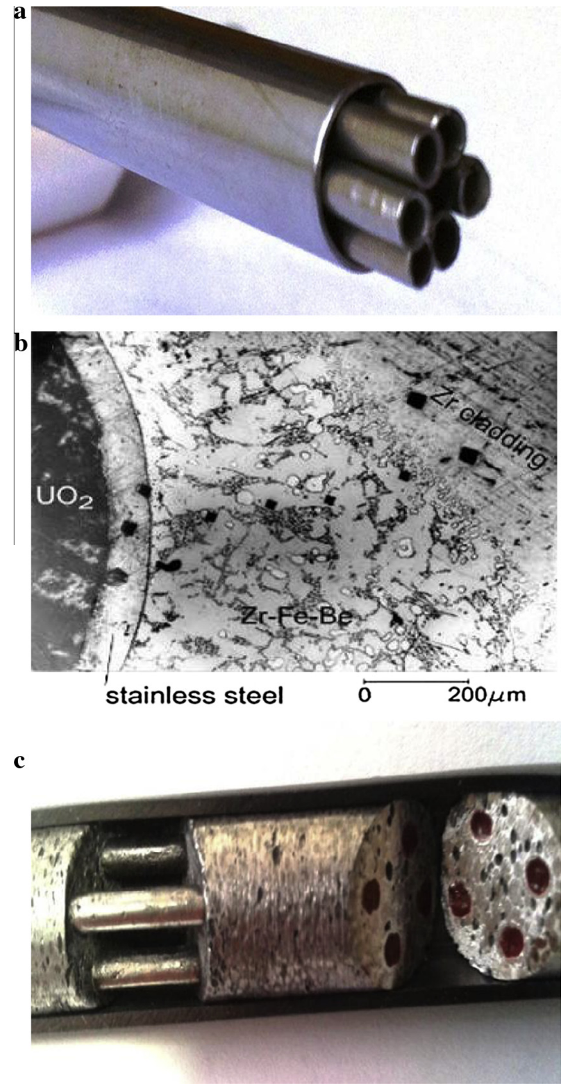

Fig. 3. (a) Six fuel mini-elements inserted into a fuel cladding, (b) microstructure of fuel element with Zr-matrix alloy, and (c) cross section of fuel element – plutonium burner containing four fuel mini-elements.

A fuel mini-element has the following functions:

1. Prevent the fuel from interacting with the matrix and the cladding.
2. Provide protection against corrosion.
3. Use as a barrier against fission products release.
4. Accommodate fuel swelling.

The fuel mini-elements (from 1 to 6 of them) are inserted in the fuel cladding. The metallurgical contact between the fuel mini-ele-

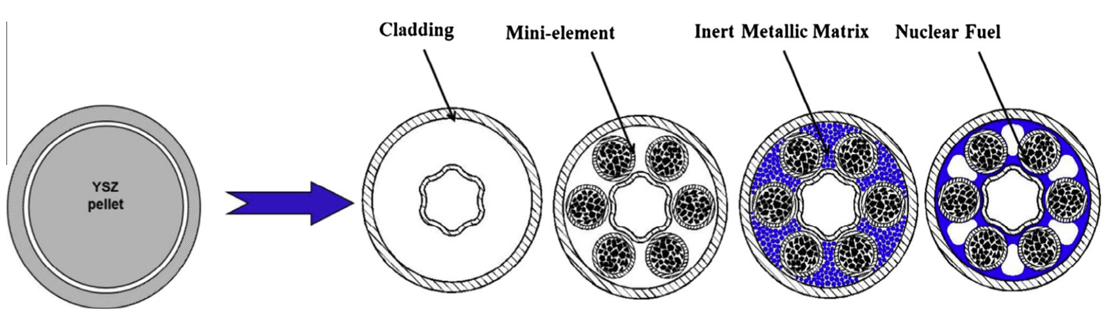

Fig. 2. Approach to fuel development and IMF process fabrication stages.