Fukushima Fuels and Materials Department
R & D of nuclear fuels and materials for FBR in FMD*

Outline of FBR

FBR (Fast Breeder Reactor) is a fast neutron reactor designed to breed fuels by producing fissile materials. FBR usually uses a uranium and plutonium mixed oxide (MOX) fuel core. The plutonium can be supplied from spent fuels of light-water reactor (LWR) and FBR by reprocessing. Therefore, the FBR is the key technology for Japan from the view of energy security and effective utilization of resources.

JAEA promotes R & Ds of FBR cycle system, i.e. FBR plant, fuels and materials for FBR, reprocessing and disposal of high level waste.

R & D activity in FMD

Higher burn-up of nuclear fuels is required for FBR with an high economical efficiency. Since core conditions in FBR such as temperature and neutron fluencies are much more severe than in LWR, the fuels and materials during irradiation up to high burn-up should be newly investigated.

To satisfy these needs, FMD has investigated the irradiation behaviors of fuels and materials for FBR by the various post-irradiation examinations (PIEs) of fuels and materials irradiated in experimental reactors (JOYO, JMTR and others). FMD has achieved a lot of reliable data which can be reflected to the nuclear design of FBR.

Based on these technology and experiences, FMD also promotes R & Ds of the high-performance fuels and materials.

R & Ds of nuclear fuels

- PIEs of nuclear fuels and analysis of their irradiation behavior
- R & Ds of the high-performance fuels (oxide fuels)

R & Ds of materials

- PIEs of core/structural materials and analysis of their irradiation behavior
- R & Ds of the high-performance materials

The experimental fast reactor “JOYO” was constructed to achieve technical experience for future FBR. In addition, irradiation test of advanced fuels and materials have been carried out.

FMD has four hot laboratories; FMF, AGF, MMF and PFRF.
Outcomes from PIEs and R&D activities in FMD

Post Irradiation Examination of Fuel Assembly

Both non-destructive and destructive tests for fuel assembly irradiated in experimental fast reactor, JOYO, are carried out to evaluate the effect of irradiation.

Fuels and materials irradiated as a fuel assembly in JOYO are transferred for the intermediate inspection. Irradiated specimens are re-assembled and reloaded into JOYO after the inspection, making it possible to achieve higher burn-up of fuels and obtain irradiation data of materials at higher dose.

X-ray computed tomography (X-ray CT) provides cross-sectional image of a fuel assembly, configuration of fuel pins, and also distribution of central void formed in the irradiated fuel pellet.

The X-ray CT images are obtained non-destructively and utilized for evaluating irradiation behavior of fuel assembly.

Post Irradiation Examination of Control rod

PIE of control rod is carried out for developing long-lived control rod.

Elements of the control rod are composed of absorber pins, $\text{B}_4\text{C}$ pellets, and outer protecting tube.

The X-ray CT images are utilized to understand deformation behavior of these elements of control rod due to irradiation.

In addition, density measurements and microstructural observations of $\text{B}_4\text{C}$ pellets are performed to evaluate the irradiation behavior of control rod.

$1\text{nm} = 1 \times 10^{-9}\text{m}$
**PIEs of nuclear fuel**

PIEs of uranium-plutonium mixed oxides (MOX) fuels for a FBR are carried out, and their irradiation behavior are evaluated for a fuel design.

Melting temperature and source term of irradiated MOX fuels have been investigated for the evaluation of fuel behaviors under normal and accident conditions. The phase relation, elements distribution and microstructure changes of irradiated MOX fuels have been also investigated to understand the mechanisms of the irradiation behavior.

The fuel burn-ups of MOX fuels have been determined with a high degree of accuracy by the measurements of uranium, plutonium and Neodymium isotopes in irradiated fuels. The transmutation behaviors of minor actinides (MAs: Np, Am and Cm) have been also experimentally investigated.

**Development of MAs-containing MOX fuel**

MAs recovered from spent nuclear fuels are of special concern because of their lasting radiotoxicity. Therefore, recovery and recycling of MAs in FBR should be key technology for the reduction of environmental burden and a sustainable energy supply for the future.

The R&D of MAs-containing fuels, i.e. Am-containing MOX fuel and inert matrix fuel such as Cercer and Cermet fuels, have been carried out. The MAs-containing fuels with good characteristics, i.e. having no defects, a high density and a homogeneity, were successfully fabricated by a remote handling system.
Outcomes from PIEs and R&D activities in FMD

Post Irradiation Examination of core materials

Influence of fast neutron irradiation and irradiation environment on mechanical properties/microstructure of core structural materials developed for Japan sodium-cooled fast reactor (JSFR) are evaluated.

Tensile properties for cladding tube specimens irradiated at systematic irradiation condition are investigated using tensile test machine, and irradiation data of cladding tube materials have been accumulated for the core materials design of JSFR.

In addition direct observation of lattice image of precipitate with the size of a few nanometer is conducted using field emission transmission electron microscope (FE-TEM) and utilized for the evaluation of phase stability under irradiation.

Development of High Performance fuel cladding by optimizing grain-boundary-character distribution (GBCD)

Based on a concept of grain-boundary engineering, the R&D of high performance cladding materials are carried out for the purposes of expanding its application areas and improving properties of the existing core structural materials.

Developmental austenitic steels with extremely high density of coincidence site lattice (CSL) boundary are successfully fabricated by the modification of former thermo-mechanical processing.

*EBSP: Electron Back Scattering Pattern
**Glove box**

A glove box has a highly air-tightness. Examinations of low-level radioactive fuels and materials can be carried out with relative ease in a glove box through the acrylic window.

**Cask**

A cask is a shield-flask. FMD has the various cask specified based on weight, size and radioactive levels of specimens. Irradiated fuels and materials can be safely transported between the facilities by using the appropriate cask.
Research facilities of fuels and materials department (FMD) have been utilized by internal/external researchers and engineers.

In Plutonium Fuel Research Facility (PFRF), one of FMD facilities, R&D has been progressing on a nitride fuel and a metallic fuel for fast reactor application. In addition, fundamental studies on transmutation target for long-lives minor actinides and on pyrochemical reprocessing using molten salt have been carried out.

Although nitride fuel and a metallic fuel have several advantages compared with oxide fuel in terms of elemental density of heavy metal and thermal conductivity, they easily react with oxygen and moisture.

In PFRF, fabrication and preparation of fuels are carried out in glove boxes with high-purity argon (Ar) gas atmosphere. Advanced fuels with fascinating properties and experimental samples for physical property measurement can be manufactured. In addition, microstructure observations at high magnification and elemental analyses of fuels have been performed to determine the chemical morphology by Scanning Electron Microscope (SEM) connected with a glove box.

FMD have received visiting researchers from various oversea institutes (including graduate students of domestic university) in the frameworks of joint research program. These frameworks offer active supports for human resources development in the research field of nuclear energy.
Time-line of FMD

**Establishment of Japan Atomic Energy Agency in 2005**

- In 1994
  - Start installation of the remote fuel fabrication equipments

- In 1999
  - Start hot testing in the additional AGF
  - Start fabrication tests of Am-MOX fuels by the remote handling system

- In 2002
  - Success of high-resolution imaging of irradiated materials by the Field Emission Transmission Electron Microscope (FE-TEM)

- In 2006
  - Assembling of fuel assemblies contained MA (reload into MK-Ⅲ Core)

- In 2005
  - Start PIEs of materials irradiated by CMIR rig at MK-Ⅲ Core of JOYO

- In 1972
  - Completion of the AGF

- In 1971
  - Start hot testing in the AGF

- In 1998
  - Establishment of the method of molten salt electrolysis of Pu nitride and Np nitride

- In 2000
  - Success of simultaneous recovery of U and Pu at the liquid Cd electrode by molten salt electrolysis

- In 1977
  - Completion of the AGF

- In 1978
  - Start PIEs of fuel assemblies irradiated at MK-Ⅰ Core of JOYO

- In 1979
  - Start PIEs of irradiated fuels from Rapsodie

- In 1980
  - Received irradiated specimen from Phenix, a French FBR
  - Start PIEs of materials irradiated at MK-Ⅱ Core of JOYO

- In 1984
  - Start hot testing in the MMF-2
  - Start PIEs of materials irradiated at MK-Ⅱ Core of JOYO

- In 1989
  - Manufacturing nitride fuel pins mixed U-Pu for irradiation test in JMTR

- In 1993
  - Manufacturing nitride fuel pins mixed U-Pu for irradiation test in JOYO

- In 2003
  - Establishment of fabrication process of Am-MOX fuels by the remote handling system

- In 2004
  - Start PIEs of fuel assemblies irradiated at MK-Ⅲ Core of JOYO

- In 1973
  - Completion of the MMF
  - Start PIEs of materials irradiated at MK-Ⅱ Core of JOYO

- In 2005
  - Completion of U-Pu-Zn alloy fuel pins used to irradiation test in JOYO

- In 2010
  - Start PIEs of materials irradiated by CMIR rig at MK-Ⅲ Core of JOYO

- In 1993
  - Completion of the additional AGF

- In 1999
  - Start fabrication tests of Am-MOX fuels by the remote handling system

- In 2006
  - Start PIEs of fuel assemblies (Am-1 fuels) irradiated at MK-Ⅲ Core of JOYO

- In 1972
  - Completion of the MMF

- In 1977
  - Completion of the AGF

- In 1978
  - Start of hot testing in the FMF

- In 1979
  - Start PIEs of irradiated fuels from Rapsodie, a French FBR

- In 1980
  - Completion of the FMF

- In 1983
  - Completion of the additional FMF

- In 1982
  - Start PIEs of fuel assemblies irradiated at MK-Ⅰ Core of JOYO

- In 1983
  - Completion of the additional AGF

- In 1988
  - Start PIEs of fuel assemblies irradiated at MK-Ⅱ Core of JOYO

- In 1997
  - Completion of the additional AGF

- In 1974
  - Completion of the PFRF

- In 2002
  - Success of imaging of irradiated fuel assemblies by X-ray CT testing

- In 1980
  - Start PIEs of irradiated fuels from Rapsodie, a French FBR

- In 1982
  - Start PIEs of materials irradiated at MK-Ⅱ Core of JOYO

- In 1987
  - Received the first specimen from the ATR confirmation test

- In 1998
  - Start PIEs of fuel assemblies irradiated at MK-Ⅱ Core of JOYO

- In 2000
  - Success of simultaneous recovery of U and Pu at the liquid Cd electrode by molten salt electrolysis

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