Conceptual Design of an Engineering-scale Plant applying the Simplified MA-bearing Fuel Fabrication Process

Yoshikazu YAMADA[1], Tomoomi SEGAWA[1], Masato KATO[1]

[1]Japan Atomic Energy Agency (JAEA), Tokai, Japan

E-mail contact of main author: yamada.yoshikazu@jaea.go.jp

Abstract. Researchers at Japan Atomic Energy Agency (JAEA) have proposed the transmutation of minor actinides (MAs) by both fast reactors (FRs) and accelerator driven system (ADSs) as a way to contribute significantly to the reduction of the volume and the potential radiotoxicity of radioactive wastes. In order to achieve this transmutation goal, it is important to introduce a fully automated and remotely operated fuel fabrication plant with shielded hot cells and manipulators to deal with the extremely strong radiation dose and high heat generation from MAs. JAEA's facilities including the Plutonium Fuel Production Facility (PFPF) have fabricated MOX fuel. On the basis of the operational and technical experience obtained in those facilities, the conceptual design was made of an engineering-scale plant applying the simplified MA-bearing fuel fabrication process with shielded hot cells and manipulators. It was judged to be possible to fabricate high MA-bearing fuel and to perform the maintenance and repair of each piece of equipment by using the manipulators. A plant will be constructed based on this concept and development plan.

Key Words: MA-bearing fuel, Simplified fuel fabrication process, Fuel fabrication plant

1. Introduction

A high-decontamination Pu recycling system in light water reactors (LWRs) has already been industrialized, and many experiences on MOX fuel fabrication for fast reactors (FRs) have also been accumulated. However, most of the technologies on fuel production applied to date are not suitable for high minor actinide- (MA-) bearing fuel fabrication, because that requires a fully automated and remote operation system with shielded hot cells and manipulators to deal with the extremely strong radiation dose and high heat generation from MAs. Researchers of the Japan Atomic Energy Agency (JAEA) have studied a simplified MOX fuel fabrication process to decrease the fuel fabrication cost of FRs since 1995. Previous studies [1-4] of the simplified MOX fuel fabrication process showed that highly homogeneous MOX pellets were obtained without difficulty in laboratory-scale tests. The simplified MOX fuel fabrication process will be a strong candidate for the MA-bearing fuel fabrication process in Japan, because most of the powder handling process can be skipped.

Researchers at JAEA have proposed the transmutation of MAs by both FRs and accelerator driven system (ADSs) as a way to contribute significantly to the reduction of the volume and the potential radiotoxicity of radiation wastes. [5,6] In order to achieve this transmutation goal, it is important to introduce a fully automated and remotely operated fuel fabrication plant with shielded hot cells and manipulators when considering a future mass production plant of high MA-bearing fuel. As a first step, a conceptual design was done of an engineering-scale plant applying the simplified MOX fuel fabrication process with shielded hot cells and manipulators on the basis of the operational and technical experience obtained in JAEA's facilities. It was judged possible to fabricate high MA-bearing fuel and to perform the maintenance and repairing of each apparatus with manipulators.

2. Concepts of the New Fuel Fabrication Plant

The conceptual design of the engineering-scale plant was conducted as the reliability verification test plant by considering a future mass production plant of high MA-bearing fuel.

The aims of this new fabrication plant are as follows.

- To provide high MA-bearing MOX fuel for both FRs and ADSs
- To perform the maintenance and repair of each apparatus by using manipulators
- To realize a fully automated and remotely operated fuel fabrication plant

2.1. Target Fuel to be Fabricated in New Facility

As mentioned above, this new plant is expected to introduce the MA-bearing MOX fuel fabrication line capable of fabricating fuel for both FRs and ADSs, based on JAEA's research and development project. The MA-bearing fuel with the highest dose to be handled in this new plant was for fuel of the Transmutation Physics Experimental Facility (TEF-P). [7] The TEF-P fuel specifications are listed in Table 1. As described later, the handling amount of powders per batch and the shielding thickness wall of the hot cell were determined on the basis of these fuel specifications.

Table 1: TEF-P fuel secifications (Initial phase)

Fuel / Target	MA-bearing oxide target
Chemical form (Composition)	(Pu, Am) $O_{2\pm X}$ + ZrO_2 or MgO
Inert matrix	ZrO_2, MgO, etc.
Volume proportion of inert matrix	≤50 vol.%
^{241}Am:Pu	1:1
Density	≥90%TD
Pellet diameter	9mm

2.2. Fuel Fabrication Process

JAEA researchers have studied the simplified MOX fuel fabrication process to decrease the FR fuel fabrication cost. This process uses the concept accurately adjusting plutonium content in the solution mixing step of plutonium nitrate and uranyl nitrate, converting from the solution mixture to MOX powder by using the microwave direct de-nitration method, and directly pelletizing the flowable MOX powder without mixing in additives. [8,9] By introducing this process, it is possible to omit the powder preparation steps in the conventional process as shown in Figure 1. To realize this innovative process, three element technologies have been developed for (1) Pu/U ratio adjustment in the nitrate solution, (2) improvement of MOX powder flowability, and (3) realization of a pressing machine with a die-wall lubrication system. As mentioned above, previous studies [1-4] of the simplified fuel fabrication process showed that highly homogeneous pellets for both FRs and ADSs were obtained without difficulty in laboratory-scale tests.

The microwave heating (MH) process has been adopted in the Rokkasho reprocessing plant and its commissioning test has been successfully completed. Whereas 50%U-50%Pu mixed nitrate solution is co-converted by microwave heating in the MH process, MAs are mixed into nitrate solution with the MA content precisely adjusted to the fuel specification and then co-converted by microwave heating in the simplified MA-bearing fuel fabrication process.

This converted MA-bearing powder is tumbling-granulated to improve its flowability. After granulation, the obtained MA-bearing powder is directly pressed into green pellets without adding lubricant into the powder, because a die wall lubrication system is applied. As well the amount of lubricant introduced into green pellets from the equipment lubricant is so small that de-waxing and degassing steps can be skipped. The green pellets are sintered, and subsequently density and appearance of each pellet are inspected.

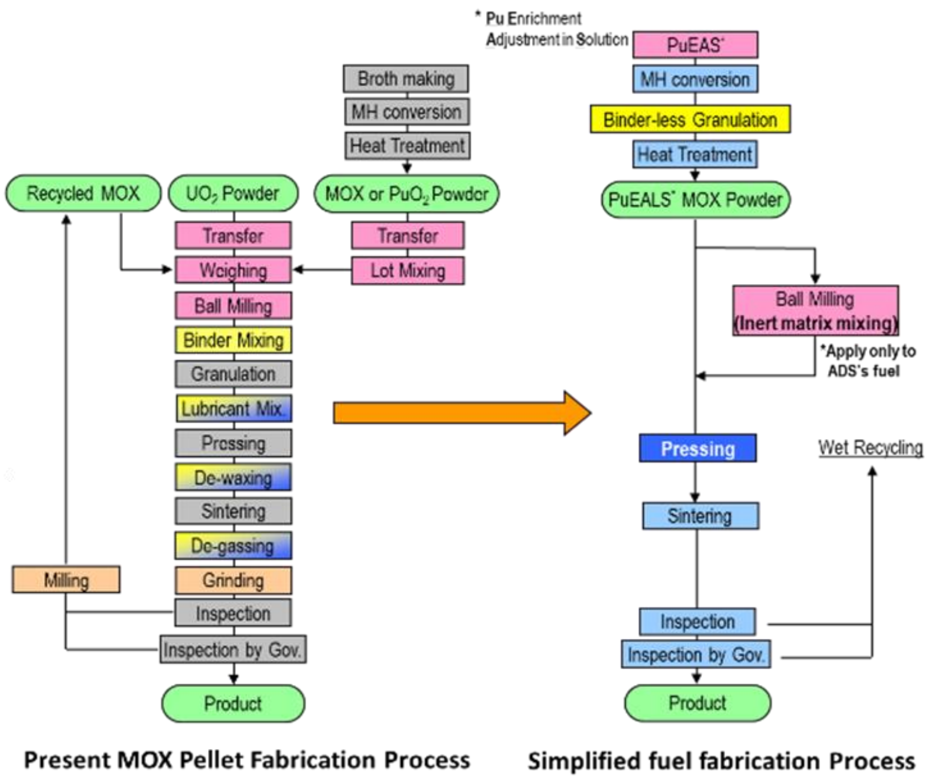

Figure 1.Comparison of fuel fabrication process flow

2.3. Structure of Hot Cell

Space dose rate was calculated using the one-dimensional discrete ordinate code, ANISN, and the handling amount of powders per batch and the shielding thickness wall of hot cell were determined to get a rate lower than 20 μSv/h at the working position of the manipulators. As a result, the handling amount of powder per batch was set at 400g in the powder treatment process. Furthermore, the pellet inspection equipment was designed by taking into consideration the influence on electric devices to process the diameter measurement, weight measurement and pellet visual inspection. The lifetime of the electronic device in the pellet inspection equipment was estimated to be about 2 years with application of the appropriate shielding material.

As described below, apparatuses were designed to do maintenance and repair work with master-slave (MS) manipulators. The hot cell is to place the hoist crane (0.5ton or less) to the celling in addition to the master-slave manipulators. Figure 2 shows the hot cell structure.

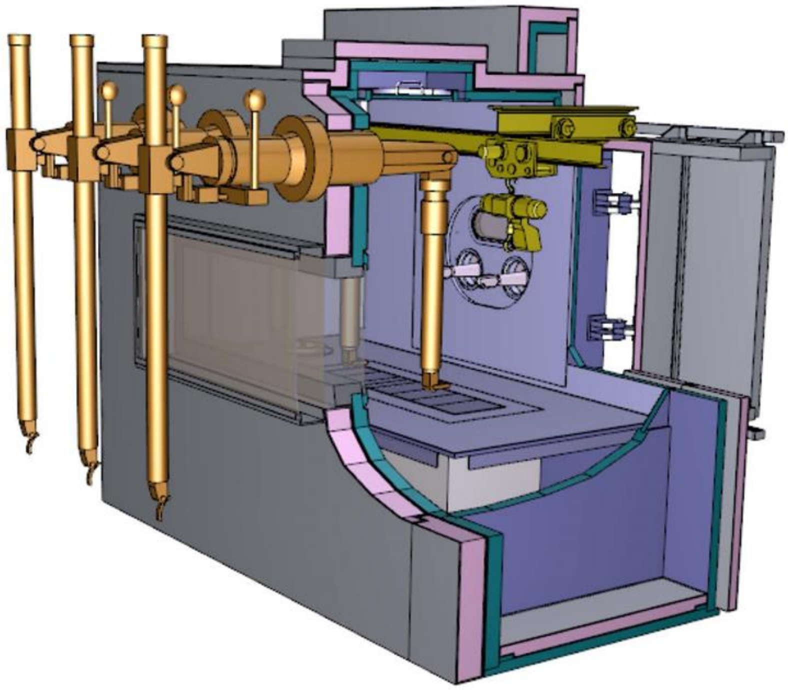

Figure 2. The hot cell structure

2.4. Fuel Fabrication Equipment

The engineering-scale plant applying the simplified MA-bearing fuel fabrication process with shielded hot cells and manipulators will consist of the following equipment.

* Raw material process: Raw material container opening apparatus
* Mixing process: Ball milling apparatus
* Pressing process: Withdrawal uniaxial pressing machine (300MPa)
* Sintering process: Batch type heat treatment furnace
* Pellet inspection process:
    1) Inspection unit apparatus with both line sensor and area sensor
    2) Grinding apparatus (for larger diameter pellets)

The history of operation problems and contents of maintenance tasks, which were encountered through operation of the Plutonium Fuel Production Facility (PFPF), were investigated and both the apparatus design and the layout design capable of performing maintenance and repair work with MS manipulators were conducted.

As a typical example, Figure 3 shows the layout design of the pressing machine. All the objective parts which are selected will be disposed within the movable range of MS manipulators. (The yellow areas on the drawing represent the movable range of the MS manipulators.) It was confirmed with a mock-up test (Figure 4) that the work of changing the forming punch, which is the item with the highest frequency of exchange in the pressing machine, can be completed within 10 minutes.

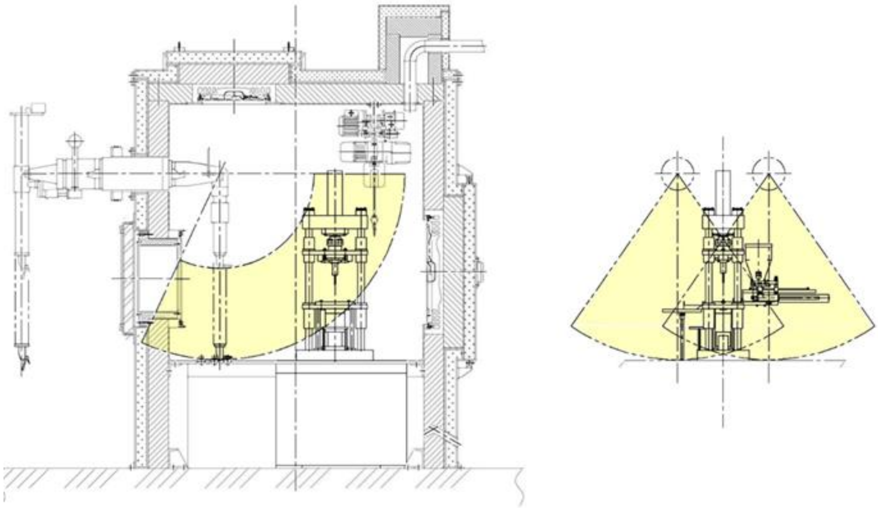

Figure 3. Layout design of pressing machine

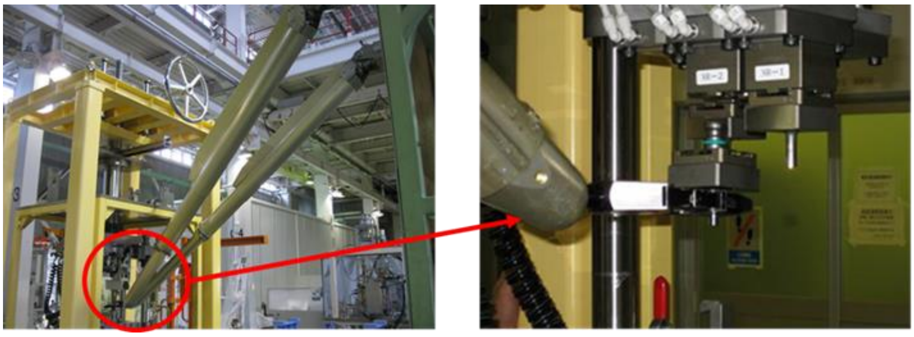

Figure 4. Exchanging the forming punch in a mock-up test

2.5. Transfer Device

A conveyer device is adopted for the transfer device from container opening apparatus to the pressing machine, and a vibration feeder device is adopted after pelletizing, taking into consideration operation performance. The dedicated pellet handling device to transfer pellets onto the inspection table for their visual inspection, and measurement of their diameter and weight is adopted.

2.6. New Fuel Fabrication Plant applying the Simplified Fuel Fabrication Process

Figure 5 shows the plant layout of the new fuel fabrication facility applying the simplified MA-bearing fuel fabrication process. Taking into consideration the processing capacity of each device, productive capacity of this new facility will be about 80kg MOX fuel per year with 200 operation days. The plant building will have a width of 50m, a length of 66m, and be four stories high.

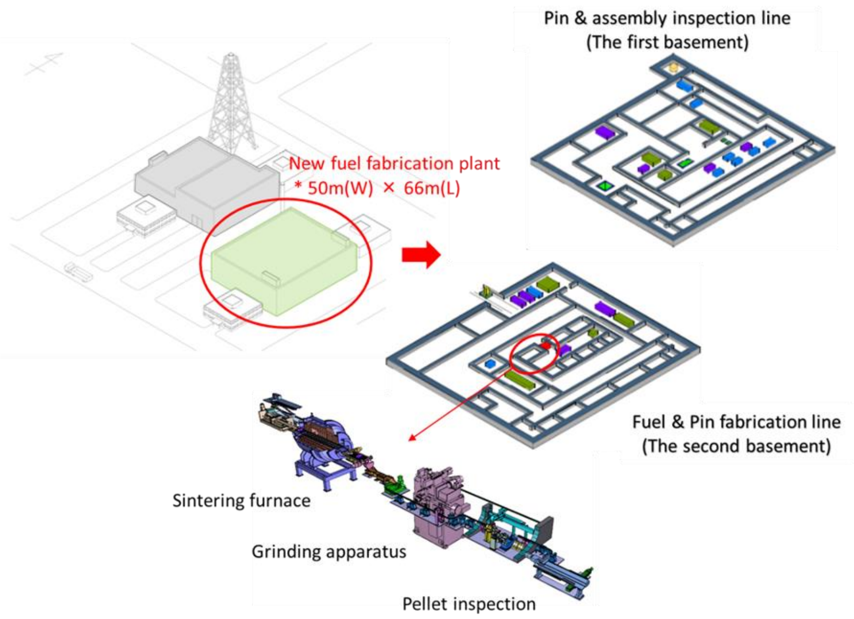

Figure 5. The layout of the new fuel fabrication plant

2.7. Operation Control System

The operation of this new plant will apply a remote automatic control system based on the experiences in operating the PFPF. The operation system computer for apparatus monitoring control will be set in a control room, and the job site control touch panel devices, capable of operating apparatuses, will be set near their respective apparatuses from the viewpoint of easily carrying out maintenance work. Figure 6 shows the components of the basic operation control system.

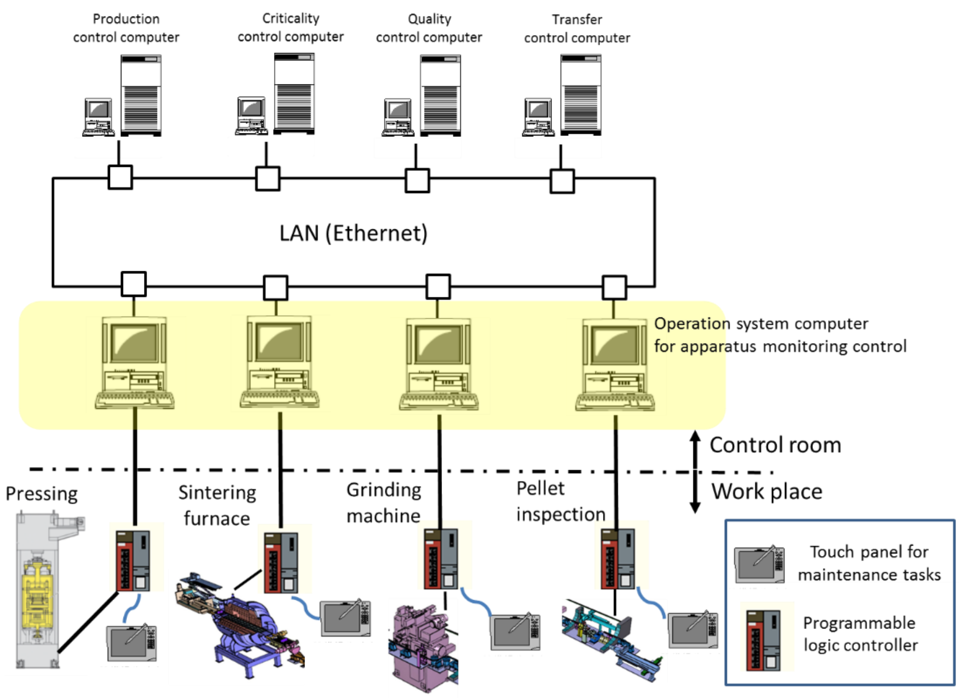

Figure 6. The components of basic operation control system

3. Conclusion

On the basis of the operational and technical experiences obtained in various JAEA facilities, the conceptual design was completed for the engineering-scale plant applying the simplified MA-bearing fuel fabrication process with shielded hot cells and manipulators. The following results were obtained.

1) The new plant will be able to fabricate high MA-bearing fuel and the maintenance and repairing of each piece of equipment will be able to be done by using MS manipulators.
2) The operation of this new plant will be accomplished with a remote automatic control system that is based on the operating experiences of the PFPF.
3) The productive capacity of the facility will be about 80kg MOX fuel per year for 200 operation days.
4) The plant will be a building with a width of 50m, a length of 66m, and height of four stories.

A plant will be constructed based on this concept and development plan.

References

[1] K. Takato, et al. “Engineering Scale Development Test of MOX Fuel Fabrication Technology to Establish Commercialized Fast Reactor Cycle (1) Fabrication Test of MOX Pellets by Die Wall Lubrication Method for Simplified Pelletizing Process”, Proc. Fall Meeting of the Atomic Energy Society of Japan, Hiroshima, Japan (2012) (CD-ROM).

[2] T. Makino, et al. “Development of the Simplified MOX Pellet Fabrication Process”, Proc. GLOBAL 2005, Tsukuba, Japan, Paper No.416.

[3] K. Sudo, et al. “Development of Pressing Machine with a Die Wall Lubrication System for the Simplified MOX Pellet Fabrication Method in the FaCT Project”, Proc. GLOBAL 2011, Makuhari, Japan, Paper No.387512.

[4] K. Asakura, et al. “Feasibility Study on a Simplified MOX Pellet Fabrication Process, the Short Process, for Fast Breeder Reactor Fuel”, Nuclear Technology, (2009) Vol.167, No.3, pp. 348-361.

[5] K. Minato, et al. ”Research and Development Activities on Partitioning and Transmutation of Radioactive Nuclides in Japan”, 9th Information Exchange Meeting on Actinide and Fission Product Partitioning & Transmutation, Nimes, France, 26-29 September (2006)

[6] H.Kamide, “R&D on fast reactor cycles and role of Monju and Joyo”, International Symposium on Present Status and Future Perspective for Reducing Radioactive Wastes ~Challenge for the Relife in the Next-generation~, Feb.17, Tokyo (2016).

[7] T. Sasa, et al., “CURRENT PLAN OF J-PARK TRANSMUTATION EXPERIMENTAL FACILITY”, AccApp’07, Pocatello, Idaho, July 29- August2, USA (2007) 949–955.

[8] H. Ojima, et al. “Status of MOX Development for FBR System in JAEA”, Proc. GLOBAL 2011, Makuhari, Japan, Paper No.391260.

[9] T. Abe, et al. “Oxide Fuel Fabrication Technology Development of the FaCT Project (1)”, Proc. GLOBAL 2011, Makuhari, Japan, Paper No.387478.