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NUCLEAR FUEL REPROCESSING AND MIXED-OXIDE FABRICATION SERVICES

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PNC
Tokai Mura Fuel Fabrication Facilities

1. Development and Status

The Power Reactor and Nuclear Development Corporation (PNC) is a semigovernmental organization responsible for the development of advanced power reactors and nuclear fuels in Japan. At Tokai Works, the development and fabrication of plutonium-bearing fuels had to be accelerated to meet the requirements of the FBR and ATR programs and the new prototype plants being designed. The process for conversion of the Pu-U nitrate-mixed solution to mixed-oxide powder was required to be developed by coconversion in Japan to meet safeguarding requirements and techniques. Several reactor programs were dependent on the mixed-oxide fuels produced.

Extensive research, process development, and facilities are required for plutonium utilization in reactor fuel. In the early 1960s, PNC started conducting research and development in the back end of the nuclear fuel cycle on plutonium-related technologies. The utilization of plutonium required that efficient techniques be found for conversion of plutonium and for fabrication of plutonium fuels. The research in Japan was conducted primarily by the PNC Plutonium Fuel Division. In accordance with a 1977 U.S.-Japan agreement, fuel reprocessing called for uranium and plutonium coprocessing. Plutonium fuels were permitted to be used for research.

The development of plutonium fuel technology proceeded concurrently with development of the heavy water and fast breeder reactor programs. As progress was made in proving the plutonium processes and successful operation of the test reactors, fuel production facilities became essential and were constructed at Tokai Works.

The mixed-oxide fuel fabrication facilities of PNC are located at Tokai Works and include the following facilities:

- conversion facility
- plutonium fuels development facility
- plutonium fuels fabrication facility
- plutonium fuels production facility

The production of mixed-oxide fuels is now under way at Tokai. The plutonium fuel fabrication facility has completed delivery or is currently continuing production to supply to Fugen for the initial core loading. Also it is supplying to the Joyo reactor 259 fuel assemblies for the original as well as the upgraded core. The principal design characteristics of the fuel for the fast breeder reactors and the heavy water reactors are as follows:

Joyo Fuel Description

Fuel material	Pu-U mixed-oxide fuel
Number of elements per assembly	127
Number of fuel assemblies	67
Number of blanket assemblies	188 (UO_2)

Monju Fuel Description

Fuel Material	Pu-U mixed-oxide fuel
Number of elements per assembly	169
Number of fuel assemblies	198 (PuO_2 - UO_2)
Number of blanket assemblies	172 (UO_2)

Fugen Fuel Description

Fuel material	1) Slightly enriched (1.5 or 1.9%) uranium 2) U-Pu mixed-oxide of 1.4 or 2.0% average fissile content
Pellet diameter	14.4 mm
Cladding material	Zircaloy-2
Number of fuel assemblies	28-rod cluster
Total length of fuel assembly	about 4.4 m

Through 1982, the PNC mixed-oxide fuel fabrication facilities were operational. Fuel assembly production lines were established for production of both fast breeder reactor and advanced thermal reactor fuels.

2. Site Description

The mixed-oxide fuel fabrication facility in Japan is located at Tokai Works some 150 kilometers northeast of Tokyo. The site encompasses a number of major nuclear facilities including the spent-fuel reprocessing facility and the PNC developmental laboratories. Tokai Works adjoins the Japan Atomic Energy Research Institute and is near the Tokai Nuclear Power Plant.

The overall site of Tokai Works consists of 220,000 square meters. The mixed-oxide fuel fabrication facilities form a complex within the boundaries of the site in a region in the southeast corner. Ample space was allocated for the new conversion facility and the fuel fabrication building. The overall site is bounded on the east by the Pacific Ocean and on the north by the Shinkawa River.

Access to the plant is provided by connector Highway 245 which leads to Highway 6, the main north-south route along the east coast of Japan. Katsuta, located about 15 kilometers west of the site, is the nearest town and railroad. There are docks at the Tokai Nuclear Power Plant site just to the north of Tokai Works.

3. Facility Description

The mixed-oxide fuel fabrication facilities consist of the plutonium conversion facility and the plutonium fabrication facilities. These facilities are described on the next page.

a. Plutonium Conversion Facility

The Tokai Reprocessing Plant supplies plutonium nitrate solutions and uranium nitrate solutions, which must be converted to mixed-oxide (MOX) fuel. From nonproliferation considerations, the United States-Japan agreement of 1977 specified that the conversion of the nitrate solution from the fuel reprocessing operation would not involve denitration to yield pure plutonium. Instead, a new co-processing method was developed wherein the mixed solution of plutonium nitrate and uranyl nitrate was denitrated directly.

A small-scale development facility was initially built at Tokai. That facility, having a capacity of 2 kg per day, was completed in 1979 and has produced approximately 1 MTU of MOX powder for the Fugen reactor. PNC has recently completed a new and larger capacity, $30.3 million, facility to convert the mixed nitrate solution into mixed oxide. Completion of the conversion plant was announced March 11, 1983. This latest plant, also located at the Tokai Works, is designed to produce 10 kilograms of MOX daily. This conversion facility is large enough to process all the nitrate solution produced at the adjacent 210 MTU per year reprocessing plant.

The development of the plutonium and uranium co-conversion process by PNC was a significant achievement, representing a first anywhere in the world for the completion of this type of plant. The denitrification process is a relatively simple process, when conducted on a batch basis, and can be carried out in a relatively compact area of about 1,200 square meters. The total floor space of the new conversion facility measures only 5,000 square meters. The building consists of a basement and four stories above ground. Construction of the facility began in August 1980 and was completed February 28, 1983, after a series of cold testing. A trial run using uranium will be conducted and later in the year the plant is scheduled to initiate the production of MOX in powder form.

The plutonium fuel fabrication projects in the past have obtained the Pu raw material from two sources. One source is pure PuO_2 powder imported from Europe, mostly from British Nuclear Fuel Ltd. (BNFL), who reprocessed MAGNOX fuel from Japan Atomic Power Company's Tokai Works reactor. This PuO_2 powder has been used for Joyo fuel. The UO_2 powder for Joyo fuel has been prepared from UF_6. The blending of the PuO_2 powder with UO_2 was followed by ball-milling to obtain the proper powder texture for pellet production. The second source of Pu material is the co-converted powder, which has been used primarily in Fugen. The mixed oxide is prepared by denitrification at the Tokai facility and, after the reduction process, is ball-milled to produce the powder.

b. Plutonium Fabrication Facilities

1) Plutonium Fuels Development Facility

Research and development on the production of mixed-oxide fuel has been in progress in Japan since 1965. This effort has been conducted at the Plutonium Fuel Development Facilities (PFDF) at Tokai Works. Facilities have been built and used for research and development of fabrication technologies for plutonium fuels. The urgency of this development program came in response to the progress being made with heavy water reactors (HWR) and liquid-metal fast breeder reactors (FBR).

The early development efforts at the PFDF were directed toward safe handling techniques for plutonium. A fuel assembly production line for HWRs and BWRs was completed and initial charge fuel for Joyo and Fugen was manufactured. The primary production method of the PFDF involved hand-operated equipment in glove boxes and shielded cells.

2) Plutonium Fuels Fabrication Facility

The plutonium fuels fabrication processes have been improved, new and improved equipment installed, and two production lines set up--one line for advanced thermal reactor (ATR) fuel and a second line for fast breeder reactor (FBR) fuel. This production capability is incorporated in the Plutonium Fuels Fabrication Facility (PFFF).

This fabrication facility is in full production and supplies fuel assemblies for Fugen and Joyo, respectively from the ATR and FBR production lines. The ATR line is planned to provide the capacity to produce up to 56 assemblies (approximately 10 tons) per year. The FBR line will produce irradiation reactor core fuel for Joyo MK-II at a rate of 50 fuel assemblies (nearly 1 ton) per year. The MK-II core is being fabricated to a demanding specification involving more advanced technology, increased plutonium enrichment ratio, and smaller diameter fuel pins.

The PFFF is located in a two-storied building with a basement that serves for the ATR and FBR fuel fabrication lines. The basement serves primarily to house the utility sources, the air supply, and the ventilation equipment. The process steps of powder mixing, pelletizing, fuel inspection, and fuel assembly fabrication are performed on the first and second levels. The fabrication equipment in PFFF was improved over the original glove-box facilities used in the PFDF. Some automation of equipment and tools was incorporated and the operational process steps utilize mechanical handling. These changes assist in reducing operator exposure and assuring product standardization and improved quality.

3) Plutonium Fuel Production Facility

Plans for construction of a new fuel production facility were developed to support the fuel requirements of the development of the prototype fast breeder reactor, Monju. Approval of the plans by both the national and local governments was received in late 1981 and construction was authorized to begin in July 1982 at Tokai Works. The fuel production facility, scheduled for completion in 1985, is estimated to cost from $108 to $130 million.

The main structure is a windowless, steel-reinforced concrete building with stories above ground and a basement. The total area of the building is 27,000 square meters, of which 8,900 square meters is devoted to fuel fabrication. The facility is to be used to produce plutonium fuel for Monju and, in the future, for a new type ATR experimental reactor. The capacity of this production plant is 5 tons MOX per year. The facility, if completed in 1985 as scheduled, will precede completion of Monju by about four years. The production fuel for the new type conversion demonstration reactor is to be built at the same site to share utilities and to minimize production costs of fuel.

These production facilities are the first to adopt remote control and automatic operation technologies, which are considered essential for full-scale MOX fuel fabrication. The methods and equipment were derived from the plutonium fuel development efforts and mock-up testing. PNC indicates that their techniques are the first such advanced methods in the industry and the PFPF may well serve as a model for future MOX production plants worldwide.

4. Process Description and Technology

a. Sources of Technology

Concerns over the potential for developing nuclear weapons discouraged the use of technology that provides pure plutonium during spent-fuel reprocessing. This influenced developments in Japan, since they were required by agreement to develop and to implement a co-conversion process for mixed-oxide fuel in order to initiate a plutonium-fuels program. As a result of carrying out the research and development of these new processes, PNC originated the techniques, developed the equipment, and established the technology for the co-conversion process. Similarly, the equipment, the automation, the remote handling techniques, and the fuel fabrication systems being specified for the new plutonium fuel production facility derive from PNC's internal developments.

b. Conversion Process

The new conversion plant will use the co-conversion process, which is based on technology called direct denitrification. The process involves receipt of the plutonium nitrate, $Pu(NO_3)_4$, and uranyl nitrate, $UO_2(NO_3)_2$, as supplied from the reprocessing plant, and mixing of the solutions in a dissolver at the conversion plant. The Pu-U mixed-nitrate solution is adjusted to a plutonium and uranium unit molar ratio at a concentration of about 260g (Pu + U)/L.

PNC established the co-conversion technology by developing a microwave heating denitrification process. The second step in the process is denitration of the mixed solution in a microwave generator apparatus. It consists essentially of heating the solution for an hour in a microwave oven to yield a mixture of plutonium dioxide and uranium trioxide (PuO_2 - UO_3).

Next, the oxide is scraped from the denitration vessel and processed through a reduction furnace, using an atmosphere of nitrogen/hydrogen gases and a crusher to obtain PuO_2 - UO_2 mixed-oxide powder suitable for the preparation of pellets. Large MOX particles may require a second crushing for proper powder characteristics. Tests and inspections confirm that the process supplies superior powder characteristics, is simple in operation, and minimizes liquid space requirements. Waste liquid generation is reduced to about one-fifth of the amount a conventional process generates.

c. Co-conversion Process

1. Dissolving:
   Mixed solution of plutonium nitrate and uranyl nitrate

2. Denitrating:
   Microwave heating of solution

3. MOX Scratching:
   Scraping of oxide from heating vessel

4. Reducing Furnace:
   Atmosphere of nitrogen/hydrogen gases

5. Crushing:
   Reduce particles to powder

6. Containerizing:
   Mixed-oxide powder

The entire process is performed in six tall, airtight enclosures or glove boxes. Currently, it is a batch operation and requires about eight hours to complete.

To operate the co-conversion facility, to develop new technology, and to provide maintenance and other services, PNC formed a conversion technology development division composed of about 80 members. About half the group is assigned to production plant operation, with the other half devoted to development activities. One future objective is the realization of a continuous flow process.

d. Fabrication Process

The plutonium fuel fabrication process involves all the process steps required from the receipt and storage of the PuO_2 - UO_2 powder through the powder mixing, pellet molding, pellet storage, fuel rod fabrication operations, to completion of the final fuel assemblies. In the original development facilities, all operations were carried out in glove boxes. With further development efforts, advances were made in the equipment and methods used in the fuel fabrication facility where FBR and ATR fuel flow lines are now in operation. Mechanical handling in almost all of the processing steps has been incorporated for better quality control of the fuel product. The plutonium fuels production facility now under construction will have remote control and automatic operation fabrication techniques and equipment.

The ATR fuel rods are longer and have a larger diameter than those of the FBR. Accordingly, the size of the pellets are significantly larger and the overall fuel weight is extremely heavy. This factor resulted in equipment differences between the two fuel flow lines. The fabrication facility was expanded, compared to the earlier processing capacity of the development facility, equipment was improved, and some automation introduced so that replacement fuel is being produced on a continuous basis.

Although the processes will not be materially changed in the new fuel production facility being built, remote control handling and process automation will be incorporated on an expanded scale. The fabrication steps will be designed with emphasis on product quality, process reliability and economy, and personnel safety.

e. Fabrication Process

Mixed Oxide Powder:
- Receiving
- Weighing
- Mixing

Pellets:
- Molding
- Sintering (Two stages)
- Grinding
- Degassing
- Storage

Fuel Rod Fabrication:
- Cutting
- Welding bottom-end stopper
- Helium exchange
- Pellet filling
- Decontaminating
- Degassing and drying
- Welding upper-end stopper
- Inspection
- More wrapping

Assembly of Elements:
- Element Cleaning
- Assembling of rods
- Assembly cleaning
- Inspection

f. Dry Recovery of Mixed-Oxide Fuel Pellets

PNC has established a technique for dry recovery of MOX fuel pellets in the plutonium fabrication facility. Studies were made of the process to assess tab and prove out an effective oxidation method for the pulverization of the sintered pellet scraps. To minimize radiation exposure of the workers during the dry recovery of the highly enriched Pu pellets, the process was simplified to the maximum extent feasible. The dry recovery process developed is summarized in the following steps:

1. Collect strap pellets and sinter at 1,650°C to 1,770°C
2. Crush pellets in jaw crusher
3. Oxides in air at 600°C to 700°C
4. Reduce in 5% H_2N_2 at 700°C to 800°C
5. Cycle through oxidation and reduction 2 to 3 times
6. Mill scrap in ball mill
7. Product is recovered powder

g. Criticality Control and Safety

Criticality safety is a key consideration in the development and operation of the plutonium fuel fabrication facilities. Each process step, each storage area, and each piece of equipment is arranged, sized and controlled to assure subcriticality of the fuel materials. Space layouts, material quantity control, and engineered safety features are all utilized in the MOX manufacturing facilities.

Operations are carried out within airtight enclosures or other sealed confinement to avoid ingestion of toxic plutonium or exposure to alpha particles by production workers. Work areas and personnel are monitored by a competent health physics staff to verify the integrity of the protective systems installed, the acceptability of the work station radiation exposure levels, and overall personnel radiation safety conditions.

5. Fuel Fabrication

a. Historical MOX Production

Planning and research and development work for MOX production was initiated in Japan in the early 1960s. Twenty years of experience has now been gained and fuel production facilities are in operation.

The plutonium fuel fabrication facility has completed delivery, or is currently continuing production to supply, 300 fuel assemblies (about 53 tons) to Fugen for the initial and replacement core loading. Also, it is supplying to Joyo 119 fuel assemblies (about 1.6 tons) for the MK-I core and 140 fuel assemblies (about 2 tons) for the MK-II core.

Through 1981, PNC had produced 289 Fugen assemblies, consisting of some 9,300 fuel rods and over 1.5 million pellets. In addition, through 1981, PNC had produced 139 Joyo fuel assemblies, consisting of 15,599 fuel rods and 959,592 pellets.

The Fugen fuel produced includes assemblies for the initial core loads and for the second and third cycle operations, as well as higher enrichment MOX fuel for higher burnup. MOX fuels for the MK-II core of the Joyo reactor, which was being converted to a new core with a power rating of 100 MWt from a 75 MWt core, were fabricated in full scale at the newly equipped and more advanced plutonium fuel fabrication facility.

b. Planned MOX Production

From now on, the ATR flow line has the capacity to produce 56 assemblies (about 10 tons) per year based on calculations for the type of fuel used for Fugen and on the production experience with the ATR fuel. In keeping with the alteration of the Joyo core from MK-I to MK-II, the FBR line plans to produce 50 assemblies (about 0.6 tons) per year. The production of the first 60 assemblies of the fuel for the MK-II core was accomplished without any special difficulties.

The new production facility for plutonium fuel is under construction and is scheduled to be completed in 1985. A production capacity of 5 tons MOX fuel per year is planned for this facility. The fuel produced will be for the initial core loading for the prototype fast breeder reactor, Monju. In the future, the production facility will be further expanded to provide a dependable, high-quality fuel supply source for the new type of conversion demonstration reactor in parallel with the production of fuel for the prototype fast breeder reactor. When completed, the new facility will be used to establish a mass-production technology for fabrication of MOX fuels.

Table 1

BASIC DATA

NAME:	PNC Mixed-Oxide Fuel Fabrication Facility
ORIGINAL NOMINAL DESIGN CONVERSION CAPACITY:	2 kg per day of MOX powder
EXPANDED CONVERSION CAPACITY/DATE	10 kg per day of MOX powder/ Production scheduled for late 1983
ORIGINAL NOMINAL DESIGN FUEL FABRICATION CAPACITY	56 assemblies, approx. 10 MT MOX per year ATR fuel and 50 assemblies; Approx. 1 MT MOX per year FBR fuel
EXPANDED FUEL FABRICATION CAPACITY/DATE	5 MT MOX per year FBR fuel/ production to begin 1985. Plans being developed for new HWR fuel fabrication facility.
STATUS	Operating
OWNER	PNC
OPERATOR	PNC
MILESTONES	
• **INITIAL FUEL DEVELOPMENT FACILITY**	1972
• **INITIAL MOX FUEL PRODUCTION**	1975 FBR fuel 1978 HWR fuel
• **CO-CONVERSION FACILITY COMPLETED**	1983
• **AUTOMATED FUEL PRODUCTION PLANT**	1985

Table 2

SITE DATA

LOCATION	:	Tokai
NEAREST LARGE TOWN	:	Katsuta
MAIN CONNECTIONS		
• **NEAREST HIGHWAY**	:	Highway 6 (12 km)
• **NEAREST RAILWAY STATION**	:	Katsuta (15 km)
• **NEAREST PORT**	:	Tokai Nuclear Power Plant (Approx. 10 km)
CASK ARRIVAL MODE	:	NA

Table 3

FACILITY DATA

STORAGE OF FEED

URANIUM

- **CAPACITY/FORM** : Capacity not specified/Uranyl nitrate solution $UO_2(NO_3)_2$
- **STATUS** : Operating

PLUTONIUM

- **CAPACITY/FORM** : Capacity not specified/Plutonium nitrate solution $Pu(NO_3)_4$
- **STATUS** : Operating

PRODUCTION/FABRICATION

- **CAPACITIES**

  PLUTONIUM-OXIDE : NA

  MIXED-OXIDE BLENDING : NA

  MIXED-OXIDE PELLETS : 10 MT MOX per year for ATR fuel; 1 MT MOX per year for FBR fuel

  MIXED-OXIDE RODS : 10 MT MOX per year for ATR fuel; 1 MT MOX per year for FBR fuel

  MIXED-OXIDE ASSEMBLIES : 56 assemblies per year ATR fuel and 50 assemblies per year FBR fuel

- **PROCESS TYPE** : Co-conversion of mixed nitrate solutions to mixed-oxide powder
- **SUPPLIER OF PROCESS TECHNOLOGY** : PNC
- **DESIGNER** : PNC
- **CONSTRUCTOR** : PNC
- **STATUS** : Completed

Table 3

FACILITY DATA
(continued)

STORAGE OF PRODUCT

- **RODS**

CAPACITY/DATE	:	Not specified
STATUS	:	Operating

- **ASSEMBLIES**

CAPACITY/DATE	:	Not specified
STATUS	:	Operating