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FABRICATION OF PuO_2-UO_2 MIXED-OXIDE FUEL FOR THE INITIAL LOADING OF HEAVY WATER REACTOR "FUGEN"

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FOR THE INITIAL LOADING OF A PROTO-TYPE
HEAVY WATER REACTOR "FUGEN"

K. Naruki, T. Itaki, T. Muto

Tokai-Works, Power Reactor and
Nuclear Fuel Development Corporation
Tokai-mura, Ibaraki-ken, Japan

T. Amanuma

Power Reactor and Nuclear Fuel Development Corporation
1-9-13, Akasaka, Minato-ku, Tokyo, Japan

ABSTRACT

The fabrication work started in fall, 1975 for "FUGEN" initial core mixed-oxide fuel of hundred fuel assemblies, which amounts to 18 tons PuO_2-UO_2 pellets. So far about 7.7 ton pellets and 1326 fuel rods of 0.8% Pu-fissile fuel have been produced with strict quality control, and the production work of 0.55% Pu-fissile fuel and fuel assembly are under way. Amount of MUF in 0.8% Pu-fissile fuel production were 0.18% Pu and 0.15% U. The various presentive measure to personal radiation resulted in the low dose rate of 160 mrem per three months in maximum. The preliminary evaluation of fabrication cost showed a reasonable value in a comparatively small scale production.

I. INTRODUCTION

The Power Reactor and Nuclear Fuel Development Corporation (PNC) is constructing a prototype reactor"FUGEN", which is a heavy water moderated, boiling light water cooled, pressure tube type reactor designed to generate 165 MWe. FUGEN is scheduled to achieve criticality in early 1978. In the initial core of FUGEN, 96 mixed-oxide (PuO_2-UO_2) fuel assemblies are loaded in the center region and 128 oxide (UO_2) fuel assemblies in the outer region. Use of plutonium fuel not only gives relief to an enriched uranium burden in a fuel material, but also is effective to decrease void reactivity in FUGEN type reactor (Ref. 1). The fabrication of the mixed-oxide fuel of 100 assemblies including four spare assemblies, which amount to about 18 tons of mixed-oxide pellets, started in fall, 1975 in the Plutonium Fuel Fabrication Facility (PFFF). The whole fabrication work is to be completed by early 1978.

This paper describes the fabrication program, the experience and the information obtained so far in the course of fabrication work.

II. FUEL DESIGN and SPECIFICATION

Table 1 and Table 2 indicate the main specifications of the fuel. Fig. 1 shows the structure of fuel assembly and fuel rod. Composition of fuel rods in fuel assembly is shown in Fig. 2. The fuel assembly is a cylindrical bundle of fuel rods, which is composed of 16 low plutonium enriched fuel rods (0.55% Pu-fissile) and 12 high plutonium enriched fuel rods (0.8% Pu-fissile). 0.55% Pu-fissile rods are arranged in the outer layer, and 0.8% Pu-fissile rods in both the middle layer and the inner layer of the fuel assembly. Fig. 3 shows the shape of fuel pellet in a diametrical section.

III. FUEL FABRICATION PROCESS AND QUALITY ASSURANCE

1. Fabrication Process

All the work for pellet production are carried out in the glove boxes. Each box houses the equipment for each production step such as powder blending and sintering. Therefore, the production is conducted in batchwise, and the product at each production step is transfered from a glove box (Step) to another glove box (Step) by an electric mini-cart through a tunnel which is attached to the array of glove boxes. (Ref. 2) Production capacity is about 10 tons mixed-oxide per year, and batch size for each production step is 30 kg mixed-oxide.

Capacity of fuel rod fabrication is 10 rods per day, which is governed by the ability of pellet loading process. The fuel rod is transfered by the special tray and wagon.

From the view point of both personal radiation and quality control, some degree of effort were exerted to mechanize the operation, as seen in the following process, (1) pellet density inspection, (2) pellet loading into a cladding tube and (3) fuel rod assembling.

The process flow sheets shown in Fig. 4 and Fig. 5 are very similar to that used for UO_2 fuel. Natural UO_2 powder, PuO_2 powder, zircalloy cladding tube, end plug and other hardwares were procured from vendors. Weighed quantities of natural UO_2 powder, PuO_2 powder and recycled UO_2-PuO_2 are blended in two steps; firstly V-shape blender or a mixer and then ball-milling. The ball-milled powder mixed with the lubricating zinc-stearate binder is fed to the hopper of press step without granulation.

All sintered pellets are centerless ground, and treated in vacuum annealing to control the water content. Finally, all pellets are visually inspected by comparison with quality standard, and the pellet weight and dimensions are determined on a statistical base with the mechanical instrument. Acceptable pellets are arranged on the tray which is designed to be adaptable to pellets loading process.

Loading of pellets into the cladding tube held horizontally was conducted with a mechanized equipment which does the automatic sequence work of length adjustment, weighing and loading of pellets stack, and recording of these measurements. The second plug welding is carried out after the pellet loaded tubes are treated to vacuum heating for the final drying. The fuel rods are, then, monitored for surface contamination and undergo a series of inspection; X-ray inspection, γ-ray scanning etc.

Assembling of rods into bundle is also carried out with the mechanized equipment. Feeding and insertion of rods into spacers and measurement of gap distance between rods are done mechanically. The inspection of the fuel assembly covers the measurement of dimension, and visual check of any defects.

2. Quality Assurance Program

Prior to initiation of the production work, the quality assurance program was established, conforming to Japan Electricity Association Guidelines to Electric Technology "Quality Assurance Manual for Nuclear Power Plants (JEAG 4101/1972) and USAEC Standard 10CFR50, Appendix B 1971, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants. The QA program is based on the basic design and specifications given by the reactor installer, the Heavy Water Reactor Development Project of PNC. In this program, as many as 160 documents were prepared to define clearly for responsibility of every organization and personnel, and procedures of all the necessary action for quality assurance.

Foremost precaution was paid to prevent unwitting mixing of different plutonium enriched fuels. As the principal measure for it, production campaign was definitely divided for different plutonium enriched fuel, and the complete clean up of the boxes and other facilities was done in the transitional period between the campaign for 0.8% Pu-fissile fuel and the campaign for 0.55% Pu-fissile fuel. γ-ray scanning inspection of fuel rod can detect the existence of different Pu-fissile pellet mingled, and the shape of end plug was designed to discriminate apparently the kind of rods.

Triplicate inspection is conducted for the cladding and other hardwares, fuel pellets, fuel rods and the fuel assemblies;

the first inspection by the Quality Control Section, the second by The HWR Project and third by the officer of Ministry of Trade and Industry.

All the data concerning quality control are gathered into computer files to be traced back in the occasion of inquiry.

IV. FABRICATION EXPERIENCE

1. Pellet Production

The production work for 0.8% Pu-fissile pellets has been accomplished after about one year operation, and the work for 0.55% Pu-fissile pellets is undrway. As received PuO_2 powder is used without any processing, and plutonium spots distribution in pellet measured by alpha-autoradiograph were controlled less than 150μm as shown in Fig. 6. Ball milling condition is very important for the control of both plutonium spot size and green density. It was found that shape with dish and chamfer and size of the pellet were not favorable to pellet fabrication since pellet was liable to fine crack and capping compared with the LWR type pellets with 10 cm diameter. Pellets densities were controlled to 95.0 ± 1.2% T.D. and plutonium-fissile content to 0.80 ± 0.03%. In each sintered lot, about 10% of pellets were rejected by the visual inspection mainly due to chipping and micro-crack. Rejected pellets are recycled by the oxidation-reduction cycle. Through the production of 0.8% Pu-fissile pellets, about 7.7 tons mixed-oxide pellets were produced by 340 lots. The material flow is controlled by a computer system which can print out material inventory in a real-time basis. (Ref. 3) The amount of MUF was found to be 0.18% for Plutonium and 0.15% for Uranium, respectively.

2. Fuel Rod Fabrication

The work for 0.8% Pu-fissile fuel rods has also completed with the fabrication of 1326 fuel rods, and presently, that for 0.55% Pu-fissile fuel rod is proceeding. Considerable amount of preproduction work had been carried out to find a suitable welding conditions for the better quality of end plugs welding. Intimate contact of end plug and tube end, and cleaning of these parts have a considerable effect on the occurrence of defects in welds. Table 3 shows the primary result of X-ray inspection of endplug welds, and re-welding of the rejected rods improved the yield. Fixed contamination level at the fuel rod surface of the welded part of upper-endplug was mainly less than 10 dpm.

3. Fuel Assembly Fabrication

In assembling of fuel bundle, both bundle diameter and rod gap distance are carefully inspected, since the specifications to them are rather rigid. Usually bundle diameter was 111.5 to 112.0 mm (Spec.; less than 112.2 mm) and rod gap was 1.97 to 2.33 mm (Spec.; more than 1.7 mm). It was found that long scratches less than 10 μm depth occurred on the rod surface during insertion through spacers.

4. Personal Radiation Exposure

The following measure were taken to protect the personnel from radiation dose, (1) to shield by lead glass panel from γ-ray radiation, (2) to keep the glove box as clean as possible, (3) to hold the fuel material at a distance from the worker, and (4) to mechanize the operation as much as possible.

Usually, gamma-ray radiation ratio on the glove box pannel have been controlled less than 5 mrad per hour, and the record shows that maximum personal radiation does has been 160 mrem per three months as a total of γ-ray radiation and neutron radiation.

The maximum was registered to the operator in the pellet production process, while radiation does to the operator both fuel rod and fuel assembly fabrication were found far less than 100 mrem for three months.

5. Fabrication Cost

The preliminary evaluation of fabrication cost of the FUGEN fuel are indicated in Table 4. The cost of FUGEN (UO_2) was inferred from the details of contract cost, since the fabrication of the FUGEN (UO_2) fuel was ordered to another manufacturer. Accordingly, the cost of FUGEN (UO_2) fuel should include a profit. The value for FUGEN (MO) fuel may be reasonable if the production scale is considered in comparison with FUGEN (UO_2) fuel. There are many conceivable factors for cost reduction by the increased production scale.

V. CONCLUSION

The fabrication work of hundred fuel assemblies for the initial loading of a prototype reactor "FUGEN" was initiated with the program well-deliberated, since this is the first experience for PNC to produce such a large amount of PuO_2-UO_2 fuel for POWER reactor. The fabrication work is proceeding as scheduled. Regarding the safety of plutonium handling, personal radiation has been controlled to relatively low dose rate and there has been no serious accident except minor troubles.

We believe that the experience by this work will make a milestone for a large scale of "Plutonium Utilization for Thermal Reactor".

REFERENCE

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(3) T. MUTO, M. AOKI, M. TSUTSUMI, H. AKUTSU, "SAFEGURDING NUCLEAR, MATERIALS, (IAEA), Vol. 1, p-353.

Table 1 Specifications of Mixed-oxide Pellet

Material	: PuO_2-UO_2 (natural)
Pu content $(\frac{Pu\text{-}fissile}{U + Pu})$	: (i) 0.55±0.05% Pu-fissile for the outer layer fuel rods. (ii) 0.80±0.05% Pu-fissile for the middle and the inner layer fuel rods.
Density	: 95.0±1.5% T.D.
Diameter	: 14.40±0.05 mm
Height	: 18±1 mm
Dish dia.	: 8±1 mm
Dish depth	: 0.2±0.1 mm
Chamfer height	: 0.5±0.2 mm
H_2O content	: less than 10 μℓ/g MO
Total gas content	: less than 60 μℓ/g MO
Content of impurities	: less than 4 ppm EBC
O/M ratio	: 1.97∿2.02
Plutonium spot	: less than 400 μm

Table 2 Specifications of Fuel Rod and Fuel Assembly

Fuel rod

Clad material	: Zircalloy-2
Outer diameter	: 16.46 $^{+0.00}_{-0.08}$ mm
Inner diameter	: 14.70 ± 0.05 mm
Active length	: 3700 ± 5 mm
Leak rate	: less than 3×10^{-8} atm.cc/sec.
Surface contamination	: less than 20 dpm/rod

Fuel assembly

Total length	: 4388 $^{+1}_{-5}$ mm
Bundle diameter	: less than 112.2 mm
Rod gap	: more than 1.7 mm

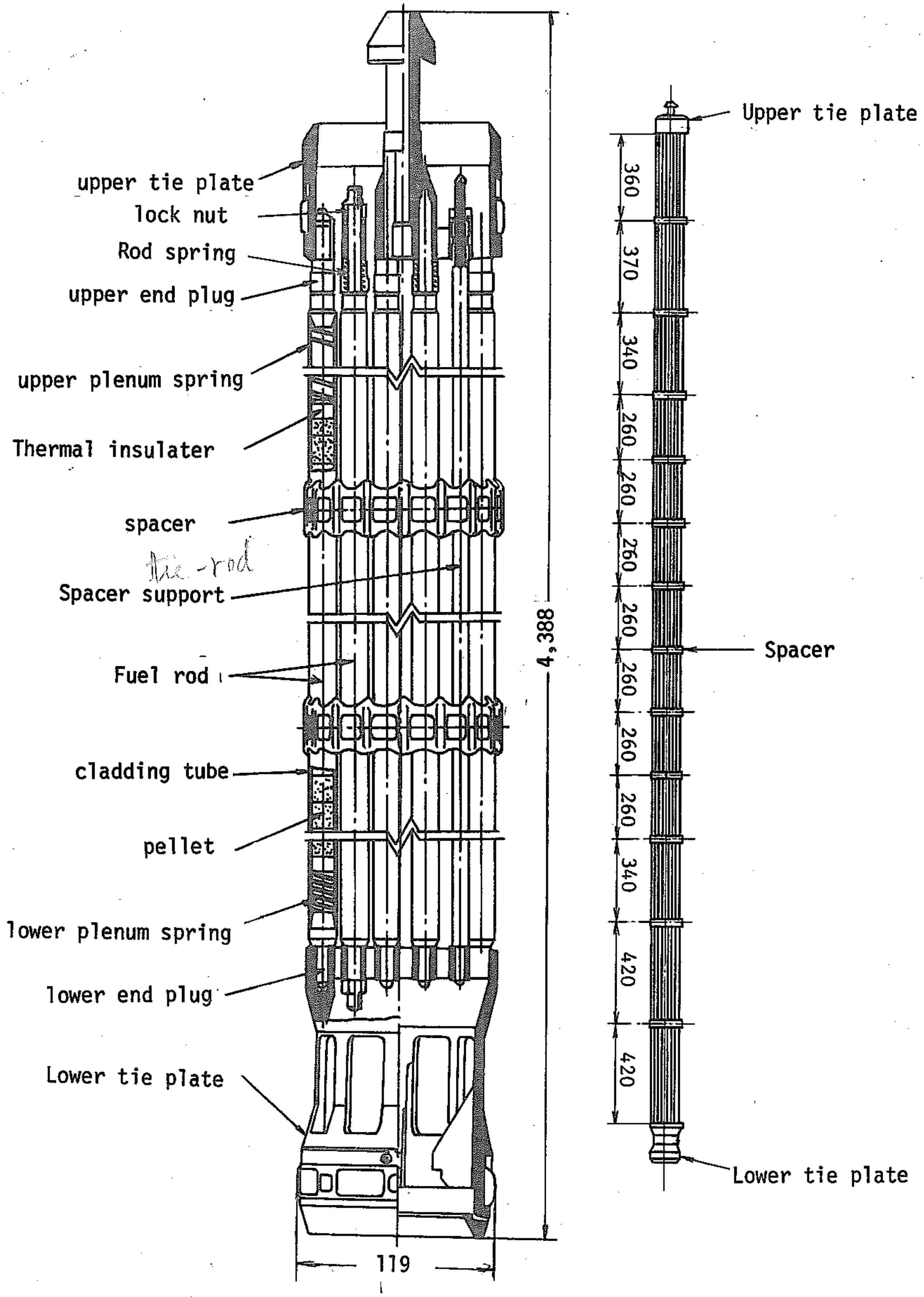
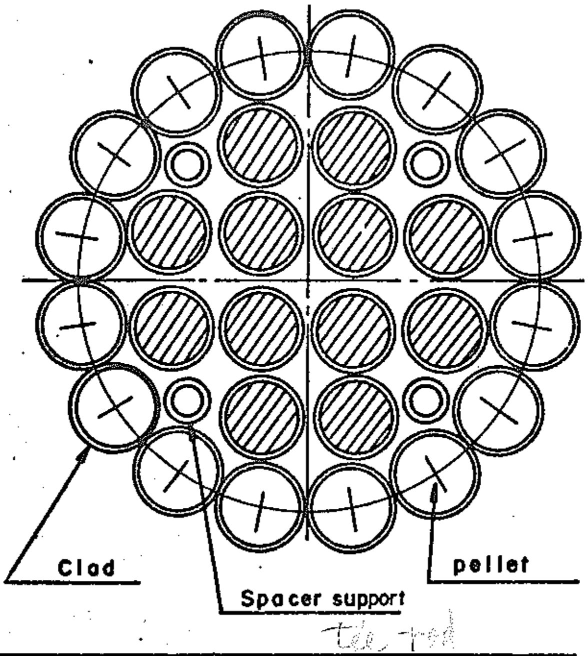


Fig. 1 Structure of The Assembly



Pellet	Region	Pu-fis. content	PuO_2 content
(hatched circle)	High enriched	0.80 %	~ 0.995 %
(open circle)	Low enriched	0.55 %	~ 0.664%

Fig. 2 Composition of Fuel Rods

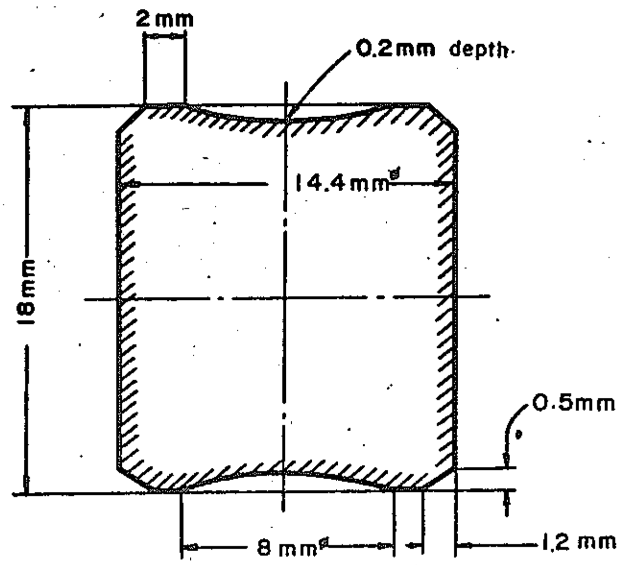


Fig. 3 Shape of Pellet

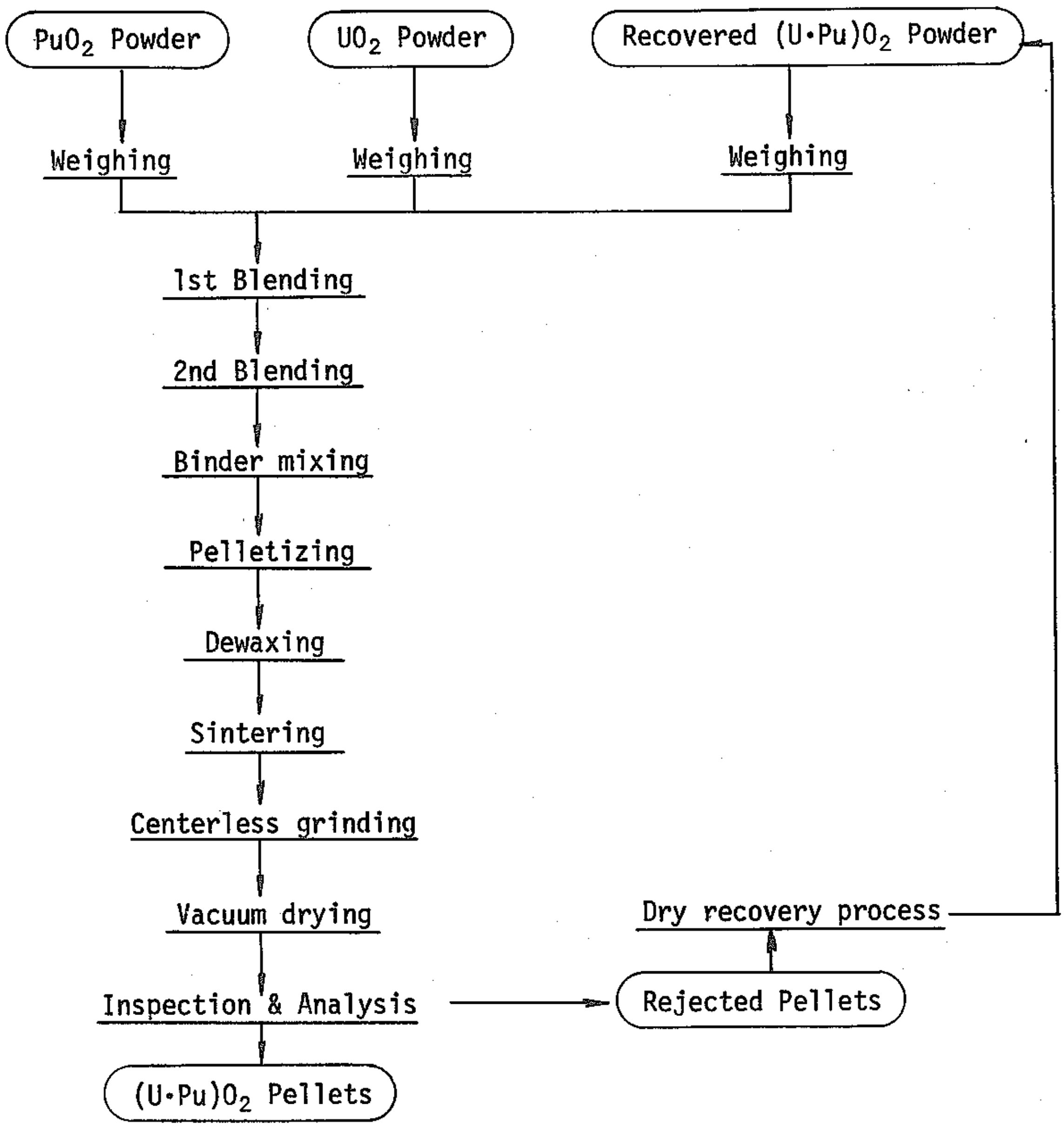


Fig. 4 Flowsheet of Pellet Production Process

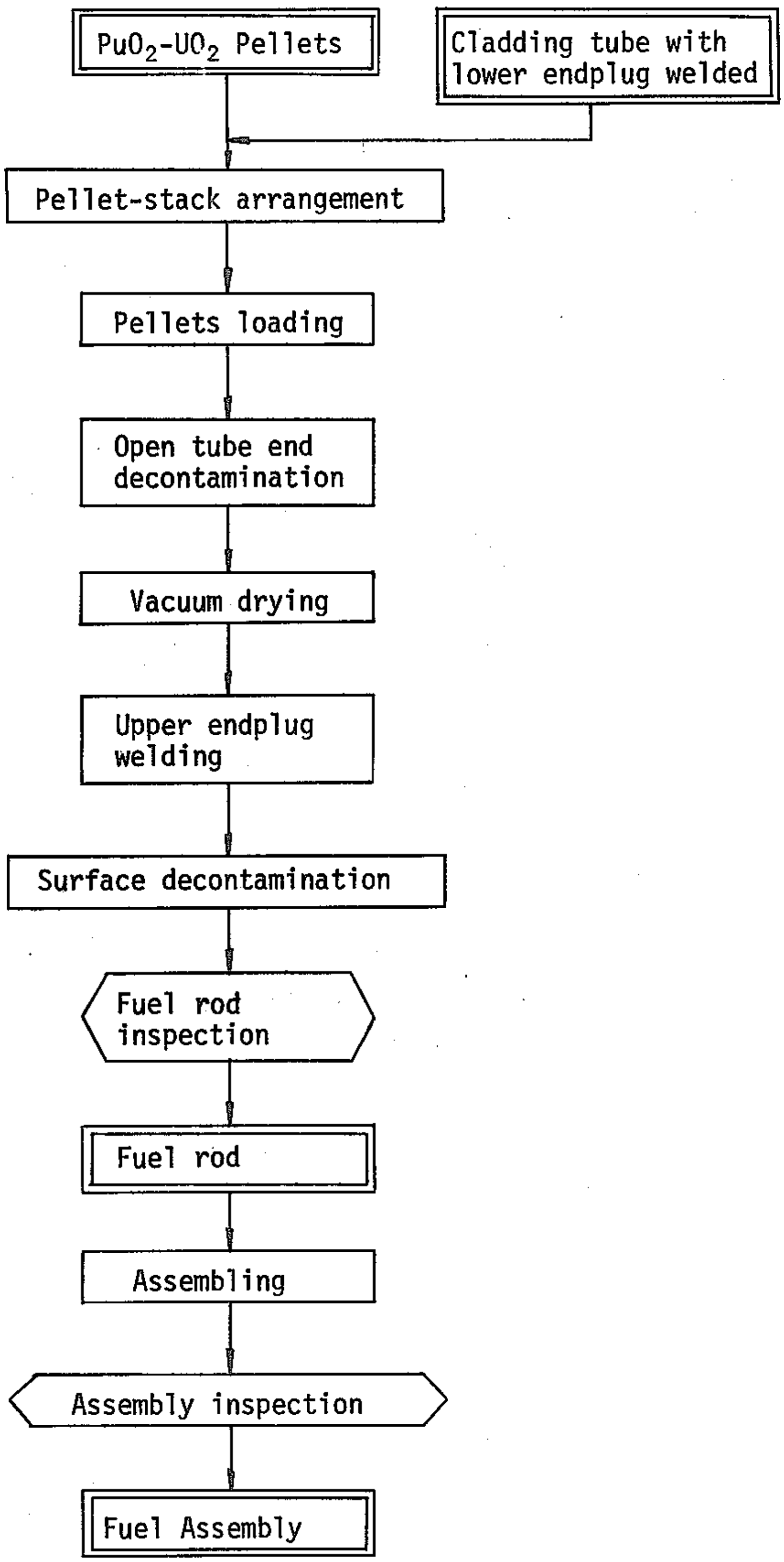


Fig. 5 The Flow Sheet of the Fabrication of Fuel Assembly

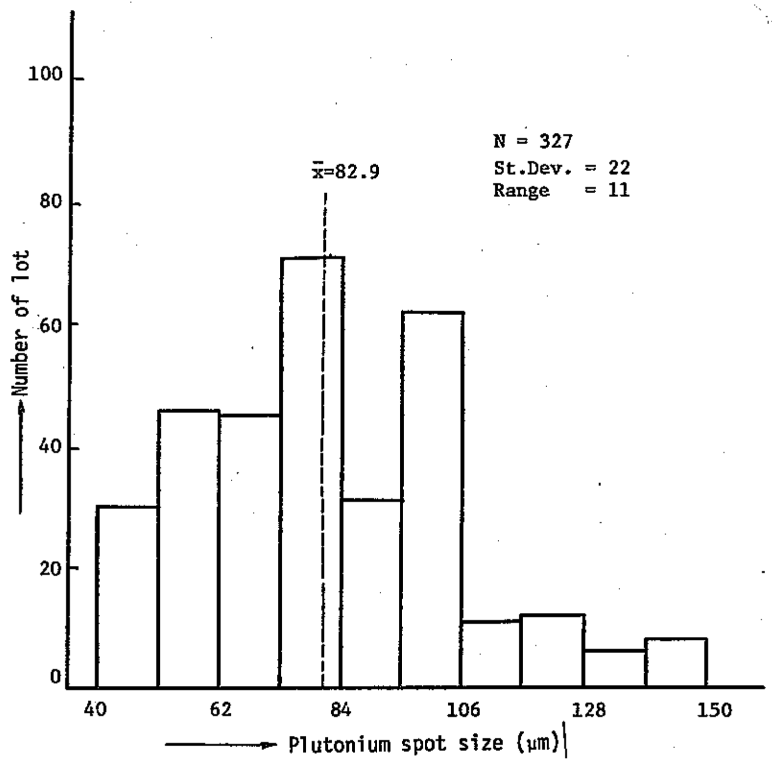


Fig. 6 Plutonium Spot Size in 0.8% Pu-fissile Pellet

Table 3 Result of X-Ray Inspection of Endplug Welds

	Number of rods	Accepted	Rejected	Yield
Lower endplug weld	3045	3028	17	99.4%
Upper endplug weld*	1250	1232	18	98.6%

* Data of 0.8% Pu-fissile fuel rods only

Table 4 Fabrication Cost of Mixed Oxide Fuel

	FUGEN(MO)	FUGEN(UO_2)
	%	%
Nuclear material	19.0	34.2
Hardware	16.0	31.5
Miscellaneous expense	30.0	31.2 (Miscellaneous expense, Labor, Depreciation of facility combined)
Labor	21.3	
Depreciation of facility	12.9	
Transportation	0.9	3.2
Number of fuel assembly	100	130
Cost ($/kg MO)*1	520	252*2

*1. Cost excluding nuclear materials.
*2. Including profit. Other values are the prime cost.