PWR FUEL PERFORMANCE

AND FUTURE TREND IN JAPAN

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ABSTRACT

Since the first PWR power plant Mihama Unit 1 initiated its commercial operation in 1970, Japanese utilities and manufacturers have expended much of their resources and efforts to improve PWR technology. The results are already seen in significantly improved performance of 16 PWR plants now in operation. Mitsubishi Heavy Industries Ltd. (MHI) has been supplying them with nuclear fuel assemblies, which are over 5700. As the reliability of the current design fuel has been achieved, the direction of R&D on nuclear fuel has changed to make nuclear power more competitive to the other power generation methods. The most important R&D targets are the burnup extension, Gd contained fuel, Pu utilization and the load follow capacibility.

I. INTRODUCTION

Since the first PWR power plant Mihama Unit 1 initiated its commercial operation in 1970, Japanese utilities and manufactures have expended much of their resources and efforts for making the PWR technology matured. The results are already seen in significantly improved performance of 16 PWR plants now in operation. MHI has been supplying them with nuclear fuel assemblies, which are over 5700. Although there were some fuel trouble experiences in early days, the progressive efforts on fuel design and to improve manufacturing technology have been carried out and have led to the superior performance of Mitsubishi fuels.

Since the fuel of current design should comply with the limitation of the maximum discharged fuel assembly average burnup less than 39,000 MWd/t in Japan, the maximum burnup experience is around 37,000 MWd/t now. However the relaxation of this burnup limitation is strongly requested by our utilities to make the nuclear power more economic, clearly competitive to the other power generation methods.

This paper presents the summary of the design improvements of Mitsubishi fuel, the demonstration programs of the current design fuel to prove its superior reliability, and R&D status on the future burnup extension, application of Gd contained fuel and Mox fuel utilization in PWR in future. In addition, the fuel investigation system of Mitsubishi is briefly mentioned.

II. SUMMARY OF THE DESIGN IMPROVEMENTS OF MITSUBISHI FUEL

The design of Mitsubishi fuel was originally introduced from Westinghouse. However it was necessary to implement several design improvements to correspond to the strict nuclear environments in Japan.

Most of the past fuel troubles encountered in Japanese PWRs are:

(1) fuel rod bowing
(2) grid damage during fuel handling
(3) fuel rod damage due to baffle jetting
(4) pin hole type leakage

The rod bowing and the grid damage have not directly caused fuel leakage so far affecting plant operation, but the assemblies with excessive rod bowing and with grid damage unrepairable are removed from the next core without completing their duty, which is considered economically undesired and made the design improvement necessary.

One of the important changes of fuel assembly design is the introduction of 8 grids assembly design for 14 x 14 fuel instead of 7 grids and 9 grids assembly design for 17 x 17 fuel instead of 8 grids, respectively. In addition to the increase of grid number, some other design changes have been introduced such as the optimization of grid spring force, rod bottom off design. After these improvement combined, no significant rod bowing is observed.

MHI has made the extensive evaluation of grid damage experiences and found that the most of them occured at the top grid corners during fuel loading. After analysing the damage mechanism Mitsubishi has developed the fuel loading program, which can optimize the fuel loading sequence to reduce the possibility of the interference between assemblies during their loading. Mitsubishi has also modified the grid corner design, which has the better loading capability. Due to the grid design improvement and the application of the sophisticated fuel loading sequence, grid damage problem have been resolved.

It should be pointed out here that the change in grid design has carried out not only in considering loading capability, but also in other respects such as structural integrity for earthquakes. The safety criteria for plant and core components are very severe in Japan, becoming more strict especially in recent years. Accordingly fuel assemblies for a new plant are required to have higher reliability for earthquakes. Under this situation Mitsubishi has developed higher strength grid design and were applied for current 17 x 17 PWR fuels.

Several years ago, the trouble of fuel rod damage due to baffle jetting were occured in Japan, and the extensive R&D efforts were made to resolve them. As the tentative resolution for baffle jetting, MHI invented the anti-vibration clip, which can be easily attached to the assemblies in front of baffle plate joints, but our utilities decided to choose the fundamental resolution of the problem, that is to change the direction of coolant flow from original down-flow to up-flow. The conversion work for down flow plant was done by MHI.

The pin hole type leakage was sometimes observed in the age of introducing PWR plants. However Mitsubishi has made much efforts in quality control and inspection in manufacturing, and improved design specification. As a result, the pin hole type leakage rarely occures at the present days.

III. VERIFICATION PROGRAM OF THE PERFORMANCE OF MITSUBISHI FUEL

As described in the previous section, Mitsubishi fuel has been satisfactorily used in Japanese PWRs with several design improvements implemented. The irradiation experience of Mitsubishi fuels as shown in Fig. 1.

The following programs has been performed in order,

1) to demonstrate the integrity and reliability of current Mitsubishi fuel assemblies,
2) to confirm the design-integrity and the design-margin for the fuel assemblies during irradiation,
3) to accumulate the fuel irradiation data.

The summary of important programs is described in this section, while the survey of the accumulated data is discussed in the next section.

A. Proving test on the reliability of Mitsubishi 15 x 15 fuel assemblies[1]

The 15 x 15 monitoring fuel assemblies, which were selected from standard products and characterized by collecting much more fabrication data than obtained by usual inspections, were loaded in Mihama Unit 3 and irradiated from its second to fourth reactor cycle under the sponsorship of MITI. One of these assemblies after each reactor cycle was examined at the JAERI hot cell. PIE results verified the reliability of current fuel design.

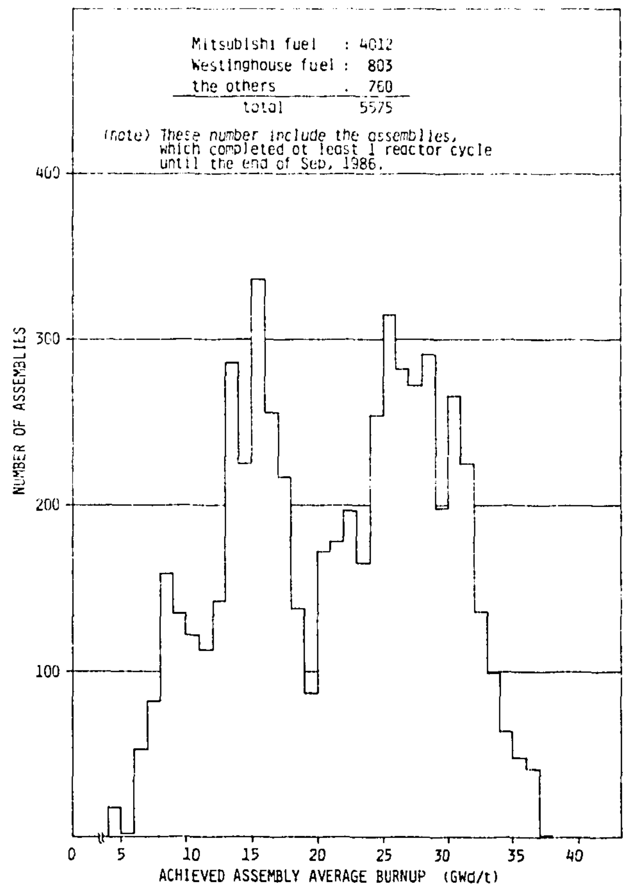


Fig. 1 Irradiation Experience of PWR Fuel in Japan

B. PIE program of high burnup fuel of 14 x 14 type

To enhance the data base of irradiation behaviour of Mitsubishi fuel, with focussing of the data at high burnup, one 14 x 14 type assembly with the average assembly discharged burnup 37,000 MWd/t approximately was examined nondestructively and desctructively at JAERI hot cell laboratory from 1981 to 1985 and the data showed enough integrity and margin.

C. PIE program of PRD (Power Ramp Demonstration) assembly exposed under cycling

In order to verify the load following capability of Mitsubishi fuel, a series of demonstration program has been in progress from 1978.

The first verification was to investigate the PCI resistance of the current design fuel by power ramping tests, following by power cycling tests to confirm that there is no adverse effect on fuel performance due to cyclic power transients, where the number of cyclings reached about 600. These tests were done with Mitsubishi type fuel rods at the experimental reactors at Studsvik and Halden, under simulating PWR conditions.

After these verification tests, the demonstration program of load following capability at domestic commercial reactor - so-called PRD (Power Ramp Demonstration) tests - were completed recently. Some test assemblies have been subject to the on-site profilometry after PRD to evaluate the cycling effect on the rod diameter, while one PRD assembly is now examined at JAERI hot cell laboratory to confirm that there are no difference between normal operation fuel and PRD fuel.

IV. IRRADIATION BEHAVIOUR OF MITSUBISHI FUEL ASSEMBLY

In this section the irradiation behaviour of Mitsubishi fuel assembly will be described with the data accumulated by the programs mentioned in the previous section. The irradiation behaviours to be described are fuel assembly growth, fuel rod growth, fuel rod bowing, FP gas release, cladding waterside corrosion and PCI resistance.

A. Fuel assembly growth

The fuel assembly growth data of Mitsubishi fuel[1] are compared with those of Westinghouse in Fig. 2. The magnitude of the assembly growth of Mitsubishi fuel is larger than that of the others[2], however, is well below the acceptance limit to interfere with the core plates. The larger growth in Mitsubishi fuel is thought to be owing to the increase of grid numbers compared with Westinghouse fuel, introducing the more creep strain with the larger tensile stress on RCC thimble tubes by the rod growth through grids.

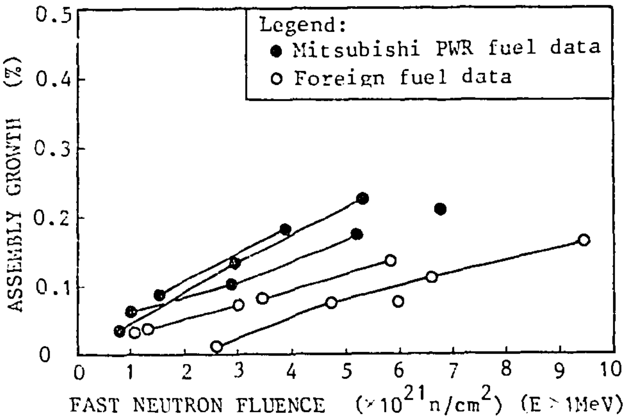


Fig. 2 Fuel Assembly Irradiation Growth

B. Fuel rod growth

The fuel rod growth data[1,2] are plotted in relation to the fast neutron fluence (> 1MeV) in Fig. 3. There can be seen no difference between fuel types. It should be noticed that the rod growth rate is almost same as that of zircalloy tube itself given by Adamson.

C. Fuel rod bowing

The various data of channel closure due to rod bowing are shown in Fig. 4. The channel closure of Mitsubishi fuel[1] is small as CE[8] and B&W fuel[7], which have more grids than Westinghouse fuel[2]. It can be seen that the channel closure has the trend to saturate with burnup and would not be the critical behaviour at higher burnup.

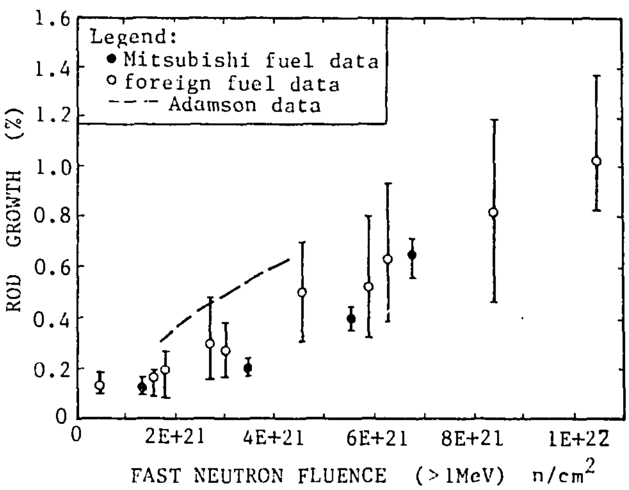


Fig. 3 Fuel Rod Irradiation Growth

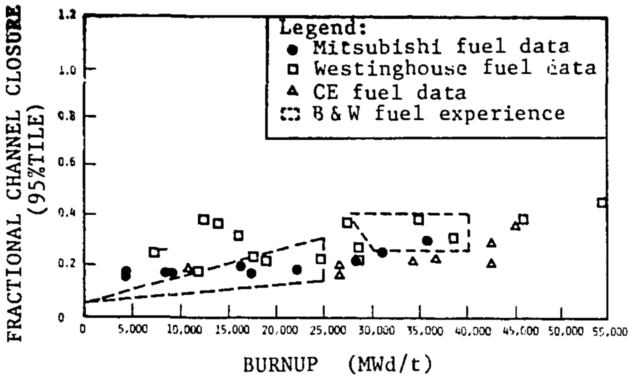


Fig. 4 Worst Span Channel Closure Behaviour

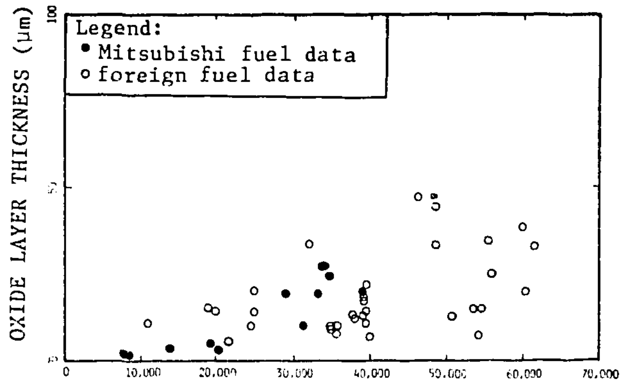


Fig. 6 Fuel Cladding Waterside Corrosion

D. FP gas release

The FP gas release data are gathered at PIE programs to verify the design integrity of Mitsubishi fuel. Fig. 5 shows that the FP gas release from Mitsubishi fuel irradiated steadily at domestic commercial reactors is less than 1% even at rod average burnup 40,000 MWd/t approximately [1, 5, 6].

E. Cladding waterside corrosion [1, 3, 4, 7, 8]

In Japanese PWRs the coolant chemistry is well controlled and the crud deposition on fuel rods is very small, leading to the superior corrosion behaviour shown in Fig. 6. The hydrogen uptake is small enough not to lose the fuel cladding ductility.

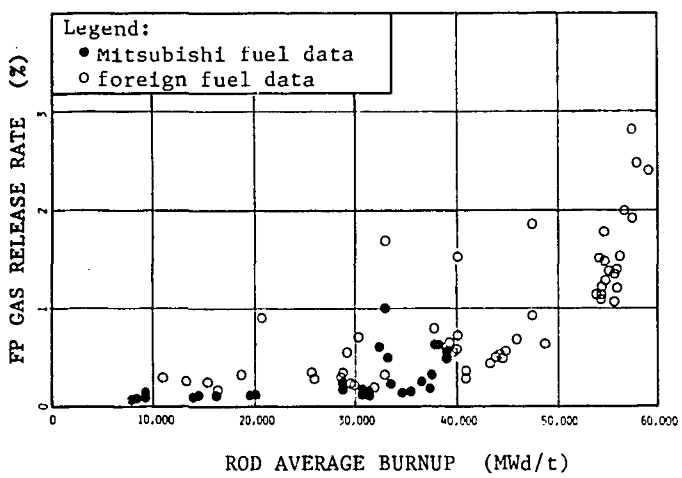


Fig. 5. FP Gas Release Rate

F. PCI resistance

The PCI threshold for Mitsubishi type of fuel has been established with the data of various power ramping data as shown in Fig. 7 with respect to Pmax and ΔP respectively. There is the tendency of PCI threshold to keep constant level after exceeding burnup 20,000 MWd/t approximately; that is Pmax = 40 kW/m and ΔP = 8 kW/m approximately.

It has been confirmed that there is no adverse effect on PCI resistance due to power cycling. The fuel behaviour during power cycling reaches the state of equilibrium after several cycles as shown in Fig. 8. Also no enhancement of FP gas release due to power cycling was seen during the cycling test with about 600 cycles [9].

The load follwoing capability of Mitsubishi fuel has been demonstrated by a series of PRD test at commercial reactors. Their results are summarized in Fig. 9.

V. BURNUP EXTENSION PROGRAM IN JAPAN

In recent days Japanese utilities have been extending the operational cycle length from the conventional length of 9 or 10 months to increase plant availability and to obtain better economics, while for the moment it is obliged to perform the plant inspection with the maximum interval of 13 months in Japan. In order to extend cycle length with considering better fue cycle cost under the maximum cycle length of 13 months, the relaxation of the assembly average discharged burnup limitation to 48,000 MWd/t is planned for the present time, and the extensive R&D programs are going on. The long term goal of burnup extention is to further lift the ristriction of discharged burnup to about 55,000 MWd/t with combining the extension of plant inspection intervals to 15 months approximately.

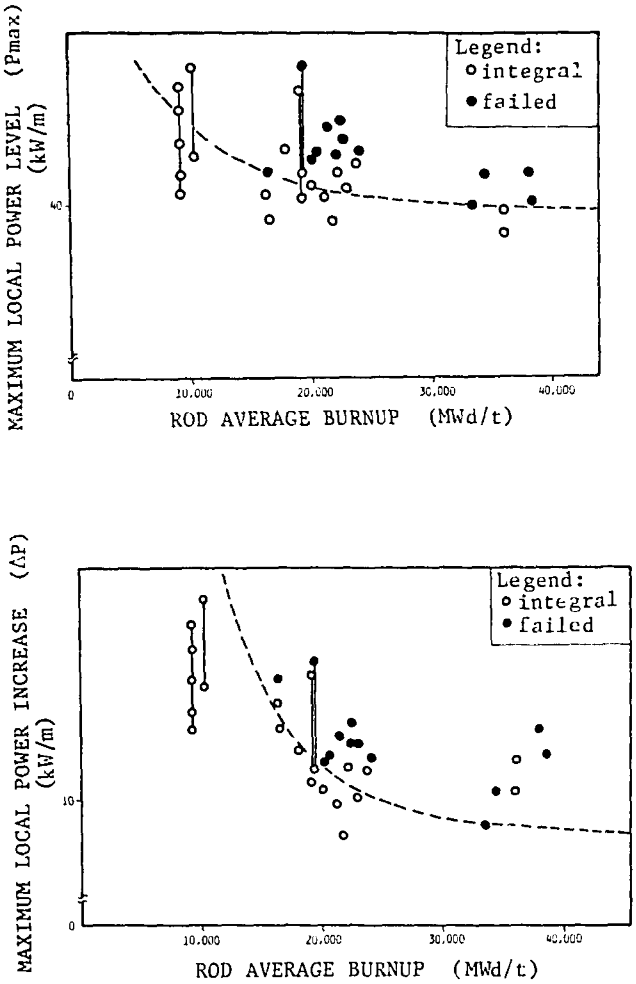
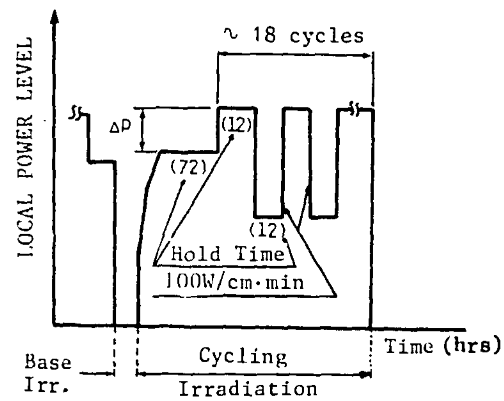
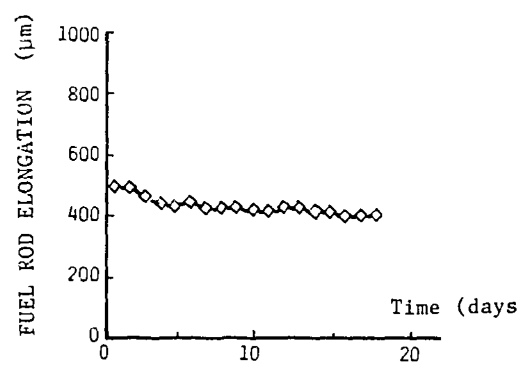


Fig. 7 PCI Threshold of Mitsubishi Type of Fuel



(a) POWER CYCLING TEST PATTERN



(b) FUEL ROD ELONGATION DATA DURING POWER CYCLING

Fig. 8 Relaxion Behaviour of Fuel Rod Elongation During Power Cycling

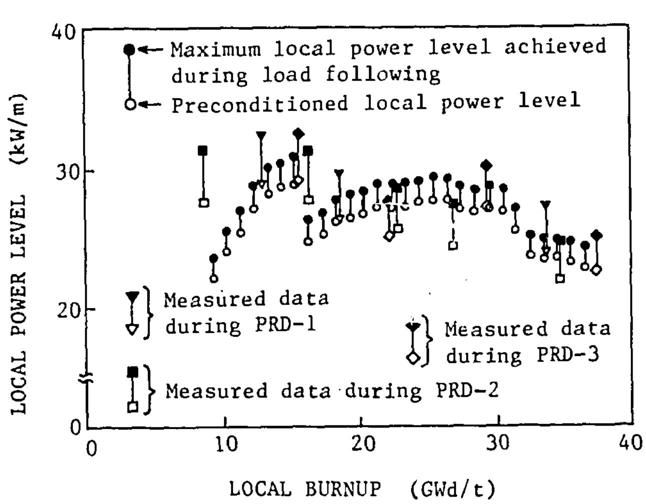


Fig. 9 Results of Power Ramp Demonstration Tests

VI. Gd_2O_3 CONTAINED FUEL

The burnable poison rod, which consists of Pyrex glass with stainless steel cladding, has been used successfully in PWR core to control the excess reactivity. However, in extending the operational cycle length, the reactivity penalty due to stainless steel cladding will be important concern from the view point of fuel economy, because the more burnable poison rods will be necessary in longer cycle operation and the resultant reactivity penalty due to water displacement will be concerned at the end of cycle. For such reason MHI has developed the integral burnable poison design, Gd contained fuel rod which has less reactivity penalty. The 6 wt% Gd contained fuel rods and fuel assemblies are being irradiated in BR-3 and a commercial plant in Japan as demonstration. The commercial use is expected in near future.

Furthermore, the higher Gd contained (5 to 10 wt%) is now under development. Fig. 10, 11 show the typical Gd contained rods pattern in fuel assembly and the effective multiplication coefficient (Keff) vs. burnup for 17 x 17 fuel assembly core [10].

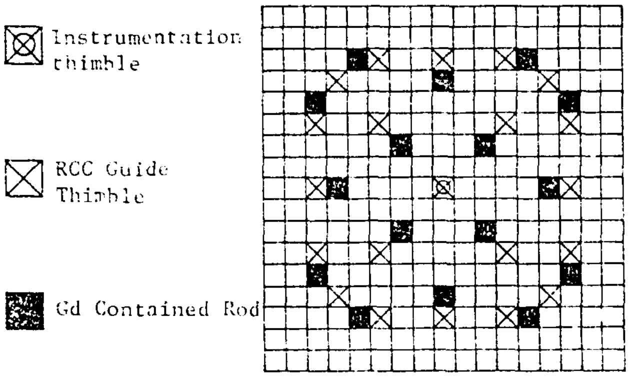


Fig. 10 Typical Gd Contained Rods Pattern (17 x 17)

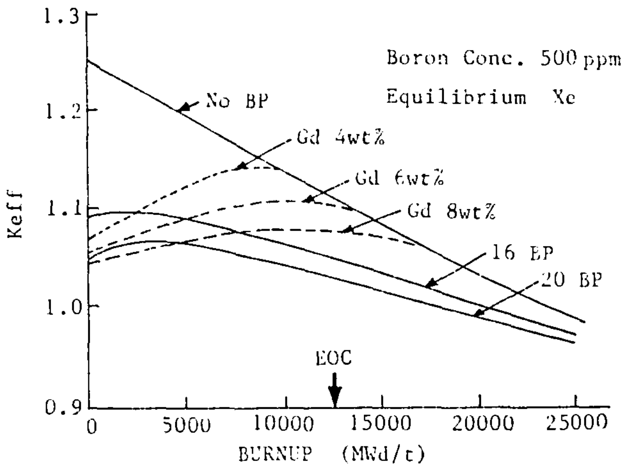


Fig. 11 Effective Multiplication Coefficient vs. Burnup (17 x 17, 16 Gd contained rods)

VII. MOX FUEL UTILIZATION FOR PWR

The Mox fuel utilization for PWR, so-called Pu thermal utilization, is also being studied in Japan. The design of Mox fuel assembly for PWR is generally the discrete type where fuel rods are all Mox rods. The merit of discrete type is the relatively more Pu loadability with less number of Mox fuel assemblies. Since the Mox fuel has the same structure as the standard UO_2 fuel concerning with thermal and hydraulic design, the adjustment of rod-wise Pu enrichment is necessary to attain the local power distribution equivalent to UO_2 fuel. Fig. 12 shows an example of Pu enrichment distribution within Mox fuel assembly. The Mox fuel utilization for PWR in Japan will be advanced step by step with verification tests.

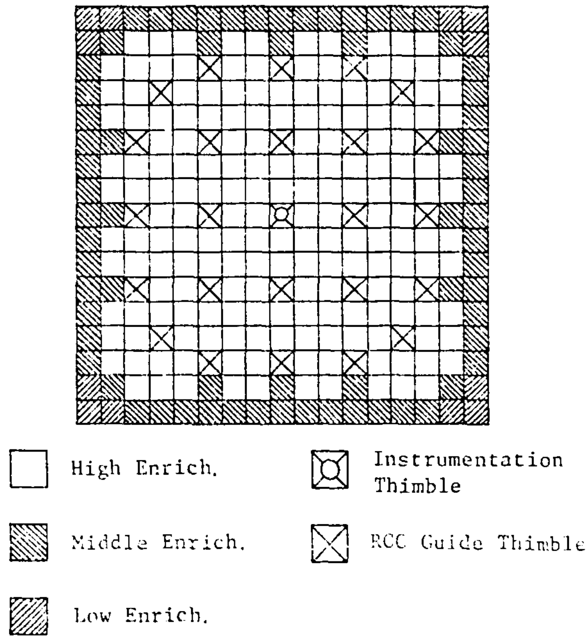


Fig. 12 Pu Enrichment Distribution in Mox Fuel Assembly (Example)

VIII. MITSUBISHI FUEL INVESTIGATION SYSTEMS

In order to investigate the performance of fuel under development and the cause of fuel anormaly, Mitsubishi estabilished the following equipments and facility as the total fuel investigation and development system.

(1)	UT examination equipment	:	Identification of leaked rod within fuel assembly
(2)	Fiberscope visual Inspection (Fig. 13, 14) equipment	:	Observation of anomalous portion on the specified fuel rod surface
(3)	Disassembling and reconstitution equipment of fuel assembly (Fig. 15)	:	Removal of specified fuel rod from the fuel assembly and assembly reconstitution
(4)	Transportation cask for PIE rod and assembly (MSF-1)	:	Transportation for PIE fuel rods and assembly (leaked fuel if necessary)
(5)	Hot Cell (MHL, Tokai)	:	Nondestructive test and destructive test Fuel up to maximum rod average burn up of 56,000 MWd/t.

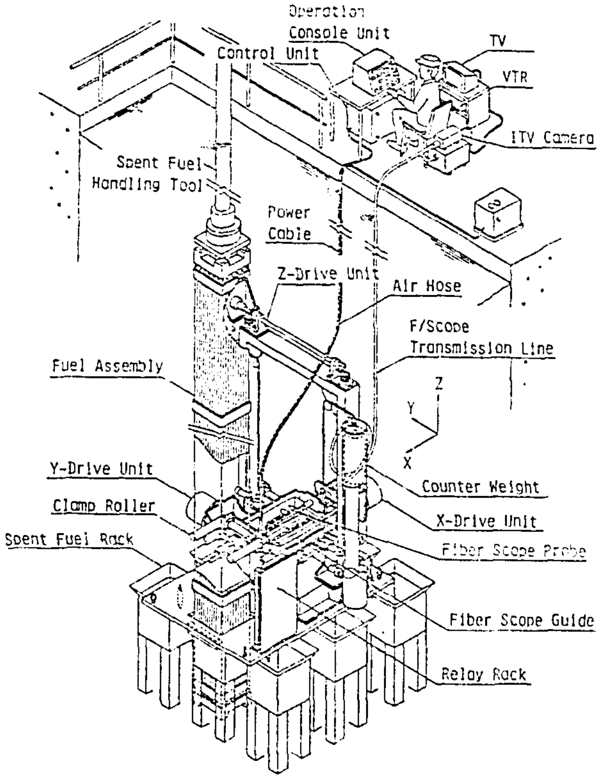


Fig. 13 Mitsubishi Fiber-Scope

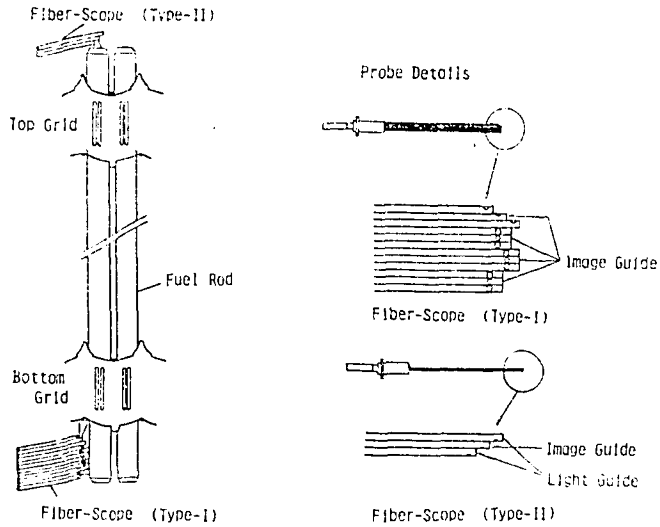


Fig. 14 View of Fuel Rod Surface Inspection with Fiber-Scope

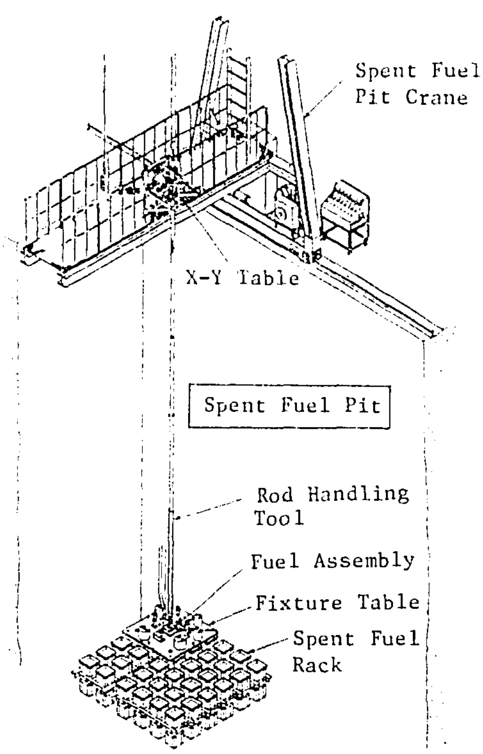


Fig. 15 Disassembling and Reconstitution Equipment for Fuel Assembly

IX. CONCLUSION

It could be summarized that our PWR current fuel has superior reliability and integrity within the burnup limitation of 39,000 MWd/t based upon many efforts on fuel design and manufacturing technology since the first PWR came into operation in 1970. With the accumulative data of high burnup fuel and various R&D program, the extension of discharged burnup limitation to 48,000 MWd/t will be possibly realized within two years and also the 6% Gd contained fuel will be commercialy used this year. The next step of burnup extension is aimed at 55,000 MWd/t approximately. The higher Gd contained fuel introduction considered (8 to 10 w/o) and the Mox fuel utilization are necessary at the stand point of nuclear fuel economy.

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