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Study on the Performance of 14X14 PWR Type Fuel Rod Pulse Irradiated at Burn-up of 39 MWd/kgU

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ABSTRACT

A study was made of the transient fuel performance under a reactivity initiated accident (RIA) with a 14x14 PWR type fuel rod, preirradiated to an average rod burn-up of 39MWd/kgU with a linear power of 18 kW/m. The transient pulse irradiation was performed at the Nuclear Safety Research Reactor (NSRR), JAERI. Fuel performance was evaluated by in-core instrumentation and by postirradiation examinations. The energies deposited in the fuel were 60, 68 and 83 cal/g·fuel. Transient FP gas release (FGR) of up to 4.3% resulting in hard pellet-cladding mechanical interaction (PCMI) was observed. No fuel failure, however, was caused in any cases.

1 INTRODUCTION

In-core experiments have been conducted in the NSRR program to study transient fuel peformance under RIA conditions. Present work was done by using the PWR type fuels preirradiated to a burn-up of 39 MWd/kgU. Attached in-core instrumentation, and prepulse and postpulse irradiation examinations (PIEs) provided transient fuel performance data, especially the data on FGR and PCMI.

Table I SUMMARY OF AS-FABRICATED CHARACTERISTICS OF OTFR

FUEL	SINTERED UO_2
DENSITY (g/c.c.)	10.41 (95%TD)
PELLET O.D. (mm)	9.29
PELLET LENGTH (mm)	15.2
ENRICHMENT (wo)	2.6
CLADDING	STRESS RELIEVED ZIRCALOY-4
CLADDING O.D. (mm)	10.72
WALL THICKNESS (mm)	0.62
ASSEMBLY	14x14 PWR
DIAMETRAL GAP (mm)	0.19
ACTIVE COLUMN (m)	3.657
FILLER GAS (MPa)	He, ca. 3.0
PLENUM VOLUME (c.c.)	12.6

2 EXPERIMENT

2.1 Characteristics and preirradiation of the test fuel rod

As-fabricated characteristics of the fuel rod are shown in Table I. The active fuel column was approximately 3.66m in length. The fuel

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rod was a 14x14 PWR type having an outer diameter of 10.72mm. Initial enrichment of the fuel was 2.6 w/o. A longitudinal section of this fuel rod is shown in Fig. 1. Henceforth, this is called the original test fuel rod, abbreviated OTFR.

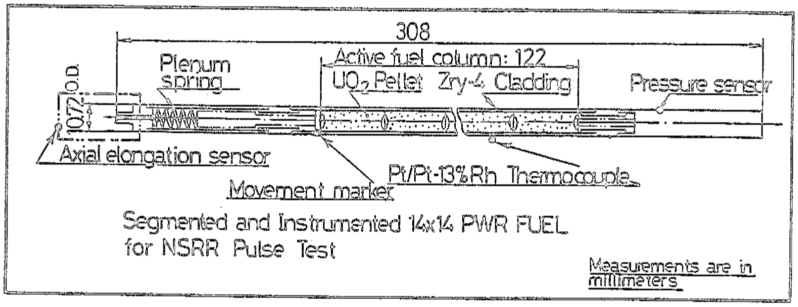

Fig. 1 CROSS SECTION OF STFR

The OTFR was preirradiated with an average linear power of 18 kW/m. Coolant pressure was 15.82 MPa and the coolant inlet and outlet temperatures were 289° C and 320° C.

2.2 Refabrication of the OTFR

Due the limited height of the NSRR core, 0.38m, the active column length of the OTFR had to be shortened to approximately 0.122m. Henceforth, these are called segmented test fuel rods, abbreviated STFRs. The axial flux distribution of the STFRs was smooth and almost unity.

During the refabrication process, pure helium was refilled to the rod to 4.23 MPa (0° C) to realize the OTFR condition based on the result of gas puncturing of the OTFR. Refabricated plenum volume was 1.5 cm^3.

2.3 Pulse irradiation of the STFR

To monitor the transient fuel performance during pulse irradiation, in-core instruments were installed on each STFR. The locations are shown in the lower part of Fig. 1. A cladding axial elongation sensor and a fuel stack axial elongation sensor were installed on the rod top location. A Pt/Pt-13%Rh thermocouple was welded to the axial midpoint of the cladding surface. A strain gauge pressure sensor was installed on the rod bottom.

As shown in Fig. 2, the STFR was loaded and located in the center of the irradiation capsule. All pulse irradiations were conducted in stagnant water at room temperature (~20° C) and at 1 atmosphere of pressure inside the double sealed irradiation capsule.

The deposited energy E_g (cal/g·fuel) in each test rod was estimated from the integral value of reactor power P(MW·s) measured by two γ-chambers. The power conversion ratio K_g (cal/g·fuel per MW·s), that is, the ratio of fuel rod power to the reactor power, was deter-

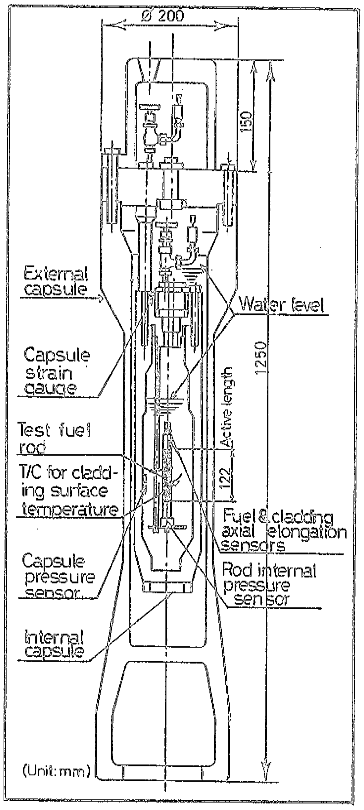

Fig. 2 IRRADIATION DOUBLE CAPSULE FOR PREIRRADIATED STFR

mined through the fuel burn-up analysis taking radial and axial power skew into consideration.

3 RESULTS AND DISCUSSION

3.1 Steady-state fuel performance during preirradiation stage

The FGR of the OTFR was 0.17% of Xe+Kr at 39 MWd/kgU. The gas composition was 99.3%He+0.1% Kr+0.6%Xe. Obtained FGR was the same magnitude as other domestic PWRs[2]. The FGR might be governed by the recoil/knockout mechanisms.

Increased rod internal pressure will be one of the life limiting factors for PWR fuels. The rod internal pressure of the OTFR obtained was 4.66MPa. This value was similar to other domestic PWRs[2].

Cladding creep-down occurs in PWRs as a function of burn-up. Fuel performance will be significantly affected by this, especially at higher burn-up stages. Creep-down data obtained recently from domestic PWRs[2,3] and earlier from Westinghouse of the USA[4] are compared. The creep-down in those referential PWR fuel rods was less than 1%. The creep-down of the OTFR was 0.06%.

Waterside corrosion of the cladding is enhanced with increased burn-up. This might affect fuel performance. The OTFR and its sister rods preirradiated in the same assembly had oxide films with thickness from 14μm to 30μm. These are not much different from others at the similar burn-up ranges[2].

3.2 Transient fuel performance during pulse irradiation

Integral energies of 60, 68 and 83 cal for unit gram of UO_2 were deposited by pulse irradiation to the STFRs denoted MH-1, MH-2 and MH-3, respectively. No indication of fuel failure during pulse irradiation was observed for any of these STFRs. Figure 3 shows in-core data obtained from attached instrumentation for MH-1. The discussions on performance of the STFRs during pulse irradiation will be made in the followings.

3.2.1 FGR

As clearly indicated in Fig. 3, rod internal pressure increased very rapidly during pulse irradiation. This pressure increase is partly due to FGR from the hotter fuel. As shown in Fig. 4, MH-1 had a net FGR of 3.7% during pulse irradiation. While, MH-3 had a net FGR of 4.3%. It is clear that released amounts of FGR are dependent on deposited energy levels.

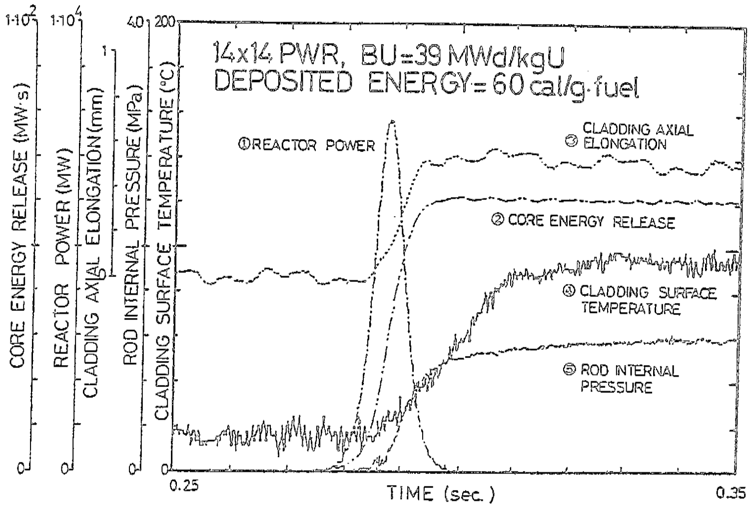

Fig. 3 IN-CORE BEHAVIOUR OF PULSE IRRADIATED STFR: ATTAINED BURN-UP=39 MWd/kgU,DEPOSITED ENERGY=60 cal/g·fuel

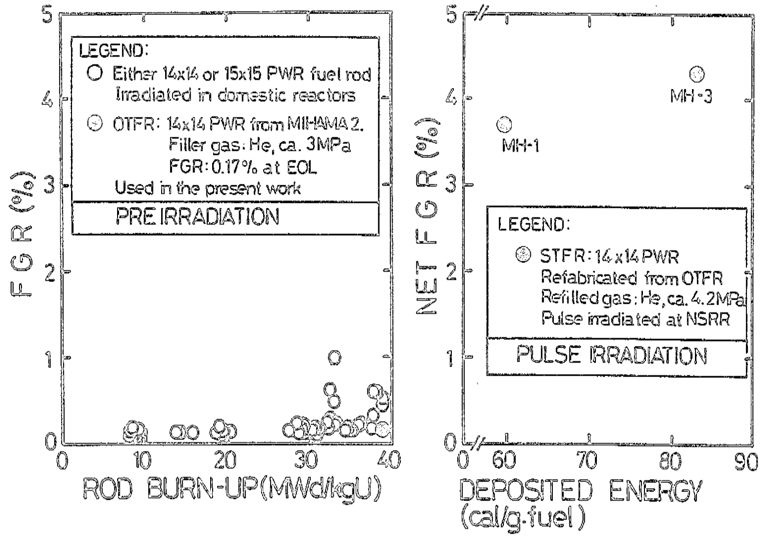

Fig. 4 FGR OF PWR FUELS DURING PREIRRADIATION STAGE IN COMMERCIAL PWRs (LEFT) AND NET FGR OF FUELS DURING PULSE IRRADIATION AT NSRR (RIGHT)

Code prediction against these was made by using the transient/accident computer code FPRETAIN [5]. Calculated peak fuel centerline temperature was approximately 720℃ for MH-1 and 980°C for MH-3, respectively. While, calculated net FGR by Booth type diffusion model was almost 0% in each cases. It can be said from this discrepancy that the possible mechanism to explain the observed FGR is a FGR burst from the cracked fuel. This was confirmed from the fuel microstructural study in PIE.

Cladding surface temperatures at the tested energy deposition levels did not show any DNB (departure from nucleate boiling).

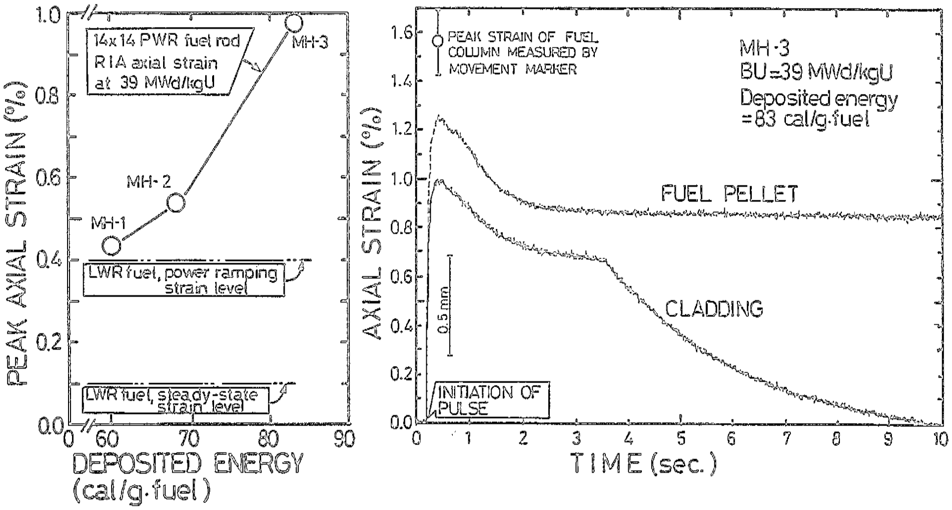

Fig. 5 PEAK AXIAL STRAIN OF STFRs AS A FUNCTION OF DEPOSITED ENERGY (LEFT), AND FUEL AND CLADDING AXIAL STRAIN OF MH-3 (RIGHT)

3.2.2 PCMI

Figure 3 showed that in the early stage of the pulse irradiation cladding axial strain increased very rapidly, indicating the occurrence of PCMI.

As shown in Fig. 5, a peak axial strain of cladding increased with increasing energy deposition levels. MH-3 was intact even though the strain level reached as high as 0.99%. This result gives us an important suggestion from the fuel reliability point of view since LWR fuel in Japan is not allowded to exceed the axial plastic hoop strain level of 1%[6] to prevent fuel failure by PCMI. One of major reasons preventing the used STFRs from failure might be attributed to a strong fuel relaxation occurred following PCMI. This is apparent from the right-hand side of the figure.

Usually, the cladding axial strain in steady-state operation is of the order of 0.1%[7]. In the case of power ramping, the observed cladding strain is as high as 0.4%[3]. A 14x14 type PWR rod used in TRANS-RAMP Ⅱ (BU=30 MWd/kgU) showed an axial strain of 0.08% and then failed by PCI[8]. It should be noted that the rod was power ramped with a rate of 1.5 kW/ms and held at 60 kW/m for 34s without causing a significant relaxation.

Consequently, observed strong relaxation in the STFR was thought to have prevented the fuel from PCMI or PCI failure.

3.3 PIE AFTER PULSE IRRADIATION

3.3.1 Dimensional measurement

Visual inspection revealed no significant damage to the STFRs used. Diameter profile data showed that there were a little ridge formations in MH-1 and MH-2. In-core PCMI observed from cladding axial movement of these was elastic. While, a significant PCMI occurred in MH-3 rod. This was clear not only from greater axial strain obtained from in-core measurement(0.99%) but from greater residual diametral strain from PIE(1.3%).

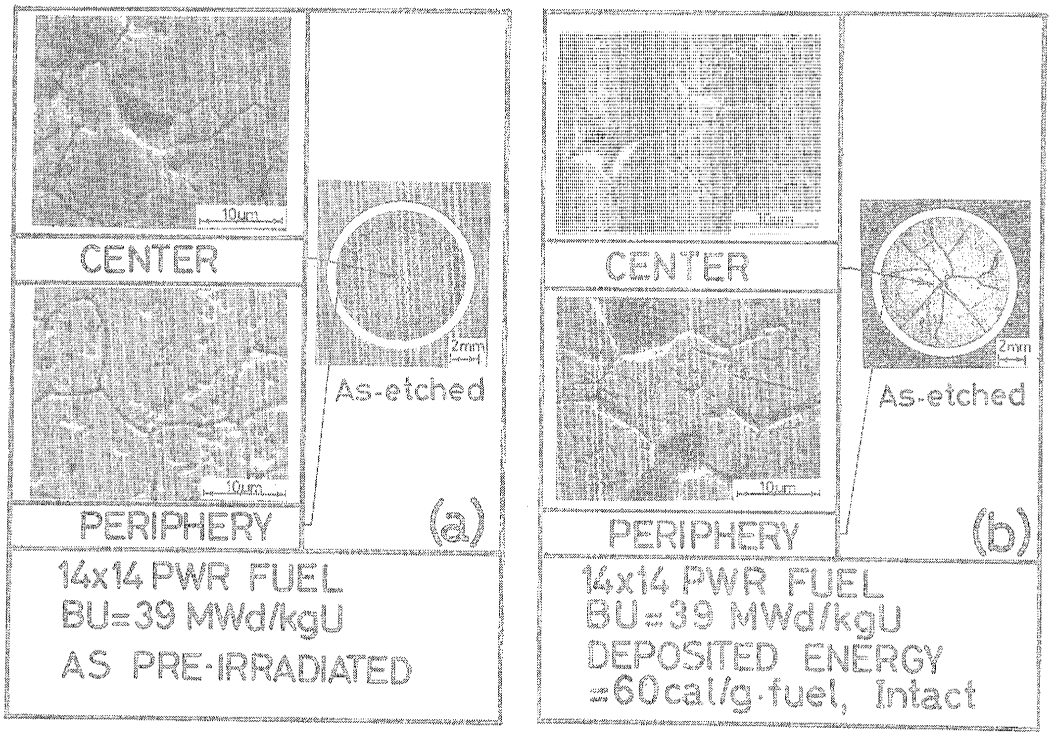

Fig. 6 FUEL MICROSTRUCTURE OBTAINED (a) FROM PREPULSE CONDITION AND (b) FROM POSTPULSE OF 60 cal/g·fuel CONDITION, ETCHED

3.3.2 Fuel microstructural study

Fuel microstructures obtained from the prepulse condition and from the postpulse condition are shown respectively in Fig. 6(a) and 6(b).

Comparing the macroscopic photographs, the fuel cracks in the postpulse condition are larger than those in the prepulse case. The comparison of the microscopic photographs reveals that the grain boundary in the prepulse condition seems to be more tight than that in the postpulse condition. This observation suggests that the grain boundary separation occurred during the pulse irradiation.

The grain size across the fuel was uniform. Average grain size was 6 μm for the prepulse condition and 8 μm for the postpulse case. Hence, grain growth of the STFRs due to pulse irradiation was minimal.

4 CONCLUSION

A study was made on transient fuel performance of a 14X14 PWR fuel rod preirradiated to a rod average burn-up of 39 MWd/kgU with a linear power of 18 kW/m. The results obtained are as follows:

(1)The FGR during steady-state (preirradiation) stage was 0.17%. The net FGRs during pulse irradiation at energy depositions of 60 and 83 cal/g·fuel were 3.7 and 4.3%, respectively. The magnitude of FGR is dependent on the deposited energy level. The most probable mechanism to explain the resultant net FGR is thought to be the FGR burst. Increase of the fuel cracks and grain boundary separations observed in PIE might be responsible for the FGR burst. Grain growth was minimal.

(2)There was little evidences of hard PCMI during the preirradiation stage. However, hard PCMI occurred at pulse irradiation of 83 cal/g·fuel where on-power cladding axial strain reached approximately 1%. However, fuel failure did not occur within this experimental range due mainly to rapid relaxation.

5 ACKNOWLEDGMENT

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6 REFERENCES

[1] Suzuki, T. et al., (1990) Fall Mtg. At. Energy Soc. Japan, H17
[2] Yanagisawa, K. et al., (1991) ANS/ENS Topl. Mtg. on LWR Fuel Performance, Avignon, France
[3] Yanagisawa, K. et al., (1986) J. At. Energy. Soc. Japan, Vol.28, no.7, p.641 (in Japanese)
[4] Melehan, J. B. et al., (1976) Proc. ANS. Topl. Mtg. on LWR Fuel Performance, Portland, Oregon, U.S.A., p.29
[5] Yanagisawa, K., (1989) JAERI-M 89-095, (in Japanese)
[6] Nuclear Safety Commission, (1985),(in Japanease)
[7] Yanagisawa, K., (1986) Nucl. Technol. Vol.73, p.361
[8] H. Mogard, D. A. Howl, M. Grounes, (1988) ANS Topl. Mtg. on LWR Fuel Performance, Williamsburg, Virginia, U.S.A., p.232