Status and Activities of PIEs on Nuclear Fuel in NPIC

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Abstract. Development and status of hot laboratory in Nuclear Power Institute of China was presented. Main activities of post irradiation examination on nuclear fuels, including testing fuel bundles for PWRs and dispersion fuels for research reactors were also generally described.

1. INTRODUCTION

Nuclear Power Institute of China (NPIC) was a research center for PWRs in China. Two research reactors were operated by NPIC, one of which, was the High Flux Engineering Test Reactor (HFETR, Figs 1.1–1.2). Since 1980, HFETR was in operation for more than 30 years. Various kinds of testing fuel assemblies have been irradiated, and, then examinated in hot laboratory. An overview of activities and an status of those post-irradiation examinations (PIEs) is briefly presented in this paper.

FIG. 1.1. Main building of HFETR.

FIG. 1.2. Reactor core of HFETR.

2. HOT LABORATORY

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A complex of hot cells was built just aside the HFETR during same period of construction. Two lines on the second floor were used for PIE of fuels (Fig. 2.1), which is connected with the spent fuel pool of HFETR by an underwater transfer channel. A line of semi hot cell on the first floor (Fig. 2.2) was used for mechanical testing of reactor structure material. From 2006–2011, two rounds of refurbishments and upgrading of hot cell facilities were performed. The main capacity of the hot laboratory is listed in Table 2.1.

TABLE 2.1. MAIN CAPACITY OF THE HOT LABORATORY

Majority	Items
Physical analysis	Metallurgical analysis（OM), SEM, EDS, corrosion, differential scanning calorimeter (DSC), high temperature annealing, density measurement.
Mechanical testing	Tensile testing, pendulum impact testing, drop-weight impact testing, compression testing, low cycle fatigue, fracture toughness, bend testing, microhardness testin, burst testing.
Non destructive testing	Visual inspection（VT), X-ray and γ ray testing（RT), ultrasonic testing (UT), leakage testing (LT), penetration testing（PT), eddy current testing（ET), profilometry measurement.
Radiochemical analysis	Water chemistry analysis, burn-up determination, isotope separation.

FIG. 2.1 Hot cells for dismantling and NDT.

FIG. 2.2. Semi hot cells for mechanical testing.

3. POST IRRADIATION EXAMINATIONS ON FUELS

3.1 Disassembly of fuel elements

For the disassembly of irradiated fuel assemblies, 2 miller and 1 laser cutting machines were deployed in 3 hot cells respectively. A small cutting saw was also used for precious sampling.

3.2 Visual examination

Visual examination was performed in the spent fuel pool and hot cell respectively. Surface conditions, such as obvious deformation, defects, damage could be determined (Fig 3.1). Water-proof and radiation resistance cameras were used in most occasions.

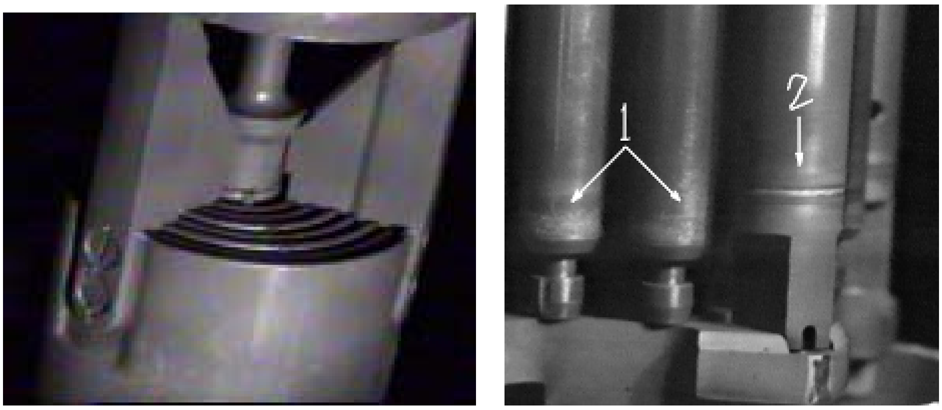

FIG. 3.1. Underwater visual inspection of fuel element (left: top end of HFETR fuel element; right: bottom end of a testing PWR fuel bundle).

3.2 Profilometry measurement

Deformation and curvature of fuel elements were measured in hot cell with a remote controlled 3-D coordinator machine. Also a LVDT apparatus and a laser beam device were used to measure the variation of fuel rod diameter (Fig. 3.2).

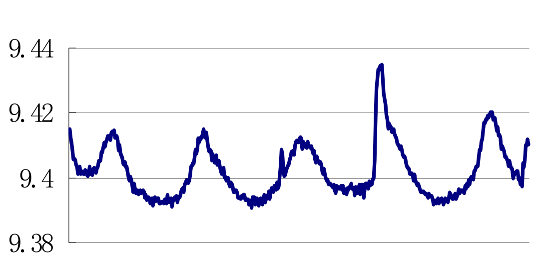

FIG. 3.2. Fuel rod diameter variation (mm).

FIG. 3.3. HFETR fuel element X-ray radiography.

3.4 X-ray radiography

X-ray radiography was used as a non-destructive testing to inspect the defects, uniformity and structural integrety of fuel elements (Fig. 3.3). The X-ray generator can reach high voltages up to 450 kV.

3.5 γ profilometry scanning

Relative burn-up distribution of fuel elements was measured by γ profilometry scanning. ^{137}Cs was used as the monitoring isotope for counting. Axial distribution of burn-up of a HFETR fuel elements is shown in Fig 3.4. Due to tubular structure and core loading of HFETR, the outer fuel tube reached high burn-up, and lowest burn-up corresponding to 3rd tube which was in the middle layer.

3.6 Burn-up determination

Fuel elements could be dismantled and sampled to absolute burn-up determination. The uranium isotope was separated and measured by massspectrometer. Averaged burn-up of HFETR fuel tube and axial distribution were in good accordance with the γ profilometry results (Fig. 3.5).

3.7 Microstructure analysis

The evolution of microstructure was a big concern during irradiation. Microstructure was examinated by a remote controlled optical microscopy (OM, LeikaMef4A, Fig. 3.6) in hot cell. Conjunction between cladding and fuel meat (Fig 3.7), cracks and microvoids in pellets can be examinined.

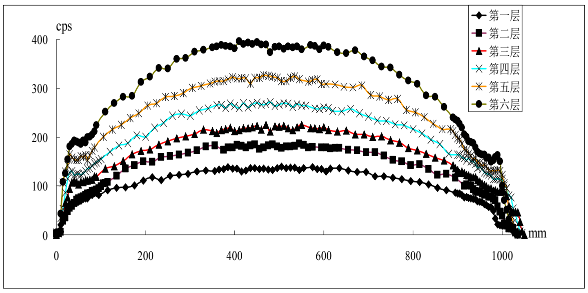

FIG. 3.4. γ-profilometry of fuel tubes.

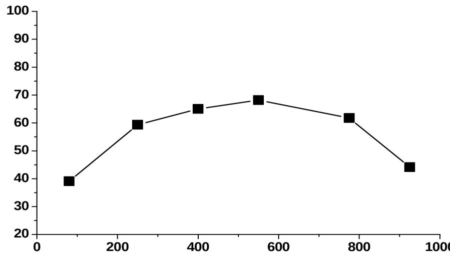

FIG. 3.5. Burn-up distribution of fuel tube (axial position (mm) vs. burn-up (at%)).

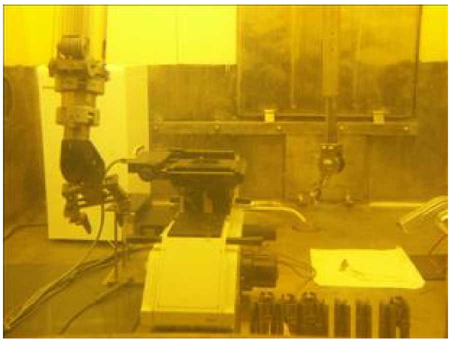

FIG. 3.6. OM in hot cell.

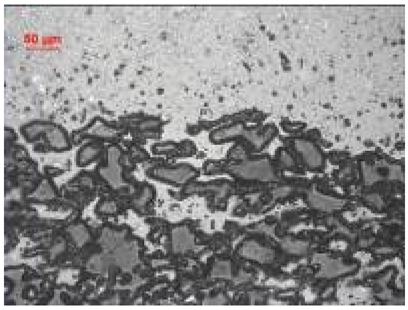

FIG. 3.7. Conjunction of fuel meat and cladding.

Further more, a customized scanning electron microscopy (SEM) was used for fractograghy of irradiated materials. Fig. 3.8 showes microviods and porosity of a PWR fuel pellet.

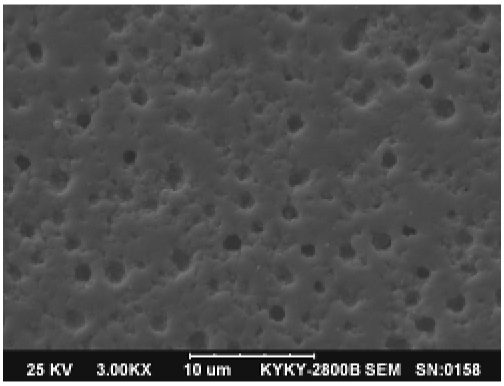

FIG. 3.8. 11 SEM of irradiated UO_2.

3.8 Blistering testing

For dispersion fuel elements, high temperature blistering can lead to fuel failure. So it was important to determine the initial threshold temperature at which blistering occurs. A high temperature furnace was installed in hot cell to perform blistering testing for fuel tubes in full length. A blistering test for a HFETR fuel tube showed that threshold temperature was more than 500℃. Results are showen in Figs 3.9–3.10.

FIG. 3.9. 12 Blistering of fuel tube.

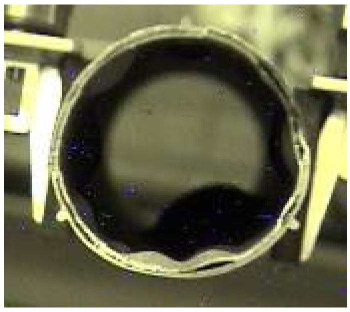

FIG. 3.10. 13 Separation of cladding and fuel matrix.

3.9 Burst testing

Burst testing of cladding tube for PWR fuel, could be performed in hot laboratory, both at ambient temperature and 350℃. A failed tube and strain vs. inner pressure relationship of burst testing is shown in Figs 3.10–3.11.

FIG. 3.10. Failed tube.

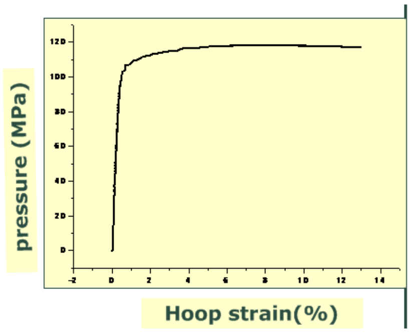

FIG. 3.11. Strain vs. inner pressure relationship.

4. CONCLUSIONS

NPIC hot laboratory plays a very important role in PIE of nuclear fuel in China. With the reconstruction of several hot cells and a renewal of instruments and facilities, more PIE work will be performed in the NPIC hot laboratory in the next decade.

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