The Pool-Side Inspection of Post-Irradiation Fuel Assembly in QINSHAN NPP

S. Wang[a]

Abstract. Pool-side inspection of post-irradiative fuel assembly is used to evaluate the integrity and reliability of reloaded FAs in Qinshan NPP during reloading outage, and find out the failure assemblies and locate the position of failure rods before repair. And the pool-side inspections also play a significant role in burn-up increment test in Qinshan NPP. Main results of pool-side inspections testify that the relevant requirement of performance of FAs can be satisfied as the burn-up increment within the range of test. Some others examinations and pool-side inspections of post-irradiative fuel assembly are introduced briefly also.

1. INTRODUCTION

In these years the prosperity of nuclear power development in China is just beginning. There are 13 nuclear power units in operation now. There are 24 units under construction with construction permit (CP) issued by National Nuclear Safety Administration (NNSA). And 8 units whose PSARs are being reviewed by NNSA are waiting for CP. And the nuclear power development has been confirmed as the important policy for china national energy in 21st century. According to the scenario the total installed nuclear power capacity will be 70–80 GWe untul 2020.

But since the accident of Fukushima nuclear power plant in Japan, every country reconsidered their nuclear policy and plan, and China is included certainly. Many measures were forced to implement. A series of comprehensive inspections and reviews are obliged to execute in nuclear power plants throughout country and in the near future there may be some significant modifications in plant such as movable diesel generator, passive containment hydrogen recombining system, etc. To the nuclear power plants under construction, it is required to evaluate and review its safety standard based on the most advanced standards. New issues of CP have already been suspended until the adjusted and improved nuclear power development programming is unveiled.

As the second generation of nuclear power plant, Qinshan nuclear power plant (QNPP) with capacity of 310 MWe came into operation in 1991, the current cycle is C13 just at the ending part of its 30 years design life. QNPP is the first nuclear plant which is designed and constructed by ourselves in china mainland.

The core of QNPP 310 MWe unit consists of 121 FAs designed by Shanghai Nuclear Engineering Research and Design Institute and supplied by China Jianzhong Nuclear Fuel Co., Ltd (CJNF). Any FA comprises 204 fuel rods, 20 guide thimbles and 1 instrument thimble arrayed in a matrix of 15 × 15 and the enrichment of U-235 is 3.4% since balance cycle. The cladding material is Zr-4. The 8 grid spacers Inconel (GH4169) and the top and bottom nozzles are stainless steel (0Cr18Ni10Ti). There are two main modifications after cycle 7, the bottom nozzle filter and dish chamfers of pellet are

[a] QinshanNuclear Power Company Ltd., China

added. Now all of the spent FAs store in the pool in FX and will transport to the reprocess factory in future.

2. METHOD AND APPLICATION OF POOL-SIDE INSPECTION IN QNPP

Method of pool-side inspection in QNPP included: sipping inspection, VT inspection, and dimension measurement for example: verticality, twist, variation of rod spacer and irradiative growth, etc., and disassembly inspection such as ET and oxidation film thickness for rods.

2.1 The welding joint form

The pool-side inspection methods are used to evaluate and check whether a FA is failure or not. Based on daily operational monitoring on Fuel Reliability Index and Iodine Equivalent Value, there will be a preliminary judgment of fuel integrity. If no FA failure happens, inspection of VT and dimension measurement will be arranged at a specified ratio of fuel assembles to evaluate the reliability and integrity of reloaded FAs during reloading outage. But if judgment goes to the contrary, sipping inspection for all FAs need to reload will be arranged in order to find out the damaged FAs. If success, there will be a comprehensive inspection include VT, dimension measurement inspection, and disassembly inspection by ET before repair it by take the place of failure rods with intact rods, if necessary.

In cycle 4, many FAs damaged due to the loose of bolt of the barrel. After that only a few FA failures happened during fuel handling. QNPP has device and skills to repair the damage FAs. Evidence proves that the repaired FAs have the same performance with the intact assemblies. The failure history of FAs in QNPP are shown in Table 1.

TABLE 2.1 FAILURE HISTORY OF FAS IN QNPP

Cycle	FAs failure history
C1–C3	No FA failure monitored.
C4	9 FAs breakage, 2FAs have grid spacers deformation, and 6 FAs have mix wing damage.
C5–C6	1 FAs damage.
C7–C12	No FA failure monitored.

2.2 In-core burn-up increment test of FAs in QNPP

As fuel management developed, the burn-up of FA is requested to increase properly in order to prolong the cycle life [1]. The pool-side inspection in QNPP also gives the method to verify the fuel property after burn-up increment test in core. Restricted by level of design, technology and verification test at that time, QNPP 310 MWe FAs' burn-up limit was only 30000 MW·d·t^{-1}U initially, large margin was reserved. Under the precondition that safety of the FAs and reactor must be guaranteed, many tests were performed aim to increase the burn-up step by step. After more than 7 cycles effort, the test was complete successfully till the ending of cycle 11. After this fuel management improvement, average burn-up of assembly is nearly to 32000–3000 MW·d·t^{-1}U, max burn-up of FA achieve to 40000 MW·d·t^{-1}U, and max rod burn-up is 44000 MW·d·t^{-1}U.

Main test items and results can be found at [2].

Irradiative growth: no irradiative growth of FAs is occurring. Nevertheless irradiative growth of fuel rods was observed. The distribution of irradiative growth value versus burn-up is shown in Fig. 2.1. The relevant results of 3 × 3 FA during the design verification test are also shown in Fig. 2.1.

Measurement of oxidation film of rod: Max-thickness of oxidation film is 49 µm much lower than the requirements of regulation and guideline [3–4] that corrosion thickness at the end of life should be less than 10% (0.7 mm) of cladding wall. That means the anti-corrosion performance of fuel cladding is sufficient in the range of burn-up test, and the fuel rod is safe.

As shown in Fig. 2.2, it is obvious that the oxidation film thickness of rod is linearity with its endured cycle number. That is corresponding with the results of relevant compute code.

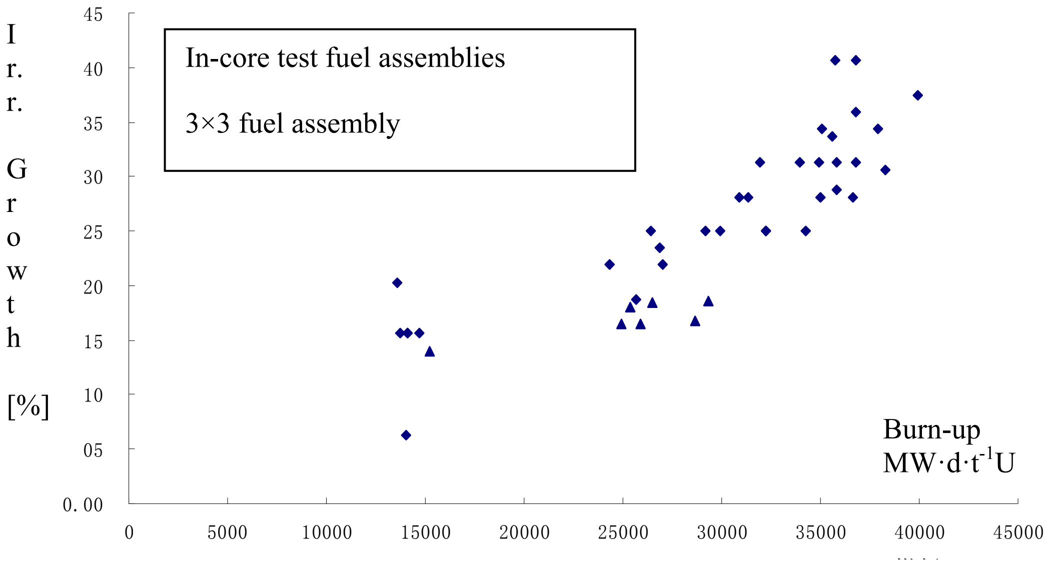

FIG. 2.1. Irradiative growth effects in fuel rods.

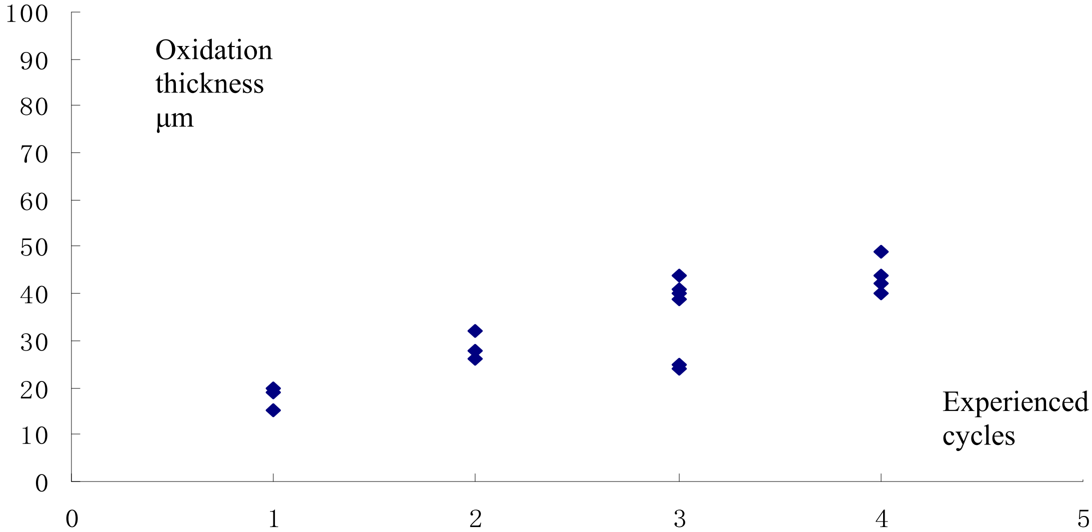

FIG. 2.2. The effect of oxidation film in fuel rod.

ET inspection on fuel rod: ET results shown that no inner and outer wall defects, holes, ring ridges happened. That means no occurrence of PCI, abrasion, hydrogen brittleness.

Through the pool-side inspection of post-irradiative FAs, the conclusion can be made that after 4 cycles, up to 40000 MW·d·t^{-1}U BU, no obvious irradiative growth happened, and the thickness of oxidation film still fulfills requirement of the regulations, and no PCI effect occurred. Combined with some other necessary tests such as rod drop test and many calculation results of computer codes, the following conclusion can be made. The high performance of FAs of QNPP can be guaranteed within the burn-up test range, and are capable to satisfy the operation safety after 4 cycles, and 40000 MW·d·t^{-1}U BU.

3. OTHER METHODS AND APPLICATIONS IN CHINA

3.1 Hot cell inspection of post-irradiative FAs

China Institute of Atomic Energy undertakes a nuclear energy science and technology research subject, post-irradiative inspection of FAs of PWRs. By means of the post-irradiative inspection on the FAs of QNPP, CIAE will obtain the data such as structures, performance, and stability, and verify the rationality and dependability of domestic FAs, and then evaluate the in-core behaviors of FAs, meanwhile accumulate the behavior data of PWRs.

In fact, the inspection methods of FAs in QNPP site are no more than pool-side inspection, so to understand the entire nature performance of the post-irradiative FAs by hot-cell examination, especial to the FAs after burn-up increment test, is very attractive. All of these can be preparations for further burn-up increments. According to this subject, 8 rods were extracted from specified FAs. The selected rods are shown in the Table 3.1.

TABLE 3.1 THE EXTRACTED RODS INFORMATION

Operation cycles	Enrichment	Burn-up [MW·d·t^{-1}U]	Unload date	Position of rod
4	3.4%	39922.18	2006-6-25	A-15, K-08, N-04
3	3.4%	36006.96	2006-6-25	A-15, K-08, N-04
4	3.0%	33956.02	2002-4-14	K-08, N-04

The hot cell examination in of CIAE will consist of four parts mainly. The non-destructive will include VT, ET, dimensions measurement and Gamma spectrometry of fuel rod, and the destructive inspection will involve release rate of fission gas, axial tension test of cladding, observation, measurement and analysis of macro and micro structure of UO_2 pellets, micro-structure analysis and SEM of section of tension sample of cladding. Determination of absolute burn-up of fuel rods by precise analysis of the concentration of Cs-137 and Nd-148, and in-core behavior analysis and performance evaluation of fuel rods by compare the results of hot-cell examination and calculation results of computer code are also involved. But for many reasons the examination was postponed many times. No more information can be acquired now.

3.2 Pool-side inspection of FAs [5]

Since 2003, Qinshan nuclear power plant Phase 2 and Research Institute of Nuclear Power Operation researched and developed cooperatively the ultrasonic measurement system of deformation of post-irradiative FAs. Calibrated with a standard FA, the system can measure the deformations of FA rapidly during outage. Now this set of system has already been put into use and do help greatly. This system has its advantage in technical such as less measurement time (less than 5mins/assembly), higher accuracy (less than 0.3mm of system errors), etc. so that any bending and twist of FAs can be detected precisely and rapidly. The measurement results can be a very useful guide to fuel loading in order to mitigate the difficulty due to deformation of post-irradiative FAs. And at the same time data of measurement can be accumulated for FAs design institute and manufacture plant.

4. SUMMARY

1. Pool-side inspection in QNPP is an efficient way to evaluate the reliability and integrity of FAs;

2. The results of pool-side inspection and analysis support the conclusion sufficiently that the integrity of FAs can be guaranteed in in-core test of burn-up increments in QNPP, and then improve the fuel management level and the economy of plant;

3. Specialization, integration and high technology of pool-side inspection increase the work efficiency, save the human resource cost significantly, shorten the time of outage, and then improve the economy of plants in general.

The post-irradiative examination and pool-side inspection of FAs are playing more and more important role in nuclear power plants.

REFERENCES

[1] KONG, D., LIAO Z., WU X., Improvement of in-core fuel management in qinshan npp. Nuclear Power Engineering, Vol.27, No.**2** (2006) 5–8.
[2] LIAO, Z., KONG D., LI, Z., et al., The in-core burn-up test and evaluation of Qinshan 310 MWe FA, Academic Annual Meeting of Chinese Nuclear Society (2009).
[3] EJ/T 1029-1996, Regulation For Design Limits of Fuel System in PWR Nuclear Power Plant [S] (1996).
[4] EJ/T 323-1998, Design Guideline of Fuel Assembly in PWR Nuclear Power Plant [S] (1998).
[5] QINGSHAN, B., Deformation management of fuel assembly in Qinshan NPP phase 2, Meeting on Communication of Technical Field in Six Nuclear Plants in China (2010).