Post Irradiation Examination of the Fuel Rods Operated in WWER-1000 Mixed Cores

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Abstract. Ukraine has been implementing Ukraine Nuclear Fuel Qualification Project (UNFQP), within the frame of which SU NPP has been pilot operating mixed cores of nuclear fuel supplied by different vendors – OJSC TVEL and Westinghouse. The first stage of the project witnessed six Westinghouse LTAs loaded into the SU NPP Unit 3 core for a four-year operation fuel cycle. Westinghouse and TVEL fuel assemblies differ in some structural components and structural materials. It is, therefore, of interest to monitor not only compatibility and performance of various FA designs, but also mutual influence of various materials on their corrosion behavior in the WWER-1000 water chemistry. Inspections were held after each year of operation: visual examination of fuel rods and FAs, measurement of FA top nozzle axial positions, FA drag force measurements during core loading, FA leakage tests. Due to certain design features associated with fixing fuel rods in Westinghouse FAs (fuel rods are kept in place by grids only), in some cases fuel rods slipped to the bottom nozzle and contacted the adaptor plate. After each year of operation, fuel assembly leakage test was performed. No loss of fuel cladding integrity was observed. The Russian fuel assemblies were examined on the faces adjacent to the Westinghouse FAs. The new core structural materials have not been observed to impact the corrosion behavior of the fuel rod cladding and top and bottom nozzles of either TVEL or Westinghouse fuel. Visual inspection of the fuel rods and FAs revealed no visible defects (pitting, cracks, etc.), which confirms reliability of this weld under WWER-1000 operating conditions. Pilot operation of the Westinghouse LTAs allowed a conclusion that they can be operated in the WWER-1000 mixed core at the thermal loads provided for by the reactor operating specifications and RCS parameters corresponding to GND 95.1.06.02.001-07. Positive results of the LTA operation allowed loading of a reload batch of 42 fuel assemblies in the SU NPP Unit 3 core and concluding a contract between NNEGC Energoatom and Westinghouse for delivery of nuclear fuel for three WWER-100 units.

1. INTRODUCTION

Ukraine has been implementing Ukraine Nuclear Fuel Qualification Project (UNFQP), within the frame of which SUNPP has been pilot operating mixed cores of nuclear fuel supplied by different

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vendors – OJSC TVEL and Westinghouse. The first stage of the project witnessed six Westinghouse LTAs loaded into the SU NPP Unit 3 core for a four-year operation fuel cycle. Westinghouse and TVEL fuel assemblies differ in some structural components and structural materials (ZIRLO^{TM} as fuel cladding, Zr-1%Nb and A718 as spacer grid materials). It is, therefore, of interest to monitor not only compatibility and performance of various FA designs, but also mutual influence of various materials on their corrosion behavior in the WWER-1000 water chemistry. Besides, it was a first time application of Zr-1%Nb material for spacer grids in a Westinghouse fuel design. Inspections were held after each year of operation: visual examination of fuel rods and FAs, measurement of FA top nozzle axial positions, FA drag force measurements during core loading, FA leakage tests.

Design of 6 Westinghouse Lead Test Assemblies (WLTA) provides maximum compatibility with resident fuel (i.e. Russian fuel that operated at the time in the SUNPP Unit 3. Basic design features a given below:

- 15 spacer grids located to match the axial locations of the resident fuel grids;
- bottom additional grid for trapping fine particles;
- WLTA has dismountable design (top and bottom nozzles are detachable for substitution of leaking fuel rods);
- top nozzle design provides compatibility with shipping-and-handling devices of power unit);
- top and bottom nozzle designs assure adequate fit with upper core plate and bottom support tubes, as well as appropriate fuel assembly lateral alignment and support;
- grid tabs and nozzle features are designed to preclude inadvertent hang up the WLTAs and the resident FAs;
- grids are robustly connected to the guide thimbles;
- the grid loss coefficient is higher than for the resident fuel.

2. LOADING OF FUEL ASSEMBLIES INTO CORE

WLTAs were loaded into the SU NPP Unit 3 core during 2005 outage. For loading WLTAs were used resident shipping-and-handling devices and procedures. Drag forces during installation in the core did not exceed 75 kgf [1].

After 4th cycle of operation drag forces during unloading from the core did not exceed the design values and met the requirements of normative documents.

During unloading WLTAs from the core the data of changes in the weight of the refueling machine mast were recorded on a strip chart. The measurement error was 2%. The data obtained were used to determine the FA drag force during their unloading from the core. The analysis of measurement data [2] demonstrated that:

- The maximum WLTA drag force during unloading from the core was as follows:
    - for WLTA AA01-03 ~ 60 kgf,
    - for WLTA AA02-03 ~ 42 kgf,
    - for WLTA AA03-03 ~ 58 kgf,
    - for WLTA AA04-03 ~ 56 kgf,
    - for WLTA AA05-03 ~ 55 kgf,
    - for WLTA AA06-03 ~ 50 kgf;
- The drag force of all WLTAs during their unloading from the core did not exceed the minimum setpoint of 75 kgf;
- The maximum WLTA drag force during installation into the storage pool rack was as follows:
    - for WLTA AA01-03 ~ 87 kgf,
    - for WLTA AA02-03 ~ 52 kgf,

  - for WLTA AA03-03 ~ 148 kgf,
  - for WLTA AA04-03 ~ 96 kgf,
  - for WLTA AA05-03 ~ 61 kgf,
  - for WLTA AA06-03 ~ 78 kgf;
- The drag force of all WLTAs during their installation into the storage pool rack did not exceed a setpoint of 150 kgf.
- The drag force during WFA unloading from the core did not exceed the design values and met the requirements of document [3].
- For purposes of comparison, below are the maximum drag forces of three TVS-Ms after their second operation cycle during installation into the storage pool rack:
  - TVS-M 02918 ~ 174 kgf,
  - TVS-M 02919 ~ 174 kgf,
  - TVS-M 02920 ~ 140 kgf.

3. AXIAL TOP NOZZLE POSITIONS

At the first load in 2005 the height difference of top nozzle positions did not exceed 2 mm (the maximum value according to the document TRBE is 5 mm).

Before the unloading from the core after 4th cycle of operation the height difference was 1 mm. This value corresponds to that obtained by the beginning of the 4th cycle.

4. WATER CHEMISTRY

During all cycles of WLTAs operation the core coolant chemistry was maintained within the RCS chemistry norms for different reactor power levels.

Coolant quality control was effected using plant control methods and with the frequency which meets the regulatory requirements for V-320. The data provided shows that:

- coolant quality during all cycles was consistent with the regulatory parameters for RCS chemistry;
- no deviations in RCS chemistry from the regulatory requirements for reactors at power were observed;
- RCS boron concentration was maintained at the level which ensured reactor operation at the prescribed power level in accordance with the Technical Decision.

5. VISUAL INSPECTION

Visual inspection was carried out after each cycle during outages for all WLTAs. The inspection of the WLTAs was done in the storage pool using a special television system STS-PM-100V. Each LTA was inspected on all six faces for visible cladding defects, damaged LTA components, or other damages. During the inspection the Westinghouse LTAs were taken pictures of.

After the fourth cycle of operation the surface of WLTAs had oxide films of various shades. On the dark gray background of the clad in lower part of the fuel rod (between the 1st and 3rd spacer grids) had contrasting light-gray spots, and the fuel rod surface showed good reflective properties. The size of gray spots increased towards the top of the WLTA. Starting with grid 5, the fuel rod clad surface was gray with observable light-gray spots which increased in size towards the top of the WLTA. There were no spots in the plenum region, and the cladding surface was an even dim light-gray color.

The visual inspection did not observe any visible mechanical damages of fuel rods. It should be noted that the bottom end plug of the corner rod between WLTA AA02-03 faces 4 and 5 showed marks visually resembling wear signs or a foreign particle (Fig. 5.1). The technical capabilities of the resident video and measuring equipment do not allow to unambiguously identify the nature and type of the marks.

Minor foreign objects were observed on the WLTA AA04-03 bottom nozzle and grids. Some of the particles observed on WLTA AA04-03 were flushed in the sipping test cask. WLTA AA04-03 requires further examination to identify the nature and type of the elements observed using the inspection stand to be supplied by Westinghouse under a separate contract.

Some grids on WLTAs had burnishes resulting from friction against the adjacent FAs during FA installation into and withdrawal from the core (Fig. 5.2).

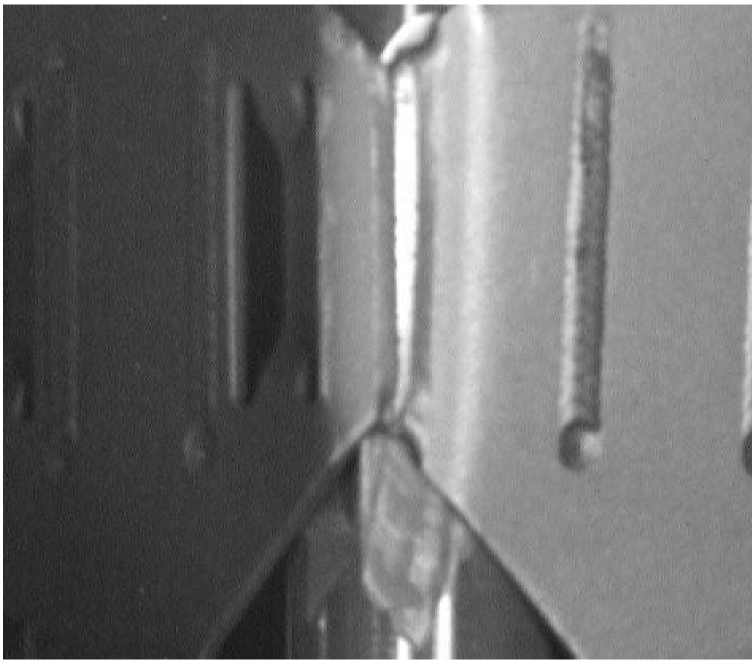

FIG. 5.1. Marks on the corner fuel rod bottom end plug, WLTA AA02-03, juncture of faces 4–5.

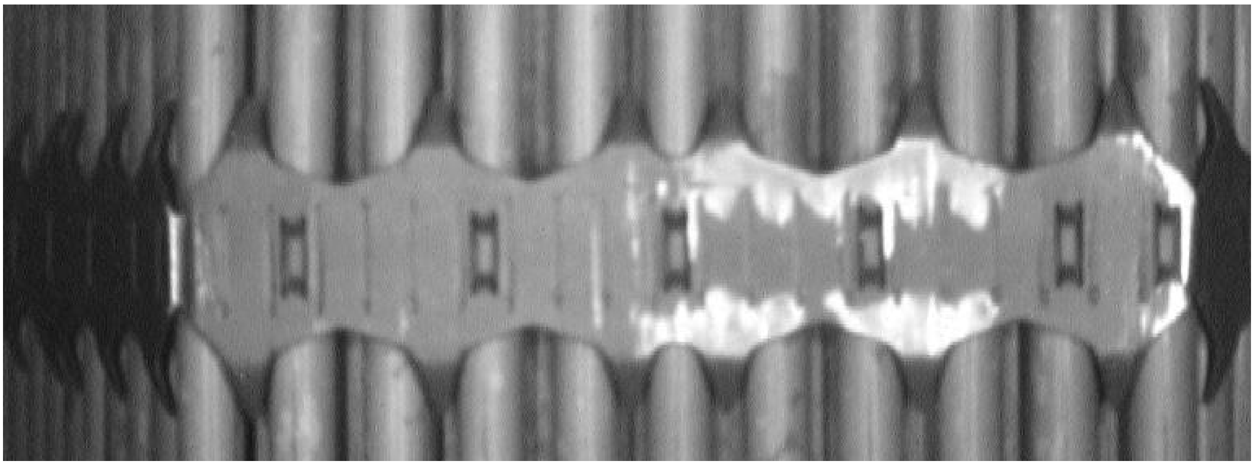

FIG. 5.2. Burnishes on Inconel grid 6 on WLTA AA03-03 face 3 after fourth operation cycle.

Visual inspection of the WLTAs on all faces demonstrated integrity of all spacer grids and absence of their axial displacement. The relative axial positions of the spacer grids were determined using the resident video system and selsyn readings during WLTA axial movement.

Fuel rod displacement (Figs 5.3–5.5) resulted in making contact between some bottom end plugs and the bottom nozzle plate. No fuel rod was observed, however, to have been displaced towards immediate proximity with the WLTA top nozzle.

Fuel rod downward displacement until making contact between the bottom end plugs and the WLTA bottom nozzle is a design feature and does not adversely affect nuclear, mechanical, and thermal hydraulic core parameters and does not result in violation of fuel rod and FA operability criteria.

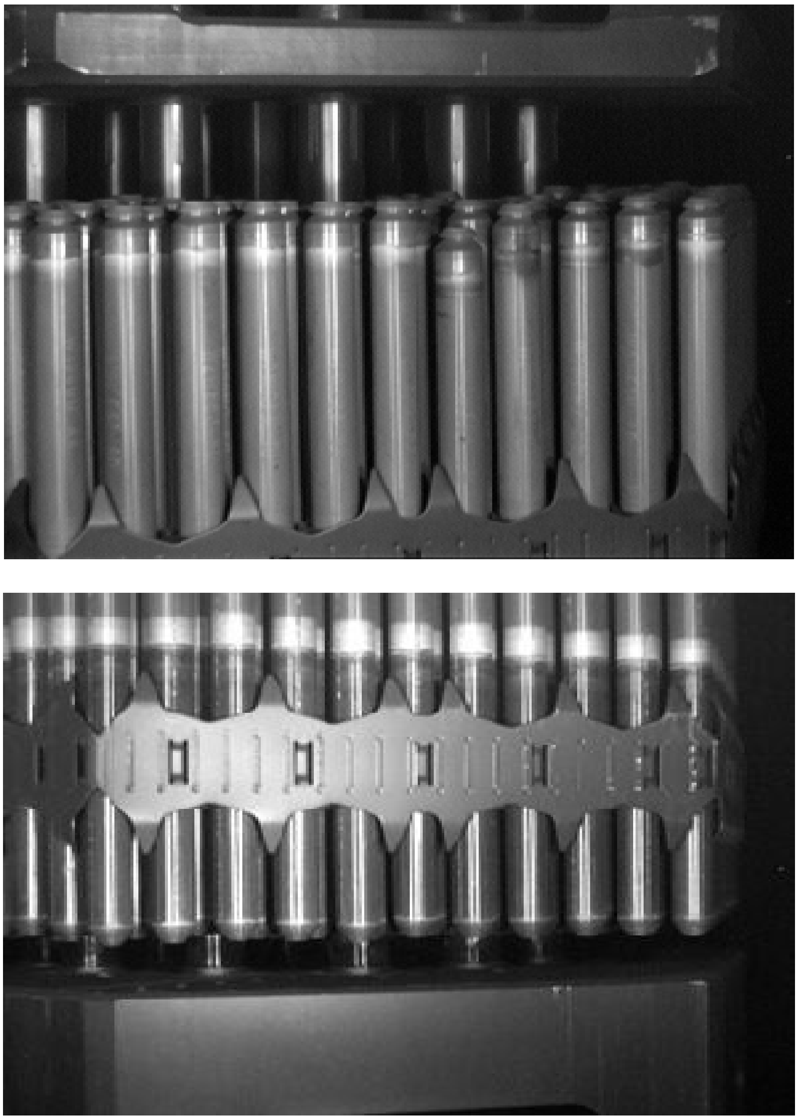

FIG. 5.3. Fuel rod displacement, WLTA AA02-03, face 4, inspection 2007.

The weld joints of the fuel rod top and bottom end plugs were uniformly light-grey (Figs 5.6–5.7). Some fuel rods, however, were observed to have cladding dimness in the weld joint area of the top/bottom end plug.

FIG. 5.4. Fuel `, WLTA AA02-03, face 4, inspection 2008.

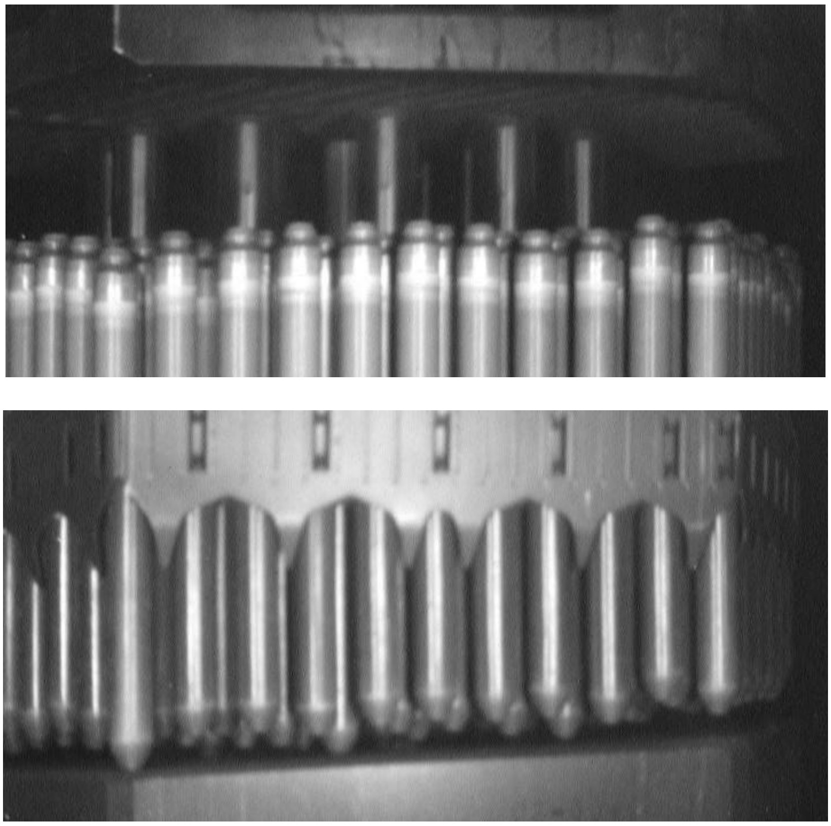

FIG. 5.5. Fuel rod displacement, WLTA AA02-03, face 4, inspection 2010.

No damaged weld joints on the visible parts of the outer and inner strips of Zr1%Nb grids were observed [1–2, 4]. Along the weld joint on the outer side of the external Zr1%Nb grid straps, as well as on the surface of external strap surface there were light-gray spots (see Figs 5.8–5.11), which evidence presence of oxide films on Zr1%Nb grid straps after the fourth operation cycle. The surface of zirconium grids had better reflecting properties than Inconel grids.

The inspection did not identify any visible damage to or non-design positions of individual WLTA components, which could result in the engagement with the adjacent core components, equipment or FA handling devices. None of the six WLTAs had any sings of damage, deformation or other defects preventing their handling.

It is necessary to mention that during all inspections were not observed visible changes of geometrical dimensions of fuel rods as a consequence of irradiation growth and irradiation-induced swelling that can influence on decrease of operability [2,4].

Zirconium alloys Zr-1%Nb and ZIRLO^{TM} showed excellent corrosion resistance operability [2,4].

FIG. 5.6. Weld joints of top end plugs, WLTA AA05-03, face 1, inspection 2010.

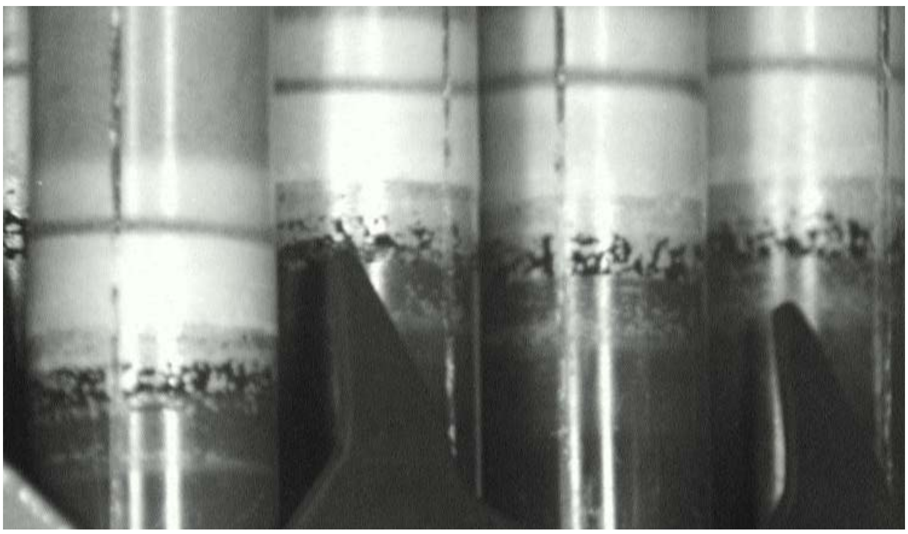

FIG. 5.7. Weld joints of bottom end plugs, WLTA AA02-03, face 4.

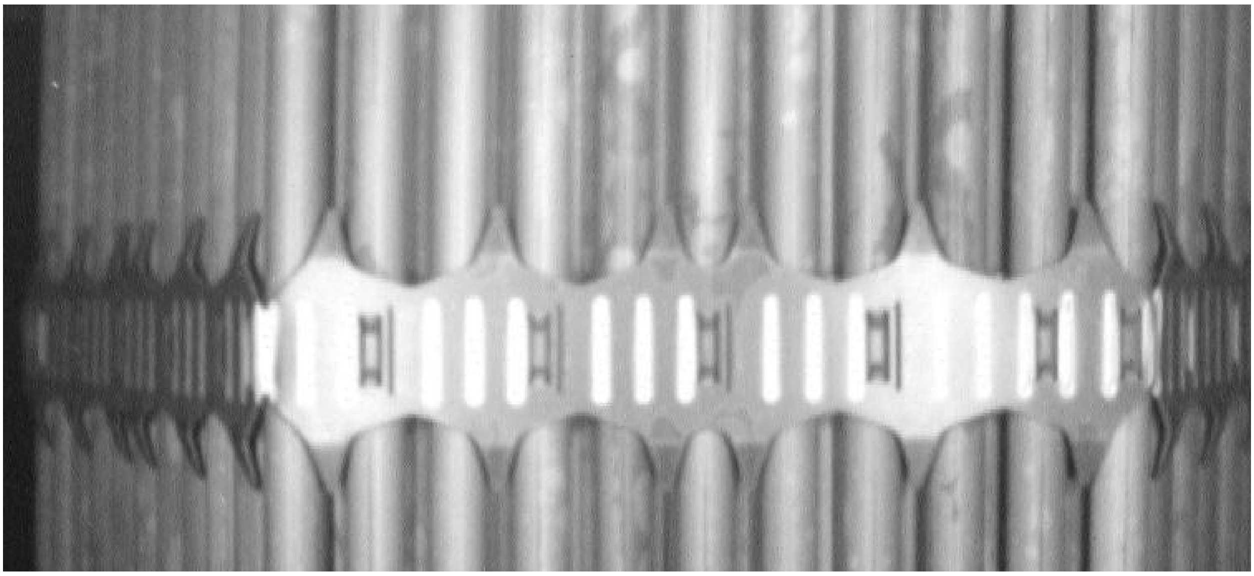

FIG. 5.8. Zr1%Nb grid 9, WLTA AA01-03, face 1, inspection 2010.

FIG. 5.9. Condition of Zr1%Nb grid 14 weld joints, WLTA AA03-03, face 1, inspection 2007.

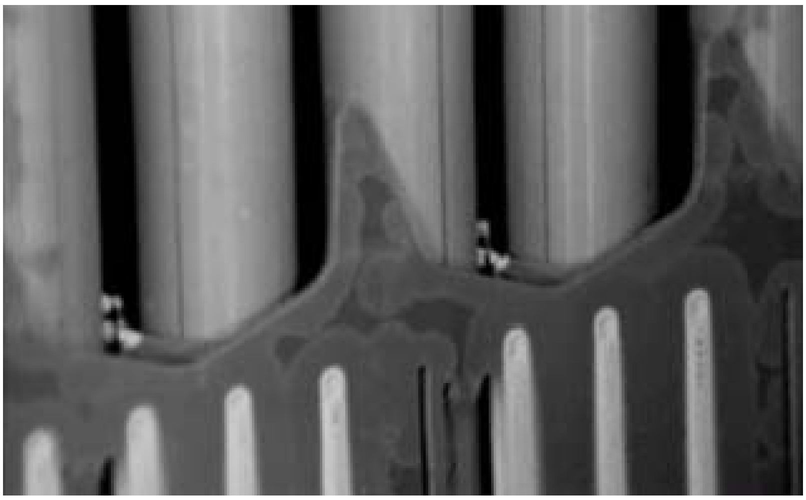

FIG. 5.10. Condition of Zr1%Nb grid 14 weld joints, WLTA AA03-03, face 1, inspection 2008.

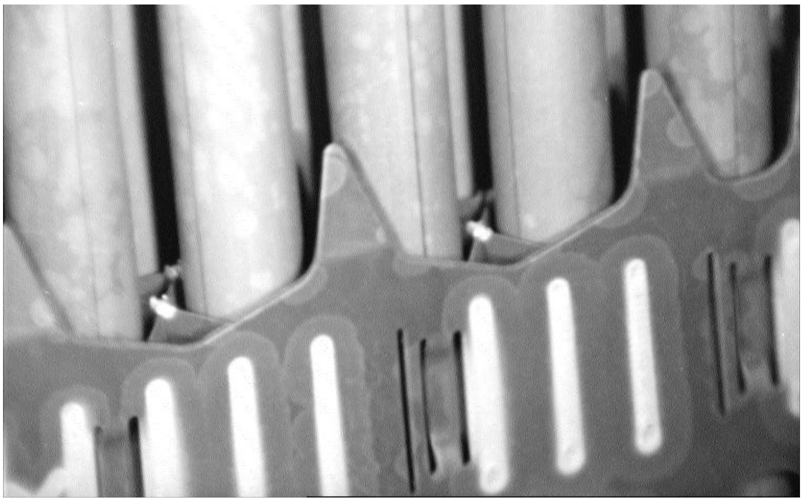

FIG. 5.11. Condition of Zr1%Nb grid 14 weld joints, WLTA AA03-03, face 1, inspection 2010.

Also the inspection of Russian fuel which faced WLTAs was done. Visual inspection has not revealed any appreciable impact of the new set of structural materials in the core on the corrosion behavior of the fuel rod cladding, FA spacer grids, and FA top and bottom nozzles of either Russian or Westinghouse fuel.

During visual inspection were not observed any visible defects such as corrosion plaques, pittings or cracks in the area of weld joints. It gives the opportunity to state that this type of weld joint is operational in WWER-1000 conditions.

Also in mixed core conditions were not observed any mechanical mutual influence both Russian and Westinghouse fuel.

6. LEAKAGE TEST

Leakage test was done after each operation cycle using a standard SODS stand with further analysis of water samples in a gamma-spectrometer. Statistical processing of the results thus obtained was done by I-131. The results obtained for Cs-134 and Cs-137 were also statistically treated.

After the 4th cycle one WLTA had fuel rod non-tightness [2]. The defect was assumed to be minor "gas leakage" (in the leakage test sample the I-131 activity was 7.5×10^{-8} Ci·kg^{-1}; Xe-133 activity was 2.6×10^{-6} Ci·kg^{-1}; no activity of solid fission products, such as Ce-141,143 and Ru-103,106, was found in the leakage test sample).

The FA leakage test done in the operating reactor and during the outage found that after the 4th operation cycle five WLTAs were leakage-tight. It should be noted that FAs found to be leaking based on statistical analysis, but having I-131 activity in the leakage test samples below 1.0×10^{-6} Ci·kg^{-1}, can be further operated.

According to results of 4 cycles of operation it was concluded that Westinghouse fuel can be operated in mixed cores of WWER-1000 reactors at temperature loads corresponding to the regulatory basis and in primary water chemistry corresponding to [5].

7. SUMMARY

The post irradiation examination of WLTAs after 4 cycles of operation did not reveal any visible damage to or non-design position of individual FA components, which could result in the engagement with the adjacent core components, equipment or FA handling devices. Neither were there observed visible changes of geometrical dimensions of fuel rods as a consequence of irradiation growth and irradiation-induced swelling that could adversely affect operability. Further, PIE did not show any mutual influence of different sets of structural materials of both WLTAs and the resident fuel on corrosion resistance.

Positive results of WLTAs operation allowed to install during 2010 outage 42 FAs produced by Westinghouse and enabled NNEGC Energoatom to enter into a contract with Westinghouse for delivery of fuel for three WWER-1000 units.

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