Visual Inspection and Sipping of the IEA-R1 Irradiated MTR Fuel Assemblies

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ABSTRACT

Fuel performance and nuclear fuel qualification require a post-irradiation analysis. Non-destructive methods are utilized both in irradiated fuel storage pools and in hot-cells laboratories. The Fuel Engineering Division (CENC) at IPEN/CNEN-SP developed facilities for irradiated fuel elements inspections in the IEAR1 research reactor pool. This work presents the methods of sipping test and visual inspection performed at IEAR1 research reactor. These inspections were adopted to evaluate the behavior of the fuel elements fabricated at IPEN/CNEN-SP in use at the IEAR1.

I. INTRODUCCION

IEA-R1 is a pool type research reactor that operates since 1957 at IPEN-CNEN/SP in São Paulo, Brazil. Although designed to operate at 5 MW it has been operating, since the beginning, at 2 MW and has been used for radioisotope production and research. Several programmed improvements in reactor systems were made and others are in progress in order to upgrade the reactor power to 5 MW thermal in the next year (2002).

Since the 80's IPEN has been producing and qualifying its own LEU (19,75% of ^{235}U) MTR fuels. Fuel element assemblies had been constructed with U_3O_8-Al dispersion fuel plates with densities of 1.9 gU/cm^3 (from 1988 to 1996) and 2,3 gU/cm^3 (from 1996 to 1999) and also, using U_3Si_2-Al dispersion fuel plates with 3,0 gU/cm^3 since September/99.

The strategy adopted by IPEN-CNEN/SP for characterization the own fuel elements was to conduct the fuel tests and fuel performance evaluations in pile, during reactor operation, Ref. [1]. Testing events and procedures were planned to qualify the initial fuels. It started with irradiation of some U_3O_8-Al miniplates at the border of the reactor core just to identify any abnormal event. A fuel element assembly (FA) with only two fuel plates (the external plates) and 16 aluminum plates was placed in the IEAR1 reactor core to start fuel qualification (July 1985). After this, a fuel element assembly with 10 fuel plates and 8 aluminum plates was also placed in the core (November 1985). These two fuel element assemblies were identified as the precursor fuels and a periodic monitoring and evaluation was done upon them. After good experience with the precursor fuels it was decided to start loading standard fuel element assemblies in the reactor core (September 1988). The criteria adopted was that each IPEN fuel element assembly had to start irradiation at peripheral positions of the core, with lower power densities, up to 4 % burnup (almost one year of irradiation) and then it could go to higher power density positions in the core. It was decided that a complete fuel assembly could stay in the core up to the time to equal their burnup with the reached precursor fuels burnup.

The program of evaluation has been consisted of the following items:

i) Monitoring: reactor power; time of operation; neutron flux calculation at the position of each fuel assembly; burnup calculation; inlet and outlet water temperature in core; water pH; water conductivity; chloride content in water; radiochemistry analysis of reactor water.

ii) Periodic underwater visual inspection of fuel assemblies and eventual sipping tests for suspect fuel assembly.

The precursor fuel assemblies irradiated at IEAR1, the fuel material, densities and the respective average burnup reached are showed in the Table 1.

Table 1- Precursors FA irradiated in the IEAR1. Ref [.2]

FA Id	Material	Fuel Density gU/cm^3	Discharged on	Burnup Q (%U-235)
128 (*)	U_3O_8-Al	1,9	21/12/90	12,58
129 (**)	U_3O_8-Al	1,9	29/09/93	18,44
130	U_3O_8-Al	1,9	08/09/97	36,10
153	U_3O_8-Al	2,3	In core	26,75
165	U_3Si_2-Al	3,0	In core	9,75

(*) Partial fuel assembly with 2 fuel plates
(*) Partial fuel assembly with 10 fuel plates

Up to now (November 2001) a total number of 54 fuel element assemblies were done by IPEN/CNEN-SP to the IEAR1 reactor, which 24 FAs are loaded in the reactor core, 21 spent FAs are stored in the reactor pool racks and 09 new ones FAs are stored at IEAR1 reactor safe, waiting its loading in the core.

Recently (July 2001), a standard fuel element loaded in core since September 1999 (IEA-156; with an actual 25% burnup (average) was taken off operation due to

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present gas bubbles liberation. This FA was exhaustibly examined on visual inspection. It was not possible to localize the defective fuel plate because the bubbles liberation occurred only during few seconds after be vertically moved to the camera level depth. The pressure reduction of about 7 meters water column permitted the gas liberation until the pressure equalization. The bubbles come from an unidentified internal fuel plate. The confirmation of this defective fuel element was done by a sipping test.

Others fuel elements assemblies actually stored at the racks were discharged from the core reactor with an average burnup about 30% (maximum peak burnup around 50% in the fuel plate) without any defect or integrity problem. However, some fuel element assemblies, still in use in the reactor core, present corrosion stains caused due a 48 hours experimental operation at 5 MW performed in 1997. These FA are being followed by programmed visual inspections once in every three months. No radioactive liberation is founded or detected in the pool reactor water. The corrosion stains areas of these FA present a low increasing during this period of 4 years.

Making use of the underwater camera of the Irradiated Fuel Element Visual Inspection System (SIVCI), several corrections on the positioning of several reflector elements and plugs on the reactor matrix core plate were made, increasing the in-core water cooling flow about 26% over the previous value of the mentioned experimental operation performed in 1997, Ref. [3].

II. SYSTEMS DESCRIPTION

Irradiated Fuel Element Visual Inspections System-(SIVCI)

Irradiated fuel element assemblies have been visually inspected by an underwater radiation resistant video camera, inside the IEAR1 reactor pool, to verify its integrity and its general surfaces conditions. This system have been used also to exam visually graphite reflector elements, control rods, the reactor core matrix plate and others reactor core components.

At the fuel element visual inspections, the available video camera equipment permit the visualization of the only two external fuel plates and two external support plates surfaces conditions. The internal fuel plate`s conditions are not visible.

The phenomena and visual occurrences that eventually can be observed at an irradiated fuel element or in-core component under visual inspection are corrosion stains, coloration gradient showing the different power regions at the fuel plate, corrosion pitting, loss of material due to corrosion, loss of corrosion layer over the fuel plate cladding, risks, wears, shooting marks and deformations due inadequate operational handling, Ref. [4].

Equipment

The SIVCI system is composed by an underwater radiation resistant video camera IST-REES ETV 1258 Black and White, equipped with a set of standard lens (22mm – 90mm), Pan and Tilt Equipment and with two 75 watts lights. The zoom, focus, iris, pan and tilt motion, light intensity (right and left) are controlled by remote control. A 12 inches B&W video monitor Panasonic and an additional 8 inches are used to exam the images from the camera. For images recording is used a professional videocassette recorder Panasonic, model AG-1980P and, for printing images, a video graphic printer Sony, model UP-880 has been used.

The video images obtained are recorded in videotapes. The images can be transferred to a digital file using a available VITRA VGA+TV Combo Board, installed at a PC IBM compatible, located at the CENC- Fuel Engineering Division, outside the IEAR1 reactor building.

Methodology

The underwater camera is supported by a metallic tube arrested at the pool reactor mobile bridge as showed in the figure 1.

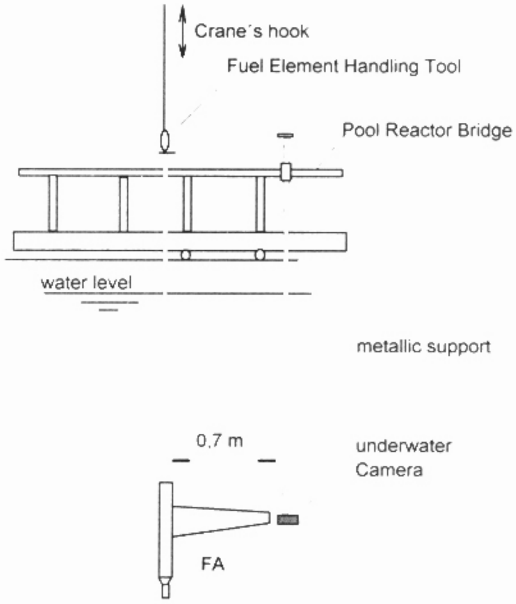

FIGURE 1 – Fuel Inspection arrangement

The camera is placed about 2,8 m dept. Using the reactor crane, each fuel element is withdrawal from its position at the reactor core or from its storage rack and it is positioned about 0,70 m distant from the camera, in order to obtain the best images and to prevent damages in the camera due its radiation.

The fuel element assembly is maintained in a fixed position in front of the camera. The camera is moved by remote control using the pan and tilt system to perform the visual inspection along the complete FA length. The four FA lateral faces are observed attentively from the top to the bottom. If a visual occurrence is observed, the image is approximated by zoom for better examinations.

Before a fuel element examination, a standard form containing the FA schemes and is filed, annotating the FA identification number, date and hour of the inspection. Eventual visual occurrences during the inspection are annotated. The recorded videotapes are the effective visual inspections registers.

The visual inspection operation must be monitored by the reactor radiological protection group.

Comment

As mentioned, the actual method consists in maintain the camera in a fixed dept position in front the fuel element in observation. It is a very simple method. The camera movements to observation of the whole fuel element length are done by the pan and tilt system. When the camera is moved to observe an interesting visual occurrence, the focus must be adjusted by the operator to that focal distance in order to achieve the best image. However, if the camera is moved again and a new focal distance is defined, another focus adjust is also necessary. This procedure implicates in a constant needs of focus adjusts, by the technician in charge, always the camera is moved. Another aspect is the parallax effect in the image caused by this.

In order to provide an improvement in this actual fuel inspection method, a linear guide to support the camera are being constructed at CENC- IPEN. This guide will permit the camera vertical motions in front of the fuel assembly during the inspection, without need of constant focus adjusts and eliminating the parallax effect.

Sipping Test System

Sipping tests are performed to detect eventual defects in fuel elements. The operational procedures for the sipping tests performed at IEAR1 reactor are defined in the Ref. [5].

The sipping system is basically composed by an aluminum tube (12 cm inside diameter and 300 cm width) which has its bottom extremity closed and is vertically maintained. A fuel element besides a ¾" PVC tube are introduced into the sipping tube, as showed at figure 2. The PVC tube is connected at demineralyzed water circuit or at compressed air reactor system, depending the operation phase.

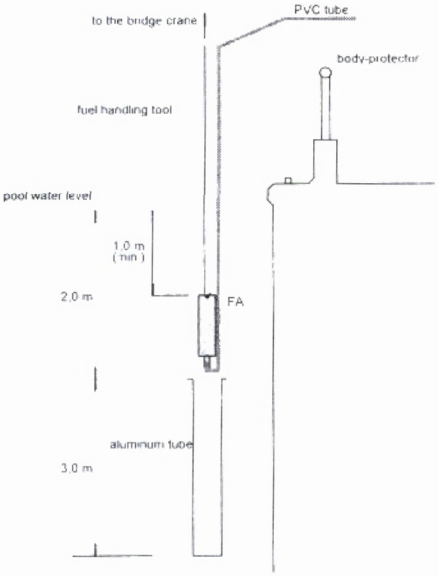

Figure 2- Sipping tube loading operation

After that, the open tube extremity is elevated over the pool water level, in order to maintain the tube internal water volume separated from the pool water volume. Then, an internal washing is promoted by ascendant circulation of fresh demineralyzed water, supplied by the PVC tube, to remove the eventual contaminants from the proper pool water or accumulated impurities during the storage time, as showed at figure 3.

After the water homogenization, the first water sample collection is done in plastic flasks. This sample will be characterized as background (BG) level.

The fuel element stays in rest, inside the sipping tube, by an established time (four hours). In this condition the tube entrance is about 15 cm over the water level.

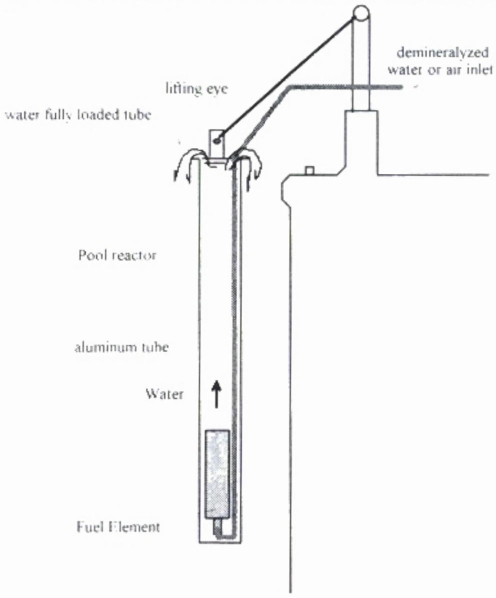

Figure 3- Fuel element position into the sipping tube.

After the rest time, the compressed air system is connected to the PVC tube. Compressed air is injected during 2 minutes to promote a new water homogenization,

The second water sample is collected and characterized as the "sipping sample for that in test FA".

Additional data collection are: water temperature from inside the sipping tube, the sample collection time and the reactor power during the sipping test; as well the demineralyzed water characteristics used in the washing (pH, conductivity, chlorides).

Radiochemistry analyses are made on the collected samples. The presence of chemistry elements fission products at the samples indicates the existence of some defective part in the fuel element cladding.

The reactor radiological protection group must monitor the sipping test operation.

III. WORKS AND EXPERIENCE OBTAINED

Visual Inspection on Irradiated Stored Fuel Elements at the IEAR1 Pool Reactor Storage Racks. Ref. [1] - In 1996, the visual inspection on stored irradiated fuel elements at the IEAR1 reactor pool for about 40 years showed the existence of accentuated corrosion at external fuel plates of several fuel elements.

The principal cause of this corrosion in the aluminum cladding of the fuel plates was the galvanic corrosion, due its storage racks were constructed in stainless steel. The corrosion occurred even so in presence of the excellent water conditions existent at the IEAR1 reactor pool (pH 5,5 – 6,5; conductivity < 2μSiemens/cm; chlorides < 0,05 ppm).

The visual inspection indicated two different corrosion pits, which were concentrated at the fuel plate central region and at the interface of the fuel plate with the lateral support plate.

Due the existents corrosion pits dimensions, they initiated a long time ago, probably on 70´s, occasion when the stainless steel pool liner was installed and the aluminum racks were substituted by new ones in stainless steel.

The conclusions recommended two actions:

i) Construction of new aluminum racks for fuel elements storage (action already accomplished) and,

ii) Use of an aluminum isolating between each rack position and its stored fuel element. (Fabrication already contracted).

Ordinary Visual Inspection of Irradiated Fuel Elements at the IEAR1. – Programmed visual inspections are performed on the in-use fuel elements, once in every three months. Figures 4 to 8 shows examples of visual occurrences in IEAR1 standard fuel elements.

Visual Inspection of IEAR1 Control Rod Bars. During the occasions of loading in core of four new ones control fuel elements (two in March-1998 and two in Dezember-2000), visual inspection of their respective control rod bars were performed.

Each IEAR1 control rod bars are composed by two Ag-In-Cd neutron-absorbing plates, which are assembled inside the control fuel element. The plates are covered by nickel-plating (nickel layer about 50 μm thickness). That four control rods were acquired from CERCA (Fr) in 1972. Since then these bars are in use in the reactor core. The examinations were done in order to verify the general conditions of the neutron absorbing plates and the integrity of their lateral guide fillets.

The images obtained indicated that 50 % of the absorbing plates presented corrosion bubbles, probably due *the internal corrosion under the external nickel layer. The* figure 9 shows bubbles corrosion at an absorbing plate.

The integrity of the lateral fillets was verified and no relevant problem was observed.

The visual inspections showed the general conditions of the IEAR1 control rod bars. Following this work, it was recommended the substitution of the four actual control rods by new ones. This action is in progress.

Visual Inspections of the reactor core and components associated. – The camera of the SIVCI system is used also to exam structural components in the pool reactor or verifies if the components installed at the reactor core are in their correct positions.

Sipping tests at the Spent Fuel Elements Stored at IEAR1. Ref. [1] In 1996, during the programmed activities to send back the 127 spent fuel elements stored in the IEAR1 to USA (US-DOE American fuel take back program), sipping tests on 62 stored spent fuel elements were conduced.

At the conclusion of the tests were determinate which fuel element presented 137Ce escape to the water and also which was the liberation rate. It was done a correlation with the visible characteristic presented (corrosion pits on the external fuel plates).

The Savannah River Side (SRS-DOE) team adopted this Ipen/Cnen-SP technique as a comparative basis for the MTR fuel transportation criteria in shielded casks and as a basis for futures analyses at others MTR storage installations, at the US-DOE program.

IV. CONCLUSIONS

The visual inspection has been an important and essential non-destructive method to follow and verify the general conditions and behavior of the fuel element assemblies irradiated at the IEAR1 reactor.

The visual inspection has been also, an important instrument to inspect the positioning of in core components and the conditions of structures inside the pool reactor.

The sipping tests performed in 1996, by Fuel Engineering Division- CENC, showed be efficient in the determination of the defective fuel elements stored at IEAR1 storage pool. A correlation among the visual inspection of fuel plates presenting pits at the active region and water activities obtained in the sipping samples was done.

Recently, sipping tests besides visual inspection showed a defective fuel element assembly (IEA-156).

V. REFERENCES

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[2] Yamaguchi, Mitsuo. - (CENF), Personal communication on 12 November 2001, - IPEN/CNEN-SP.

[3] Maximo, Walmir. – (CENT-), Personal communication on 12 November 2001, - IPEN/CNEN-SP.

[4] Doc. IT-CENC-0001-00 – **Inspeção Visual de Elementos Combustíveis Tipo Placa Irradiados**- Instrução de Trabalho.- August 2001

[5] Doc. IT-CENC-0003-00 – **Testes de Sipping em Elementos Combustíveis Tipo Placa Irradiados**- Instrução de Trabalho.- August 2001

[6] Norma CNEN-NN-1.17 – **Qualificação de Pessoal e Certificação Para Ensaios Não Destrutivos em Itens de Instalações Nucleares**- September 1999

VI- IMAGES

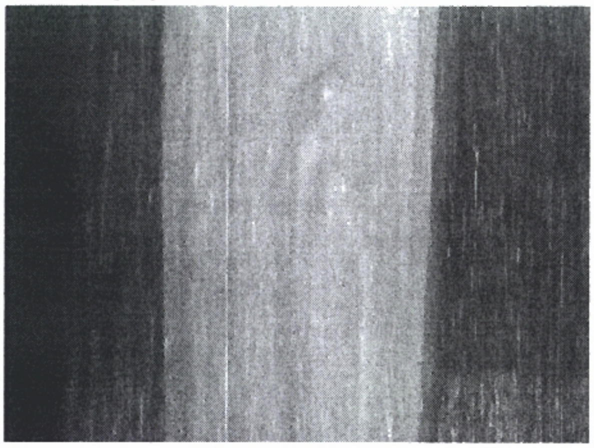

Figure 4 - Loss of Corrosion Layer over the lateral fuel plate; IEA 153; June-2000

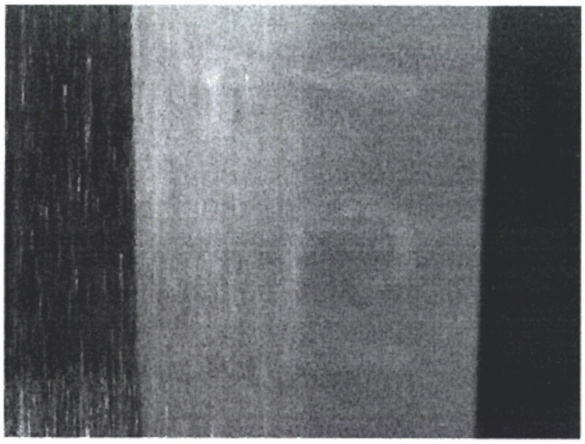

Figure 5 - Pits corrosion on the lateral support surface at the FA Id number region (low relief). IEA 157, Jun/2001

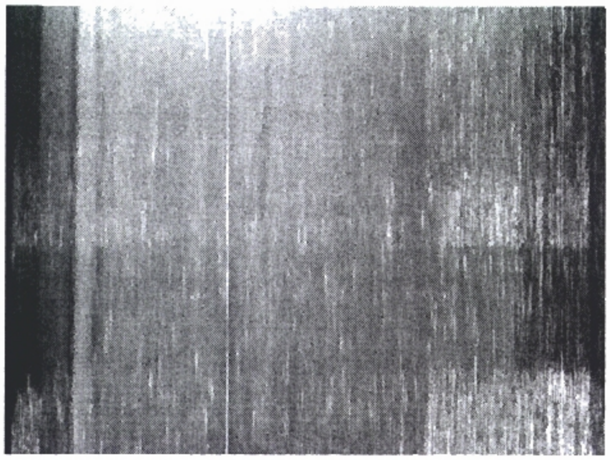

Figure 6 – Risk due handling over the external fuel plate surface (IEA 150, Jun/2001)

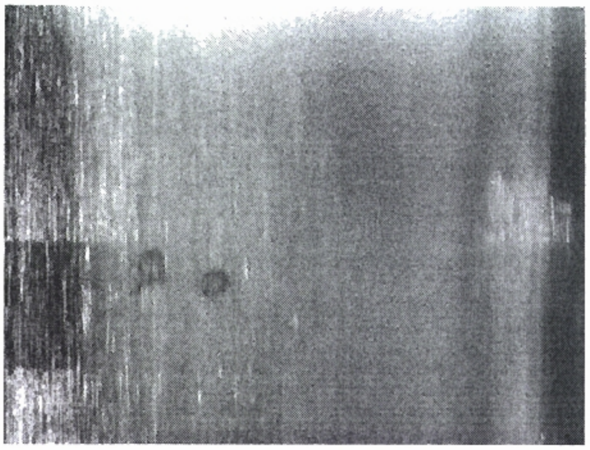

Figure 7- Loss of Corrosion Layer over the external fuel plate; IEA 153; June-200

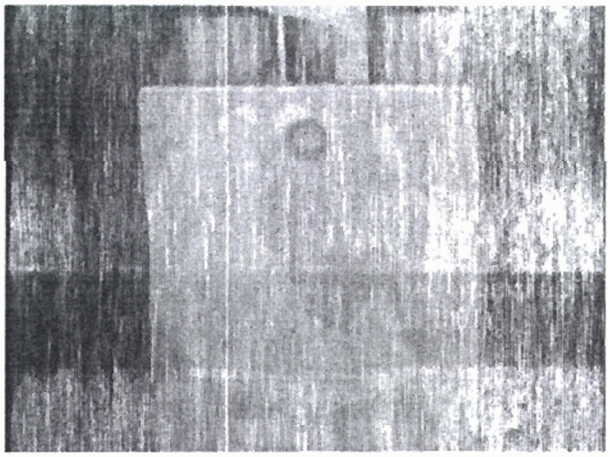

Figure 8 - Corrosion stain at the fuel element [illegible] support (IEA 163, Oct/1999).

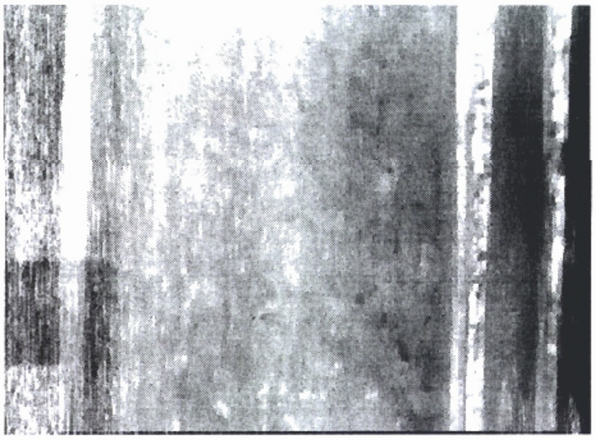

Figure 9- Control Rod Bar - Ag-In-Cd neutron absorbing plate presenting bubbles corrosion under the nickel layer