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NON DESTRUCTIVE TESTING OF IRRADIATED FUEL ASSEMBLIES AT THE IEA-R1 RESEARCH REACTOR

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ABSTRACT

Fuel performance and nuclear fuel qualification require a post-irradiation analysis. Non-destructive methods are utilised both in irradiated fuel storage pools and in hot-cells laboratories. As Brazil doesn't have hot-cells facilities for post-irradiation analysis, a qualification program for the Material Testing Reactor (MTR) fuel elements made at IPEN/CNEN-SP was adopted, based on non-destructive tests. The IPEN Fuel Engineering Group – CENC developed basic facilities for fuels post-irradiated analysis inside the reactor pool, which gives indications of: i) general state, by visual inspection; ii) the integrity of the irradiated fuel cladding, by sipping tests; iii) thickness measurements of the fuel miniplates during the irradiation time, for swelling evaluation; and, iv) local burn-up evaluation by gamma spectrometry along the active area of the fuel element. This work describes that facilities, equipment and examples of some irradiated fuels analysis performed.

1. INTRODUCTION

Fuel performance and nuclear fuel qualification require a post-irradiation analysis of this fuel. Non-destructive methods are utilised both in irradiated fuel storage pools and in hot-cells laboratories. 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 dispersions 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 [1]. To follow this fabrication program, as Brazil don't has hot-cells facilities for post-irradiation analysis and due the high prices for abroad irradiation services and post-irradiation analysis services in miniplates, IPEN adopted a fuel qualification program based on non-destructive tests performed periodically during the irradiation time of the fuel in the reactor core. Basic facilities were developed by IPEN Fuel Engineering Group – CENC for characterisation of irradiated fuel elements inside the IEA-R1 reactor pool, in order to attend the fuel qualification program.

2. SYSTEMS DESCRIPTION

2.1. Irradiated Fuel Element Visual Inspection System

Irradiated fuel element assemblies have been visually inspected by underwater video camera inside the IEA-R1 reactor pool, to verify its integrity and its general surfaces conditions. This system also have been used to exam visually graphite reflector elements, control rods, the reactor core matrix plate and others reactor core components.

The phenomena and visual occurrences that eventually can be observed at an irradiated fuel element 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. [2]

The available video camera equipment permit the visualization of the only two external fuel plates and two external support plates surfaces conditions of the MTR fuel element, as well the upper handling pin, screws and the nozzle. The internal fuel plate's conditions are not visible. However, the IPEN-CENC will receive in next days (~August-2007) from IAEA a new camera (endoscopy optical fiber probe type) that will possibility obtaining images from internal fuel plates surfaces, along their total length. This probably will allow the visualization and identifying of the defective fuel plate of the failed fuel element IEA-156, discharged from the core and stored at IEA-R1 reactor pool, since July/2001.

2.1.1. Equipment and apparatus for visual inspection of irradiated FE at IEA-R1

For performing visual inspection of irradiated fuel elements, two underwater video camera systems are available. The first one is a radiation resistant video camera system 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 are remotely controlled. A 12 inches B&W video monitor Panasonic and a 14 inches B&W video monitor Sony are used to exam the images from the camera. For images recording is used a professional videocassette recorder Panasonic, model AG-1980P and, for images printing, a video graphic printer Sony, model UP-880. The second one is a non-radiation resistant color video camera system (IST Color Underwater Outstation – model R982) equipped with an auto-focus system that allows a sharper focusing, thus improving the image quality, however, we received this camera without any illumination device. So, we have been used the external available black and white camera's illumination system. A 13 inches Sony color monitor has been used to the observation of the images. For imaging record the same equipment Panasonic model AG-1980P have been used. The basic system apparatus is showed at Fig.1.

The video images obtained from the camera are recorded in VHS 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 Group, outside the IEAR1 reactor building.

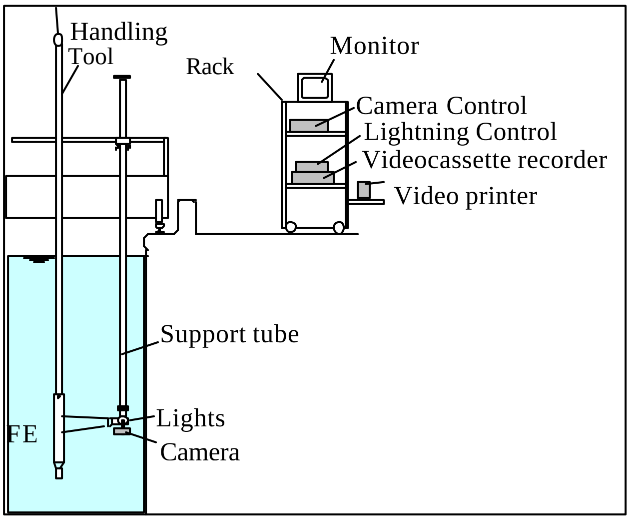
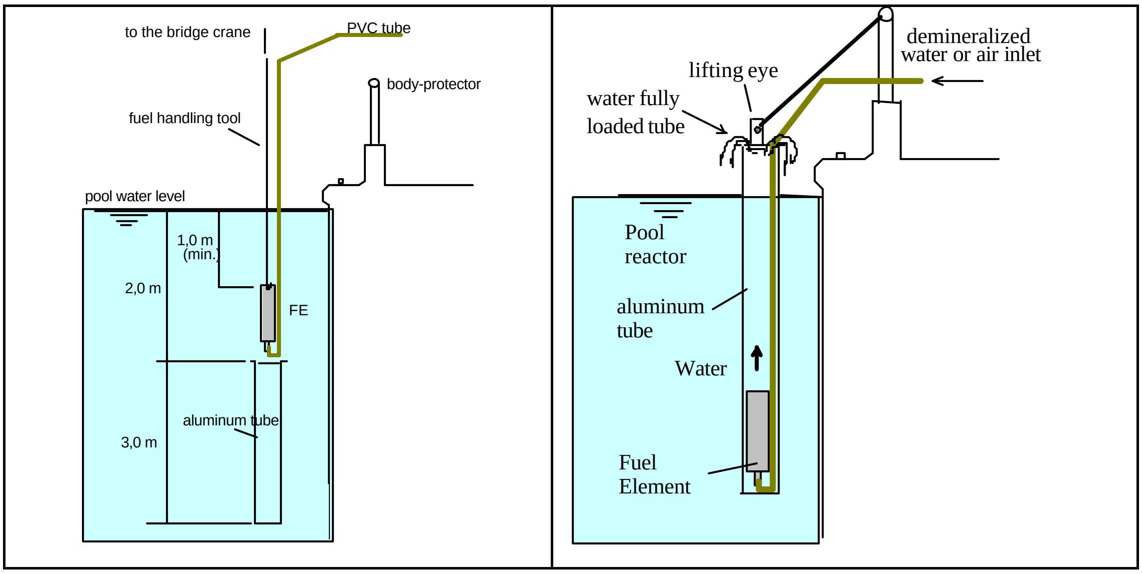


Figure 1 – Fuel inspection apparatus at the IEA-R1 reactor pool.

2.2. Sipping Tests of Irradiated Fuel Assemblies

Sipping tests are performed to detect eventual radioactive fission products leakage from some defective part in the fuel element cladding. The system [3, 4] is basically composed by an aluminum tube (12 cm inside diameter and 3 m length, approximately 33 l volume) which has its bottom extremity closed and is vertically maintained. A fuel element besides a ¾ " PVC tube are introduced into the sipping tube. The PVC tube is connected at demineralized water circuit or at compressed air reactor system, depending the operation phase.



(A) **(B)**

Figure 2-. Sipping test; (A) Sipping tube loading operation; (B) Fuel element into the sipping tube.

After that, the open tube extremity is elevated over the pool water surface level, in order to maintain the tube internal water volume separated from the pool water volume. Then, an internal washing is promoted by the ascendant circulation of fresh demineralized 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 Fig. 2. Done 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 a given time (four hours). In this condition the tube entrance is about 15 cm over the water level. 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 FE". 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 demineralized 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.

2.3. System for Fuel Miniplate Thickness Measurement

A system for fuel swelling evaluation, by mean of the fuel miniplate thickness measurement during the irradiation time, was designed and constructed within the framework of IAEA Project BRA/4/047 and is available at CENC. This device, showed at Fig. 3, shall be used inside the reactor pool, at the fuel storage area. It has to be operated from the reactor pool border, and be able to measure the fuel miniplate thickness along its surface. It is composed, basically, of a stainless steel structure for positioning the miniplate and to perform the scanning along the miniplate surface [5].

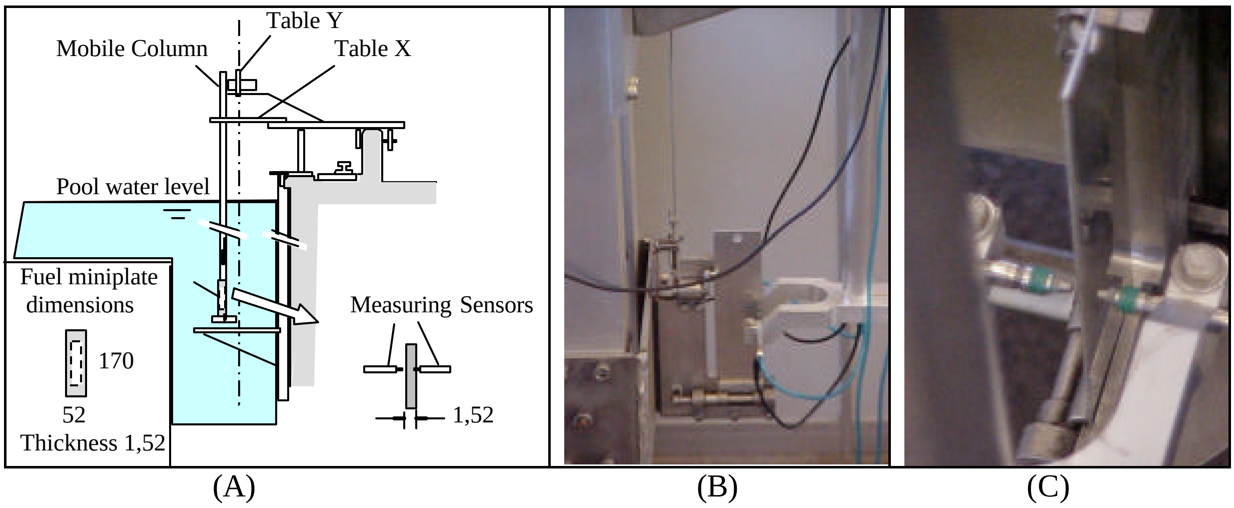


Figure 3 – Fuel miniplate thickness measurement apparatus at IEA-R1. (A) Schematic view at the reactor pool border; (B) Lateral view; C) Profile View (thickness).

The thickness measurement is performed by electronic probes (LVTD- Linear Variable Differential Transformer). The results are obtained by measurement instrumentation connected to the probes and the data are stored and/or processed by a laptop computer. For the miniplate positioning, a mobile metallic column, held by a X-Y coordinate table system, is used. This table is supported by another metallic structure fixed at the border of the reactor pool. The system, as well the positioning of the X-Y coordinated table that holds the mobile column (with the sensors) for thickness measurement is remotely actuated by the operator, positioned outside the pool. That system allows the measurement of the total area of the fuel miniplate, at the two surfaces.

2.4. Fuel Local Burnup Evaluation

The gamma-ray spectrometry method was used by Fuel Engineering Group - CENC during the period from 1995 to 2000, as an experimental method for determination of the local fuel burnup of MTR plate type fuel elements irradiated at IEA-R1. After 2000, no more burnup measurements in irradiated fuel elements were performed, due the difficulty of installation of the equipment at the reactor pool (weight of the shielded collimator and X-Y table structure) and also, due the actual precision burnup results given by neutronic computational programs. Although, this method gives good results compared to the calculated ones and is presented as follow. The analysis is carried out using an experimental apparatus that, by means the collimating and gamma-rays detection emitted by the radioactive fission products, allows the obtaining, storage and analysis of the gamma spectra [6]. The analysis of the gamma spectra gives indication of the local burnup along the active length of the fuel element.

3. WORKS AND EXPERIENCE OBTAINED

Several works related with the utilization of the mentioned NDT techniques on characterization of irradiated fuel elements were performed at IEA-R1, with considerable experience gain obtained by the IPEN-CENC team. Some works are mentioned in following:

Sipping tests at the spent fuel elements stored at IEA-R1: In 1996, during the programmed activities to send back the 127 spent fuel elements stored in the IEA-R1 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 technique as a comparative basis for the MTR fuel transportation criteria in shielded casks and as a basis for future analysis at others MTR storage facilities, at the US-DOE program.

Sipping tests for determination of the failed fuel element at IEA-R1: In 2001, sipping tests besides visual inspection showed a defective fuel element (IEA-156). This Fuel element has been maintained stored in wet-storage conditions at IEA-R1 pool, inside an aluminum tube.

Visual inspection of the spent fuel elements stored at IEA-R1 racks: In October 2004, it was promoted a campaign effort, in order to perform visual inspection of all spent fuel standard elements stored at the IEA-R1 storage racks. The images from the 36 fuel elements, as well all the information available about then, including sipping tests results were compiled and presented in the document "Catalogue of the IEA-R1 Research Reactor Spent Fuel" [7]. The Fig. 5 shows an example of image data of an irradiated fuel element.

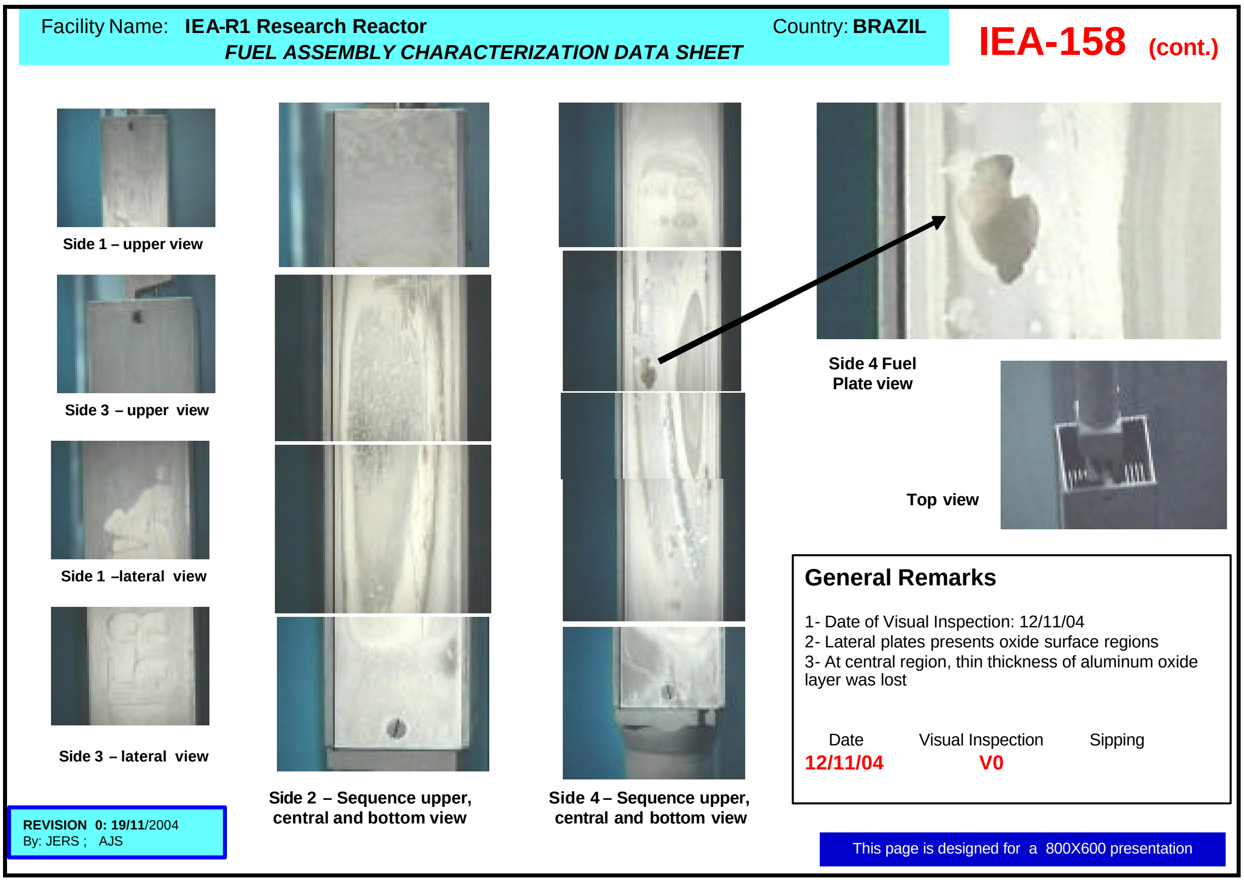


Figure 5 – Example of a data sheet of the fuel element IEA-158 [7]

Visual inspection of the IEAR1 control rod bars: In order to change the neutron absorbing control rod bars constructed by CERCA (Fr) in work at the IEA-R1core reactor since 1972, IPEN constructed at 2004-2005 four new ones Ag-15In-5Cd control rod bars. That control rod bars were put in operation, in substitution the old ones, during 2005. Since that, ordinary visual inspections are being performed in order to verify the performance of that neutron absorbing control rod bars, once in every six months.

Ordinary visual inspection of the fuel elements at IEA-R1: Programmed visual inspections have been performed on the in-use fuel elements during the fuel element qualification time (U_3O_8-Al and U_3Si_2-Al), once in every three months from 1997 to 2001 and once in every six months from 2002 to nowadays.

Sipping tests for determination of the failed fuel element at IEA-R1: During March to July-2007, a campaign of sipping tests showed two defective U_3Si_2-Al that were loaded in core in the beginning 2007 (IEA-174 e IEA-175). Both fuel assemblies present very low burnup and were discharged of the core reactor and were stored at pool reactor racks.

3. CONCLUSIONS

All the presented non-destructive tests particularly both the visual inspection and sipping test have been important and essential to characterization, verification of the general conditions and behavior, and, the integrity of the cladding of the irradiated fuel element assemblies at the IEA-R1 reactor.

The acquired experience at the sipping tests performed in 1996, by the Fuel Engineering Group-CENC has been very important and has helped the actual works related to sipping tests at IEA-R1.

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