FABRICATION, FABRICATION CONTROL AND IN-CORE FOLLOW UP OF 4 LEU LEADER FUEL ELEMENTS BASED ON U_3SI_2 IN RECH-1

J.C. CHAVEZ, M. BARRERA, L. OLIVARES and J. LISBOA
Department of Nuclear Materials
Chilean Nuclear Energy Commission, Amunategui 95, Santiago 6500687 – Chile

ABSTRACT

The RECH-1 MTR reactor has been converted from HEU to MEU (45% enrichment) and the decision to a LEU (20% enrichment) conversion was taken some years ago. This LEU conversion decision involved a local fuel development and fabrication based on U3Si2-Al dispersion fuel, and a fabrication qualification stage that resulted in four fuel elements fully complying with established fabrication standards for this type of fuel. This report presents relevant points of these four leaders fuel elements fabrication, in particular a fuel plate core homogeneity control development. A summary of the intended in core follow-up studies for the leaders fuel elements is also presented here.

1. Introduction

Since1995 a 50 LEU fuel elements fabrication program for the RECH-1 research reactor has been in progress at the Chilean Nuclear Energy Commission, CCHEN. The final goal is the MEU to LEU conversion of this reactor in the year 2001. During the years 1995 up to 1997, the fuel fabrication facility implementation was completed, low enriched metallic uranium and structural materials were acquired, the fuel element design study was finished, and the fuel element fabrication specifications were produced, tested in operational runs, and finally approved [1],[2]. During this period of time the nuclear safety assessment and almost all the licensing of the proposed fabrication process were achieved.

In 1998, and after finishing the licensing process, the LEU U_3Si_2-Al fuel fabrication started with a qualification stage that extended to the required fuel plates for the assembly of 2 fuel elements. This meant a minimum of 32 fuel plates, 28 fuel plates had 3.4 gU/cm^3 density, and 4 had 1.7 gU/cm^3 density. Two fuel elements were fabricated immediately after this qualification stage. These 4 elements were currently called the "leaders" fuel elements, because besides being the first batch of LEU fuel elements ever produced in the country, they were going to be early introduced in the reactor core. They were delivered to the RECH-1 reactor in November 1998, and two fuel elements were introduced in the reactor on December 29, 1998. This early in core irradiation is done in order anticipate the behavior and performance of the standard fuel elements.

This report presents relevant points of these four leaders fuel elements fabrication, in particular a fuel plate core homogeneity control development. A summary of the intended in core follow-up studies for the leaders fuel elements is also presented here.

2. Fuel fabrication

The RECH-1 fuel element has a nominal mass of 214,8 g of U-235, and consists of 16 fuel plates, two side plates, one filter box, and one nozzle (end adapter). The fuel plates have different core densities depending on their relative position in the fuel box: the 2 external plates has a nominal core density of 1.7 Ug/cm^3, and the 14 internal fuel plates has a nominal core density of 3.4 Ug/cm^3. These 16 fuel plates are attached to the side plates by mechanical means (roll swaging); the filter box and nozzle (end adapter) are attached to the fuel box section by welding. A general view of the fuel element is presented in Fig.1.

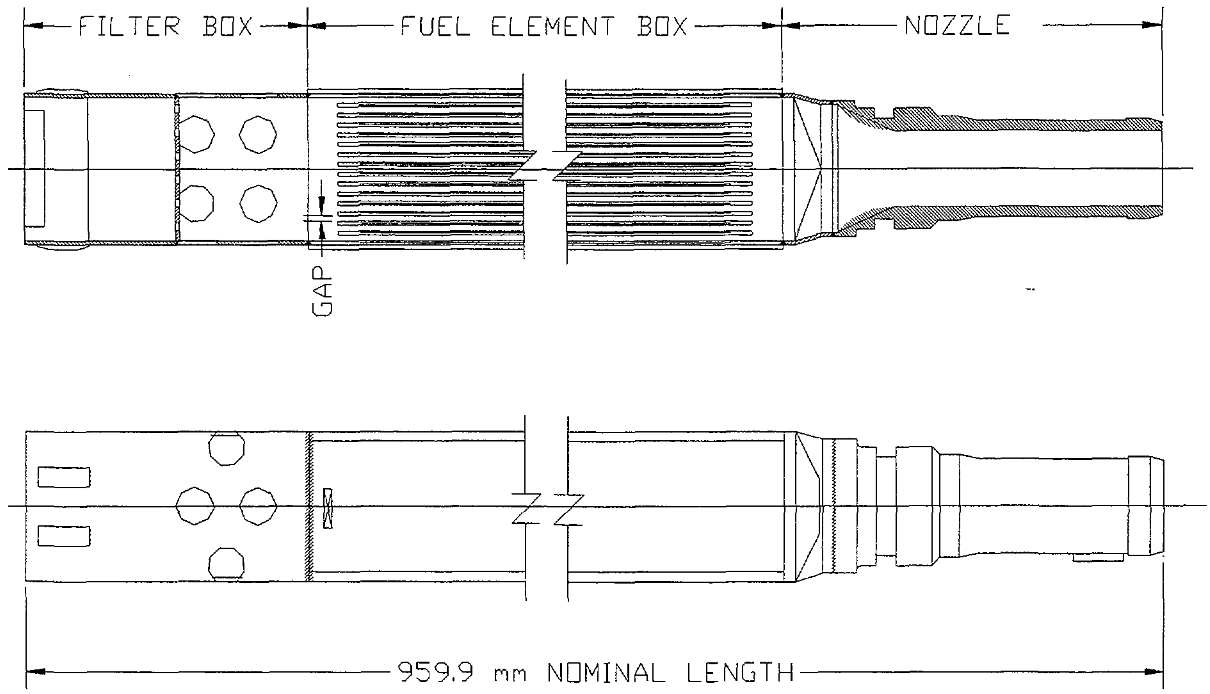

Fig. 1 Sketch of the RECH-1 Fuel Element.

The leaders fuel element fabrication program involved the fabrication of 76 fuel plates. The main results have been previously presented [3], and a summary is presented here.

2.1 U_3Si_2 powder production

The U_3Si_2 powder had a specified particle size range between -150 to +45 μm. The fines allowed were less than 25 % of -45 μm. The U_3Si_2 powder production was carried out in a glove box line (3 glove box units) with a controlled Nitrogen/ Oxygen atmosphere, with and Oxygen content of less than 5%. The chemical analysis results showed a powder complying with the specifications.

2.2. U_3Si_2 – Al compacts fabrication.

The U_3Si_2 - Al compacts were produced in a glove box line (5 glove box units), with a controlled atmosphere similar to one employed for U_3Si_2 powder production. A typical fabrication batch consisted of 7 compacts. The compacts consolidation was accomplished in a floating die with a 200 Tons uniaxial hydraulic press. The compacting pressure was 353 MPa. The compacts were inspected by weight, thickness and surface defects. There were no rejected compacts at this stage of the fabrication.

2.3 Fuel Plates Fabrication.

The established rolling procedure was 86% total reduction and included 84% hot reduction followed by 10 % maximum cold reduction. The blister test extent was 100 % of the plates in hot rolled condition. A bending test and metallographic inspection was applied to test the integrity of the bond obtained, after completion of the hot rolled stage. The test applied showed good bond integrity.

2.4 Plates and cores dimensional controls.

The fuel plates and cores dimensional controls were: length and width of the fuel core, fuel core location, length of the homogeneous and heterogeneous core zones, fuel core homogeneity and out of core defects, and external dimensions of the fuel plate. The dimensional controls applied to all the fabricated plates, and 3 X-ray plates – 2 for core location and 1 for core homogeneity- were obtained from each fabricated fuel plate with a Balteau GFD 208 X ray generator.

Two internal an two external plates were submitted to destructive cladding thickness measurements by cutting rectangular sections of 1.5 cm width x 3 cm length at the positions shown in Fig. 2. After metallographic preparation, the sections were inspected with a Zeiss ICM 405 optical microscope. The results showed an average cladding thickness of 0.46 mm and average core thickness of 0.61mm. The deviations between the expected cladding thickness values and the actual measured values were within ± 0.02 mm. No dog boning was found in the metallographic inspection of the corresponding sections.

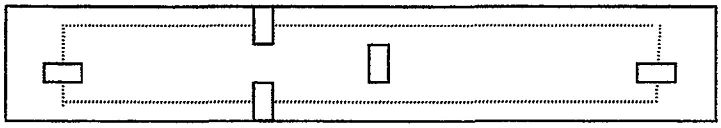

Fig. 2. Sections for the cladding and core thickness measurements.

2.5 Fuel Elements Assembly. -

The fuel element assembly involved the mechanical assembly of the fuel box, and the final joining of the nozzle and filter box to the fuel box by TIG welding. The fuel box was obtained by roll swaging the fuel plates to the box side plates with a nominal 0.8 mm indentation depth. This indentation depth gave an average value of 61 N/mm of swaged joint in pull tests. The gap measurement was done with a special probe provided by NPIC of China. An average value of 3.18 mm was found in these four fuel elements, and the lowest measured value was 2.92 mm.

The TIG welding attachment of the filter box and of the nozzle to the fuel box required anticipating the inherent distortion introduced by this type of joining. A welding device that minimizes the distortion has been implemented and tested. At the same time, a procedure that corrects the welding distortion when needed has been established. These measures made possible to comply with the alignment tolerances, and all the fuel elements have passed this final control

3. Homogeneity control development

The development of the fuel plates homogeneity control has been made employing two methods. One has been densitometric analysis and the other has been image analysis.

3.1 Densitometric analysis.

In the homogeneity radiographic plate, surface density standards (a step wedge) covering from – 30% to +30% of a nominal surface density were used to measure and control the fuel homogeneity in the plates. The standards were prepared from an Al- 30wt% U alloy, as described in the literature[4]. The specified nominal surface densities were 0.2054 Ug/cm^2 and 0.1027 Ug/cm^2 for internal and external plates, respectively. The radiographic evaluation involved the densitometric measurement of 300 points per plate, and a typical result, in graph form, is shown in Fig. 3.

Besides and as a check of the densitometric measurements, disks with a 1 cm^2 area, were punched in internal and external plates at the 4 positions indicated in Fig. 4.

Chemical analysis for total uranium in these disks gave reference values of the surface density at the punched positions. The densitometric results, when compared to the reference values obtained by chemical analysis, showed a positive deviation of less than 4% and 1% for the homogeneous zone of internal and external fuel plates. When the heterogeneous zones were considered the maximum deviations increased to 10% and 5% for internal and external fuel plates. Of all the controlled plates, only one was rejected by homogeneity reasons.

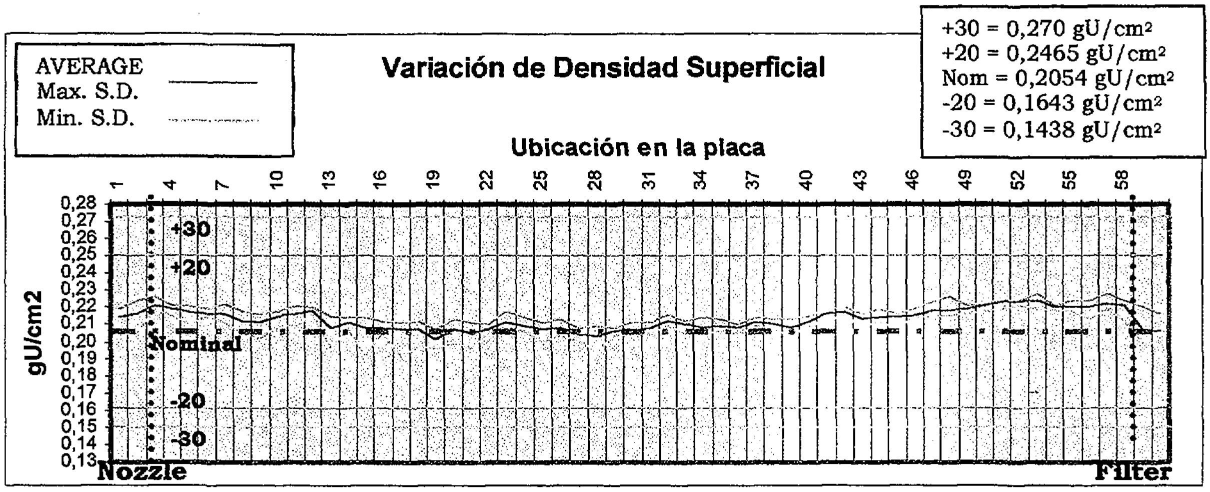

Fig. 3. Surface density graph for an internal fuel plate

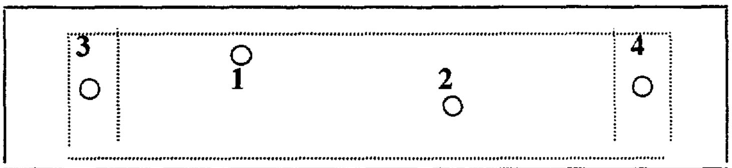

Fig. 4. Punching positions for the surface density measurement.

3.2 Image Analysis.

In this method the homogeneity radiographic plate was scanned, and the image so obtained was analyzed in a PC with a dedicated software program for image analysis [5]. In this method the program analyzes the pixel values of the radiographic plate scanned and a typical result is presented in Fig.5. The image analysis results can be presented as an image (Fig.5B) or as a graph (Fig. 5C).

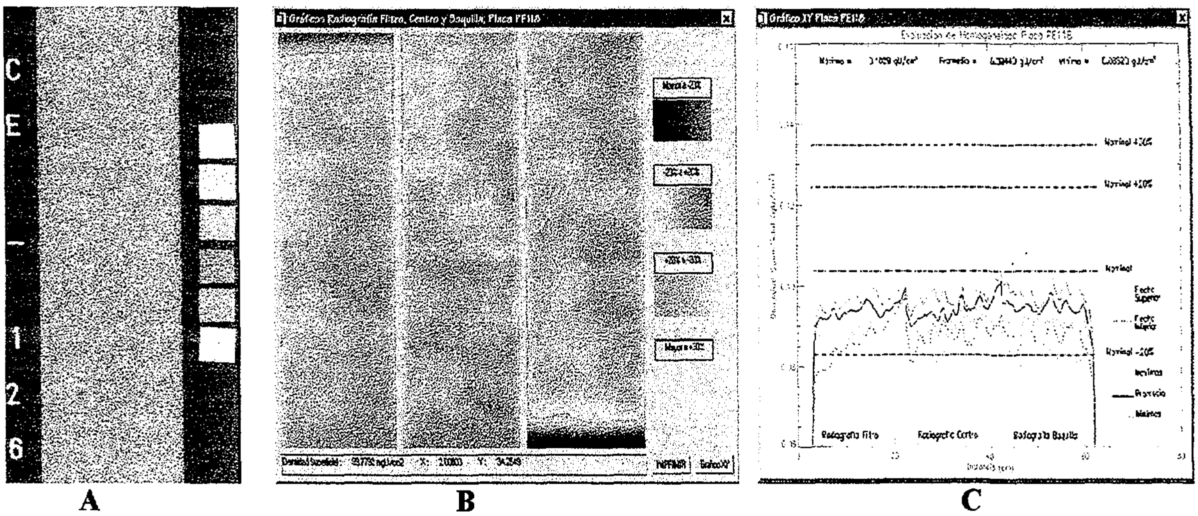

Fig. 5. Homogeneity Image Analysis. A: scanned image,
B: results in image form, C: results in graph form

This method of "image analysis", once properly established and checked, has the advantages of a less time consuming homogeneity evaluation, and that un-homogeneous zones can be easily spotted and evaluated.

4. In-core follow-up.

The main objective of the in-core follow up is to know and register the behavior of the leaders fuel elements under irradiation up to a 50 % burn-up in the RECH-1 reactor. On one hand, this follow up will anticipate in at least 2 years the in pile behavior of the standard fuel elements and on the other hand, from a neutron physics and core calculation stand point, will correlate burn up data from code calculated values to actually measured values. Considering the lack of a PIE facility, the following measures had been taken into account:

- Visual inspection of the fuel elements that will include video and photographic registers.
- Burn up determination: the code calculated burn up will be periodically correlated to experimentally measured burn-up via gamma spectroscopy.
- Instrumentation of one fuel element with thermocouples in order to measure inlet an outlet water temperature.
- Water chemistry monitoring in the reactor pool and a sipping test loop implementation, in order to measure fuel or fission products release from these LEU fuel elements.

5. Conclusions.

- CCHEN's Fuel Fabrication Group has fabricated four LEU U_3Si_2 – Al fuel elements for the RECH-1 reactor. These four leaders fuel elements have complied with internationally adopted fabrication standards.
- The irradiation of these leaders fuel elements sets a starting point for the MEU to LEU fuel conversion of RECH-1 reactor.

6. References.

[1] IAEA – TEC- DOC-467, "Standardizations of specifications and inspection procedures for LEU plate – type research reactor fuels", 1988.

[2] CCHEN EPEC- RECH-1 specification, "Especificaciones para elementos combustibles en base a siliciuro de Uranio de bajo enriquecimiento para el reactor RECH-1 de la CCHEN", May 1997.

[3] H. Contreras et al., " The beginning of the LEU fuel elements manufacturing in the Chilean Commission of Nuclear Energy", Proceedings of the 21st RERTR Meeting, October 18-23,1998, Sao Paulo - Brazil.

[4] T. C. Wiencek, "Summary report on fuel development and miniplate fabrication for the RERTR program, 1978 to 1990", ANL/RERTR/TM-15, August 1995.

[5] IDL Version 5.02. IDL is a ® software of Research Systems, Inc.