THE BEGINNING OF THE LEU FUEL ELEMENTS MANUFACTURING IN THE CHILEAN COMMISSION OF NUCLEAR ENERGY

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ABSTRACT

The U_3Si_2 LEU fuel fabrication program at CCHEN has started with the assembly of four "leaders" fuel elements for the RECH-1 reactor. This activity has involved a stage of fuel plates qualification, to evaluate fabrication procedures and quality controls and quality assurance. The qualification extent was 50% of the fuel plates, equivalent to the number of plates required for the assembly of two fuel elements.

Destructive tests had been used in two random selected plates, with 3.4 and 1.7 gU/cm^3 nominal densities in order to verify the uranium content, surface density and meat and cladding thickness. The chemical analysis of a dissolved compact showed a total uranium content within the specified range of 72.48 g $\pm$ 2%. The results of chemical analysis of 1 cm^2 area disks, punched from critical zones of fuel plates, were compared with the values obtained via standard densitometry measurements of radiographic plates. The average difference was less than 7% and the fuel plates homogeneity was found to be within international standards for this control. Core and cladding thickness results were obtained via metalography and they were within the specified values of 0.61 and 0.46 $\pm$ 0.03 mm. Besides, it was not found "dog boning".

After this plate qualification stage, the fabrication program has proceeded to the assembly of the four leaders fuel elements. They were delivered to the RECH-1 reactor, and soon after a core reconfiguration will be located in the core of the reactor.

1. INTRODUCTION

Since1995 a 50 LEU fuel elements fabrication program for the RECH-1 Chilean research reactor has been in progress at the Chilean Commission of Nuclear Energy, CCHEN. During the years 1995 up to 1997, the fuel fabrication facility implementation was completed, raw materials were acquired, the fuel element design study was finished, and the fuel element fabrication specifications were discussed, tested in operational runs, and finally approved. Besides, the nuclear safety assessment, and almost all the licensing of the proposed fabrication process were achieved [1].

During this present year, after finishing the licensing process, the LEU U_3Si_2-Al fuel fabrication has started with a qualification stage that extended to a minimum of 32 fuel plates. This stage was a demonstration of the fabrication process capability to comply with the established specification [2],[3]. 28 fuel plates had 3.4 gU/cm^3 density, and 4 had 1.7 gU/cm^3 density. These fuel plates made possible the assembly of 2 fuel elements.

Two fuel elements were fabricated immediately after this qualification stage. These 4 elements are currently called the "leaders" fuel elements. The term " leader" in this case means that they are going to be early introduced in the reactor, after a core reconfiguration. These leaders fuel elements, also serves the purpose of studying the in pile irradiation behavior of CCHEN produced silicide fuel elements.

This report presents relevant points of these four leaders fuel elements fabrication.

2. FUEL FABRICATION DESCRIPTION

The RECH-1 fuel element with a nominal mass of 214,8 g of U-235, consists of 16 fuel plates - 14 internal fuel plates with a nominal core density of 3.4 Ug/cm^3, and 2 external fuel plates with a nominal core density of 1.7 Ug/cm^3, two side plates, one filter box, and one nozzle (end adapter). The 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.

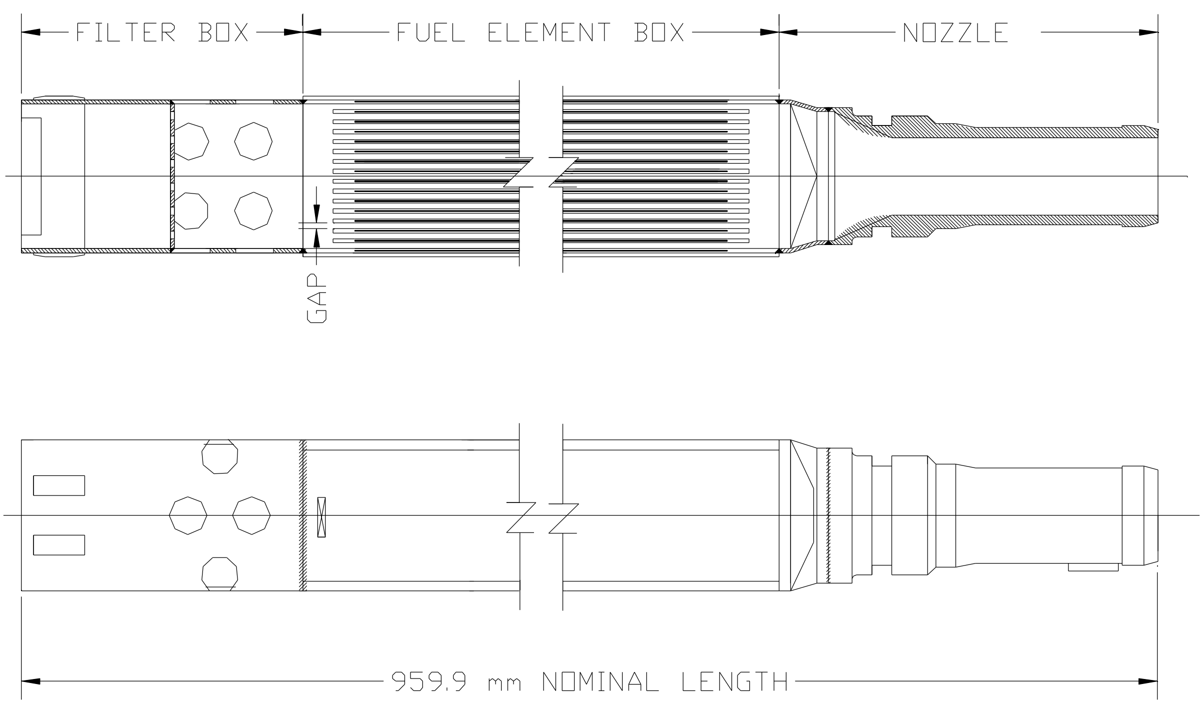

Fig. 1 Sketch of the RECH-1 Fuel Element.

A work program for the 4 leaders fuel elements was established as a preliminary part in the 50 fuel elements fabrication program. This reduced program involved the fabrication of 76 fuel plates, and the main 5 fabrications steps results are presented here.

2.1 U_3Si_2 powder production

The U_3Si_2 synthesis, was carried out in an induction melting furnace under argon atmosphere. The powder was produced in a mill with titanium blades with a final particle size range between -100 to +325 US standard mesh (-150 to +45 μm). The fines allowed were less than 25 % -325 mesh (-45 μm). All the silicide powder production and handling operations were carried out in a glove box line (3 glove box units) with a controlled Nitrogen atmosphere and oxygen content of less than 5%.

A chemical analysis of the silicide powder produced is presented in table 1.

Element	Specification	Actual (ppm)
Al	3200	2701
B	30	< 5
Cd	10	< 5
Co	10	< 2
Cu	80	15.1
Fe / Ni	1000	94
Li	10	< 4
Zn	1000	< 5
C	1000	370
H	200	19
N	500	23
O	7000	1420

Table 1. Chemical Composition of the U_3Si_2 powder.

The relatively high Aluminum content is due to the silicide synthesis that is carried out in high allumina crucibles.

2.2. U_3Si_2 – Al compacts fabrication.

All the U_3Si_2 – Al powders operations were carried out in a glove box line (5 glove box units), with a controlled Nitrogen atmosphere and Oxygen content of less than 5%. A typical fabrication batch involved the handling of powders to produce 7 compacts and finally 7 fuel plates. 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 visual inspection. There were no rejected compacts at this stage of the fabrication.

2.3 Fuel Plates Fabrication.

The fuel plates were produced with an established 86% total reduction rolling procedure that included 84% hot reduction followed by 8 % maximum cold reduction. No blisters were found in the plates and the blister test extent was 100 % of the plates in hot rolled condition. Besides, a bending test and metallographic examination was applied to test the integrity of the bond obtained, after completion of the hot rolled stage. Visual and microscopic examination showed good bond integrity.

2.4 Plates and cores dimensional controls.

The dimensional controls applied to the fuel plates and cores were the following:

Fuel core controls applied to location and homogeneity X-ray core plates.

- Length and width of the fuel core.
- Fuel core location
- Homogeneous and heterogeneous core zones lengths.
- Fuel core homogeneity and out of core defects.

Fuel Plates dimensional controls applied to all the fabricated plates, and core cladding thickness destructive tests were applied to 2 internal and 2 external plates.

2.5 Fuel Elements Assembly. -

2.5.1 Fuel Box.

As stated previously, this step involved a roll swaging operation with a typical 0.8 mm indentation depth of the roll swaging tool in the side plates of the fuel box[1]. A pull test specimen was prepared during this operation resulting in an average test value of 61 N/mm of swaged joint.

The gap measurement was done with a special probe provided by NPIC of China. The probe delivered 168 discrete point measurements in every measured channel. At the same time had the capability to give the location of particular points in the channel. An average value of 3.18 mm was found in these four fuel elements, and the lowest measured value was 2.92 mm, i.e. the specified minimum.

2.5.2 Final welding assembly of the Fuel Element

This assembly involves the attachment of the filter box and of the nozzle to the fuel box by TIG welding. A tight dimensional tolerance in the alignment of these components after welding, requires to anticipate 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 together with metrology controls -made with a coordinate measuring machine- have made possible to easily comply with the alignment specified by a containment gage. This gage, actually a virtual gage with a 76x76 mm cross section created by a metrology software, is applied to the full length of the welded fuel element and all the fuel elements have passed this virtual containment gage.

3. QUALIFICATION CONTROLS

In these leaders elements fabrication program, besides the established standard controls, the following controls were included:

3.1 Uranium content analysis.

By standard chemical analysis techniques a random selected compact from the fabrication of internal plates, was dissolved and its total uranium content was measured. This content resulted in 71.596 ± 0.056 g, well within a specified content of 72.48 g ± 2%.

3.2 Core and cladding covers thicknesses

The core and cladding covers thicknesses were measured in an internal and in an external plate via a metallographic study. Rectangular sections of 1.5 cm width x 3 cm length were cut at the positions shown in Fig. 2. After mounting, polishing and etching, the sections were inspected with a Zeiss ICM 405 optical microscope.

An average measured value of 0.46 mm was found for the cladding thickness, and the average value for the core thickness was 0.61 mm. The deviations between the expected cladding thickness values and the actual measured values were within ± 0.02 mm. No dog bonning was found in the metallographic inspection of the corresponding sections.

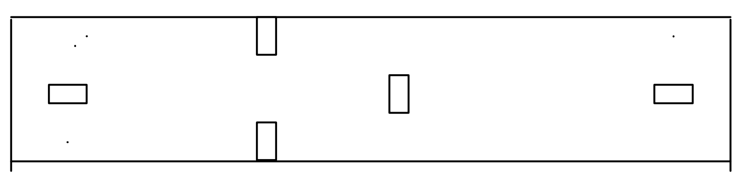

Fig. 2. Sections for the cladding and core thickness measurements

3.3 Homogeneity analysis.

Disks with a 1 cm^2 area, were punched in an internal and in an external plate at the positions indicated in Fig. 3. Chemical analysis for total uranium in these disks gave reference values of the surface density at the punched positions. Besides, in the homogeneity radiographic plate, surface density standards (a step wedge) covering from – 30% to +30% of a nominal surface density were used, as a secondary method, to measure and control the fuel homogeneity in the plates. The standards were prepared from an Al- 30wt% U alloy, as previously 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 the results, in graph form, are shown in Fig. 4 and 5. These 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. Punching positions for the surface density measurement.

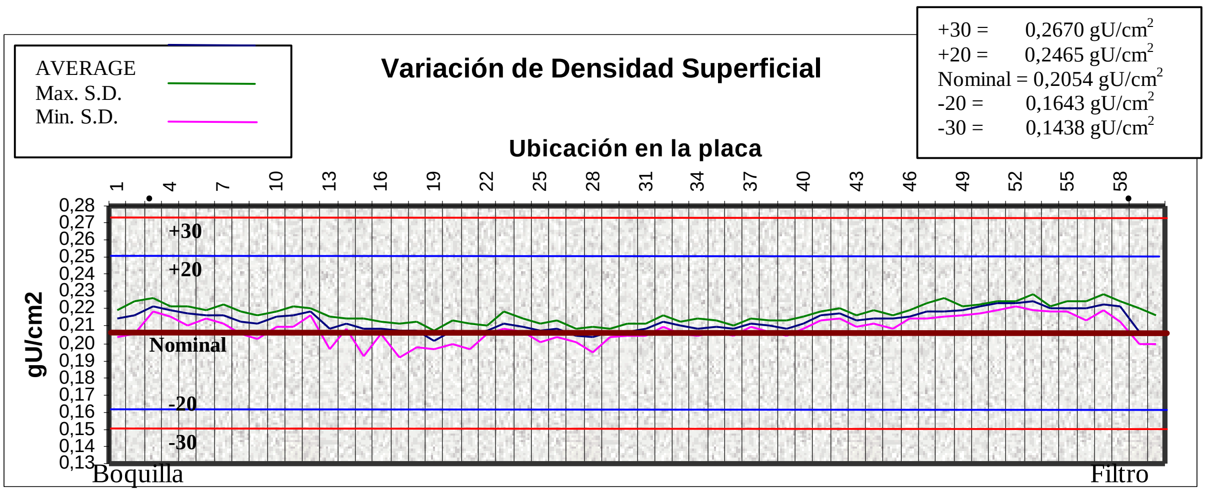

Fig. 4. Surface density graph for an internal fuel plate.

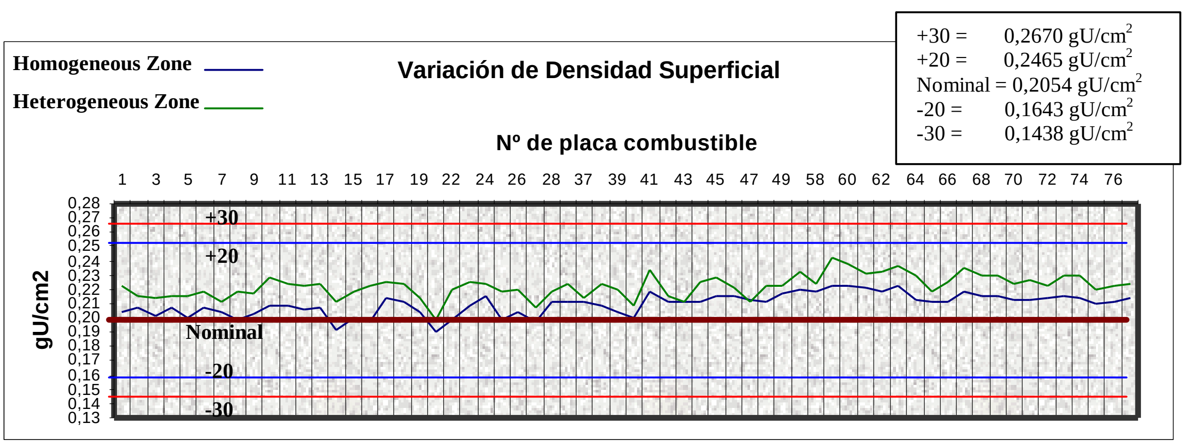

Fig. 5. Surface density graph for the fabricated fuel plates.

4. CONCLUSIONS.-

The main conclusions, at this stage of CCHEN's LEU fuel conversion and development efforts are the following:

- 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, and they are ready to initiate the MEU to LEU fuel conversion at the RECH-1 reactor.
- This fabrication sets the starting point of the first serious and sustained effort to fabricate LEU fuel in the country.

5. ACKNOWLEDGEMENTS.

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6. REFERENCES.-

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