RECH-1 TEST FUEL IRRADIATION
STATUS REPORT

J. Marin, J. Lisboa, L. Olivares, J. Chavez
Department of Materials
Comision Chilena de Energia Nuclear, CCHEN, Amunategui 95, 6500687 Santiago – Chile

ABSTRACT

Since May 2003, one RECH-1 fuel element has been submitted to irradiation at the HFR-Petten, Holland. By November 2004 the irradiation has achieved its pursued goal of 55% burn up. This irradiation qualification service will finish in the year 2005 with PIE tests, as established in a contractual agreement between the IAEA, NRG, and CCHEN.
This report presents the objectives and the current results of this fuel qualification under irradiation. Besides, a brief description of CHI/4/021, IAEA's Technical Cooperation Project that has supported this irradiation test, is also presented here.

1. Introduction

Chile's RECH-1 reactor, a 5 MW open pool reactor, has been in operation since 1974, and in 1985 was converted from HEU (80% enrichment) to LEU (45% enrichment) fuel. In 1995 a LEU U_3Si_2 -Al fuel fabrication program started with the licensing and implementation stage of the fuel fabrication plant. A local qualification stage followed in 1998 that resulted in the fabrication of four fuel elements. They were introduced in the RECH1 reactor core, two in December 1998 and two in July 1999, as "leader" LEU fuel elements. Since 1999 the standard fuel fabrication has been in progress, resulting in 47 fuel elements delivered to the reactor by November 2004, and two modified fuel element are expected for 2005, after approval of some design modifications by the Chilean Regulatory Board.

At the very beginning of the local qualification, it was realized that the time required for this qualification was going to be longer than the fabrication stage and, in order to advance the RECH-1 LEU fuel conversion, an external qualification was required. This report presents the current results of the irradiation test started in May 2003, and a description of IAEA's CHI/4/021 technical cooperation project that has made this irradiation possible.

2. Irradiation Objective

The objective of the irradiation test and subsequent PIE is to provide the experimental evidence needed to qualify the RECH-1 test fuel element fabricator, i.e. CCHEN's Planta de Elementos Combustibles-PEC, as a manufacturer of LEU fuel elements for research reactors. This qualification should be achieved when it can be demonstrated that, throughout their entire utilisation period at full nuclear and thermal load conditions, the element:

- Has shown rigidity enough to withstand the mechanical and hydraulic forces associated with normal handling and irradiation;
- Has been resistant to local or general deterioration by normal corrosion (scaling, pitting and cracking) of the fuel plate cladding;
- Has not released either fuel or fission products to the reactor coolant;
- Has not deformed due to swelling, blistering or other irradiation or temperature induced mechanisms, to such an extent that the minimum cooling channel dimensions required for safe heat removal cannot be maintained;

- Has not deformed (twisting, bowing, etc.) due to swelling, differential thermal expansion, hydraulic forces, etc. to such an extent that the proper fitting of the elements in the core grid structure cannot be maintained;
- Has not reached abnormal fuel or cladding temperature levels, so that the mechanical properties required for proper fuel plate strength and rigidity cannot be maintained;
- Can finally be handled, stored and, after a reasonable decay period, transported to hot cell laboratories without deformation, fission product release or other defects.

The irradiation test program has addressed and will address all the above listed qualification requirements and will further include all necessary measurements and analyses to determine the conditions at which the test irradiation has been carried out. The execution of the irradiation and subsequent Post Irradiation Examination (PIE) is dedicated to NRG, Petten, under a contractual agreement between IAEA, NRG and CCHEN. The irradiation test name is "CHIP" an acronym for **CH**ilean **I**rradiation **P**roject and the HFR project code is TP349.

3. RECH- 1 Test Fuel Element

The design of the RECH-1 test fuel element (LCC01) is based on drawings supplied by NRG, together with an agreed specification[1]. This RECH-1 test fuel element has been designed and manufactured according to the basic specifications of the current HFR LEU fuel elements. The main characteristics of the RECH-1 test fuel element, as compared with the standard HFR fuel element, are presented in Table 1.

Table 1. Main characteristic of RECH-1 (LEU) vs Standard HFR(HEU)

Characteristic	RECH-1 (LEU)	HFR (HEU)
Element identification code	LCC01	-
Manufacturer	CCHEN's (Chile)	CERCA (France)
Number of fuel plates	16	23
^{Tot}U [g]	1159.7	483.87
^{235}U mass [g]	229.1	450
Enrichment [%]	19.75	93
Burnable poison [g]	Not applicable	1.0 (^{10}B)
Upper inlet section	Open, square area	Cylindrical piece
Fuel matrix	U_3Si_2-Al	UAl_x-Al
U-density [g.cc^{-1}]	3.4	1.2
Fuel volume fraction [%]	32	20
Porosity [%]	3	< 5
Meat thickness [mm]	0.61	0.51
Plate thickness [mm]	1.53	1.27
Coolant gap [mm]	2.46	2.18
Total heat transfer surface [m^2]	1.26	1.74
Total coolant cross section [cm^2]	27.18	33.5

Figure 1 shows horizontal cross sections of the RECH-1 LEU and the HFR HEU element, while in Figure 2, an overall view of the RECH-1 test fuel element is given.

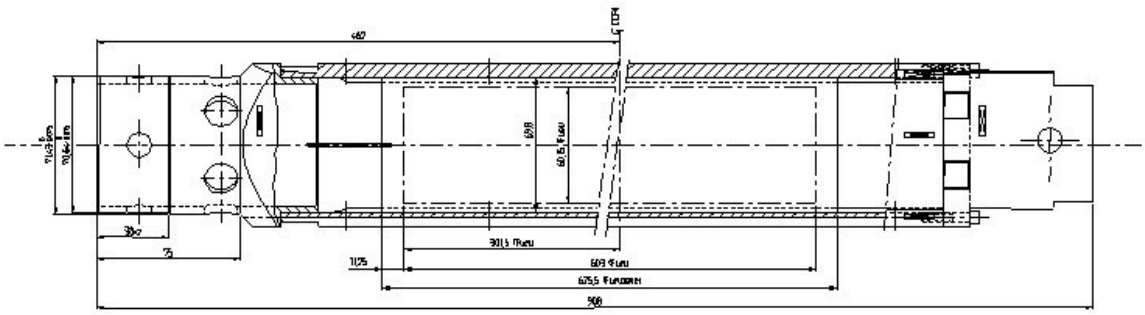

Fig 1. RECH-1 LEU test fuel

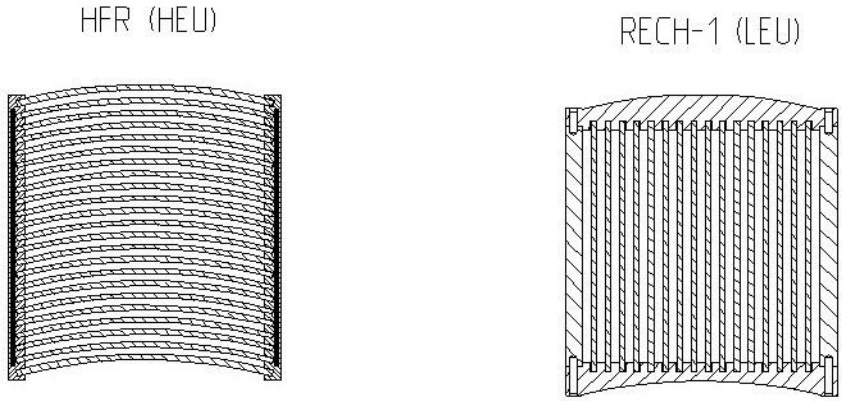

Fig 2. Horizontal cross sections

As stipulated in the contractual agreement between CCHEN, NRG and IAEA, prior to the delivery by the Chilean side and acceptance by NRG of the LCC01 LEU fuel element, a qualified inspector of NRG visited the fuel production plant (PEC) in Chile, and performed the following qualification steps:

- Qualification of the fuel plate and fuel element production, inspection and equipment procedures, including fabrication control and testing procedures. The inspection results of this qualification step were reported[2];
- Qualification of the actually produced fuel plates, including the corresponding QA reports [3];
- Qualification of the actually produced LCC01 fuel element, including the corresponding QA reports [4].

After these qualification steps the LCC01 fuel element was accepted by NRG in November 2002, but only in March 2003 its transport to the HFR- Petten was possible, after solving problems related to international transport licenses, and air cargo bureaucracy.

4. Irradiation Test

During the irradiation only off-line measurements, like visual inspection and coolant gap measurements have been performed. Prior to the start, a hydraulic test of the RECH-1 test fuel

element was carried out to verify, qualify and compare the hydraulic behaviour of the RECH-1 test fuel element with reference measurements of standard HFR fuel element.

4.1 Irradiation Program

The irradiation started in cycle 2003-05, May 2003. Initially, the element would be irradiated in the HFR up to a burn up of at least 55 % ^{235}U. This initial target burn up was achieved in almost 13 HFR cycles, prior to cycle 2004-06, about 58% according to the calculation of HFR code "HFR-TEDDI". Due to possible uncertainties in the neutronics computations, the in-pile test of the RECH-1 test fuel element has continued until a calculated HFR-TEDDI burn up of approximately 65 % ^{235}U. This means that the irradiation program has extended up until approximately 18 HFR cycles, finally ending in November 2004.
The RECH-1 test fuel element has been irradiated in HFR position H7 (or equivalent position H3) throughout the entire testing period. Figure 3 shows the irradiation positions in the HFR.

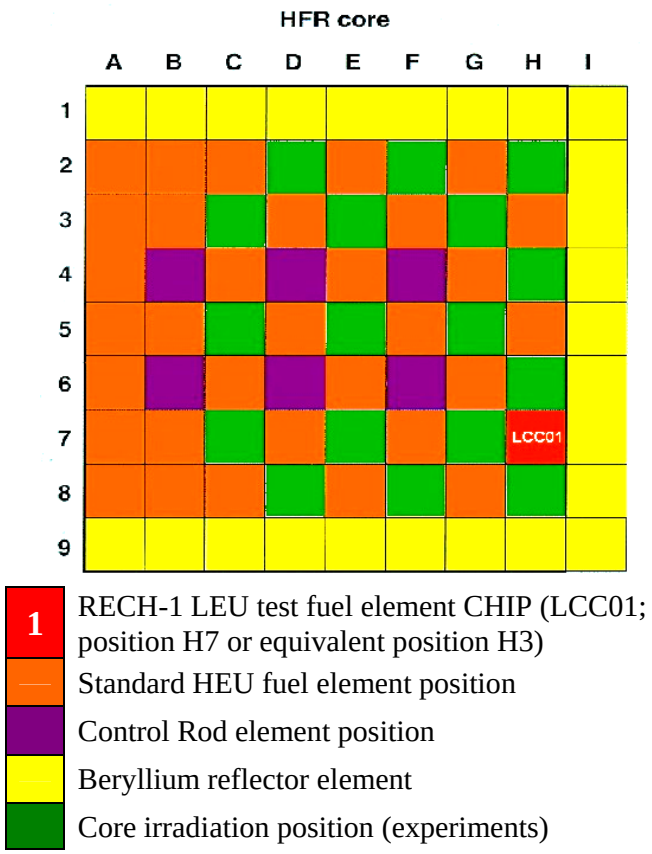

Fig. 3. HFR core irradiation positions including RECH-1 test fuel element (H7 or H3 equivalent position)

Figure 4, presents a view from above the HFR core, and shows the core loading pattern at the start of irradiation cycle 2003-05. The RECH-1 test fuel element position is clearly identified.

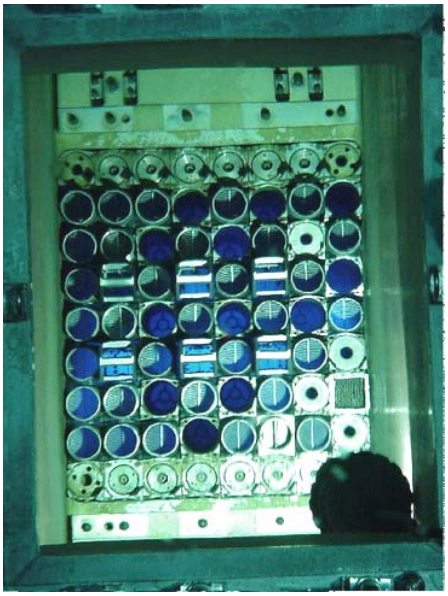

Fig. 4. HFR core loading pattern at the start of cycle 2003-05

4.2 Hydraulic Test.

Prior to the irradiation start, on 8-10 April 2003 and on 14-15 April 2003, the LCC01 fuel element was submitted to hydraulic tests. The test objective was to verify, qualify and compare the hydraulic behaviour of different fuel elements at a hydraulic out-of-pile test loop available at the HFR-Petten. In this particular test the reference measurement was made against element F1466, a standard HFR HEU element. Moreover, the measured experimental values were compared to RELAP5 expected values [5]. Figure 5 presents the hydraulic resistance data for both series of measurements [6].

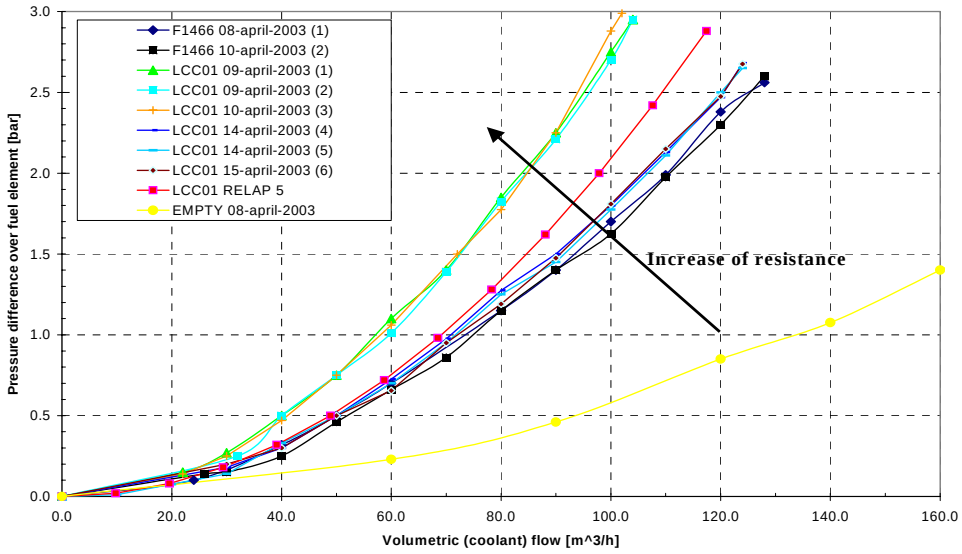

Fig. 5. Hydraulic Test data.

4.3 Visual Inspection

The LCC01 fuel element was inspected visually prior to the first cycle and after cycles 1,3,5,7,9,11,13,14,15,16,17 and 18. If deviations had been detected, then the irradiation would have been suspended until an approval from the Reactor Manager and the Petten Reactor Safety Committee had been obtained. Fig. 6 shows two pictures obtained at these visual inspections.

Fig. 6. Visual inspections

4.4 Gap Measurement

Cooling channel gap measurements, by means of a calliper, have been carried out at regular intervals throughout the irradiation time. At distinct cycles, the coolant gaps have been checked with a specially designed calliper with an upper dimensional limit of 2.15 mm corresponding to the lower limit of the coolant gap. This coolant gap (go- no go) measurement has been done on 5 gaps (arbitrarily) after every other cycle (1,3,5,7,9,11 and 13), and during the supplementary irradiation after each cycle (14 to 18). Prior to irradiation all the gaps were measured. The lower limit of the coolant gap is based on maximum plate-thickness tolerance and maximum swelling behaviour for U_3Si_2- Al fuels [7]. The coolant gap measurements of the RECH-1 test fuel element have shown no deviations from the initial values, so far [8]. Fig 7 shows a picture of this gap measurement.

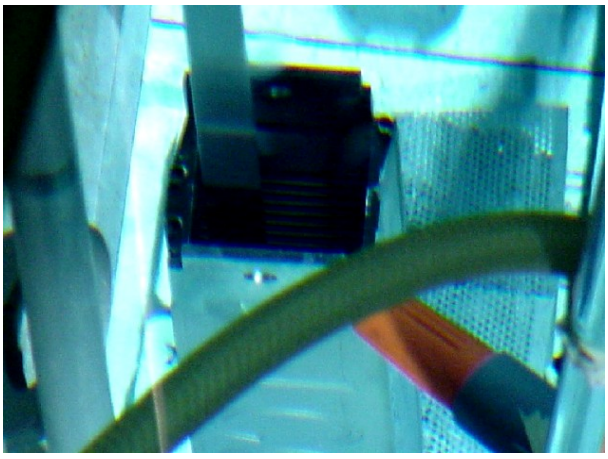

Fig. 7. Cooling channel gap measurement.

4.5 Burnup calculations.

Using the HFR core management code, HFR-TEDDI, the total calculated burnup after 13 cycles was ≈ 58 % ^{235}U [9]. But considering that the operational experience has indicated that this code tends to overestimate the burnup by a maximum of 10 % [10], the adapted/corrected calculated burnup is about 52 %, as shown in Figure 8.

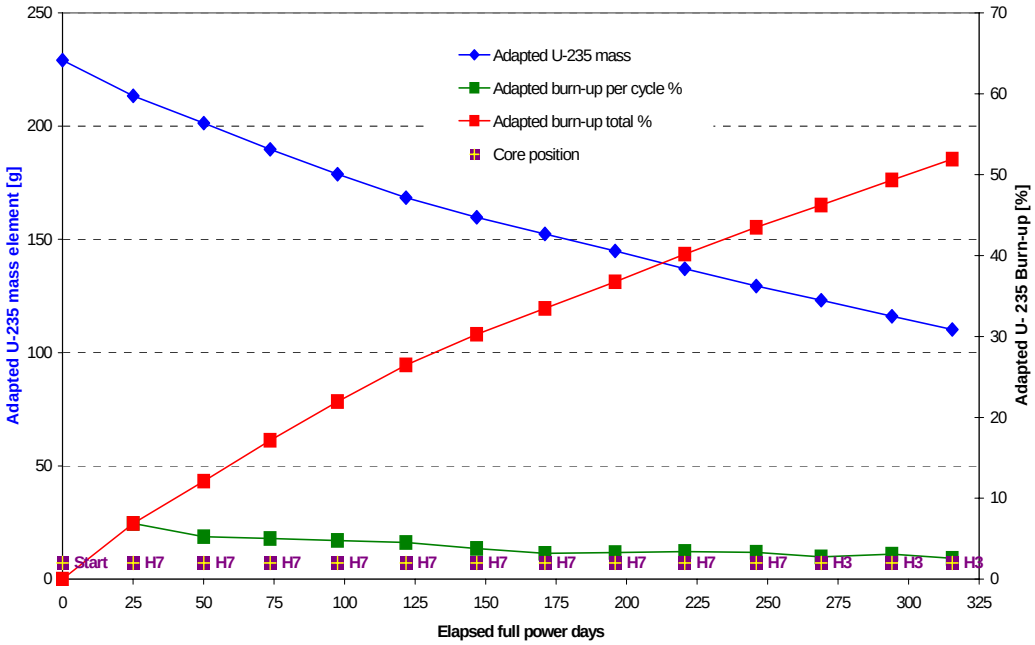

Fig. 8. Adapted burnup of ^{235}U of the RECH-1 test fuel element "CHIP" after 13 cycles.

Since irradiation Cycle 03/2004, the RECH-1 test fuel element has been irradiated in core position H3. This core position is symmetrical with regard to H7 position, flux levels are identical in both positions, and will result in a more homogeneous burnup of ^{235}U in the entire element. Considering the centre of the core, the element has been irradiated slightly more from the north at position H7 and slightly more from the south when at position H3.

At the end of irradiation cycle 2004-10, November 2004, on completion of 18 irradiation cycles, the RECH-1 test fuel element average burnup approaches the extended target burnup level of 65 % ^{235}U. So far the irradiation has been successful and no deviations from the initial values have been observed during the periodic coolant gap measurements. When the irradiation program finishes, the RECH-1 test fuel element with regard to in-pool cooling requirements and transport decay heat generation, will be submitted to the same limitations applied to standard HFR fuel elements. This implies that for the ≈ 65% burnup element, a cooling time of 6 months must be observed prior transport to the hot cells laboratories (HCL).

4 PIE Tests

After dry transport to the HCL, the irradiated RECH-1 fuel element will be submitted to significant PIE. This PIE, considering that the U_3Si_2 used in this fuel element is an internationally qualified and licensed type of fuel [10], consists of:

- Visual Inspection of the complete fuel element;
- Gamma scanning of the assembled fuel element;
- Visual inspection of one removed plate;
- Gamma spectrometry on the removed plate (3 axial lines)
- Thickness measurement on the removed plate (1 axial scan)
- Oxide layer thickness measurement on the removed plate on ten (10) positions of the fuel plate.

5 TCP CHI/4/021

By the year 2000, the fabrication program in progress pointed out two main issues in which optimization was possible and needed:

- Fabrication issues: mainly related to QC issues where implementation and training in ultrasonic and gamma scanning were needed to improve the controls and measurements for the metallurgical bond and the U^{235} content in the fuel plates, respectively.

- Qualification Issues: the current operation of the RECH-1 reactor indicated that 55% burn up would be achieved by the year 2008 at best.

These issues had been addressed and solved through the presentation in 2000, approval in 2001 and implementation during 2002 until 2004, by means of a technical cooperation project supported by IAEA, Project CHI/4/021. This technical cooperation project has made it possible for CCHEN's Fuel Fabrication Plant – PEC, to solve the issues indicated above through the following actions:

- Implementation at the fuel fabrication plant of the ultrasonic and Gamma scanning tests for fuel plate's fabrication; equipment received at the plant site in November 2003;
- Scientific visits and training for technical personnel directly involved in the above mentioned techniques from 2002 to 2004;
- What's more, it has made a contract possible (2001-937) between IAEA, Nuclear Research and Consultancy Group (NRG), and CCHEN, concerning the irradiation and post-irradiation tests for qualification purposes of a fuel element fabricated in Chile, LCC01. This contract was signed in November 2001, and the development of the on-going activities involved in this contract has been presented in this report.

The irradiation at the HFR-Petten, experiment TP 349 CHIP has recently ended. The only pending activity in this TC Project is the PIE that will soon proceed, after a decay period of 6 months for the irradiated LCC01 fuel element.

6 Conclusions

The conclusion at this stage of the RECH-1 test fuel qualification is that the successful irradiation results enhance CCHEN's expectations to qualify its fuel fabrication plant as a manufacturer of LEU fuel elements for research reactors.

7 Acknowledgements

The authors gratefully acknowledge the support provided by IAEA, through the implementation of the technical cooperation project CHI 4/021.

8 References

[1] F.J. Wijtsma, ″ Specification for uranium-silicide CCEN fuel element to be irradiated in the HFR Petten″, 25136/01.44809/I rev. 3, NRG Petten, 7 January 2002.

[2] F.J. Wijtsma, "Review of CCHEN's fuel fabrication capabilities and inspection methodology, Experiment CHIP″, Report 25136/02.47133/I, NRG Petten, May 2002

[3] F.J. Wijtsma, ″Inspection of LEU fuel plates and related documents. Experiment TP349 CHIP″, Report 25136/02.49079/I, NRG Petten, September 2002.

[4] F.J. Wijtsma, ″Inspection and transport preparation of fuel element LCC01 LEU fuel. Experiment TP349 CHIP″, Report 25136/02.50464/I, NRG Petten, November 2002.

[5] M.M Stempniewics, "RELAP5 Analyses of CHIP Fuel",Note 20785/02.52132 PPT/MSt, NRG Arnhem, May 2002.

[6] M.A.C. van Kranenburg, "RECH-1 Test Fuel Element Irradiation Experiment TP349 CHIP; Design and Safety Report", Report 25138/02.47726/I, Rev. D July 2004 Petten.

[7] J. Riesle (CCHEN), email with an attachment (3 pages) of the fuel swelling behaviour, March 2002.

[8] M.A.C. van Kranenburg, "RECH-1 Test Fuel Element "CHIP"Intermediate Irradiation Report", Report 25138/04.60852/I, July 2004 Petten.

[9] C.M. Sciolla, ″HFR TEDDI Post Cycle Output Cycle 2004-05″, 25138/04.60375/I, June 2004 Petten.

[10] J.A. Hendriks; "Nauwkeurigheid burnupberekeningen HFR-TEDDI t.b.v. LCC01/CHIP", Note 25138/04.60854 IS-HFR/JAH/LE, July 14 2004, Petten

[11] IAEA-TEC-DOC/467 "STANDARDSITION OF SPECIFICATIONS AND INSPECTION PROCEDURES FOR LEU PLATE TYPE RESEARCH REACTOR FUELS", June 1988