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MAIN ASPECTS OF THE SEU FUEL PROGRAM AT THE ATUCHA I PHWR AFTER FIVE YEARS OF OPERATING EXPERIENCE

J. M. FINK, M. HIGA, R. PÉREZ, J. PIÑEYRO, J. SIDELNIK, J. A. CASARIO (*),
L. ALVAREZ (*)

Nucleoeléctrica Argentina S.A. Buenos Aires. Argentina.

(*) Comisión Nacional de Energía Atómica. Buenos Aires. Argentina.

Abstract

Atucha I is the first nuclear station in Argentina and started operation in 1974. It is a pressure vessel type reactor, moderated and cooled with heavy water, and was designed by Siemens (Germany). Fuelling is on-power and the plant was originally fuelled with natural uranium.

To reduce fuel costs a program was initiated in August 1993 to introduce gradually slightly enriched uranium (SEU) fuel (0.85 w% U235) with an associated burnup increase from 5900 MWd/tU to 11300 MWd/tU. The introduction of SEU fuel started in January 1995 and the program was divided in three Phases with an upper limit of SEU FA in the core: 12, 60 and 252 (full core). This paper describes the most important aspects of the project and the operating experience in the period 1995-1999.

After five years of the program and with 86% of core positions (217 FA) loaded with SEU fuel, the operating experience has been fairly good. In particular, the new criteria to prevent PCI failures in power ramps for higher burnup SEU fuel in refueling operations, plant startups or power cycling has been effective. The average discharge burnup of the SEU fuel that completed their irradiation in 1999 was 11346 MWd/tU. The average discharge burnup of the natural fuel in the same year was 6549 MWd/tU, with an increase of about 11% of the original value for a natural fuel core. The average number of fresh fuel assemblies per full power day was being reduced from 1.31 to 0.92 in 1998 and 0.86 in 1999. The fuel costs dropped gradually during the program from 9.38 (with natural uranium fuel) to 6.81 U$S/MWh in 1999 (taking as reference the NU and SEU FA costs for 1998 and 1999). Because of this the SEU fuel program has been an important contribution to the reduction of Atucha I operating costs and to the improvement of the competitiveness of nuclear power generation against other sources of generation in the deregulated electrical market in Argentina.

The use of SEU fuel also produced a small increase of the time to reach full power in plant startups or power cycling, and some increase to the susceptibility to axial xenon induced power oscillations.

It is planned to explore in the future the technical feasibility and economical convenience to start an SEU fuel irradiation program in the Embalse Nuclear Station.

INTRODUCTION

Atucha I is a 357 MWe (gross) nuclear station, pressure vessel type designed by Siemens (Germany), moderated and cooled with heavy water, located 120 km NW of Buenos Aires. Fuel assemblies (FA) are 36 active rod vertical clusters, originally with natural UO_2 (NU), 5.3 meters long

Fuelling is on power. Average FA discharge burnup for NU fuel was ≈ 5900 MWd/tU and maximum rod burnup (m.r.b) ≈ 8400 MWd/tU. With the objective of reducing the fuel costs a program of utilization of slightly enriched uranium (SEU) (0.85 w% U235) fuel was initiated in 1993 and the introduction of SEU fuel started at the beginning of 1995. A factor acting as a driving force for the program was the deregulation of the electricity production in Argentina, that started in 1992 and introduced more pressure to reduce operating costs.

The introduction of SEU fuel was gradual and the Project was divided in different Phases. At the present time 217 fuel channels (86 % of the core) are loaded with SEU fuel and, since the end of December 99, only SEU fuel is introduced in the reactor. It is expected to reach a full SEU core by the end of the year.

This paper presents a general description of the Atucha I SEU Project activities and the operation experience for the five years of the program.

BRIEF DESCRIPTION OF THE ATUCHA-I REACTOR

Atucha I is the first nuclear station in Argentina and started operation in 1974. It has a gross electrical power of 357 MW and a thermal power of 1179 MW. The reactor core has 252 vertical coolant channels, which contain the FA and separate the coolant from the moderator. The average coolant temperature is 280°C and the average moderator temperature is 200°C. A section of the core can be seen in figure 1.

Power regulation is made through six absorber rods, three made of hafnium, usually called black, and three made of steel, called gray. In normal operation the insertion corresponds to an excess reactivity of 6.5 mk. Additional 21 hafnium rods are used for shutdown purposes. Power measurements for the regulation are obtained with four out of core compensated ion-chambers.

The fuel movement scheme is radial. For natural uranium the core was divided in three approximately concentric annular regions (see figure 1). The fresh fuel is introduced in the intermediate zone, left there until it reaches ~2700 MWd/tU, later transferred to the central zone until it reaches ~5100 MWd/tU, then moved to the outer zone, from which it is taken out at ~5900 MWd/tU. In some cases the fuel is moved through four positions instead of three to reduce power ramps.

The coolant flow in the fuel channels is reduced from the center to the periphery of the core according to the channel powers, in such a way as to have approximately constant outlet channel temperatures. The temperature increase in the channels at full power is about 35 °C. No coolant boiling is allowed at the channel outlets. To obtain that, there are 8 "hydraulic regions" with different nozzles, numbered 1 to 8, from the periphery to the center. To keep an adequate margin to outlet boiling, channel power limits are defined for each hydraulic region. The reactor has outlet temperature measurements in 28 channels, and 48 in-core vanadium flux detectors give indications of local flux to the operators.

ECONOMIC INCENTIVES FOR USING SEU FUEL IN ATUCHA I

It is well known that in heavy water reactors, initially designed for natural uranium fuel, a slight increase in enrichment from 0.711 w% U235 to values from 0.85 to 1.2 % produces a much larger improvement in fuel discharge burnup and fuel economy. These advantages have been presented in many reports for CANDU type heavy water reactors and also for Siemens pressure vessel type (see for example [2] to [4]). In Germany there was a similar program about 20 years ago with the 50 MWe MZFR (a smaller version of the Atucha I reactor) in which the fuel, originally NU, had a first transition to 0.85 % enrichment and then a further transition to 1 %.

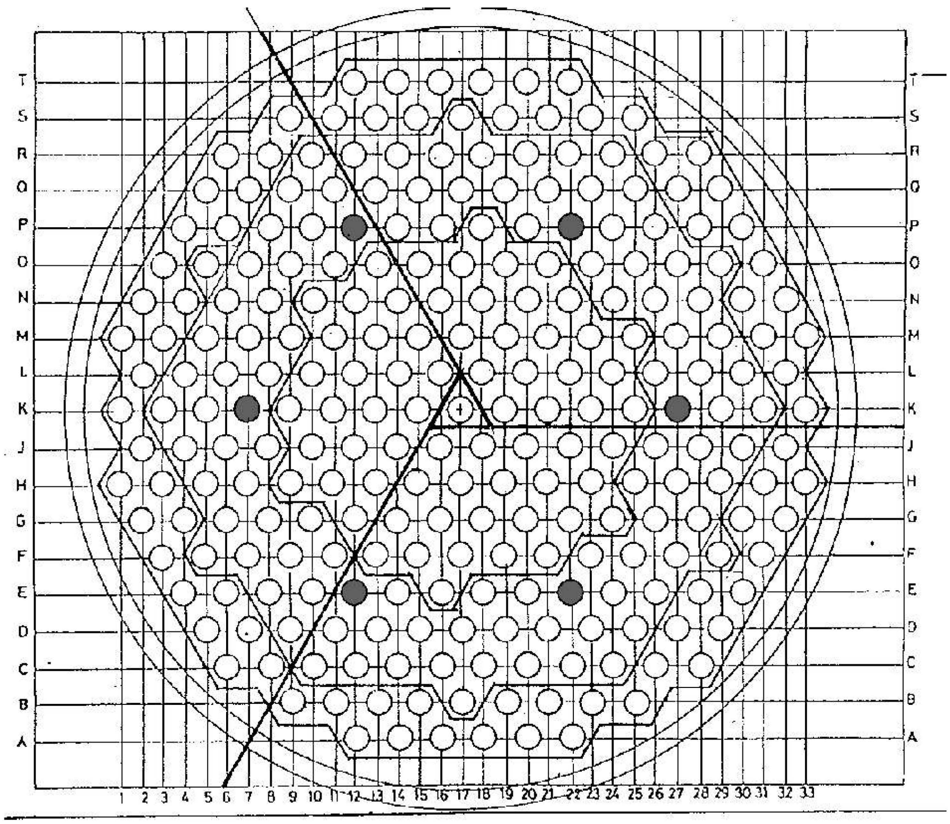

FIGURE 1: Section of the Atucha I core indicating the fuel channels, and the burnup zones for natural uranium fuel. The six channels selected for the introduction of the first fresh SEU FA are also shown

The Atucha-I fuel is manufactured by CONUAR, an Argentine Company and because of the type of design, assembly, dimensions and small production scale its fabrication cost is high compared with CANDU reactors. For that reason any improvement in the extension of the life of the fuel in the reactor has an important economic impact in the unit energy cost.

Basically the main advantages of using SEU fuel (comparing an equilibrium full NU core with an equilibrium full SEU core), are reflected in four areas:

a) An increase of the fuel discharge burnup from 5900 MWd/t U to 11300 MWd/t U

b) A reduction of the new fuel loading requirements from 1.31 to 0.7 FA per full power day (fpd)

c) A fuel cycle cost reduction of about 39 % if the costs for NU and SEU fuel in 1998 and 1999 are taken as a reference.

d) A reduction of the spent fuel volume of about 42 %, which extends the useful life of the spent fuel pools and represent a positive contribution to environment protection.

1.1 Reduction of Fuel Assemblies Required per Year

The reduction of new fuel requirements per fpd with SEU fuel reduces the yearly FA requirement from 430 to 230 (assuming a load factor of 0.9). This also means an important decrease of fueling machine use.

1.2 Reduction in the Unit Energy Cost

The reduction of the number of FA required per year, implies a corresponding decrease in the yearly fuel expenses. With natural uranium fuel, the component of the unit energy cost due to fuel was 9.38 U$S/MWh. Considering these factors the fuel cost when the full SEU equilibrium core is reached is estimated at 5.70 U$S/MWh, a reduction of about 39% (for this cost comparisons 1999 unit FA costs for NU and SEU FA were used).

1.3 Reduction in the Spent Fuel Volume

The reduction in the consumption of FA implies a decrease in the irradiated fuel volume of about 45 %. Although detailed calculations of final spent fuel storage costs have not been done, if a value of 100 U$S/kg U given for CANDU fuel in [5], is used as a lower bound, we obtain estimated minimum annual savings of about 2.8 MU$S are obtained for this concept.

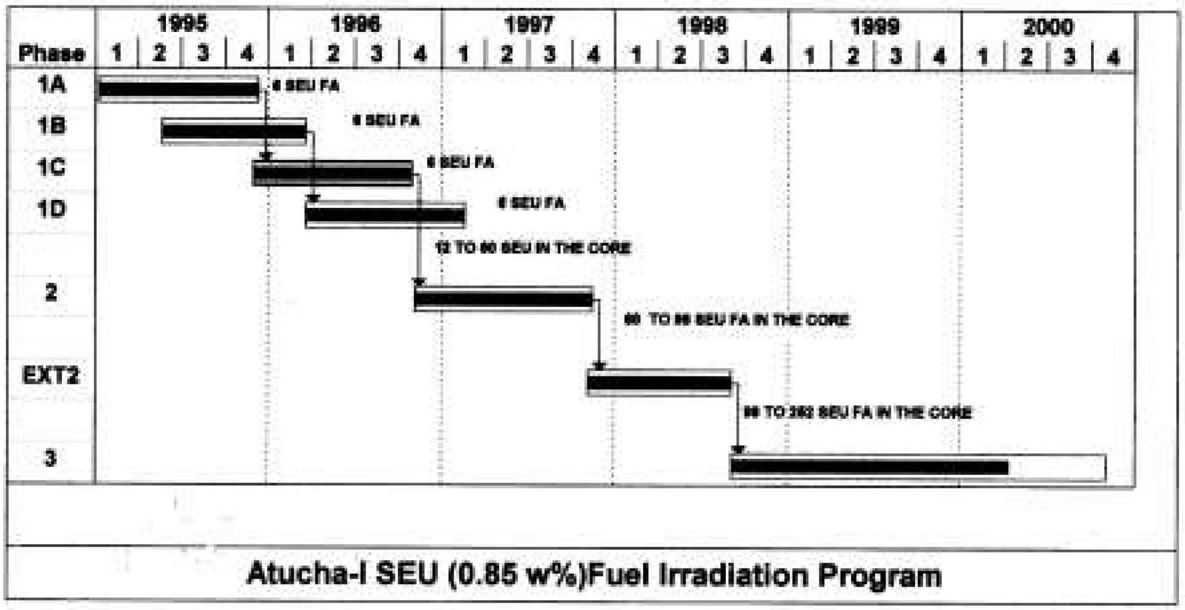

FIGURE 2: Different Phases of the Atucha I SEU Fuel Program

PROGRAM OF INTRODUCTION OF SEU FUEL

Different activities related to the use of SEU fuel, mainly reactor physics and economics calculations, have been carried out in Argentina in the late seventies and eighties without starting a concrete irradiation program. In August 1993, a SEU Project for Atucha I was created. Licensing documentation and authorizations from the Nuclear Regulatory Authority were associated with each Phase. At the beginning of the Project the Quality Assurance Manual and Procedures were prepared, and also a qualified Independent Revision Group was established for the Project. During the rest of 1993 and 1994 the Safety Report for the First Phase was prepared and completed in November 1994.

Phase 1 consisted in the introduction of SEU FA not exceeding twelve at any time in the core. It began in January 1995 and ended in November 1996. The initial average discharge burnup was set at 10000 MWd/tU.

During Phase 1, the fresh SEU FA were introduced in six predetermined channels (shown in figure 1) selected because they have the following convenient features:

- A larger margin to the channel power limits which is important to accommodate the higher power increase when introducing fresh SEU fuel.
- The channel power is relatively high, which reduces the irradiation time, until the FA is transferred to another position.

- They have outlet channel temperature measurements and five out of the six had in-core detectors in the vicinity. Both features allow comparisons with calculations.

The main objectives of the Phase 1 of the irradiation program were:

a)To verify the suitability of the fuel design to the new requirements associated with the higher burnup and residence time, closer to the values expected for equilibrium SEU fuel. In particular, to verify the behavior in power ramps arising in refueling operations, reactor power increases, and reactor startups and power cycles.

b)To verify predictions of neutronic calculations like reactivity gain, channel power increase and detector flux increase when introducing SEU fresh FA.

c)To test operating procedures developed for SEU fuel.

Phase 2 was initially defined as the transition period from 12 to 60 SEU FA in the core, but was later extended to 99. Phase 3, from 100 to full core, was initiated in September 1998 and it is expected to reach the full SEU core by the end of 2000. In Phases 2 and 3 the average discharge burnup of the SEU fuel was increased to 11000 MWd/tU.

The main objectives for Phases 2 and 3 were

d) To verify the performance of the SEU fuel in the core with exit burnups and burnups at which they are moved from one channel to another in the core similar to the corresponding ones for the full SEU core.

e) To verify the global behavior of the core with a larger proportion of SEU fuel

f) To prepare the location of SEU FA in the core for the transition to a full SEU core.

FUEL DESIGN AND PERFORMANCE EVALUATION

The fuel assembly for Atucha-I is a single 36 fuel rod bundle with an overall length of about 6 m. Fuel rods are in a circular array with three concentric rings and one central fuel rod. A structural tube occupies one position in the outer ring. The fuel rods are kept in their positions using Zircaloy solid spacer grids. Fuel claddings are free standing. Bearing pads welded to the outer surface of the sheaths provide the interaction with the spacer grids. Sliding shoes attached to the spacer grids and to the structural tube are used to set the assembly position in the coolant channel. The fuel rods and the supporting tube are hanging from an upper tie plate which is also made of Zircaloy. The bundle fixation at the lower end of the fuel assembly is increased with an additional spring-loaded sliding shoe attached to the lowest spacer grid. It assures proper radial positioning of the bundle end inside the coolant channel even under unfavorable coolant conditions. For neutron economy practically only Zircaloy was used as structural material in the active region. Figure 3 represents a schematic description of the Atucha-I fuel assembly.

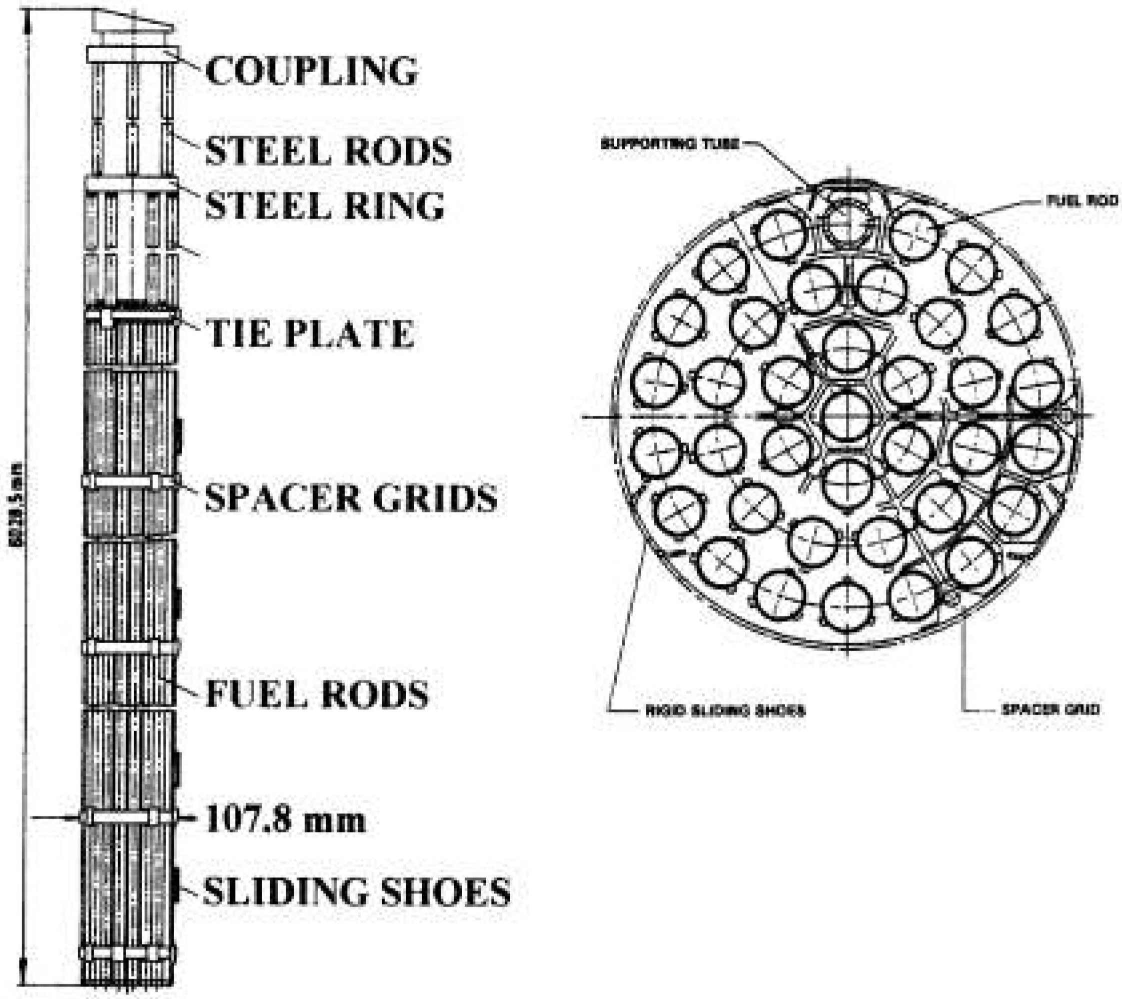

Figure 3: *Schematic description of the Atucha-I fuel assembly*

The internal designs of Atucha-I and LWR fuel rods are very similar. Each Atucha-I fuel rod has a 5300 mm long stack of UO_2 pellets, isolating pellets, a gas plenum and a compression spring. The plenum and the spring are in the upper end of the rod. End plugs are welded by tungsten inert gas (TIG) process. The Zircaloy-4 fuel cladding is free-standing (non-collapsible). Fuel rods are pressurized during manufacturing with helium gas at 17 bar. In the outer surface resistance welded wearing pads reduce the risk for fuel rod defects by fretting, facilitate the assembling procedure and are also used in certain outer fuel rods for the axial positioning of the spacers grids.

The design analysis of the Atucha-I SEU fuel was performed with the aim of satisfying three key considerations:

- Atucha-I fuel performance should not be adversely affected.
- Safety margins for SEU fuel should be kept as close as possible to the margins for natural fuel.
- The reduction of the operational flexibility at the power plant must be as low as possible.

Several changes have been introduced in the design of both, the fuel rod and the fuel assembly to optimize them for SEU requirements:

- The plenum length was increased to provide more volume for gas release.

- Bearing pads with longer contact surfaces were adopted to assure reliable interaction between spacers and fuel rods during the whole life of the fuel.

- The ductility of the cladding material was increased to reduce the fuel rod susceptibility to PCI failures on power ramps.

- Regarding the fuel assembly structural design, Inconel 718 was used to replace the original material for spring-loaded sliding shoes (SS A286) to compensate the higher relaxation produced by the increase in neutron fluence. In addition to its superior spring characteristics Inconel was chosen because of its good resistance against stress relaxation, providing similar safety margin for fuel assembly holding in position that in natural uranium fuel. The effect of this modification on the neutron economy is practically negligible.

SEU fuel performance was evaluated using the following information:

- Data obtained from fuel management calculations, including local linear powers, local burnups, discharge burnup distribution and residence times.

- Visual inspection in a pool-side station of all the discharged SEU fuel assemblies.

- Fuel rod axial growing measurements in some of the irradiated FA.

The irradiation behavior of the structural design was satisfactory. Unacceptable spacer grids movements, rod bowing or fretting wears were not detected.

FUEL MANAGEMENT

The reactor physics studies were done with WIMS-D4 [6], and the 3D diffusion multigroup reactor code PUMA [7], developed in Argentina, and presently used for the fuel management calculations of the Atucha-I and Embalse operating stations.

Fuel management studies were done in two steps. The first step was with "time-average" type calculations for a given fuel movement strategy, which give the burnups at which the fuel is moved from one region to another and the discharge burnup and also provides time averages of the flux and power distributions. They do not give fluctuations due to refueling operations. These types of studies were later completed and confirmed with detailed refueling simulations for 6-12 months which permitted to make final adjustments.

In Phase 1 (up to 12 SEU FA in the core) the situation can be considered as a relatively small perturbation of the natural uranium core, except for the larger channel powers in the six channels where the fresh SEU FA are introduced.

Before the beginning of Phase 2, "time average" studies for configurations with 12, 30, 60 have been completed. A detailed simulation of 1 full power year was done for the transition period from 12 to 60 SEU FA in the core to verify channel and bundle power limits, and that PCI prevention criteria were met.

To develop the fuel movement strategy for the transition and equilibrium core, it was decided not to modify the nozzles that regulate the coolant flow in the channels that were defined for the power distribution of the natural uranium original fuelling strategy, but rather adjust the burnup zones and fuel movement in such a way that channel power limits and PCI prevention criteria could be accomplished.

Later, the efforts were directed to develop the fuel strategy for the full SEU core, first with time average calculations and later confirmed with a detailed simulation of 702 fpd for the transition period from 60 to 252 SEU FA in the core, and continued for the full SEU core up to 803 fpd. This work was done in a very close and fruitful interaction between NASA Headquarters Physics Group and the Fuel Engineers at the plant. In general, the original idea of introducing fresh fuel in intermediate regions, moving them later to central positions and then to the periphery for the last part of the irradiation period was maintained. However in some regions it was found necessary to combine SEU fuel with high and low burnups to avoid local channel power peaking. This fuelling strategy has been applied at the plant during the transition 60 to 217 FA in the core with good results.

These studies confirmed the fuel strategy but provided other results like a) data to estimate the NU and SEU fuel requirements for the following year, which has to be made almost a year in advance. b) Fuel power and burnup histories representative of the transition. c) A decreasing trend of the reactor maximum linear power with the proportion of SEU fuel in the core due to a larger axial flattening of the power distribution.

LICENSING ASPECTS

For the safety studies, complete revisions of the Safety Report (SR) were prepared for each Phase of the Project and were revised by the Independent Revision Group of the Project. Besides, and following the Procedure for Design Changes Related to Safety, they were reviewed by the Internal Safety Committee of Atucha I (that makes recommendations to the Atucha I Manager) and by the Technical Revision Committee (that makes recommendations to the General Manager of NASA) and submitted to the Nuclear Regulatory Authority.

OPERATING EXPERIENCE

1.4 Phase 1

The irradiation of SEU fuel at the plant started in January 9, 1995, with the beginning of the introduction of six SEU FA in the six preselected channels described before, which continued during the rest of the month. During each introduction, relevant operating data like control rod positions, inlet heat transport system temperatures, outlet heat transport temperatures at the six channels, in-core detectors, etc, were collected. Between May and June 1995, the first six FA were moved to the central region of the reactor, and another set of 6 fresh SEU FA was inserted. Between October 30 and December 5 1995 a third group of 6 fresh SEU FA was introduced, and the first group of six taken out from the reactor with an average discharge burnup of about 10000 MWd/tU.

The first SEU fuel assemblies remained in the channel they entered the core until they reached an average burnup of 5500 to 6000 MWd/tU, and were later moved to the central region, were they remained until the average burnup reached ≈ 8000 MWd/tU. From there they were transferred to the outer region until they reached 10000 MWd/tU.

The core reactivity gain when introducing fresh SEU fuel was about 0.7 mk (compared with about 0.35 mk for natural fuel), while the channel power increase was about 15 - 20 % (compared with a very small change for natural fuel).

1.4.1 Comparison between Calculations and Measurements of Relevant Parameters

The data collected was used for comparisons with neutronic calculations, similar to the ones used for design and fuel management using WIMS-D4 and PUMA. In particular, the relative increase in ΔT in the channels with the SEU fuelling was compared to the relative increase of the calculated channel power (Atucha I has no coolant boiling at the outlet of the channels) , and the increase in the vanadium detector readings close to the refueled channels were compared with calculated values. The consistency of the calculated and measured reactivity change due to the SEU refuelling was done comparing the calculated core reactivity before and after the refuelling with the corresponding rod positions in each case, which should be the same. The agreement was good and in most of the cases within the uncertainty of the measurement errors.

1.4.2 Fuel Performance

The performance of the 18 SEU FA during the irradiation period was good, without any indication of failures.

After the first 6 SEU FA that completed their cycle were taken out of the core, examinations and measurements were performed showing no abnormalities and that the elongation of the fuel rods was within the expectations considering the larger fuel burnup and residence time.

1.5 Present Operating Experience (Phases 2 and 3)

1.5.1 General Aspects

In March 2000 the plant reached 217 SEU FA in the core (86 % of the total of 252) with 150 irradiated SEU FA. The maximum linear power shows the decreasing trend (about 6 % relative to NU fuel) anticipated by the fuel management studies. The larger reactivity increase per refueling with SEU fuel makes it easier to normalize operating situations with low reactivity reserve, than when using NU fuel.

The Atucha-I core is susceptible to xenon induced axial flux oscillations. These oscillations are particularly noticed in power reductions (100%-80%-100%) because of the associated regulating rods movement. Measurements of in-core flux detectors and simulations were done with increasing number of SEU FA in the core for these power cycles. A slight increase in the susceptibility to xenon oscillations in power cycles was noticed.

1.5.2 Effects of the SEU Fuel on the Plant Fuel Consumption

The average consumption of fuel assemblies per full power day showed a decreasing trend since the beginning of the program. During 1993 and 1994 the average fuel consumption with natural uranium fuel per day (fpd) was 1.31 FA/fpd. In 1995 during Phase 1 the average fuel consumption was decreased to 1.22 FA/ fpd. In 1996, most of the year still in Phase 1, it was 1.23. In 1997 dropped to 1.12 in Phase 2. In 1998 dropped to 0.92 and in 1999 to 0.88. It is interesting to remark that, during the transition period the discharge burnup of the natural uranium bundles showed an increase due to the positive contribution to the core reactivity of the SEU FA with a burnup distribution biased toward the fresh side, an effect that had been anticipated before. In 1998 for example it was 6640 and in 1999, 6549 MWd/tU, about 11 % more than with a pure natural uranium core.

Table 1: Actual Consumption of Natural and SEU Fuel In Atucha-I During The SEU Fuel Project

YEAR	Energy Produced (FPD)	New NU F.A. Loaded	New SEU F.A. Loaded	F.A. Loaded Total	F.A./FPD	Fuel Cost (U$S/MWh)	Relative Saving vs. NU Fuel
1994 (NU)	313.6	410	0	410	1.308	9.377	0.0%
1995	339.0	394	18	412	1.215	8.767	6.5%
1996	266.3	308	20	328	1.232	8.906	5.0%
1997	341.5	325	59	384	1.124	8.231	12.2%
1998	295.5	139	133	272	0.920	7.036	25.0%
1999	175.8	32	119	151	0.858	6.815	27.3%
Full SEU Core	328.5	0	230	230	0.7	5.697	39.2%

Notes: Fuel costs are calculated using 1998 and 1999 NU and SEU FA unit cost.

For the full SEU Core a load factor of 0.9 was assumed.

1.5.3 Effects on Fuel Costs

The fuel cycle costs (front end), as can be seen in table 1, dropped gradually during the program from 9.38 (with natural uranium fuel) to 6.81 U$S/MWh in 1999, (taking as reference the NU and SEU FA costs for 1999). One aspect to remark is that the average consumption of FA per fpd or the cost reductions are associated with the fraction of SEU fuel in the fuel loaded (not the fraction of SEU fuel in the core) so the full benefits are achieved when the loading of NU fuel ends. Since the end of December 1999 only SEU FA are being loaded in the reactor.

1.6 Fuel Performance in Phases 2 and 3

Between 1995 and the first half of 1997, no fuel failures have been detected. In 1997 two failed fuel assemblies were detected. Both were correlated with manufacturing flaws and the failure rate was not affected either by the higher burnup or by the higher residence time.

In February and March 2000, three SEU and one NU FA failed were taken out from the reactor. The cause of these failures is presently being evaluated, but they do not seem to be associated to burnup extension or pellet cladding interaction (PCI).

Considering only the SEU FA that completed successfully their irradiation period, the average discharge burnup in 1998 was 11263 MWd/tU, and in 1999, 11346 MWd/tU, which are very close to the design studies predicted value of 11000 MWd/tU. The corresponding values for NU fuel assemblies were 6640 and 6549 MWd/tU, with increases of 12% and 11% relative the average value for a NU core. Maximum local burnups were close to 15000 MWd/tU. The dwelling time went from 300 to 500 fpd, almost doubling the corresponding value for natural uranium.

1.6.1 Prevention of PCI Failures

The existing PCI prevention criteria were developed for natural uranium fuel and were based on estimations of maximum core linear power based on the readings of in-core detectors. For SEU fuel new criteria were developed for fuel of higher burnup based on the verification of the final linear powers and change in linear powers for all the fuel assemblies in the core using data files with burnups and linear powers from the fuel management calculations. These revised criteria were applied to power ramps arising during operation as a result of fuel movements, reactor power increases, and associated control rod movement and as a consequence of them the time to reach full power in a plant startup was increased from 28 to 35 hours. The overall experience with the new criteria seems good as no fuel failures due to PCI were observed after 150 irradiated SEU FA.

1.6.2 Database with Fuel Burnup and Linear Power Histories

Using results from the plant fuel management calculations a database with local linear powers and local burnups for all the SEU FA that have been irradiated in the program was prepared and is maintained. This data is useful to generate burnup and linear power histories during the permanence of the SEU FA in the reactor for fuel performance evaluation purposes.

CONCLUSIONS

In January 1995, a gradual program to irradiate SEU fuel in the Atucha I nuclear station was started. At the present time, about five years later, the operating experience and economic benefits of the SEU program have been reasonably good and it can be considered an effective tool to reduce fuel and operating costs at this plant.

The main aspects to remark are:

a) In March 2000 the core has 86 % of the coolant channels loaded with SEU fuel (217 SEU FA) and the operation experience has been fairly good. The two adverse effects noticed were a small increment of the time to reach full power from a hot shutdown condition or in power cycles due to PCI prevention criteria for higher burnup SEU fuel and some increase in the susceptibility to xenon induced axial power oscillations. It is expected to reach a full SEU core by the end of this year.

b) The fuel consumption of about 1.31 FA/ fpd with natural uranium was gradually reduced to 0.92 FA/ fpd. in 1998 and 0.86 in 1999, getting closer to the value of 0.7 predicted for a full SEU core. The average discharge burnup of the SEU FA that completed the irradiation in 1998 was 11263 MWd/tU, and in 1999, 11346 MWd/tU.

c) The front end fuel cycle cost dropped from 9.38 to 7.04 U$S/MWh in 1998 to 6.82 U$S/MWh in 1999, taking as reference the NU and SEU unit FA costs for 1998 and 1999.

d) At the present time 150 SEU FA completed their irradiation and 6 failed fuel assemblies have been observed. Two isolated cases of failures occurred in FA manufactured in 1997, that are attributed to fabrication causes. Three other cases (together with a case of a NU FA), were detected in February and March 2000. The cause of these failures is presently being evaluated, but they do not seem to be associated to burnup extension or pellet cladding interaction (PCI). The experience has been good with respect to the power ramps that occur in fuelling operations, reactor startups or power cycling This indicates that the design improvements and PCI prevention criteria developed for SEU fuel seem to be adequate.

e) The comparison of calculated channel power variations, reactivity increases and detector reading changes with measured values with the introduction of the first six fresh SEU fuel at the beginning of the program showed good agreement.

Considering the results obtained with the Atucha-I SEU program, it is planned to explore in the future the technical feasibility and economical convenience to start an SEU fuel irradiation program in the Embalse Nuclear Station.

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