NUCLEAR FUEL CYCLE ACTIVITIES IN ARGENTINA

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ABSTRACT

The activities related with the nuclear fuel cycle are carried out in Argentina by a combination of public and private undertakings. The tasks connected with the commercial production of fuel are in charge of private companies or state owned societies that are under privatization processes. The research and development activities and specialized services are performed by the National Atomic Energy Commission (CNEA), which constitutes the nucleus of generation of the advanced nuclear technologies. The CNEA is also responsible for the title of the spent fuel originated either in research reactors or nuclear power stations, the policies for the back end of the fuel cycle and the dismantlement of nuclear facilities.

In this report we will present an overview of the present status of the nuclear fuel cycle in Argentina, putting emphasis on fuel improvements, fuel performance and on the description of the ongoing Projects and Studies included in the CNEA's Nuclear Fuel Cycle Major Program.

1. COMPONENTS OF THE NUCLEAR FUEL CYCLE INDUSTRY IN ARGENTINA

A new Nuclear Law, passed in 1997, regulates all the nuclear activities in Argentina. According to this law the responsibilities in nuclear fuel cycle related activities are distributed among different organizations and companies. The general tendency is to concentrate industrial fabrication of nuclear fuel and electricity generation in the private sector. On the other hand, research and development activities and specialized services are under the responsibility of the National Atomic Energy Commission (CNEA), which constitutes the nucleus of generation of the advanced nuclear technologies. The CNEA is also responsible for the title of the spent fuel originated either in research reactors or nuclear power stations, the policies for the back end of the fuel cycle and the dismantlement of nuclear facilities [1]. CNEA's activities will be fully considered in section 4.; a short description of the organizations, other than CNEA, involved in the nuclear fuel cycle follows:

- DIOXITEC SA, created in 1997 is responsible for the production of sinterable uranium dioxide in the plant located in Córdoba City, property of CNEA. This Company belongs 99 % to CNEA and 1 % to Nuclear Mendoza SE, it will be privatized in the near future.

- CONUAR SA, founded in 1981, manufactures fuel for Nuclear Power Stations and Research Reactors. This is a stock company belonging 67 % to a private corporation (Pecom Nuclear SA) and 33 % to CNEA. The company is located in Ezeiza, Buenos Aires Province. Since its startup in 1981 CONUAR has supplied more than 4400, six meters long Fuel Assemblies (FA), for Atucha I PHWR and more than 40.000 CANDU bundles for

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Embalse NPP. CONUAR is also responsible for the fabrication and supply of standard MTR fuel (U_3O_8 based) for research and radioisotope production reactors.

- FAE SA, belonging 68 % to CONUAR SA and 32 % to CNEA was established in 1985 for the production of Zircaloy components. Since the beginning of its operation FAE SA has supplied more than 2500 kilometers of tubes for the Argentinean's NPPs. The company also manufactures Zircaloy tubes for PWRs, titanium tubes for condensers and stainless steel tubes for the conventional industry.

- Engineering and Services Neuquén (ENSI SE), a joint company between CNEA and the Government of the Neuquén Province operates the Heavy Water Industrial Plant (PIAP). Plant capacity is 200 tons of heavy water per year.

- Nucleoeléctrica SA (NASA), which is 100 % controlled by the Ministry of Economy, is responsible for the operation of Atucha I, a Pressure Vessel Natural Uranium-Heavy Water Reactor of 340 Mwe, in operation since 1974 and Embalse NPP, a CANDU-600 Reactor, in operation since 1984. This company will be privatized in the near future. The new owner will be bound to finish the construction of Atucha II NPP, which is, at present, 85 % completed.

- INVAP SE, a nuclear technology company, initiated in 1976, as a joint venture between CNEA and the Government of the Province of Rio Negro, was responsible for the development of the zirconium sponge and uranium enrichment technologies. This company participated actively in the development of zircaloy tubes and Candu fuel technologies, especially in supplying self developed equipment for the commercial fuel fabrication line. Some of the INVAP developed devices were exported to different CANDU owner countries. As an international research reactor supplier, INVAP installed the NUR Reactor in Algeria and the MPR, a radioisotope production and research 22 MW reactor, commissioned in 1997, in Egypt. INVAP is also a main contractor of CNEA for the development of the CAREM reactor. INVAP SE developed and installed the facilities for the dry storage of spent CANDU fuel at Embalse, Córdoba Province.

2. FUEL MANUFACTURING EXPERIENCE AND IN-REACTOR PERFORMANCE

More than 7900 fuel assemblies from three different suppliers have been irradiated in the Atucha I reactor since 1974 [2]. A historic overview of Atucha I fuel utilization, discriminated by supplier, is shown in Table I.

RBU GmbH, a German company supplied the first core and subsequent reloads until 1982 when the domestic manufacturing at industrial scale started. Domestic capabilities for design, fabrication processes and product engineering were developed in CNEA and then transferred to CONUAR. So far, more than 4400 FA made by CONUAR have been irradiated in Atucha I. Table II shows the relevant data for Atucha I fuel performance.

The overall fuel failure rate was generally very low with some periods of increased failure frequency. The reasons for these increments were the following: fuel operation beyond limits during reactor startups, manufacturing flaws concentrations and mechanical interaction with large objects and damaged reactor internals. The total cumulative fuel assembly failure rate adding manufacturing and operational causes, as PCI and mechanical interaction is about 1 %.

More than 40000 FA produced by CONUAR have been irradiated in Embalse NPP. A historic overview of Embalse fuel, discriminated by supplier, is shown in Table III. The average discharge burnup of those fuels was approximately 7400 MWd/tU and the overall failure rate, after almost ten years of domestic supply, has been 0,15 %. Manufacturing failure rate, without considering some "failure excursions", is almost 0,1 %. "Failure excursions" were mainly produced by faulty materials or incomplete endcap welding. Summaries of the 1997 - 1998 fuel performance for both NPPs, are displayed in Table IV and V.

3. COMMERCIAL NUCLEAR FUEL IMPROVEMENT PROJECTS

3.1. ATUCHA I FUEL

3.1.1. Slightly Enriched Uranium (SEU) Utilization

A program for loading SEU fuel assemblies at 0,85 W % ^{235}U in Atucha I NPP was started in January 1995 [3]. The use of slightly enriched uranium (SEU) instead of natural uranium is beneficial from the point of view of the fuel cycle cost. The main advantages derived from the utilization of SEU in Atucha I are:

- Increase the discharge burnup of Atucha I fuel.
- Reduction in the spent fuel volume.
- Reduction in the total fuel cost.
- Reduction in the frequency of (on-power) refueling.

During the transition to a full SEU core there is also an increase in the discharge burnup of natural uranium fuel. Reloading of spent natural uranium fuel assemblies to extend their original low discharge burnup is also under analysis. Several changes were introduced to the design of both, fuel rod and fuel assembly to adapt them to the SEU requirements.

At present, 74 SEU fuel assemblies were discharged with an average FA burnup of about 11 MWd/kgU and other 120 SEU FA are under irradiation. The overall performance of SEU fuels and the results of poolside post-irradiation examinations and measurements are satisfactory.

Based on these results the number of SEU FA in the core will be gradually increased to a full core in about two years (2000). Estimations predict that at that time the front-end fuel cycle component of the generation cost will be reduced in 20 - 25%. A comparison between natural uranium and SEU fuels is shown in Table IV.

3.1.2. Increment in the Quantity of Fuel Rods

A program to reduce the fuel cost increasing the UO_2 content of the fuel assemblies by using an additional fuel rod, instead of the supporting tube of the present design, is under development. The uranium content per fuel assembly will increase about 2,8%.

Other relative small advantage from the use of 37 fuel rods assemblies is a reduction of both; the frequency of refueling and the quantity of spent FA. After out of pile testing, irradiation of the first prototypes of SEU + 37 fuel rods assemblies will be performed in Atucha I reactor.

3.1.3. Grid Spacers and Tie Plate Thickness Reduction

A program to reduce spacers and tie plate thickness in about 28 % is being performed in parallel with the increase in the quantity of fuel rods. Low and high-pressure loop testing are being used to evaluate the behavior of the fuel with these modifications.

3.1.4. Additional Increment in the Fuel Assembly Uranium Content

Another program to increase the U content of the Fuel Assembly is under development. In a first step the increment will be about 3,3 % and more than 6 % considering 37 fuel rods. This increment will be accomplished through relatively small changes in fuel rod design. The fuel manufacturer may easily apply these modifications. Subsequent steps may increase the U content up to 20 % but complete thermalhydraulic and neutronic evaluations are necessary.

3.1.5. Improvements in Fuel Manufacturing

CONUAR introduced several modifications to the manufacturing equipment in the last years. The main objective was to increase fuel reliability and to reduce manufacturing costs. The Fuel Engineering Branch of CNEA contributed with the evaluation and qualification of each modified process. New product specifications and drawings were also prepared. In some case irradiation programs were designed and agreed with the utilities. The main improvements in Atucha fuel manufacturing are modifications to the wearing pad welding and end cap welding.

3.2. EMBALSE FUEL

3.2.1. Increment in Uranium Content

To increase the uranium content of Embalse fuel assemblies several design optimizations have been proposed and developed. At a first stage, these modifications affected only the dishing volume of the fuel pellets and the length of the fuel stack. An additional increment is also possible through the manufacturing of fuel rods with diameters close to the upper limit of the current design specification. The increment of the density of the fuel pellets also produces good results but its application depends on another factors like powder quality and pellet fabrication technology. New optimizations, like the increment of both, fuel pellets and fuel sheath diameters are under analysis and, depending on the results, new modifications will be applied in the near future.

3.2.2. Improvements in fuel manufacturing

Main achievements are:

- Automation of the end plate welding process in order to reduce the welding time and improve the quality of welds.

- A new graphite-baking oven was installed. The capacity was increased from 200 sheaths/batch to 1700 sheaths/batch and the quality of the coating is more reproducible.

- A new highly automated and integrated system for tack welding and brazing of spacers and bearing pads increased the reliability and speed of this process and also produced a reduction of the rejection rate.

- A new semi-automatic multicycle end cap welder assisted with pneumatic force is under qualification. More reliable and sound welding are expected.

4. NUCLEAR FUEL CYCLE ACTIVITIES AT CNEA

As mentioned before, the new Nuclear Law regulates all nuclear activities in Argentina. This law clearly determines the mandate of CNEA [4]. According to its mandate CNEA launched a Strategic Plan consisting in four Major Programs:

- Nuclear Fuel Cycle.

- Reactors and Nuclear Power Stations.

- Nuclear Waste Management and Decommissioning of Nuclear Facilities.

- Radioisotopes and Applications.

The Nuclear Fuel Cycle Program consists in a coherent approach to a set of very well defined Fuel Cycle Activities. The Program structure considers short and medium to long term actions. Short-term tasks are carried out through three main Projects:

- Advanced Fuel for Argentine NPPs (CARA).

- Advanced diffusion technology for uranium enrichment (SIGMA).

- High Density MTR fuels.

An important achievement, which will improve in the near future CNEA's fuel development and qualification capabilities, is the installation of the new Post-Irradiation Examinations Laboratory (LAPEP). This hot cells facility is now ready to carry out PIE on CANDU, CARA and MTR fuels.

All the Projects have fully established objectives, human resources, schedules and budgets. Medium to long term actions include Studies and Working Lines.

4.1. Advanced Fuel for Argentine NPPs (CARA)

The nuclear fuel elements for the two operating NPPs in Argentina (Atucha I and Embalse) are completely different in design and fabrication technology. Embalse fuel bundle is a domestic developed CANDU with 37 rods, 0.5 meters long. Atucha I uses a 6 meters long fuel assembly very similar to PWR fuel. This diversification in fuel production impairs the nuclear generation competitiveness because it results in an increment in the fuel fabrication costs, especially at the relative small-scale of the Argentinean production scenario.

The driving force to develop a completely new generation of advanced nuclear fuels is the need to reduce fuel fabrication costs, introducing at the same time all the new technological trends in nuclear fuel design: higher burnup, lower temperatures, more flexibility and safety. A very important additional requirement is to simplify the whole fuel fabrication system by using the same fuel element for both types of NPPs.

CARA is conceived to provide an answer to all the above mentioned requisites [5]. This fuel element is being developed with the following design objectives:

- To use the same fuel for both NPPs.
- To increase the heat transfer area.
- To use a single type of fuel rod diameter.
- To reduce the fuel center temperature.
- To decrease the mass ratio between zircaloy and uranium.
- To keep the uranium content of the more dense fuel.
- To avoid modifying the hydraulic pressure drop per channel of each NPP.
- High burnup using Slightly Enriched Uranium (SEU).
- Do not exceed the fabrication cost of the CANDU fuel.

The key design issue in the CARA solution, is a fuel element twice as long as the usual CANDU bundle, thus substituting a couple of conventional CANDU assemblies for a single one, bearing many thin fuel rods. An external zircaloy basket will be employed to arrange a stack of 5 CARA bundles in order to build a full Atucha type fuel element. CARA consists in a 52 fuel rod assembly, advanced pellet design using homogeneous slightly enriched uranium, low linear power rating, similar hydraulic pressure drop to the usual commercial fuel and better critical heat flux. CARA is also applicable in the Atucha II NPP, at present under construction.

The CARA project is a cooperative undertaking of CNEA, NASA and CONUAR. The project term, including an irradiation program in Atucha and Embalse, is planned to be four years.

4.2. Advanced Diffusion Technology for Uranium Enrichment (SIGMA)

The objective of this project is to develop a competitive gaseous diffusion technology, especially considering capital costs reduction, economy at low scale production, short construction time and lower energy consumption.

The SIGMA concept addresses all these goals introducing several technological solutions [6], but still using the well-known gaseous diffusion experience. It overcomes the problem of the large volumes needed to obtain good economic performance at the smallest scale sizes. A new modular design simplifies the manufacture, assembling and commissioning, determining an optimum size for the major components.

At the present project phase, all the computational models used to design the SIGMA concept have been validated using Pilcaniyeu Gaseous Diffusion Plant (GDP) experience and published experimental data. The models have been developed up to full cascade calculation and basic economical evaluation.

SIGMA design advantages may be summarized as follows:

- Reduce major component weights (reduced costs).
- Less piping length, coupling, flanges and supports.
- Lower thermal losses.
- Small sealing systems losses.
- Less land requirement for SIGMA lay out.
- Excellent module transportability (weights compatible with cranes).
- Competitive at small production scale.
- Lower energy consumption.

Several components and concepts are different to the classical GDP technology, then strong efforts are being carried out in the demonstration of this new components and concepts, to produce a full validation of all the engineering models used in the designing step.

The engineering models employed are mainly devoted to calculate the smallest economical module for the SIGMA design. At present, the smallest economical module envisaged is an order of magnitude lower than in the classical GDP technology.

An experimental SIGMA module that will be used for validation of the engineering model is currently under construction at Pilcaniyeu. This module has been designed to simplify the instrumentation of all the components, and to provide fast and low cost equipment replacement.

4.3. High Density MTR Fuels Project

CNEA has built a wide experience on designing, development, qualification and fabrication of MTR fuel elements. Since 1987, CNEA is an active participant of the Reduced Enrichment for Research and Test Reactors Program (RERTR). CNEA is responsible for the supply of non-standard MTR fuel and of all the R&D tasks related to this type of fuel. CNEA carries out the conversion of LEU (low enriched uranium) UF_6 to U_3O_8 and metallic uranium. Since the beginning of MTR fuel activities at CNEA, more than 600 MTR fuel elements of different kind have been supplied to domestic and overseas clients. So far, no defective or failed items have been reported by the reactor operators.

The objective of the High Density MTR Fuels Project is the development and qualification of the technology associated with the fabrication and utilization of these fuels [7]. The aim of the project is the implementation of high-density fuels in the Argentinean research and radioisotope production reactors and the satisfaction of the new requirements of CNEA's customers in international supplies.

This project relies on the favorable fact that CNEA has, at present, closed the circuit of development of this type of fuels. This circuit starts in the laboratory basic research and ends at the post-irradiation examinations of the experimental prototypes. CNEA's capabilities include: laboratory research in new nuclear materials, characterization facilities, pilot plants for the preparation of nuclear raw materials and experimental fuel, test reactor and hot cells laboratory for post-irradiation examinations. It is also worth mentioning the well-developed capabilities in neutronic and thermalhydraulic calculations, simulation codes, modeling, fuel engineering and quality assurance.

The background of this project goes back to the beginning of the RERTR program in 1978 promoted by the U.S. DOE (Department of Energy) and coordinated by the ANL (Argonne National Laboratory). Argentina, as an active participant of this program, prepared, as a first step, three series of miniplates of U_3O_8, UAl_x and U_3Si_x dispersed in aluminum powder, that were subsequently irradiated in the Oak Ridge Research Reactor. For the following step, full-scale prototypes were prepared and successfully irradiated. This gave place to the conversion of the core of the Argentine RA-3 reactor to LEU in 1983.

The present phase of the project consists in the development and qualification of the technology related to uranium silicide (U_3Si_2) and other very high-density fuels. This step began with the preparation of a first experimental full-scale fuel bundle (P04), which was irradiated in the RA-3 reactor. At present, the post-irradiation examinations of this prototype are being carried out in the Post-Irradiation Examinations Laboratory (LAPEP), being this the first time that an inspection of this type is carried out in hot cells, in Argentina.

The following step of the project consists in the preparation, irradiation and PIE of two full-scale prototypes. The first projected prototype fuel element (P06) is being designed as a dismountable bundle, with the aim of developing an irradiation and inspection tool, that will be very valuable for the whole project. The second experimental silicide fuel prototype (P07) will be similar to the conventional RA-3 bundle.

The most advanced stage in the project began in 1999, involving research and development in the last generation of very high-density fuel materials. U-Mo alloys have been chosen as the more promissory candidates to study. Considering the potential advantages, regarding flexibility and safety, of these alloys, this phase of the project is focused on preparing and characterizing U-Mo alloys and assessing their comparative advantages as fuel for research reactors. The present target is to develop alternative processes to prepare U-Mo powder and to manufacture and irradiate experimental miniplates, to assess the behavior under irradiation of these materials.

4.4. Medium to Long Term Activities

Medium to long term tasks are organized in specific interdisciplinary studies and working lines. An enumeration of some of them follows:

- Evaluation and validation of self-developed behavior simulation codes for fuel rods and plates.
- Evaluation of CNEA available irradiation data and participation in NEA (OECD) Task Force.
- Evaluation and qualification of reprocessed uranium as SEU for CARA fuel.
- Assessment of Atucha II fuel design.
- Development of advanced prediction and calculation methods for fuel design, isotopic separation and nuclear materials design.
- Building of a Materials Properties database.
- Development of MOX fuel.

5. CONCLUSIONS

Argentina has a well-established Nuclear Fuel Cycle Industry technologically supported by the Atomic Energy Commission. Fuel performance in both NPPs improves continuously as operational experience is accumulated and fabrication processes and quality assurance procedures are optimized. Some fuel developments like the use of SEU in Atucha I and the increase of the uranium mass in Candu fuel have been successfully implemented with a major economical impact. Fuel Cycle Activities in CNEA are now organized under a centralized Major Program. A set of well defined Projects, Studies and Working Lines covers all the fuel related activities in CNEA.

6. REFERENCES

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TABLE I. HISTORIC OVERVIEW OF ATUCHA I FUEL UTILIZATION

SUPPLIER	RBU SIEMENS		CNEA		CONUAR		TOTAL	
	1974 - 1983		1978 - 1981		1982 - 1998		1974 - 1998	
FUEL BUNDLES	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
	3314	41.5	240	3.0	4429	55.5	7983	100

TABLE II. RELEVANT DATA FOR ATUCHA I FUEL PERFORMANCE

Irradiated Assemblies	Discharge Burnup [MWd/tU]	Fuel Failures Rate [%]
7983 (a)	5940 (b)	0,58

(a) Including SEU (0.85 % ^{235}U) FA.
(b) For natural uranium FA.

TABLE III. HISTORIC OVERVIEW OF EMBALSE FUEL UTILIZATION

SUPPLIER	CANADIAN SUPPLIERS		CNEA		CONUAR		TOTAL	
	1984 - 1998		1986 - 1988		1988 - 1998		1984 - 1998	
FUEL BUNDLES	AMOUNT	%	AMOUNT	%	AMOUNT	%	AMOUNT	%
	17636	28.9	2100	3.5	41195	67.6	60931	100

TABLE IV. 1997 - 1998 ATUCHA I FUEL PERFORMANCE

YEAR	IRRADIATED ASSEMBLIES	FAILED	FUEL FAILURE RATE [%]
1997	402	4	1.0
1998	272	1	0.4

TABLE V. 1997 - 1998 EMBALSE FUEL PERFORMANCE

YEAR	IRRADIATED ASSEMBLIES	FAILED	FUEL FAILURE RATE [%]
1997	4980	3	0.06
1998	4884	2	0.04

TABLE VI. COMPARISON OF NATURAL URANIUM vs. SEU FUELS IN ATUCHA I

	NATURAL URANIUM FUEL	SEU FUEL
AVERAGE FA DISCHARGE BURNUP [MWd/KgU]	5.9	11
PELLET PEAK DISCHARGE BURNUP [MWd/KgU]	8.4	16
AVERAGE FA RESIDENCE TIME [fpd]	195	362
AVERAGE REFUELING FREQUENCY [FA/fpd]	1.3	0.7