ANNEX VI.

NATIONAL ARGENTINEAN SCENARIO WITH COOPERATION OPTIONS

VI-1. INTRODUCTION

The Project SYNERGIES [VI-1] ("Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability") is an activity sponsored by the International Atomic Energy Agency (IAEA) under the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) [VI-2]. This project aims at developing a regional-level assessment over a period up to 2050 and a hypothesis of the period between 2050 and 2100 for the following areas of work:

- Development of scenarios at the domestic and regional levels which identify where cooperation with other countries is required for the development of a national nuclear programme, and where the country or the region may assist other countries with the same objective;
- Development of scenarios in which fast reactors are deployed;
- Assessment of alternatives for actinide management;
- Design of indicators for analysis.

Although the project presents a regional analysis, Argentina is currently the only country in Latin America to participate in the project; thus, domestic development strategies and possible international cooperation described in this paper represent an Argentinian perspective.

Currently, Argentina participates in the first and fourth areas of work. Since it is of interest for the country to consider all the technological options available for the future, fast reactors technology will be studied thoroughly for a future incorporation into the Argentine nuclear power fleet. Even though Argentina does not participate in the second area of work, it discusses the topic within the first area of work. To achieve this, a specialized team must be formed as detailed in CNEA Strategic Plan [VI-3].

The structure of the annex will be presented as follows[1]:

- Section VI-2 presents scenarios of electricity demand for the period 2013 to 2050 to determine the role of nuclear power in the national electricity supply.
- Sections VI-3, VI-4 and VI-5 describe the historical evolution of nuclear activity in the country and the current state of its nuclear fuel cycle infrastructure, with the aim of describing the development strategy in the sector for which nuclear energy expansion scenarios are projected.
- Section VI-6 presents nuclear scenarios to estimate the foreign resource requirements for nuclear technology.
- Section VI-7 presents areas in which a country could assist the rest of the region, highlighting Argentina's actual ongoing cooperation with Latin America and how it could be increased in the future.
- Section VI-8 includes a comparative assessment of Generation IV reactors in order to define the technologies of greatest interest for the country.
- Finally, Section VI-9 presents conclusions of the research.

[1] The analysis presented in the argentine case is based on information available by December 2013.

VI-2. HISTORICAL DEVELOPMENT OF THE NUCLEAR SECTOR IN ARGENTINA

A few years after Enrico Fermi achieved the controlled chain reaction, thus, introducing the nuclear subject in the worldwide scientific community, Argentina established the National Commission of Atomic Energy (CNEA) in 1950 with the mission of developing and controlling nuclear energy for peaceful purposes in the country.

The creation of CNEA was framed within an industrialization process promoted by the Government, with the firm intention of not only possessing nuclear technology but to become its producer. Today CNEA is the entity responsible for all civil nuclear activity [VI-4, VI-5, VI-6, VI-7, VI-8 and VI-9] in Argentina at the national level.

Argentina was the first country in its region to operate an experimental nuclear reactor, the RA-1, which achieved its first criticality in January 1958. It pioneered the formation of human resources to deal with nuclear power plant installation projects in Argentina and produced the country's first radioisotopes for medical and industrial use. From this experience and knowledge, Argentina was able to realize other larger enterprises such as the RA-3 and RA-6 reactors CNEA exported to Peru, Algeria, Egypt and Australia. Also the RA-1 Reactor was pioneered in the formation of human resources to deal with nuclear power plants installation projects in Argentine. Later in 1974 CNEA began operating Atucha I (CNA I), the first nuclear power plant (NPP) in Latin America to produce electricity from nuclear fission.

Nuclear infrastructure development of the following decade (1980-1989) was characterized by the completion of the front end of the nuclear fuel cycle, including the following events:

- Prospection of new uranium deposits in the Industrial Mining Complex San Rafael (CMFSR) Sierra Pintada (Mendoza), Los Gigantes (Cordoba), La Estela (San Luis) and Los Adobes (Chubut) Industrial Mining Complex;
- In 1982, the start of operations of a concentrated uranium and uranium dioxide production purifying plant with a 150 t capacity per year in the Cordoba Industrial Nuclear Complex;
- In 1982, the start of operations of a fuel element plant to supply the NPP in CAE (CONUAR S.A.); a year later it delivered the first fuel element for CNA I;
- In 1983, the uranium enrichment technology was mastered by means of the gaseous diffusion method developed by CNEA with the collaboration of INVAP company, in Pilcaniyeu, Province of Río Negro;
- In 1984, start-up of a special alloy plant mainly dedicated to produce Zircaloy clads and components for fuel elements in CAE;
- In 1986 the corporation FAE S.A. was created.

In relation to the band-end stages of nuclear fuel cycle, a pilot plant for spent fuel reprocessing was built, which in the mid-eighties was deactivated.

Argentina's second NPP, CNE, was built by the Atomic Energy of Canada Ltd. and the Italian Construction Company (Italimpianti) at Embalse Rio Tercero, Cordoba Province. CNE's startup was conducted in January 1984 with a net power of 0.648 GW(e). The Canadian offer consisted of the agreement of technological transfer, which would be used to gain the knowledge to guarantee future independent production of nuclear energy.

Since 1996 CNA I has used slightly enriched uranium fuel (ULE, with 0.85% uranium-235), and since 2001 is the first and only heavy water power reactor in the world that operates entirely with ULE. The change from natural uranium to ULE has led to a 45% decrease in fuel consumption with a reduction of about 30% in fuel costs.

On 23 August 2006 the government announced its policy “Reactivation of the Nuclear Activity in Argentina” which included a nuclear program for the short and medium term based on two main topics: applying nuclear technology to public health and the industry, and strengthening the nuclear energy as an electrical power source by intending to increase its participation in the national electrical market, including by completing the Construction of CNA II (Atucha II).

It should be noted that in early 1980, CNA II was projected to be Argentina’s third NPP to be built on the same site as CNA I. The experience gained during the construction of CNE led authorities to award the contract to ENACE, a joint venture of Kraftwerk Union (KWU) and CNEA, for the construction of a 0.7 GW(e) Siemens reactor cooled and moderated by heavy water (the same design as CNA I). This project began in 1981, but experienced considerable delays, mainly due to financial reasons. Despite having about 80% of work completed, work was completely paralyzed in the mid-1990s by a political decision to privatize markets and minimize government activities.

Some relevant milestones of the CNA II construction are listed below:

- In September 2011 the President of Argentina Cristina Fernandez de Kirchner inaugurated the commissioning phase of the CNA II, which consists of testing and individual verification of each of the 566 subsystems;
- In December 2012 the National Industrial Heavy Water Plant completed the production of 637 tons of heavy water for the initial load of CAN II;
- In February 2013 the loading of the first’s 451 fuel elements belonging to the first reactor core was completed, containing 85 tons of uranium; these pieces have been produced entirely in Argentina by the company Fae S.A.;
- In September 2013 a successful test was performed to synchronize CNA II to the National Electricity Network by driving a turbine at 1500 rpm, the first time the NPP was synchronized to the grid with no nuclear steam source;
- Extending the life cycle of CNE;
- Beginning preliminary feasibility studies to construct a fourth NPP;
- Concluding feasibility studies to construct the prototype modular facility of lower power (0.025 GW(e)) and national design which began before nuclear activities were brought to a halt under the name of “Central ARgentina de Elementos Modulares” (CAREM, Argentine Modular Elements Facility) in accordance with Law N° 25064, Law N° 25160 and Law N° 26566;
- Producing heavy water to be used in CNA II;
- Reactivating both uranium prospecting throughout the country and the construction of the uranium enrichment pilot plant/facility; both activities had been suspended in the second half of the 1900s for political reasons.

Finally, it is worth mentioning that Argentina has experience in design, construction and assembly of experimental reactors and up to the present day it has exported the following reactors:

- RP-0 Training Reactor of zero power operating since 1978. It was sold to the “Instituto Peruano de Energía Nuclear” (IPEN, Peruvian Institute of Nuclear Energy) by CNEA;
- Research reactor, radioisotope fabrication and training of personnel, RP-10 of 10 MW in operation since 1988. Sold to IPEN by CNEA;
- Multipurpose facility 1MW named as NUR (a word of Arabic origin which means "luminosity") in operation since 1989; it was sold to the Algerian "Haut Comissariat pour la Recherche";

- Multipurpose reactor ETRR-2 of 22 MW in operation since 1997. It was sold to the Egyptian Atomic Energy Authority (AEA);
- Radioisotope production facility with medical and industrial application located in Inshas, next to the ETRR-2 reactor; it was sold to the Egyptian Atomic Energy Authority;
- CENTIS radioisotope production and fractioning facility inaugurated in 1995. It was sold to the company "Inversiones Gamma" dependent on the Ministry of Nuclear Topics of the Cuban Republic;
- Reactor that produces radioisotopes supplies for microelectronic and research into materials, known as OPAL of 20 MW, in operation since 2005, located in Lucas Heights, Sydney, Australia; sold to the Australian Nuclear Science Technology Organisation (ANSTO).

VI-3. NATIONAL NUCLEAR POWER PLANTS: OVERVIEW

At present, around 5% of the electricity in Argentina is produced by two nuclear facilities in operation, CNA I and CNE, which have a total installed facility capacity of 1.01 GW(e) with a net contribution of 0.94 GW(e).

During the period 1984-1990, nuclear energy represented around a 15% of the country's total generated electricity. This has been gradually reduced as a result of the extension of the installed capacity based on other technologies and the discontinuity of the nuclear plan, which resulted in the halt of building activities concerning NPP CNA II, located next to CNA I.

While nuclear generation kept a normal dispatch since March 2011, Embalse NPP has been operating at 80% capacity in preparation for its life extension.

On 28 September 2011 the process of implementation of Atucha II NPP began, which consisted of testing and individual verification of each one of the 566 subsystems. During 2012 the verification of each power plant's sector performance continued. This process leads to the production of steam and energy generation, finally entering the plant into commercial production.

The main characteristics of NPPs in operation [VI-10, VI-11, VI-12] in Argentina are presented as follows.

VI-3.1.CNA I

CNA I is sited on the right bank of the river Paraná de Las Palmas, Lima, Zárate, province of Buenos Aires, 100 km from the City of Buenos Aires. The thermal power of the NPP is of 1.179 GW and 0.357 GW(e) of electric power. In April 2013 0.005 GW(e) were added due to design change of the blades of the high pressure stage of the generator. In 1974 it was connected to the 220 kV of the Interconnection Argentine System (SADI).

The reactor is a pressurized heavy water reactor (PHWR) cooled and moderated with heavy water. At first, fuel elements were designed based on natural uranium (0.7% of uranium-235), but by a modification performed in 1995 it was replaced with slightly enriched uranium (0.85% of uranium-235) in order to raise the degree of fuel element burn-up by reducing the number of consumed elements. It became the first reactor in the world to operate with this degree of enrichment and heavy water.

The NPP engulfs the following facilities: reactor, primary, secondary and tertiary refrigeration circuits, the pressure maintenance system, the moderator system, auxiliary and secondary facilities, turbine building and the electric operations area. It also has two spent fuel elements pools located in an adjoining building. A particular characteristic of this reactor is that it has a machine to replace fuel elements which avoids the interruption of the service,

something different from the NPPs with PWR (Pressurized Water Reactor) or BWR (Boiling Water Reactor).

VI-3.2. CNE

Chronologically, CNE is the second Argentine NPP and the largest thermal unitary (machinery) Argentine reactor with an electric nominal power of 0.648 GW(e).

CNE is located in the southern coast of Embalse de Río Tercero, province of Córdoba, 665m above the sea level. It is 100 km away from Córdoba city and 700 km from the City of Buenos Aires. It began its commercial service on January 20, 1984 and uses a CANDU (Canadian Deuterium Uranium) reactor with PHWR technology. It uses natural uranium as fuel and heavy water as refrigerant and moderator. Just like CNA I, loading and unloading of the fuel is performed during the operation of the NPP.

Apart from generating electrical power for SADI, this NPP also produces cobalt-60 (Co60), used in medical, industrial and research applications. It is the third largest producer of the radioisotope worldwide.

The relevant characteristics of the operating NPPs are presented in Fig. VI-1.

EMBALSE NPP Operating Since 1984	
Type of reactor	CANDU
Thermal power	2109 MW_t
Electric power	648 MW_e
Moderator and cooling System	Heavy water (D_2O)
Nuclear Fuel	Natural uranium
Steam generator	4 vertical "U" tubes Incalloy 800
Turbine	1 high pressure step and 3 low pressure step. Speed: 1500 rpm
Generator	4 poles 22 kV Voltaje, 50Hz

ATUCHA NPP Operating since 1974	
Type of reactor	Pressure vessel
Thermal power	1179 MW_t
Electric power	362 MW_e
Moderator and cooling System	Heavy water (D_2O)
Nuclear Fuel	Slightly enriched uranium (0,85%)
Steam generator	2 vertical "U" tubes Incalloy 800
Turbine	1 high pressure step and 3 low pressure step. Speed: 3000 rpm
Generator	4 poles 21 kV Voltaje, 50Hz

FIG. VI-1 Site and characteristics of the operating NPPs.

The main characteristics of the NPP, which construction is finished and is under start operation process, are described in the following section.

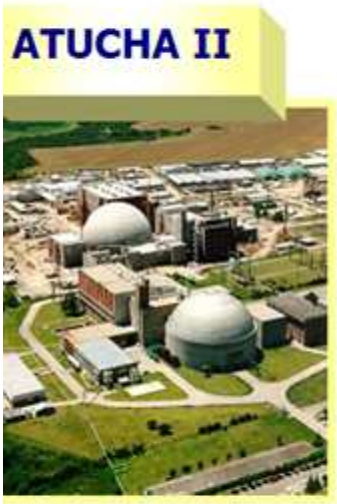
VI-3.3.CNA II

CNA II is sited on the right bank of the river Paraná de Las Palmas, in Lima, Zárate, province of Buenos Aires, 100 km from the City of Buenos Aires, next to CNA I.

In the same case as its neighbour NPP, CNA II is a Pressurised Heavy Water Reactor (PHWR) whose fuel will initially be natural uranium following the original design.

The characteristics of the NPP (which is undergoing start of operations) is presented in Fig. VI-2.

- 2 NPP operating
- 1 NPP Construction Finish- Start operation process



ATUCHA II NPP Status: construction finish 2014 first operation year estimated	
Type of reactor	Pressure vessel
Thermal power	2175 MW_t
Electric Power Gross/ Net	745/692 MW_e
Moderator and cooling System	Heavy water (D_2O)
Nuclear Fuel	Natural uranium
Steam generator	2 vertical "U" tubes Incalloy 800
Turbine	1 high pressure step and 2 low pressure step. Speed: 1500 rpm
Generator	4 poles 21 kV Voltaje, 50Hz

FIG. VI-2 Site and characteristics of Atucha II NPP.

The thermal power of the NPP is 2.175 GW, thus obtaining an electric gross power of 0.745 GW(e), which will represent the largest power unitary machine to enter SADI upon full operation.

In Table VI-1, the characteristics of the NPPs in Argentina are presented.

TABLE VI–1. STATUS AND PERFORMANCE OF NUCLEAR POWER PLANTS

Central	Type	Net Capacity (GW(e))	Operator	Situation	Reactor Supplier	Construction Date +	Net connection ++	Commercial Date	FC (2011)*
ATUCHA I	PHWR	0.362	NA-SA	In operation	Siemens	01/06/68	19/03/74	24/06/74	79.30%
EMBALSE	PHWR	0.648	NA-SA	In operation	AECL	01/04/74	25/04/83	20/01/84	68.55%**
ATUCHA II	PHWR	0.692	NA-SA	Construction finish - Start operation tests	Siemens	14/07/81	-	-	

\+ Date, when performing the first major casting of concrete, generally for the base mat of the reactor building, is done.
++ Date of first connection to the grid.
* UCF (Unit Capability Factor) for the latest available year (only applicable to reactors in operation). Latest data available December 2011.
** The decline of the UFC of Embalse NPP is because the full capacity is limited to 80% (0.520 GW(e)) due to life extension tasks.

VI-4. NUCLEAR FUEL CYCLE INCLUDING WASTE MANAGEMENT

Every activity of the nuclear fuel cycle is oriented towards satisfying the objective of guaranteeing reserves of national uranium for the actual and long term fuel requirements for the operation of existing and future NPPs and research reactors.

The main activities of the nuclear fuel cycle which are currently performed in Argentina are uranium prospecting, conversion and purification, mining waste management, fuel elements fabrication/manufacturing, and interim storage of spent fuels and radioactive waste. Moreover, there is research and development at lab and pilot plant scales for uranium concentrate production, uranium enrichment, reprocessing, and radioactive waste management.

As regards the strategies of radioactive waste management, every activity is oriented towards guaranteeing the protection of the environment, public health and the rights of future generations in accordance with the regulations set forth by ARN and regulations at national and provincial levels and regulations from the City of Buenos Aires, as well as relevant international agreements.

The stages and characteristics of the national nuclear fuel cycle in the country are detailed as follows.

VI-4.1.Mining, prospecting and production

The Argentine Mining Code, sanctioned under the Law N° 1919 entitles CNEA to perform prospecting, exploration and exploitation of nuclear minerals. With the aim of developing uranium prospecting and exploration of uranium resources, CNEA performs prospecting and expeditious exploration tasks in "prospecting areas" within the country, selected as follows:

- Salta Province: Santa Rosa, La Angostura, Piedra Colorada and Huayco Hondo in Vaquería mountain chain;
- Catamarca Province: Cerro Hoyada, San Buena Ventura, Istataco, El Portezuelo, Antinaco, Aguada del Médano and Real Grande;
- La Rioja Province: Donato VI and V and Miguelito I to VI;

- Chubut Province: Soledad, El Picahueso and El Curioso;
- Santa Cruz Province: Laguna Sirven raid.

Detailed exploration tasks and resources assessments are undertaken in mineralized areas nominated as "manifestation of discovery" and "site". Among the first, there are Cuesta Vieja, in Salta province; Donato II, Bárbara I to V, Coco I and Alipán in La Rioja province, and Sierra Cuadrada Sur, Sierra Cuadrada, El Cruce, Mirasol Chico, La Salteada, La Meseta and Cerro Chivo in Chubut province.

With regard to uranium deposits, the following ones are known (listed according to size and quantity of knowledge of the ore, in decreasing order): Cerro Solo, El Molino, Arroyo Perdido, El Ganso and Puesto Alvear. All are located in Pichiñan Este uranium district and in the Laguna Colorada site (in Chubut Province). Mina Franca, in Catamarca province, and Don Otto, in Salta province, are also listed.

As regards the production of uranium concentrates, in Mendoza province, the San Rafael Industrial Mining Complex has been brought to a standstill in 1995 since imported uranium concentrate was more economical.

VI-4.2. Uranium conversion

The conversion of uranium to UO_2 is performed in DIOXITEK S.A. The nominal production capacity of the plant is 150 t of UO_2 per year, although in recent years it has reached a production of 175 t of UO_2 per year to meet the requirements of Atucha II NPP.

Currently the concentrate is completely imported. Studies to improve the capacity and to transfer the plant with the aim of meeting new requirements, deriving from the startup of CNA II and the future NPPs, are being undertaken.

VI-4.3. Fuel fabrication

The factory of Special Alloys, FAE SA, manufactures Zircaloy rods and pellets used in the manufacturing of fuel elements coming from imported trex tubes [2]. The technology applied was developed in CNEA and is continuously updated. The fabrication of stainless steel alloys and titanium is undertaken, as well as the development of products of incalloy used as supplies in different components of NPPs.

Fuel element fabrication is performed by CONUAR SA, where UO_2 pellets are fabricated and fuel elements are assembled for Atucha I, Atucha II and Embalse NPPs. MTR fuel is also assembled for the RA-3 research and production reactor.

The manufacturing methods of the fuel elements for future nuclear power plants of Argentina are under development, currently focusing on CAREM 25 power plant.

In late 2011, the delivery of the 451 fuel elements constituting the first core of the CNA II was completed. The fuels were manufactured by CONUAR S.A. and FAE SA, with the UO2 produced by DIOXITEK and the engineering was provided by CNEA.

VI-4.4. Temporary storage of spent fuels

Temporary storage of spent fuels is performed in situ in NPPs. In CNA I, fuels are stored in two pools containing all spent fuels from the beginning of the operation of the NPP. In the short term, it will also have a dry storage facility. In CNE, storage is initially performed in decaying pools in order to be transferred to dry silos after 6 or 8 years of storage at the same site of the NPP.

---

[2] Trex: Semi or heavy wall pipes that after their laminate give rise to fuel pods.

VI-4.5. Radioactive waste management

Radioactive waste management is contemplated in laws of nuclear activity No. 24804 in which CNEA's responsibilities are described. Subsection "d" states that CNEA has to "exert the responsibility for managing radioactive wastes by fulfilling the tasks assigned to the specific legislation" as long as in subsection "g" regulates that CNEA has to "exert the state property of special fissionable radioactive materials contained in irradiated fuel elements". In article 16, ARN´s tasks are mentioned and its subsection "c", licenses, permits or authorizations for facilities are granted for radioactive waste or waste management.

Law N°25018 establishes that CNEA is in charge of enforcing the law and establishes the "National Program of Radioactive Waste Management" (PNGRR) to carry out the necessary actions to give effect to the obligations listed in the Law. In order to achieve this, CNEA should produce a "Strategic Plan for Radioactive Waste Management" (PEGRR) and submit it to the National Executive, which after consulting the ARN, send it to the Congress of the Nation (HCN) for its approval by Law. The PEGRR must be updated every three years.

CNEA developed the PEGRR project, which had been updated and approved by the authorities of CNEA in late 2012. This latest version was elevated to the NRA before been sent to the Energy Secretariat to begin the evaluation process by the various agencies and then be sent to HCN.

With respect to wastes produced by uranium mining, a Programme on Environmental Restitution of the Uranium Mining (PRAMU) is under development and its objective is to achieve the environmental restitution of those sites where activities related to uranium mining were developed. Sites where the programme is applied are the following: Malargüe and Huemul (Mendoza Province), Córdoba and Los Gigantes (Córdoba Province), Pichiñán (Chubut Province), Tonco (Salta Province), La Estela (San Luis Province) and Los Colorados (La Rioja Province).

In a first step, the restoration project was financed by CNEA; Argentina has since received a World Bank loan, applicable in principle in Malargüe site, whose works have already been started. Work will continue with the other sites.

VI-4.6. Policy for the final disposition of high level waste

Argentina has adopted the radioactive waste classification proposed by the IAEA, mainly based on considerations of long-term safety and disposal systems.

As regards the final disposal of high level radioactive waste, during the eighties, CNEA began a feasibility study and engineering draft for the construction of a deep geological repository. Stable granite formations were looked for in low seismic regions with scarce hydraulic conductivity. One of the possible options was the town of Gastre, province of Chubut, and where characterization studies were performed and submitted to the National Congress. Subsequently, as a consequence of the public opinion, studies were suspended in that site, but there is an ongoing project to find a new site for this activity.

VI-5. FUTURE DEVELOPMENT OF NUCLEAR POWER

VI-5.1. Nuclear power development strategy

The Argentine strategic nuclear plan [VI-13, VI-14, VI-15] is designed to reactivate the nuclear energy sector, including by revitalizing nuclear power as well as medical and industrial applications.

This reactivation plan is based on Argentina's knowledge and experience in disciplines of a high technical and technological level, which place the country in a competitive

worldwide context. Even though there was paralysis in some nuclear activities during the nineties, today Argentina's technical expertise transcends its own barriers and is known by the rest of the industrial and service sectors. Thus it is forecasted that Argentina is likely to recover those capacities not widely used during the last decade. Moreover, it is expected that Argentina will prepare and train the necessary human resources that will bear the responsibility to continue and improve nuclear development in order to supply present and future energy needs.

Notwithstanding the political definition provided in 2006, on September 1st, 1999 Law N° 25160 was sanctioned (enacted on September 27th, 1999), thus enabling CNEA to create the CAREM Project.

More details about the nuclear plan were announced on August 23rd, 2006 by means of the speech delivered by the Minister of Planning, Public Investment and Services, Julio De Vido, whose main parts are transcribed as follows:

> "(...) This reactivation is based on two technical, pragmatic main points which have a mere strategic content: In the first place, a massive production of nucleoelectric energy (.) Second, nuclear technological applications to public health and industry (…). (...) As part of the plan, building activities of Atucha II NPP will be concluded and this NPP will be commissioned."

National Law No. 26566 (sanctioned on 25 November 2009, promulgated on 17 December 2009) provides guidelines and facilities for the revival of nuclear activity, authorizing extension of the operating license and other necessary tasks for CNE's life extension, as well as:

- Beginning of previous studies for the definition of life extension of CNAI;
- Execution of pending building activities so as to conclude the construction, commissioning and operation of CNA II;
- Beginning of preliminary studies of feasibility to construct a fourth NPP;
- Design, execution and commissioning of a CAREM prototype reactor.

As regards prospecting and exploitation activities, Argentina plans to reopen certain mining areas previously developed and incorporate new reserves through reactivation of national uranium prospecting.

Continuing with the activities required by the fuel cycle, Argentina is continuing the gaseous diffusion uranium enrichment project at the Pilcaniyeu Technological Complex in the province of Río Negro. Currently it is close to restarting operation of the pilot module enrichment plant.

Taking into account the global market for enriched uranium and light water reactors, studies have been undertaken to determine the feasibility of incorporating this line of reactors in Argentina. These studies have concluded that given the internal and external implications from a technological, economic and human resource point of view, "Argentina has to incorporate an enriched uranium NPP which should resemble a 3rd generation NPP", as incorporation of NPPs with enriched uranium would enable the optimization of the fuel cycle in Argentina through the application of both technologies.

In December 2009, CNEA sent the Preliminary Safety Report (PSR) prepared by CAREM to the ARN, thus fulfilling all the necessary requirements to obtain the license to build the reactor; the license has since been obtained.

The policy related to the nuclear fuel cycle includes the recovery of all the national fuel cycle stages already developed, mainly the enrichment and the reprocessing processes.

In accordance with the National Law Nº 25018 “Management of Radioactive Wastes”, CNEA is responsible for supervising and treating low, medium and high level radioactive wastes.

Spent fuel elements coming from NPPs have a high level of radioactivity but are not considered radioactive wastes. Thus, they are temporarily stored in decaying pools and/or dry storage silos.

According to the same federal law, CNEA is responsible for receiving each Argentine NPP at the end of its operation life and for all its stages of its decommissioning and decontamination.

According to this law, the “Fund for Radioactive Waste Management” is expected to be created. This fund would be destined for financing the National Programme of Waste Management in charge of CNEA, and would be established by contributions from radioactive wastes.

The National State makes financial contributions through CNEA for the National Programme of Radioactive Wastes budget until this article of the law is regulated. Since neither this fund nor the percentage of the invoicing has been created, the operator of the NPP should contribute to its constitution.

VI-5.2. Projections of the expansion of nuclear power for the 2013-2050 period

In order to make projections, it was assumed that Argentine nuclear technology would continue to be developed and implemented. Almost the same number of Argentine-designed and constructed CAREM 150 NPPs was foreseen, both in high and low projections of the role of nuclear power in the national energy mix.

According to current plans and recent announcements of the Ministry of Planning, the fourth NPP (2 modules of 0.750 GW(e) each) will be in operation and a fifth NPP (1 or 2 modules of 1.200 GW(e) each) will be incorporated into the power grid by 2023.

By adopting the projections of electricity demand described in Section VI-3 as a reference, the objective is to reach 30% of nuclear energy participation in the final energy demand considering a diversified energy mix formed by 30% of nuclear energy, 30% fossil, 30% hydraulic, and 10% of other renewable energies.

The participation of nuclear energy in the low projection is calculated by taking into account a scenario of minimum electricity production, and the scenario of a higher participation of nuclear energy is calculated with the values for the high demand scenario.

As follows, particular considerations are described for both projections:

- Values of power are expressed in Gross Power Capacity;
- In 2013, there is 0.005 GW(e) increase as a result of modifications in CNA I;
- In 2014, CNA II starts operating and Embalse starts its lifetime extension programme and repowering;
- In 2015, Embalse will produce half of its power and, in 2016, the remaining half. This is indicated in this way only for practical purposes to calculate the annual accumulated power generated. Power is obtained in two halves since Embalse works are expected to have an 18-month duration; therefore, the NPP will be available during the second semester of 2015;

- Calculations of NPPs were developed with an operation factor of 0.85. By applying this factor to the gross generation, the participation in generation regarding the energy demanded for the national interconnected system is higher than real energy, since what the system actually receives is the net energy that results from the gross energy minus the energy required by the NPP consumption. As power values of the future nuclear power plants (as of the fourth NPP) have not been defined yet, generic values are adopted, and calculations were made from the gross power output;
- The reactor(s) corresponding to the fourth NPP will need heavy water, and in the case of the fifth NPP, is considering that they will be light water reactors;
- In 2018, CAREM 25 will start operating;
- In 2019, CNA I starts with the lifetime extension programme to restart operation in 2021;
- In 2020, CAREM 150 starts operating along with the first reactor out of the two 0.750 GW(e) reactors that will be part of the fourth Argentine NPP. The second reactor will start operating in 2022;
- In 2023, the fifth NPP starts up with a 1.200 GW(e) reactor;[3]
- In 2027, another CAREM 150 reactor starts operation;
- Atucha I and Embalse would be permanently shut down in 2046 and 2050, accordingly.

Particular considerations for the low projection:

- In both 2033 and 2043 a 1.200 GW(e) reactor starts operating;
- In each of 2034, 2041 and 2048, one module of the CAREM 150 reactor starts up.

Particular considerations for the high projection:

- In 2025, 2030, 2035, 2040 and 2045 a 1.200 GW(e) reactor starts operating;
- In 2032, 2037, 2042, 2047, a module of CAREM 150 reactor starts operating.

In Table VI–2 the two proposed scenarios present the following information about power: input, output, accumulated annually and the participation of nuclear power in the electricity demand.

[3] This value of power was adopted (instead of a generic one of 1 GW(e)) since it was the one provided by the Ministry of Federal Planning, Public Investment and Services of Argentina in the speech delivered in St Petersburg in June 2013.

TABLE VI-2. NUCLEAR SHARE AND EVOLUTION OF INSTALLED CAPACITY.

Year	Low projection of nuclear power capacity				High projection of nuclear power capacity			
	Participation of nuclear power in electricity demand %	Nuclear Power (input), GW(e)	Nuclear Power (output), GW(e)	Nuclear Power Balance, GW(e)	Participation of nuclear power in electricity demand, %	Nuclear Power (input), GW(e)	Nuclear Power (output), GW(e)	Nuclear Power Balance, GW(e)
2010	7.2	1.005		1.005	7.2	1.005		1.005
2011	6.7			1.005	6.7			1.005
2012	6.5			1.005	6.5			1.005
2013	6.4	0.005		1.010	6.3	0.005		1.010
2014	6.8	0.745	0.648	1.107	6.6	0.745	0.648	1.107
2015	8.7	0.342		1.449	8.4	0.342		1.449
2016	10.5	0.341		1.790	10.1	0.341		1.790
2017	10.3			1.790	9.8			1.790
2018	10.2	0.025		1.815	9.7	0.025		1.815
2019	8.0		0.362	1.453	7.6		0.362	1.453
2020	12.6	0.900		2.353	11.9	0.900		2.353
2021	14.3	0.362		2.715	13.4	0.362		2.715
2022	17.9	0.750		3.465	16.6	0.750		3.465
2023	23.7	1.200		4.665	21.8	1.200		4.665
2024	23.2			4.665	21.2			4.665
2025	22.8			4.665	26.0	1.200		5.865
2026	22.4			4.665	25.3			5.865
2027	22.7	0.150		4.815	25.3	0.150		6.015
2028	22.3			4.815	24.7			6.015
2029	21.9			4.815	24.1			6.015
2030	21.5			4.815	28.2	1.200		7.215
2031	21.0			4.815	27.8			7.215

TABLE VI-2. NUCLEAR SHARE AND EVOLUTION OF INSTALLED CAPACITY (cont.).

Year	Low Projection of Nuclear Power Capacity				High Projection of Nuclear Power Capacity			
	Participation of nuclear power in electricity demand %	Nuclear Power (input), GW(e)	Nuclear Power (output), GW(e)	Nuclear Power Balance, GW(e)	Participation of nuclear power in electricity demand, %	Nuclear Power (input), GW(e)	Nuclear Power (output), GW(e)	Nuclear Power Balance, GW(e)
2032	20.7			4.815	27.9	0.150		7.365
2033	25.4	1.200		6.015	27.5			7.365
2034	25.7	0.150		6.165	27.0			7.365
2035	25.3			6.165	30.9	1.200		8.565
2036	24.9			6.165	30.5			8.565
2037	24.6			6.165	30.6	0.150		8.715
2038	24.2			6.165	30.1			8.715
2039	23.9			6.165	29.7			8.715
2040	23.5			6.165	33.2	1.200		9.915
2041	23.6	0.150		6.315	32.6			9.915
2042	23.2			6.315	32.5	0.150		10.065
2043	27.1	1.200		7.515	32.0			10.065
2044	26.7			7.515	31.4			10.065
2045	26.2			7.515	34.6	1.200		11.265
2046	24.6		0.362	7.153	33.0		0.362	10.903
2047	24.2			7.153	32.9	0.150		11.053
2048	24.3	0.150		7.303	32.4			11.053
2049	23.9			7.303	31.9			11.053
2050	21.3		0.683	6.620	29.5		0.683	10.370

VI-5.3. Requirements of uranium for nuclear expansion 2013–2050

The following values were considered as future requirements of natural uranium for NPPs that are operational or contemplated in the electric system expansion scenarios.

For existing plants, 50 and 70 t U are required per year respectively.

The CNA II will operate with natural uranium at the beginning, with a projected annual requirement of 92 t U. For the fourth NPP, each of the 2 modules of 0.750 GW(e) will require on the order of 81 t U per year. For the 1 200 GW(e) NPPs each module will consume in the order of 216 t U.

For the CAREM 25 NPP, annual consumption was estimated as 5 t U, while for the CAREM 150 NPPs the requirements were estimated in the order of 27 t U each.

The cumulative natural uranium requirement for the Low scenario will reach 26 775 t of U for the year 2050, while for High scenario the cumulative requirement would be of the order of 37 390 t U.

Natural uranium requirements were calculated taking a value of enrichment for PWR NPPs of 4%; from 2023 it is assumed that all new NPPs will be of that kind of technology.

Figures VI-3 and VI-4 show the annual natural uranium requirements for both scenarios.

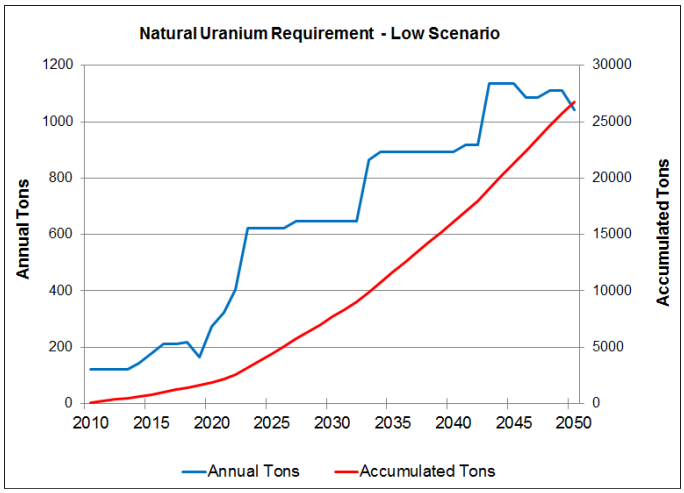


FIG. VI-3. Annual requirement and cumulative natural uranium - Low scenario.

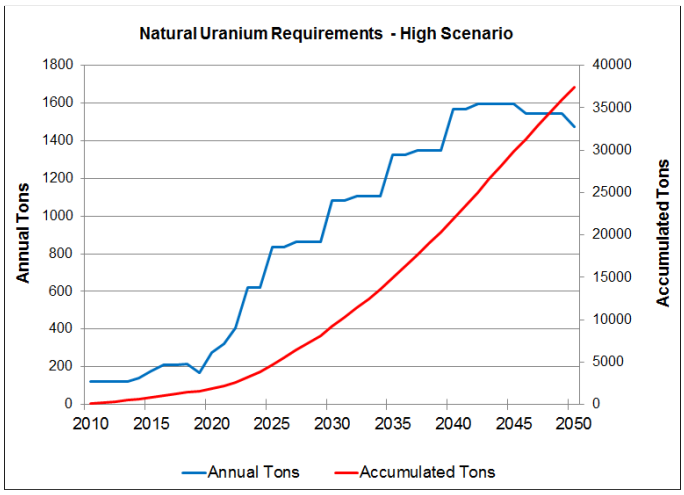


FIG. VI-4 Annual Requirement and cumulative natural uranium – High scenario.

VI-5.4. Uranium reserves status in Argentina

The requirements of uranium for the NPPs warrant particular attention, since by 2050 both scenarios project requirements to exceed 25 000 t of natural uranium.

There are different projects for exploration and production of CNEA fields specified in the CNEA Strategic Plan 2010–2019, developed by the areas of exploration and production of uranium resources. This plan contemplates a gradual replacement of imports with national production. However, it is necessary to analyze the availability and the intermediate processes of these projects. This means having an appropriate policy of public communication, essential to achieving societal consensus and clear legislation with a clear view focus on the production and the development of the regional economy.

Uranium reserves can be further distinguished.

Reasonably Assured Resources (RRA) are those for which size, shape, arrangement and tenor of the mineral are defined by specific tasks and the characteristics of similar deposits known in the same geological environment, so that its continuity and consistency are guaranteed.

Inferred Resources (IR) are those for which continuity exists on the basis of proven geology, but where specific tasks are deemed unsuitable for reaching the level of certainty of the RRA category. The U recoverable from delimited areas and costs of delineation and recovery are based on available sampling and knowledge of the known deposit characteristics, in the best explored areas or similar deposits neighbors in the same geological environment.

Finally, there are undiscovered resources (predicted and speculative), which are resources that are expected to appear based on geological knowledge previously discovered deposits and regional geological mapping. Both predicted and speculative resources require significant amount of exploration before its existence can be confirmed and laws and tonnages can be defined.

The status of uranium resources reported by the Exploration of Uranium Resources Management CNEA in Argentina, September 2012, is presented in the following Table VI-3, Table VI-4 and Table VI-5.

TABLE VI-3. STATUS OF URANIUM REASONABLY ASSURED RESOURCES.

Reasonably Assured Resources (tons U)					
Deposit Type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery Factor
Sandstone	2890	2890	4599	4599	72%
Volcanic	2240	2240	4000	4000	72%
Total	5130	5130	8599	8599	

TABLE VI-4. STATUS OF URANIUM INFERRED RESOURCES.

Inferred Resources (tons U)					
Deposit Type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery Factor
Sandstone	1951	2201	3763	4812	72%
Volcanic	480	1800	6170	6170	72%
Total	2431	4001	9932	10 982	

TABLE VI-5. STATUS OF URANIUM PROGNOSTICATED RESOURCES.

Prognosticated Resources (tons U)		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	13 810	13 810

Currently in different parts of the country CNEA continue to conduct searches and studies to identify and expand uranium mining reserves.

VI-5.5. Uranium enrichment in Argentina

The two currently operating NPPs in Argentina are PHWR technology, and a third PHWR will be launched in 2014. Although all were designed to use natural uranium, in case of Atucha I the reactor core was modified to use slightly enriched uranium (0.85% ^{235}U) reaching a burn-up increase of 80% and therefore a decrease of approximately 45% in fuel consumption.

The successful experience gained in modifying the fuel of Atucha I NPP could allow in the near future the modification of the Atucha II NPP due to the similar technology used in it.

In the medium term two more NPPs of foreign origin are expected to be incorporated, a PHWR-type which will have 2 reactors and a PWR-type that will have 1 or 2 reactors. The CAREM 25 (0.025 GW(e)) will also be incorporated, as well as the scaled model of this plant, the CAREM 150 (0.150 GW(e)), both with domestic design and construction and use of enriched uranium. Thus, while the current requirement for enriched uranium is low, it will be higher in the medium and long term.

According to this scenario, CNEA is working on uranium enrichment R&D for strategic reasons and for the security of the supply of enriched uranium to the national nuclear expansion.

CNEA is working on three different lines of work at different levels of progress. The first line is uranium enrichment using gaseous diffusion technology, which is consolidating and modernizing the technology. In parallel CNEA is working on the development ultracentrifugation technology process (study materials, rotors, magnetic couplings, etc. – without nuclear material yet), and conducting research on laser enrichment technology at laboratory scale.

All activities described are included in the CNEA Strategic Plan| 2010-2019 as objectives to accomplish during that period, and CNEA considers further that uranium enrichment technology to be used and the features for a plant-scale production should be defined by 2019. The enrichment plant capacity and year of production start will be defined by the end of this decade.

All these activities are carried out within the framework of peaceful uses of nuclear energy.

VI-5.6. Fuel reprocessing

Reprocessing activities in Argentina began in the 1960s. Since then several projects during the 1970's and 1980's reached different levels of progress.

Reprocessing Plant 1 (PR1)

The RP1 was designed, built and operated between 1965 and 1970 at the Ezeiza Atomic Center. PUREX[4] process was operated with mixer decanters as contactors. Installation successfully processed the first reactor core (RA1)[5], which consisted of aluminide fuel containing 20% enriched uranium with very low burning (~ 500 MWday/tHM). During that activity about 500 mg of high radionuclidic purity Pu was obtained in the plutonium-239 isotope.

The PR1 demonstrate the national capacity to separate and purify Pu from irradiated fuel in the 1960s, being an important milestone in the country's nuclear development. Later during the 1970s, the PR1 was dismantled, giving way to the Reprocessing Plant Project 2 (PR-2). The PR2 project was discontinued to make way Reprocessing Project Experimental Assembly (ERE) which was active between 1971 and 1977.

Radiochemical Processing Laboratory (RPL)

In 1977 the ERE project was abandoned to build the Radiochemical Processing Laboratory (LPR) which constitutes in a jump scale 1.5 times the ERE. Installation must operate with multiple flow-sheets PUREX process.

CNAI fuel reprocessing

Thirty three fuel elements per year, with a burn-up of 7000 MWday/tHM. Getting 5000 kg of reprocessed uranium and 15 kg of Pu per year.

MTR fuel reprocessing RA3

Fuels are based on AlU90 %. The construction of the plant LPR underwent successive delays until, in the late 1980s stopped, leaving without completing the assembly of some process lines and auxiliary systems.

Perspectives on activity

In 2008 CNEA instructed to restart activities to recover the ability to reprocess spent fuel. Given the possibility of having facilities suitable for hot process development on a small scale, these objectives were included in the CNEA Strategic Plan for 2011-2019.

The ability to reprocess was demonstrated at PR1 forty years ago. Today we must work to ensure the commitment to non-proliferation, study the management of actinides in advanced nuclear fuel cycles, study the management of fission products, and develop life-long treatment processes of nuclear waste in order to minimize the impact of the activity in the new generations.

Forming and sustaining a group of people trained in these issues will help to the authorities to make appropriate policy decisions when the time comes.

---

[4] Plutonium URanium EXtraction

[5] First Argentine reactor “national construction”, with a conceptual design of Argonaut type.

VI-6. INTERNATIONAL COOPERATION

VI-6.1. Argentina: nuclear profile

The Argentine Republic has a wide trajectory developing scientific and technological capabilities in the fields of peaceful uses of nuclear energy. CNEA was created on 31 May 1950 and thereafter gained a number of achievements that transform it in a benchmark at regional and worldwide levels.

Regionally, it actively participates in the Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL) and the Latin American Network for Education in Nuclear Technology (LANENT), both within the framework of the activities promoted by the IAEA. It also became a nuclear technology supplier in Latin-America, highlighting the relationships with countries such as Brazil, Cuba, Peru and Venezuela; and furthermore has developed capabilities in regional human resources training through its Academic Institutes.

This experience has positioned Argentina as an unquestioned point of reference country within Latin-America and has allowed an actively participation in Internationals Organisms such as the IAEA, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) Review Conference, the Nuclear Suppliers Group (NSG), the International Framework for Nuclear Energy Cooperation (IFNEC), the Nuclear Security Summit (NSS), and the Global Initiative to Combat Nuclear Terrorism (GICNT).

Its dedication for the responsible development of nuclear technology and its applications, with full respect for the non-proliferation regime and the interest to cooperate with other countries, is reflected in the celebration of an important quantity of intergovernmental and inter institutional agreements with their respective counterparts all over the Latin-American region.

VI-6.2. Argentina as a nuclear technology supplier

It's worth mentioning that along with the development of the national capabilities, Argentina has exported nuclear technology to the world, particularly to four Latin-American countries: Brazil, Cuba, Peru and Venezuela.

Research Reactors

Argentina's first large export in this field was the research reactor RP10 sold to Peru, designed and built for the Nuclear Energy Institute of Peru (IPEN) by CNEA and the Argentine company INVAP. This reactor started up at the end of the 1980s and has been used mainly for radioisotope production, as well as training for IPEN staff in material irradiation, reactor physics, applied research and nuclear engineering, and granting technology transfer.

The historical cooperation in the nuclear fields and the uses of nuclear energy with peaceful purposes, plus the experience gained from the creation of the Argentine-Brazilian Agency for the Accounting and Control of Nuclear Materials (ABACC) and the Binational Commission for Cooperation on Nuclear Energy (COBEN), makes the Argentine-Brazilian relationship a worldwide example on regional cooperation. The agreement between CNEA and CNEN for the construction of two "mirror" multipurpose research reactors, the Argentine RA-10 and the Brazilian RMB, can also be recognized. Both reactors are devoted to radioisotope production, fuel and materials irradiation tests, and research with neutron beams. With a power of 30 MW, both reactors have similar designs regarding the reactor systems and, especially, the instrumentation and control and neutron beams. At present, the basic engineering of the RMB will be provided by INVAP and the contract has been already signed,

while CNEA has advanced on the basic engineering of the RA-10 and at the moment this phase is completed.

Other nuclear installations

Argentina not only has demonstrated its exportable technological capabilities regarding research reactors, but also has developed important commercial ties concerning radioisotope production plants and other nuclear medicine installations. Examples include the design, construction and commissioning of a Radioisotope Production Plant to Cuba in 1996 to produce and fractionate isotopes at the Nuclear Affairs Secretary requirements. This work was executed by CNEA and INVAP through joint technical participation and collaboration during all the installation stages and this way, favouring technology transfer, operation, and license of the exported facility.

On the other hand, in the case of the Republic of Venezuela – a country with strong bilateral cooperation ties over the last years – Argentina provided 19 Radiation Therapy Centers to hospitals of different cities of Venezuela under the "turnkey" system, including parts and the maintenance of the installations and equipment.

Further examples include the signature with Brazil of the Intention Letter to provide Radioisotopes to that market by 2009. Through its National Atomic Energy Commission (CNEA), Argentina provides molybdenum-99 (Mo-99) for cancer diagnosis and treatment, covering more than the third part of Brazil's internal demand through the shipment of 200 Ci (Curies) per week. The CNEA is one of the world's leading producers of Mo-99, developing the process based on the use of low enriched uranium (LEU) in the targets unlike the rest of the producers which use highly enriched uranium (HEU).

VI-6.3. Experience in human resources training

Since its origins, and in support of the requirements of the National Nuclear Plan, CNEA has taken the responsibility to build capacities for high specialized human resources training in strategic areas of the nuclear sector, the national scientific and technological system and the national productive system. Accordingly, CNEA, together with two National universities, have created three Academic institutes: Balseiro Institute, Sábato Institute and Dan Beninson Institute. Scientists and technicians at these institutes teach and research with local and foreign students, allowing a close connection between teachers, students and workers, with a permanent access to the labs, equipment and experimental facilities.

Balseiro Institute

The Balseiro Institute is located in Bariloche Atomic Center (CAB). It was founded in April 1955 and has an academic association with the National University of Cuyo. Since its creation, it has acquired great expertise on training professionals in the areas of Physics and Engineering.

The under-graduate courses offered by the Institute include Physics and Nuclear, Mechanical and Telecommunications Engineering. There are also postgraduate courses in the disciplines mentioned above and in Engineering Sciences, Masters in Physical Sciences, Engineering and Medical Physics, and the latest course being offered together with FUESMEN.

Furthermore, CNEA created the CEATEN, a specialization course in Nuclear Technology Applications. This course provides basic knowledge about technological applications of nuclear energy to professional that will perform their work in areas related to the peaceful uses of nuclear energy. This degree is awarded jointly by the University of Cuyo and the University of Buenos Aires.

At the moment, the Institute has an interesting and attractive scholarship system which provides opportunities for potential students and professionals of Latin America, reflected in the large number of applicants showed in the last years: Only in 2012 the Balseiro Institute received more than 15 students from Bolivia, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Peru, Uruguay and Venezuela.

Last but not least, on 16 September 2009, the IAEA nominated the Balseiro Institute as an "IAEA Collaborating Centre for Human Resources Development for Nuclear Technologies and their Applications", the only one in Latin America with such distinction. The CAB, IB and IAEA have signed an agreement for the use of RA-6 Research Reactor as an "Online Regional Reactor" for human resources training.

Sabato Institute

The Sabato Institute is located in Constituyentes Atomic Center. Based on the Pan-American Course on Nuclear Metallurgy given for the first time in 1962, CNEA founded this Institute in 1993. It has an academic association with the National University of San Martín.

The Sabato Institute constitutes a teaching structure that sustains and reinforces the technological and scientific projects carried out by CNEA, as well as the requirements form industrial companies and R+D institutes within their scope. Apart from the undergraduate course in Materials Engineering, this Institute offers specializations in science and technology (Physics and Material mentions) and in Non-Destructive Tests.

Dan Beninson Institute

The Dan Beninson Institute is located in Ezeiza Atomic Center (CAE) and it was founded in 2006 by means of an agreement between CNEA and the National University of San Martín. The main aim of this Institute is to train human resources in nuclear technology, encouraging creativity and critical analysis in this field and stimulating the necessary bondage among diverse fields of action within science and technology.

The Degree in Nuclear Applications leads, together with the specialization in Nuclear Technology, the academic offering of this Institute, which also includes specializations in Radiochemistry and Nuclear Applications, Nuclear Reactors and Nuclear Fuel Cycle, Radionuclides, PET/CT for Nuclear Medicine Technicians and Radiotherapy Dosimetry.

Nuclear Medicine School Foundation (FUESMEN)

The Nuclear Medicine School Foundation (FUESMEN) located in the Province of Mendoza was created by CNEA after a strong experience with the first Postgraduate School in nuclear medicine and radioisotopes in 1986. The interest in promoting some applications of nuclear energy regarding health, allowed this Institution to provide academic and technical infrastructure to ensure the creation of an area of excellence.

In this sense, the initiative was jointly organized with the Cuyo National University and the Government of the Province of Mendoza in 1999, giving to FUESMEN the experience of human resources and advanced equipment. Today this Centre has the international recognition and becomes an Institute of Reference in the field of Nuclear Medicine and Diagnosis for being the first one in Latin America.

RA-6 online project

On 12 April 2013, the IAEA Department of Nuclear Energy and CNEA signed an Agreement on the Internet Reactor Laboratory (IRL) Project in Latin America. It is expected to use the RA-6 as an on-line training tool for regional students. The project objective is to

endow CNEA, Latin America and the Caribbean with an educational and/or distance training tool that contributes to human resources formation in nuclear engineering based on the RA-6 remote access.

To achieve this objective, the research reactor RA-6 uses signs that allow, through the internet, the monitoring and realization of typical nuclear reactor experiences focused on training in instrumentation and control, critical focus, calibration of control rods (drop rods), temperature coefficient of reactivity and void coefficient calculation. This system allows the students and teachers of local institutions or countries of the region that do not have research reactor facilities to obtain online experience and training in the area of Physical Reactors, having the possibility to be in contact with facilities of this type.

The Project uses the infrastructure of CNEA in the Bariloche Atomic Center and the Nuclear Engineering Area for the training in undergraduate and postgraduate courses of Human Resources in the country and in the region, increasing the possibilities and opportunities of success in nuclear reactors fields. For example, Cuba, Uruguay and Ecuador have been interested in being part of the Project, participating as users of the system in the framework of their University Nuclear Engineering Programs.

Nuclear perspectives for the Latin American region

Argentina's experience in nuclear technology, along with its commitment in regional cooperation, has positioned the country as a reference in Latin America and as a partner with other countries that opt for the peaceful development of nuclear energy and its different applications. In this direction, the country has prioritized technology transfer as an important issue to consolidate regional integration.

Argentina has maintained a clear policy considering different degrees of development of the counterpart. On one hand, Argentina has established relationships with countries of similar relative development for the purpose of strengthening collaboration, integration and complementation searching for synergies and scale economies; on the other hand, it has established relationships with less developed countries to support cooperation and technical assistance in the field of bilateral and multilateral outreach projects. This pattern allows fostering the Argentine knowledge of nuclear technology abroad and opens new possibilities in potential regional nuclear programs. Governmental and institutional agreements in the nuclear field are strong milestones for the country, providing a political and legal framework to promote joint scientific and technological activities.

Argentina has adopted the South–South Cooperation as a philosophical matrix of its international nuclear policy. This bilateral nuclear cooperation with Latin American countries contributes to the consolidation of integration mechanisms, promoting better understandings and advancing together to ensure mutual benefits and regional symmetries.

Argentina's international cooperation in the nuclear field is consistent with the commitment and willingness to promote the peaceful use of such energy in strict compliance with international legislation and based on national capacities achieved. Human resources training is the strategic asset and cornerstone of technological development. Academic institutes and universities have strengthened their educational programs in order to educate and train a large number of students in various disciplines both nationally and regionally. Regarding this, Argentina and its international referenced institutes have received many Latin American and Caribbean students for specializations and develop practice.

VI-6.4.INTERGOVERNMENTAL AGREEMENTS

TABLE VI-6. INTERGOVERNMENTAL AGREEMENTS OF ARGENTINA.

AGREEMENT	YEAR	COUNTRY
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Bolivia"	1970	Plurinational State of Bolivia
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Federative Republic of Brazil"	1980	Federative Republic of Brazil
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Chile"	1976	Republic of Chile
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Colombia"	1967	Republic of Colombia
"Memorandum of Understanding between the Nuclear Energy Agency of the Republic of Cuba and the Atomic Energy Commission of Argentina"	2009	Republic of Cuba
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Ecuador"	1977	Republic de Ecuador
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Guatemala"	1986	Republic of Guatemala
Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the United States of Mexico".	2002	United States of Mexico
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Paraguay".	1967	Republic of Paraguay
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Republic of Peru".	1968	Republic of Peru
"Agreement on cooperation in the peaceful uses of nuclear energy between the Republic of Argentina and the Eastern Republic of Uruguay".	1968	Eastern Republic of Uruguay
"Complementary Agreement of scientific cooperation between the Republic of Argentina and the Republic of Venezuela in the peaceful uses of nuclear energy"	1979	Bolivarian Republic of Venezuela

VI-6.5.INTERINSTITUTIONAL AGREEMENTS.

TABLE VI-7. INTERINSTITUTIONAL AGREEMENTS OF ARGENTINA

AGREEMENT	YEAR	COUNTRY
"Memorandum of Understanding between the Minister of Federal Planning, Investments and Services of the Republic of Argentina and the Minister of Hydrocarbon and Energy of the Plurinational State of Bolivia".	2013	Plurinational State of Bolivia
"Cooperation Agreement between the Atomic Energy Commission of the Republic of Argentina and Brazilian Nuclear Companies (by succession from 1988 Nuclear Industries of Brazil) of the Federative Republic of Brazil"	1980	Federative Republic of Brazil
"Industrial Cooperation Protocol between the Atomic Energy Commission of the Republic of Argentina and Brazilian Nuclear Companies (by succession from 1988 Nuclear Industries of Brazil) of the Federative Republic of Brazil"	1980	
"Technical Cooperation Protocol between the Atomic Energy Commission of the Republic of Argentina (by transfer from 1994: Nucleoeléctrica Argentina S.A) and FURNAS Centrais Elétricas of the Federative Republic of Brazil".	1993	
"Letter of Intent on the Pacific Uses of Nuclear Cooperation between the Atomic Energy Commission of the Republic of Argentina (CNEA) and the Nuclear Energy Commission of the Federative Republic of Brazil (CNEN)"	2009	
"General Disposals between the Atomic Energy Commission of Argentina (CNEA) and the Nuclear Energy Commission of Chile (CCHEN) regarding the Agreement between the Government of the Republic of Argentina and the Republic of Chile for the cooperation in the peaceful uses of Nuclear Energy".	1990	Republic of Chile
"Letter of Intent between the Nuclear Affairs Institute and the Atomic Energy Commission (CNEA)"	1982	Republic of Colombia

TABLE VI-7. INTERINSTITUTIONAL AGREEMENTS OF ARGENTINA (cont.)

AGREEMENT	YEAR	COUNTRY
"Memorandum of Understanding between the Atomic Energy Commission (CNEA) and the Nuclear Energy and Advanced Technologies Agency (AENTA)".	2009	Republic of Cuba
"Memorandum of Understanding between the Ministry of Electricity and Renewable Energy of the Republic of Ecuador and the Ministry of Federal Planning, Federal Investment and Services".	2008	Republic of Ecuador
"Cooperation Agreement between the Atomic Energy Commission and the Ministry of Science and Technology".	2005	Bolivarian Republic of Venezuela

VI-7. GENERATION IV REACTORS - COMPARATIVE ASSESSMENT

In this section, the current situation of the worldwide nuclear technology development is presented and a group of advanced concepts is assessed (Generation IV reactors) which are of interest to Argentina due to the reasons to be presented.

A comparative assessment will be presented in the following paragraphs to determine which of the six types of Generation IV reactors are more important to have a follow-up in order to assess if they will potentially become part of the future Argentine energy mix.

Consequently, the areas of assessment will be identified and specific indicators will be developed to value the performance of each type of reactor in said areas.

VI-7.1.Introduction

The Argentine Atomic Energy Commission studies and takes an interest in analyzing worldwide perspectives and tendencies towards advanced reactors and their fuel cycles. In line with this, the Argentine Atomic Energy Commission Strategic Plan 2010-2019 [VI-16] presented the following objectives in the area of nuclear power plants:

- Strategic objective 3: Implement a follow-up program of new Generation IV nuclear reactors and their fuel cycles technologies to evaluate and create related research and development lines.
- Specific objective 3.1: Conduct studies and evaluations so as to define the Generation IV Argentine major interest's line(s).
- Specific objective 3.2: Promote the participation in international projects through the collaboration in specific projects.
- Specific objective 3.3: Develop experimental facilities.

In relation to the Specific objective 3.1, in March 2010, an ad-hoc working group (Working Group Generation IV) was formed by professionals of the following Sections from the Department of Nuclear Energy (GAEN, by its Spanish acronym): Reactors and Nuclear Power Plants Section (DERC), Reactors Physics and Radiation Section and Materials Division. Also the group is formed by professionals from the Research and Non-Nuclear Applications Department (GAIyANN, by its Spanish acronym) and the Nuclear Fuel Cycle Section (GCCN, by its Spanish acronym). The objective of the working group was to draft a report [VI-17] to comparatively assess the six concepts of Generation IV of the GIF project in order to conclude with recommendations to define the Generation IV technological line(s) to set the basis for a future investment on the part of CNEA in economic and human resources.

VI-7.2. Assessment methodology

The GIF Project selected 6 concepts of nuclear reactors [VI-18], known as Generation IV, fulfilling requirements of sustainability (efficient use of uranium reserve and minimal generation of nuclear waste), enhanced safety and reliability, efficiency, economics, proliferation resistance. These concepts are:

- Sodium Fast Reactor (SFR);
- Lead Fast Reactor (LFR);
- Gas Fast Reactor (GFR);
- Supercritical Water Reactor (SCWR) in its fast and thermal version;
- Very High Temperature Reactor (VHTR); and,
- Molten Salt Reactor (MSR).

The main characteristics of these designs are presented in Table VI-8 [VI-17].

The methodology applied to conduct a comparative assessment of these concepts is inspired in the one presented in the IAEA-TECDOC 1434 “Methodology for the Assessment of Innovative Nuclear Reactors and Fuel Cycles” [VI-19] developed by INPRO. This methodology is based on a series of requirements known as “indicators” which are the parameters selected to assess the performance of a nuclear system for a particular area of interest.

The areas of interest selected to assess the reactors were as follows:

- Viability of the concept;
- Design and nuclear safety;
- Economics;
- Proliferation resistance;
- Sustainability;
- Fuels;
- Reprocessing;
- Materials;
- Balance of plant (BoP).

The indicators for each area have a value on a scale of 1 to 6, for which 6 means an optimum performance and 1 a comparatively deficient performance.

As six reactors are compared, the assessment of an indicator may result in values such as: 6,6,6,6,6,6 (in case 6 reactors are optimum for that indicator); 1,1,1,1,1,1 (if the 6 reactors were significantly deficient in the comparison), or any other combination of different values (such as 6,5,4,4,3,1) that reflects the individual qualification of each indicator. The example is shown in Table VI-9.

TABLE VI-8. MAIN CHARACTERISTICS OF GENERATION IV REACTORS

Characteristics per reactor	VHTR	GFR	SFR	SCWR	LFR	MSR
Spectrum	Thermal	Fast	Fast	Thermal / Fast	Fast	Fast
Coolant	He	He	Na liquid	H_2O supercritical	Pb liquid	Molten salts
Primary temperature, ºC	900-1000	850	550	510-625	480-800	700-800
Primary pressure, atm	70	70	1	250	1	1
Power, GW(e)	0.25-0.30	1.20	0.03-1.50	0.30-1.50	0.02-1.20	1.00
Fuel	- TRISO - UO_2	- Plate / rod - MOX UC-N	- Rod - MOX	- Rod - UO_2	- Rod - MOX	Molten salt: LiF-UF_4-PuF_3
Burn-up, MWday/t	150 000 / 200 000	140 000	150 000	45 000	100 000 / 150 000	---
Fuel cycle	open	closed	closed	open / closed	closed	closed
Thermal efficiency, %	50	50	42	44	42 / 44	50
Thermal cycle	Brayton (He)	Brayton (He)	Brayton or Rankine	Rankine H_2O superc.	Brayton or Rankine	Brayton (He)

TABLE VI-9. EXAMPLE OF CHART FOR COMPARATIVE ASSESSMENT

Indicators	Coefficient	SFR	GFR	LFR	SCWR	VHTR	MSR
Ind. X.1.	1	6	5	3	3	5	2
Ind. X.2.	1	4	5	4	2	3	5
Ind. X.3.	2	10	8	8	6	6	4
Sum		20	18	15	11	14	11
Normalized sum		0.83	0.75	0.63	0.46	0.58	0.46

The value of each indicator was multiplied by a relevant coefficient to specify its relative importance before other indicators of the area.

In order to assess performance, in each area a comparative chart was built as shown in Table VI-10. In the columns, there were 6 reactors and, in the lines, there appear all the indicators for each reactor in the area. In the last line of the chart, the value of each column was added up, which is the value of the indicators for each reactor. The resulting value for

each reactor is used to measure the comparative performance. Finally, the addition is normalized to the unit to compare and add up different areas.

TABLE VI-10. AREA OF VIABILITY OF THE CONCEPT

Areas	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
					F	T		
International cooperation	1	4	2	2	2	1	4	1
Level of progress	1	6	4	6	1		5	1
Experience in operation	1	6	1	2	1		5	2
					F	T		
Proven systems/technologies	1	5	3	2	2	3	5	2
					F	T		
Sum		21	10	12	6	6	19	6
					F	T		
Normalized sum		0.88	0.42	0.50	0.25	0.25	0.79	0.25

VI-7.3. Assessment results per area

The comparative assessment conducted in each area of interest shows the results to date which are detailed in the following items [VI-17, VI-18 and VI-20 – VI-29].

VI-7.3.1. Viability of the concept

The indicators selected in this area were as follows:

- International cooperation: defined by taking into account the number of Member States of the GIF Project participating in the concept development considered;
- Level of progress: the level of progress of different concepts was evaluated taking into account milestones such as construction of an NPP, construction of a prototype and projects under execution;
- Experience in operation: it was assessed whether there was background of reactors built by following the technological line of each of the concepts or not;
- Systems/proven technologies: defined by taking into account the level of development of systems or technologies used in different concepts and to what extent these have been proved even at an experimental level.

In Table VI-10, the assessment result in this area is presented. The order of merit of the reactors is the following: SFR, VHTR, LFR, GFR, SCWR (T), SCWR (F) and MSR.

VI-7.3.2. Design and nuclear safety

The indicators selected in this area were the following:

- Number of barriers to release fission products to the environment: the number of physical barriers was taken into account which is present in each of the concepts to prevent fission products release to the environment;
- Reactivity coefficients: the reactivity coefficients of different concepts were assessed;
- Excess reactivity: the average excess reactivity of each concept was assessed taking into account fissile material enrichment and the scheme of fuel refill;
- Use of passive safety systems: the level of use of safety passive system was assessed;
- Coolant efficiency: the coolant capacity to extract heat was assessed by means of the parameters of density, specific heat and thermal conductivity and the necessary power for its circulation by means of parameters of dynamic viscosity and density;
- Stability of the coolant phase: the coolant capacity not to change phases in case of changes of pressure and temperature of the system was assessed; fission temperatures and boiling temperature of each coolant were taken into account;
- Chemical reactivity of coolant/toxicity/activation: the coolant chemical reactivity with the elements of the environment, water and air, its toxicity and its neutron activation degree was assessed;
- Operation pressure: the operation pressure of the different concepts was taken into account considering those that require high operation pressures at a disadvantage;
- Inspection capacity: the inspection capacity was considered and the radioactivity level, coolant opacity and transparency were taken into account.

In Table VI-11, the result of the assessment in this area is shown. The order of merit of reactors is the following: VHTR, LFR, SFR, SCWR (F), SCWR (T), GFR and MSR.

TABLE VI-11. NUCLEAR SAFETY AND DESIGN AREA

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
Number of barriers to prevent fission products release	4	24	24	20	20		20	8
Reactivity coefficient	3	6	9	18	18		15	18
Excess reactivity	2	8	8	8	F	T	6	12
					8	6		
Use of passive safety systems	3	12	3	12	12		18	15
Coolant efficiency	2	12	2	8	6		2	10
Coolant phase stability	3	9	18	6	9		18	6
Coolant chemical reactivity/toxicity/activation	2	8	12	8	8		12	4

TABLE VI-11. NUCLEAR SAFETY AND DESIGN AREA (cont.)

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
Operating pressure	1	6	2	6	1		2	5
Inspection capacity	1	2	5	3	4		5	1
Sum		87	83	89	F	T	98	79
					86	84		
Normalized Sum		0.69	0.66	0.71	0.68	0.67	0.78	0.63

VI-7.3.3. Economics

The indicators selected in this area were the following:

- Simplicity in the balance-of-plant (BoP) design: the level of simplicity of the BoP was taken into account, considering that the greatest simplicity favours the concept from an economic viewpoint. The cycle may be direct, indirect or tertiary and, at the same time, simple or combined in a decreasing order of simplicity. “Combined” means the case in which a Brayton cycle along with a Rankine fit in the BoP;
- Simplicity in the systems design: the complexity of the safety and process systems were taken into account, considering that the requirement of a lower number of systems and its simplicity favour the concept from an economic viewpoint;
- Thermal efficiency: a greater thermal efficiency of the BoP favours the concept from an economic viewpoint;
- Interval between fuel refills: a longer duration of the cycle between fuel refills increases the availability of the plant, which favours it from an economic viewpoint;
- Capacity to produce fissile material: the capacity of each concept to produce fissile material was assessed by taking into account the type of spectrum. As long as the conversion factor equals or exceeds the unit, a more efficient use of fissile material will be done improving the economy of the related fuel cycle;
- Other applications: the capacity of each concept was taken into account to produce hydrogen or heat of processes and/or to transmute actinides aside from producing electricity;
- Burn-up: the average burn-up of extraction of every concept was taken into account considering that a higher level of burn-up means more energy extracted per mass unit of fuel material.

Table VI–12 presents the result of the assessment in this area. The order of merit of the reactors has been: GFR, VHTR, LFR, MSR, SCWR (F), SFR and SCWR (T).

VI-7.3.4. Sustainability

The indicators selected in this area were the following:

- Volume of waste;
- Breeding capacity of fissile material.

In Table VI–13, the assessment result is presented in this area. The order of merit of the reactors is the following: MSR, SFR, GFR, LFR, SCWR (F), SCWR (T) and VHTR.

TABLE VI-12. AREA OF ECONOMICS

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
Simplicity in the BoP design	1	2	4	4	3		4	2
Simplicity in the system design	1	3	3	3	4		4	1
Thermal efficiency	1	4	5	4	F	T	6	4
					4	5		
Interval between two fuel refills	1	5	5	5	F	T	6	6
					5	6		
Fissile material breeding capacity	1	6	6	6	F	T	1	6
					6	1		
Other applications (transmutation/hydrogen)	1	3	6	4	F	T	4	4
					3	1		
Burn-up	1	5	4	5	F	T	6	6
					4	3		
Sum		28	33	31	F	T	31	29
					29	23		
Normalized sum		0.67	0.79	0.74	F	T	0.74	0.69
					0.69	0.55		

TABLE VI-13. AREA OF SUSTAINABILITY

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
Waste volume	1	5	5	5	F	T	1	6
					5	1		
Fissile material production	1	6	6	6	F	T	1	6
					6	1		
Sum		11	11	11	F	T	2	12
					11	2		
Normalized sum		0.92	0.92	0.92	0.92	0.17	0.17	1

VI-7.3.5. Proliferation resistance

The indicators selected in this area were the following:

- Necessary degree of enrichment;
- Breeding capacity of fissile material.

In Table VI-14, the assessment result in this area is presented. The order of merit of reactors is the following: SCWR (T), VHTR, MSR, SFR, GFR, LFR and SCWR (F).

TABLE VI-14. AREA OF PROLIFERATION RESISTENCE

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
					F	T		
Enrichment level	1	2	2	2	1	5	3	6
					F	T		
Breeding of fissile material	1	3	3	3	3	6	6	3
Sum		5	5	5	4	11	9	9
Normalized sum		0.42	0.42	0.42	0.33	0.92	0.75	0.75

VI-7.3.6. Fuels

The indicators selected in this area were the following:

- Experience in the use of the compound: this indicator stresses the difference between information and practical experience in the use of the different compounds;
- Fuel manufacturing: the level of complexity in the fuel element manufacture is assessed;
- Thermal demand: it is assessed the fact that in each reactor there will be particular conditions of temperature profiles and heat transfer;
- Demand to the cladding: this indicator is key in the design since greater efforts in research and development in Generation IV reactors are devoted to materials and particularly to the cladding material;
- Capacity to retain fission products: the capacity of fuel elements to retain gaseous fission products is assessed;
- Modelling feasibility.

In Table VI–15, the assessment result is presented in this area. The order of merit of reactors is the following: VHTR, SFR, SCWR, MSR, GFR and LFR.

VI-7.3.7. Reprocessing

The indicator selected in this area was the following:

- Reprocessing process: the available knowledge of this technology is assessed, which is associated to different fuels of the six reactors.

In Table VI-16 the assessment result is presented in this area. The order of merit of the reactors has the following result: SCWR, SFR, LFR, MSR, GFR and VHTR.

TABLE VI-15. AREA OF FUELS

Indicators	Coefficient	SFR	GFR	LFR	SCWR	VHTR	MSR
Experience in the use of the compound	1	6	3	2	6	6	1
Fuel fabrication	1	4	2	3	4	4	5
Thermal demand	1	4	4	5	4	5	6
Demand to the cladding	1	5	5	4	3	5	6
Capacity to retain fission products	1	4	5	4	4	6	3
Modelling feasibility	1	3	3	4	3	3	3
Sum		26	22	22	24	29	23
Normalized sum		0.72	0.61	0.61	0.67	0.81	0.64

TABLE VI-16. AREA OF REPROCESSING

Indicator	Coefficient	SFR	GFR	LFR	SCWR	VHTR	MSR
Reprocessing	1	5	2	5	6	2	3
Normalized sum		0.83	0.33	0.83	1	0.33	0.5

VI-7.3.8. Materials

In the area of Materials, the assessment was developed by means of preparing three charts of the three following sub-areas:

A. Conditions of service, by which were designed the following indicators:

- Resistance to high temperature: the severity of the operating conditions is taken into account in relation to the temperature for different designs.
- Resistance to radiation: the severity of the operating conditions is taken into account in relation to the radiation field.
- Coolant corrosion: the relative corrosion of different coolants is taken into account.

In Table VI-17, the result of the assessment is shown in the sub area Conditions of Service of the Area of Materials. The order of merit of reactors is the following: SCWR (T), SFR, GFR, SCWR (F), VHTR, LFR and MSR.

B. Property of materials, considering the following characteristics:

- Fragility,
- Rendered by irradiation,
- Swelling,
- Stress corrosion cracking (SCC),
- Fluence,

- ASCC (Reduction in radiation fields and minimization of irradiation assisted stress corrosion cracking),
- Oxidation,
- Helium fragility.

These properties were assessed for materials in cladding, in the core and outside the core.

In Table VI-18, the result of the assessment is presented in the sub area Properties of the Materials of the Area of Materials. The order of merit of reactors is the following: VHTR, MSR, SCWR, SFR, GFR and LFR.

TABLE VI-17. SERVICE CONDITIONS AREA OF MATERIALS

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
Resistance to high temperature	1	5	2	4	5		1	3
Resistance to radiation	1	2	4	3	F	T	5	1
					3	5		
Coolant corrosion	1	4	5	2	3		5	1
Sum		11	11	9	F	T	11	5
					11	13		
Normalized sum		0.61	0.61	0.50	F	T	0.61	0.28
					0.61	0.72		

TABLE VI-18. PROPERTIES OF MATERIALS AREA OF MATERIALS

Indicators	Coefficient	SFR	GFR	LFR	SCWR	VHTR	MSR
Cladding	1	4	3	4	4	4	-
In the core	1	3	4	3	4	4	4
Outside the core	1	3	3	3	3	4	4
Sum		10	10	10	11	12	8
Normalized sum		0.55	0.55	0.55	0.61	0.66	0.66

C. Needs of research and development (R&D), taking into account just the following indicator:

- Necessary efforts in R&D of materials: a value of 6 states that future research is not deemed necessary and a value of 1 states that there has been no progress in the selection of materials.

In Table VI-19, the assessment result is presented in the sub area of Needs for Research and Development in the Area of Materials. The order of merit of reactors is the following: SFR, GFR, VHTR, LFR, SCWR (T), SCWR (F) and MSR.

In Table VI-20, the final results are presented for the area of Materials taking into account the results obtained in the areas of Conditions of Service, Properties of Materials and

Needs for Research and Development. The final order of merit in the area of Materials has been: SFR, VHTR, SCWR (T), GFR, LFR, SCWR (F) and MSR.

TABLE VI-19. NEEDS FOR R&D AREA OF MATERIALS

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
					F	T		
Necessary efforts of materials R&D	1	5	4	3	2	3	4	2
					F	T		
Sum		5	4	3	2	3	4	2
					F	T		
Normalized sum		0.83	0.66	0.5	0.33	0.5	0.66	0.33

TABLE VI-20. AREA OF MATERIALS

Indicators	SFR	GFR	LFR	SCWR		VHTR	MSR
				F	T		
Conditions of service	0.61	0.61	0.50	0.61	0.72	0.61	0.28
Properties of materials	0.55	0.55	0.55	0.61	0.61	0.66	0.56
Needs for R&D	0.83	0.66	0.5	0.33	0.5	0.66	0.33
Average	0.66	0.61	0.52	0.52	0.61	0.64	0.42

VI-7.3.9. Balance of plant

The indicators selected in this area were the following:

- Simplicity of the cycle design
- Level of progress
- Thermodynamic efficiency
- Safety in case of a chemical reaction

The assessment result in this area is presented in Table VI-21. The order of merit of reactors is the following: VHTR, GFR, SCWR (T), SCWR (F), LFR, SFR and MSR.

VI-7.3.10. Final results and conclusions

In Table VI-22, the final results to date are presented with regards to the comparative assessment [VI-17, VI-18 and VI-20–VI-29] between the six concepts of Generation IV reactors selected by the GIF project taking into consideration the nine areas dealt with in the previous sub-sections.

TABLE VI-21. AREA OF BALANCE OF PLANT

Indicators	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
					F	T		
Simplicity of the cycle design	1	3	5	5	4	4	5	3
					F	T		
Level of progress	1	3	2	1	2	2	3	1
					F	T		
Thermodynamic efficiency	1	4	5	4	4	5	6	4
					F	T		
Safety in chemical reaction	1	3	6	4	5	5	6	4
					F	T		
Sum		13	18	14	15	16	20	12
					F	T		
Normalized sum		0.54	0.75	0.58	0.63	0.67	0.83	0.5

TABLE VI-22. FINAL RESULTS

Areas	Coefficient	SFR	GFR	LFR	SCWR		VHTR	MSR
					F	T		
Viability of the concept	2	0.88	0.42	0.50	0.25	0.25	0.79	0.25
Nuclear safety and design	3	0.69	0.66	0.71	0.68	0.67	0.78	0.63
Economics	2	0.67	0.79	0.74	0.69	0.55	0.74	0.69
Sustainability	2	0.92	0.92	0.92	0.92	0.17	0.17	1.00
Proliferation resistance	2	0.42	0.42	0.42	0.33	0.92	0.75	0.75
Fuel	3	0.72	0.61	0.61	0.67	0.67	0.81	0.64
Materials	2	0.66	0.61	0.52	0.52	0.61	0.64	0.42
Reprocessing	2	0.83	0.33	0.83	1.00	1.00	0.33	0.50
Balance of plant	1	0.54	0.75	0.58	0.63	0.7	0.83	0.50
Sum		13.52	11.54	12.40	12.09	11.72	12.44	11.53
Normalized sum		0.71	0.61	0.65	0.64	0.62	0.65	0.60

Considering that a relative importance coefficient was assigned to each area, the final sum of qualifications resulted in the following order of merit: 1: SFR, 2: LFR and VHTR, 3: SCWR (F), 4: SCWR (T), 5: GFR and 6: MSR.

In accordance with the results presented in Table VI-22 and Fig. VI-5, the following can be inferred:

- All the concepts assessed have a good overall performance.
- The highest score corresponds to SFR. Its overall performance was better than the rest of the concepts of GIF taken into account, which in this sense is the one with widest operational experience currently gained, also the result of the excellent sustainability characterizing fast reactors.
- The second highest score corresponds to LFR and VHTR. In the case of LFR, there is a current significant number of related R&D projects along with plans to build prototype reactors in the mid term
- For VHTR, this score is achieved mostly due to the excellent performance foreseen of its fuel and its quick answer shown to mitigate severe accidents. However, since it is a thermal reactor, its performance in the area of Sustainability is quite poorer than the one of LFR since, in comparison to the fast reactors, it makes a poorer use of the natural resources of fissile materials due to its lower conversion factor. The major interest in this reactor is a result of its high temperature of gas outlet from the primary circuit that enables its use for hydrogen production and heat of processes that require high temperatures.
- The third score is assigned to SCWR (F). It has an average performance with respect to the rest of the concepts. However, it is worth mentioning that it has the lowest partial score in quite an important area such as Viability of the Concept. Notwithstanding, it has an important advantage which is the fissile material production which is reflected in its high score in the area of Sustainability.
- The fourth score is the SCWR (T). As in the case of the SCWR (F), it has an average performance in comparison to the other reactors. However, as it is a thermal reactor, its performance in the area of Sustainability is quite lower than the performance of assessed fast reactors.
- The fifth score is GFR. It has an average overall performance as in the case of the previous three reactors, resulting in an outstanding score in the areas of Economics and Sustainability.
- The lowest score corresponds to MSR. It has an average performance in the several areas that were taken into account. Even though it has a high score in the area of Sustainability, it currently presents the lowest partial score in important areas such as Viability of the Concept and Materials.

It is highly probable that the results of this work will be kept in the mid-term. However, research and development programmes related to the concept of Gen IV reactors are under performance and one of the GIF objectives is the update of its Technology Roadmap [VI-18]. Therefore, there could be possible changes in the future as a consequence of the results obtained.

It is important to highlight that the thermal reactors VHTR and SCWR(T) make a less efficient use of the natural resources of fissile material and its performance is lower than those fast reactors assessed in the important area of Sustainability. The fast reactors may have a conversion factor greater than 1 even though it would be considered 1 in the context of GIF.

As stated before, the strategic objectives defined in the area of power reactors in the Argentine Atomic Energy Commission Strategic Plan [VI-16] are worth mentioning:

Therefore, and as mentioned in the introduction, this assessment and its results correspond particularly to the Specific objective 3.1. Within that scope, it is advisable to continue with the follow-up of these new technologies to update the related research and development.

Graphic presentation of the final results is provided in Section VI-7.

VI-8. FIGURES

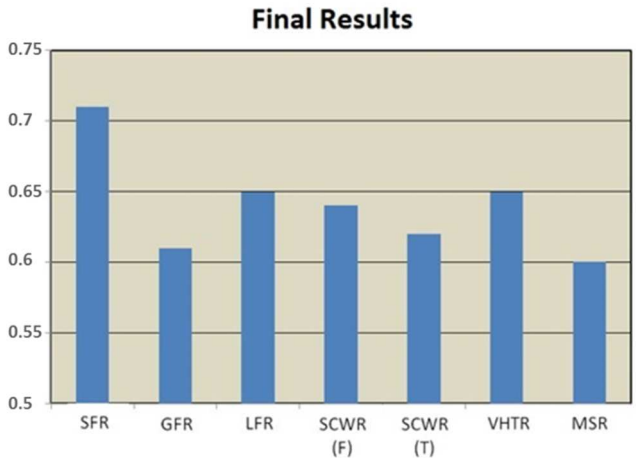


FIG. VI-5. Final results.

VI-9. CONCLUSIONS

Since the creation of CNEA in 1950, Argentina has maintained a policy of national development through the training of human resources and research and development of technologies for peaceful uses of nuclear energy. The socioeconomic volatility the country has experienced slowed some of the activities carried out in the field, but the direction of local development was never lost.

The experience gained through the increased participation of local companies involved in the construction and operation of NPPs is an example of that. If this strategy continues in the future, Argentina can reach the capacity to build nuclear power plants of foreign design. Also Argentina currently has the productive capacities of all stages of its current nuclear fuel cycle.

When the national NPP CAREM 25 (0.025 GW(e)) starts operating in the near future, the country will have consolidated the power reactor technology, and will open a new era in which this prototype can scale to higher core power and that NPP will be the CAREM 150 (0.150 GW(e)).

The scenarios presented in Section VI-6 indicate that it will require an amount of nuclear installed capacity between 6.620 GW(e) and 10.370 GW(e) to achieve the objectives in the medium and long term, and as observed the amount of CAREM 150 projected could cover between 8% and 11% of the power required, so the difference must be covered by external suppliers.

Uranium mining was stopped in 1995 for economic reasons and it is imported since then to supply domestic requirements. In order to replace imports by domestic uranium, and to reach the future nuclear fuel to the NPP planned, it is essential explore to discover new uranium resources, in parallel accompanied production with the objective of replacing uranium imports gradually.

When taking into account the Reasonably Assured Resources (RAR) and Inferred Resources (IR, <USD 130/kgU), there are 18 531 tons of uranium, and that amount is not enough to completely cover requirements until 2050. Given the current and future situation the country may temporarily reach self-sufficiency in this resource, but for now this depends on foreign countries.

From the point of view of international cooperation, the vast experience gained by Argentina over the last 63 years, and the consolidation of this through the national educational institutes, the country is positioned as a focal point for human resources training in the region.

Finally, once the nuclear CAREM 25 and CAREM 150 are operational, they can be exported, and it will complement the research reactors and radioisotope production exports for which the country is already internationally recognized.

VI-10. ACKNOWLEDGMENT

This Section is to acknowledge the effort of Gómez de Soler, Susana Marta, Coppari Norberto Ruben, Jensen Mariani, Santiago Nicolás, Cañadas Valeria, Barbarán Gustavo, Torino Aráoz Inés, Ramilo Lucía Beatriz, Azpitarte Osvaldo Enrique, Marchi Daniel, Sassone Ariel, Vaccaro Jorge, Deluchi Facundo, Ferrer Juan, Cruz and Andrea Carolina of the National Atomic Energy Commission (Argentina) who collectively were the authors of this study and the developers of this report.

REFERENCES TO ANNEX VI

[VI-1] Terms of Reference for INPRO collaborative project "Synergistic nuclear energy regional group interactions evaluated for sustainability" (SYNERGIES)

[VI-2] Web page of the International project on innovative nuclear reactors and fuel cycles (INPRO): http://www.iaea.org/inpro/

[VI-3] CNEA web site: http://www.cnea.gov.ar

[VI-4] National nuclear country profile – National Atomic Energy Commission, Edition 2013. IAEA web site: http://www.pub.iaea.org/MTCD/Publications/PDF/CNPP2013_CD/countryprofiles/Argentina/Argentina.htm

[VI-5] NATIONAL ATOMIC ENERGY COMMISSION web page: http://www.cnea.gov.ar/

[VI-6] INVAP SE web site: http://www.invap.com.ar/

[VI-7] LEGAL INFORMATION, CENTRE OF DOCUMENTATION AND INFORMATION OF THE MINISTRY OF ECONOMY AND PUBLIC FINANCES web page: http://www.infoleg.gov.ar/

[VI-8] NUCLEOELÉCTRICA ARGENTINA S.A. web page: http://www.na-sa.com.ar/

[VI-9] NUCLEAR REGULATORY AUTHORITY web page: http://www.arn.gov.ar/

[VI-10] NATIONAL ATOMIC ENERGY COMMISSION web page: http://www.cnea.gov.ar/xxi/

[VI-11] NUCLEOELÉCTRICA ARGENTINA S.A. web page: http://www.na-sa.com.ar/

[VI-12] INTERNATIONAL ATOMIC ENERGY AGENCY, Power Reactor Information System (PRIS): http://www.iaea.org/pris

[VI-13] NATIONAL ATOMIC ENERGY COMMISSION web page: http://www.cnea.gov.ar/

[VI-14] NUCLEOELÉCTRICA ARGENTINA S.A. web page: http://www.na-sa.com.ar/

[VI-15] LEGAL INFORMATION, CENTRE OF DOCUMENTATION AND INFORMATION OF THE MINISTRY OF ECONOMY AND PUBLIC FINANCES web page: http://www.infoleg.gov.ar/

[VI-16] NATIONAL ATOMIC ENERGY COMMISSION. Strategic Plan 2010-2019: http://www.cnea.gov.ar/comunicacion/publicaciones.php

[VI-17] AZPITARTE, O; VILLANUEVA, A; RAMOS, R; RAMILO, L; ALVAREZ, M; YORIO, D; HERRERO, V., Evaluación comparativa de los conceptos seleccionados en el marco del proyecto GIF, CNEA, 2011. Presentado en la "XXXIX Reunión Anual de la Asociación de Tecnología Nuclear" - Buenos Aires, Argentina, December 2012.

[VI-18] GENERATION-IV ROADMAP 2002, A Technology Roadmap for Generation VI Nuclear Energy Systems, US DOE and the Generation VI International Forum: https://www.gen-4.org/gif/jcms/c_9352/technology-roadmap

[VI-19] INTERNATIONAL ATOMIC ENERGY AGENCY, Methodology for the assessment of innovative nuclear reactors and fuel cycles, IAEA TECDOC Series No. 1434, Vienna (2004).

[VI-20] 2012 Annual Report, GIF Symposium Proceedings, San Diego, California, USA, 12 - 15 November 2012.

[VI-21] Education and training seminar/ workshop on fast reactor science and technology organized by IAEA, Bariloche, Argentina, 1 - 5 October 2012.

[VI-22] Forty-sixth meeting of the IAEA Technical working group on fast reactors, Vienna, Austria, 21 - 24 May 2013.

[VI-23] SAGAYAMA YUTAKA, Fast reactor and worldwide cooperation in Generation VI International Forum, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-24] PETER LYONS, U.S. research program to support advanced reactors and fuel cycle options, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-25] THOMAS FANGHÄNEL, EURATOM contributions in fast reactor research programmes, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-26] SHUNSUKE KONDO, Deliberation of post 3.11 fast reactor R&D strategy in Japan, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-27] P.R. VASUDEVA RAO, P. CHELLAPANDI, G. SRINIVASAN, K.K. RAJAN, R. NATARAJAN, P.V. KUMAR, T. JAYAKUMAR AND S.C. CHETAL, A perspective on the Indian programme on fast reactors and associated fuel cycles, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-28] DONGHUI ZHANG, YUANYU WU, HONG YU, Fast reactor development strategy in China, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4 – 7 March 2013.

[VI-29] V.I. RACHKOV, E.O. ADAMOV, A.V. LOPATKIN, V.A. PERSHUKOV, V.M. TROYANOV, Fast reactor development program in Russia, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, Paris, France, 4-7 March 2013.