CAREM REACTOR: AN INNOVATIVE AND ACHIEVABLE OPTION FOR ENHANCING NUCLEAR ENERGY SUPPLY. Silvia Lucila Molina[1], Natalia Sofía Tucci Branco[2], María Noelia Dusau[3]

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"Abstract"

The paper addresses the role that the Argentinean CAREM SMR may play in meeting the world's need for flexible power generation. CAREM SMR appears as an interesting option for enhancing energy supply both in expanding and embarking countries interested in nuclear energy programmes.

Introduction

The world's population continues to increase exponentially, and as a result the demand for energy grows at levels unthinkable decades ago. That is why nuclear power has once again positioned itself as the cleanest and most efficient alternative for the supply of the high rates of base-load energy that society demands today.

The excellent performance of the NPPs over the past decades stimulated the industry to develop plants with increasing generation capacity (above 1000 MWe). However, experience has shown that this type of 'mega-plants' are only suitable for certain countries and under very specific circumstances (a solid distribution network, highly populated areas, etc.), since they are very costly and difficult to finance, with acceptable rates of return only over a long period. Many times, the size of the necessary investments have caused long delays in the execution of the projects, causing detrimental financial effects. In addition, when it is necessary to shut down a reactor, it causes a very negative impact on the grid.

Several years ago the so-called SMR (Small Modular Reactors) began to gain consideration among experts: a generation of small and medium NPP with a whole range of new technical features that make them more flexible and efficient, potentially adaptable to a huge range of sites, and which are also economically and financially affordable, not only in comparison with larger NPPs, but also with other sources of electricity generation.

In this context, CAREM SMR has potential for enhancing the energy supply security in both expanding and embarking countries, particularly in the last ones. Moreover, it appears as an option to meet some challenges in power generation worldwide, such as:

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- The need for flexible power generation for wider users and applications
- Replacing the ageing fossil fuel-fired power plants
- Enhancing safety performance
- Better upfront capital cost affordability
- Suitability for co-generation and non-electric applications
- Options for remote regions with less developed infrastructures
- Synergetic hybrid systems that combine nuclear and alternate energy sources, including renewables (1)

The CAREM Project

A little bit of history

For more than three decades the National Atomic Energy Commission of Argentina (CNEA) has been working on its first small nuclear power plant called CAREM *("Central Argentina de Elementos Modulares"*).

The main purpose of the CAREM Project is to develop, design and construct an innovative, simple and small nuclear power plant.

The CAREM concept was first presented in 1984 in Lima, Peru, during the International Atomic Energy Agency (IAEA) Conference on Small Modular Reactors (SMRs), being one of the first of the new generation reactor designs.

Since then, CNEA continued developing the project, which gained acceptance among the international nuclear community, and it was assessed by the International Project of Innovative Nuclear Reactors and Fuel Cycles Programme of IAEA (INPRO).

CAREM design criteria, or similar ones, have been adopted by other plant designers, originating a new generation of reactor designs, of which CAREM was, chronologically, one of the first.

The Prototype

After several years of development, the CAREM Project reached such a maturity level that the Government of Argentina decided the construction of the CAREM Prototype, known as CAREM25.

CAREM25 is the first nuclear power plant fully designed in Argentina and with the construction of the prototype the country consolidates its advanced position in the market of this new generation of small power reactors.

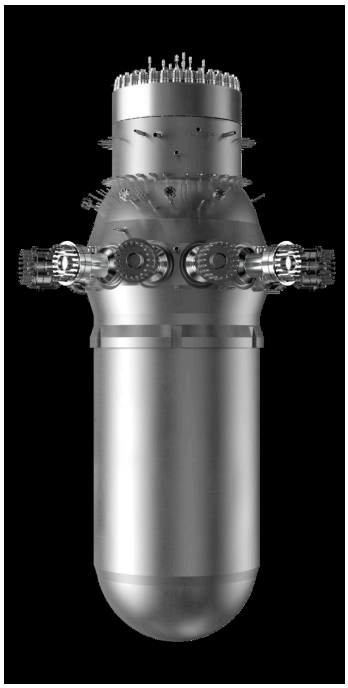
Originally designed to generate 25 electric MW (from that original power derives its name), thanks to new technologies the CAREM prototype will be able to generate about 32 MWe. It is a reactor designed with the highest safety requirements since its original design, with some very specific features.

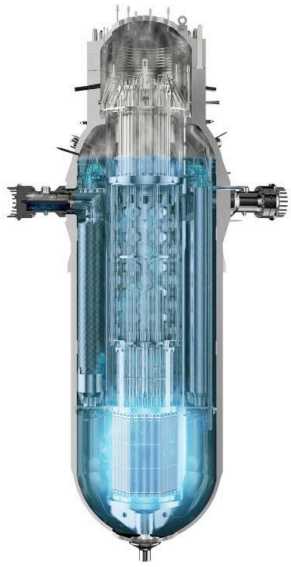
The main aim of CAREM25 is to validate the innovation of CAREM design, especially regarding safety features. Therefore, the CAREM25 will not only be to perform as a standard

electricity generator, but to gather information (operational, simulation of incidents, activation of the different systems, fuel replacement, etc.) after its start-up, with the purpose of obtaining the data required to complete the engineering of the commercial versions of this reactor. In addition, once in operation the prototype will allow to offer to potential buyers an ideal facility to train operators and to study the overall operation of this kind of reactors.

Besides providing the information needed to engineer the commercial scale NPP, the CAREM25 prototype will also facilitate the licensing process of the commercial future versions of this kind of reactors.

Fig. 1. CAREM25





CAREM 25 Innovation

CAREM 25 is a pressurized water reactor (PWR) with some distinctive and characteristic features that greatly simplify the design and support the objective of achieving a higher level of safety (2).

Some of the high level design characteristics of the plant are:

- The reactor coolant is light water, which is transported by natural convection.
- All primary circuit is integrated (steam generators and the state-of-the-art hydraulic control rod mechanisms are contained in a single and self-pressurized pressure vessel).
- Passive safety systems are designed to act according to the basic laws of physics (such as gravity) without requiring external electrical power.
- The fuel is based on enriched uranium.

The distinctive integration concept of CAREM means that the core, the primary reactor system, the pressurizer, the control rod mechanisms and the steam generators are located inside the reactor vessel.

The location of the steam generators above the core produces natural circulation in the primary circuit. The secondary system circulates upwards inside the steam generation tubes, while the primary system circulates in a counter-current flow (3).

The core of the reactor has 61 nuclear fuel assemblies of low enriched uranium (3.1% and 1.8%) moderated by light water and fully designed by CNEA.

The estimated operation cycle length is 18 months.

Nuclear Safety concept

The defence in depth concept has been internalized in the design, in order to improve nuclear safety significantly, compared with the current generation of nuclear power plants. Many intrinsic characteristics contribute to the avoidance or mitigation of eventual accidents.

CAREM safety systems are based on passive features; neither AC power nor operator actions are required to mitigate the postulated design events during a long period.

The safety systems are duplicated to fulfil the redundancy criteria, and the shutdown systems diversified to fulfil regulatory requirements.

Plant Design

The CAREM 25 nuclear island is placed inside the containment system, which includes a pressure suppression feature to contain the energy of the reactor and the cooling systems, and to prevent a significant fission product release in the event of accidents.

The building surrounding the containment has been designed in several levels and it is placed in a single reinforced concrete foundation mat. It supports all the structures, allowing the integration of the reactor pressure vessel, the safety and reactor auxiliary systems, the spent fuels pool and other related systems in one block.

The plant building is divided in three main areas: control module, nuclear module and turbine module.

Finally, CAREM has a standard steam cycle of simple design.

Project Status

CAREM 25 is one of the first SMRs in the world that is under construction and the Project is fully funded by Argentine government.

Site excavation work began in 2011, next to Atucha I and Atucha II NPPs in Lima, Buenos Aires Province and near the Paraná de las Palmas river.

Regarding regulation, as CAREM 25 is the first of its kind, the Nuclear Regulatory Authority

(ARN) structured a specific licensing process after CNEA submitted the Preliminary Safety Report, which contains all the information related to the NPP, from the design to the decommissioning, and in 2013 the ARN issued the Site and Construction License.

On the 8th February 2014, the civil works of the reactor building started. Since that day the CAREM 25 is officially under construction, according to the IAEA standards.

The main contracts and agreements between stakeholders, like the construction of the reactor pressure vessel, the containment airlocks, the steam generators, fuel assemblies, the balance of plant components and some engineering works, are awarded and well advanced.

Fig. 2. CAREM25 Site

Licencing process

As it was mentioned before the ARN structured a specific licencing process for CAREM 25, consisting in several stages. CNEA must provide the ARN with information according to the stage and the ARN makes an assessment of it. In case it is needed it will ask CNEA for more detailed information, or it can issue the licence requested.

In 2013 the ARN issued the Site and Construction License for CAREM25 NPP Prototype.

The main stages are construction of the reactor building, testing without fuel, power testing and start-up.

Legal framework

Regarding legislation, in 2009 the government passed the Law N° 26.566 to declare CAREM Project of national interest and to give CNEA the administrative and financing tools needed to run the project.

Among those tools, there is the creation of an administration trust to make all the purchases related to the construction of the prototype.

Despite this specific domestic regime, CAREM Project is carried out within the Nuclear Activity Law N° 24.804, the Decree N° 1390/98, and all the international treaty framework adopted by Argentina.

CAREM 480 NPP

Considering the progress of the CAREM25 and the experience already acquired in the engineering, design and developments, and its management capacity, CNEA is analyzing a conceptual design base for a commercial scale NPP of 480 MWe with four CAREM reactors.

The Project includes the development of larger scale modules, which can be deployed as multiple-module power plants. Units of up to 120 MWe can be constructed following the main design of the prototype.

CAREM480 NPP is projected to have four of these modules, sharing an extensive list of services and systems therefore reducing significantly capital and operational expenditures and the cost of generation per MW.

The implementation of safety criteria is also optimized.

Challenges to meet when facing a nuclear power project

Investing in a nuclear power project implies financial, legal, regulatory and social aspects, and a robust understanding of the scope of this analysis is critical for project developers, host governments and prospective financers.

In the case of newcomer countries, governments are required to create a suitable environment for investment, including professional and independent regulatory regimes; policies on peaceful uses of nuclear energy; involvement with international non-proliferation measures.

In this context, CAREM SMR can provide a candidate solution to fulfil the energy need, especially in emerging nuclear markets.

Economic aspects

A key challenge to meet when facing a nuclear power project is the financing.

CAREM NPP, as other SMRs, has lower capital risk and lower upfront capital investment requirements due to their small size and simpler design.

Moreover, CAREM NPP is competitive because it balances size reduction with technical solutions (integrated vessel, incorporating heat exchangers, able to rely on natural circulation), and it has one of the enabling factors to build cost competitive SMRs, the modularisation.

Its small size makes it suitable to small electric grids so it is a good option for locations that

cannot accommodate large-scale plants. The CAREM NPP can be located closer to the final consumer (due to improved safety) and thus energy losses and the associated costs can be significantly reduced.

The modular construction process would make it more affordable by reducing capital cost and construction times. Its small size would also increase flexibility for utilities since they could add units as demand changes, use it for on-site replacement of ageing fossil fuel plants, and supply remote communities and industrial sites.

As CAREM NPP consists in multiple units at a single site, it will allow the investors to make incremental capacity additions in a pre-existing site. This leads to co-siting economies: the set-up activities related to siting (e.g. acquisition of land rights, connection to the transmission network) have been already carried out, certain fixed indivisible costs can be saved when installing the second and subsequent units. The larger the number of co-sited units, the smaller the total investment cost for each unit.

Another advantage to address is the on-site learning obtained from the construction of successive units on the same site, and a reduced construction time due to reduced size and assumed design simplification (4).

To sum up, the significant reduced costs and investments required to deploy a CAREM NPP, make it a promising alternative to improve a country's sustainability and energy independence.

Legal aspects

The first step in the process of creating a framework for nuclear legislation should be an assessment of the national programmes and plans involving the use of nuclear techniques and materials.

States interested in developing nuclear power programmes, such as emerging countries, find SMRs like the CAREM NPP as a very interesting option because of their easier construction and lower capital risk and lower upfront capital investment requirements.

Despite those advantages, a nuclear legal framework must be created, revised or updated, depending if it is a country with a nuclear programme or an embarking one.

The primary objective of nuclear law is: To provide a legal framework for conducting activities related to nuclear energy and ionizing radiation in a manner which adequately protects individuals, property and environment (5).

In most national legal systems, many provisions not specifically directed towards nuclear related activities are conducted. In addition to general environmental laws, legislation concerning economic matters (e.g. taxation, liability, regulatory fees, monetary penalties and the setting of electricity rates), worker health and safety, criminal enforcement, land use planning, international trade and customs, and many other areas, may impinge on enterprises engaged in nuclear related activities. Furthermore, most States already have some laws applicable to nuclear energy and regulatory bodies that deal with nuclear matters. However, those laws and bodies must be thoroughly assessed to determine if they are adequate for regulating the State's nuclear power plan or must be altered (6).

At international level, the nuclear power industry operates within an international treaty

framework that covers a number of subject areas, involving commitments at a member state level.

The host government of CAREM NPP should be a member state for this recognised set of international treaty commitments that reflect international best practice. These international agreements fall into four key categories: safety (of generation), security (of the physical asset), safeguards (ie, non proliferation), and nuclear liability (to third parties in the event of a nuclear incident). It is important to mention that the presence of an international body -the IAEA- which provides a pseudo-governance function for the industry has no comparison with other forms of power generation of infrastructure (7).

It is also essential that the host State of CAREM NPP adopts national legislation that implements their obligations under relevant international instruments (conventions, treaties, agreements) to which they have become a Party or are otherwise bound under international law. Examples of such instruments include Vienna Convention on Civil Liability for Nuclear Damage, the Convention on Physical Protection of Nuclear Material and the International Convention for the Suppression of Acts of Nuclear Terrorism.

Regarding International Standards and Practices, the prospective CAREM NPP will meet internationally recognised standards. Technical Assessment of the project ensures that the NPP complies with requirement, especially given the sensitivities (both real and perceived) involved in an NPP.

In most States exist the legal hierarchy mentioned above. This hierarchy consists of three basic levels, with constitutional instruments at the top (International Treaties), followed by enactments by a parliament or legislature at the statutory level (national laws and acts), and regulations promulgated by expert governmental bodies as a subsidiary set of detailed and often technical rules.

It is very important that States make a major effort necessary when creating a framework for nuclear legislation. Governments must be prepared to make firm decisions on the scope and character of the type of nuclear development that they wish to support. The responsible authorities must carefully assess their current nuclear energy activities and their plans for future nuclear energy development so that the legislation ultimately adopted is adequate.

Regulation aspects

A fundamental element of an acceptable national framework for the development of nuclear energy is the creation or maintenance of a regulatory body with the legal powers and technical competence necessary in order to ensure that operators of nuclear facilities and users of nuclear material and ionizing radiation operate and use them safely and securely.

The central consideration in structuring a regulatory body is that it should possess the attributes necessary for correctly applying the national laws and regulations designed to protect public health, safety and the environment.

In order to play this oversight role, the nuclear regulatory authority must be independent within the host government's structure.

There is no single option to structure a regulatory body. Determining the best structure for a particular State requires a careful evaluation of many factors, including: the nature of the

national legal infrastructure; the State's cultural attitudes and traditions; the existing governmental organization and procedures; and the technical, financial and human resources available in that State.

In addition, the regulatory body needs a structure and size commensurate with the extent and nature of the facilities and activities it must regulate. Furthermore, it is important that the nuclear law contains provisions that ensure that the regulatory body is provided with adequate personnel, financing, office quarters, information technology, support services and other resources.

It should be noted that for newcomer countries this tasks will be particularly challenging, and the host governments will need to take measures in terms of human resources development, to instill confidence in the regulatory process.

The greater flexibility afforded by the use of CAREM NPP from technical and managerial standpoints, can be the critical factor for many emerging countries.

The CAREM NPP can represent the ideal solution for nuclear newcomers without significant prior experience in building and operating nuclear reactors and may facilitate the licensing process.

Host government commitment

As a result of the nuclear incidents at Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011), NPPs are surrounded by a heightened sensitivity by the general public. NPP risks and safety case are often misunderstood, and the project developers and host governments will need to work with the public in order to develop the necessary level of local support for the project. Such engagement will be critical at the earlier stages (eg. Pre-feasibility study, site selection, pre-construction) of the project's life cycle.

Government support is critical to the successful development of NPPs. This support manifests in several fashions:

- Financial support, both from the exporting country and the host country for both, the NPP and the overall civilian nuclear programme
- Consisted and sustained support in the legal and regulatory framework within the host country
- Legal regulatory support to facilitate the import/export of nuclear technology
- Overall leadership in the dialogue with the public regarding the need and accountability for nuclear power plant, and
- Stakeholder engagement across government agencies, applicable non-nuclear regulatory authorities and industry.

The host government through a commitment to transparency, engagement and international practices (in the areas of safety, security, safeguards and nuclear liability), can create the necessary alignment between the public and the nuclear power programme.

Changing public attitudes can have dramatic impacts on individual projects and overall nuclear programmes.

In this context, investing in CAREM NPP seems to be a viable option, mainly because of its

distinctive characteristics: modularisation, less fuel inventory, smaller scale, simpler design and higher level of safety. Furthermore, it is a low-carbon, reliable energy source and has the potential to use it for other services like water desalination.

Final remarks

The development and deployment of CAREM SMR appears to be an interesting option for enhancing the energy supply security both in expanding and embarking countries. Financing and contracting nuclear projects imply risks and challenges due to the unique and sensitive nature of nuclear power, the heightened level of regulations and international regimes, high capital costs and technical complexity. Advantages of CAREM SMRS such as flexible power generation; enhanced safety and reliability; design simplicity; facilitation of licensing processes and regulatory and legislative frameworks, and easier financing schemes, among others, make this SMR an achievable option for newcomer countries or those interested in increasing its nuclear power capacity.

CAREM NPP is most attractive in scenarios with limited financial resources, newcomers or private utilities, willing to reduce risk and the upfront investment and are keen to exploit learning. It offers unique opportunities to address many of the challenges confronting emerging countries, in particular water scarcity and small size grid, through the introduction of nuclear in the country as part of the energy mix.

For Argentina CAREM SMR would not only help to meet future energy demand, but also to develop skills, local employment and build a future export business.

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