CAREM Prototype Construction and Licensing Status

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Abstract. CAREM is a CNEA (Comisión Nacional de Energía Atómica) project. This project consists on the development, design and construction of a small nuclear power plant. First, a prototype of an electrical output of about 27 MW, CAREM 25, will be constructed in order to validate the innovation of CAREM concept and then developed to commercial version. After several years of development the CAREM Project reached such a maturity level that the Argentine government decided the construction of CAREM prototype. Several activities are ongoing with the purpose of obtaining the Construction License for CAREM Prototype.

1. INTRODUCTION

The Argentine CAREM project consists on the development, design and construction of an advanced, simple and small Nuclear Power Plant (NPP). CAREM design criteria, or similar ones, has been adopted by other plant designers, originating a new generation of reactor designs, of which CAREM was, chronologically, one of the first. The first step of this project is the construction of the prototype of about 27 Mwe (CAREM 25). This project allows Argentina to sustain activities in the nuclear power plant design and construction area, assuring the availability of updated technology in the mid-term [1]. The design basis is supported by the cumulative experience acquired in Research Reactors design, construction and operation, and Pressurized Heavy Water Reactors (PHWR) Nuclear Power Plants operation, maintenance and improvement, as well as the finalization of the CNA-II and the development of advanced design solutions [2].

2. CAREM 25 INNOVATION

CAREM 25 is an indirect cycle reactor with some distinctive and characteristic features that greatly simplify the reactor and also contribute to a higher level of safety:

- Integrated primary cooling system.
- Primary cooling by natural circulation.
- Self-pressurised.
- Safety systems relying on passive features.

2.1. Primary system

The CAREM 25 reactor pressure vessel (RPV) contains the core, steam generators (SG), the whole primary coolant and the absorber rods drive mechanisms (Fig 1). The RPV diameter is about 3.2 m and the overall length is about 11 m.

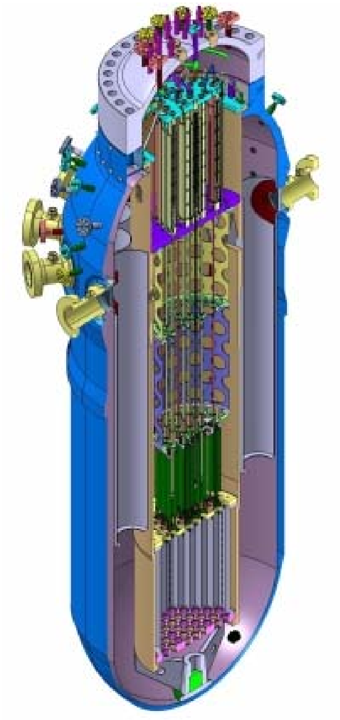

Fig. 1. Reactor Pressure Vessel

The core of the prototype has 61 hexagonal cross section fuel assemblies (FA) having about 1.4 m active length. Each fuel assembly contains 108 fuel rods, 18 guide thimbles and 1 instrumentation thimble (Fig 2). Its components are typical of the PWR fuel assemblies. The fuel is enriched UO_2. Core reactivity is controlled by the use of Gd_2O_3 as burnable poison in specific fuel rods and movable absorbing elements belonging to the Adjust and Control System. Chemical compounds are not used in the water for reactivity control during normal operation. Fuel cycle can be tailored to customer requirements, with a reference design of 390 full-power days and 50% of core replacement.

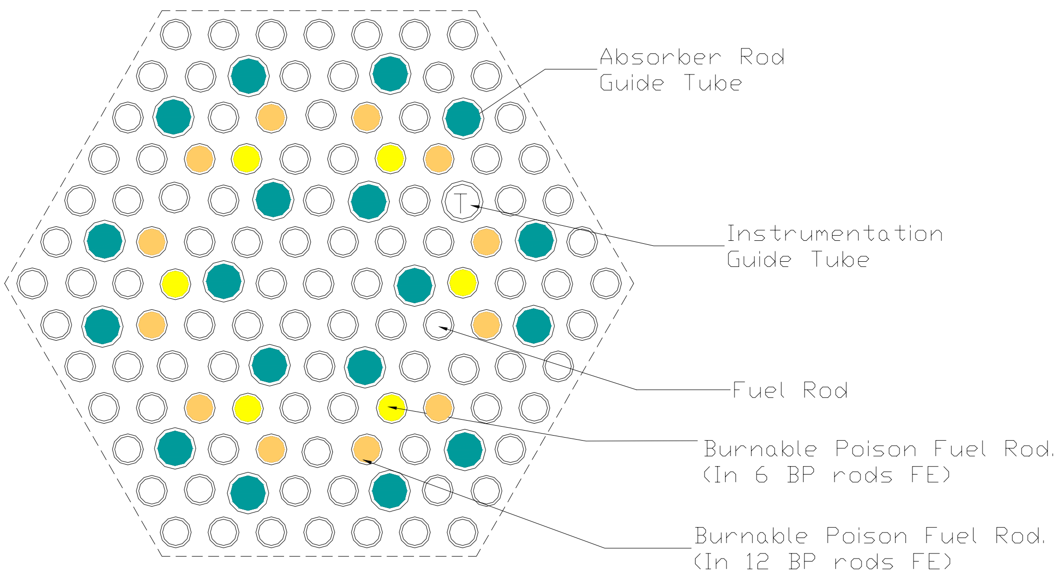

Fig. 2. Fuel Assembly diagram. Fuel rods, guide thimbles and instrumentation thimble distribution.

Each Absorbing Element (AE) consists of a cluster of rods linked by a structural element (namely "spider"), so the whole cluster moves as a single unit. Absorber rods fit into the guide thimbles (Fig 3). The absorbent material is the commonly used Ag-In-Cd alloy. The AE are used for reactivity control during normal operation (Adjust and Control System), and to produce a sudden interruption of the nuclear chain reaction when required (Fast Shutdown System).

Fig. 3. Fuel Assembly and Absorbing Element

Twelve identical 'Mini-helical' vertical SG, of the "once-through" type are placed equally distant from each other along the inner surface of the RPV (Fig 4). They are used to transfer heat from the primary to the secondary circuit, producing dry steam at 47 bar, with 30°C of superheating.

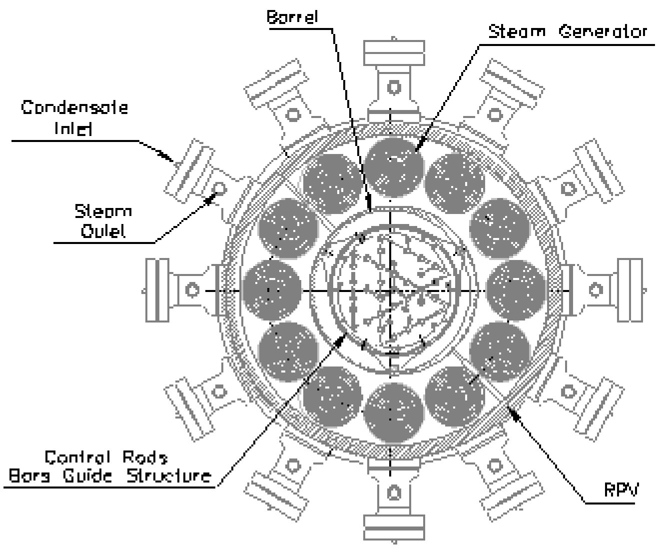

Fig. 4. Steam Generation lay out

The location of the SG above the core produces natural circulation in the primary circuit. The secondary system circulates upwards within the tubes, while the primary goes in counter-current flow. An external shell surrounding the outer coil layer and adequate seal form the flow separation system. It guarantees that the entire stream of the primary system flows through the SG.

In order to achieve a rather uniform pressure-loss and superheating on the secondary side, the length of all tubes is equalized by changing the number of tubes per coil layer. Thus, the outer coil layers will hold a larger number of tubes than the inner ones. Due to safety reasons, SG are designed to withstand the primary pressure without pressure in the secondary side and the whole live steam system is designed to withstand primary pressure up to isolation valves (including the steam outlet / water inlet headers) for the case of SG tube brake. The natural circulation of de coolant produces different flow rates in the primary system according to the power generated (and removed). Under different power transients a self-correcting response in the flow rate is obtained [3].

Due to the self-pressurising of the RPV (steam dome) the system keeps the pressure very close to the saturation pressure. At all the operating conditions this has proved to be sufficient to guarantee a remarkable stability of the RPV pressure response. The control system is capable of keeping the reactor pressure practically at the operating set point through different transients, even in case of power ramps. The negative reactivity feedback coefficients and the large water inventory of the primary circuit combined with the self-pressurisation features make this behaviour possible with minimum control rod motion. It concludes that the reactor has an excellent behaviour under operational transients.

2.2. Nuclear safety

Nuclear safety has been incorporated in CAREM 25 since the beginning of the design. The defence-in-depth concept has specially been considered. Many intrinsic characteristics contribute to the avoidance or mitigation of eventual accidents.

CAREM 25 safety systems are based on passive features and must guarantee no need of active actions to mitigate the accidents during a long period. They are duplicated to fulfill the redundancy criteria. The shutdown system should be diversified to fulfill regulatory requirements.

The First Shutdown System (FSS) is designed to shut down the core when an abnormality or a deviation from normal situations occurs, and to maintain the core sub-critical during all shutdown states. This function is achieved by dropping a total of 25 neutron-absorbing elements into the core by the action of gravity. Each neutron absorbing element is a cluster composed of a maximum of 18 individual rods which are together in a single unit. Each unit fits well into guide thimbles of each FA.

Hydraulic Control Rods Drives (CRD) avoid the use of mechanical shafts passing through RPV, or the extension of the primary pressure boundary, and thus eliminates any possibilities of big Loss of Coolant Accidents (LOCA) since the whole device is located inside the RPV. Their design is an important development in the CAREM concept [4]. Six out of twenty-five CRD (simplified operating diagrams are shown in Fig 5) are the Fast Shutdown System. During normal operation they are kept in the upper position, where the piston partially closes the outlet orifice and reduces the water flow to a leakage. The CRD of the Adjust and Control System is a hinged device, controlled in steps fixed in position by pulses over a base flow, designed to guarantee that each pulse will produce only one step.

Both types of device perform the SCRAM function by the same principle: "rod drops by gravity when flow is interrupted", so malfunction of any powered part of the hydraulic circuit (i.e. valve or pump failures) will cause the immediate shutdown of the reactor. CRD of the Fast Shutdown System is designed using a large gap between piston and cylinder in order to obtain a minimum dropping time thus taking few seconds to insert absorbing rods completely inside the core. For the Adjust and Control System CRD manufacturing and assembling allowances are stricter and clearances are narrower, but there is no stringent requirement on dropping time.

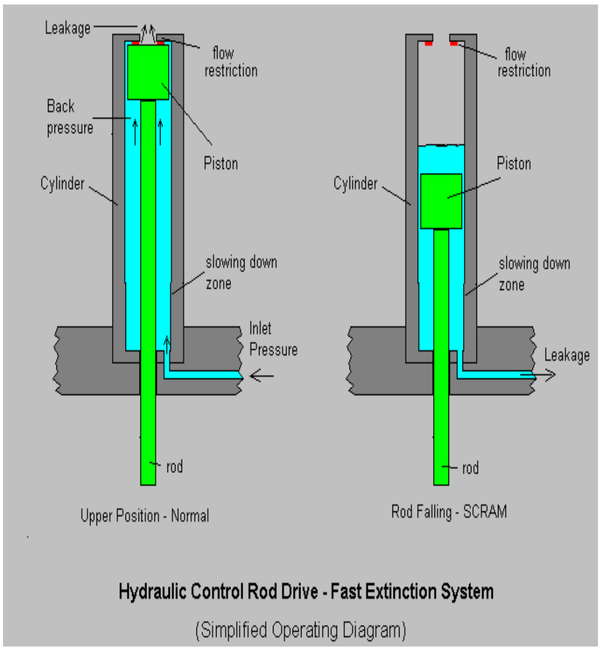

Fig. 5. Simplified operating diagram of a hydraulic control rod drive (Fast Shutdown System)

The second shutdown system is a gravity-driven injection device of borated water at high pressure. It actuates automatically when the Reactor Protection System detects the failure of the First Shutdown System or in case of LOCA. The system consists of two tanks located in the upper part of the containment. Each of them is connected to the reactor vessel by two piping lines: one from the steam dome to the upper part of the tank, and the other from a position below the reactor water level to the lower part of the tank. When the system is triggered, the valves open automatically and the borated water drains into the primary system by gravity. The discharge of a single tank produces the complete shutdown of the reactor.

The residual heat removal system has been designed to reduce the pressure on the primary system and to remove the decay heat in case of loss of heat sink. It is a simple and reliable system that operates condensing steam from the primary system in emergency condensers. The emergency condensers are heat exchangers consisting of an arrangement of parallel horizontal U tubes between two common headers. The top header is connected to the reactor vessel steam dome, while the lower header is connected to the reactor vessel at a position below the reactor water level. The condensers are located in a pool filled with cold water inside the containment building. The inlet valves in the steam line are always open, while the outlet valves are normally closed, therefore the tube bundles are filled with condensate. When the system is triggered, the outlet valves open automatically. The water drains from the tubes and steam from the primary system enters the tube bundles and is condensed on the cold surface of the tubes. The condensate is returned to the reactor vessel forming a natural circulation circuit. In this way, heat is removed from the reactor coolant. During the condensation process the heat is transferred to the water of the pool by a boiling process. This evaporated water is then condensed in the suppression pool of the containment.

The Emergency Injection System prevents core exposure in case of LOCA. In the event of such accident, the primary system is depressurised with the help of the emergency condensers to less than 15 bar, with the water level over the top of the core. At 15 bar a low pressure water injection system comes into operation. The system consists of two tanks with borated water connected to the RPV. The tanks are pressurized, thus when during a LOCA the pressure in the reactor vessel reaches 15 bar, the rupture disks break and the flooding of the RPV starts.

Three safety relief valves protect the integrity of the reactor pressure vessel against overpressure, in case of strong unbalances between the core power and the power removed from the RPV. Each valve is capable of producing 100% of the necessary relief. The blow-down pipes from the safety valves are routed to the suppression pool.

The primary system, the reactor coolant pressure boundary, safety systems and high-pressure components of the reactor auxiliary systems are enclosed in the primary containment - a cylindrical concrete structure with an embedded steel liner. The primary containment is of pressure-suppression type with two major compartments: a drywell and wetwell. The lower part of wetwell volume is filled with water that works as the condensation pool, and the upper part is a gas compression chamber.

2.3. Advantages of CAREM 25 design

Technical and economical advantages are obtained with the CAREM 25 design compared to the traditional design:

- No large LOCA has to be handled by the safety systems due to the absence of large diameter piping associated to the primary system. The size of maximum possible break in the primary is 38 mm.
- Innovative hydraulic Drive Control Rods avoid Rod Ejection Accident..
- Large coolant inventory in the primary results in large thermal inertia and long response time in case of transients or accidents.
- Shielding requirements are reduced by the elimination of gamma sources of dispersed primary piping and parts.
- The large water volume between the core and the wall leads to a very low fast neutron dose over the RPV wall.
- The ergonomic design and layout make the maintenance easier. Maintenance activities like the steam generator tubes inspection does not compete with refueling activities because it will be carried out from outside the vessel.
- The use of less active components increases plant availability and load factor, reducing the frequency and kind of initiating events.

3. PLANT DESIGN

The CAREM 25 nuclear island is placed inside a containment system, which includes a pressure suppression feature to contain the energy of the reactor and 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 with the same seismic classification, allowing the integration of the RPV, 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 25 NPP has a standard steam cycle of simple design.

4. CONSTRUCTION AND LICENSING STATUS

Several activities are ongoing with the purpose of obtaining the Construction License for CAREM Prototype. The Preliminary Safety Analysis Report is under development in order to be presented by November this year. Site activities such as soil studies and environmental analysis are being performed.

The construction of a high pressure and high temperature rig for testing the innovative Hydraulic Control Rod Drive Mechanism will be finished next year. This rig can also be adapted for testing the structural behaviour of the FA.

The Civil Engineering and Process detail engineering are ongoing as well as the preparation of the site facilities to start the construction during the second half of 2010.

In the fuel area, both the fuel pellets and the FA itself are under development. Uranium dioxide, burnable poison oxide and the appropriate equipment for pellet manufacturing will soon be available. FA dummies that will be used to analyze mechanical integrity and test the behaviour under different flow conditions are under construction.

The use of robotics and the development of a plant simulator are included in the developments.

Contracts and agreements are being taking with different Argentinean stakeholders to perform detail engineering.

The procurement process of main components such as the RPV is being started with local suppliers.

5. CONCLUSIONS

The CAREM project consists on the development, design and construction of the prototype of an advanced small nuclear power plant. CAREM 25 is an indirect cycle reactor with some distinctive features that greatly simplify the reactor and also contribute to a higher level of safety. Some of the high level design characteristics of the plant are: integrated primary cooling system, self-pressurised, primary cooling by natural circulation, safety systems relying on passive features. Therefore, many technical and economical advantages are obtained with the CAREM 25 design compared to the conventional designs. After several years of development the CAREM Project reached such a maturity level that the Argentine government decided the construction of CAREM prototype. Several activities are ongoing with the purpose of obtaining the Construction License for CAREM Prototype. The construction of the CAREM 25 is expected to be finished by the end of 2014.

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