Hindawi Publishing Corporation
Science and Technology of Nuclear Installations
Volume 2011, Article ID 140373, 6 pages
doi:10.1155/2011/140373

Project Report

CAREM Project Status

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Received 31 August 2010; Accepted 17 December 2010

Academic Editor: Juan Pablo Ordonez

CAREM is a CNEA (Comisión Nacional de Energía Atómica) project. This project consists of 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 built in order to validate the innovation of the 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 on the construction of CAREM prototype. Several activities are ongoing with the purpose of obtaining the construction permit for the CAREM prototype.

1. Introduction

The Argentine CAREM project consists of the development, design, and construction of an advanced, simple, and small nuclear power plant (NPP). 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 firsts. The first step of this project is the construction of a 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 midterm [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:

(i) integrated primary cooling system,

(ii) primary cooling by natural circulation,

(iii) self-pressurized, and

(iv) safety systems relying on passive features.

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

The core of the prototype has 61 hexagonal cross section fuel assemblies (FA) having about 1.4 m active length.

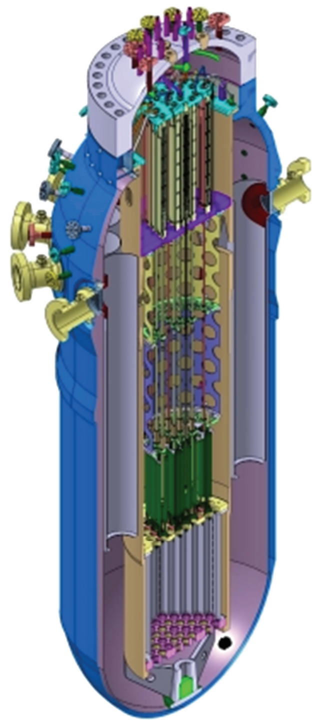

Figure 1: Reactor pressure vessel.

Each fuel assembly contains 108 fuel rods, 18 absorber rod guide tubes, and 1 instrumentation guide tube (Figure 2). Its components are typical of the PWR fuel assemblies. The fuel is enriched with UO_2. Core reactivity is controlled by the use of Gd_2O_3 as burnable poison (BP) 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. The fuel cycle can be tailored to customer requirements, with a reference design of 390 full-power days and 50% of core replacement.

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 absorber rod guide tubes (Figure 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).

Twelve identical "minihelical" vertical, "once-through" type steam generators are placed equally distant from each other along the inner surface of the RPV (Figure 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.

The location of the SGs 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 an adequate seal form the flow separation system. It guarantees that the entire stream of the primary system flows through the SGs.

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, the SGs are designed to withstand the primary pressure without pressure in the secondary side and the whole live steam system is designed to withstand the primary pressure up to the isolation valves (including the steam outlet/water inlet headers) for the case of an SG tube break. The natural circulation of the 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-pressurizing 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-pressurization feature make this behavior possible with minimum control rod motion. The reactor thus has an excellent behavior under operational transients.

2.2. Nuclear Safety. Nuclear safety has been incorporated in CAREM 25 from the very conception of the design. The defense-in-depth concept has been especially considered. Many intrinsic characteristics contribute to the avoidance or mitigation of hypothetical accidents.

CAREM 25 safety systems are based on passive features and must guarantee that active actions are not required to mitigate accidents during a long period. They are duplicated to fulfill the redundancy criterion. The shutdown system must 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 subcritical 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 up to 18 individual rods which are coupled in a single unit. Each unit fits well into the absorber rod guide tubes of each FA.

Hydraulic control rod drives (CRD) avoid the use of mechanical shafts passing through the RPV, or the extension of the primary pressure boundary, and thus eliminates any possibilities of large 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 Figure 5) form the fast shutdown system. During normal operation they are kept in the upper position, where the piston partially closes the outlet orifice and reduces

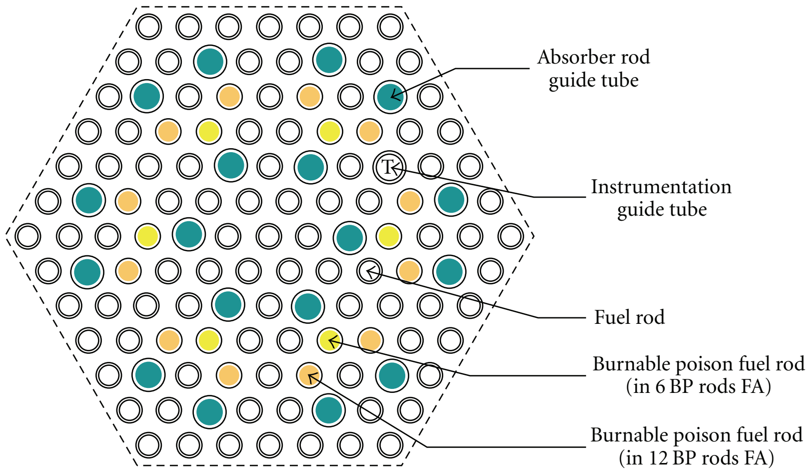

FIGURE 2: Fuel assembly diagram. Fuel rods and guide tubes distribution.

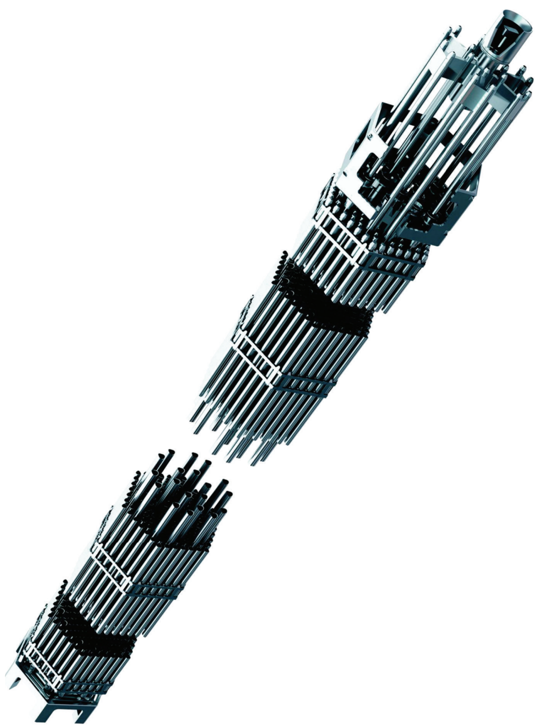

FIGURE 3: Fuel assembly and absorbing element.

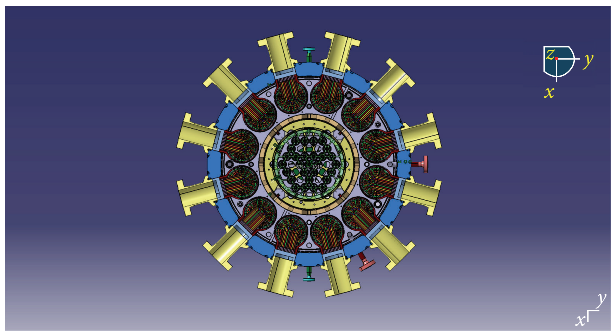

FIGURE 4: Steam generation lay out.

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, and designed to guarantee that each pulse will produce only one step.

Both types of devices perform the reactor shutdown function by the same principle: rod drops by gravity when the flow is interrupted; therefore a failure of any powered part of the hydraulic circuit (i.e., valve or pump) will cause rod insertion. The CRD of the fast shutdown system is designed with a large gap between piston and cylinder in order to insert absorbing rods completely inside the core in a few seconds. 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.

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 failure of the first shutdown system. 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 passive 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 condensers. The 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,

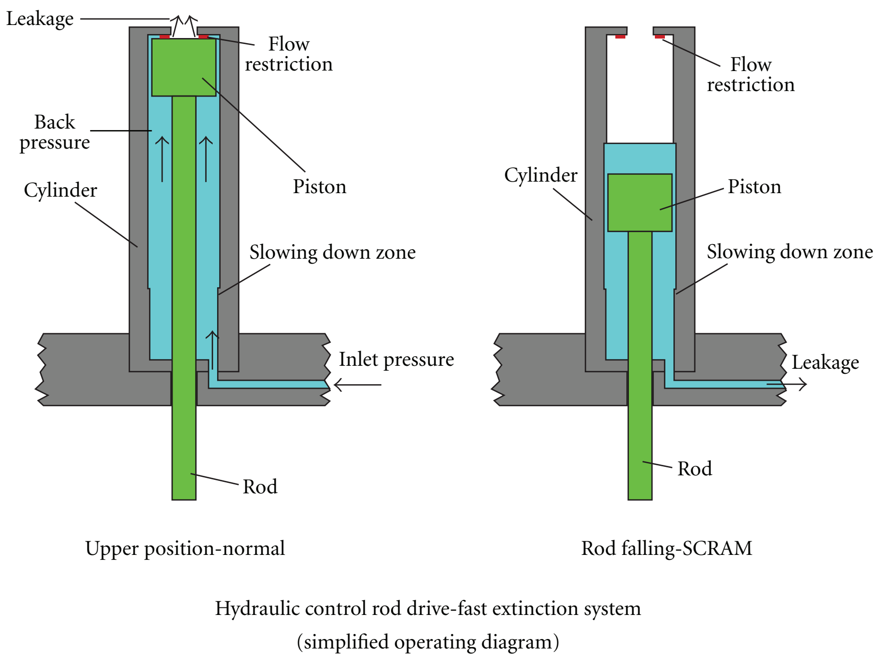

Figure 5: Simplified operating diagram of a hydraulic control rod drive (fast shutdown system).

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 into the tube bundles and is condensed on the cold surface of the tubes. The condensate is returned to the reactor vessel, and a natural circulation circuit is established. 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 uncover in case of a LOCA. In the event of such an accident, the primary system is depressurized with the help of the emergency condensers, in case of very small tube ruptures, to less than 15 bar. At 15 bar, accumulators inject borated water into the RPV, keeping the water level over the top of the core during the grace period.

Three safety 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, that is, in postulated cases of failure of the steam generators heat removal and the passive heat removal system. Each valve is capable of producing 100% of the required relief. The blow-down pipes from the safety valves are routed to the suppression pool. During anticipated operational events such as valves are not required.

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

2.3. Advantages of CAREM 25 Design. Technical and economical advantages are achieved with the CAREM 25 design compared to the traditional design:

(i) the use of less active components increases plant availability and load factor, reducing the frequency and kind of initiating events,

(ii) no loss of flow accident as the core is cooled by natural circulation,

(iii) 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,

(iv) innovative hydraulic control rod drives avoid the rod ejection accident,

(v) large coolant inventory in the primary results in large thermal inertia and long response time in case of transients or accidents,

(vi) passive safety systems with a grace period of 36 hours,

(vii) shielding requirements are reduced by the elimination of gamma sources of dispersed primary piping and parts,

(viii) the large water volume between the core and the wall leads to a very low fast neutron dose over the RPV wall, and

(ix) the ergonomic design and layout make the maintenance easier; maintenance activities like steam generator tubes inspection does not compete with refueling activities because it will be carried out from outside the vessel.

3. Plant Design

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

The building surrounding the containment has several levels, and it is placed in a single reinforced concrete foundation. It supports all the structures with the same seismic classification, allowing the integration of the RPV, the safety and reactor auxiliary systems, the spent fuel pool and other related systems in one block.

The plant is divided in two main buildings: the administrative and nuclear module and the turbine module.

Finally, CAREM 25 NPP has a standard steam cycle.

4. Construction and Licensing Status

Several activities are ongoing with the purpose of obtaining the construction permit for the CAREM Prototype. The Preliminary Safety Analysis Report and the Quality Manual were submitted to the Argentine Regulatory Authority in 2009. 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 this year (Figure 6). This rig can also be adapted for testing the structural behavior of the FA.

Figure 6: High-pressure and high-temperature rig.

The civil engineering and process detail engineering is ongoing as well as the preparation of the site facilities to start the construction during the first half of 2011.

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. The FA dummies that will be used to analyze mechanical integrity and test the behavior under different flow conditions are under construction. Fuel rod irradiation tests are under preparation.

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

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

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

5. Conclusions

The CAREM project consists of the development, design, and construction of an advanced small integral type PWR. CAREM 25 is the prototype of the concept. This plant has 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 CAREM 25 are integrated primary cooling system, self-pressurized, primary cooling by natural circulation, and safety systems relying on passive features. Therefore, many technical and economical advantages are obtained with the CAREM design compared to the conventional designs. After several years of development, the CAREM Project has reached such a maturity level that the Argentine government decided on the construction of CAREM prototype. Several activities are ongoing with the purpose of obtaining the construction permit for CAREM prototype. The construction of the CAREM 25 is expected to be finished by the end of 2014.

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