4. BORON AND WATER MAKEUP (REA [RBWMS])

4.0. SAFETY REQUIREMENTS

4.0.1. Safety functions

The boron and water makeup system (REA [RBWMS]) does not play a direct role in fulfilling the three basic safety functions.

However, as the REA [RBWMS] conveys a fluid containing radioactive products, its pressure boundary must be designed to contain radioactive products (containment barrier).

This system also contributes to controlling reactivity in normal operation by adjusting the primary system boron concentration, using the Chemical and Volume Control System (RCV [CVCS]), in order to control power variations (in addition to the control rods), during the reactor start-up and shutdown phases or to offset fuel burn-up.

4.0.2. Functional criteria

Since the boron and water makeup system (REA [RBWMS]) does not fulfil any active safety function, there are no safety-related criteria.

4.0.3. Design-related requirements

4.0.3.1. Requirements issued by safety classifications

- Safety classification

The REA [RBWMS] is safety-classified in accordance with the classification principles given in Chapter C.2.

- Single failure criterion (active and passive)

Not applicable

- Emergency electrical supplies

Not applicable

- Qualification to operating conditions

Not applicable

- Mechanical, electrical and instrumentation and control classifications

The REA [RBWMS] mechanical, electrical and instrumentation and control classification is established according to the classification principles given in Chapter C.2.

- Seismic classification
The REA [RBWMS] must be seismically classified in accordance with the classification principles given in Chapter C.2.

- Periodic tests

The REA [RBWMS] fulfils no active safety function and is designed for normal operation of the plant, during which is it used regularly. No periodic test is therefore required.

4.0.3.2. Other regulatory requirements

- Regulatory texts

To follow.

- Basic safety rule

To follow.

- Technical directives

No specific requirements (see Chapter C.1.2).

- Texts specific to the EPR project

Not applicable

4.0.3.3. Hazards

There is no requirement for protection of the REA [RBWMS] against internal and external hazards.

4.1. ROLE OF THE SYSTEM

The REA [RBWMS] is used to control the boron concentration of the primary circuit, using the chemical and volume control system (RCV [CVCS]): it is used to control all planned variations in reactivity, including the effects of xenon.

When the reactor is operating, the quantity of boric acid stored in the REA [RBWMS] for injection into the primary system via the RCV [CVCS] is sufficient to bring the core to sub-criticality in cold shutdown, taking into account reactivity due to Xenon decay.

The REA [RBWMS] is used to control, via the RCV [CVCS], the slow reactivity variations by adjusting the primary system boron concentration and thus control the expected load variations (including Xenon effect).

The REA [RBWMS] and the RCV [CVCS] are designed to protect the primary system against the risks of homogeneous and heterogeneous boron dilutions.

The REA [RBWMS] system is also designed to fulfil the following main functions:
- regulate makeup of boric acid and/or demineralised degassed water to the primary system using the RCV [CVCS] in order to control the level of primary water in the pressuriser (by the RCV [CVCS]) or to offset a leak in the primary system during normal operation (by the RCV [CVCS])

- prepare and distribute boric acid at 4%

- ensure filling and makeup of boric acid at 4% to the two boration tanks of the RBS [EBS] (extra boration system)

- ensure filling and makeup of boric acid at 4% to the spent fuel pool and the IRWST using the PTR [FPCPS].

4.2. DESIGN BASIS

4.2.1. General system design assumptions

For pressurised water reactors, slow reactivity variations are controlled by makeup or decrease of boric acid (H₃BO₃) in the primary water.

When it is necessary to increase the boron concentration of the primary water, boric acid from the REA [RBWMS] is injected into the primary system via the chemical and volume control system (RCV [CVCS]).

If it is necessary to reduce the boron concentration of the primary water, demineralised water from the REA [RBWMS] is injected into the primary system via the RCV [CVCS].

All the other systems containing boric acid used to control reactivity are also supplied by the REA [RBWMS].

4.2.1.1. System-related requirements

The following requirements are established for the system design:

- mixing and storage of boric acid with concentration of 4% (i.e. 7,000 ppm of boron)

- boric acid makeup (7,000 ppm) of the extra boration system tanks (RBS [EBS])

- preparation of boric acid for filling the fuel pools and the IRWST using the PTR [FPCPS]. The quantity required to fill the RIS [SIS] accumulators is injected from the IRWST. The boron concentration of the pools is chosen according to requirements related to refuelling

- reduction of the boron concentration in the primary water for plant start-up

- adjustment of the boron concentration of the primary water to offset the reactivity variations due to Xenon and Samarium poisoning, load follow or fuel burn-up

- injection of boric acid and demineralised water, determined according to the boron concentration of the primary system, to offset leaks in the primary system during normal operation

- increase in the boron concentration in the primary water during cooling of the plant
4.2.1.2. Design of the system

The boric acid storage capacity is determined by the maximum mass of boric acid to be stored, generated by all systems containing primary water and contributing to dilution due to fuel burn-up during a cycle. These systems are the primary system (RCP [RCS]) with the pressuriser, the RCV [CVCS], the vent and drain system (RPE [NVDS]) and the Primary Effluent Treatment System (TEP [CSTS]).

The parameters listed below have an impact on the design of the injection means and consequently on the characteristics of the boric acid pumps and on those of the recirculation pumps and associated regulating valves:

- regulation functions of the control rods
- LCO (limiting conditions of operation) for surveillance of the position of the control rods
- control rods protection functions
- control of RCV [CVCS] volume control tank level
- actual flow rate of boric acid and/or demineralised degassed water injection systems to the RCV [CVCS]

4.2.2. Other design assumptions

4.2.2.1. Maximum boron concentration

The saturation concentration of boric acid dissolved in the water depends on the temperature. To avoid the risk of boron crystallization, the temperature in the compartments containing boric acid (7,000 ppm) must be kept above 20°C by the ventilation system.

For reasons of availability, the power for ventilation of these premises must be backed up in the event of LOOP (see Chapter C.3).

4.2.2.2. Protection against excess pressure

The boric acid tanks have large dimensions and are designed for a pressure lower than the rest of the system. A safety valve installed on the top of each storage tank prevents the maximum allowed pressure being reached. The safety valve flow rate design is based on the assumption that the tank is isolated from the gaseous effluent treatment system (TEG [GPWS]) and that the boric acid pump, which takes suction from the other tank, delivers into this tank.

4.2.2.3. Emergency electrical supplies

For reasons of availability, the REA [RBWMS] components contributing to boric acid and degassed demineralised water makeup must be backed up, since the RCV [CVCS] is required in the event of loss of external supply.
4.3. DESCRIPTION AND CHARACTERISTICS OF EQUIPMENT

4.3.1. Description of the system

4.3.1.1. Mixing and distribution of boric acid

The boric acid mixing and distribution portion of the REA [RBWMS] mainly comprises a boric acid mixing tank with agitator, a boric acid supply pump, a filter upstream of the pump and the associated piping.

The boric acid mixing tank is used to produce boric acid by dissolution of “nuclear quality” boric acid in powder form in the demineralised water – preferably hot – to achieve a concentration of 4% of $\text{H}_3\text{BO}_3$. This 4% concentration is required for filling the boric acid storage tanks of the REA [RBWMS] and the extra boration system tanks (RBS [EBS]). The RIS [SIS] accumulators, the safety injection system, the IRWST, the primary system and the fuel pools are initially filled with boric acid diluted to the required concentration for refuelling. During normal operation of the plant, the $\text{H}_3\text{BO}_3$ preparation is used only to offset losses or, very rarely, to replace depleted boric acid.

4.3.1.2. Injection line and boric acid storage

The requirement for inspection of tanks and the requirements relating to installation of the fuel building result in the boric acid storage capacity being distributed between two tanks. Once the initial filling is complete, the boric acid at 4% comes from the evaporator column of the primary effluent treatment system (TEP [CSTS]). Two boric acid pumps, with downstream control valves, are installed to inject the required boric acid into the chemical and volume control system (RCV [CVCS]).

4.3.1.3. Demineralised water injection line

The effluents from the primary system are treated by the TEP [CSTS] by separating the boric acid from the demineralised water. The demineralised water obtained is degassed and stored in the tanks of the TEP [CSTS], one of which is always aligned to the pumps. For reasons of redundancy and in consideration of the low water output, two 100%-capacity pumps with downstream regulation valves, are installed to inject the demineralised water required to the RCV [CVCS].

For reasons of availability, the power to the REA [RBWMS] components contributing to boric acid and degassed demineralised water makeup is backed up by the main diesels in order to ensure the boron concentration and level are maintained in the RCV [CVCS] tank.

4.3.2. Installation of equipment

The boron and water makeup system is installed in the fuel building. Only the demineralised water injection pumps, as well as their pipes, valves and measuring devices are located inside the nuclear auxiliary building.

4.4. OPERATING CONDITIONS

The Water and Boron Makeup System (REA [RBWMS]) is designed to be operated only during normal operation of the plant.
The system performs the following functions:

- mixing and distribution of boric acid
- storage and injection of boric acid
- Injection of demineralised water

### 4.4.1. Mixing and distribution of boric acid

The largest proportion of the boric acid is needed for the initial filling of boric acid tanks, the extra boration system tanks (RBS [EBS]), the primary system, the fuel pool, the IRWST and all the other systems and components containing boric acid or a mixture of boric acid and demineralised water. In normal plant operation, the boric acid preparation is needed only for offsetting normal losses.

The boric acid mixing tank is used to prepare a boric acid solution by dissolution of “nuclear quality” boric acid in powder form in the demineralised water, preferably hot (mixture containing 4% of $\text{H}_3\text{BO}_3$). The agitator is used to dissolve the powder in the preheated water, thus producing a homogeneous solution. Once dissolved, the boric acid is distributed by starting up the feed pump. The boric acid at 4% is delivered to the boric acid storage tanks and to the two extra boration system tanks (RBS [EBS]). All the other systems and components are filled with diluted boric acid. The required concentration is prepared by mixing boric acid at 4% with demineralised water.

The feed pump can also be used for mixing the tank via the mixing line to avoid formation of boric acid deposits.

### 4.4.2. Storage and injection of boric acid

#### Storage of boric acid

The boric acid storage tanks contain all the boric acid required as an absorber of neutron flux during normal plant operation. The maximum tank fill level is reached when the primary system boron concentration approaches 0 ppm at the end of life (EOL).

The lowest level in the tanks is reached when the primary system is at the concentration required for refuelling and the pressuriser is water solid. In this case, the storage capacity is sufficient for the following phases (start-up, load follow operation, shutdown and refuelling) and takes account of fuel management and $^{10}\text{B}$ enrichment.

The boric acid storage tanks are initially filled with boric acid at 4% from the mixing and distribution portion of the system. The two tanks are separated by motor-driven valves. After the first filling, boric acid is recovered from the TEP [CSTS] storage tanks, which enables the treatment of primary water into 4% of boric acid and demineralised water.
**Injection of boric acid**

A boric acid pump is allocated to each of the two boric acid storage tanks. If a tank is empty, it is possible to switch to the other tank. In the event that a pump is not working or does not start, the other pump may be started to inject boric acid into the primary system via the RCV [CVCS]. The connection between the discharge of each pump and the allocated tank enables recirculation of boric acid to avoid crystallization inside the boric acid storage tank. During this operation, the other pump may be used to inject boric acid into the primary system. However, the alignment of storage tanks on makeup pumps, as well as management of the tanks, is currently under investigation.

A regulation valve located upstream of each pump regulates the flow of boric acid injected into the RCV [CVCS].

**4.4.3 Injection of demineralised water**

The demineralised water injection portion of the system comprises two parallel lines. Each of these lines has an injection pump whose suction is connected to the demineralised water line of the TEP [CSTS] and a control valve located downstream to inject the demineralised water to the RCV [CVCS].

**4.5 PRELIMINARY SAFETY ANALYSIS**

**4.5.1 Compliance with regulations**

To follow.

**4.5.2 Observance of functional criteria**

The REA [RBWMS] does not play a direct role in fulfilling the three basic safety functions. There is no safety-related functional criterion (see 4.01. and 4.0.2 within Sub-chapter I.3).

**4.5.3 Compliance with design requirements**

**4.5.3.1 Safety classification**

The compliance of design and construction of materials and equipment with requirements derived from classification rules is detailed in Chapter C.2.

**4.5.3.2 CDU [SFC] or Redundancy**

The Single Failure Criterion does not apply to the REA [RBWMS]. No redundancy is therefore required.

**4.5.3.3 Qualification to operating conditions**

Not applicable.
4.5.3.4. Instrumentation and control

The compliance of design and manufacture of instrumentation and control with requirements derived from classification rules is detailed in Chapter C.2.

4.5.3.5. Emergency electrical supplies

Not applicable.

4.5.3.6. Hazards

Not applicable (see 4.0.3.3 within Sub-chapter I.3).

4.6. TESTS, INSPECTION AND MAINTENANCE

The (REA [RBWMS]) is designed for in-service inspection; preventive maintenance operations must be able to be performed during plant operation.

The REA [RBWMS] is regularly used during normal operation. It fulfils no direct safety function and no periodic test is required.

4.7. FUNCTIONAL FLOW DIAGRAMS

See I.3.4 FIG 1:
I.3.4 FIG 1 PAGE 1/3: FUNCTIONAL FLOW DIAGRAM OF THE REA [RBWMS] - MIXING AND DISTRIBUTION OF BORIC ACID
I.3.4 FIG 1 PAGE 2/3: FUNCTIONAL FLOW DIAGRAM OF THE REA [RBWMS] - STORAGE AND INJECTION OF BORIC ACID
I.3.4 FIG 1 PAGE 3/3: FUNCTIONAL FLOW DIAGRAM OF THE REA [RBWMS] - INJECTION OF DEMINERALISED WATER