UK EPR	Title: PCSR – Sub-chapter 6.7 – Extra Boration System (RBS [EBS])
	UKEPR-0002-067 Issue 04

Total number of pages: 18	Page No.: I / IV
Chapter Pilot: M. LACHAISE *Name/Initials* [signature] *Date* *05-10-2012*	
Approved for EDF by: A. MARECHAL *Name/Initials* [signature] *Date* *05-10-2012*	Approved for AREVA by: G. CRAIG *Name/Initials* [signature] *Date* *05-10-2012*

REVISION HISTORY

Issue	Description	Date
00	First issue for INSA information	11-12-2007
01	Integration of technical and co-applicant and comments	26-04-2008
02	PCSR June 2009 update: – Clarification of text – Inclusion of references – Design evolutions to account for December 2008 design freeze (power of the motor, update of pressure sensors and valves in simplified flow diagram)	26-06-2009
03	Consolidated Step 4 PCSR update: – Minor editorial changes – Clarification of text – Update of references – Text added regarding the automatic actuation of EBS upon very low SG pressure	30-03-2011
04	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc - Minor editorial and typographical changes - Clarification of text (§3.3, §3.4, §4.1, §6.3) - Figure 1 corrected (double valves and REA [RBWMS] make-up)	05-10-2012

For information address:

AREVA NP SAS
Tour AREVA
92084 Paris La Défense Cedex
France

EDF
Division Ingénierie Nucléaire
Centre National d'Equipement Nucléaire
165-173, avenue Pierre Brossolette
BP900
92542 Montrouge
France

TABLE OF CONTENTS

SUB-CHAPTER 6.7 – EXTRA BORATION SYSTEM (RBS [EBS]) [REF-1] TO [REF-4]

0. SAFETY REQUIREMENTS

0.1. SAFETY FUNCTIONS

0.1.1. Reactivity control

In the event of PCC-2 to PCC-4 conditions, the Extra Boration System (RBS [EBS]) must ensure boration of the RCP [RCS], irrespective of the primary coolant pressure, in order to:

- achieve a controlled state (when necessary),
- compensate for the reactivity insertion caused by the RCP [RCS] cooldown in reaching a safe shutdown state (RIS/RRA [SIS/RHRS] connected) from the controlled state. Boration is terminated when the boron concentration required for the safe shutdown state is achieved.

In particular, the RBS [EBS] is used during a small break LOCA (PCC-3) when the boron concentration of the injected fluid is not sufficient to reach the boron concentration in the primary system necessary for RIS/RRA [SIS/RHRS] connection.

In the event of ATWS (RRC-A condition), the RBS [EBS] ensures automatic boration of the RCP [RCS].

0.1.2. Decay heat removal

The RBS [EBS] does not contribute to this safety function.

0.1.3. Containment of radioactive substances

The RBS [EBS] participates in the integrity of the third barrier. It must ensure the containment isolation function is achieved at each of its containment penetrations.

0.2. FUNCTIONAL CRITERIA

0.2.1. Reactivity control

In PCC-2 to PCC-4 and RRC-A accident conditions and events, the negative-reactivity provided by the RBS [EBS] must enable the core to be brought to a subcritical state (controlled state) or to RIS/RRA [SIS/RHRS] connection conditions (safe shutdown state), in order to comply with fuel limits.

Boron precipitation must be avoided during normal operation. Precipitation inside equipment must also be avoided in shutdown states for which the RBS [EBS] does not need to be available.

The capacity of each boron tank must be sufficient to ensure the required boration allowing for reactivity introduced by xenon.

0.2.2. Decay heat removal

Not applicable.

0.2.3. Containment of radioactive substances

Each of the RBS [EBS] lines crossing the containment boundary must be equipped with two isolation valves and leak monitoring devices.

0.3. REQUIREMENTS RELATING TO DESIGN

0.3.1. Requirements due to safety classification

0.3.1.1 Safety classification

Since the system is required for achieving a safe shutdown state, the RBS [EBS] must be safety classified according to the classification principles presented in Sub-chapter 3.2.

0.3.1.2 Single failure criterion (active and passive)

For the components that perform an F1 function, the single failure criterion must be applied to ensure a sufficient level of redundancy (Sub-chapter 3.2).

0.3.1.3 Emergency power supplies

The power supply for components that have an F1 function must be backed up so that their function is ensured in the event of loss of external power supplies.

0.3.1.4 Qualification for operating conditions

The RBS [EBS] must be qualified in accordance with the requirements of Sub-chapter 3.6, so that none of the accidents considered in Chapters 14 and 16 prevent the system from performing its safety functions.

0.3.1.5 Classification of the mechanical, electrical and instrumentation and control equipment

Mechanical, electrical and instrumentation and control classifications must follow the classification rules in Sub-chapter 3.2.

0.3.1.6 Seismic classification

To meet the safety requirements in terms of resistance to earthquakes, the RBS [EBS] must be seismically classified, according to the classification rules in Sub-chapter 3.2.

0.3.2. Other statutory requirements

0.3.2.1 Basic safety rules

See Sub-chapter 1.4.

0.3.2.2 Technical guidelines

See Sub-chapter 3.1.

0.3.3. Internal and external hazards

0.3.3.1 Internal hazards

The RBS [EBS] must be protected against internal hazards, in accordance with Sub-chapter 13.2.

0.3.3.2 External hazards

The RBS [EBS] must be protected against external hazards, in accordance with Sub-chapter 13.1.

0.4. TESTS

0.4.1. Pre-operational tests

Pre-operational tests are required to confirm the design and performance of the system.

0.4.2. Periodic tests and in-service inspection

This system must be designed to enable periodic visual inspection of its main components.

The RBS [EBS] must be designed to enable periodic tests to be carried out in accordance with the maintenance schedule.

1. SYSTEM ROLES

1.1. SAFETY ROLES

In the event of PCC-2 to PCC-4 conditions, the Extra Boration System (RBS [EBS]) ensures boration of the RCP [RCS] for all primary coolant pressures, in order to:

- achieve a controlled state (when necessary),
- compensate for the reactivity insertion caused by the RCP [RCS] cooldown in reaching a safe shutdown state (RIS/RRA [SIS/RHRS] connected) from the controlled state. Boration is terminated when the boron concentration required for the safe shutdown state is achieved.

1.2. FUNCTIONAL ROLE

In normal operation, the RBS [EBS] is used to perform primary cooling system hydrostatic testing. The testing is carried out using one of the two RBS [EBS] pumps, known as the "test pump" since this RBS [EBS] pump is capable of injection into the RCPB at the RCP [RCS] test pressure.

2. DESIGN BASES

RCPB hydrostatic test

The RBS [EBS] is used in the RCPB hydrostatic tests, since the equipment used to perform this function is consistent with safety requirements described in section 0.1, i.e. a low flow, high head pump supplying the RCP [RCS]. The pump head required to reach the RCPB test pressure is greater than the pump head strictly necessary for the injection of safety boron; therefore, the hydrostatic test function plays a direct role in the design of the system components.

Nevertheless, to carry out the test, only one pump is required. As the test frequency is very low, there is no need to allow for component redundancy. Therefore, a single pump, called the "test pump" is used for RCPB hydrostatic testing.

3. EQUIPMENT DESCRIPTION AND CHARACTERISTICS

3.1. RBS [EBS] BORATED WATER SOURCES

Since the RBS [EBS] flow rate must be limited to be compatible with the RCP [RCS] contraction rate, water with a high boric acid concentration is used to achieve a sufficient boration rate (in particular to compensate for reactivity insertion due to cooling).

The boron concentration ranges from 7000 ppm to 7300 ppm [Ref-1]. The maximum concentration ensures that boron crystallisation limits are not exceeded.

Provisions are made to prevent boron crystallisation in the RBS [EBS] tanks.

The boration function can be performed with a flow rate of 2.78 kg/s of 7000 ppm boric acid from a single train. The RBS [EBS] system (up to the containment input lines) together with the associated RBS [EBS] tanks is located inside the fuel building.

Note: RCPB hydrostatic test

The RCP [RCS] "test pump" suction is connected to the RCV [CVCS] during a RCPB hydrostatic test. Outside of the test period, the connection is normally isolated using a manual isolation valve. Given its role in the hydrostatic test, and as the RCV [CVCS] is located in the second section of the fuel building, the RBS [EBS] test pump is the pump which belongs to train 2 of "fuel building 2".

3.2. RBS [EBS] INJECTION DEVICES AND PROTECTION

The RBS [EBS] pumps are able to inject into the RCP [RCS] at pressures between 1 bar and the set pressure of the pressuriser safety relief valves, at a minimum constant flow rate of 2.78 kg/s. The pumps are reciprocating pumps which are suitable for carrying out RCPB hydrostatic testing.

Each injection line is protected against overpressure when the pump is operating, via a relief valve which discharges into the corresponding RBS [EBS] tank. This does not apply during hydrostatic tests.

Since the RBS [EBS] pumps are safety classified components, they are capable of being tested at any time using a dedicated "minimum flow" line known as the "test line". This is connected between the injection line of each pump and the corresponding RBS [EBS] tank using a section of the relief valve discharge line, which allows the characteristics and availability of the pumps to be checked. This operation (start-up of the closed loop pump to circulate through its tank) can also be used to mix the tank contents.

3.3. RBS [EBS] INJECTION LINES

The injection line of each RBS [EBS] train penetrates into the reactor building and contains a power-operated valve outside the reactor building and a check valve inside the reactor building. These two valves have a containment isolation function.

Each injection line then divides into two sections to inject into two of the RCP [RCS] cold legs through the RIS/RRA [SIS/RHRS]. Thus, in combination the two RBS [EBS] trains inject into all four RCP [RCS] cold legs, ensuring, as far as possible, a uniform distribution of the boron in the core. Each connection to the cold leg contains a power-operated isolation valve, closed during normal operation. These valves are part of the RCPB.

This design ensures that the total flow from each train reaches the core, even if an RCP [RCS] loop becomes "inactive" (i.e. there is no coolant circulation). Under these circumstances the corresponding RBS [EBS] isolation valve may be closed in order to inject the entire flow from the train into the RCP [RCS] via the second injection line, which is connected to an "active" loop.

Due to minimum operating temperature considered for the reactor building (15°C) and for the space between the fuel building and the reactor building (7°C), an electrical heat tracing is used to avoid boron crystallisation in any part of the RBS [EBS] injection lines.

3.4. EQUIPMENT CHARACTERISTICS

Pumps

Only the train 4, pump is used in RCPB hydrostatic testing. Nevertheless, since the aim is for both trains to be as identical as possible, the two pumps are identical. The motor of the pump is cooled by air.

The following table gives main parameters related to the boration function [Ref-2]:

Usual parameters	Boration function
Flow rate in normal operating conditions	11 m^3/h
Required minimum flow rate	10 m^3/h
Maximum flow rate	12.4 m^3/h
Maximum suction pressure	3 bar g
Minimum operating temperature (*)	20°C
Normal operating temperature	~25°C
Maximum operating temperature	100°C
Total head for the pump piston (independent of flow rate)	up to 260 bar
Minimum available NPSH	14 m
Pumps: motor power	~110 kW

(*): Due to electrical heat tracing outside the fuel building and the local temperature inside the fuel building.

Tanks

Both RBS [EBS] tanks are filled with clean boric acid from the REA [RBWMS] boric acid preparation tank. They are maintained at atmospheric pressure using a vent located on the upper section. Each RBS [EBS] pump suction line is connected to the bottom of the corresponding RBS [EBS] tank to maximise the useable volume available.

The contents of each tank may be mixed using the corresponding RBS [EBS] pump. Provisions are also made for carrying out periodic sampling.

A connecting line connects the bottoms of the two tanks. This line is normally isolated with manual valves but enables injection from the two tanks (or their drainage) using a single RBS [EBS] pump. Hence the total capacity of the two tanks may be injected using a single pump (in approximately one hour of operation).

The level in the RBS [EBS] tanks is constantly monitored by two redundant sensors. Associated low level thresholds are provided to detect any loss of level (unscheduled or otherwise), and in particular to help ensure the tank contents do not to drop below the required safety level. A temperature measurement is also provided for each tank by two redundant sensors, associated with a low temperature threshold, to help prevent any boron precipitation.

3.5. SERVICE LIFE

The RBS [EBS] equipment is designed for a power plant service life of 60 years [Ref-1].

3.6. CONSTRUCTION MEASURES

Materials used

The system (pipes, valves and components) is constructed from austenitic stainless steel.

Construction

All of the connections and pipe joints are welded, except where flange connections are required to facilitate dismantling during maintenance or hydrostatic tests (e.g. pump connections).

Thermal insulation

The pipes outside the fuel building, in particular in the annulus, are provided with thermal insulation to avoid boron precipitation in the pipes.

4. OPERATING CONDITIONS

4.1. GENERAL DESCRIPTION

Safety boration is carried out by two separate 100% capacity trains (corresponding to the quantity of boron that must be injected into the RCP [RCS]).

Each RBS [EBS] train consists of a tank of boric acid, and a suction line connected to a reciprocating pump which injects into two primary coolant loops via two isolatable lines. A relief valve is installed downstream of the pump. A test line allows boric acid solution to be injected into the tank, during periodic pump tests and tank mixing, without injecting into the RCP [RCS].

The RBS [EBS] system is always filled (in normal and accident operations) with liquid (water containing boric acid). The system has no connections with any gas systems and hence there is no risk of gas ingestion. Also, the design operating temperatures and pressures are such that there is no risk of gas formation within the system. Hence, there is no situation that could lead to RBS [EBS] malfunction due to a gas lock forming in the system.

A minimum capacity is required in each RBS [EBS] tank to achieve the safety boration injection requirements.

The RBS [EBS] pumps are reciprocating pumps with a high dynamic head to allow RCPB hydrostatic testing to be carried out. An electric motor with a power of around 110 kW will be used for each pump. Only one of the two pumps is used for hydrostatic testing.

4.2. STATE OF THE SYSTEM IN NORMAL OPERATION

In normal operation, the pumps are shut down (except during periodic tests). All of the manual valves between the boron tanks and the RCP [RCS] are open (except manual valves in the line connecting the two tanks). The power-operated isolation valves for the test lines are closed.

The power-operated isolation valves in the injection lines to the RCP [RCS] are also closed because they contribute to the RCPB containment isolation function.

The containment isolation valves that are located outside the containment are open.

4.3. SAFETY BORATION

The safety boration carried out by the RBS [EBS] is normally activated manually by the operator from the control room, with two separate on/off controls for each train. However, in the event of ATWS, or if a very low steam generator pressure is detected, the RBS [EBS] starts automatically.

The isolation valves in the RCP [RCS] injection lines are opened and the pumps are started; the isolation valves on the test lines are confirmed and locked in the closed position, the containment isolation valves are confirmed and locked in the open position.

Two special cases are anticipated during the safety boration operation:

- A primary coolant loop becomes inactive with no natural circulation, reactor coolant pump shut down and steam generator isolated – injection into this loop may be isolated using the power-operated isolation valve on the corresponding injection line,

- At containment isolation signal, the RBS [EBS] power-operated isolation valves located outside containment remain open.

The safety boration by the RBS [EBS] is performed during RCP [RCS] cooldown to compensate for the increased reactivity produced by the cooldown itself. The RBS [EBS] flow rate into the RCP [RCS] compensates for the RCP [RCS] fluid contraction without causing overfilling. Safety boration is then performed with the following flow rates [Ref-2]:

- 5.56 kg/s if two trains are in operation (assuming no system failure), for a cooldown of 50°C/hour,

- 2.78 kg/s if one train is in operation (taking account of the single failure criterion) for a cooldown of 25°C/hour.

The achievable cooling rate, therefore, depends on the number of RBS [EBS] trains available.

Once the RBS [EBS] has been started for safety reasons then it continues to operate until the boron concentration required for the safe shutdown state is reached. The RBS [EBS] can be shut down manually by the operator when the targeted RCP [RCS] boron concentration is reached.

4.4. RCPB HYDROSTATIC TEST

This test is carried out with an RBS [EBS] pump drawing suction from the RCV [CVCS] with the suction from the corresponding RBS [EBS] tank isolated. This system is configured using manual valves. The relief valve downstream of the pump is locked using a mechanical device and the test line is closed.

The RBS [EBS] test pump is started and the RCPB pressure is increased gradually until the test pressure is reached.

5. PRELIMINARY SAFETY ANALYSIS

5.1. COMPLIANCE WITH REGULATIONS

See Sub-chapter 1.4.

5.2. COMPLIANCE WITH FUNCTIONAL CRITERIA

5.2.1. Control of reactivity

Demonstration that the RBS [EBS] design characteristics (volume of water, flow rates and boron concentration) are appropriate to achieve a controlled state or safe state is confirmed by transient analysis in Chapter 14.

Justification of the RBS [EBS] design and the instrumentation and control systems provided to perform automatic actions required following an ATWS, is provided by the transient studies presented in Chapter 16.

The RBS [EBS] system temperature is monitored in all of the rooms that house the system to ensure that a sufficiently high temperature is maintained to prevent the risk of boron precipitation. The water temperature in the tanks can be monitored directly. The boron concentration in the tanks is checked by sampling and a homogeneous mixture is ensured by periodic operation of the pumps using their test lines.

5.2.2. Decay heat removal

Not applicable.

5.2.3. Containment of radioactive substances

Each RBS [EBS] containment penetration is equipped with two different isolation valves: a check valve inside the reactor building and a power-operated valve outside the reactor building.

The power-operated isolation valves in the injection lines to the RCP [RCS] are normally closed. As they are in series with containment isolation check valves, there is a minimal risk of water from the RCP [RCS] bypassing the containment.

5.3. COMPLIANCE WITH DESIGN REQUIREMENTS

5.3.1. Safety classification

Compliance of the design, construction, materials and equipment with the requirements of the classification rules is described in Sub-chapter 3.2.

5.3.2. Single Failure Criterion (redundancy)

In the event of a single failure in an individual RBS [EBS] train, at least one RBS [EBS] train remains available to achieve a safe shutdown state. A passive single failure is not considered in the RBS [EBS] design, as it operates only for a limited time in post-accident conditions.

The RBS [EBS] consists of two separate trains (fluid, power supply and Instrumentation and Control). This arrangement ensures that the system remains operable even in the event of a single active failure when the system is initiated.

5.3.3. Qualification for operating conditions

The equipment is qualified in accordance with the requirements of Sub-chapter 3.6.

5.3.4. Instrumentation and control

Compliance of the design and construction of instrumentation and control and equipment with the requirements of the classification rules is described in Sub-chapter 3.2.

5.3.5. Emergency power supplies

Any power-operated pump or valve required for a safety action can be supplied (by means of cross connexions) from two different backed-up electrical trains. Trains 1 or 2 can supply RBS [EBS] train 1. Trains 3 or 4 can supply RBS [EBS] train 4.

Maintenance can therefore be carried out on a diesel generator set while the availability of the two RBS [EBS] trains is maintained.

Even after a PCC event with a loss of the external power supply and loss of an additional power supply train due to a single failure of a diesel generator set, the availability of an RBS [EBS] train is ensured.

In the event of total loss of external power supplies at least one RBS [EBS] train remains powered.

5.3.6. Hazards

Internal hazards which could result in a PCC-2, PCC-3 or PCC-4 accident would not affect the RBS [EBS] system second train (first train being assumed unavailable due to application of the single failure criterion). The physical separation between the two separate trains ensures that in the event of an internal hazard affecting one of the trains, the other train remains available.

The RBS [EBS] is designed to withstand external hazards in accordance with Sub-chapter 13.1.

Aircraft crash

The RBS [EBS] protection against aircraft crash is provided by its location in the fuel building and reactor building.

External explosions

The RBS [EBS] is able to withstand the design basis explosion pressure wave defined in Sub-chapter 13.1 because it is designed to withstand the vibrations produced by the design basis earthquake which envelope the loads produced by the pressure wave.

5.3.7. Other requirements

This system is considered in the demonstration of the practical elimination of the containment bypass risk (see Sub-chapter 16.3).

6. TESTS, INSPECTION AND MAINTENANCE

6.1. PERIODIC TESTS AND IN-SERVICE INSPECTIONS

6.1.1. RBS [EBS] pumps

The pumps may be tested (availability and characteristics) by starting them on their corresponding test line, with their injection line to the RCP [RCS] closed. Under these circumstances the fluid is circulated through the corresponding RBS [EBS] tank.

6.1.2. Containment penetrations

The leak-tightness of the containment penetrations is tested in accordance with appropriate general procedures and criteria.

6.2. PREVENTIVE MAINTENANCE

As the RBS [EBS] comprises two trains, preventive maintenance is only carried out on its mechanical components during a unit shutdown.

When the plant is in operation, preventive maintenance is only envisaged on the diesel generator power supplies; consequently, electrical connections are provided to ensure availability of the two trains during these maintenance operations.

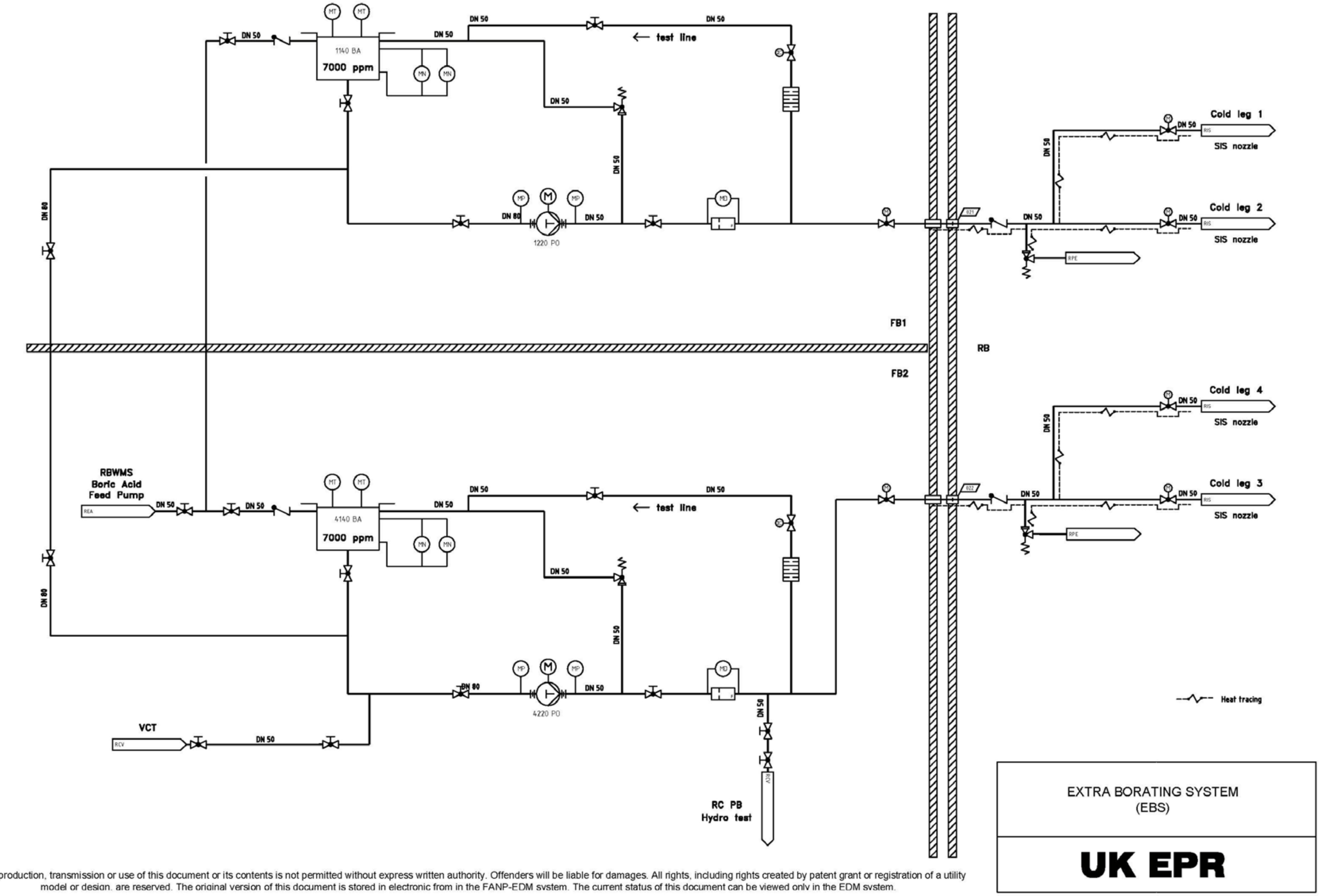
6.3. MAINTENANCE DURING SHUTDOWN

Provisions for the system drainage, inspection and filling are provided, in particular for the RBS [EBS] tanks. Complete drainage of the tanks is restricted where possible to minimise the consumption of boric acid. A header is provided in order to transfer water between tanks.

7. SCHEMATIC DIAGRAM

A simplified flow diagram [Ref-3] for the RBS [EBS] is presented in Sub-chapter 6.7 - Figure 1.

SUB-CHAPTER 6.7 - FIGURE 1: SIMPLIFIED FLOW DIAGRAM FOR THE RBS [EBS]



SUB-CHAPTER 6.7 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

The following references are used throughout this sub-chapter:

[Ref-1] System Design Manual. Extra Boration System - Part 2: System Operation. NESS-F DC 535 Revision A. AREVA. April 2009. (E)

[Ref-2] System Design Manual Extra Boration System - Part 3: System and component sizing. NESS-F DC 536 Revision A. AREVA. May 2009. (E)

[Ref-3] System Design Manual Extra Boration System - Part 4: Flow diagrams. NESS-F DC 537 Revision A. AREVA. May 2009. (E)

[Ref-4] System Design Manual – Extra Boration System - Part 5: Instrumentation & Control NESS-F DC 615 Revision A. AREVA. November 2009. (E)