Potential Jamming of recirculation system valves in the safety injection (SI) and containment spray (CS) systems for 1300 MWEP'4 PWR's

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Abstract: By the end of the year 2000, an anomaly has been found in the recirculation system valves of the Safety Injection (SI) and Containment Spray (CS) systems on twelve French 1300 MWe/P'4 pressurized water reactors. This anomaly might block the valve and prevent its opening, especially in case of loss of coolant primary accident (LOCA), due to an operating stress exceeding the value considered for motorization sizing. The reason is a high overpressure in the valve body caused by a temperature rise of the water contained in the body ("thermal binding"). This fault constitutes a potential common-mode failure risk, which could cause the inoperability of the recirculation flow both redundant tracks of the SI and CS systems. The Institute for Protection and Nuclear Safety estimated the core damage risk in this situation at $3x10^{-4}$ per unit per year. The emergency of processing the generic anomaly led the utility Electricité de France (EdF) to develop a modification in two steps (temporary solution and final solution).

1. INTRODUCTION

The thermal binding risk on two seal surfaces valves (2 gates and 2 seats) had already been reviewed after an opening failure in 1991, following a routine test on a containment isolation valve in the 900 MWe unit 5 of Bugey. The utility, Electricité de France (EdF), carried out corrective actions in 1994 for a number of valves in 900 and 1300 MWe standardized plants. This resulted in the implementation of modifications (especially, installation of a one-way bypass line with calibrated valve, or two-way bypass line with three-way valve). This measure was not applied to the containment isolation valves of the SI and CS systems redundant sucking lines to the reactor building (RB) sumps, as they were assumed to be protected against the thermal binding by a sufficient water seal. At that time, IPSN reminded the importance of sump fill-up and actions necessary to ensure the water seal level in operation. It should be noted that all 12 reactors of the 1300 MWe/P'4 standardized plants were fitted with a visible level indicator enabling to check the water level in the sucking pipes to sumps. Also, monthly inspections of the water seal had been implemented. Those sumps are called "recirculation sumps" hereafter.

2. FUNCTIONAL BACKGROUND

(see figure 1)

With regard to safety, the purpose of the safety injection system (SIS) is to maintain a water inventory in the reactor core and to provide an appropriate anti-reactivity margin in case of primary system breaks (loss of coolant accident LOCA) or of secondary system breaks (steam pipe break and feedwater pipe break). Injection is performed in 2 phases :

- Direct injection phase : the MPSI and LPSI pumps inject the borated water from the refueling water storage tank (RWST) into the primary system cold legs, also the accumulators are drained when the primary pressure drops below 45 bars.
- Recirculation phase: when the RWST is empty, the isolation valves of the pump minimum flow lines to the RWST tank close and the valves of the Recirculation sumps open. Pump sucking is thus transferred from the RWST to the Recirculation sumps that collect the water from the primary break and from the containment spray system (CSS), if required.

The basic purpose of the CSS is to limit the containment pressure and temperature after a break in the primary system or secondary system and to lower a part of released fission products in the sumps. This system insures also the cooling of recirculation water. As for the SIS, the pumps first suck up the borated water in the RWST and second, the water contained in the recirculation sumps.

3. CAUSE OF THE FAULT

The motor-driven isolation valves from the sucking lines to the sumps are double-disk parallel seat gate valves. In case of LOCA in the inside containment, hot fluid fills the sump in the reactor building. In particular, this water may penetrate the SIS/CSS suction line if the cold water seal is initially drained. Due to conduction, then convection, this hot water supply may generate a temperature rise in the fluid contained in the inter-gate gap of the sump valve. This results in overpressure inside the valve and a possible jamming of this valve, as the operating stress exceeds the value considered for motorization sizing, and a distortion of the valve body: this is called thermal binding (see figure 2). It should be noted that tests demonstrated that a 1°C heating increase the inter-gate pressure of the valve from 1 to 2 bars. Consequently, during reactor design, a sufficient water seal is required to protect the valves against the thermal binding generated by the supply of hot water into the sumps.

4. FAULT DESCRIPTION ON THE 1300 MWE REACTORS OF THE P'4 TRAIN

Since the incident occurred on the reactor 3 (900 MWe) in the Dampierre plant in September 1993 (IRS 01582), the utility evidenced a generic problem of air presence in the sucking lines of the SIS and CSS pumps. The cause was a failure in pipe filling and venting. The important air bubbles presence in these pipes could jeopardize the safety systems during recirculation mode, due to loss of prime pump (loss of prime threshold: 50 l). Consequently, actions were taken; more specially, the venting lack generated a modification on the reactors of the nuclear power plants, consisting in installing additional venting intakes on the upper sections of the lines, and a sump level indicator outside the RB. To date, this modification has been implemented on most 900 MWe reactors and started in 2001 on the 1300 MWe reactors.

In November 1999, during an inspection of the water seal in the RIS/EAS recirculation sumps of a reactor B3 in the Chinon plant (900 MWe), that integrated the above-mentioned modification, a drop in the water seal was reported.

This drop was not due to the modification as it was also reported in February 2000 on reactor B4 in the Chinon plant (3 sumps out of 4 had a water level less than 120 liters for a threshold set to 25 l), that did not integrate the modification. This report resulted in implementing a two-monthly inspection of the recirculation sump level with supply of additional borated water if required, for all the 900 and 1300 MWe standardized plants not fitted with the modification. Two phenomena may explain the drops reported for the water seal in the recirculation sumps: evaporation of the sump water in the containment and water transfer from the sump to the sump valve. This upstream/downstream transfer would be due to the presence of an air bubble in the pipe section between the sump valve and the check valve of the SIS and CSS. This air bubble would be generated by water degassing in the RWST during stirring (water temperature rise in the tank from 10 to 20°C during routine operating tests of the SIS/CSS pumps), considering that the check valve is not air-tight (under a 1-bar pressure difference, the leak rate would be equal to some tens of liters per hour) and, that the SIS/CCS pipe are steeping from the pumps to the sumps (see figure 3).

To summarize, the water level drop could be explained by the migration of an air bubble trapped in the "sump valve/check valve" section to the RB sump upon opening of the sump valve during routine tests. An additional investigation and test program was initiated on a reactor to validate this hypothesis. It should be noted that hypotheses concerning a high evaporation of the sump water mass or the presence of leaks in the lines were disregarded after assessment of the evaporated quantity over a cycle (8 l) and check of the lines.

At the end of year 2000, investigations to assess the filling margins of the water seal with regard to the "thermal binding" risk on the sump valves, demonstrated that the water seal on the reactors for the 1300 MWe/P'4 and 1450 MWe standardized plants was not sufficient to prevent the " thermal binding" risk. Indeed, on these sections, the vertical water seal provided during design is 20 cm only, while the other standardized plants (900 MWe/CP0, 900 MWe/CPY, 1300 MWe/P4) have a water seal equal to or higher than 3 m (see figures 4 and 5). It is thus required to protect the suction valves (09 and 10 VP) of the 1300 MWe/P'4 standardized plant against this thermal binding, as were the valves of the 1450 MWe standardized plant, since the conception.

5. SAFETY IMPLICATIONS

The anomaly in the design of isometry for the water seal on the 1300 MWe/P'4 reactors would result in a potential risk for non opening of the valves in the recirculation sumps due to thermal binding. In case of primary break or secondary break accident, the recirculation function on the recirculation sumps might be inoperative and, consequently, the core cooling function would not be provided. In situations of major primary breaks and intermediate primary breaks, when recirculation is quickly required, this failure results in a significant increase of the risk for core damage with a factor 30 with regard to the calculated yearly probability, i.e. a yearly probability for core damage of approximately $3x10^{-4}$.

6. CORRECTIVE ACTIONS

In order to remedy this major design anomaly, EDF proposed a modification in two steps for all 12 1300 MWe/P'4 reactors concerned: a short-term interim solution (called phase A) and a medium-term final solution (phase B) to be set up during refueling outage (see figure 6).

Short term temporary solution

The temporary solution consists to set up, in line with the plug used more specially to blow the valve rod packing-gland out, a one-way decompression line consisting of a calibrated valve and a manual shutoff valve. The decompression line exhaust is connected to the nuclear drain and vent system (RPE) via the leak-recovery system of the valve packing-gland. The fluid is collected in a 1 m^3 tank and is then exhausted to sumps. The decompression line is also fitted with a versatile venting plug (venting, leak test and packing-gland driving). The calibrated valve is designed to ensure tightness up to a 4-bar relative pressure and full opening at 6.6 bars. The integrity of the reactor containment is thus ensured by the tightness between the seat and the downstream gate of the valve and by the calibrated valve.

Final solution

The final solution (currently design in progress) would in fact complement the temporary solution, by improving the confinement of the exhausted fluid, in case of thermal binding, by setting the tubing on the downstream pipe of the SIS to which the decompression line would be connected (see figure 6).

IPSN safety assessment

IPSN compared the benefits and drawbacks of the various solutions proposed by the utility. The temporary solution shows various drawbacks, namely:

- A risk for containment bypass, both during normal operation of the reactor and in post-accident situation, if the calibrated valve failed in open position. The potential consequences include a loss of the water seal in the recirculation sumps during normal operation that may generate a loss of the SIS/CSS pumps when switching to recirculation by air suction, and a loss in water stock in the containment sumps in primary loss-of-coolant accident.
- A risk for loss of water stock in the RWST during normal operation, in case of the jamming calibrated valve in open position combined with a failure tightness of the downstream gate of the sump suction valves (09 VP and 10 VP) and downstream check valves (13 and 14 VP) – see figure 4.
- A risk for autoclave effect up to a 6.6-bar pressure (calibration pressure of the calibrated valve corresponding to full opening), which may impact the motorization (reminder: an autoclave effect occurs when, with the sump valve closed, a relative overpressure in the adjacent pipe makes one of the gates untight, when the pressure drops in the pipe, the pressure remains contained in the body of the valve).

However, the risks involved in the temporary solution are not redhibitory as the calibrated valve leakage can be detected and isolated during normal operation, and re-injected into the reactor building sumps via the highly contaminated effluent re-injection systems in case of primary break accident. Provided some additional actions are taken, IPSN considered the implementation of the temporary solution as acceptable.

The final solution has the advantage of better ensuring the “containment” safety function. Indeed, any leakage on the decompression line remains contained in the RIS system. This solution is more appropriate.

7. CURRENT SITUATION OF THE 1300 MWE/P'4 REACTORS

To date, the temporary solution is set on all the 1300 MWe reactors of the P'4 train.
The final solution is planned for first implementation on reactor 4 in the Cattenom plant by early 2002. The integration of this solution should be achieved by 2005.

8. LESSONS

Although incorporated in the design of the 1300 MWe/P’4 standardized plant, the thermal binding risk had been excluded on the valves of the recirculation lines from the sumps in the SIS and CSS. In fact, this risk did exist due to an insufficient water seal. The reactors thus operated from the beginning with a potential jamming risk of the sump valves in closed position when required. A incident involving a level drop in the water seal of the sumps on a 900 MWe reactor (Chinon B3) in 1999, was necessary for the utility of the French nuclear plants, Electricité de France, to detect the anomaly during an investigation campaign on all standardized plants, thus resulting more specially in reviewing the margins available for water seals. It should be noted that in 1994, Electricité de France considered that implementing operating actions was enough to prevent a possible thermal binding resulting from a drop in the sump water seal.

This anomaly is a common mode failure that may result, in case of accidental breaks in the primary system or secondary system of the reactor, in inoperability of the recirculation function and consequently, the core cooling function. The major potential consequences of this fault led the safety authorities to classify this incident as level 2 in the INES scale.
In front of the unacceptable potential consequences with regard to safety (risk of core damage increased by a factor 30 for accidental primary major breaks and primary intermediate breaks), a quick action had to be implemented to resolve this issue. In a first stage, an temporary solution was developed, expecting the final solution studies, the implementation of which is planned for early 2002.

As a conclusion, in this case we can only state the defense in-depth lines (concerning basic designs, installation and operation) did not allow a quick detecting this fault. At this stage, it is interesting to emphasize that the analysis by the operator of an incident that occurred on a 900 MWe reactor, allowed discovering a generic fault existing for several years on the reactors of the 1300 MWe/P’4 standardized plants. Once again, this shows the large importance of a thorough the experience feedback analysis.

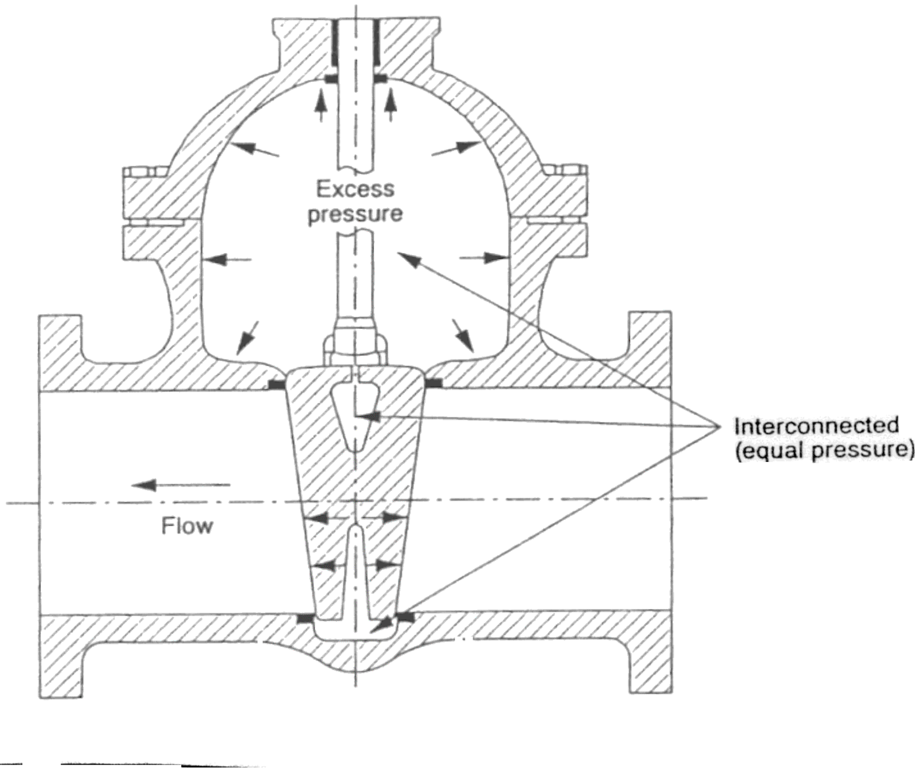

Figure 2 : Pressure locking flexible-wedge gate valve

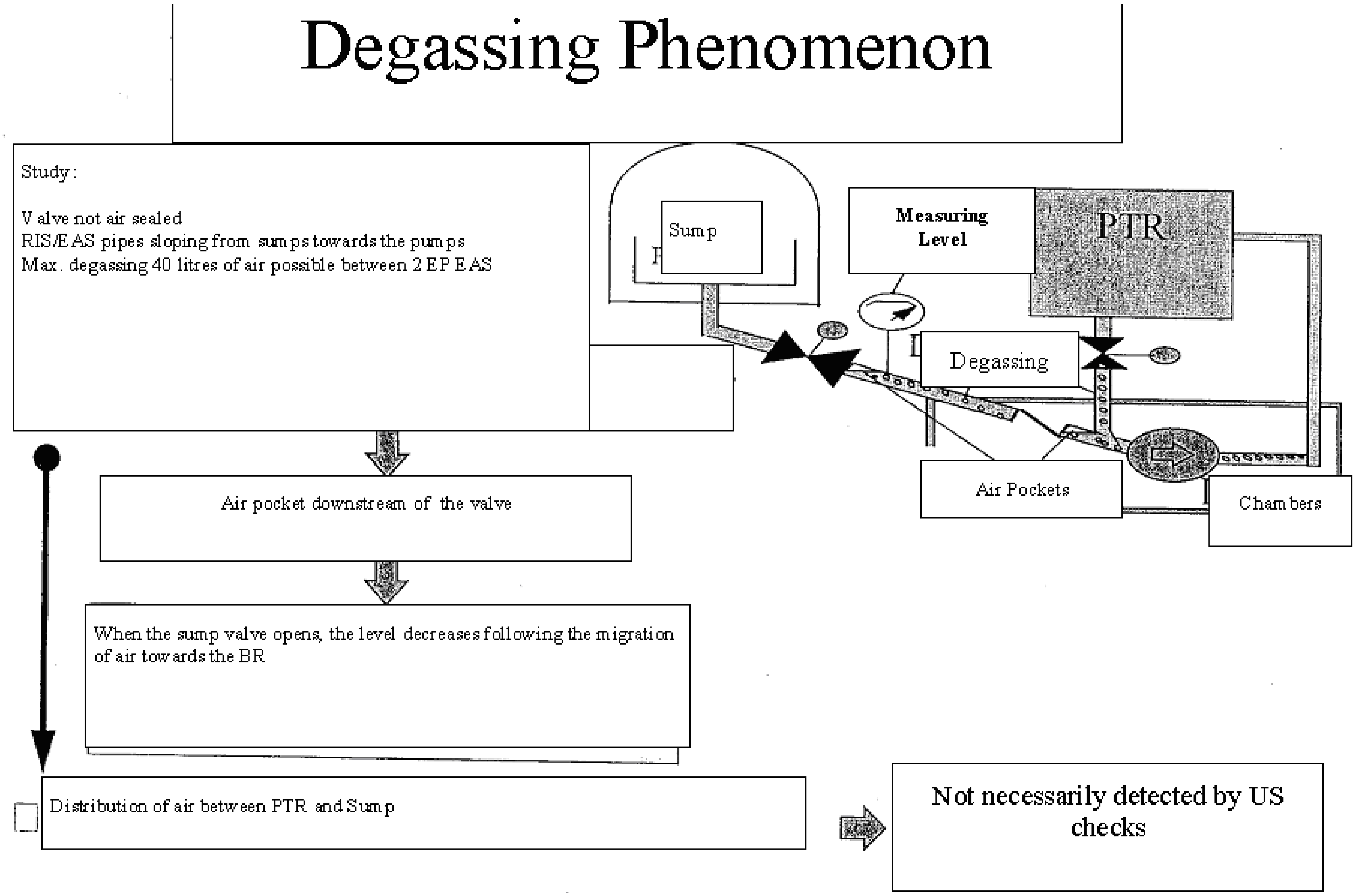

Figure 3 : Degassing phenomenon

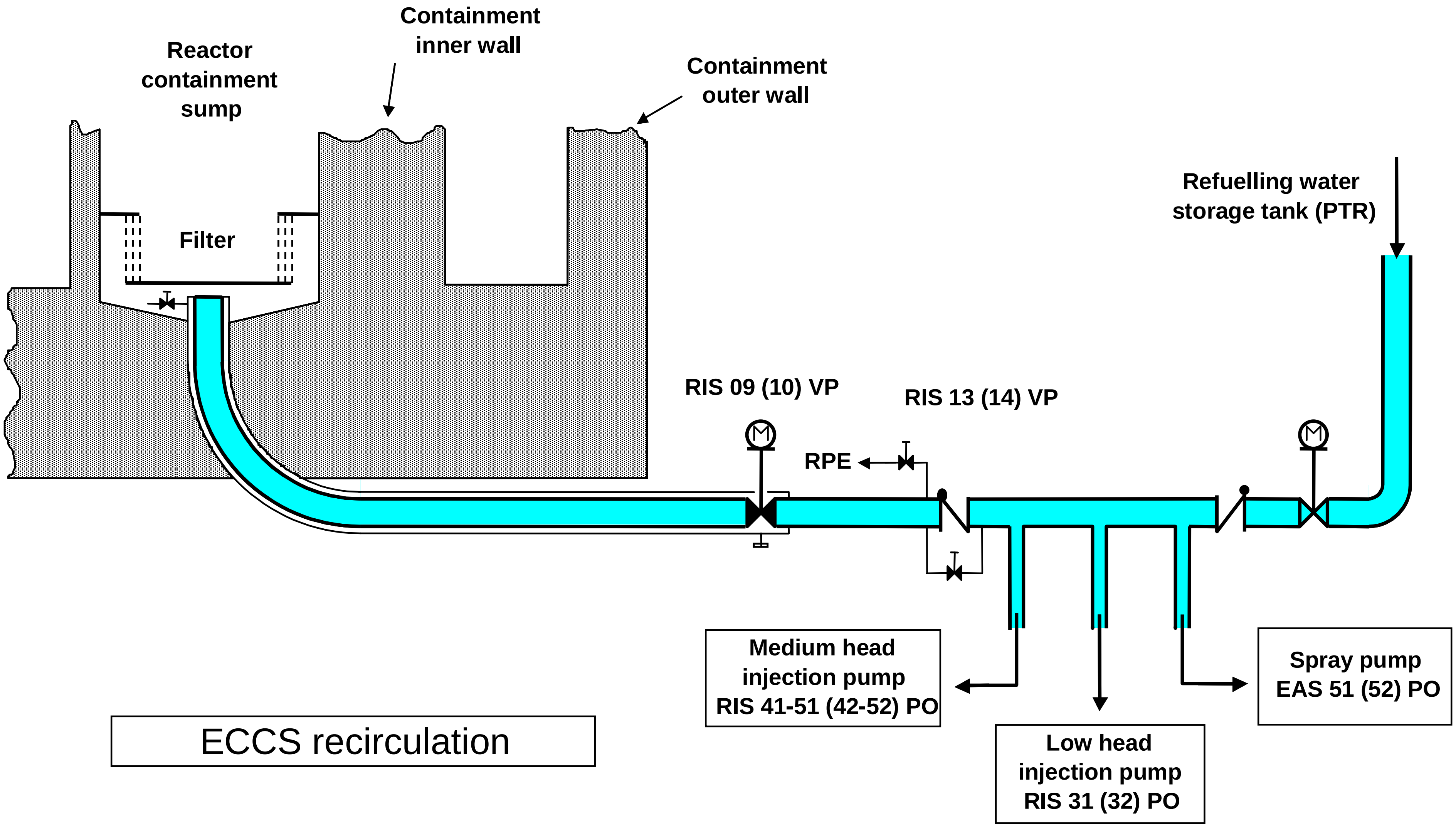

Figure 5 : diagram of isometric recirculation circuit P4 - 1300 MWe PWR series

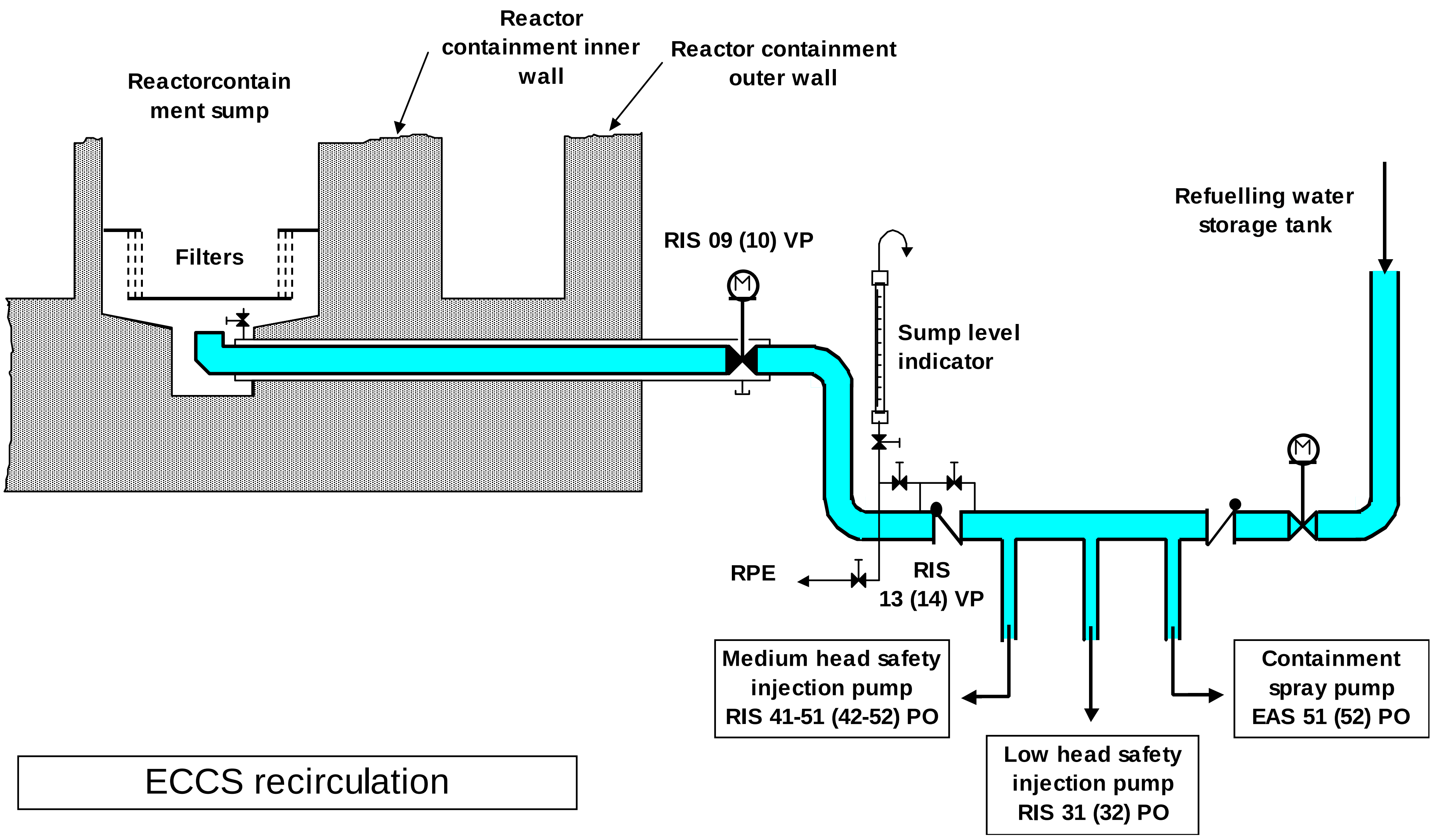

Figure 4 : diagram of isometric recirculation circuit P'4 - 1300 MWe PWR series

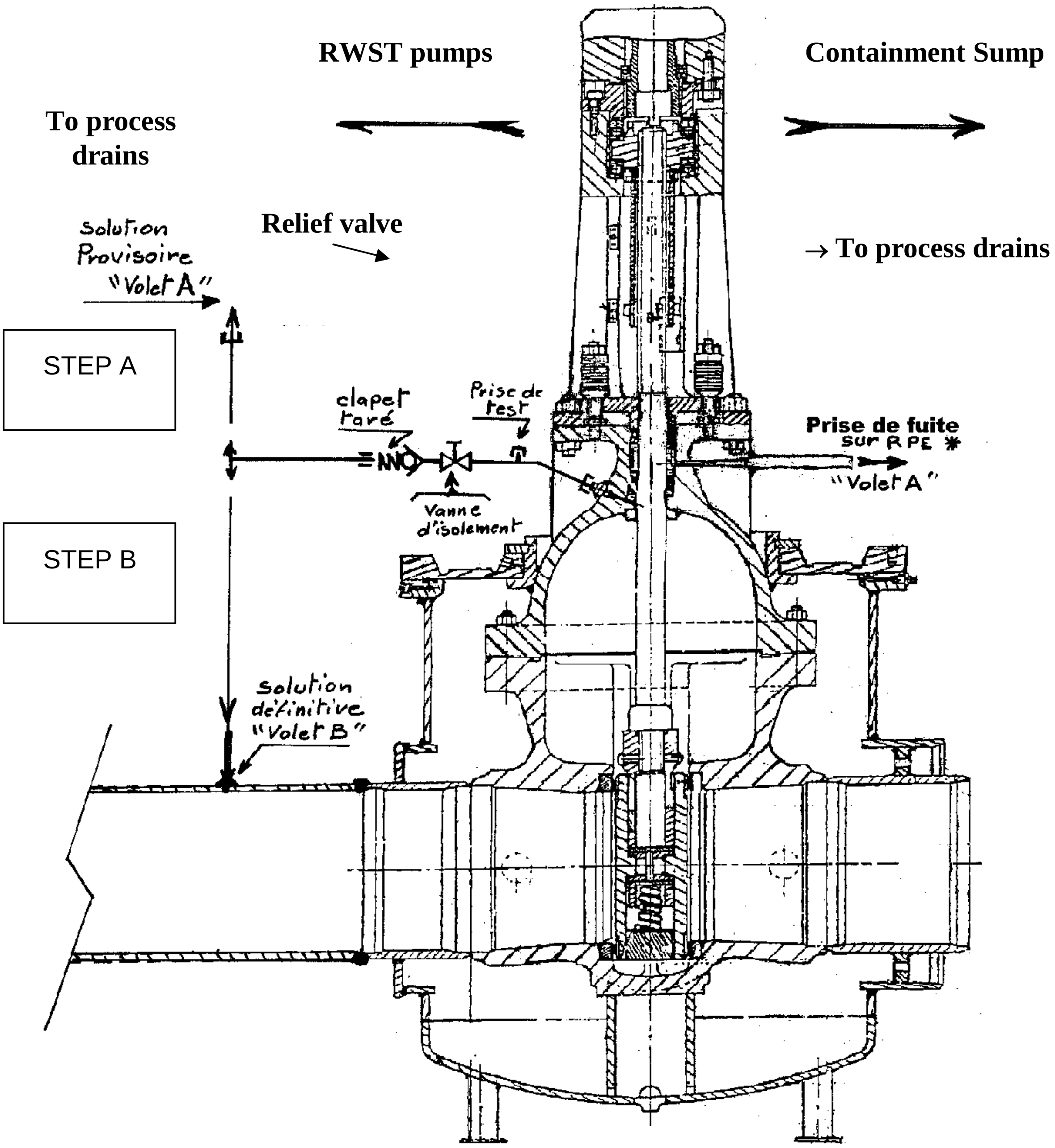

Figure 6 : Modification 'steps A & B'

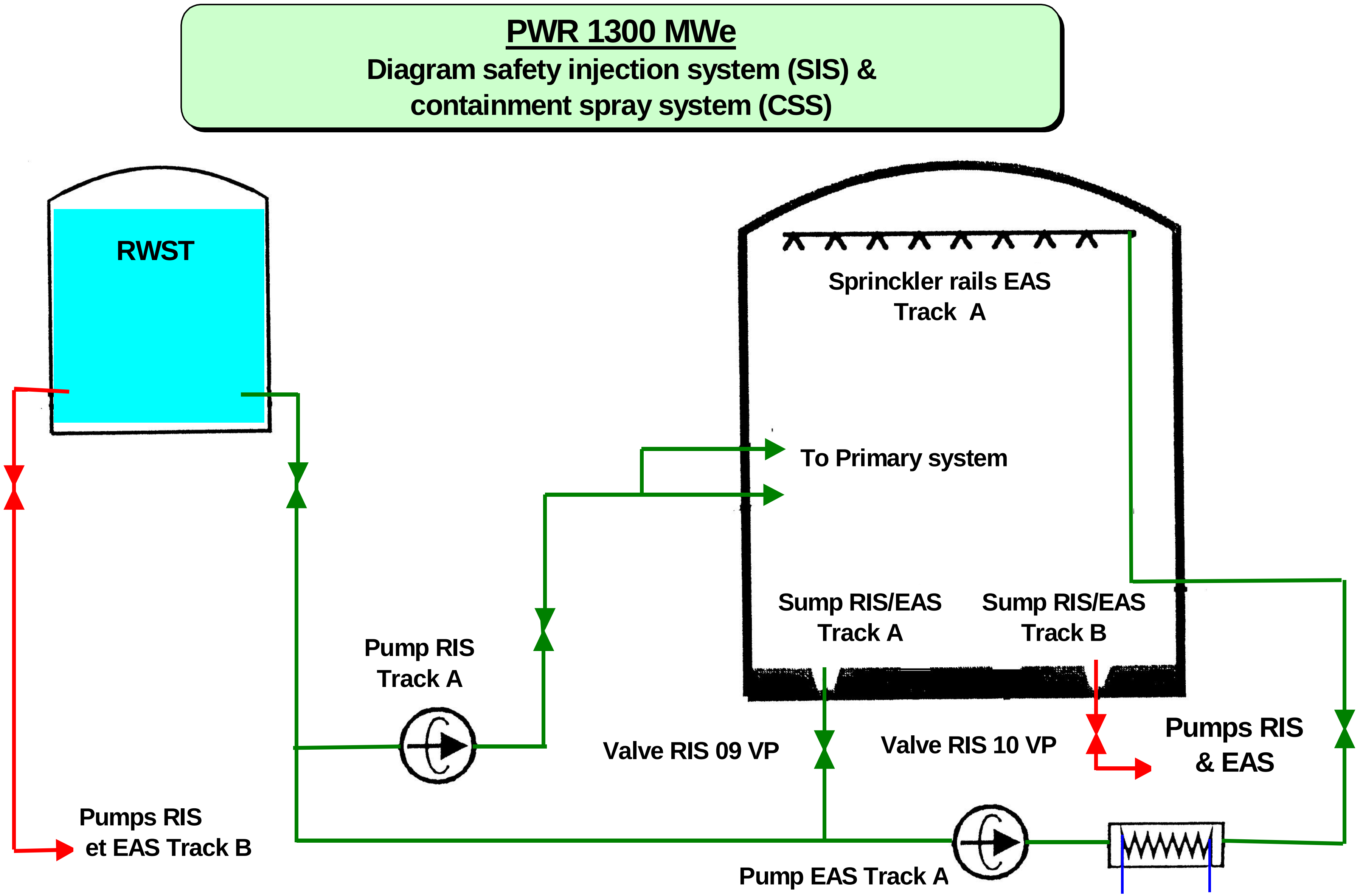

Figure 1 : Diagram of safety injection system (SIS) & containment spray system (CSS)