Lessons Learnt from the Resin Release into the Primary Circuit of the Fessenheim NPP Unit 1 in January 2004 – Impact on the Nuclear Safety

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Abstract:
On January the 24th, at the Fessenheim NPP Unit 1, a human error was committed during a boron demineralizer line-up, caused by lack of preparation. Consequently, a quantity of resin estimated at about 300 liters was released from this demineralizer, through its safety valve, into the head-tank of the Chemical and Volume Control (CVC) System and after that, into the primary circuit. The incident had a real impact on the unit: the CVC filters were clogged, the seal injection flow of the primary circuit main pumps was lost, the primary circuit main pump 2 tripped four days after the incident, as the rate of the recirculated seal leak flow (downstream the seal 1) increased up to the automatic trip set point, the shaft of the running primary circuit feed pump was found seized into the rear hydrostatic bearing following the pump stop (after ten days of successful operation), the thimble plugs were jammed into their guide tubes, the small diameter pipes were plugged. The unit shutdown for over five months was necessary to clean the primary circuit components, repair or replace the affected equipment items and carry out inspections and tests. The reinforced unit in-service monitoring program, set up during the unit start-up, confirms that, up to now, the unit operation has not been adversely affected by the residual amounts of resin which subsist in certain areas of the primary circuit. Nevertheless, it remains to verify that, in the long term, these deposits will have no negative chemical effect in the potential confined areas, such as the thermal barriers of the primary circuit main pumps. Finally, the occurrence of this incident underlines, once more, the importance of normal operating activity preparing and checking. It also reveals the implementation of an “unforgiving” design change allowing the installation of a boron demineralizer safety valve having its outlet connected to the primary circuit.

1 INCIDENT DESCRIPTION

On January the 24th, the unit 1 of the Fessenheim NPP (a 900 MWe PWR in operation since 1977) was operating at full power. As the unit was in cycle stretchout, the boron demineralizer 0BR05DE line-up on the primary circuit bleed line was necessary in order to decrease the boron concentration in the primary circuit.

Before its start-up, the demineralizer must be flushed out to the Boron Recycle (BR) System to eliminate any trace of pollution and to prevent boron release (simplified flow sheet in Figure 1).

Due to lack of preparation, a human error was committed in the demineralizer line-up to flush it out. As the valve 1CVC28VP was closed, the primary circuit bleed flow was interrupted downstream the demineralizer, causing the bleed line and the demineralizer pressurization.

The demineralizer safety valve 1CVC386VP opened, creating an unexpected flow through the demineralizer, from its bottom to the top. In such a configuration, there is nothing to prevent resins release from the demineralizer. As the outlet of this safety valve is connected to the CVC head-tank, resin particles (smaller than 1 mm diameter) were discharged into the CVC head-tank and thereafter the running primary circuit feed pump sucked them in and sent them into the primary circuit.

A quick clogging of the filter CVC03FI caused a loss of the seal injection flow of the primary circuit main pumps. The operator lined-up the stand-by filter CVC04FI in order to restore the seal injection flow, but several minutes later the flow was lost again. The thermal barriers cooling flow of the primary circuit main pumps was maintained at the normal rate throughout the incident. The rate of the recirculated seal leak flow (downstream the seal 1) of the primary circuit main pump 2 began to increase. The primary circuit bleed line filter CVC01FI was also clogged. The boron meter was unavailable from the 24th to the 29th of January.

On January the 24th and the 25th, the filters on the seal injection lines of the primary circuit main pumps and on the primary circuit bleed line were replaced several times.

Resin release into the primary circuit also caused migration of radioactive products and created hot points in the nuclear auxiliary building and in the reactor building. There were 7 cases of suspected internal exposure of power plant personnel involved in replacing CVC filters, the day of the incident and the following day. Only one person was recorded as having been exposed (to a dose of 0.5 mSv), the others having received doses below the recording threshold. 5 other employees were exposed later, but from causes that cannot be directly linked to the resin release incident.

On January the 25th, the increasing rate of the recirculated seal leak flow (downstream the seal 1) of the primary circuit main pump 2 became unstable, peaking at values close to the pump automatic trip set point. To avoid a potential primary circuit main pump trip (triggering the reactor scram), the operator decided to place himself the unit into the hot shutdown state.

On January the 28th (while the unit was in hot shutdown state), the primary circuit main pump 2 tripped as the rate of the recirculated seal leak flow (downstream the seal 1) increased up to the automatic trip set point.

Technical discussions between the operator, the IRSN and the Safety Authority began immediately after the incident occurrence. The IRSN considered that, given the primary circuit pollution degree following the resin release, only an early shutdown of the unit 1 (initially planned on February the 21st) would have allowed the components to be restored and the reactor to be restarted under acceptable nuclear safety conditions (the recommendation was taken into account by the operator).

2 INCIDENT CAUSES AND CORRECTIVE ACTIONS

2.1 Demineralizer Line-up Error

Technical meetings on site between the IRSN and the operator were held after the incident, revealing several errors in the normal operating procedures.

The demineralizer 0BR05DE start-up operation is considered as a simple one (the operator has to change the position of five valves on site and of two three-way valves in the control room). It is a rather infrequent operation, performed about once a year on each unit.

The day before the incident, the operation was entrusted to an experienced technician, but, for him, other activities took priority over this one. Therefore, he preferred to delegate this activity to somebody else, in fact, to the least experienced technician. The two technicians prepared the activity independently, but they had the same problem and they made the same error: as they did not succeed to entirely follow the demineralizer start-up procedure, they "imagined" a demineralizer line-up based on the systems flow sheets. So, instead of switching the hand key of the valve 1CVC30VP to the "BR" position, as they had to, the technicians planed to open the valve 1CVC390VP and to close the valve 1CVC28 VP, without noticing that the downstream valve 0BR19VP was also closed. The operator in charge of this operation validated the demineralizer line-up preparation. Nobody corrected the error before the incident occurrence, even though the activity was postponed for the next day and another operator checked the preparation, the day of the incident.

After the incident, the demineralizer start-up procedure was reviewed in order to make it clearer and easier to follow.

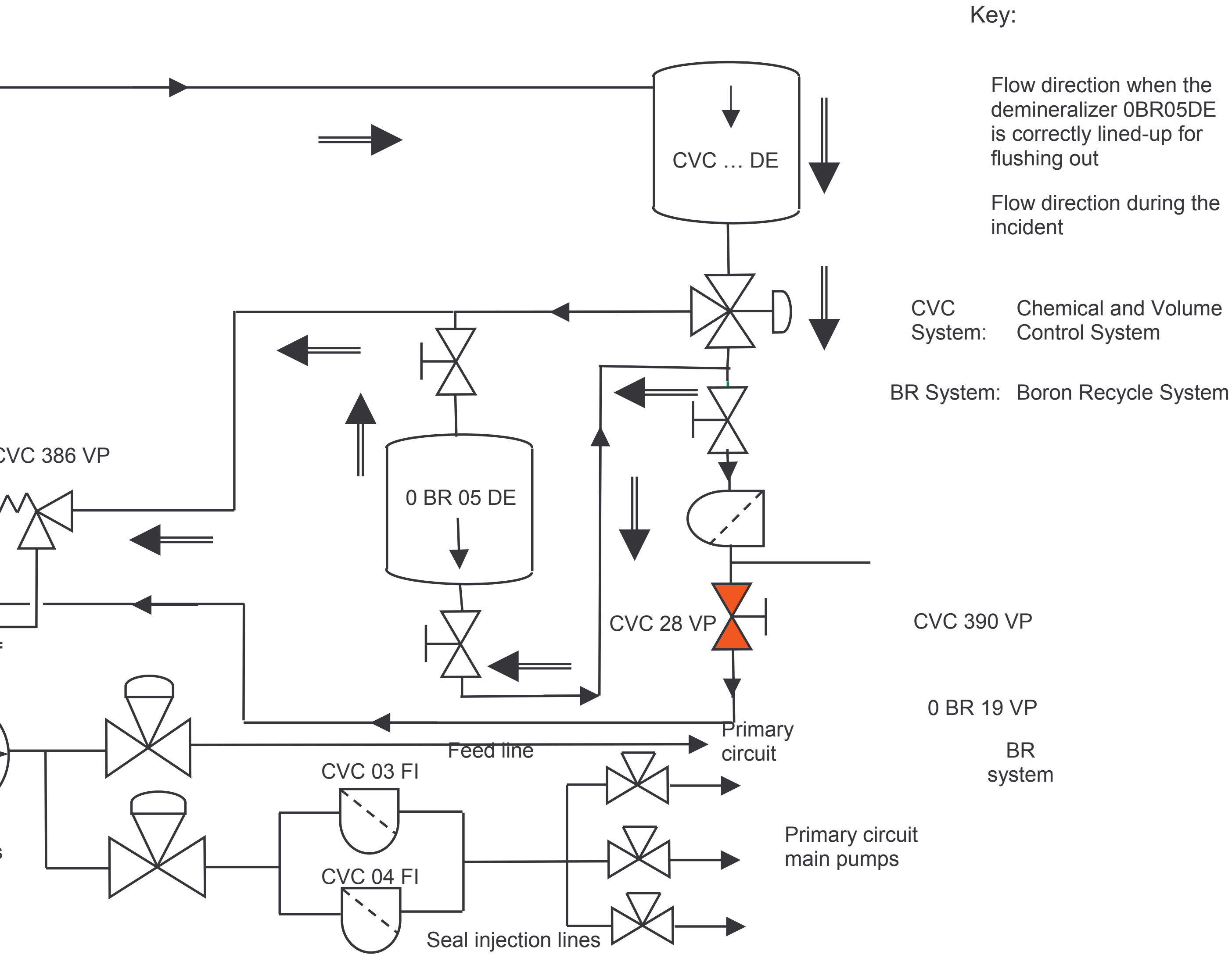

Figure 1. Simplified Flow Sheet

After discussions between the actors responsible to supervise this operation, the operator defined and implemented lines of improvement based on concrete proposals on how to make practices and decision-making process better at both individual and group level.

2.2 Design Error

The safety valve 1CVC386VP, designed to ensure the overpressure protection of the BR demineralizers, did not exist in the initial plant design. It was recently installed on the first generation of 900 MWe reactors (CP0) as part of the design change project untitled "high primary circuit purification flow" conducted since 1999 in order to reduce the shutdown periods. This design change also intended to correct a lack of design, as the operating experience feedback had shown that there was a pressurization risk of the BR demineralizers, no safety valve ensuring the overpressure protection of these components.
But, provided to cope with a lack of design, this change produced a new one. The safety analysis of the design change should not have allowed the installation of a boron demineralizer safety valve having its outlet connected to the primary circuit.
The IRSN emphasized the necessity to adjust this error as soon as possible. EDF central services are studying a design solution capable to prevent such an incident to be repeated. Waiting for the design change accomplishment, the isolating valves of the BR demineralizers have been physically locked out.

3 IMPACT ON THE UNIT

3.1 Unit Shutdown Insights

Following this incident, the unit 1 of the Fessenheim NPP was shut down for over five months (the unit was reconnected to the grid on July the 13th). During the unit shutdown, the operator found that:

- ✓ *20-out-of-48 rods failed to drop from the fifth step (Figure 2a) during a test carried out on February the 13th (while the unit was in cold shutdown state).*
  The rods jamming into the neck section of the guide tubes was explained by the clogging of the interspaces between the rods and their guide tubes (0.2 mm) during the seven-day period preceding the test, when 32-out-of-48 rods were held inserted at the fifth step. The other 16 rods, inserted at the fifth step just before the test, dropped correctly. The rods drop test was repeated the same day, this time from the 16th step and all the rods dropped correctly, as the guide tubes were well enough cleaned during the rods extraction to make it possible.
  It has to be noted that a similarly event occurred on June the 18th during the unit start-up tests. Few hours after the start-up of the primary circuit main pumps, while the unit was in cold shutdown state, the operator attempted to align the rods (found in different positions between the fifth and the seventh step) by opening the reactor scram breakers. 9-out-of-48 rods failed to drop (Figure 2b). The rod jamming was explained by the clogging of the interspaces between the rods and their guide tubes due to a "relocation effect" of the resin residue caused by the start-up of the primary circuit main pumps. This resin residue created friction, that did not allow the rods to drop.
- ✓ *It was difficult to withdraw the thimble plugs from all the fuel assemblies (109) fitted with this kind of device.*
  Resin accumulation in the interspaces between the thimble plugs and their guide tubes was possible as this interspace of 0.225 mm is of the same size as a resin particle. Generally, the extra force necessary to withdraw a thimble plug

(diameter: 11 mm; length: 20 cm; weight: 6 daN) was in the 100–250 daN range (three control rods were extracted using a maximum extra force of 300 to 400 daN).

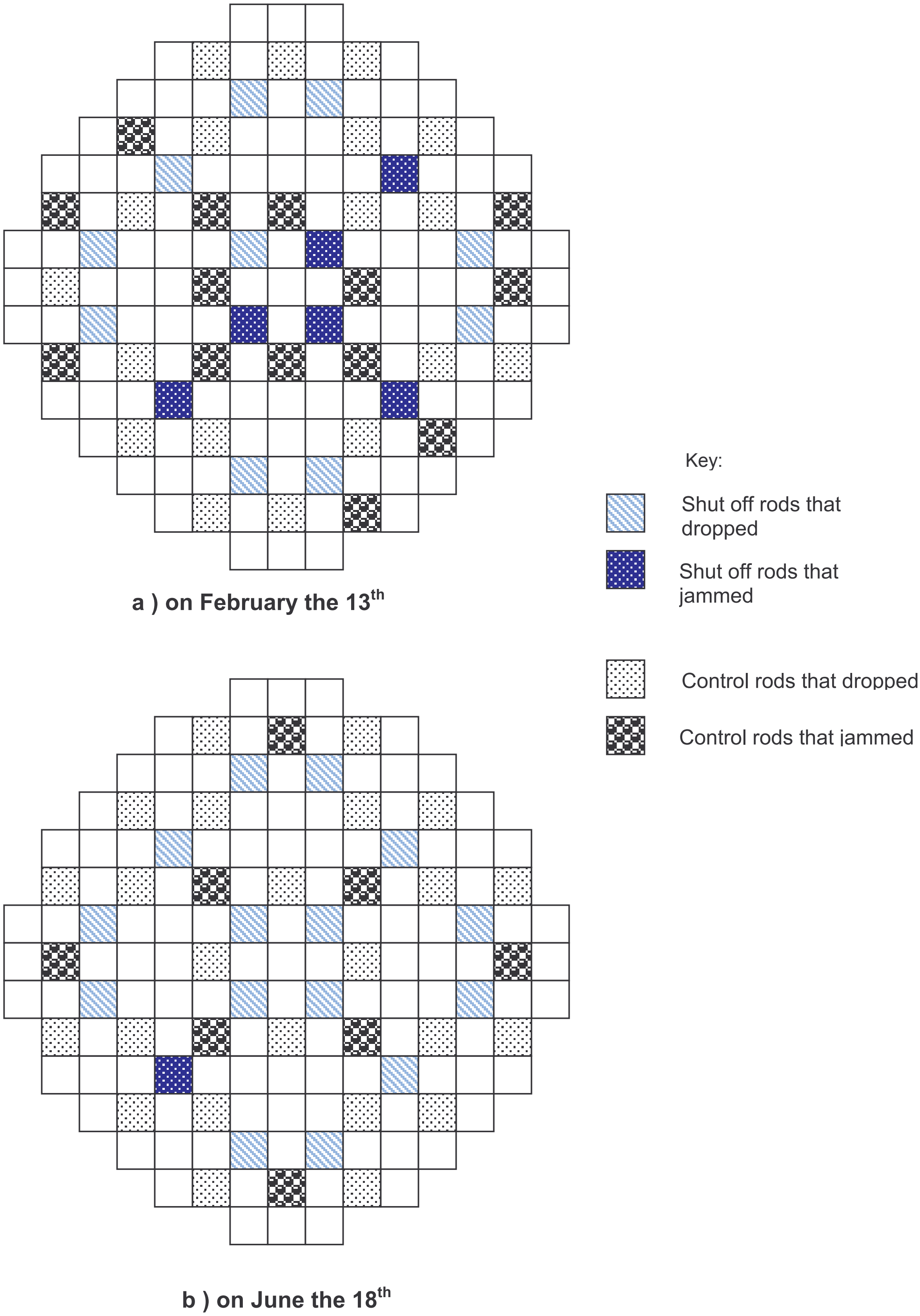

Figure 2. Rods jammed at the fifth step, in the neck section of their guide tubes

- *The shaft of the running primary circuit feed pump CVC02PO (Figure 3) was found seized into the rear hydrostatic bearing following the pump stop.*
  The operator found one-out-of-five supplying diaphragms of the rear hydrostatic bearing blocked, probably causing a pressure decrease under a required value, necessary to correctly sustain the running pump shaft. The friction between the rotor and the stator quickly worn their protective coating made of stellite and overheated the assembly. As the pump was stopped following a routine operation on February the 3rd (while the unit was in hot shutdown state) and kept in stand-by thereafter, the rotor and the stator welded together causing the pump failure to start on March the 1st (after the fuel unloading). The pump expertise revealed, besides a resin amount inside the pump components, a 0.2 mm shaft growth on its side nearby the rear hydrostatic bearing and the three adjacent impellers. A quantity of metal turnings produced by the protective coating wearing was found in the bearing and in each of the impellers of the pump discharge stage.

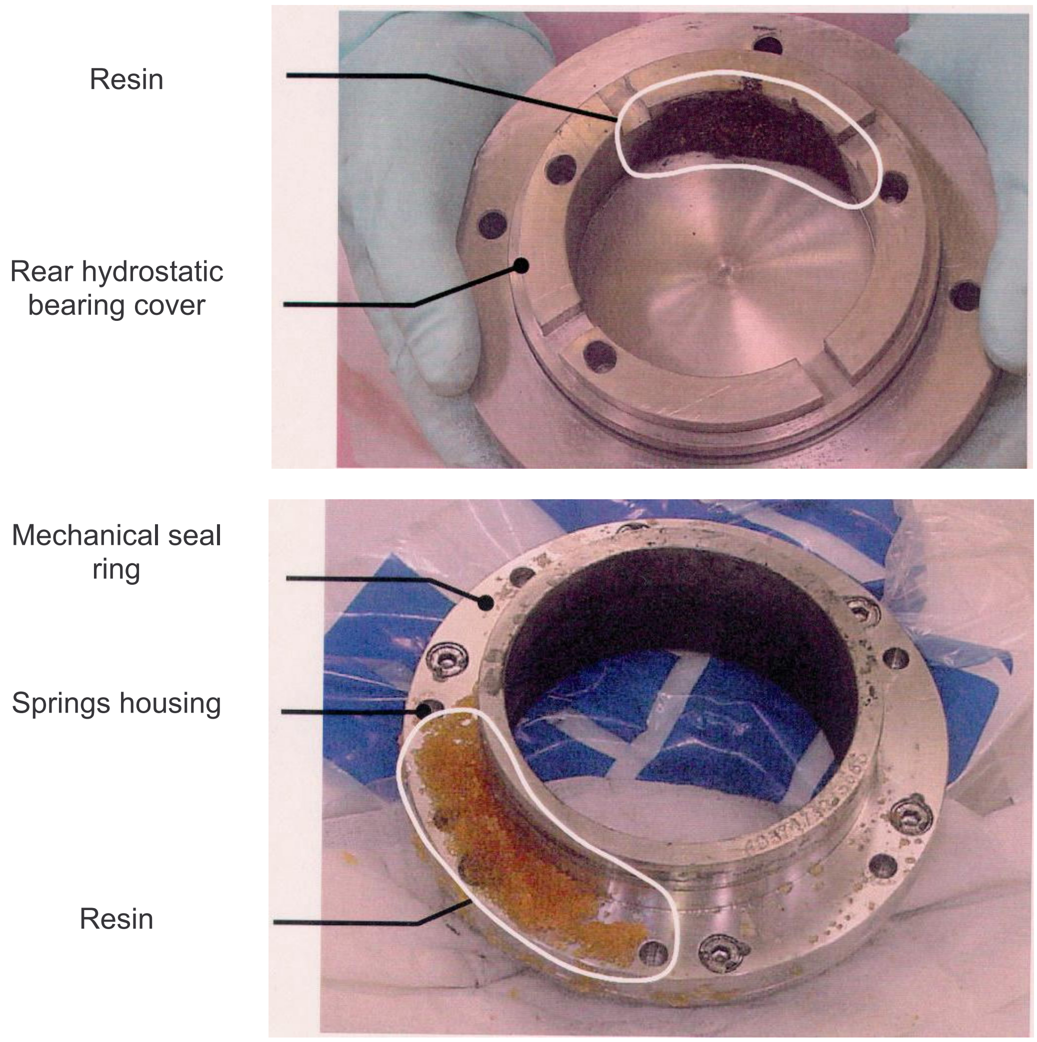

Figure 3. Rear hydrostatic bearing and mechanic seal of the pump CVC02PO

- *Resin was found in the seals and bearings of the primary circuit main pumps.*
  As the filters on the seal injection lines were clogged, non-filtered water from the primary circuit was injected into the main pump thermal barriers, after passing through the upper and the lower cooling labyrinths of these thermal barriers

(interspace: 0.5 to 0.7 mm), the bearing and the seal 1, before being evacuated via the recirculated seal leak line (downstream the seal 1, Figure 4).

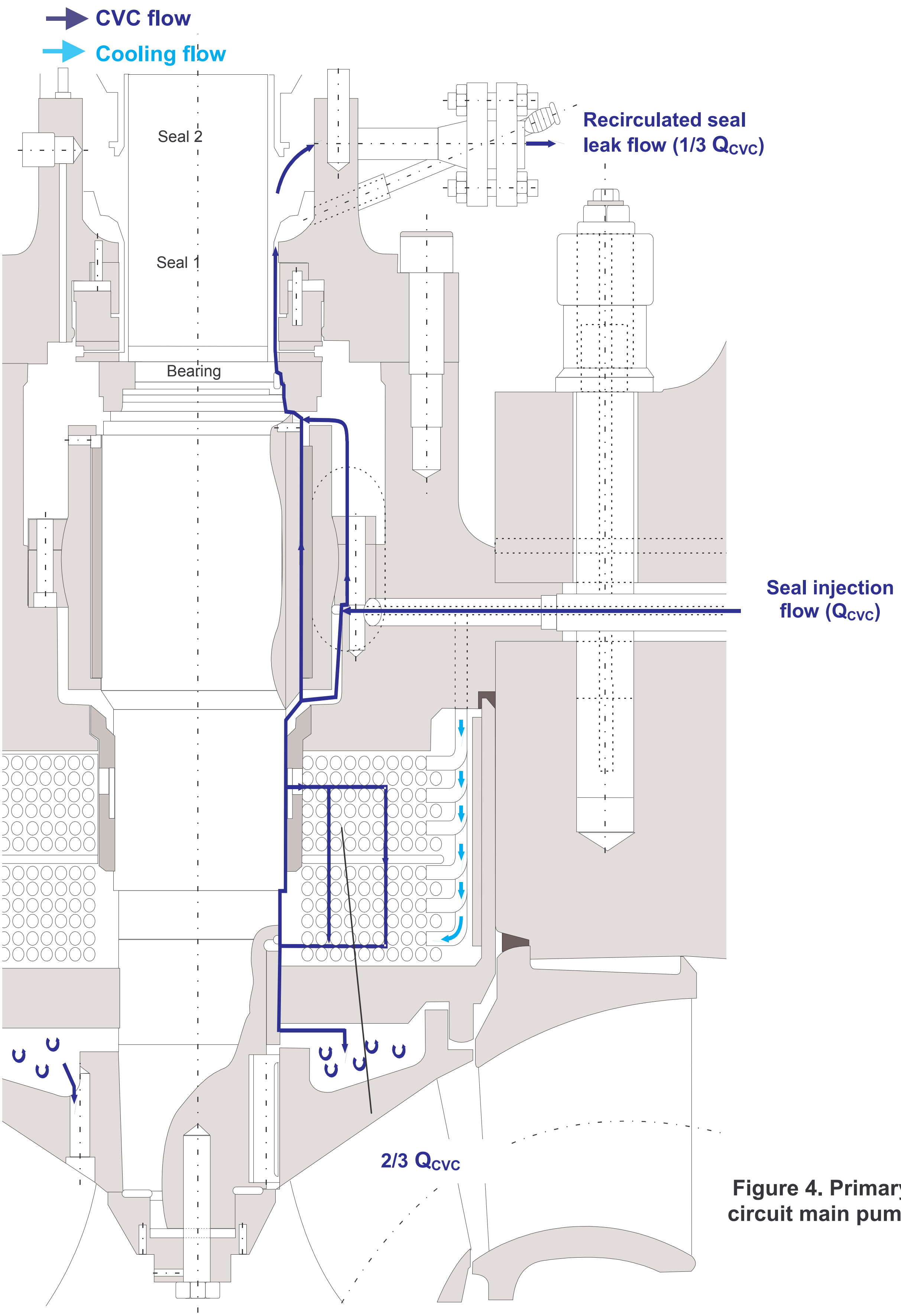

Figure 4. Primary circuit main pump

Immediately after the incident, the rate of the recirculated seal leak flow (downstream the seal 1) of the primary circuit main pump 2 began to increase. On January the 28th (while the unit was in hot shutdown state), the pump tripped as the rate of the recirculated seal leak flow increased up to the automatic trip set point. The pump seal dysfunction is probably the resin presence consequence.

- ✓ *The nuclear sampling system lines were plugged.*
  The Nuclear Sampling System lines were clogged, causing the boron meter to be out of service for five days.
- ✓ *Resin was found in the pressure vessel bottom penetrations.*
  While flushing out the two level sensor taps of the pressure vessel, a TV inspection revealed the release of a resin residue cloud. It has to be noted that in normal operation the coolant does not pass through the pressure vessel bottom penetrations and their associated guide tubes, to flush them out. For this reason, the concentration of harmful elements resulting from resin decomposition could induce a risk of corrosion.
- ✓ *Other insights.*
  Non-sticking and non-agglomerated resin was particularly found into the primary circuit feed pump lines, into the seal injection lines and recirculated seal leak lines of the primary circuit main pumps and on the bottom of the pressure vessel.
  Hot points were observed on several sensors.
  Nevertheless, the inspection of the pressurizer and steam generators did not reveal any trace of resin.

3.2 Unit Shutdown Actions

During the unit shutdown, the operator began the restoration actions by inspecting a certain number of equipment items, among those considered as the most vulnerable following the pollution incident: fuel assemblies, sensors, primary circuit main and feed pumps, Shutdown Cooling System pumps, heat exchangers, tanks, valves and pipes of the primary circuit and its auxiliary systems.

The initial list of inspections, revised following the discussions between the operator, the IRSN and the Safety Authority, was improved step-by-step during the unit shutdown, based on the expertise results previously obtained. The desired objective was to find an acceptable compromise between the radiological costs of the work done to remove a maximum amount of resin and the nuclear risk induced by the unit restart and operation with a residual quantity of resin into the primary circuit.

During the unit shutdown, the operator performed several types of actions:

- ✓ affected equipment restoration or replacement (the primary circuit feed pump CVC02PO and the rotor of the primary circuit main pump 2 were replaced),
- ✓ resin residue removal (as much as possible) and potentially affected components inspection (fuel assemblies, rods, pumps, sensors, heat exchangers, tanks, valves, pipes),
- ✓ design changes accomplishment (installation of nuclear sampling suction filters, removal of thimble plug assemblies),
- ✓ potential confined areas flushing out (thermal barriers of the primary circuit main pumps, pressure vessel bottom penetrations and in-core instrumentation guide tubes).

EDF carried out studies concluding that in the short and medium term (during unit shutdown and the next cycle) the resin will not represent a chemical risk. Analysis of the long-term chemical effect is in progress.

4 RISKS INCURRED BY THE PRESENCE OF RESIN IN THE PRIMARY CIRCUIT

Based on the incident insights revealed during the unit shutdown, the IRSN concentrated its attention on the following risks incurred by the presence of resin in the primary circuit:

4.1 Rods Failure to Drop

20 rods did not drop on February the 13th, while the unit was in cold shutdown state, after having been held for seven days inserted at the fifth step into the neck part of the guide tubes.
Concerning the risk of rods failure to drop from their normally position during a reactor scram while the unit is in full power operation, it should be noted that the interspace between a rod and its guide tube is greater on the rod dropping part (0.74 mm) than on the neck part of the guide tube (0.2 mm). The risk of rod failure to drop is also greater in a cold shutdown state than in a hot state (as at 300°C the resin turns into jelly).
It has also to be noted that, during the rods drop test on February the 6th (while the unit was in hot shutdown state, before fuel unloading and primary circuit cleaning), all the rods (extracted group by group at the 225th step) dropped correctly. The availability of the reactor scram was also verified throughout the unit start-up test program and the reinforced unit in-service monitoring program (see § 5).

4.2 Unavailability of High Pressure Safety Injection Function

The three primary circuit feed pumps also ensure the high pressure safety injection function.
On February the 3rd, the pump CVC02PO, running during the incident, was stopped and the stand-by pump CVC01PO was started (routine operation usually made each 15 days). On March the 1st, the pump CVC02PO failed to start and its shaft was found welded into the rear hydrostatic bearing (the same day, the pump CVC01PO, stopped after the fuel unloading, started successfully).
The presence of resin represents a potential common-mode failure and it could have caused the failure of the other two pumps.
However, it should be pointed out that at any time since the incident, at least one of the three pumps was available (one of them was running as a feed pump). The expertise of the pump CVC01PO started on February the 3rd did not reveal any damage, even if a large amount of resin was found inside the pump components and also into its suction, discharge and recirculated flow lines (the same for the stand-by pump CVC03PO).

4.3 Main Pump Seal Break (Loss of Coolant Accident)

The seal injection flow rate of the primary circuit main pump was low, or even lost, for two to three days. The simultaneously loss of the thermal barrier cooling would have caused the seal break, generating a loss of coolant accident.
Moreover, the IRSN considers that, taking into account the dysfunction of the primary pump 2, despite of the thermal barrier cooling successfully operation, the risk of seal break as a result of the seals wearing by the resin cannot be completely ruled out.
However, it has to be noted that the thermal barrier cooling was available and that the expertise of the other two primary circuit main pumps did not reveal any seal damage, even if resin was found inside the components of these pumps.

4.4 Main Pump Thermal Barrier Rupture (Interface Loss of Coolant Accident)

The thermal barriers of the primary circuit main pumps 1 and 3 were flushed out, but they were neither inspected nor replaced. As they are “confined” areas, the potential accumulation of resin deposits inside the thermal barriers cannot be excluded.
Long-term corrosion phenomena could be caused by this accumulation of resin deposits, which could lead to a thermal barrier rupture, generating a loss of coolant accident at the primary circuit interface with the Component Cooling Water System (containment by-pass scenario).
For this reason, the IRSN recommended the replacement of the thermal barriers of these two pumps or at least their expertise during the next unit shutdown.

5 UNIT START-UP TESTS AND IN-SERVICE MONITORING

The usually start-up test program was reinforced to ensure that, during the next cycle, the risk induced by the resin residue traces still existing into the primary circuit was insignificant. Thus, the operator preferred to repeat certain tests, already made between the incident and the primary circuit cleaning, to be sure that their results were not compromised by the presence of resin. He also carried out certain infrequent tests, when it was considered advisable to perform them ahead of the schedule. Finally, the operator completed the tests by tracking certain parameters, cross-checking the measurements, etc. The IRSN emphasized the importance of trend monitoring on the test results in order to identify any significant failure tendency of equipment items.
Following the event occurred on June the 18th, when 9 rods failed to drop from different positions between the fifth and the seventh step, special attention was given to the reactor scram function availability. The IRSN considered that several types of rod drop tests were necessary to be carried out: in cold shutdown state, after the restarting of the primary circuit main pumps (in order to reproduce the conditions of June the 18th) and also in hot shutdown state, with the control rods in different positions and the shut off rods held extracted from the core over various time intervals (in order to reproduce the full power operating conditions). No deviations were detected.
Following technical discussions between the operator, the IRSN and the Safety Authority, a reinforced unit in-service monitoring program was temporary initiated when the unit was started-up in July.
The chemical parameters of the primary circuit, the sensor performance, the frequency of the filters clogging on the seal injection lines of the primary circuit main pumps, on the primary circuit bleed line and on the nuclear sampling suction lines (the recently installed filters) are particularly monitored.
The unit in-service monitoring program also concerns:

- ✓ the control and shut off rods:
  - during the first month of full power operation, rod drop tests on a 16 step length were carried out weekly, along with sampling of non-filtered reactor coolant,
  - a rod drop time test in hot shutdown state was carried out after five weeks of full power operation, another one being planned in the middle of the cycle,
- ✓ the CVC pumps:
  - the stand-by pumps are tested monthly, vibration controls and rundown time tests being conducted besides the usually tests,
  - the running pump is cautiously monitored,
- ✓ the primary circuit main pumps: an operating procedure has been set up in the control room requiring certain operator actions if the warning values established for the “low seal injection flow rate” and for the “high recirculated seal leak flow rate” are reached.

No deviations have been detected up to date.

6 CONCLUSION

The incident occurred in January 2004 at the unit 1 of the Fessenheim NPP had a real impact on the unit: the CVC filters were clogged, the seal injection flow of the primary circuit main pumps was lost, the primary circuit main pump 2 tripped four days after the incident, as the rate of the recirculated seal leak flow (downstream the seal 1) increased up to the automatic trip set point, the shaft of the running primary circuit feed pump was found welded into the rear hydrostatic bearing following the pump stop (after 10 days of successful operation), the thimble plugs were jammed into their guide tubes, the small diameter pipes were plugged.

Technical discussions between the operator, the IRSN and the Safety Authority began immediately after the incident occurrence and went on throughout the restoration actions carrying out during unit shutdown, the unit start-up tests and in-service monitoring.

The unit shutdown for over five months was necessary to clean the primary circuit components, repair or replace the affected equipment items and carry out inspections and tests. The reinforced unit in-service monitoring program, set up during the unit start-up, confirms that, up to now, the unit operation has not been adversely affected by the residual amounts of resin which subsist in certain areas of the primary circuit. Nevertheless, it remains to verify that, in the long term, these deposits will have no negative chemical effect in confined areas, such as the thermal barriers of the primary circuit main pumps.