Hervé BODINEAU – Thierry SOLLIER – Alexis VERGNAULT – Marc LE CALVAR

Tube support plate clogging up of French PWR steam generators

1. New generic issue detection
2. The issue characterization
3. Quantitative evaluation of clogging: Means
4. Effects on plant safety
5. Steam generator chemical cleaning
6. Forthcoming actions

① New generic issue detection

2004 – 2005 – 2006

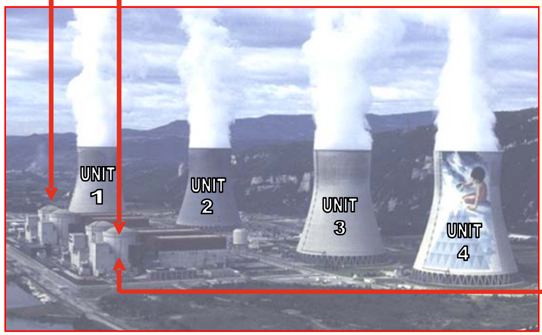
In February 2004, November 2005 and February 2006, three primary-to-secondary leaks occurred at the Cruas NPP.

→ **3 shutdowns**

Cruas-Meysse N.P.P. – Unit 1
4th February 2004
Leak of tube L008 C049
(flowrate = 3.8 l/h)

Each leak was detected by N16 channel
(Main steam radiation monitor)

Cruas-Meysse N.P.P. – Unit 4
7th November 2005
Leak of tube L008 C048
(flowrate = 10 l/h)



Cruas-Meysse Nuclear Power Plant
4 x 900 MW (PWR)

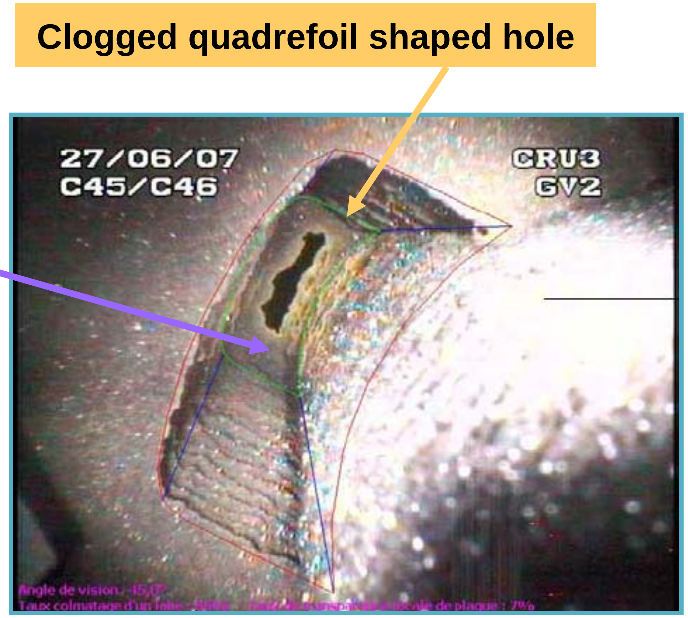
Cruas-Meysse N.P.P. – Unit 4
11th February 2006
Leak of tube L008 C047
(flowrate = 650 l/h)

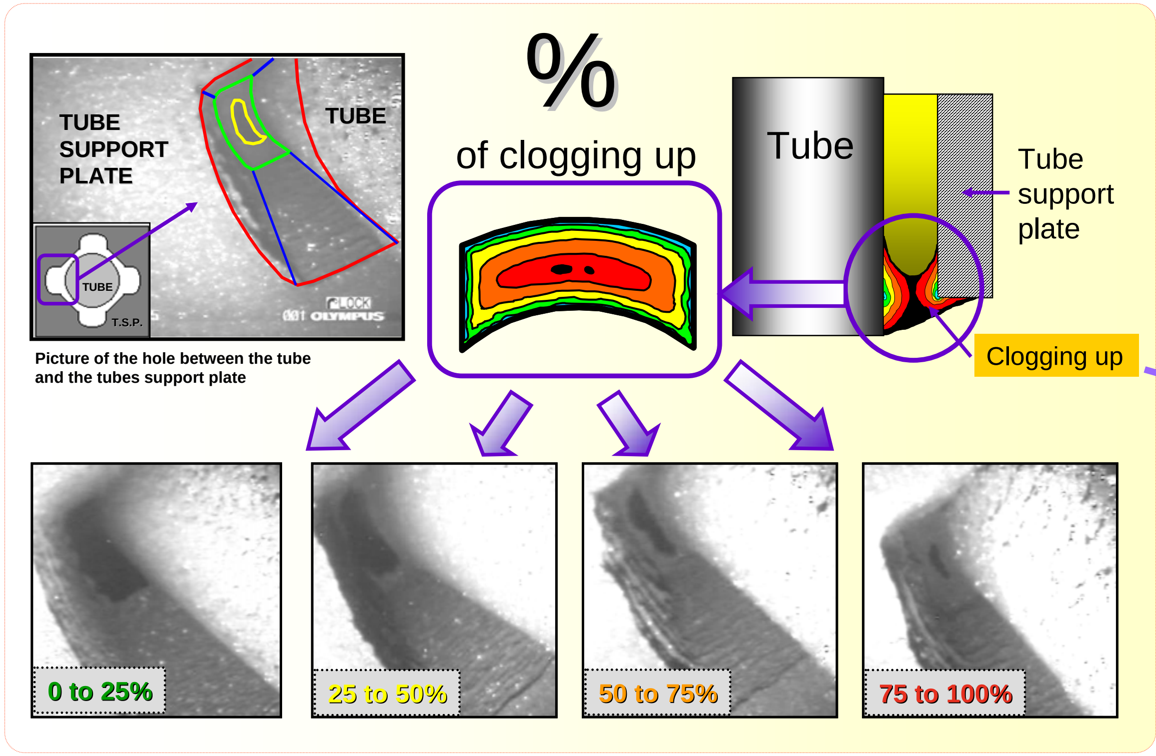
- Same S.G. type.
- All the leaks were located at the upper-most TSP (#8).
- All 3 tubes were near the center of the tube bundle near a tube-free area.

A NEW GENERIC ISSUE

② The issue characterization

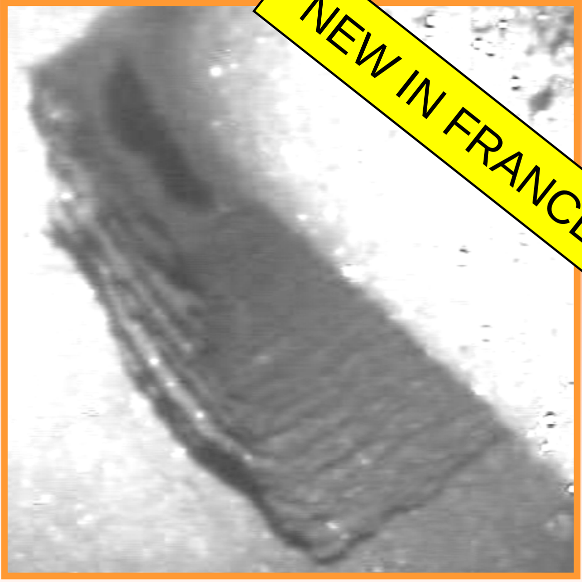
- The examinations have revealed a phenomenom of tube support plate clogging, especially for the 7th and the 8th TSPs.
- Leaks were due to circumferential cracks of S.G. tubes at the 8th TPS. The origin of cracking was determined to be high cycle fatigue.





Picture of the hole between the tube and the tubes support plate

② The issue characterization



NEW IN FRANCE

CLOGGING UP

FOULING

SPALLING

- In the past, the TSP clogging up has never been observed in France.

- Fouling and spalling were known and observed during outages.

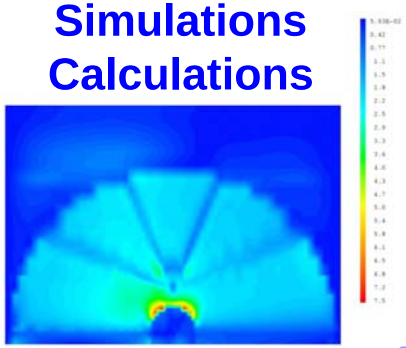
② The issue characterization

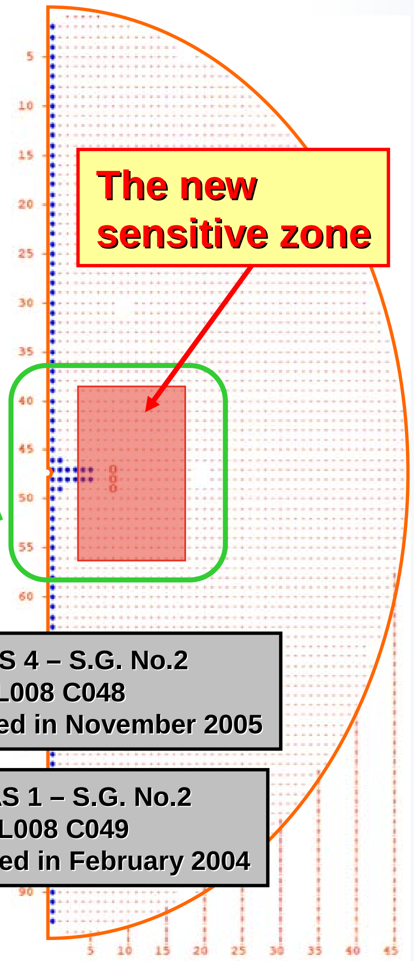
Determination of a new sensitive zone

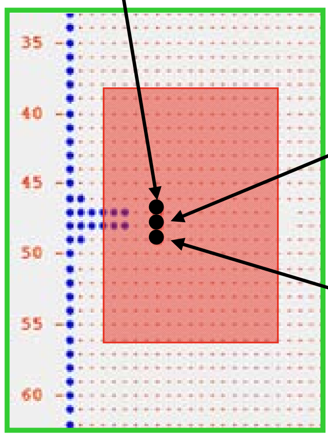
% of clogging up

+

Simulations Calculations







CRUAS 4 – S.G. No.2
Tube L008 C047
plugged in February 2006

CRUAS 4 – S.G. No.2
Tube L008 C048
plugged in November 2005

CRUAS 1 – S.G. No.2
Tube L008 C049
plugged in February 2004

Preventive actions

- Preventive plugging (58 tubes)
- Power reduction

③ Quantitative evaluation of the clogging up : Means

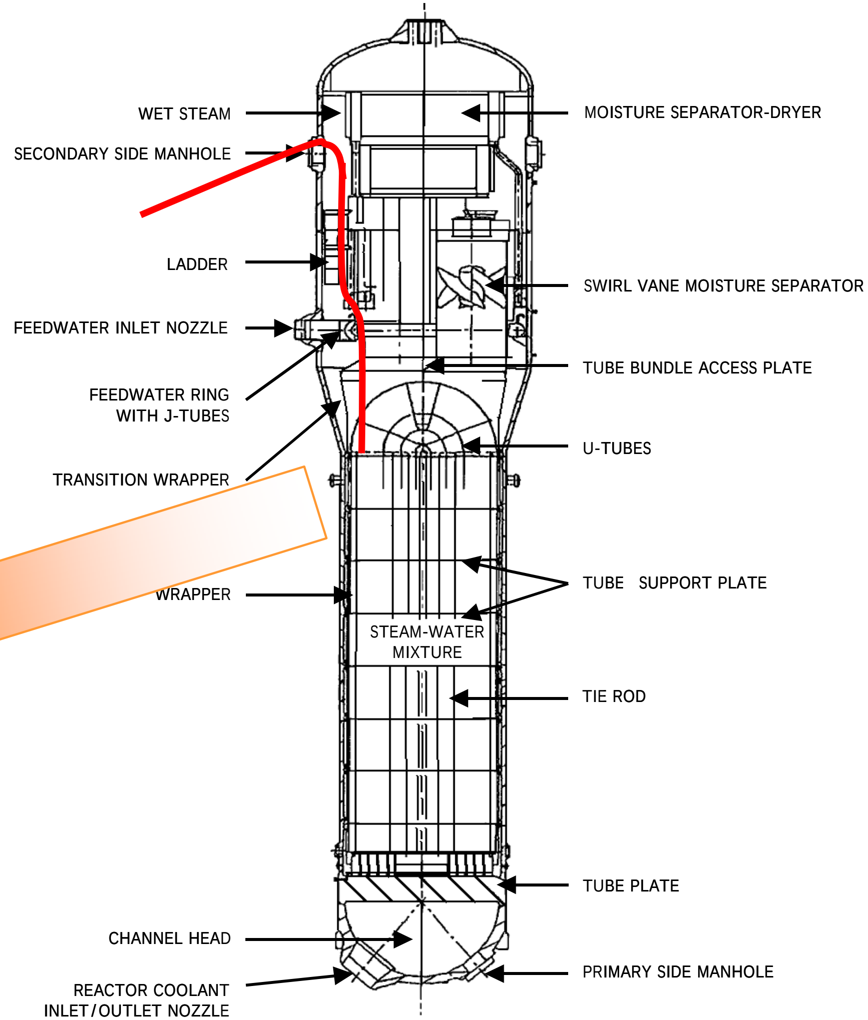
Methods for quantitative evaluation of the TSP clogging up :

- **Direct Means**: Remote Visual Inspection
- **Indirect Means**: Eddy Current (bobbin coil)
- **Global Means**: Thermal-Hydraulics Parameters (such as the drift of the wide range level)

③ Quantitative evaluation of the clogging up : Means

Direct Means : Remote Visual Inspection

Introduction of a remote visual inspection device (camera and lights) from the secondary manhole.



③ Quantitative evaluation of the clogging up : Means

Indirect Means : Eddy Current (bobbin coils)

The method is based on the standard bobbin coil which is used as the baseline inspection for the Steam Generator.

This method is indirect:

- The external deposit on the tube wall and TSPs are evaluated from the inside of the tube.
- The bobbin coil is sensitive to the magnetic component of the deposit (mostly magnetite) which deviates the magnetic flux lines.
- The eddy current signals are calibrated using the results of the remote visual inspection performed on the uppermost TSP.

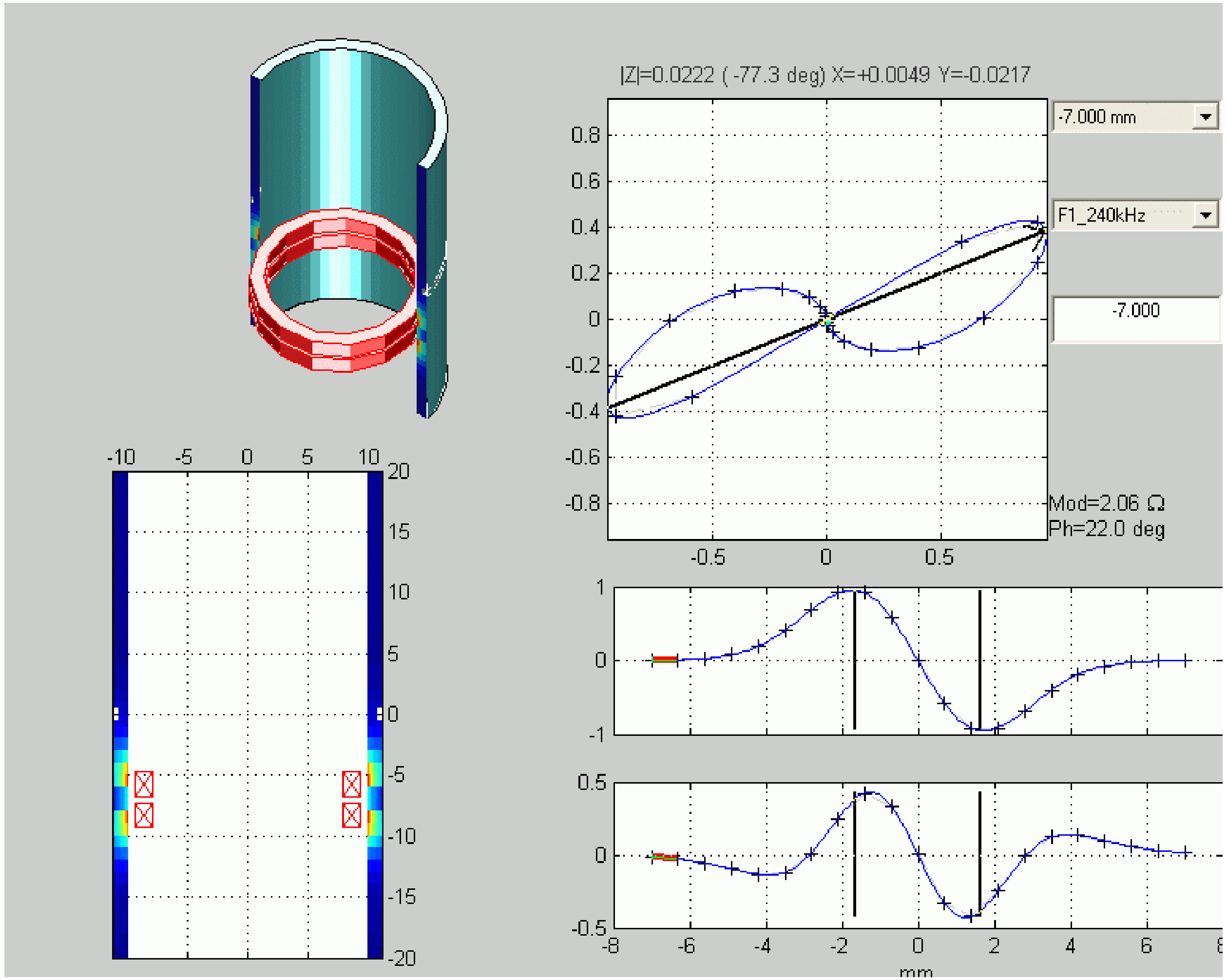
③ Quantitative evaluation of the clogging up : Means

The eddy current method is used for the quantitative evaluation of:

- each TSP (but only for 900 MWe series).
- the kinetics of the TSPs clogging up from the reactor start-up.
- the efficiency of a chemical cleaning immediately after the process.

③ Quantitative evaluation of the clogging up : Means

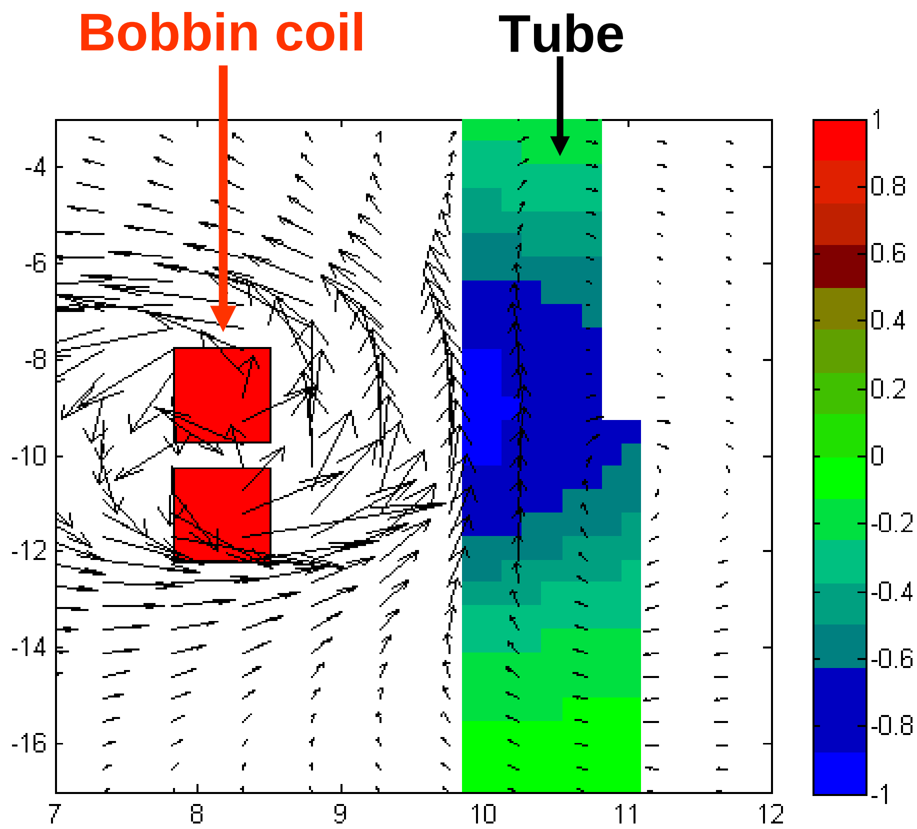
Indirect Means : Eddy Current (bobbin coils), Simulation using CIVA



③ Quantitative evaluation of the clogging up : Means

Eddy Current indirect method

- The bobbin coil produces a sinusoidal electromagnetic field inside the tube wall.
- Currents are induced inside the tube wall and produce an electromagnetic field which is opposed to the incident field.
- A magnetic and/or conductive deposit on the secondary side of the tube modifies the bobbin coil impedance.
  This impedance change as the bobbin coil passes the TSPs is used to evaluate the clogging up ratio.

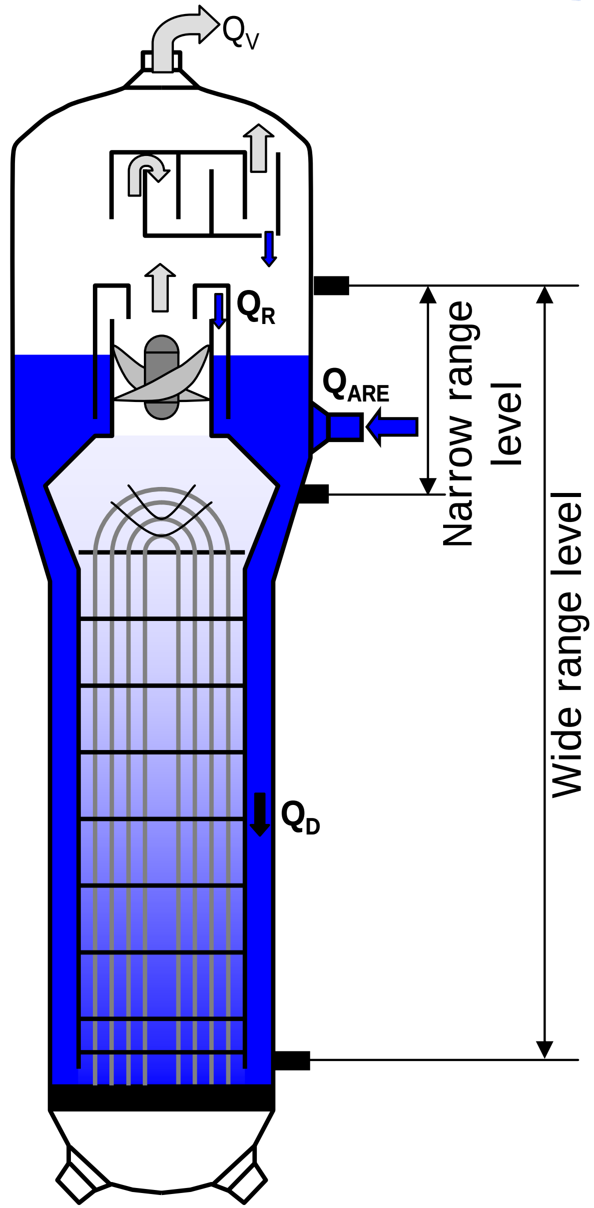


Electromagnetic field and induced currents in the tube

③ Quantitative evaluation of the clogging up : Means

Drift of Thermal-Hydraulics parameters due to tube fouling and TSP clogging up

- **Drift** of the wide range level.
- **Decrease** in the **Circulation Ratio** (CR).
- **Increase** in the tube **thermal resistance**.
- **Decrease** in the **steam pressure**.



③ Quantitative evaluation of the clogging up : Means

Means – Advantages/drawbacks

- Remote Visual Inspection
  - ☑ Direct and accurate evaluation of the clogging up ratio.
  - ☒ Quantitative evaluation only for the uppermost TSP, little or no accessibility to the other TSPs.
- Eddy Current Inspection
  - ☑ Evaluation of the clogging up ratio for all the TSPs from start-up, based on an industrial inspection technique (bobbin coil) .
  - ☒ Large uncertainties in the clogging up ratio evaluation due to various chemical composition, density and geometry of the deposits.
- Global Thermal-hydraulic Method (drift of the wide range level)
  - ☑ Global evaluation of the TSPs clogging up ratio for a SG.
  - ☒ Limited correlation, so far, with remote visual inspection for the 1300 MWe series.

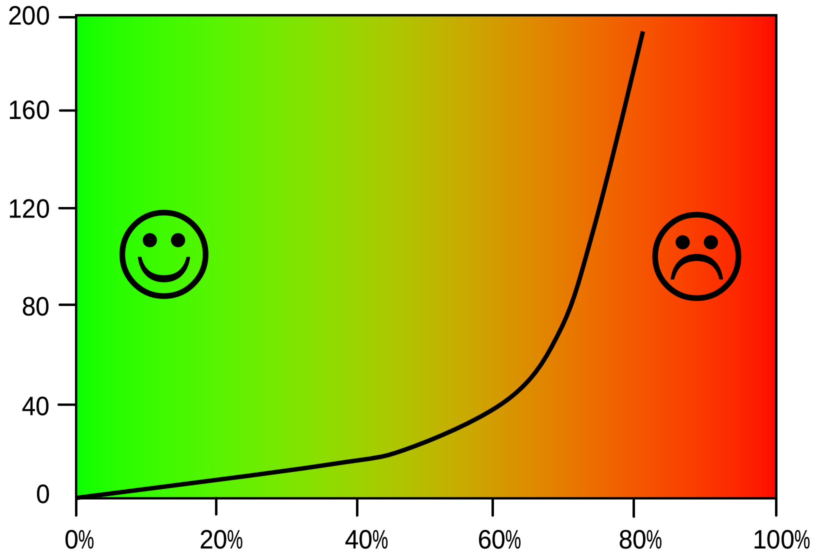
④ Effects on plant safety

Mechanical angle

① **Risk of S.G. tube rupture** due to high cycle fatigue.

② In case of **high clogging up**, TSPs and tie-rods could be subjected to **heavier loads** than considered at the design phase for transients.

Coefficient of TSP head loss



% of clogging up

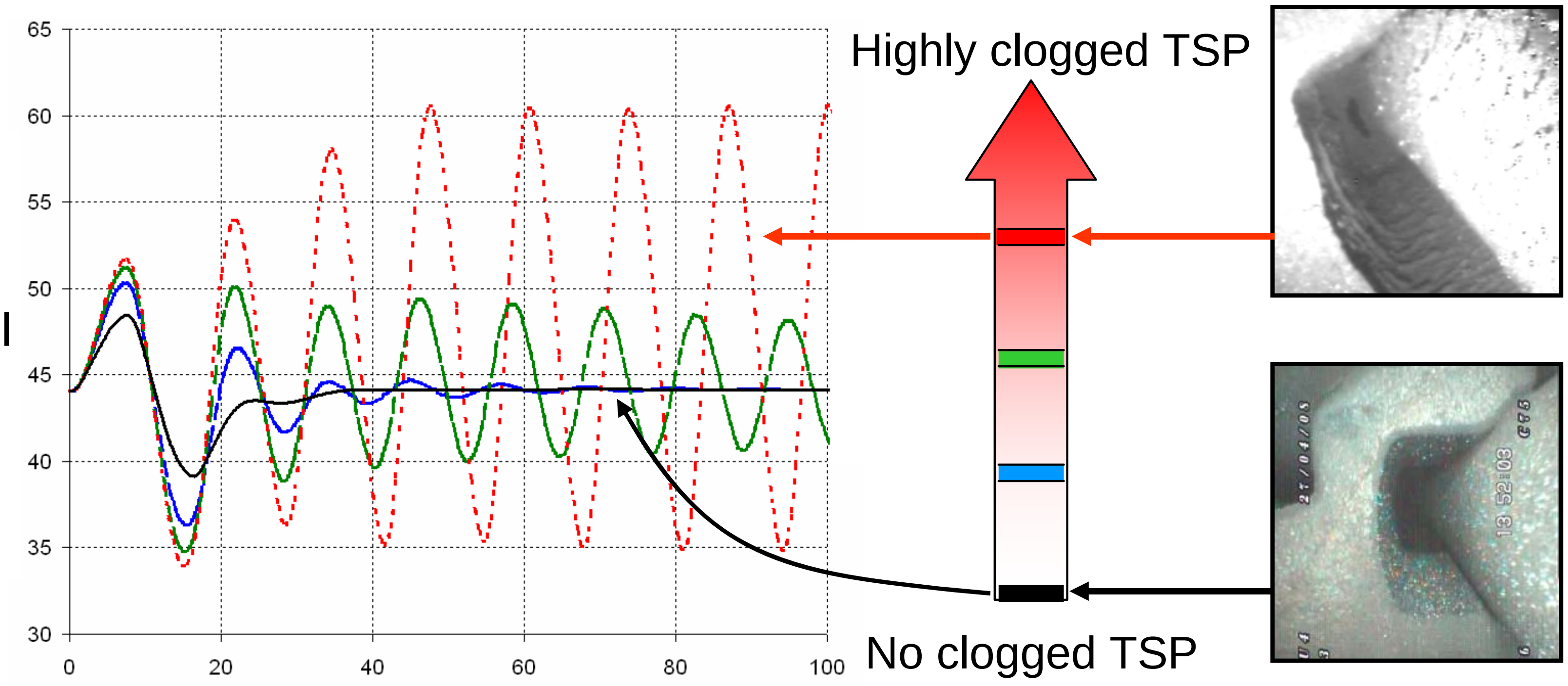
④ Effects on plant safety

Thermal-hydraulic angle

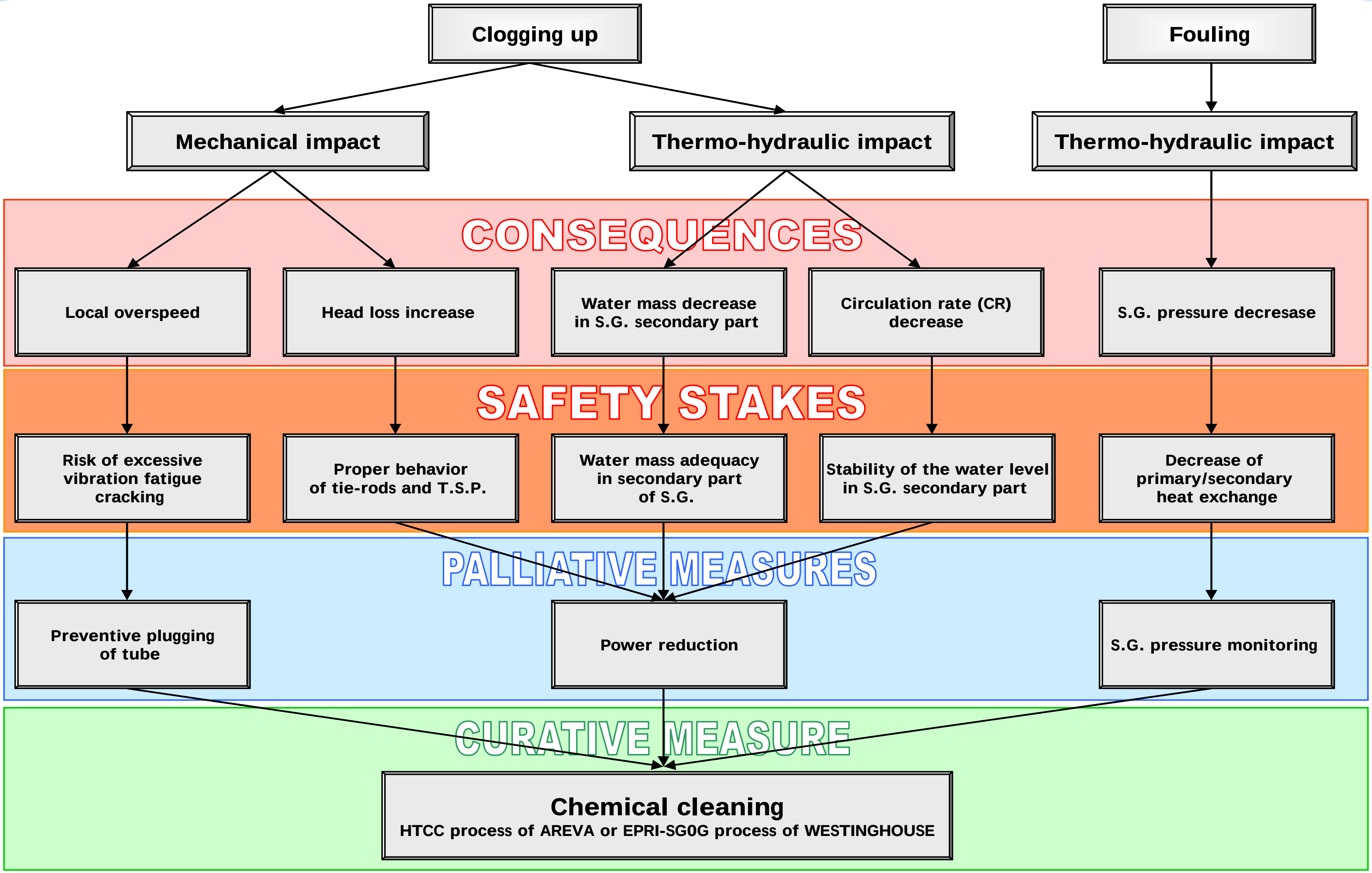
③ **Decrease of the available water mass** for cooling in the secondary part of the SG.

④ **Instability of the water level** in the SG for transients.

SG water level



④ Effects on plant safety



⑤ S.G. chemical cleaning

Faced with these safety stakes, the operator decided to operate a chemical cleaning for the units with clogged S.G.:

▷ **HTCC process of AREVA (High temperature: 160°C)**

CRUAS 4 – CRUAS 1 – CHINON B2 – CHINON B4 – ST ALBAN 1 – ST ALBAN 2

▷ **EPRI-SGOG process of WESTINGHOUSE (Low temperature: 80°C)**

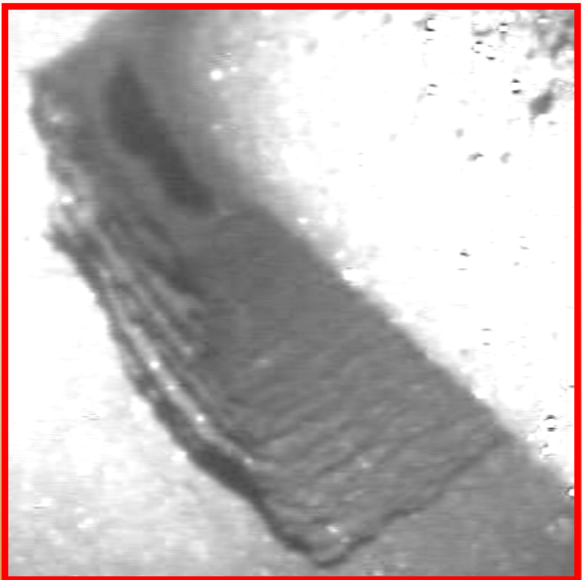
CRUAS 3 – CRUAS 2 – BELLEVILLE 1

⑤ S.G. chemical cleaning

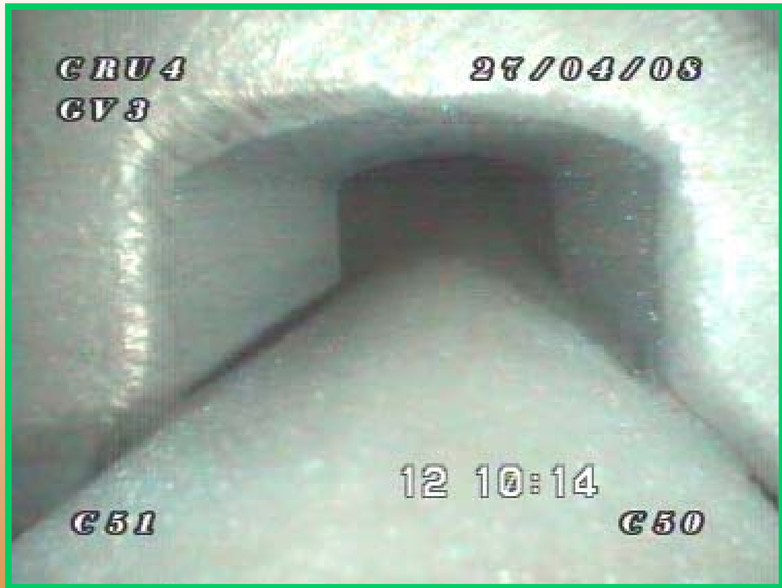
In general, the chemical cleanings were effective :

- Example of CRUAS 4 with a HTCC:

BEFORE



AFTER



Average clogging up of 70% on the 8th TSP

Average clogging up ≤ 15% on the 8th TSP

⑤ S.G. chemical cleaning

However, after the SG chemical cleaning, the operator observed that :

- It has to do **a compromise** between the global **SG corrosion** and the **effectiveness** of the chemical cleaning.
- Very often, there is the **appearance of conductive deposits** (every process, whatever its temperature…)
- The **result** could be **partial** with the HTCC process (For example : Cruas 1 or St Alban 1):

ST ALBAN 1
AFTER HTCC

In this case, there is always a drift of the SG wide range level.

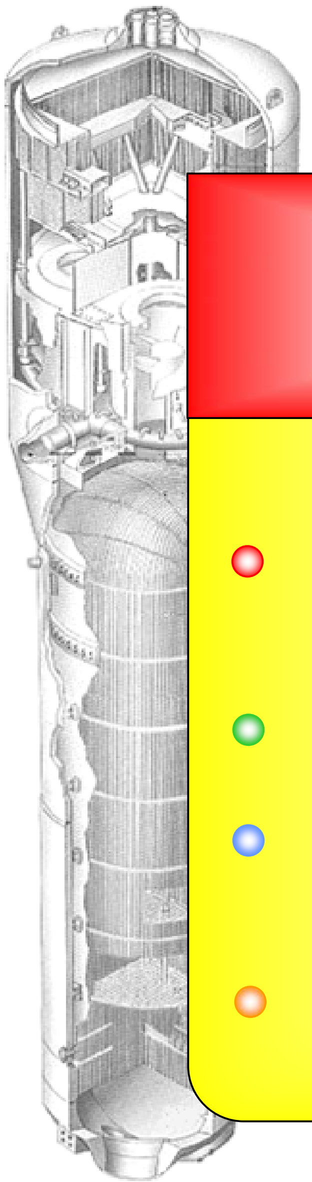
⑤ S.G. chemical cleaning

After operating experience integration, the operator improved the chemical cleaning procedures.

For Belleville 1, with the updated EPRI-SGOG process, **the result seems to be satisfactory**:

- **without conductive deposit,**
- **effective « unclogging ».**

⑥ Forthcoming actions



2008 **2009** **2010**

- **Chemical cleaning continuation** with the updated EPRI-SGOG process (Cattenom 1, Chinon B3, Belleville 2)
- **Experimentation** (Chemistry of the secondary part, pH …)
- **Phenomena understanding** (GV-scope project, kinetics, main parameters …)
- **Additional characterization** (1300 MWe and 1450 MWe series)