



## SG Internals Design Review Part II: SG Wrapper Drop Safety Studies

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### Abstract

Further to the bundle wrapper drop observed on steam generators (SG) 1 and 2 of the Blayais 3 nuclear power plant during the 1994 outage, a significant work programme has been launched in order to achieve the following objectives:

- full understanding of the phenomenon,
- evaluation of the potential extension of this phenomenon to other SGs,
- development of a curative and preventive maintenance policy.

These studies encompassed all types of SG installed on the French plants.

In parallel to the above mentioned programme, specific analyses have been performed to evaluate the safety impacts of different potential scenarios.

Three subjects were investigated:

- Possible interactions between different components of SG internals.
- Creation of loose parts, possible movement inside the SG and harmful consequences.
- Risk of departure from nucleate boiling (DNB) in the case of complete drop of the wrapper (down to the tubesheet).

This set of studies has allowed the definition of measures to be implemented in the maintenance strategy and policy in order to maintain the required safety level.

### 1. INTRODUCTION

In 1994, during the BLAYAIS 3 unit outage, the SG1 bundle wrapper was found to have dropped by about 20 millimeters. This same phenomenon occurred, but to a lesser degree (about five millimeters) on SG2.

As a result of these observations, a major program was initiated by EDF and the reactor constructor, Framatome, to understand the phenomena involved, to determine if this was a generic problem, to develop an adequate maintenance policy, and to design and use preventive and corrective tools.

The main results of these studies are presented in the first part of this presentation "Bundle wrapper studies – Status and perspectives." (reference D4-A4-FR). The tools developed are described in the third part of this presentation "corrective and preventive maintenance and in-service surveillance." (reference D4-A2-FR).

In parallel with these studies, an analysis of the safety implications of an hypothetical drop of the SG bundle wrapper was immediately initiated. The object of this analysis was the systematic examination of the safety consequences of the bundle wrapper slow and gradual or sudden dropping from its nominal original position to the secondary side of the tubesheet.

These safety analyses concern the SGs in operation (SG models 51 and 47 /22 installed on the 900 MWe units and 68/19 installed on the 1300 MWe units).

The model 73/19 TE steam generators installed on the 1450 MWe units (referred to as the N4 units) were not investigated, since wrapper drop is not possible; the tube bundle has a double wrapper, with the outer wrapper already resting on the tube sheet.

The following three aspects, related to the dropping of the bundle wrapper, were analyzed:

- The risks of interaction with other parts of the internals and the maximum allowable drop which does not compromise their safety functions during operation.
- The damage caused by any loose parts generated by the dropping of the bundle wrapper.
- The operating consequences, in particular with respect to the DNBR, resulting from a gradual or sudden dropping of the bundle wrapper onto the tubesheet.

## **2. ANALYSIS OF THE INTERACTIONS BETWEEN INTERNALS WHEN THE BUNDLE WRAPPER DROPS**

### **2.1. Methodology**

The analysis of the consequences of the gradual dropping of the bundle wrapper consisted in itemizing, step-by-step, all points of potential interaction with the other SG internal components (see Figure 1) as the bundle wrapper drops from its nominal position to the secondary side of the tubesheet.

The consequences of these various potential interactions were then analyzed.

Next, the impact on the behavior of the SG under accident conditions (earthquake protection and hold-down functions) was studied.

Lastly, the risk of moisture separator swirl vanes coming out of the vane support channels was analyzed for the various SG models, as well as effect on SG operation should this happen.

### **2.2. Results**

For each SG model, the absence of safety consequences of a bundle wrapper drop has been checked regarding three functions :

- Hold-down function (hold-down block / wrapper restraint key),
- Earthquake protection function (aseismic block / tube support plate),
- Non-generation of harmful secondary-side loose parts (due to impact and wear with respect to SG tubes).

The maximum drop beyond which the swirl vanes would come out of their support channels was also verified.

#### **2.2.1. Loss of hold-down function**

When the bundle wrapper drops, the gap between the wrapper restraint keys and the hold-down blocks increases by the same amount. The limiting value of this gap was determined to ensure that, in spite of the increase in loads in the event of a steam line break, the hold-down function is still satisfied. A maximum "allowable" drop has thus been defined.

### **2.2.2. Loss of the earthquake protection function**

In the event of an earthquake, the SG tubes are protected by the aseismic blocks which are in direct contact with the plates directly supporting the tubes, the tube bundle wrapper and the pressure shell. Should the wrapper drop beyond a certain predetermined level, there is a risk of the tube support plates being out of alignment with respect to the aseismic blocks, thus no more ensuring their function.

### **2.2.3. Risk of generating loose parts**

The first of the interactions which takes place when the bundle wrapper drops is the one that exists by design before any dropping takes place, i.e. between the support blocks and the wrapper restraint keys.

Therefore, the mechanical strength of the support blocks was analyzed during the SG internals design review and a new approach was adopted to monitor the movements of the bundle wrapper, by using a new criterion, no longer based on operating experience, but rather on the calculations of deflection at rupture and specific to each SG, depending on the dimensions of the wrapper supporting system and on the measured gaps. These calculations were performed in a very conservative manner, since they were based on obtaining the rupture stress at the most heavily loaded location (highly localized rupture).

These analyses were confirmed by a mockup with a support block taken from a Bugey 5 SG that had been taken out of service. Under conditions corresponding to a dropping of the bundle wrapper equivalent to the deflection at rupture, a local rupture of one of the support block welds was observed and not a total separation of the block from the wrapper.

The interactions with the other internals during the bundle wrapper drop (gussets, anti-rotation key, recirculation water separation baffle) were compiled and analyzed, giving, for each case, a maximum "allowable" drop.

### **2.2.4. Risk for the moisture separator swirl vanes to come out of their support channels**

This study consisted in an analysis of the risk of the loss of the moisture separation function as the result of the swirl vanes coming out of their support channels. The analysis took into account the SG transients. The corresponding limiting have thus been determined.

### **2.3. Additional Test**

In the case of a bundle wrapper drop exceeding the acceptable limit, and in order to increase the safety margins, a mockup test was carried out to determine the impact on the model 51 SG tubes due to an interaction of the stop (tube bundle anti-rotation system) and the upper tube support plate during a gradual drop (see Photo 2).

The results showed, in addition to the absence of SGTR, that the bundle wrapper would only drop partially, because it would be stopped by the upper tube support plate, which itself would be supported by the bowed tubes, which, in turn, would support the weight of the bundle wrapper.

### **2.4. Conclusion**

The maximum "allowable" drop for all the SG models of the French fleet corresponds to the deflection at rupture of the support block.

These limiting values, established in a conservative manner, are taken into account in the Surveillance an Maintenance Strategy and Policy by the mean of the specific criterion established for each SG.

### **3. SYSTEMATIC ANALYSIS OF THE POTENTIAL LOOSE PARTS**

The analyses of the consequences of an hypothetical gradual dropping of the bundle wrapper have allowed, for each SG model, the study of a certain number of secondary side potential loose parts.

In this second phase of the study, based on recent operating experience and the signs of inservice loading on the lower internals (bundle wrapper cracking associated with support block degradation, tube support plate degradation, breaking away of the aseismic block wedges), all the welds and/or all the locking systems were assumed to be broken, in contrast to the approach described in the previous section.

#### **3.1. Impact damage**

After compiling this complete list of potential loose parts, the possible paths that could be taken by these parts, under normal operation and following steam nozzle rupture were identified using a purely geometrical approach without prejudging the ability of the fluid to transport the part. The locations where these parts could be trapped were also identified because of the associated wear risks.

Next, a systematic analysis was carried out which showed that, for the concerned parts liable to come into contact with the tube bundle peripheral tubes, the risk of an instantaneous rupture of the tube wall is totally excluded for healthy tubes.

These results have been confirmed by additional impact tests on tubes exhibiting defects representative of French operating experience.

#### **3.2. Wear damage**

The method consisted in evaluating, for each part, the friction wearing power on the tubes, which is a function of the parameters characteristic of the part (weight, principal dimensions, shape, material) and characteristic of the fluid (mass flow rate, density).

Next a critical volume was defined: namely the volume (depth, length) for which the tube would become unstable in the event of a SLB.

The results obtained in that frame have been carefully taken into account and adequate measures integrated in the Surveillance and Maintenance Strategy and Policy.

#### **3.4. Conclusions**

The measures already implemented in the tube bundle Maintenance Strategy and Policy as well the implementation of the bundle wrapper Maintenance Strategy and Policy (See § 4 of D4-A4-FR) issued in accordance with the French Safety Authorities allow to avoid any risk of tube rupture due to loose parts.

Furthermore, the results of these two studies (impact and wear) were used graphically in the form of nomographs. Last of all, the proposed method permits studying, in a simple and practical manner, the harmfulness of all the loose parts, based only on their dimensions and on the material.

## 4. CONSEQUENCES OF BUNDLE WRAPPER DROP ON SG OPERATION

### 4.1. Slow Dropping

A first analysis was performed concerning the immediate impact on the SG operating parameters, since the dropping of the bundle wrapper would reduce the feedwater inlet opening under the wrapper between the annular space and the tube bundle.

It showed that a dropping of the wrapper would have little influence on parameters such as the secondary side pressure, the recirculation rate, the moisture in the SG outlet steam and the risk of vibratory instability at the tube/tubesheet interface, as long as the feedwater inlet opening is at least as large as the distance between the wrapper and the shell.

For these reasons, it appears that, even in the case of a slow and gradual drop, this phenomenon would be difficult to detect from NSSS parameters during operation.

### 4.2. Sudden Drop

#### 4.2.1. First scenario envisaged

A second analysis was then carried out to study the impact of a total and sudden drop on unit operation, taking into account realistic assumptions.

For the model 51 SGs (900 MW units), a total and sudden drop of the bundle wrapper would lead to an overpower  $\Delta T$  reactor trip. Certain alarms would be actuated, which, in conjunction with the evolution in water level in the affected SG, as read by the narrow range instrumentation, should allow the operator to recognize that the bundle wrapper has dropped.

For SG models 68/19 and 47/22, a total and sudden drop of the bundle wrapper would lead to an automatic stabilization at a power level different from the programmed one. The decrease in the capacity of the secondary to remove the heat produced by the primary system would be limited and the power from the primary system would be correctly transferred to the secondary system. In addition, the asymmetric feedwater supply and the actuation of several alarms should allow the operator to recognize that the bundle wrapper has dropped.

#### 4.2.2. Scenario with aggravating factor

One of the conditions in the study, referred to Section 4.2.1, was that the temperature of the SG loop concerned by a bundle wrapper drop was controlled by bank R. This assumption was not conservative with respect to the DNBR criteria.

The consequences of bundle wrapper drop on the DNBR were analyzed assuming the elimination of the maximum average primary temperature measurement (switched off by the operator in the control room). This leads to a significant increase of the temperature in the affected loop.

The phenomena associated with the above scenario were not within the envelope of the overheating accidents already analyzed with respect to the DNB criteria.

The analysis was carried out for the SGs on the 900 and 1300 MWe units.

For the 900 MWe units, two cases were analyzed.

In the first case, the incident occurs at the initial nominal power (100% FP). The core heats up and the primary pressure rises which then calls on the average primary temperature control system which controls the insertion of the control banks and the pressurizer spray system.

Given the thermal power level of the core and the decrease in heat transfer in the affected SG, the healthy SGs are called on to remove more heat. The temperature difference between the hot and cold leg increases. The cold legs of the healthy loops cool down by about 5°C, whereas the cold leg of the affected loop heats up by about 30°C; this phenomenon is finally stopped by reactor trip due to overpower  $\Delta T$  on the healthy loops.

The DNBR was calculated at three representative times in the transient; it was found to be constant and equal to its initial value. Thus, no degradation in the DNBR was observed during the transient up to reactor trip, since the core heatup was compensated by the decrease in nuclear power. After reactor trip, there is no risk with respect to the DNBR.

The second case corresponds to an incident occurring at an initial power level where reactor trip by overpower  $\Delta T$  cannot be obtained because the power differential to be picked up by healthy SGs is smaller than in the first cases.

Determined from a parametric study, the maximum initial power not leading to reactor trip is 72% FP, with the reactor stabilizing at a power level very close to this value, due to the operation of the reactor control system.

The temperatures of three cold legs are lower than in the previous case. The consequences with respect to the DNBR are therefore less penalizing.

For the 1300 MWe units, the sudden dropping of a bundle wrapper at 100% FP does not cause reactor trip. This envelope scenario, with respect to the DNBR was therefore the only one analyzed.

The partial loss of the feedwater, causes, fairly rapidly, a heating up of the core and an increase in pressure which triggers the pressurizer spray. The healthy SGs remove more heat, which leads to an increase in the temperature difference between the hot and cold leg, a decrease in the temperature of the cold legs of the healthy loops by about 4°C and an increase in the cold leg temperature of the affected loop by about 35°C.

The new temperature distribution leads to a new power distribution in the core. The region where the heatup is the greatest will see its average power decrease by about 20%, whereas the region where the cooling is the greatest will see its average power increase by about 10%. The changes in temperature and pressure, which have opposite effects on the DNBR, globally tend to compensate each other. Thus the DNBR varies only slightly during the transient and remains above the DNBR criterion, given the existing margins.

#### **4.3. Principal Results**

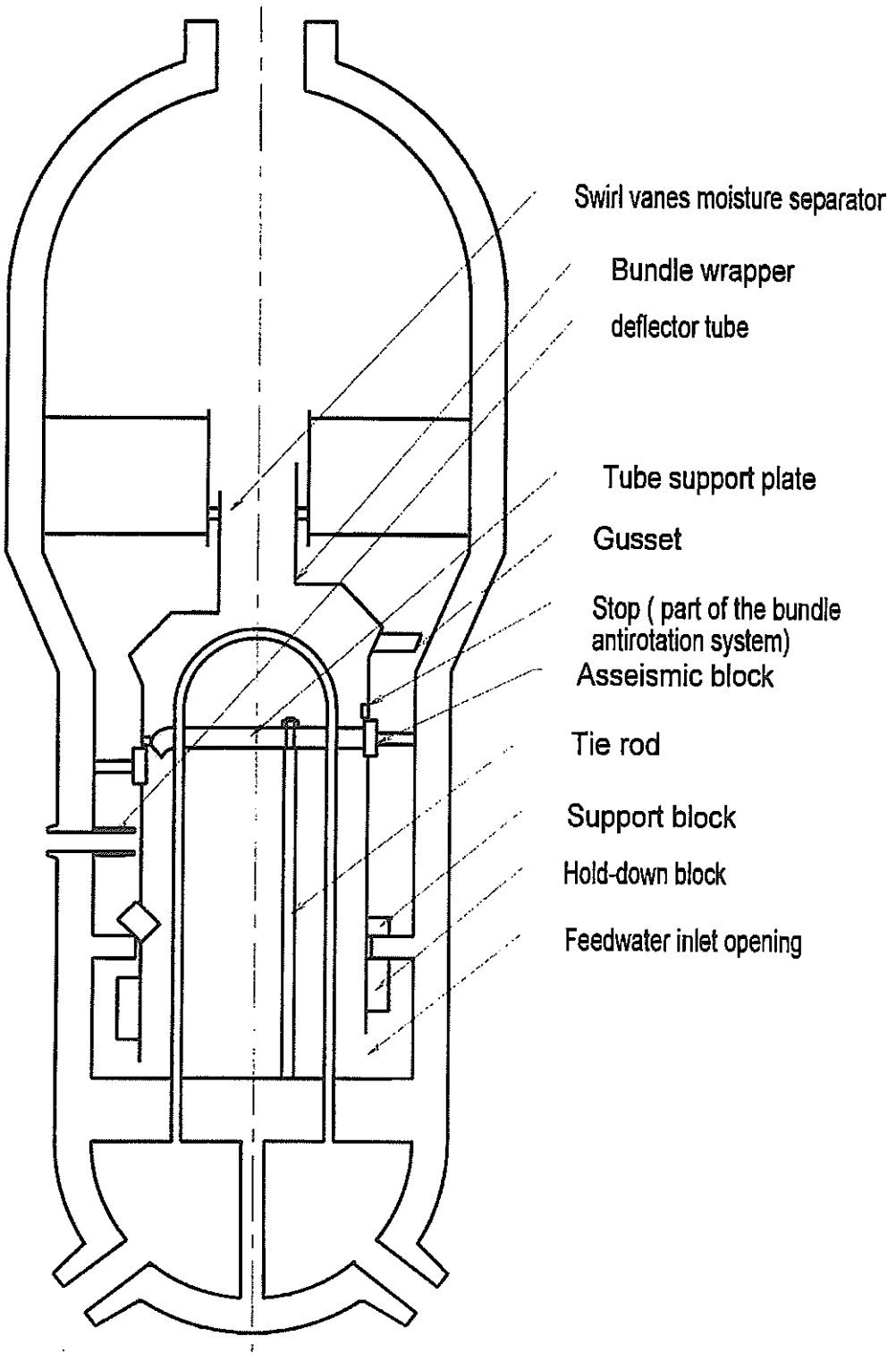
These studies permitted demonstrating that the consequences of a gradual or sudden drop of the SG bundle wrapper were not critical from the point of view of the plant safety.

## **5. CONCLUSION**

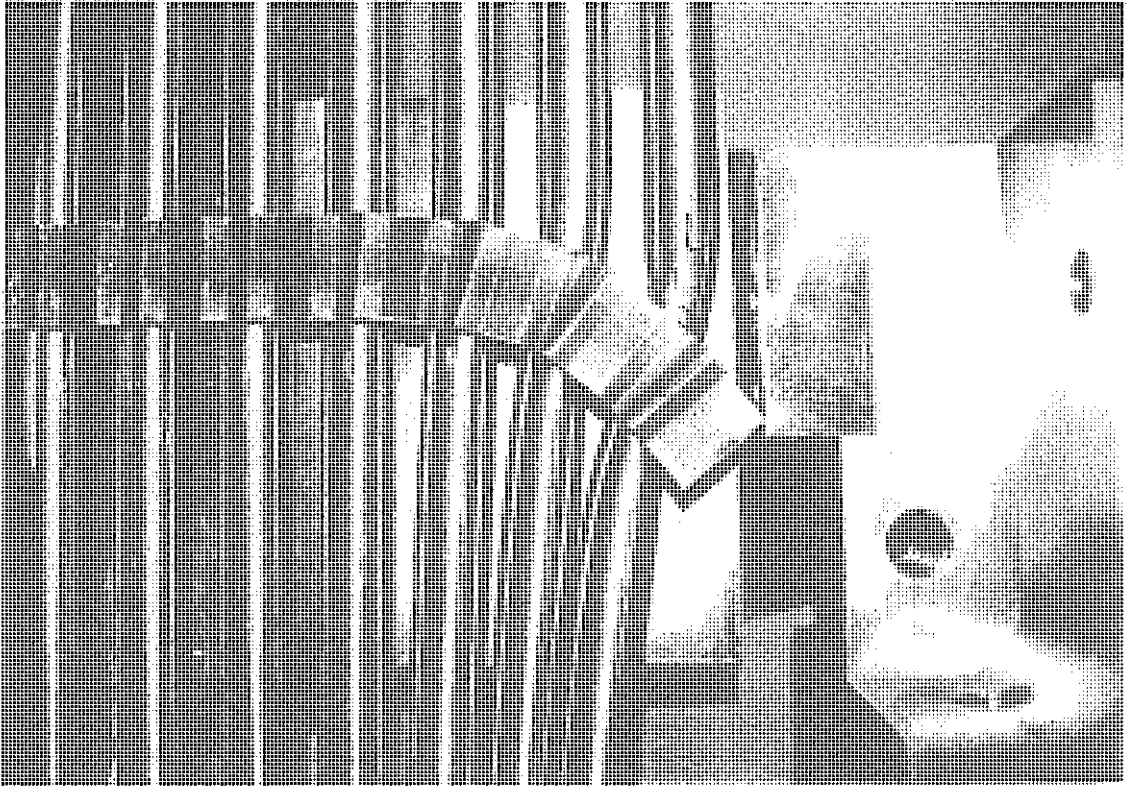
The above mentioned studies have demonstrated that the plant safety is not called into question in case of wrapper dropping, should it be gradual or sudden.

As far as SG availability is concerned, the same studies have also shown that, in case of a significant wrapper drop (which could remain undetected), implementation of the tube bundle Maintenance Strategy and Policy as well as associated maintenance actions (see D4-A2-FR) eliminates the risk of reaching an irreversible state which would lead to the replacement of the SG.

The risk revealed by operating experience and explained by Design Review (see D4-A4-FR) studies is not a safety risk but rather an economic risk.



**Figure 1**  
**SG Drawing**



**Figure 2**  
**Support Plate Bending Test**