EDF

Electricité de France

Direction des Etudes et Recherches

SERVICE RÉACTEURS NUCLÉAIRES ET ECHANGEURS
Département Mécanique et Technologie des Composants

Gestion INIS
Doc. enreg. le : 6/6/96
N° TRN : FR9662961
Destination : I,I+D,D

Juin 1995

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ECLATEMENT DE TUBES DE GENERATEURS DE VAPEUR PAR EFFET CHAUDIERE

BURSTING OF STEAM GENERATOR TUBE UNDER BOILER EFFECT

Pages : 10

96NB00065

Diffusion : J.-M. Lecœuvre
EDF-DER
Service IPN. Département SID
1, avenue du Général-de-Gaulle
92141 Clamart Cedex

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ISSN 1161-0611

SYNTHÈSE :

En octobre 1992, lors d'un contrôle télévisuel du circuit secondaire d'un des générateurs de vapeur (GV) du site de Dampierre 2, on découvrait un tube éclaté alors qu'il avait été préventivement obturé. Afin d'analyser ce phénomène ainsi que ses conséquences immédiates sur le faisceau environnant, la DER a réalisé des essais représentatifs sur maquette. L'étude montre l'absence de risques immédiats d'endommager les tubes adjacents au tube rompu par effet chaudière.

EXECUTIVE SUMMARY :

In october 1992, at the time of a television inspection on the secondary side of one of the steam generators (SG) in Dampierre 2, it was found the burst of a plugged SG tube. Since then, in order to analyze this phenomenon and its immediate consequences on the surrounding tubers, EDF has carried out model representative tests. This study shows the absence of immediate risks of damaging the tubes adjacent to the tube broken by boiler effect.

BURSTING OF STEAM GENERATOR TUBE UNDER BOILER EFFECT

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1 INTRODUCTION

Operation feedback, both in France (Dampierre 2) and abroad (Salem 2 and Ringhals 1), has shown that, in some situations, the plugged SG tubes could present a risk of bursting by boiler effect. As a result of inspections, these bursting phenomena were attributed to stress corrosion cracking in Inconel 600 plugs installed in hot leg. Some plugged tubes can fill up with water when the unit is shut down, if the tightness at the plug is not perfect. If, as a result of this, the plug becomes tight once again (diode effect), the rise in temperature once the unit has been started up produces an increase in the internal pressure, leading to excessive swelling in the tube. After several unit start-up and shut-down cycles (filling and pressurising the tube), the tube may break : this is bursting by boiler effect.

In the case of Dampierre 2 (Fig. 1), the rupture occurred in the middle of the first section of the tube, between the tube sheet and the first tube support-plate. This is a split break along approximately 55 mm, with slight circumferential branching (approximately 10°) at its extremities.

An inventory of the consequences of the boiler effect and an analysis of the harmful effects have allowed EDF to draw up a list of situations which may lead to consequences on the operation of the units. As part of this studies programme, the immediate risk of lateral impact of the broken tube on its neighbouring tubes was studied by EDF's Studies and Research Division. This first paper presents the results of these tests. The case of the axial impact on the U bend of its neighbouring tubes is studied by CEA Cadarache research center. A second paper presents these results of the U bend impact [1].

These studies set out to quantify the mechanical parameters leading to a rupture in the tube (bursting scenario, bursting pressure and temperature, etc.) and to assess the immediate consequences of the impact of the burst tube on its neighbouring tubes. It concerns the first moments which follow the bursting of the tube : dynamic opening of the break and/or the jet force could be likely to damage the surrounding tubes.

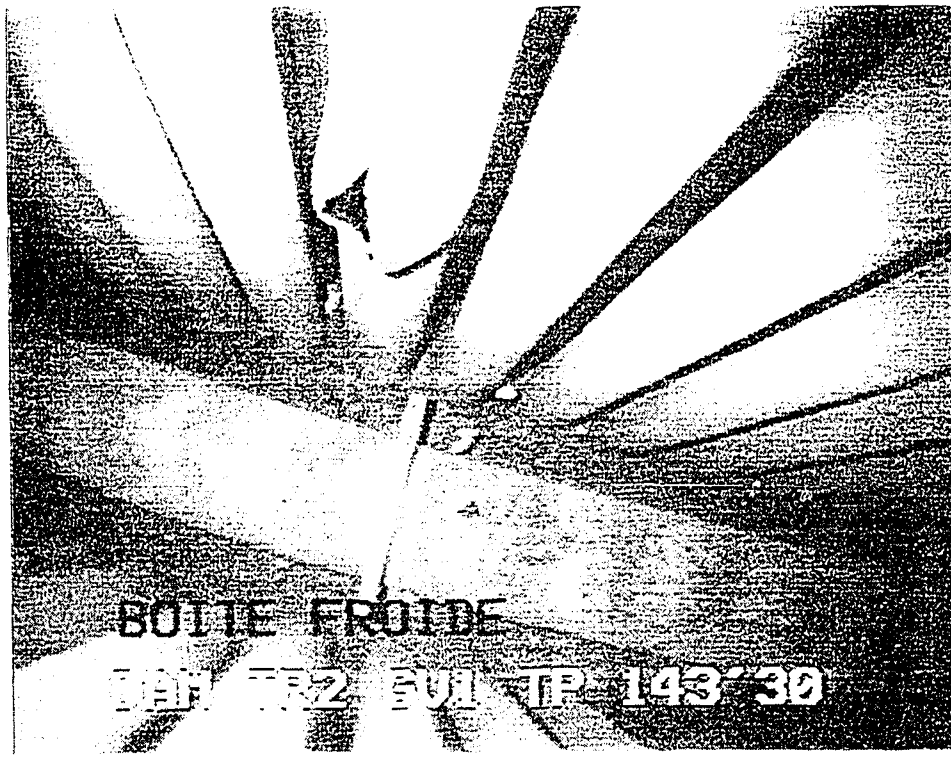

Fig. 1 Photograph of the burst tube in Dampierre 2

2 METHOD

2.1 Configurations tested

Two types of configuration were defined as critical, i.e. situations which might have consequences on the bundle of adjacent tubes :

- type 1 : a preventively plugged tube without crack, which might lead to a split break in the current tube zone.
- type 2 : a plugged tube with a non-through-wall axisymmetric crack in the roll transition zone, which might lead to a guillotine rupture.

2.2 Equipment

A test bench on a scale of 1, making it possible to test entire bends (approximately 10 m in length) was then constructed in order to simulate the conditions which could lead to bursting in a tube by diode effect. The most pessimistic conditions were presented : a tube initially filled with water, effective tightness in the plug as from the start of the test, and with initial pressure/temperature conditions in the tube $P_o = 0$ MPa and $T_o = 293$ K.

In contrast to the steam generator, the secondary side on the test bench was in air and at zero gauge pressure. The reasons for this technological choice lie mainly in its simplicity. Furthermore, it was thought that the conditions of the secondary circuit hadn't influence on the rupture of the tube. We were thus working in differential pressure, without water in the secondary side. The rise in temperature in the secondary side was brought about by circulating hot air around the tube being tested, up to the maximum temperature point in this circuit, i.e. 559 K. This point corresponds to a temperature in the secondary side at zero rated capacity. If the tube did not burst at the time of the first boiler effect cycle, the heating was stopped and the tube was depressurized. Under the initial conditions, the tube was filled and then a second heating cycle was simulated again.

For some tests, tubes under rated conditions in the SG were arranged around the tube being tested, so as to assess the consequences of its rupture on the adjacents tubes.

3 RESULTS AND DISCUSSIONS

The influence of the parameters which govern rupture (type of material, effect of the thermal heating gradient, conditions of the environment of the secondary circuit, etc.) was studied. Numerous tests made it possible to identify the main parameters influencing the rupture facies in the tube and its consequences on the adjacent tubes. The first series of tests concerning the configurations of type 1 (preventively plugged tube) showed that the thermo-hydraulic conditions in the secondary side influenced the result of the tests. At the time of these tests, much larger circumferential branching (approximately 180°) at the extremities of the break was obtained than that seen at Dampierre 2. Furthermore, the adjacent tubes were deformed by bending; this non-representative phenomenon was certainly due to the blast which could result from the tube bursting.

Indeed, an additional analysis showed that the fact of being in air and at zero pressure in the secondary side on the test bench led to vaporization of the leakage at the time the tube burst by boiler effect. This vaporisation does not exist in the actual case of the SG, on account of the thermo-hydraulic conditions in the secondary side. The non-representative conditions of the secondary side has two effects : a modification in the distribution of the pressures after bursting and a difference in the energies of the adiabatic pressure reduction.

3.1 Distributions of pressures after bursting, in the proximity of the break

Just after rupture, an area of fluid is established at the break (Fig. 2), whose pressure is near to saturation pressure, Psat (T), at the temperature considered, T. The acoustic source, ΔP, to be considered is given by the following expression of Gilbert 1980 [2] :

(1) $$\Delta P = - [P_c - P_{sat}(T)] ,$$

where Pc is the critical bursting pressure.

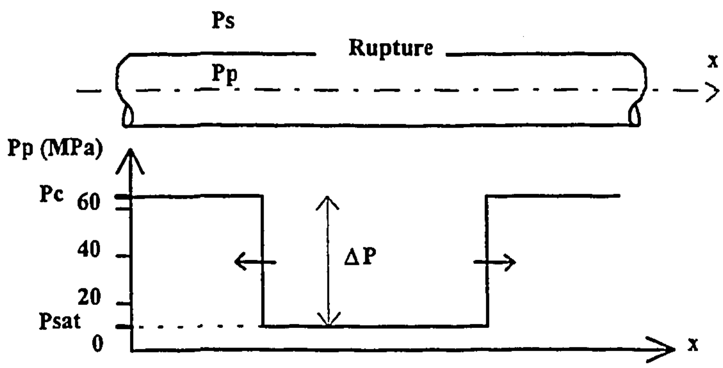

Fig. 2 Developments in the internal pressure of the tube after bursting

While depressurizing the tube, a residual pressure, Prés, remains applied to the break. This is equal to the difference in pressure between the inside, Psat, and the outside of the tube, Ps, at the break.

(2) $$P_{rés} = P_{sat} - P_s$$

By comparing the actual case of the SG and that of the first tests (Table 1), it will be noted that in the first case the residual pressure is zero and that in the second case the residual pressure is approximately 3 MPa. This residual pressure thus explains the extent of the circumferential branching observed at the time of these tests.

Table 1 Comparison of residual pressures after bursting

	Real case of the SG	Case of the first tests
ΔP (MPa)	63	63
Prés (MPa)	0	≈ 3 (Psat)

3.2 Energies released by the fluid when the tube bursts

After the tube has burst, two thermo-dynamic phases follow. The first is an adiabatic pressure reduction. On account of the speed of the bursting phenomenon, no heat exchange takes place ($\delta Q = 0$) during this phase. The second, which is much slower, allows a return to the thermo-dynamic conditions (pressures and temperatures) in the secondary side. In the continuation of the study, interest focuses only on the first phase, since it is this which corresponds to the immediate risk. A comparison of the real energies, Wr, produced by this adiabatic pressure reduction should make it possible to decide on the relevance of the similarity of the model in relation to the real case of the SG.

Expression 3 defines the effective energy, Wu. It is calculated by the enthalpy variation. It enters the initial state i and the final state f, whether the pressure reduction is reversible or otherwise, for an isentropic variation ($\Delta S = 0$). It is assessed directly on the Mollier diagram or from water/steam tables [3].

(3) $$W_u = H_i - H_f$$

Two cases may then appear : the case of the SG and the case of the first tests. In the first case, there is no vaporization of the leakage. In the second case, the leakage does vaporize. In both cases, there is actual adiabatic pressure reduction, accompanied by the creation of entropy by irreversibility, in which the expression for isentropic efficiency of the pressure reduction is defined by expression 4.

(4) $$\eta = \frac{W_r}{Wu},$$

where Wr is the energy actually released by the pressure reduction.

Taking an isentropic efficiency of 0.85, it is then possible to calculate the actual energy from expressions 3 and 4. Table 2 gives a comparison of the actual energies between the actual case of the SG and those of the first tests. It will thus be seen that the pressure reduction in the case of the first tests supplies more than twice as much energy as that in the real case of the SG. This supplementary energy explains the bending of the adjacent tubes which has been observed in the first tests.

Table 2 Comparison of actual energies

	Real case of the SG	Case of first tests
W_u (kJ / kg)	76	192
W_r (kJ / kg)	65.3	157

3.3 Partial conclusion of analyses 3.1 and 3.2

The preceding two paragraphs explain not only the extent of the branching observed at the time of the first tests, but also the bending of the adjacent tubes. The test installation does not provide an equivalent similarity in terms of energy and pressure distribution in comparison with the real case of the SG. An adaptation was sought which makes it possible to obtain energy levels and pressure distributions which are equivalent to the real case of the SG.

Thus, by imposing a temperature on bursting of not more than the saturation temperature, it is possible to reduce the energies released by the pressure reduction in the fluid and eliminate the residual pressure being applied to the break. Table 3 provides an illustration of the method. These tests make it possible to obtain an equivalent similarity in terms of energy and pressure distribution in comparison with the actual case of the SG.

Table 3 Influence of the temperature on bursting

	T_c (K)	$P_{rés}$ (MPa)	W_r (kJ/kg)
First tests	500	3	157
Tests at imposed temperature	423 373	0.4 0	62 55
Real case of the SG	230	0	64

The results of these tests confirm the above analysis, since rupture facies are obtained which are identical to those detected on site. The split break is approximately 50 mm and the circumferential branching is limited to approximately 10°. Furthermore, these tests show the absence of risk of damage to the adjacent tubes. The rupture kinetics of the tube and the associated jet forces did not generate local deformations or overall deformations in the bundle surrounding the broken tube.

Clearly, it was assumed that, during the tearing, the equipment behaved in an identical manner between a temperature for bursting by boiler effect of approximately 500 K and that of the tests at an imposed temperature of from 373 to 423 K. This case seems to be reasonable, since the almost static characteristics of Inconel 600 vary little between these two temperatures.

3.4 Synthesis of the results

For each configuration (types 1 and 2, cf. § 2.1), the scenarios leading to rupture in the tube by boiler effect were identified. Figures 3 and 4 illustrate the case of a preventively plugged tube (type 1). It is characterized by a split break in the free span, followed by limited circumferential branching. Bursting in a tube having a non-through-wall axisymmetric crack in the roll transition zone (type 2) and whose depth is greater than 50% of the thickness of the tube is characterized by a guillotine rupture.

Although in both cases there may be a mechanical interaction between the burst tube and the adjacent tubes, no consequent damage has ever been noted on these latter. In configuration of type 1, contact is possible between the lips of the break in the broken tube and the adjacent tubes. However, this contact is not likely to cause a multiple rupture. In the configuration of type 2, although this is a guillotine rupture, only barely visible, slight marks have ever been seen, without any local deformation.

4 CONCLUSION

Lastly, the rupture of a SG tube by boiler effect does not lead to any immediate risk of damage to the adjacent tubes in the cases of lateral impact (tests of EDF's Studies and Research Division) and U bend impact [1] (tests of CEA Cadarache research center). These studies provide a better understanding and prediction of this phenomenon, and it contributes to adapting the maintenance policy, by meeting the requirements of safety in French PWR.

REFERENCES

[1] Duc, B., Sudreau, F., Flesch, B., Rassineux, B. 1995. *Analytical and experimental studies of mechanical consequences of a steam generator tube rupture*, SMiRT 13, No. 60

[2] Gibert, R. J. 1980. *Quelques considérations simples sur l'évolution temporelle des efforts exercés par un fluide sur les structures lors de la dépressurisation brusque d'un circuit comprenant un tuyau raccordé à une cavité*, Commissariat à l'Energie Atomique (CEA)

[3] Schmidt, E. 1969. *Properties of water and steam in SI-Units*, Spinger-Verlag Berlin Heidelberg New York and R. Oldenbourg München

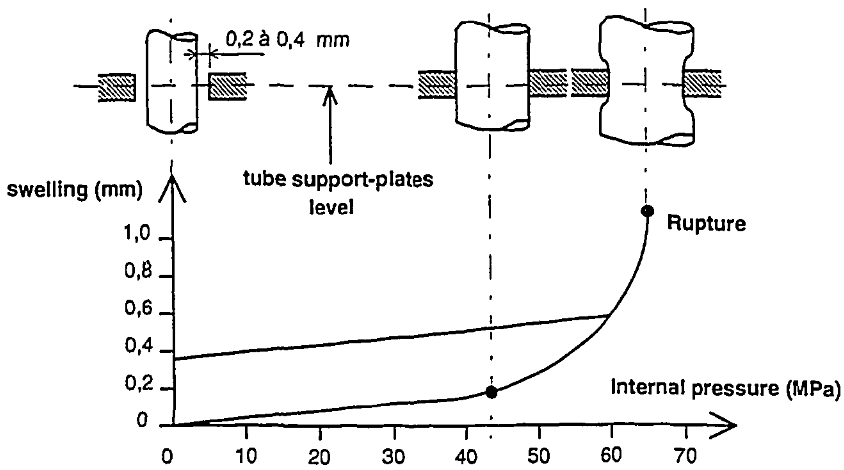

Fig. 3 Bust scenario of plugged SG tube without crack
Tube swelling versus internal pressure

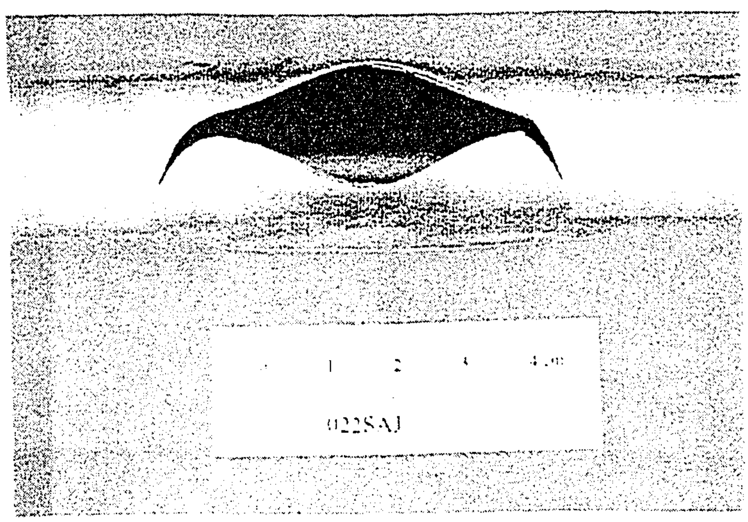

Fig. 4 Rupture facies obtained on plugged SG tube without crack