FR0200007

RECIRCULATING STEAM GENERATOR OPERATION AT VERY LOW POWER

A.HOLCBLAT

FRAMATOME ANP - Tour FRAMATOME 92084 Paris la Défense Cedex
Ph: 33 1 47 96 30 79 E-mail: aholcblat@framatome.fr

Keywords: thermal, hydraulics, simulations, experiments

Abstract

The behaviour of recirculating SG's at very low power has been thoroughly investigated by laboratory and on-site tests as well as numerical simulations. A special experimental program dedicated to recirculation threshold determination has been performed on the Freon SG mock-up CLOTAIRE. These laboratory data are completed with transients of feedwater injections at hot stand-by on two instrumented SG's, one boiler type SG and one economiser type SG. The phenomena are different on both types:

- In boiler SG's, the SG behaves like a U-tube and recirculation stops around 2% load at stand-by temperature and water level.
- In economiser SG's, the presence of 2 separate down-comers and a divider plate inside the tube bundle allows a recirculation loop by-passing the separators. The mixing of saturated and cold water induced by this loop limits down-comer cooling and thus alleviates the thermal load on the tube sheet.

These tests were used to validate the SG transient analysis 1D code ANETH.

1. INTRODUCTION

Steam generators (SG) used in most Pressurised Water Reactors are recirculating steam generators producing saturated steam. In fact, recirculation does not exist over the whole power range but appears only above a certain power level.

Operation without recirculation may be encountered at hot stand-by and during several transients such as power increase and decrease, heating and cooling of the reactor etc. Therefore it is necessary to simulate them either to assess the heat transfer capacity of the SG's or to determine the fluid temperature and heat transfer coefficient necessary for the mechanical studies.

To be able to carry out such studies, FRAMATOME uses the SG transient analysis code ANETH, presented in a previous paper and already validated at intermediate and high power level ([1]). The present paper presents the different tests performed to validate it at very low power (below 5% load).

2. THE SG COMPUTER CODE ANETH

ANETH is a one-dimensional code dedicated to SG transient simulation. Starting from the SG boundary conditions (reactor coolant flow rate and inlet temperature, primary pressure, feed flow rate and temperature, vapour flow rate, etc.), ANETH computes secondary pressure and liquid level as well as usual local thermal hydraulic parameters (void fractions, temperatures, flow rates, etc.).

The fluid domain on the primary and secondary sides is modelled as a set of control volumes and junctions. In this way, ANETH can be applied to any kind of recirculating steam generator provided that a suitable pre-processor is available.

Detailed physical modelling (especially bubble rise in stratified volumes, counter-current, thermal inertia of the shell and the tube sheet, heat transfer across the tube bundle wrapper) enables phenomena generally neglected in usual SG transient analysis codes, but significant in the very low power range, to be taken into account.

When compared with [1], the main change is the introduction of two additional terms in the energy equation on the secondary side: the first term, called "thermal bridge" option, allows modelling of the heat transfer across a wall without thermal inertia, such as the bundle wrapper, the separator risers or the divider plate between the hot and cold legs of an economiser type SG.

The second term accounts for the heat transfer occurring when a cold layer surmounts hot water. In case of feed water injection at very low or zero flow rate in the down-comer, measurements on Tricastin SG [4] have shown that the cold temperature front advances at a velocity much higher than the flow velocity. This indicates the existence of 2D or 3D natural convection induced by the Rayleigh-Taylor instability. From a 1D point of view, the main effect is a global energy transfer without mass transfer and can be assimilated to diffusion. Therefore the power received by volume i of enthalpy $hvos_i$ from volume j of enthalpy $hvos_j$ is represented by the following additional term:

$$Qdi_{i,j} = -D\frac{S}{L}(hvos_i - hvos_j)$$

D is a diffusion coefficient to be fitted experimentally, S the horizontal cross-section, L the vertical distance between the centres of the volumes i and j. D is zero when the temperature gradient is upwards. In principle, it can depend on:

$\frac{\Delta\rho}{\rho}$: relative density variation between the upper and lower layers
H : down-comer height
l : down-comer azimuthal length

3. CLOTAIRE TESTS

The CLOTAIRE mock-up was originally built in order to perform steady tests to validate 3D thermal hydraulic codes used to compute the flow inside the tube bundle [2] [3]. After this first program was completed, it was followed by a second program dedicated to SG global behaviour (level and pressure variation, onset and disappearance of recirculation) at low (between 5% and 10% load) and very low power (below 5% load). The present paper treats only the very low power tests, steady or transient, around the recirculation threshold.

3.1. Description of the mock-up CLOTAIRE

The CLOTAIRE SG uses Freon modelling. Basically the mock-up (fig.1) represents the FRAMATOME 68/19 SG fitting the French 1300 MWe power plants.

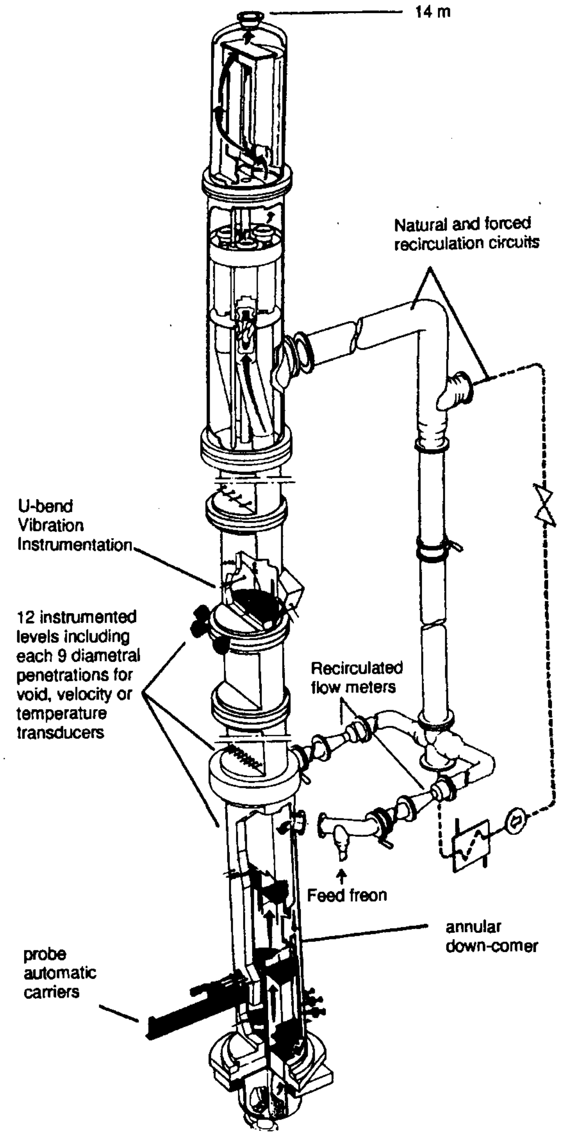


Figure 1 – **CLOTAIRE SG : General lay-out**

Its lower part consists of a half cylindrical shell containing a U-tube bundle of 184 tubes (15 by 16 rows), its upper part of a cylindrical vapour drum with 3 centrifugal separators of 0.2 m in diameter and a chevron type drier. The recirculated Freon flows down an external circuit joining the vapour drum to a 2-meters high annular down-comer similar to the one on the prototype. In comparison with the prototype, the dimensions and pitch of the tubes are scaled down by a factor 0.7. The overall height of the mock-up is 14 m.
Although the mock-up can have several configurations (simulating either boiler type or economiser type SG's), all the tests described hereafter were performed in the boiler model configuration (without divider plate in the tube bundle). The circulation ratio (i.e. the ratio of total secondary mass flow rate in the tube bundle to the vapour mass flow rate) was lowered from 4.3 (in Reference [2]) to 3.2 by partially closing the valves in the horizontal parts of the down-comers .

Tube outside/inside diameter (10^{-3} m)	13.3/11.3
Length of the bundle straight part of the (m)	6.89
Square pitch (10^{-3} m)	19.64
Number of tube rows	15
Number of U tubes (in half a cylinder)	184
Largest tube radius (m)	0.295
Number of support plates	9
Number of distribution baffles	1

Main characteristics of the CLOTAIRE SG

3.2. Instrumentation

The thermal-hydraulic instrumentation consists of two sets: a set of 164 fixed transducers and a set of mobile transducers for specific two-phase flow measurements (30 bi-optical probes to measure void fraction and velocity).
The classical instrumentation consists of thermocouples, flow meters and absolute and differential pressure transducers enabling the pressure line along the recirculation loop to be drawn. The flow meters were changed for the new campaign in which the flow rates were much lower than previously:

- Feed and vapour flow rate accuracy is 1% when the load is 5%.
- Recirculated flow rate is measured on the hot and cold sides by ultrasonic flow meters calibrated by comparison with a Venturi. According to calibration, their accuracy in ideal conditions is better than 1% above 0.35 kg/s.

The mobile instrumentation was not used during the new campaign, except 6 bi-optical probes left in fixed positions in the upper part of the tube bundle (above the 8th support plate).

3.3. Test results

Two kinds of tests were performed: steady tests just above and below the recirculation threshold, increasing and decreasing power ramps during which the recirculation threshold was crossed over. Most tests have been simulated with the ANETH code so that computational and experimental results will be presented simultaneously.

3.3.1. Steady tests

The table below summarises the operating parameters at full load in the geometrical configuration used for the very low power tests.

	test	**ANETH**
data **primary side**		
. flow rate (kg/s)	59.7	
. inlet temperature (°C)	88.7	
. pressure (bar)	9.75	
secondary side . feed flow rate (kg/s)	15.01	
. feed temperature (°C)	81.4	
. liquid-vapour interface level (m)	10.46	
results . power (kW)	1483	1491
. outlet temperature (°C)	82.8	82.7
. dome pressure (bar)	8.78	8.76
. circulation ratio*	3.20	3.21

The very good agreement between measured and computed values (respectively left and right columns) of the pressure and circulation ratio validates the geometrical model (head loss coefficients, heat transfer surface) and the correlations used in the following computations.

Five tests were carried out, two with warm feed water (around 68°C), and four with cold feed water (around 28°C).

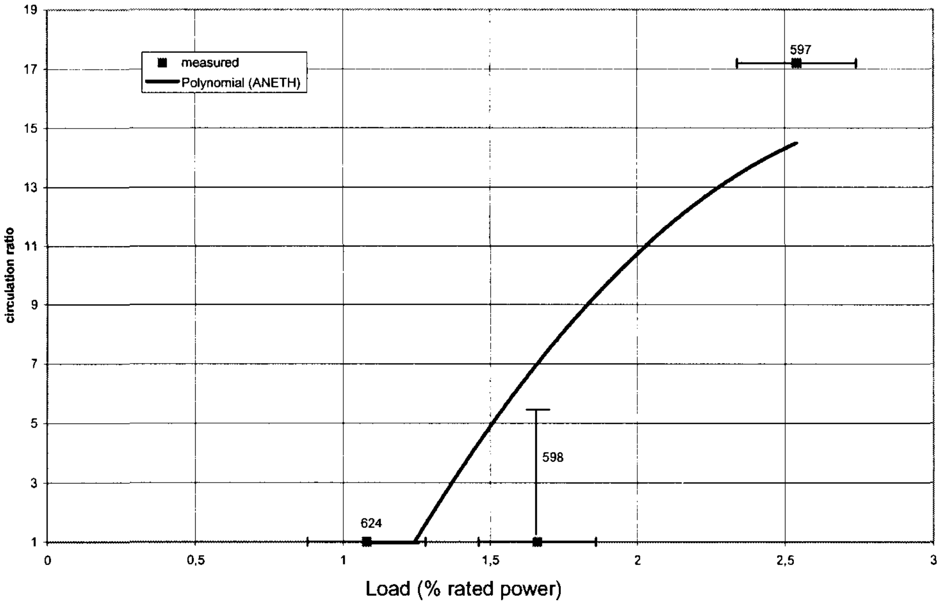


Figure 2 – **CLOTAIRE steady-state tests with warm feed water**

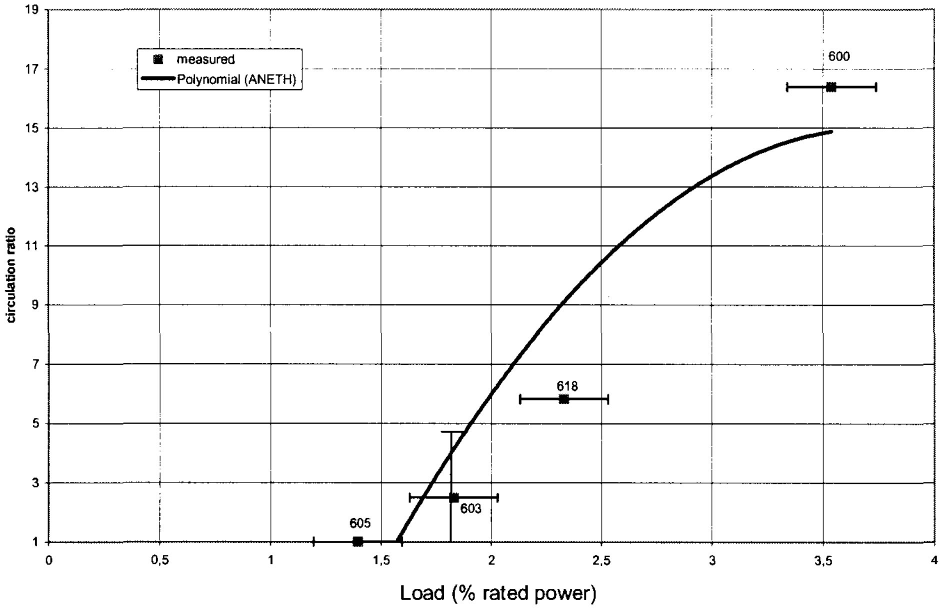


Figure 3 – **CLOTAIRE steady-state tests with cold feed water**

Figures 2 and 3 present circulation ratio versus load at each temperature. They show that the circulation ratio increases with load in this load range contrary to what happens at higher loads (above 5%). The code satisfactorily predicts the influence of the feed water temperature: when it decreases, the boiling point rises making circulation ratio decrease. According to the tests above circulation threshold (No 600 and 597), the code underestimates the circulation ratio by about 15%, probably because of an underestimation of the void fraction inside the tube bundle (Ohkawa-Lahey correlation [7] was used).

Detection of recirculation disappearance turned out to be much more difficult than expected. The simplest criterion should have been the down-comer flow rate zeroing out, but in spite of the improvement of the flow meters, flow rates lower than 1 kg/s could never be observed due to stratification problems in the horizontal parts of the down-comer. Moreover, tests showed that recirculation is somewhat unstable and

intermittent in the vicinity of the threshold. Therefore the former criterion could not be fully conclusive and had to be confirmed by water level measurement inside the risers of each of the 3 vapour-liquid separators. In fact, all three levels were different from each other and recirculation began when the lowest one reached the upper rim of the risers.
These tests bring out the specific features of SG behaviour below 4% load:

- Until recirculation starts, around 1.5% load, the SG behaves like a U-tube containing two fluids of different density: there are 2 vapour-liquid interfaces, the usual one outside the separators and another inside. As head losses are then negligible, both branches are in a quasi-hydrostatic balance. Above the boiling point, located in the upper third of the tube bundle, vapour bubbles rise in a stagnant liquid. Heat exchange across the bundle wrapper represents a substantial part of the total power and heats the feed water over a short distance, warming it before it reaches the tube sheet. As load increases -generating more and more vapour inside the tube bundle- the separator level becomes higher and higher.
- At the recirculation threshold, the liquid level inside the separators is just at top of the risers.
- Above this point, recirculation starts and the down-comer flow rate increases very rapidly, more rapidly than the feed flow rate itself so that the circulation ratio reaches a maximum around 5% load.

The code satisfactorily predicts this evolution:

- It is able to simulate steady operation on each side of the recirculation threshold; the discrepancy between the measured and computed threshold values is lower than the experimental uncertainty: 0.2% Rated Power (RP).
- It correctly predicts the effects of a lower feed water temperature: decrease in circulation ratio and increase in recirculation threshold from 1.3% RP at high temperature to 1.6% RP at low temperature.
- The fluid temperature increase from the top to the bottom of the down-comer is correctly predicted. For example, the accuracy is better than 10% in a test such as n° 605, where the increase is very large (44°C) because there is no recirculation and the feed water is cold. This validates the heat transfer modelling across the bundle wrapper. It is worth stressing this phenomenon is of utmost importance in predicting the recirculation threshold due to its influence on down-comer density.

3.3.2. Transient tests

The transient tests were performed prior to the steady-state tests to obtain a quick estimate of the threshold values. Afterwards, they allowed to check whether the threshold values are affected by dynamic and hysteresis effects: for example down-comer temperature history, way in which power varies (increasing or decreasing), etc. Four tests were performed, two with cold feed and two with warm feed. The ascending ramps began below the recirculation threshold and ended at 5% load. The descending ramps began at 5% load and ended at hot stand-by. The liquid level was regulated and kept virtually constant; the primary inlet temperature varied by less than 2°C. Of the four tests, only the descending ramp with cold feed is presented below.

In order to ensure parallel evolution of feed and vapour flow rates, it was performed very slowly and lasted about 20 mins. The main results are displayed on fig. 4. During the first phase of the test , the recirculated flow rate decreases almost linearly like the vapour and feed flow rates. Then, when 1.8% load is reached, the measured flow rate begins oscillating while the code predicts that recirculation stops: a liquid level appears in the separators and the separated liquid flow rate zeroes out. As to the liquid level, it is virtually constant and the slight final discrepancy (0.1 m) between computation and measurement can be ascribed to feed flow rate uncertainty or to underestimation of the initial void fraction by the void fraction correlation.

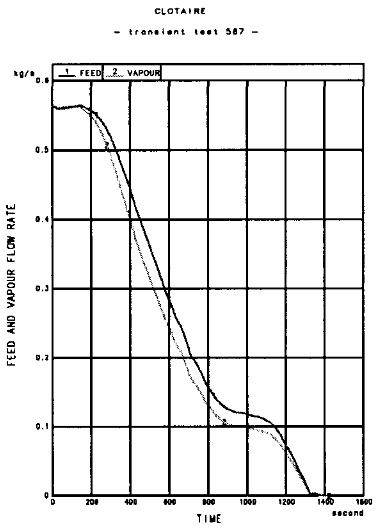


Figure 4a : **feed and vapour flow rate**

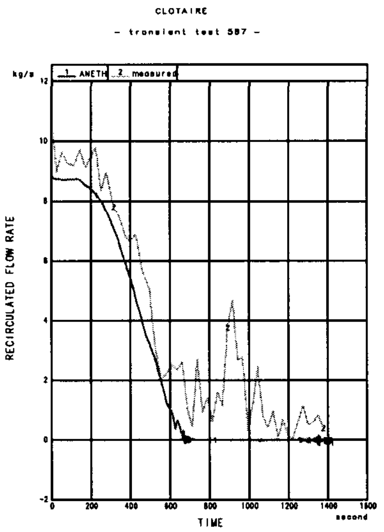


Figure 4b : **recirculated flow rate**

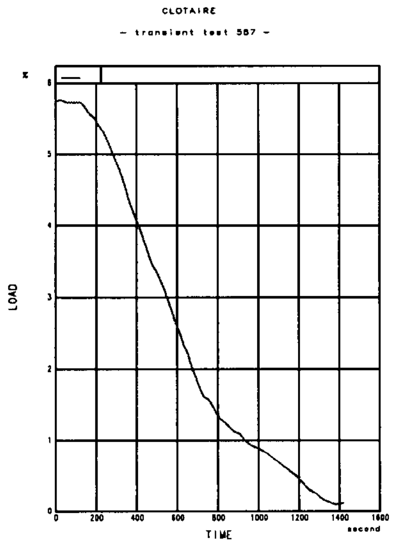


Figure 4c : **load**

Figure 4 : CLOTAIRE : descending ramp

Finally, recirculation thresholds are the same during steady-state and transient tests. The ANETH code predictions are quite satisfactory in both cases.

4. TESTS ON A BOILER TYPE SG

4.1. On–site test program

In the 1980's, a test program was performed on the 900 MWe PWR French unit Tricastin 1, equipped with series 51 SG's, in order to verify the thermal hydraulic characteristics of the secondary flow inside the SG's and check the merit of some design modifications. The test program was conducted on a specially instrumented SG and included steady-state as well as transient tests under normal or incident operating conditions. Its results allowed several 1D and 3D computer models to be validated, including the fluid-structure thermal interaction code TEMPTRON [4]. This code has been used until now to determine the thermal hydraulics in the down-comer and on the tube sheet on which the load cycle fatigue index of the pressure shell and tube sheet critical regions depends. Its validation was mainly based on the analysis of four transients: reactor trip, return to house load operation and two injections of cold auxiliary feed water. These tests were simulated again recently during the validation process of the ANETH code. The results concerning the injections at hot stand-by are presented below.

4.2. Instrumentation

The instrumentation consists of the standard instrumentation used during industrial operation and special instrumentation. The former supplies the operating data: primary temperatures, feed water and steam flow rate, small range water level. The special instrumentation shown on fig. 5 includes:

- 8 velocity probes and 8 thermocouples in the down-comer 620 mm above the tube sheet.
- 16 thermocouples measuring the wall temperature on the external side of the pressure shell: 8 at the bottom of the down-comer and 8 just below the cylindrical shell/truncated cone junction.

The velocity probes are used for measuring the dow-comer flow rate.

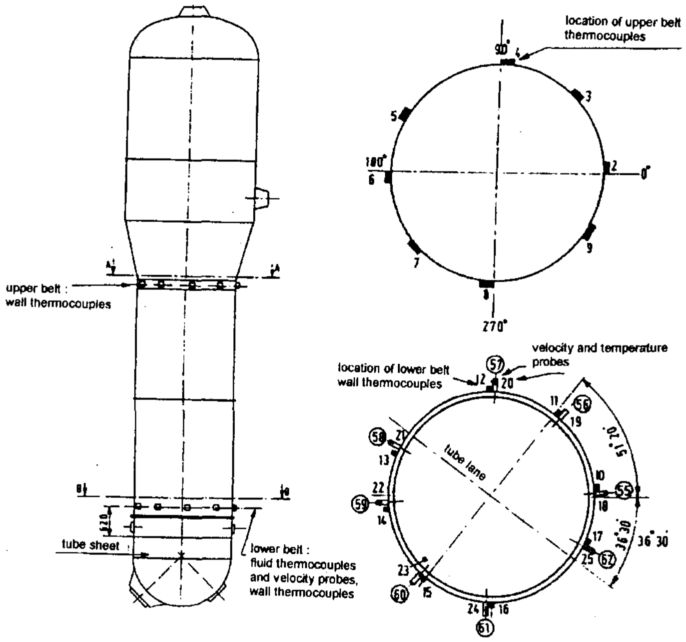


Figure 5 : **Tricastin SG : special instrumentation location**

4.3. Test results

Only significant results of the cold water (42°C) injection with a flow rate of 108 m^3/hr (6% of nominal flow rate) for 730 secs. are given. The main results are displayed on fig. 6.

The water level variation in the steam drum (fig. 6b) is correctly predicted: after a stagnation phase, it rises up to the top of the separators (13.73 m). According to the computed evolution of the internal level, recirculation starts at 400 secs. Then the down-comer flow rate steadily increases up to 400 kg/s (fig. 6c). The agreement between measurement and computation is acceptable although the velocity probes were calibrated for flow rates ten times higher and the velocity uncertainty is therefore very high (at least 50%) .
The next figure (fig. 6d) shows the average fluid temperature at the bottom of the down-comer: it keeps decreasing till recirculation onset. Later on, mixing with recirculated saturated water makes it increase. Another change due to recirculation onset is also to be noticed on fig.6e and fig.6f : whereas the temperatures keep oscillating until 400 secs, probably because of large scale eddies, they become smooth after a large flow rate is established. The computed temperature drop is slightly overestimated when compared with the measured average, because the thermal diffusion coefficient was fitted so as to envelop the minimum local measured temperature (fluid temperature was measured at 8 points). If, on the contrary, the diffusion coefficient is assumed to be zero, the bottom temperature decreases very little during the first phase and, when recirculation starts, the cold water plug accumulated at the top of the down-comer suddenly goes down and causes a very strong thermal shock, which was not actually observed. This brings out the benefit of the thermal diffusion model.

As to the external wall temperature, the last figure (fig. 6g) shows some discrepancy between the initial values due to external heat losses but the main result is that the difference between the bottom and top values in the down-comer is correctly predicted and never exceeds 8°C.

The preceding results allow the ANETH code to be used to predict thermal loading on the pressure shell during auxiliary feed water cycling at hot stand-by.

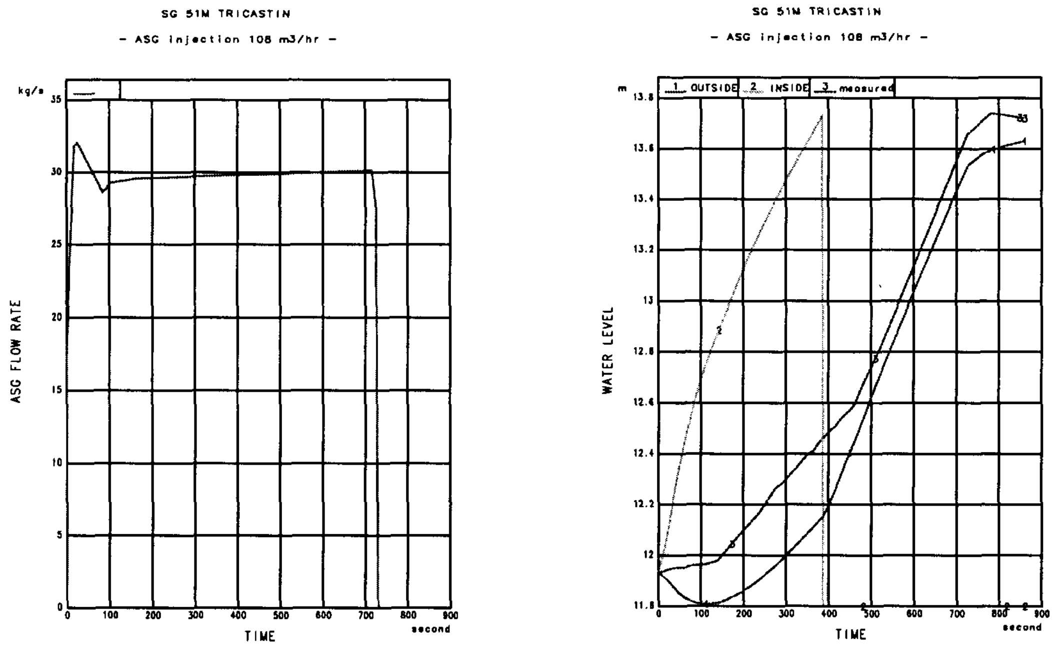


Figure 6 a : auxiliary feed flow rate

Figure 6 b : water level

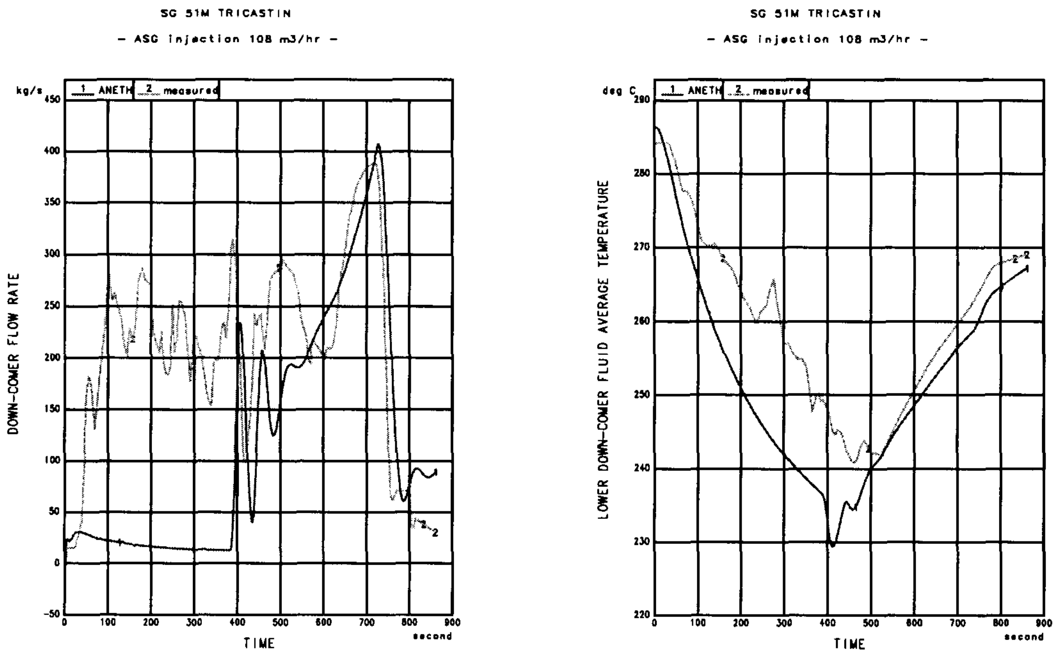
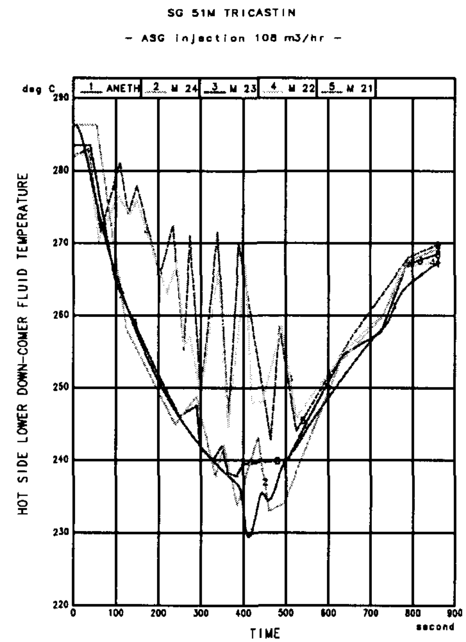


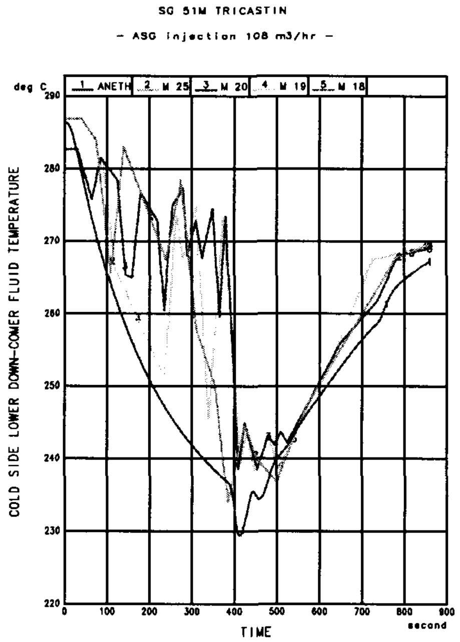
Figure 6 c : down-comer flow rates

Figure 6 d : lower down-comer temperatures

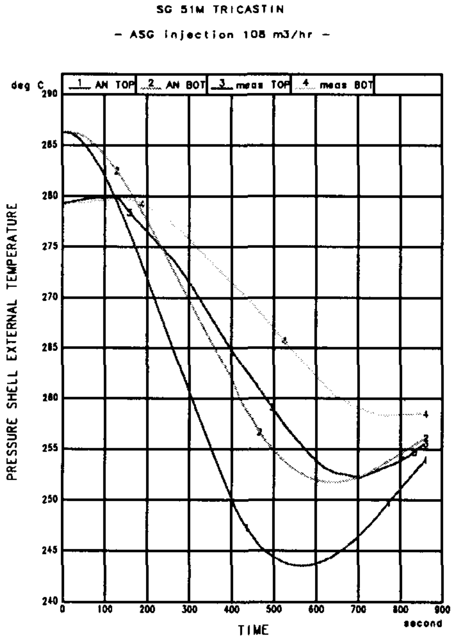
Figure 6 : Tricastin SG – Auxiliary feed water injection at hot stand-by



<u>Figure 6 e</u> : **Lower down-comer temperatures (hot side)**



<u>Figure 6 f</u> : **Lower down-comer temperatures (cold side)**



<u>Figure 6 g</u> : **Pressure shell external temperature**

<u>**Figure 6**</u> **: Triscatin SG – Auxiliary feed water injection (end)**

5. TESTS ON AN AXIAL ECONOMISER TYPE SG

The new French N4 pressurized water reactor units (1450 MWe, 4 loop plant) are equipped with an advanced SG model: the SG 73/19 E with axial economiser [5]. As in the 900 MWe and 1300 MWe series, special instrumentation was installed on one of the SG's of the first plant to be commissioned (Chooz B1) and an extensive test program [6] was carried out.

5.1. Description of the CHOOZ B1 SG's

The new SG model stands out from older models by an axial economiser and a triangular pitch tube bundle. The new design features are illustrated in fig. 7. We comment only on points relevant to the present paper. The down-comer (1c and 1h) is split into two parts (respectively called *hot* and *cold* in connection with the hot and cold legs of the tube bundle) by means of a double wrapper. A vertical plate (2) divides the lower part of the tube bundle above the tube sheet (3) into two equal parts containing, on one side, the hot up-flow part of the U-tubes (hot leg, 4h) and on the other the cooler down-flow part of the U-tubes (cold leg, 4c). In order to increase the thermal efficiency of the SG, the whole feed water flow (5) is delivered directly inside the cold side double wrapper where it mixes with a small portion of the saturated liquid recirculated by the moisture separators and dryers (7).

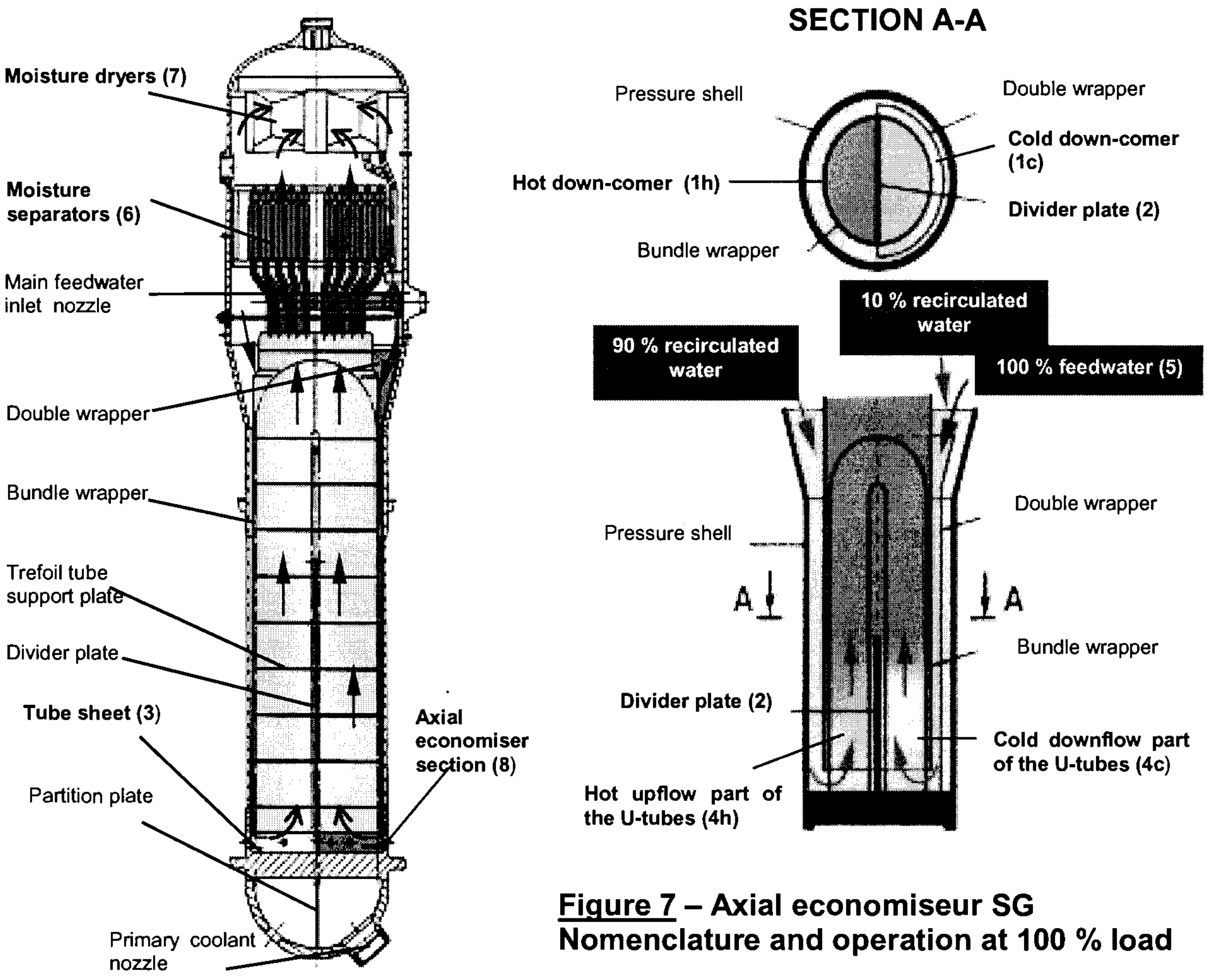
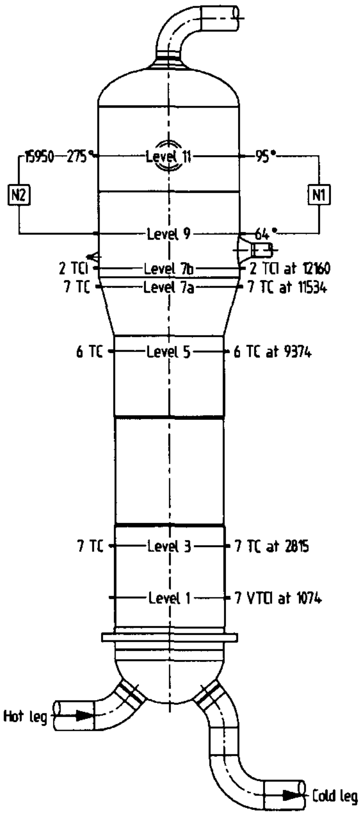


Figure 7 – Axial economiseur SG Nomenclature and operation at 100 % load

5.2. Instrumentation

The special instrumentation (fig. 8) installed on SG No 2 of Chooz B1 comprises temperature measurements of the fluid and pressure shell, absolute and differential pressure transducers and fluid velocity probes in the down-comers. The main measurements for the transient tests are the following:

- Level 1: 7 intrusive velocity and temperature probes (VTCI) introduced in the hot and cold down-comers
- Levels 3-5-7a: 3 thermocouple rings (TC) welded on the external wall of the pressure shell
- Level 7 b : 4 internal fluid thermocouples (2 on either side)
- Levels 9 and 11: 2 additional water level measurements (N1 and N2) with reduced range supplying a more accurate SG level than the standard measurement.



TC : pressure shell external thermocouple
TCi : fluid thermocouple
VTCi : fluid velocity and temperature probes

Figure 8 – Chooz B1 : Special Instrumentation location

5.3. Test results

This section concentrates on two feed water injection tests at hot stand-by that exemplify the specific behaviour of the new SG model at very low load. Previous to both injections, the SG state was stabilised with a water level lower than the set-up point so as to be able to carry out a long injection without triggering a high-high level trip. In conformity with the design assumptions used in the normal and upset transient specifications, provisions were made to avoid any steam flow rate: the SG's were isolated and steam dump opening was delayed by lowering the primary temperature or increasing the opening pressure set-point of the atmospheric steam dump valves.

5.3.1. Normal feed water (ARE) injection (300 t/hr)

This transient consists in injecting normal feed water at 120°C into the cold down-comer for 500 secs. The main results are shown in figures 9. The down-comer flow rates (fig. 9b - positive downwards) show that the weight unbalance between both down-comers generated by the injection induces a circulation loop by-passing the separators: the liquid injected into the cold down-comer rises in the cold leg, goes round the divider plate, down into the hot leg and up again into the hot down-comer (fig. 11). This phenomenon, called *hot-side reverse circulation*, is quite stable and reverses only at the end of the injection. The lower down-comer temperature drop (-40°C on the cold side – see fig. 9c) is correctly predicted as well as the temperature at level 7b near the final weld (fig. 9d). Another interesting result is the pressure increase (+11 bars – see fig. 9e), which demonstrates that condensation at the steam-water interface is very limited because the temperature of the upper layer is not greatly affected by the cold water injection. In fact, a large part of condensed steam in this test is condensed on the wall of the steam dome. This probably explains why the code –that up to now does not take this into account, but will be improved on this point in the future- overestimates the pressure increase.

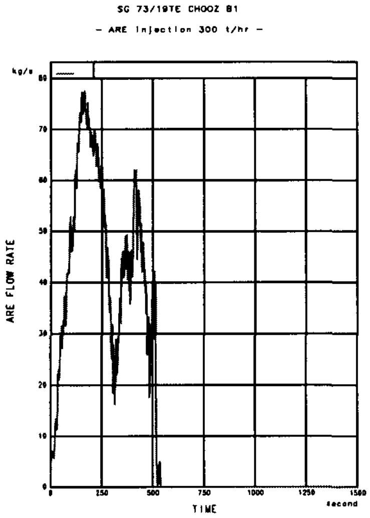


Figure 9a : feed flow rate

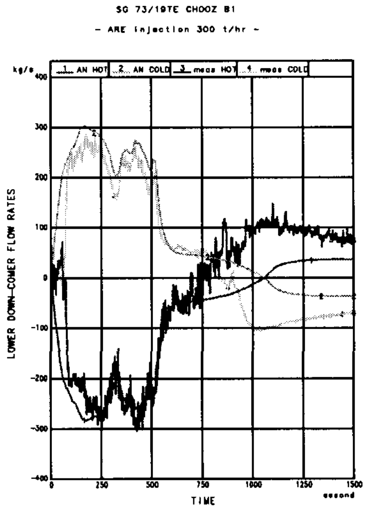


Figure 9b : down-comer flow rates

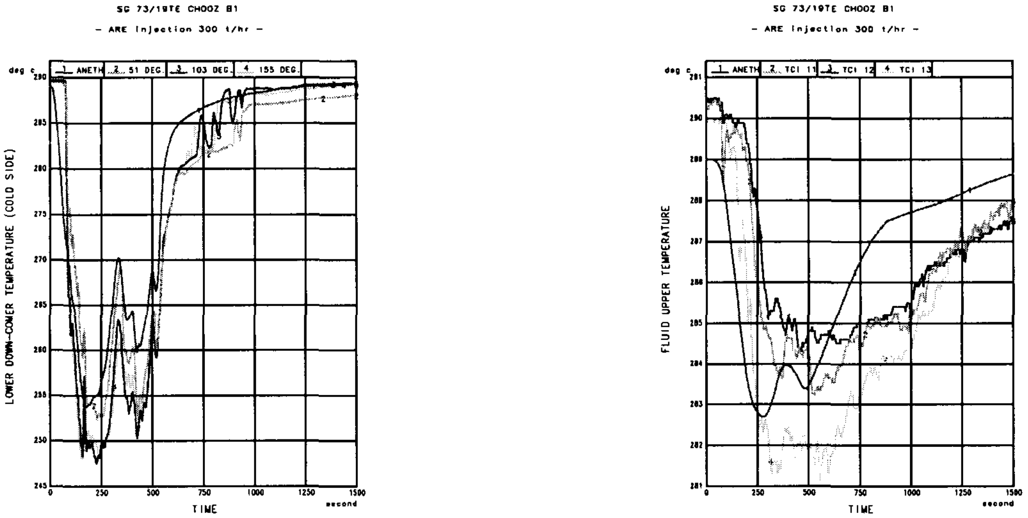


Figure 9c : lower down –comer temperature (cold side)

Figure 9d : fluid upper temperature

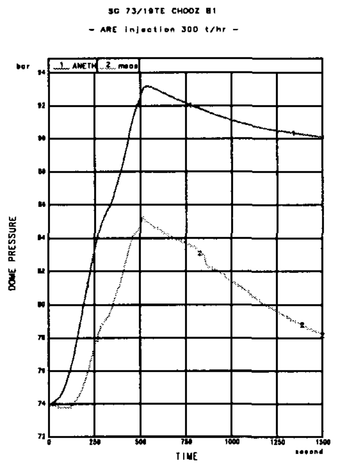


Figure 9e : dome pressure

Figure 9 : Chooz B1 – normal feed water injection at hot stand-by

5.3.2. Auxiliary feed water (ASG) injection (130 t/hr)

This transient consists in injecting auxiliary feed water at 35°C in the steam drum below the interface for 500 secs. The main results are shown in figures 10. Down-comer flow rates (fig. 10b- positive downwards) show a small recirculation loop with down-flow in the hot side down-comer. This phenomenon is similar to the *hot side reverse circulation* observed in the previous test, but as the flow is in the opposite direction, it can be called *cold side reverse circulation*. It is somewhat surprising that the whole auxiliary feed water goes down on the same side whereas the auxiliary feed ring is symmetrical, but this can be explained by the SG geometry (the cross-section of the down-comer annular part is 1.8 times larger on the hot than on the cold side). Moreover this reverse circulation is probably enhanced by the temperature difference between the hot and cold legs.

The bottom down-comer temperature drop (-30°C on the hot side – see fig. 10c) is correctly predicted. The temperature near the final weld (level 7b) drops by 30°C (see fig. 10d), but nevertheless, as in the previous test, the pressure increases (+6 bars – see fig. 10e). The heat transfer coefficient by direct condensation at the interface needed to fit the pressure rise was found to be much smaller than usually recommended in the literature [8].

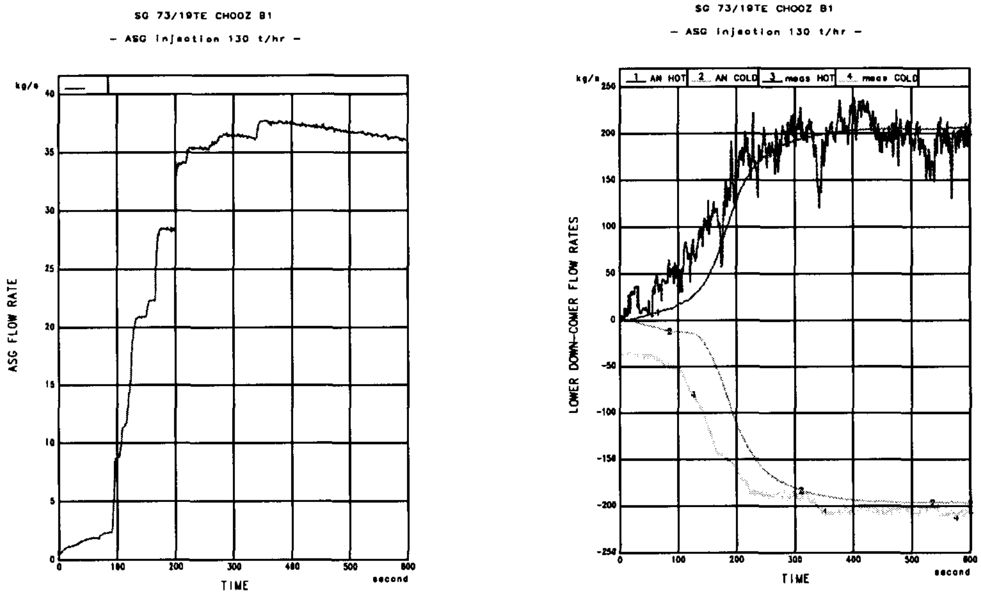


Figure 10a – feed flow rate

Figure 10b – down-comer flow rates

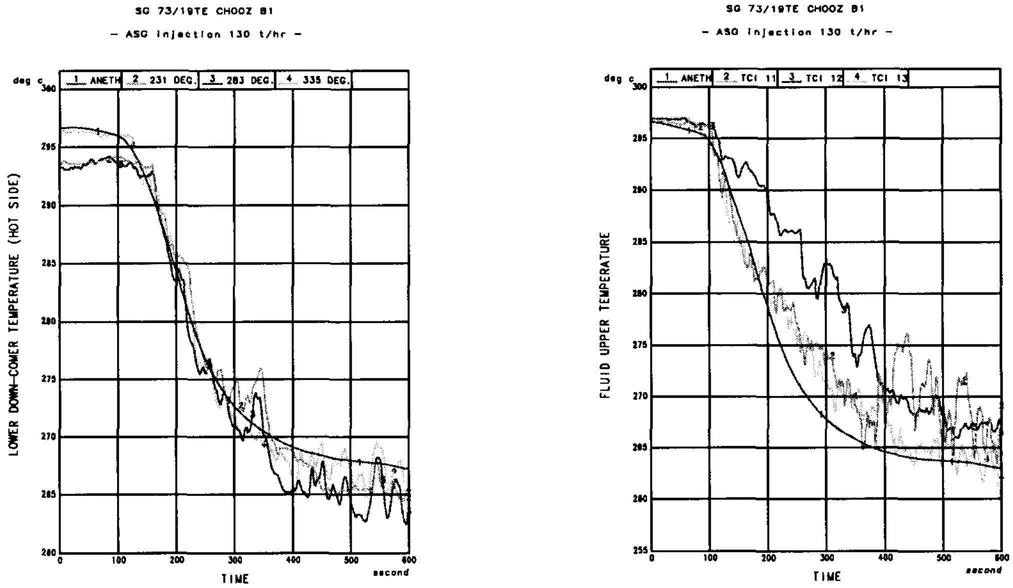


Figure 10c – lower down-comer temperature (hot side)

Figure 10d – fluid upper temperature

Figure 10 : Chooz B1 - auxiliary feed water injection at hot stand-by

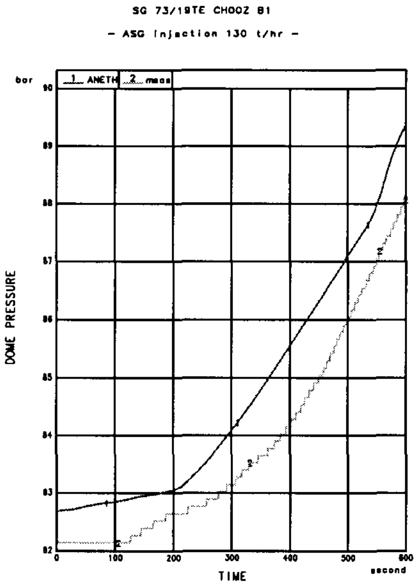
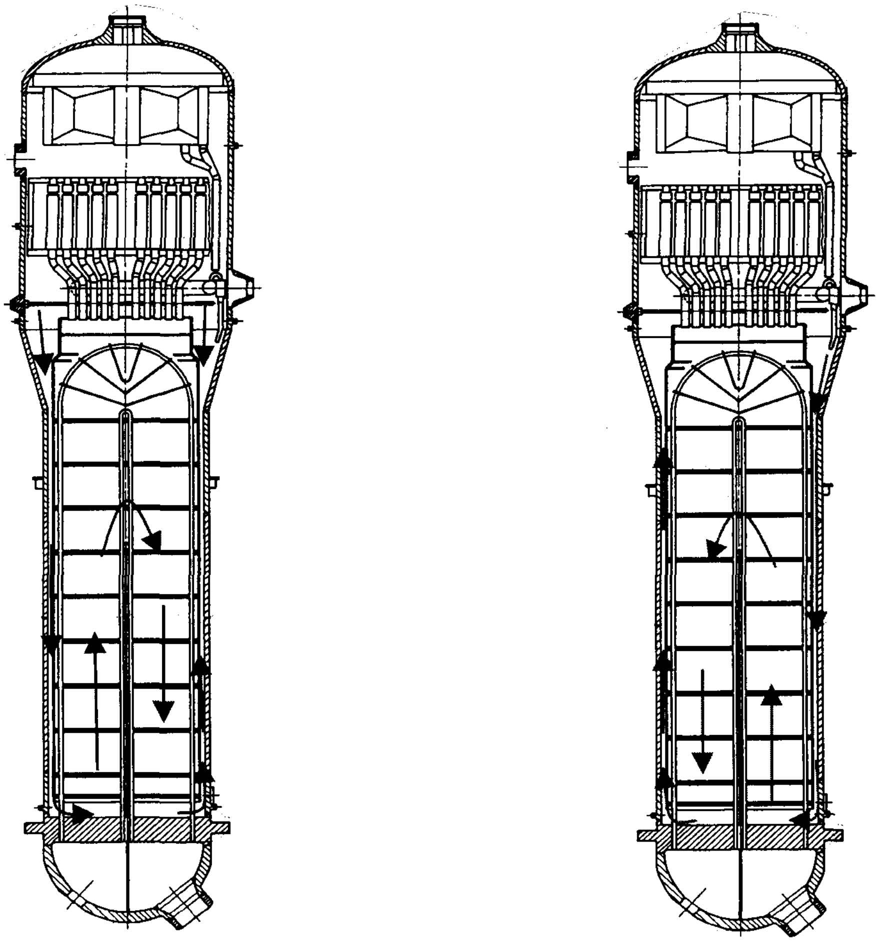


Figure 10 e – dome pressure

Figure 10 : Chooz B1 – auxiliary feed water injection at hot stand-by (end)

The preceding results demonstrate that the new options of the ANETH code (heat diffusion model, heat transfer across the bundle wrapper) are valid also for economiser SG's. This conclusion has been confirmed by analysis of the other test program transients: power step between 100 and 85% load, return to house load operation, reactor trip from 100% or 50% load, turbine trip.



Auxiliary feed water injection at hot stand-by

Normal feed water injection at hot stand-by

Figure 11 – Axial economiser SG : internal flows at very low power

6. CONCLUSION

The behaviour of recirculating SG's at very low power has been thoroughly investigated by laboratory and on-site tests as well as numerical simulations. A special experimental program dedicated to recirculation threshold determination was performed on the Freon mock-up CLOTAIRE representing the FRAMATOME 68/19 SG's:

- For normal operating conditions, recirculation starts around 2% load and is delayed when using colder feed water.
- Heat transfer across the bundle wrapper is of utmost importance in this load range: it heats the injected feed water within a very short distance and must be taken into account in computation codes to predict the recirculation onset and the thermal load on the pressure shell.

These laboratory data were completed with transients of feed-water injections at hot stand-by on two instrumented SG's: Tricastin 1 (boiler type) and Chooz B1 (economiser type).

The phenomena are different in boiler and economiser SG's.

- In boiler SG's, the SG behaves like a U-tube and recirculation stops around 2% load at stand-by temperature and water level.
- In economiser SG's, the presence of 2 separate down-comers and the divider plate inside the tube bundle allows a recirculation loop by-passing the separators. The mixing of saturated and cold water induced by this loop limits the down-comer cooling and thus alleviates the thermal load on the tube sheet.

These tests were used to validate the SG transient analysis 1D code ANETH. Correct temperature prediction requires the thermal mixing resulting from the instability of the cold layer of injected water to be modelled. In both SG types, the code results match well with the measured temperatures in the steam-drum, on the pressure shell external wall and inside the down-comer(s). Moreover, a pressure increase was observed during such transients when the steam flow rate is zero. It shows that steam condensation at the interface is very low when the feed-water is injected below the interface and that condensation on the steam dome wall may not be negligible in some cases. These results validate the use of the ANETH code to simulate very low power operation and supply thermal data for stress and fatigue analysis of the SG pressure vessel and internals.

REFERENCES

[1] A.Holcblat **Axial economizer steam generator transient simulation: the MEGEVE tests and their analysis by the computer code ANETH,** NURETH 6, October 5-8, 1993.

[2] J.C.Bouchter, J.L. Campan, P.Kalra, **Flow regimes and structure interactions within a large scale steam generator experiment: the CLOTAIRE experiment,** International Symposium on Gas-Liquid Two-Phase Flows, ASME Winter Annual Meeting, November 25-30,1990.

[3] J.L.Campan, J.M.Gouirand, **Steam Generator simulation test for thermohydraulic and flow induced vibration codes qualification: the CLOTAIRE program,** Steam generator and Heat Exchanger Conference, April 30-May1-2, 1990.

[4] F.Billon, J.David and H.Procaccia, **Severe transient tests on operating steam generator: analysis of the fluid-structure dynamic thermal interaction,** SMIRT 7, Chicago,1983.

[5] C.Cauquelin et G.Dague **Une nouvelle conception de générateur de vapeur à économiseur axial,** Revue Générale Nucléaire, année 1996, No 3, May-June.

[6] B.Bussy, G.Dague and G.Slama, **Starting up of new steam generator of N4 1450 MWe plants** Third Intern.Steam Generator and Heat Exchanger Conference, 1998, June 21-24, Toronto, Canada.

[7] K.Ohkawa and R.T.Lahey,Jr.,**The analysis of CCFL using drift-flux models,** Nuclear Engineering and Design 61 (1980), 245-255.

[8] P.Lightfoot, C.H.Green and B.Chojnowski, **A PWR steam generator for operational dynamics and control system studies (NUMAC-PWR),** European Two-Phase Flow Meeting, Brussels,1988.

ACKNOWLEDGMENTS

The author wishes to associate his colleagues of the SG department involved in the test analysis: G.Dague, N.Poudroux and G.Brunet. The CLOTAIRE tests presented in this paper were carried out at Cadarache by CEA-DRN in an R& D program supported by FRAMATOME, EDF (Electricité De France) and CEA (French Atomic Energy Commission). The Tricastin 1 and Chooz B1 tests were carried out by EDF and FRAMATOME. However, the analysis presented in this document was made by and commits only FRAMATOME.