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Seventeen years of transient monitoring experience in French PWR units

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ABSTRACT: Transient bookkeeping is the procedure implemented by ELECTRICITE DE FRANCE to meet the regulatory requirements (checking whether the design mechanical margins are respected under operating conditions). It enables damage due to main primary system equipment fatigue to be evaluated. The current procedure, by means of some provisions and precautions (complete transient file, qualified personnel) gives appreciable results that can be used for a variety of purposes (determining harmfulness, lifetime project). However, it is very restrictive and does not enable specific load areas to be followed up. The implementation of the SYSFAC process will remedy this disadvantage thanks to the use of fatigue measuring devices; it will also keep aclose check on the damage caused by main primary system fatigue in general.

1 - INTRODUCTION

ELECTRICITE DE FRANCE has implemented a procedure called "transient bookkeeping", ever since the startup of the pressurized water units. This procedure meets a regulatory requirement laid down by the decree of February 26, 1974 which determines the aims of regulatory steps during design, construction and operation phases.

After a rapid description of the procedure of transient bookkeeping which was already given during previous SMIRTS, we will present the principal experience feedback results of this activity.

2 - TRANSIENT BOOKKEEPING PROCEDURE

Transient bookkeeping ensures that, under operating conditions, the main primary system boiler is not subject to more severe or frequent stress than that provided for during the design phase. As mentioned in the introduction, it has been implemented by ELECTRICITE DE FRANCE to meet a regulatory requirement, but it also leads to a better knowledge of the real loads withstood by the main primary system boiler, as far as severity and frequency are concerned.

So, we have a data base containing more than 540 reactor-years (420 reactor-years for PWR 900 and 120 reactor-years for PWR 1300).

2.1 - Reminder of the principles and modalities of transient bookkeeping

It might be useful to briefly recall some elements which will enable to appreciate the bookkeeping contribution better as well as its limits:

- transient bookkeeping relies on the information collected by the unit's operating sensors: primary loop temperatures, primary and secondary pressure, auxiliary line temperatures, and in addition some logic signals (valve position ...); for a PWR 1300 MW unit, approximately 40 parameters are regularly observed. *No particular instrumentation* has been installed to check on an area nor particular local phenomena.

- from the above mentioned measurements, only the transients likely to increase considerably the usage factor of some points are detected. Therefore, thresholds of insensitivity to fatigue were calculated. These threshold values are low:

. primary circuit temperature	5° C/3 h
. primary pressure	10 b
. secondary pressure	5 b
. auxiliary circuit temperature	between 20° C/h and 40° C/h

It a worth noting these thresholds have been calculated very conservatively. The calculations being carried out currently within the framework of the SYSFAC process development show that for transients equivalent to the detection threshold, the calculated stress variations are far below the endurance limit for the most heavily loaded areas of the main primary system boiler.

- when a transient is detected, the operator takes the design Transient File to find "an envelope transient", i.e. a transient at least as severe in terms of its contribution to fatigue. It may be a transient of the same functional nature or not. In general, the operator looks for a transient of the same functional nature and then he checks the "envelope" character by comparing the amplitudes and variation speeds of the various parameters. Should this approach fail, he will have to assimilate the transient to a transient without any functional connection, provided that this transient evolved more severely.

Consequently, for example, at the end of the unit startup tests, power variations are sometimes already accounted for or safety injection type transients are accounted for without safety injection having taken place.

Currently, the transients are counted according to their origin (pressure evolution, temperatures), but not according to their consequences on the equipment (stress, fatigue damage).

In the design transient file, each transient is affected to a number of occurrences (estimated over 40 years of operation) as used for the design studies. We make sure that these figures have not been reached by adding all the transients which have occurred.

2.2 - Implementation of the procedure of transient bookkeeping

The doctrine of transient bookkeeping is under the responsibility of the ELECTRICITE DE FRANCE's centralizing maintenance management department, for Nuclear Power Plants. The procedure is defined by this department, then it is distributed to the various plants by an application note.

At present, transient bookkeeping is carried out on the sites by the Technical Department operators. The personnel assigned to this activity varies depending on the sites. It varies from 1 person to 2 persons for two nuclear plant units.

In Technical Divisions at least 5 people are capable of dealing with transient accountancy. The job is carried out, in rotation, on all plant units; the average time taken in one year.

Twice a year, a balance sheet of the transient consumption is sent to the deparment in charge which draws up a global balance sheet with the help of a national data base. The updated global balance sheet is then transmitted to the N.P.P.

Training sessions for transient bookkeeping have been organized since 1990. More than 200 people have been trained for transient bookkeeping (in Nuclear Power Plants, transient bookkeeping represents work for 40 EDF staff).

2.3 - Evolution of the transient bookkeeping practices in the plants

During the first 10 years of plant unit operation, the people in charge of this activity were mainly working on counting transients. Transient analysis (origin, reason for being) was rarely carried out. The procedure is now easier to apply and better mastered than at the beginning of plant unit operation, thus making it possible to spend more time analysing the transients and, in some cases, it has been possible to reduce transient consumptions, following procedure modifications.

The control personnel is increasingly involved in this activity. In some plants, "transient bookkeeping" is carried out by the Control Department, thus enabling transient "authors" to be more directly informed and improving awareness. Depending on the operating program, some plants have defined the transient consumption not to be exceeded. During the last few years, "Engineering" Departments have been set up in the plants. These Departments also contribute to the analysis of the transient situations kept in the books.

For several years, the control personnel has been growing more aware of the transient bookkeeping and the benefits appear in the consumption reduction of so-called transients "sensitive" (see Figure 1).

3 - EXPERIENCE FEEDBACK

3.1 - Transient file

At the design phase, according to the decree of February 26, 1974, the constructor defines the various demands that the plant series' boiler should be subjected to main primary system under normal or accidental operating conditions. From that file, he analyses plant series behaviour in relation to the various damage which might be initiated by the demands concerned.

Transient bookkeeping makes it possible to check whether the scenarios thus defined have been respected. If it is not the case, the operator can have the Transient File modified, but the behaviour analysis shall then be reconsidered as required by the decree of February 26, 1974.

Since plant unit startup, we have had to modify the transient files several times and thus to review the behaviour analysis.

In 1991, we reconsidered the transient file of PWR 1300 MWe plant units for the first time. At that date, for a total of 70 reactor-years, nearly 1,000 transients detected on the sites did not correspond to the descriptions in the transient file. This was essentially due to changes in operating conditions:

- decrease in the average operating temperature
- the design not having taken into account prolonged operating cycles.

The analysis of the various unclassified transients enabled us to define the design transients to be modified and those to be created.

These modifications were defined with the aim .of reaching a relatively fine breakdown of design transients, so as to follow up fatigue damage as closely as possible.

EXAMPLE: Charging line transient

Scenario A	Scenario B
12,000 occurrences with $\Delta t = 70°$ C	12,000 occurrences with $\Delta t = 70°$ C
1,000 occurrences with $\Delta t = 100°$ C	1,100 occurrences with $\Delta t = 140°$ C
100 occurrences with $\Delta t = 140°$ C	

Scenario A is preferred to scenario B as it allows for more precise accounting. So, the initial list of transients used in transient bookkeeping included 50 transients. The revised list includes nearly 100 transients (2nd category transients).

As a result of this complete overhaul of the transient file we had to reconsider the affectations previously carried out, and which represented a significant volume of work. In fact, between 300 and 400 transients are accounted for every year on each plant unit.

So, after this complete revision of transient bookkeeping on the PWR 1300 plant units, we have a reliable and homogenous data base.

Contrary to what might have been feared, the modifications and creations of new transients did not result in too significant an increase in the usage factor values for those plant series areas most frequently in demand.

The difficulty in defining these modifications lies in the fact that we have to find a compromise to meet transient consumption without increasing equipment usage factors too much. When the transient file of PWR 1300 unit was revised, we were able to take advantage of the improved calculation methods, which attenuated usage factor increases; in some cases it was possible to reduce the values.

EXAMPLE

Equipment	Area	Initial usage factor	Revised usage factor
Vessel	Inlet nozzle	.59	.046
Pressurizer	Surge nozzle	.93	.38
	NSSS weld connections	.59	.92
RCV charging line (PQY)	"Pipe 3" valve junction	.94	.74

The modifications to the PWR 1300 plant unit transient file have been incorporated into the PWR 1400 file. The first plant unit (CHOOZ B1) startup tests on this new plant series have now been completed. During testing, comprehensive accounting enabled some 400 transients to be detected for fewer than 40 unclassified transients. This ratio is low when the many atypical transients created during the startup tests are taken into account.

Since the PWR 900 plant unit startups, the corresponding transient file has been revised several times; the revisions were carried out in order to create the fewest possible consequences (reaffectations, ...). Therefore, transient bookkeeping is not homogenous from the beginning of the nuclear plant units. The latest revision was made in 1987, and a new revision is now necessary. We are at present studying the required modifications.

3.2 - Transient consumption

3.2.1 - 900 MWe plant series

As a whole, real transient consumption is lower than theoretical consumption. However, for some transients the following difficulties have been noted:

- boiler heating up - cooling down
- main primary system temperature variations in intermediate state
- cold pressure build-up
- temperature variation on the charging line
- auxiliary spraying

The difficulties encountered are described below:

Reactor heatup and cooldown: the current transient file only comprises complete heatups and cooldowns (from cold shutdown to hot shutdown or reciprocally, $\Delta t = 270$ °C). It turns out that for various operating reasons these heatups and cooldowns can be partial, e.g. the reactor can go from hot shutdown to intermediate shutdown state and then back to hot shutdown. At present, these back and forth movements are accounted for as complete heatups and cooldowns. This is a very conservative approach. It results in a "unreal" over-consumption of the complete heatup-cooldown transients.

Through this example, it is obvious that it is worth having a detailed transient file. It should be noted that in many main primary system areas, the complete heatups and cooldowns are the most significant for wear factor values.

Main primary system temperature variation in the intermediate states: in intermediate boiler states, the transients with high temperature variation speeds (> 100° C/h) are detected. Taking into account our method of transient bookkeeping and the current file, these transients cannot be classified. They constitute the great majority of unclassified transients detected today. They are mainly due to primary pump startups or shutdowns.

Therefore, we are considering creating shock-type transients in the transient file. But above all, in cooperation with the unit control personnel, we are trying to find solutions to avoid creating these transients.

Auxiliary spraying: bookkeeping has made it possible to detect very serious transients not provided for at the design phase and which the pressurizer spraying pipe is subjected to. In fact, periodic tests were set up to check valve RCV 227 VP operability at hot shutdown. When this valve opens, a cold water plug is projected towards the spraying pipe whose temperature is around 340° C. The frequency of this type of tests was every 1 to 3 years, depending on the plant unit.

At the design phase, this type of transient is considered to occur very rarely and is "limited" to incidental transients.

The criterion of progressive deformation risk is not respected for such a transient in association with a Safe Shutdown Earthquake. The above-mentionned test was therefore modified, and we are now reviewing the analysis of the spraying pipe behaviour. In order to obtain margins, we optimize the design transients which are much more severe than the real transients. Indeed, when designing we assume that the spraying pipe is subjected to the passage of the cold water plug at 20° C. On-site measurements carried show that this "cold water" plug's temperature is about 100° C.

This example shows that the design transient characteristics are more severe than those of the transients noted under operating conditions (of course, when the functional hypotheses are identical).

Temperature variations on the RCV charging line: at the beginning of the PWR plant unit operation, more transients than forecast were detected on the charging line.

Various material steps were taken in order to reduce this phenomenon (modification of the pressurizer level regulation), but above all the checking staff were sensitized to this approach and a decrease in such transients has been observed the last few years.

In Figure 2, we can observe that the lastest nuclear plant units commissioned (CRUAS 3-4, CHINON B3-B4) benefited from the experience feedback and their transient consumptions are lower than those of the older sections and conform to the forecasts.

Difficulties in counting some transients have been encountered, due to an unload isolation. Design phase isolation time is given at less then 5 mn. In fact the quicker the line can pass from unload to reload, the fewer transients will be generated: cooling will be compensated for by quick reheating. The inverse is, of course, also true.

This problem is encountered (due to current transient bookkeeping methods) for the design transients which comprise a series which is very limited in time (see Figure 3).

Cold pressure build-up at the calculated pressure: for this transient a significant consumption is noted (higher than the forecasts). This is due to the fact that the transient file does not include pressure build-ups for values lower than the calculation pressure. Therefore, the pressure build-up calculation transients are excessively accounted for. Once more we note that it is worth having a sufficiently complete range of design transients.

3.2.2 - 1300 MWe series

The 1300 MWe plants are at present completing the revision of transient bookkeeping using the new transient file.

In general, transient consumption is conform to the forecasts. However, for two types of transients, the consumption is slightly higher than the forecasts. They are:

- rapid temperature variations on the main primary circuit in the intermediate reactor states
- passage to zero flow on loading and unloading.

We must continue to analyse the above-mentionned transients in order to reduce their consumption and we must be very careful during operating manoevering. Within this framework, a particular test has recently been singed out: it resulted in the unload-load having a null output. This yearly test has been modified in order not to create such a transient in future.

3.2.3 - Unclassified Transients

The unclassified transient balance sheet is at present as follows:

Series	Unclassified Transients	Counted Transients
900	> 2,500	125,000
1,300	< 100	35,000

The unclassified transient ratio, registered for plant series 900 is higher than that of plant series 1300. As previously seen, this is due to the fact that the PWR 900 transient file is not as complete as that for plant series 1300. After revision, these ratios should be similar.

Whatever the number and frequency of the transient file modifications, a limited number of transients will not be able to be classified using current procedure. In fact, in the transient file, each transient is considered independent (the plant unit is in a steady state at the beginning and end of the transient). During some phases of operation, transients happen one after another and cannot be independently counted: the analysis must then concern all the transients.

EXAMPLE

During PENLY 1 unit hot tests (without fuel), the external power supplies were lost. The main primary system cooling was carried out without the primary pumps. The main primary system was affected by many temperature variations. More than 100 transients were detected in 4 days on the hot loops ($10° < \Delta t < 80°$). The operator had to use auxiliary spraying repeatedly to carry out the cooling.

It was impossible to count all these transients using the normal procedure. A mechanical analysis was carried out in order to determine the impact of these transients on the various main primary system areas, in terms of usage factor.

The experience feedback shows that design transients generally include real transients, and are sometimes too severe. Inversely, when the hypotheses used to define these transients in the design phase are not reproduced under operating conditions, the real transients are rarely covered by the design transients.

EXAMPLE

For PWR 1300 plant units, in case of sudden cooling (Automatic Boration Function), a volume of water with a high sludge content is injected into the main primary system. The transient file includes this transient with the reactor at nominal power as the initial state.

When this injection of cold water takes place at low power, or during hot shutdown, the amount of available heat in the main primary system is much lower than that available when the reactor is powered, thus resulting in greater cooling than that taken into account by the design.

In Figure 4, we can see that the differences between the cooling taken into account during the design phase and that recorded on CATTENOM unit 2 following an Automatic Boration at hot shutdown.

It will be impossible to account for the latter in the corresponding design transient, as the real temperature variation (cold loop) is much higher than the one allowed for during the design phase (51° C / 15° C).

In general, the incidental transient characteristics allowed for during the design phase for a powered reactor are different for these same transients under operating conditions for a reactor at low power (or hot shutdown). The latter will not be able to be counted using the normal procedure.

4 - THE ADVANTAGES TRANSIENT BOOKKEEPING FOR EDF

The transient bookkeeping which was originally considered as a compulsory constraint, increasingly appears to be a precious tool in understanding the plant units; the older the units are, the more precious it becomes !

The results of the transient bookkeeping are used by EDF on various occasions. The principal utilisations are listed below:

- when designing the 1400 MW series, we used the experience feedback from the transient bookkeeping for PWR 1300 units to define the 1400 MW series transient file. The latest modifications to the PWR 1300 transient file were incorporated. So, when testing the first unit startup of the 1400 MW series (CHOOZ B1), it was possible to count the transients detected.

- transient bookkeeping enables design situations to be adapted as closely as possible to operating transients. Thus it enables operating mode changes to be taken into account. In this way, we have been able to determine the consequences due to the load follow-up on the main primary system damage. They are very weak.

- bookkeeping makes it possible to detect the transients not accounted for during the design phase and given rise to during unit operation. After analysing these transients, the operating procedures can be modified should they penalize the equipment (cf par. 221).

- anomalies are sometimes detected during in-service inspections carried out on the main primary system equipment. These anomalies can be inherent, or they can have originated from the demands the equipment has been subjected to.

So, the operator has a choice:

- either to eliminate the anomaly (by scouring out in case of a crack)
- or to leave the anomaly as it is, provided that it is shown that it does not effect the mechanical resistance of the equipment.

In the second case, the behaviour of the anomaly has to be studied and the results of the transient bookkeeping are then used to take into account the real transient figures endured by the equipment concerned.

Currently, within the framework of the behaviour of the main primary system moulded components, an inventory of the cold water injections into the primary circuit is carried out in order to reduce occurrences due to design and the resulting temperature variations, if possible. The various files drawn up by the transient bookkeeping are used to do this.

- However, it is above all within the framework of the lifetime extension project that bookkeeping becomes the most worthwhile. If after 40 years, as it can at present be expected, it appears that only part of the potential lifetime fatigue has been consumed (and depending on specific studies relative to other types of damage: corrosion, erosion), we will be able to show that it is possible to operate the reactor over a longer period.

5 - FATIGUE MEASURING DEVICE OPERATING RESULTS

5.1 - Reminder

Transient bookkeeping as currently carried out by EDF makes it possible to count the overall transients of the Principal Primary Circuit and to determine the corresponding fatigue damage.

This method which generally meets the regulatory requirements, is very conservative and does enable observation of the main primary circuit areas subjected to particular transients due partly to localised thermo-hydraulic phenomena. To solve this problem, the Research & Study Branch has developed an algorithm (fatigue measuring device) which enables the stress undergone by the primary circuit to be calculated in real time.

The principal steps are:

- acquisition of the required operating parameters
- determination of the localised temperature and pressure variations based on thermo-hydraulical modules
- stress calculation in real time
- periodical calculation of usage factor.

5.2 - Operation of the prototype fatigue measuring devices [ref. (1)]

A prototype fatigue measuring device was installed on the charging line nozzle at BUGEY 2 in 1985. Up to 1989 its operation shows that the manual transient bookkeeping concerning this area is very conservative compared to the real fatigue damage suffered by it.

A prototype fatigue measuring device was installed in 1988 on DAMPIERRE plant unit 1.

It operated from February 1988 to July 1992. The operating profile of DAMPIERRE unit 1 was similar to that of the other units of the 900 MWe series during that period.

The principal operating results are as follows:

Charging line nozzle

- nozzle welding: the stress calculated from the loads suffered under operating conditions are lower than the endurance limit
- sleeve welding: by extending the 27 months studied over a period of 40 years, the initiation factor is lower than 0.1. It is close to 1 for the design phase.

Surge line

The amplitudes of temperature variation and occurrences of the transients detected under operating conditions are much lower than those for the design phase. We have modified the operating procedure: 2 groups of heating elements operate continuously, so, the thermal conditions are better.

The fatigue measuring device enables us to point out benefits of these modifications.

By extending the initation factor of the surge pipe sleeve weld over 40 years, a value of 0.03 is obtained while at the design phase it is between 4 - 8.

RRA injection nozzles

The stress does not generate any damage. All the cycles are lower than the endurance limit. When starting up the RRA, the cold shock is immediately followed by an inverse hot shock which blocks stress evolution. This shows that it is worth calculating the real stress in order to make a very accurate affectation for the mechanical criteria (as opposed to an affectation depending on pressure and temperature variations), or to calculate a wear factor.

Conclusion

The fatigue measuring device operating on DAMPIERRE 1 highlighted the following points:

- a low level of damage for each area studied, compared to the design studies. This was due to far less stress-severe transients than the ones provided for during the design phase
- the important role of the cooling phases for the reactor heating and of emergency shutdowns in case of expansion line damage.

6 - THE SYSFAC PROCESS

This process has already been presented (SMIRT 11 and 12). Here we will present the progress of its development after a brief reminder of its principles *[ref. (2)]*.

6.2 - Reminders

The SYSFAC process will carry out transient bookkeeping automatically on the sole basis of information provided by the standard operating sensors. It consists of four modules which are:

- The functional affectation modulus

Based on the events which have occurred on the plant unit, this modulus counts the operating transients recording to their functional origin. It will enable the plant's operating history to be traced.

- The mechanical affectation modulus

This modulus calculates the stress variations which the main primary circuit equipment is subjected to. Then it affects the transients by comparing operating fatigue damage to the design phase fatigue damage on carefully selected areas of the main primary circuit. This is the principal SYSFAC modulus. Its results will be used to fulfil the regulatory requirements.

- The fatigue measuring devices

The SYSFAC process will include fatigue measuring devices in order to be able to follow up the fatigue damage to the so-called sensitive areas, which are specifically loaded. The equipment observed is the following:

. charging line
. surge line
. RRA discharge
. Steam generator ARE pipe

- Damage balance-sheet modulus

For different main primary circuit areas, it enables fatigue damage to be calculated on the basis of the transients counted by the mechanical affectation modulus.

6.3 - Update of the SYSFAC process development

During the last 18 months, the constructor selected has drawn up the specification file from the specifications written by EDF.

We developed two mock-ups:

- TNC: used to validate the algorithm of mechanical affectation

In this algorithm the difficulty is to define the right criteria to compare the design phase damage with the damage observed under operating conditions. This mock-up will later be used to affect the unclassified transients.

- EQUATEUR: used to validate the functional affectation modulus

Sets of real data (coming from the plant unit calculator) will be used to feed these mock-ups.

In Figure 6 the computer configuration selected for SYSFAC is shown. The SYSFAC process requires one computer (work station type) by site. Various stations (max. 4) will be connected to the SYSFAC computer. From these stations, the bookkeeping proposed by SYSFAC will be validated (or invalidated if necessary). The SYSFAC process will enable us to edit the various regulatory files. All the data required for the calculations will be filed during unit operating time.

At present, the constructor is building the prototype which will be tested on a computer platform in December 1995 and will be installed on a site in January 1996.

CONCLUSION

Transient bookkeeping is an important tool in evaluating reactor safety level. It makes it possible to evaluate the potential life span consumed and its results will be increasingly appreciated.

The procedure set up by EDF from the unit startup gives a good global estimation of the fatigue damage plant units are subjected to. The installation of the SYSFAC process will make it possible to improve our knowledge and to understand better the damage to the sensitive areas with specific loads.

The SYSFAC process results will be very precious when determining and defining in-service inspection programs; they will make it possible to determine margins composed to the present procedure which is very conservative.

REFERENCES

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Results of 42 months of operation
(February 1988/July 1992)
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2 - New Development in French transient monitoring system: SYSFAC
SMIRT 12
(J. BALLEY, D. BERTAGNOLIO, F. KAPPLER, I. FOURNIER, Y. L'HUBY and C. FAIDY)
ELECTRICITE DE FRANCE

EVOLUTION OF THE SITUATION CONSUMPTION
UNLOADING ISOLATION

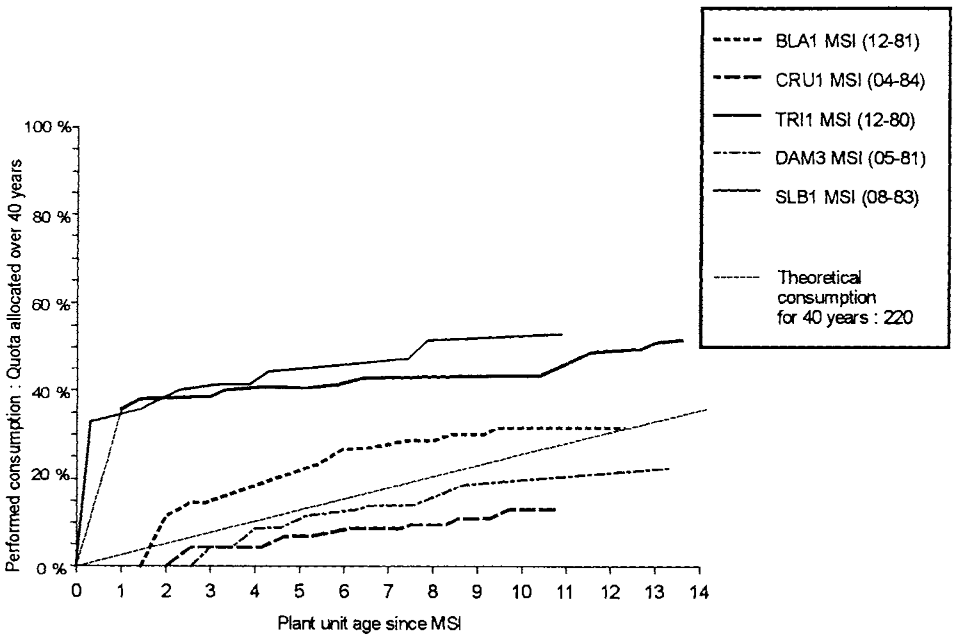
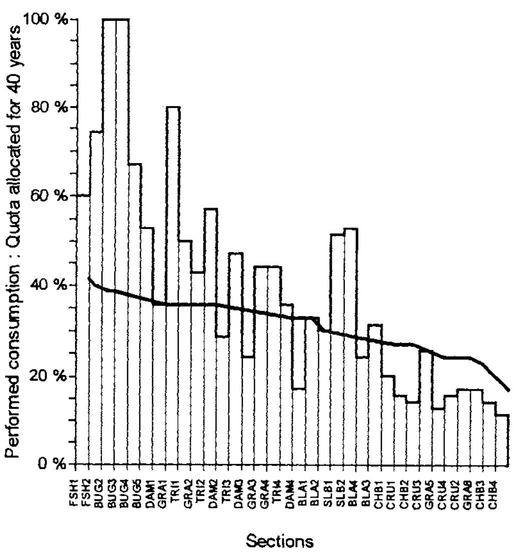


Figure 1



Quota allocated for 40 years : 220
More consuming sections

Plant unit réf.	Age ☐ (%)	Cumulated consumption	Consumption Fraction %	Consumption /age
BUG2	39	* 220	100,00	2.53
BUG3	39	* 220	100,00	2.53
GRA1	35	* 175	79,00	2.24
SLB2	28	* 117	53,00	1.87
SLB1	28	* 115	52,00	1.83
FSH2	41	* 163	74,00	1.77
BUG4	38	* 148	67,00	1.73
TRI2	35	* 124	56,00	1.60
TRI1	35	* 112	50,00	1.42
FSH1	42	* 133	60,00	1.41
BUG5	37	* 117	53,00	1.42
TRI3	33	* 104	47,00	1.38
GRA4	32	* 98	44,00	1.33
GRA3	33	* 98	44,00	1.30
GRA2	35	* 93	42,00	1.20

☐ : Relative age, since MSI, compared to the design lifetime (40 years)

* : Consumption higher than the design hypotheses

Figure 2

RCV CHARGING LINE NOZZLE : (singular zone)

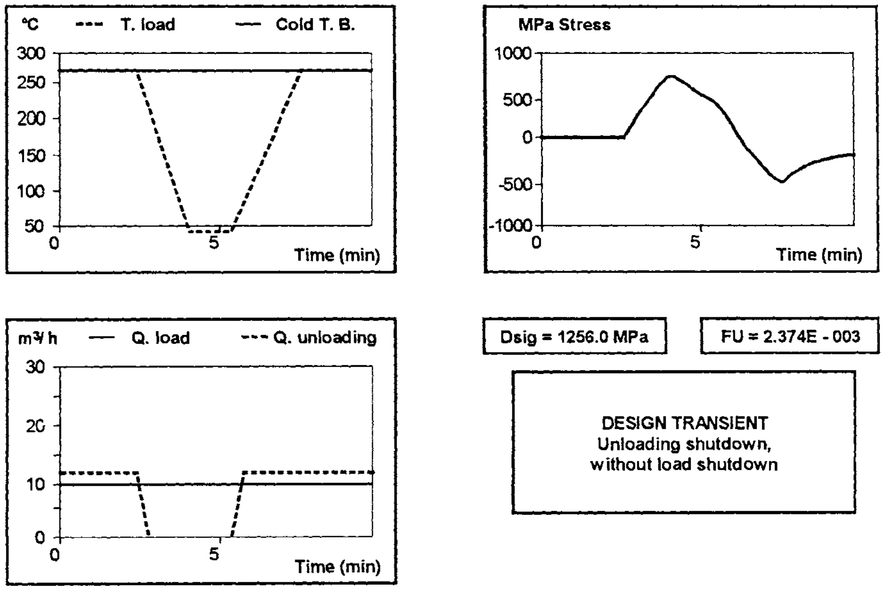


Figure 3

COMPARISON DESIGN TRANSIENTS / REAL TRANSIENTS
UNSCHEDULED COMMISSIONING OF THE AUTOMATIC
BORATION FUNCTION

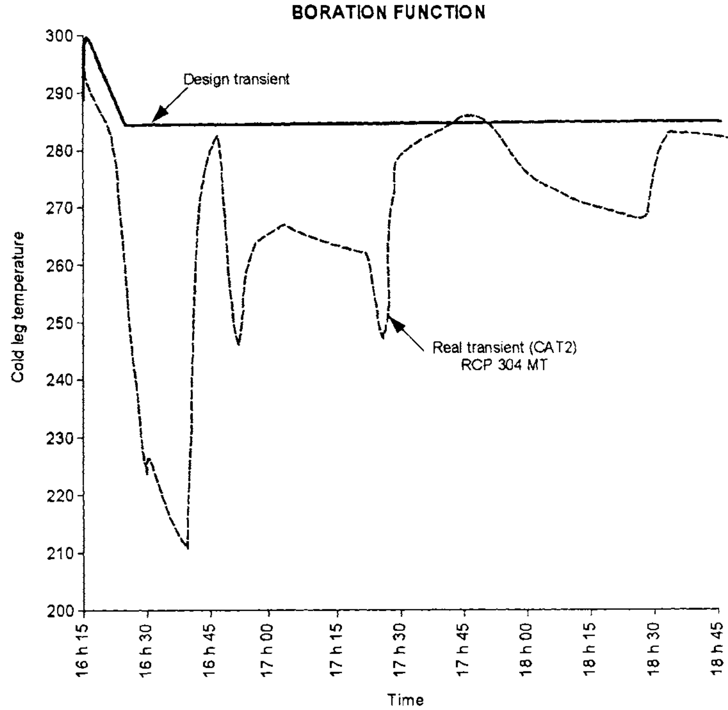


Figure 4