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MEMORANDUM FOR: Distribution

FROM: Moni Dey, Senior Task Manager
Engineering Issues Branch
Division of Safety Issue Resolution
Office of Nuclear Regulatory Research

SUBJECT: TRIP REPORT FOR MEETINGS WITH ELECTRICITE DE FRANCE, AND NUCLEAR INDUSTRY REPRESENTATIVES IN BELGIUM TO DISCUSS APPROACHES TO CONTAINMENT TESTING

The purpose of the meetings was to obtain design and implementation information of an On-Line Containment Integrity Monitoring System, and the rationale for changes in approaches to containment testing in France and Belgium. The information obtained at these meetings is being used towards formulating options for the Performance-Based Containment Testing Regulation being developed in the "Marginal to Safety" program.

Meeting with Electricite de France (EDF)

I met with representatives and technical specialists of EDF in their offices in Chatou, France on October 18, 1993. A list of attendees is enclosed. Representatives of the French regulatory authority were not available for the meeting due to unforeseen conflicts with other meetings.

EDF provided a comprehensive presentation of their approaches to containment testing, particularly for On-Line Containment Leakage Monitoring (see Enclosure A through D). Highlights of their presentation and discussions are provided below:

- EDF has always conducted a "Type A" integral containment test once every ten years compared to the current practice per Appendix J of 10 CFR Part 50 of three times every ten years. Their basis for the interval is that the "Type A" test is mainly useful for testing the containment structural integrity, and ten years is an appropriate interval since the structure is not expected to degrade in that time frame.

- In 1985, EDF initiated installation of a system for Continuous Monitoring of Containment Leaktightness (the Sexten System, see Enclosure A through D) in all their 900 MW and 1300 MW PWR plants. The on-line monitoring system measures the flow of air into the containment atmosphere from leakages of the compressed air system, temperature and humidity in the containment building, and calculates the leakage rate. The system is claimed to be capable of measuring leakages of about 0.1 to 0.4 percent volume per day (equivalent to a hole of about 1/2 in. in diameter). The system is aimed at monitoring leaktightness of the containment in a operational configuration, and was installed to allow longer time intervals for purging containment atmosphere during operations.

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- o EDF has had successful experience with the Sexten System. The system has detected small (less than 1% volume per day) leaks over the years, mostly in systems that are open during operation and would be isolated in accident conditions. The system has not detected any significant gross leaks during operations since it has been installed in all PWRs. The French nuclear regulatory authority (DSIN) has been requested to provide additional information regarding events detected by the Sexten system.

- o Other details regarding the design, operation and costs of the Sexten system were provided by EdF and have been documented in draft NUREG-1493, "Performance-Based Containment Leak Test Program."

Meeting with Representatives from the Nuclear Industry and Regulatory Authority in Belgium

On October 21, 1993, I met with representatives from the electric utility, architect engineer, vendor, nuclear research centre, and regulatory authority in Brussels, Belgium. A list of attendees is enclosed. AIB-Vincotte, the authorized Belgian Nuclear Inspection and Licensing Body presented the Belgian position/approach to Containment Leakage Testing (Enclosures E and F) which were developed based on a combined industry and regulatory authority Working Group on Containment Leakage Testing. (Enclosure G). Laborelec, the vendor of the Belgian on-line containment integrated leakage rate testing system (Enclosure I) presented details of the design and operation of its system. Highlights of their presentations and discussions that followed are summarized below:

- o In 1986, the "Type A" integrated leak rate test interval was modified from three time every ten years (based on NRC regs.) to once every ten years. The modification was implemented to decrease the risk of fires and potential equipment damage during high pressure tests, and also because it was concluded that the Pa pressure for the tests was overly conservative and not representative of the real pressure in the containment during accident conditions. Also, no degradation of the containment structure has thus been observed or is expected. The containment is tested every ten years to check for unforeseen degradation mechanisms.

- o The one in ten years "Type A" test includes a program for visual inspection of growth in cracks and deformation of the concrete in the containment structure. Stresses in containment tendons are also monitored during this inspection program.

- o An on-line containment leakage monitoring test has been implemented in Belgian nuclear plants (all PWRs) since 1986. This test is conducted at power after a cold shutdown more than fifteen days, and in principle is the same as the French Sexten system, except it is not conducted continuously. These tests during operation can detect a leak of 1 cm in diameter. About twenty tests have been conducted thus far and have not detected any breaches of containment.

Other more detailed information regarding Belgian approaches and practices regarding containment testing that were provided during the meeting are included in draft NUREG-1493, "Performance-Based Containment Leak Test Program.

ORIGINAL SIGNED BY

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Engineering Issues Branch
Division of Safety Issue Resolution
Office of Nuclear Regulatory Research

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ENCLOSURE A

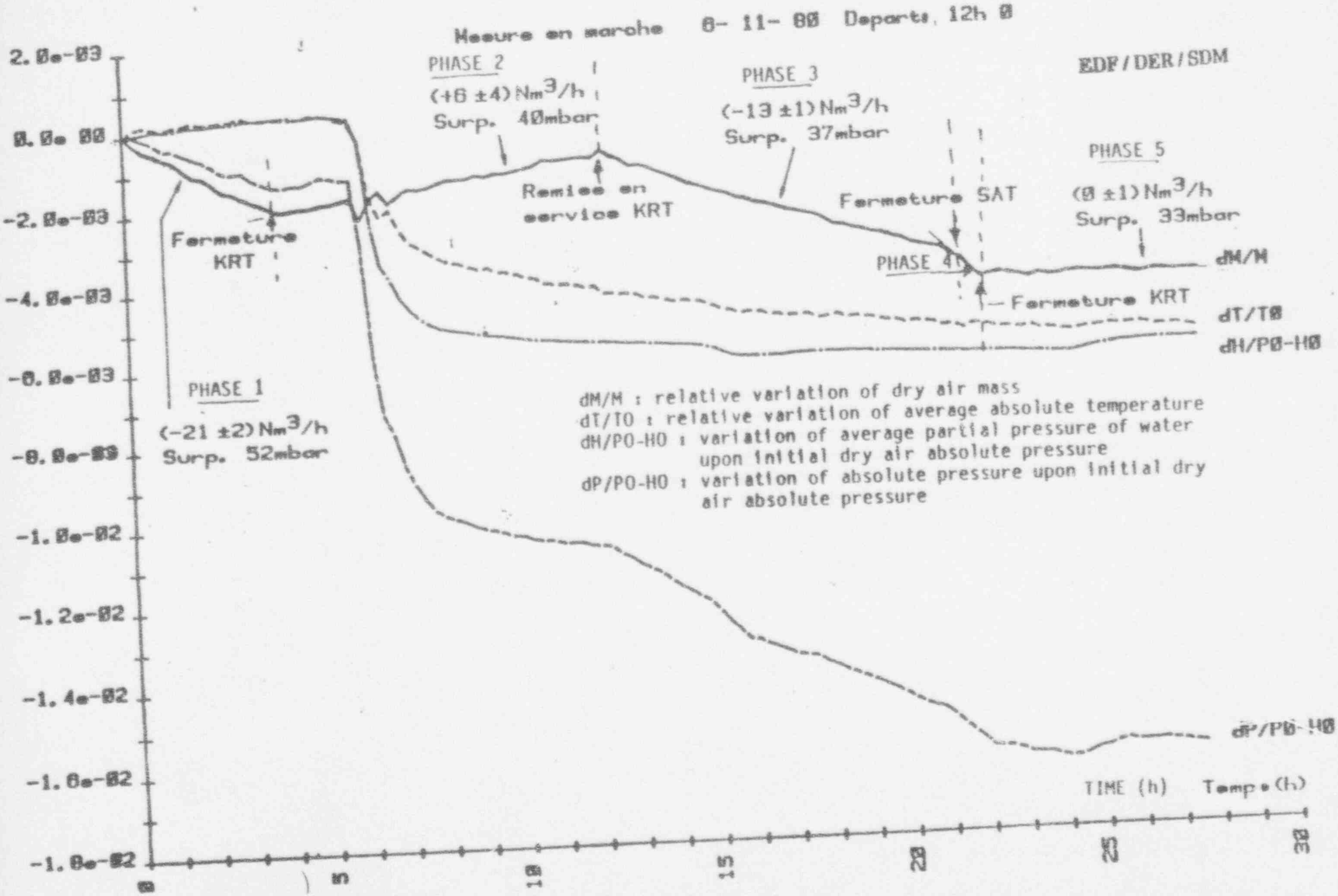
CONTINUOUS MONITORING
OF CONTAINMENT LEAKTIGHTNESS

THE SEXTEN SYSTEM

HISTORY

1979	containment leaktightness problems in operation
1980	first test in operation
1981	continuous monitoring of a plant, during one year, with an experimental system
1983	definition of the industrial system (900 MW plants), called SEXTEN evaluation in six units
1985	start of installation in every 900 MW plants
1986	definition of SEXTEN system for 1300 MW units. Start of installation.
1990	start of SEXTEN 2 studies
1992	SEXTEN 1 installed at RINGHALS 3/4
1993	SEXTEN 1 sold for RINGHALS 2 SEXTEN 2 prototype installed in 2 units in France

FIGURE 1



Mesure en marche 6- 11- 80 Depart: 12h 0
EDF/DER/SDM
PHASE 1
(-21 ±2) Nm3/h
Surp. 52mbar
PHASE 2
(+6 ±4) Nm3/h
Surp. 40mbar
PHASE 3
(-13 ±1) Nm3/h
Surp. 37mbar
PHASE 4
PHASE 5
(0 ±1) Nm3/h
Surp. 33mbar
Fermeture KRT
Remise en service KRT
Fermeture SAT
Fermeture KRT
dM/M
dT/T0
dH/P0-H0
dP/P0-H0
dM/M : relative variation of dry air mass
dT/TO : relative variation of average absolute temperature
dH/PO-HO : variation of average partial pressure of water upon initial dry air absolute pressure
dP/PO-HO : variation of absolute pressure upon initial dry air absolute pressure
TIME (h) Temps (h)
2.0e-03
0.0e 00
-2.0e-03
-4.0e-03
-6.0e-03
-8.0e-03
-1.0e-02
-1.2e-02
-1.4e-02
-1.6e-02
-1.8e-02
0
5
10
15
20
25
30

DIFFERENT VERSIONS OF SEXTEN SYSTEM

SEXTEN 1 :

realised in 1983
installed in all French units
hardware now obsolete

SEXTEN 1 for Ringhals

realised in 1992
modern harware (same as SEXTEN 2)
adaptation of SEXTEN 1 software

SEXTEN 2

prototype realised in 1993
under evaluation for one year
new software

PRELIMINARIES

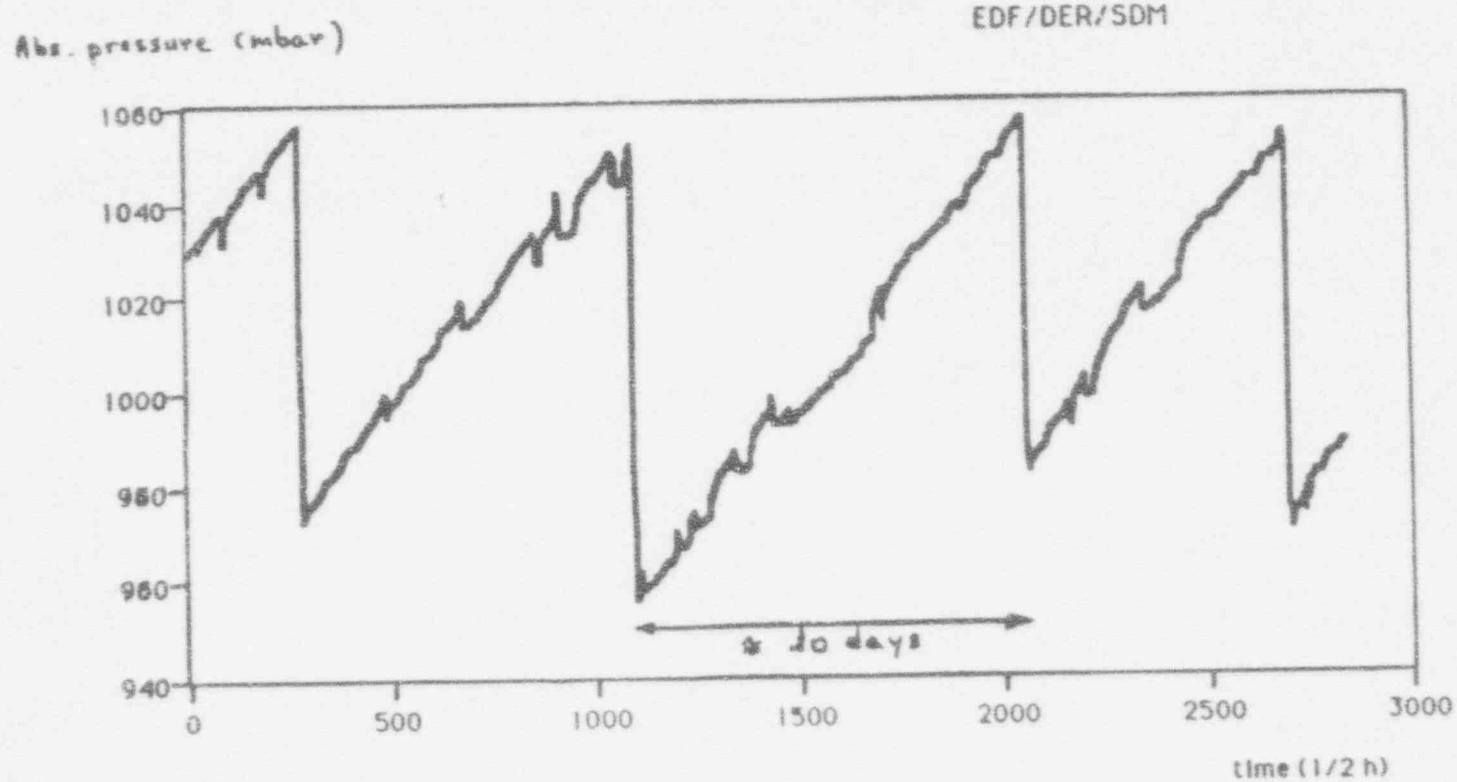
PERMANENT AIR INLET (INSTRUMENTATION COMPRESSED AIR SYSTEM)

REGULAR DEPRESSURIZATION (EVERY 20 DAYS)

SAWTEETH EVOLUTION OF THE CONTAINMENT PRESSURE

CONTAINMENT PRESSURE CYCLE OVER 2 MONTHS (mbar)

EDF/DER/SDM



PRINCIPLE

ADAPTATION OF THE "ABSOLUTE METHOD" USED FOR THE INTEGRAL LEAK RATE TEST AT LOCA PRESSURE

EVERY 30 MINUTES, MEASUREMENT OF :

.ABSOLUTE PRESSURE

.AVERAGE TEMPERATURE

.AVERAGE WATER VAPOR PARTIAL PRESSURE

.ICADS FLOWRATE

EVERY DAY : CALCULATION OF THE AVERAGE LEAK RATE

EVERY DEPRESSURIZATION : COMPLETE DIAGNOSIS

CHARACTERISTICS

THE SEXTEN SYSTEM IS MADE UP OF :

.10 TEMPERATURE SENSORS

.2 HYGROMETERS

.1 PRESSURE SENSOR

.USE OF ICADS FLOWMETER

.1 DATA LOGGER

.1 CALCULATOR (HP 9915)

.1 PRINTER

.1 PLOTTER

(data logger, calculator, printer and plotter: FOR 2 CONTAINMENT VESSELS)

.SPECIFIC SOFTWARES

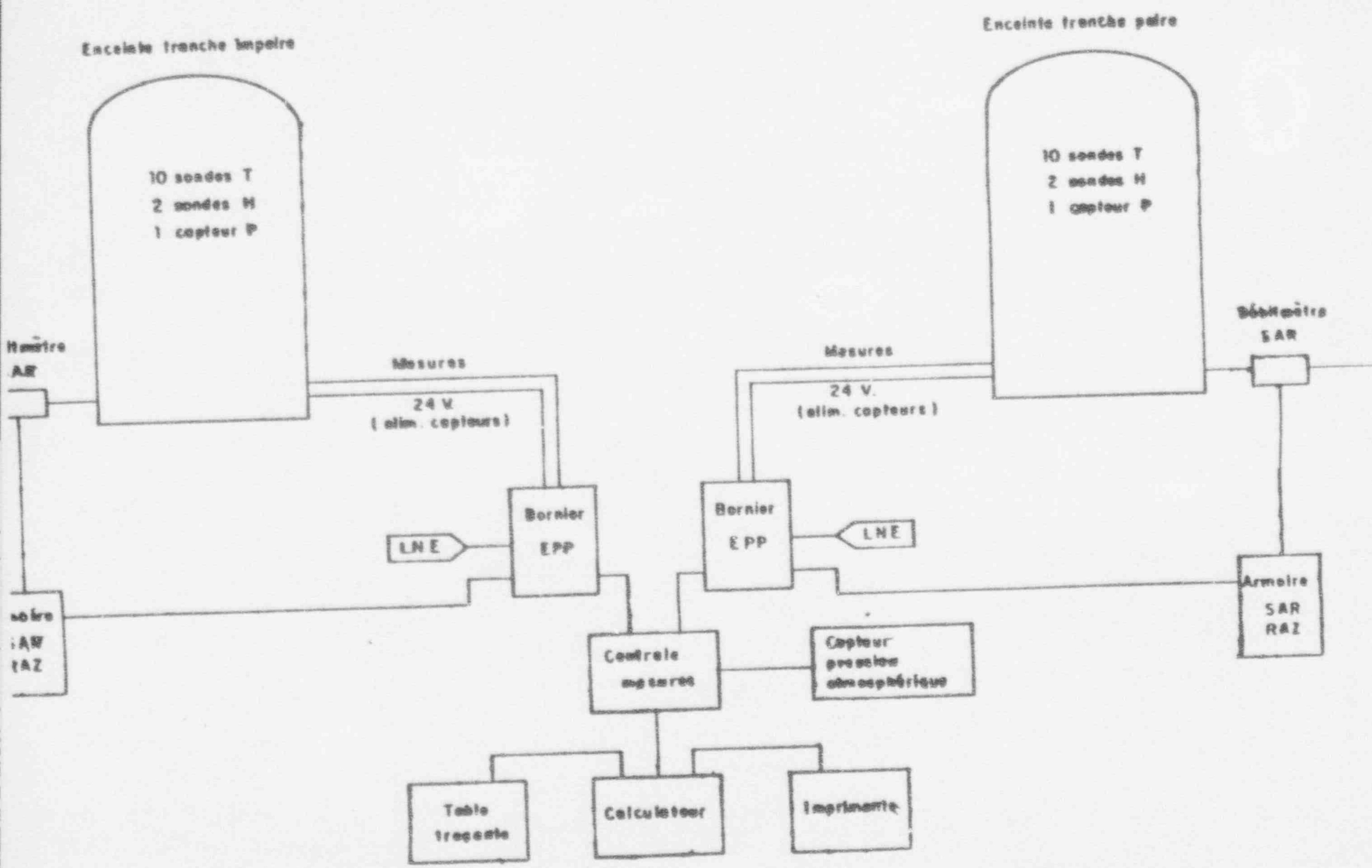


Figure 1 : Schéma du SEXTEN

SEXTEN C 4

SEXTEN C3

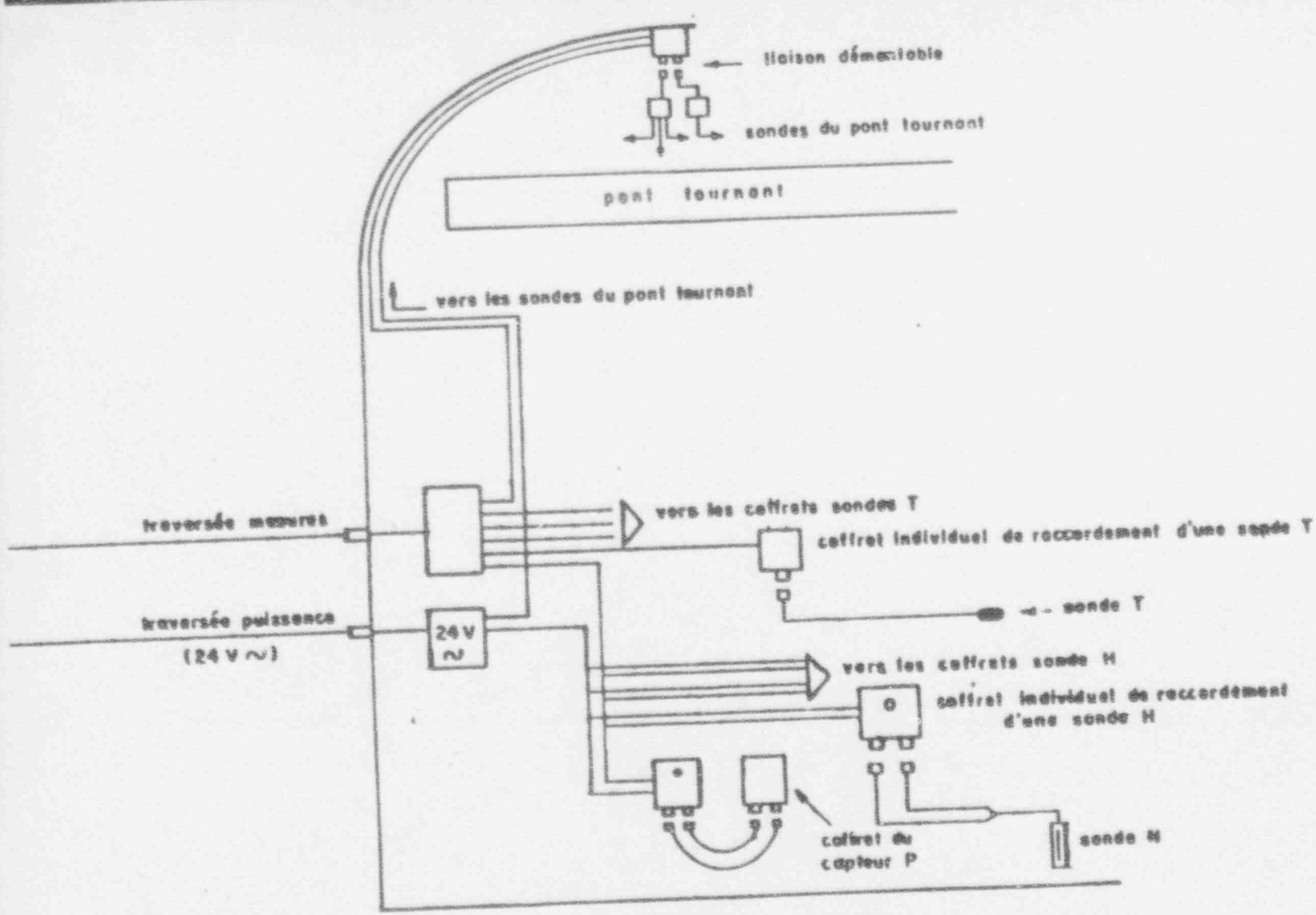


Figure 2 : Principe de l'installation des sondes dans une enceinte.

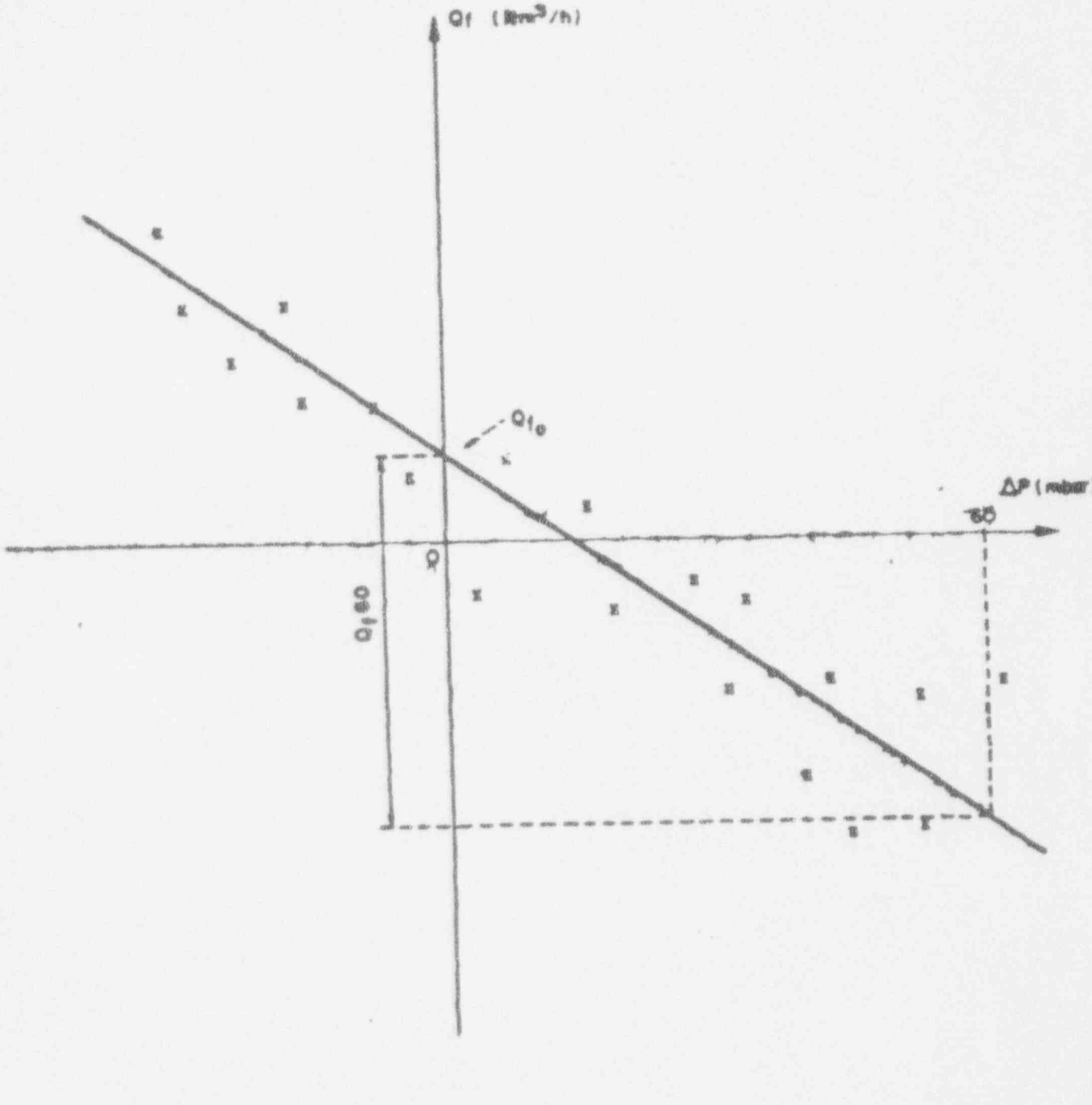


Figure 2 : exemple de courbe $Q_{f_j} = f(\Delta P_j)$ obtenue au cours d'un cycle de pression enceinte.
Avec la méthode de calcul proposée, les Q_{f_j} sont négatifs (fuites) pour $\Delta P > 0$.

CRITERION

FOR 900 MW NUCLEAR PLANTS :

Qf60 < 5 Nm3/h

IF 5 Nm3/h < Qf60 < 10 Nm3/h

THE CONTAINMENT LEAK IS TO BE LOCALIZED

IF Qf60 > 10 Nm3/h

AND IF THE LEAK IS NOT LOCALIZED AFTER 10 DAYS

=> COLD SHUTDOWN

CHARACTERISTICS

PRECISION :

AVERAGE UNCERTAINTY OF THE MEASURED VALUES FOR THE GLOBAL LEAK RATE :

1.3 Nm3/h over a day

(50 000 m3 containment structure)

AVERAGE UNCERTAINTY OF THE Qf60 MEASURED VALUES :

0.8 Nm3/h

(over 20 days : typical pressure cycle duration)

AVERAGE UNCERTAINTY OF THE Qi MEASURED VALUES :

1.3 Nm3/h

DEFINITION

Qf60 : CONTAINMENT LEAK RATE FOR A 60 mbar DIFFERENTIAL PRESSURE

Qi : ABNORMAL GAS INLETS TOTAL FLOWRATE MEASURED FOR A 0 mbar DIFFERENTIAL PRESSURE

CHARACTERISTICS

DIAGNOSIS GIVEN BY THE SEXTEN SYSTEM :

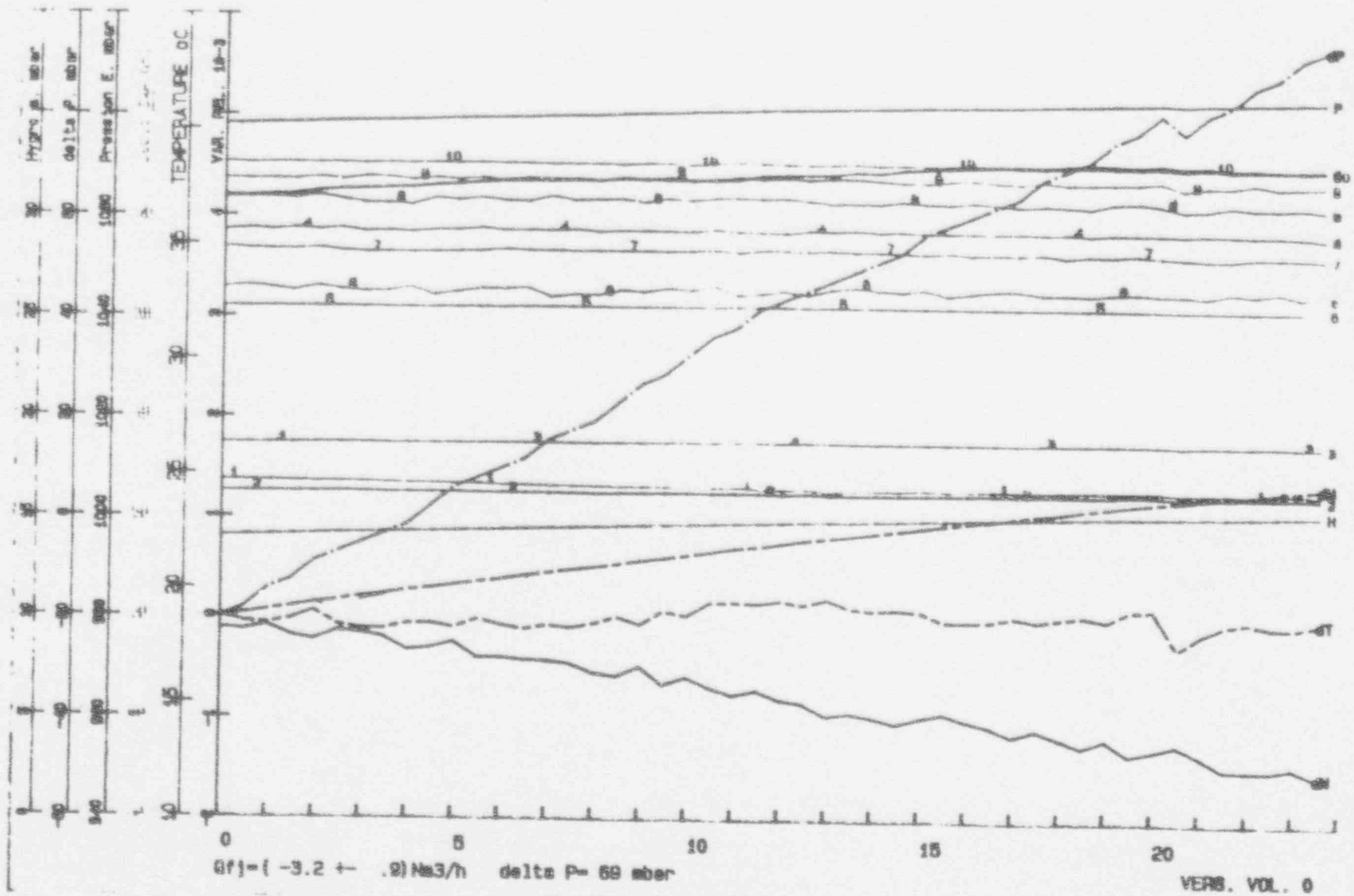
. EVERY DAY : GLOBAL LEAK RATE WITH UNCERTAINTY

. EVERY DAY, AT LEAST FIVE DAYS AFTER A DEPRESSURIZATION :
EVALUATION OF Qf60 WITH UNCERTAINTY

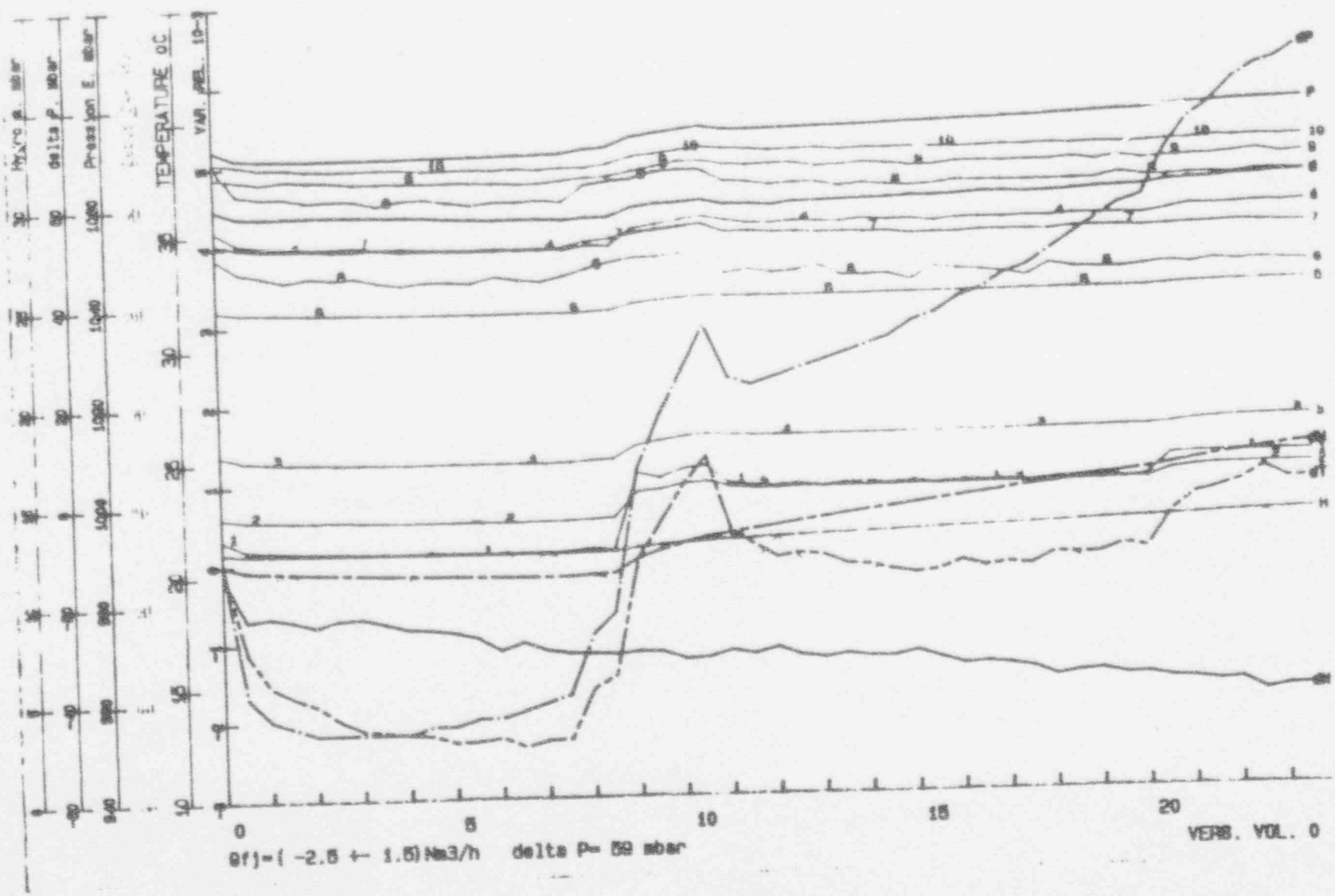
. AFTER A DEPRESSURIZATION :
PRECISE MEASUREMENT OF Qf60 WITH UNCERTAINTY
PRECISE MEASUREMENT OF Qi WITH UNCERTAINTY

. FUNCTION "ASSISTANCE FOR LEAK SPOTTING"
(PRECISE TIME EVOLUTION OF THE AIR MASS)

RELEVES SEXTEN GRAVELINES 1 LE 3/1/1990



RELEVES SEXTEN GRAVELINES 1 LE 2/1/1990



THE SEXTEN 2 PROJECT

. QUALITY ASSURANCE PROCEDURE

. REPLACEMENT OF ALL THE SEXTEN 1 IN FRENCH PWR

. BENEFIT OF THE SEXTEN 1 EXPERIENCE (about 200 year.plant) (in 1994)

. UP-TO-DATE COMPUTER AND DATA LOGGER

. SAME LEAK RATE MEASUREMENT INSTRUMENTATION

. IMPROVED POSSIBILITIES, FUNCTIONS, MAN/MACHINE INTERFACE

SEXTEN 2 IMPROVEMENTS WITH REGARD TO SEXTEN 1

. NEW COMPUTER AND DATA LOGGER

. NEW ICADS FLOWMETER

. MODEM CONNEXION WITH A CENTRAL COMPUTER (NATIONAL ANALYSIS OF THE RESULTS)

. IMPROVED PERIODIC AUTO-CONTROLS

. NO STOP IN MONITORING DUE TO NON VITAL SENSORS FAILURE

. AUTOMATIC DETECTION OF CONTAINMENT LEAK RATE MODIFICATION

. MODERN MAN/MACHINE INTERFACE (MENUS, COMMANDS)

. HISTORICAL RECORDS

. "REPLAY" POSSIBILITIES

. ALARM POSSIBILITIES

. IMPROVED RESULTS PRESENTATION

ENCLOSURE B

March 89

CONTINUOUS MONITORING OF CONTAINMENT LEAKTIGHTNESS

THE SEXTEN SYSTEM

[redacted] - [redacted]

[redacted]

Direction des Etudes et Recherches

6, quai Watier

78400 CHATOU

FRANCE

Ringhals use The Sexten System 2.
BS

1 - INTRODUCTION

The containment leaktightness is essential to the safety of PWR nuclear power plants. This was illustrated by the Three Mile Island accident where the containment efficiently played its part in preventing the release of radioactive materials to the atmosphere.

The containment leaktightness is usually checked before the unit is started and, then, periodically by performing integrated leakage rate tests. [redacted] tests are carried out before the plant startup/ [redacted] first refuelling and, after, every ten years unless a [redacted] containment leaktightness [redacted]/ In this case, tests are performed more frequently. The leeaktightness is checked at a pressure corresponding to the Lost of Coolant Accident that is at a 4 bar gauge pressure.

In France, it was decided to check the containment leaktightness on a permanent basis by installing a [redacted], the SEXTEN, working during the unit operation.

This system has now been installed in all the French PWR units. It has, on several occasions, revealed leaktightness defects in the containment of working units.

2 - HISTORY

The first containment leakage rate tests in an operating unit were performed in 1980. The results of these tests are shown in Figure 1. The solid line curve (dM/M) describes the modification of the air mass in the containment versus time.

During the first phase, the system recorded a decrease in the air mass corresponding to a leakage rate of 21 Nm^3/h at a 52 mbar positive pressure. The plant radiation monitoring system once closed, the SEXTEN system measured an air ingress into the containment of about 6 Nm^3/h (phase 2). During phase 5, once the plant radiation monitoring system and the service compressed air distribution system were closed, the containment leakage rate at a 33 mbar positive pressure was 0 Nm^3/h. In conclusion, the test system detected a leakage through the plant radiation monitoring system and an undesired air inleakage into the containment through the service compressed air distribution system.

This first test, therefore, demonstrated that integrated containment leakage rate could be measured during unit operation with an accuracy sufficient to detect leakage problems that may occur on this type of component.

Following these tests, in 1981 and 1982, another containment was instrumented and measurements were recorded for approximately one year. This test was used as a basis to define a simplified measurement instrumentation which served as a reference to build a prototype [redacted] monitoring system. [redacted] In Service [redacted] Three of these prototypes were installed in power plants in order to be perfected and validated.

In [redacted] that all EDF PWR units would be equipped with [redacted]

At present, the containment leaktightness in French units is being continuously monitored by the SEXTEN system.

3 - OPERATING PRINCIPLE

Leakage detection in containments is based on the fact that the pressure inside the containment is succesively under or above atmospheric pressure. Actually, [redacted] inside the containment goes up and down (ref. figure 2) [redacted] from the instrument compressed air distribution [redacted] consumed by the air-operated valves in the reactor [redacted]. The air drawn from outside is released in the containment where the pressure slowly rises. [redacted] the pressure reaches a set limit, then [redacted] depressurizes the containment, and a new pressurization [redacted] begins.

[redacted] leaks, these may be detected during the positive [redacted] pressure periods in the containment by assessing the gas mass [redacted].

This gas mass is measured by the absolute method. This method is widely used for containment leakage-rate tests.

It consists in measuring the average partial steam pressure and the absolute containment air pressure. The dry air content of the containment can then be calculated.

The slope of this quantity variation is equal to the integrated containment leakage mass flow.

The containment leakage rate can be measured by subtracting the ICADS air flow rate injected into the containment from the integrated containment leakage mass flow.

[redacted] consists [redacted] capable of [redacted] the average [redacted] average partial [redacted] exhibit large [redacted] especially [redacted] containment of an [redacted] happens quite [redacted]

The choice of the location of the various sensors and of their weighing for the computation of average values is essential to have accurate measurements.

For instance, Figure 1 shows that the average temperature varies by approximately 1°C and the partial steam pressure by some 5 mbars during phase 2. A disruption can be seen on the curve of the dry air mass [illegible] versus time, but the error level remains low.

As a pressurization cycle lasts some 20 days (900 MW units), an [illegible] leakage rate and an average gauge pressure in the containment can be measured every day.

Curves such as those in Figure 3 are obtained. By analyzing these curves, a precise diagnosis of the containment leaktightness can be made.

To characterize the containment leaktightness a criterion was defined for the containment leakage rate at a positive pressure of 60 mbars (Qf60). In France, in 900 MW units, the containment leaktightness is considered adequate when Qf60 is below [redacted]

4 - CHARACTERISTICS OF THE SEXTEN

Several problems likely to affect the containment leaktightness or the operator of some circuits can be detected with the SEXTEN system. These are :

- leaks of the components contributing to the containment leaktightness,
- leaks of the systems running across the containment,
- undesired gas inflow (air, nitrogen).

SEXTEN can be used, once it has detected a problem, as an aid to identifying the defective circuit or component. Indeed, thanks to the real-time plotting of the evolution of the gas mass inside the containment, the way the closing of systems or the repair of components affect the integrated containment leakage rate can be clearly seen (ref. example in Figure 1).

For a 900 MW unit containment (free volume of about 50 000 m^3), the average uncertainties with the SEXTEN system are :

- [redacted] over a [redacted]surement period for the containment integrated leakage rate,
- [redacted] for the assessment o[redacted] over a pressurization cycle in the containment.

[redacted] development [redacted]

The instruments used in the SEXTEN system are given in Figure 4.

The system, strickly speaking, consists of a processing unit, a data logger, a printer and a plotter. A SEXTEN system can monitor two containments simultaneously. The following sensors are used :

- 1 absolute-pressure tranducer in each containment,
- 10 temperature sensors in each containment,
- 2 moisture-content sensors in each containment,
- 1 flowmeter on the instrument compressed air distribution system (ICADS) in each containment,
- 1 atmospheric-pressure transducer.

- 1 flowmeter on the instrument compressed air distribution system (ICADS) in each containment,

- 1 atmospheric-pressure transducer.

[redacted] continuously and issues [redacted] cycle in the [redacted] At the operator's request, the evolution of the gas mass inside the containment can be plotted in real time when leaks are looked for.

5 - RESULT ANALYSIS

The SEXTEN system confirmed that leakage problems may sometimes occur in the containment of operating units. The leaks are generally located in the circuits running across the containment, for instance in the plant radiation monitoring system, the nuclear island vent and drain system, the containment sweeping ventilation system and the containment atmosphere monitoring system.

The SEXTEN detects these problems and helps the operator to locate the leaks.

[redacted] pressure [redacted] very largely [redacted]

[redacted] monitoring comple[redacted] to measure the [redacted] LOCA [redacted] continuously [redacted] the components [redacted] containment [redacted] good order or [redacted] is not open.

[redacted] does not [redacted] which provide [redacted] the containment [redacted]

6 - CONCLUSIONS

The tests performed from 1980 to 1982 demonstrated that the [redacted] rate [redacted] be [redacted], with an [redacted] approximately [redacted] day.

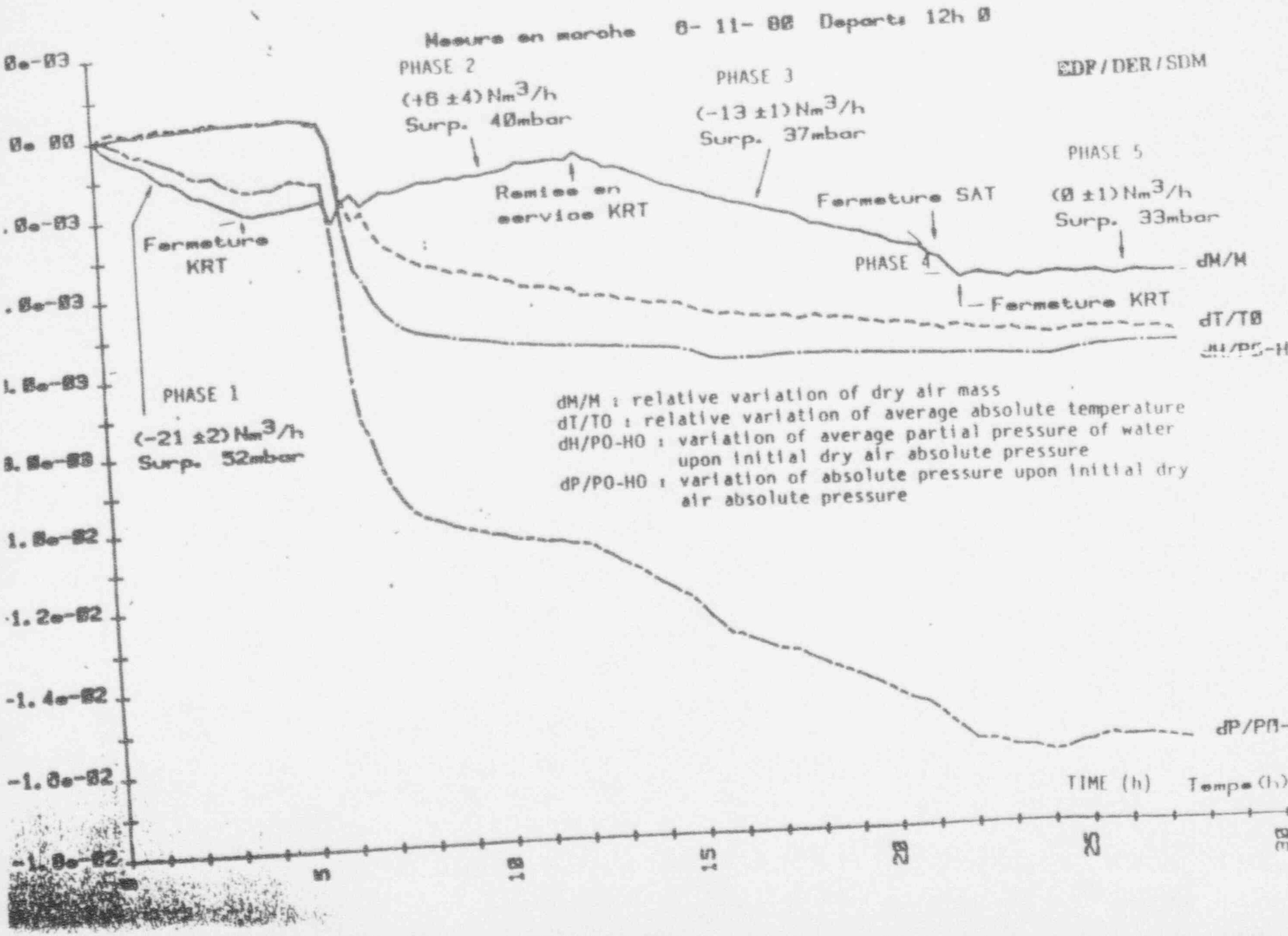
A continuous monitoring system of the containment leaktightness, called SEXTEN, has been developed by EDF. This system has been installed in all French PWR units.

This system detected some leakage problems likely to occur on certain circuits running across the reactor building connected to the containment air.

This continuous monitoring complements the tests performed to measure the leakage rates at the LOCA pressure and improves the unit safety by contributing to an adequate containment leaktightness.

LIST OF FIGURES

FIGURE 1



Mesure en marche 8- 11- 88 Depart: 12h 0
EDF/DER/SDM
PHASE 1
(-21 ±2) Nm3/h
Surp. 52mbar
Fermeture
KRT
PHASE 2
(+8 ±4) Nm3/h
Surp. 40mbar
Remise en
service KRT
PHASE 3
(-13 ±1) Nm3/h
Surp. 37mbar
Fermeture SAT
PHASE 4
Fermeture KRT
PHASE 5
(0 ±1) Nm3/h
Surp. 33mbar
dM/M
dT/T0
dP/P0-H0
dM/M : relative variation of dry air mass
dT/TO : relative variation of average absolute temperature
dH/PO-HO : variation of average partial pressure of water
upon initial dry air absolute pressure
dP/PO-HO : variation of absolute pressure upon initial dry
air absolute pressure
TIME (h)
Temps (h)
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-1.4e-02
5
10
15
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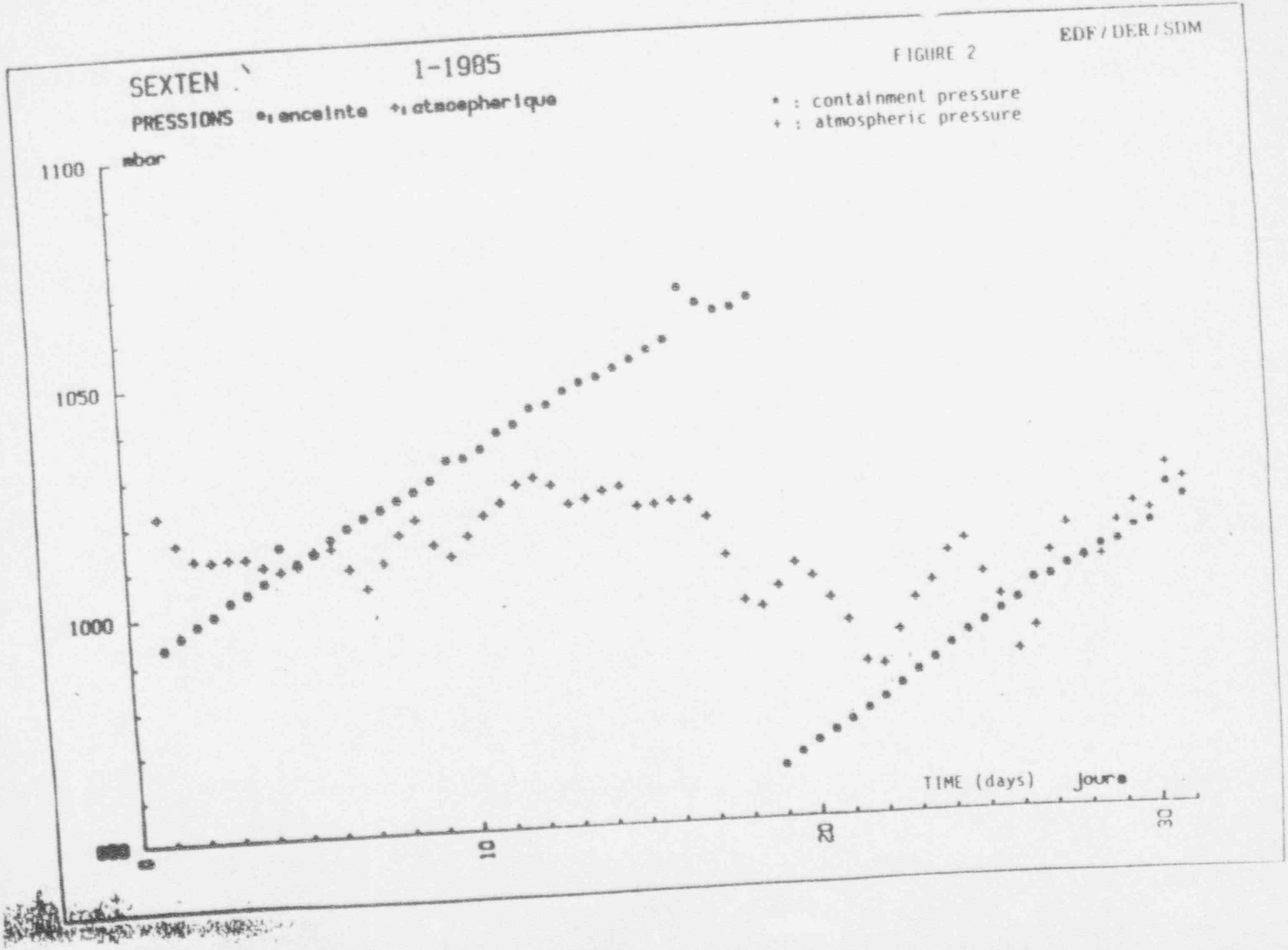
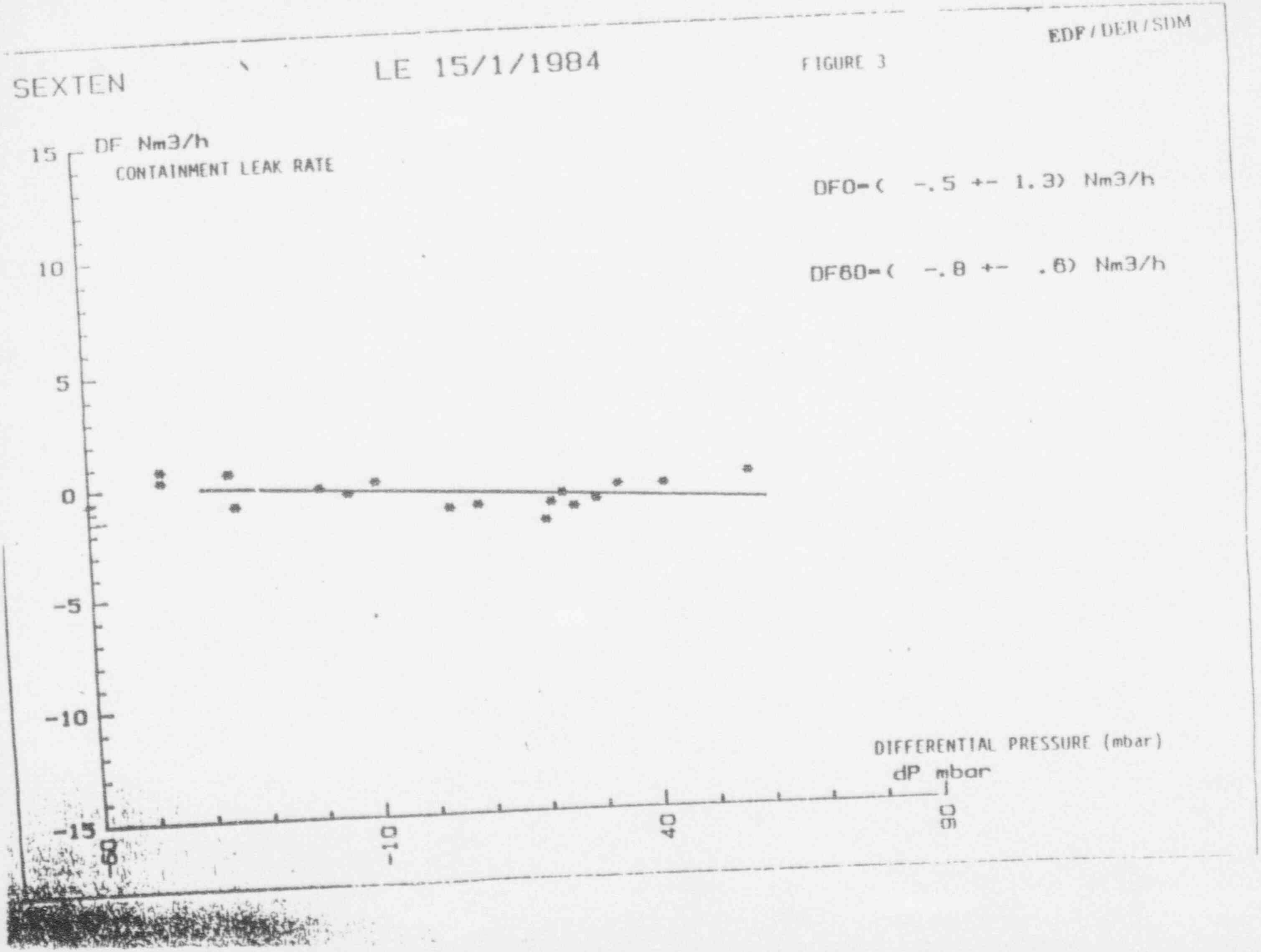

EDF / DER / SDM
FIGURE 2
SEXTEN
1-1985
PRESSIONS *; enceinte +; atmospherique
* : containment pressure
+ : atmospheric pressure
mbar
1100
1050
1000
10
20
30
TIME (days)
jours



EDF/DER/SDM
SEXTEN
LE 15/1/1984
FIGURE 3
DF Nm3/h
CONTAINMENT LEAK RATE
DF0=(-.5 +- 1.3) Nm3/h
DF60=(-.8 +- .6) Nm3/h
15
10
5
0
-5
-10
-15
DIFFERENTIAL PRESSURE (mbar)
dP mbar
-60
-10
40
90

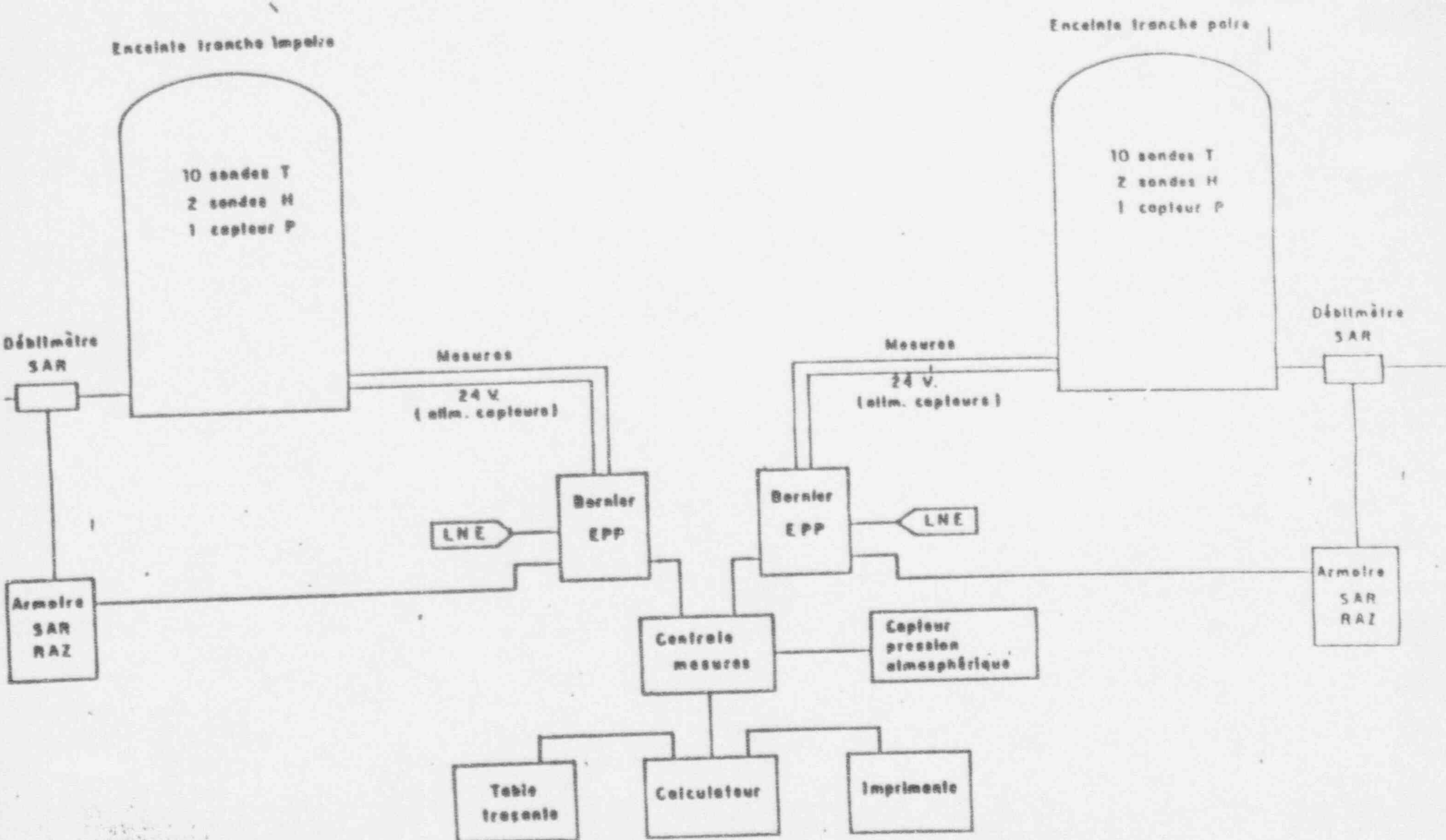


Figure 4 : Schéma du SEXTEN . Diagram of the SEXTEN system

DTG

R. POLLIER "Energy and Mechanics Department"

THE SEXTEN SYSTEM
CONTINUOUS MONITORING
OF CONTAINMENT LEAKTIGHTNESS

D4130/DTG-EM2EC/93-019-A

No. of pages : 10
No. of appendices : 3

EDF
Electricité
de France

EDF
Electricité
de France

Direction EDF Production Transport
Division Technique Générale
DTG

20/09/1993

R. POLLIER "Energy and Mechanics Department"

THE SEXTEN SYSTEM CONTINUOUS MONITORING OF CONTAINMENT LEAKTIGHTNESS

D4130/DTG-EM2EC/93-019-A
No. of pages : 10
No. of appendices : 3

Document type : Technical procedure

Associated documents

Resume :

The SEXTEN is a system used to monitor the overall leaktightness of a pressurized water reactor containment whilst it is in operation.
The principle of the method is described.

Access

- Free ☑
- EDF/ GDF ☐
- Restricted ☐
- Confidential ☐

Key words :

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Production Transport

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SUMMARY

1 - INTRODUCTION

The containment leaktightness is essential to the safety of PWR nuclear power plants. This was illustrated by the TMI accident, where the containment efficiently played its part in preventing the release of radioactive materials to the atmosphere.

The containment leaktightness is usually checked before the unit is started and, then, periodically by performing integrated leak rate tests. In France, these tests are carried out before the plant startup, during the first refuelling and, after, every ten years unless a degradation in the containment leak rate is detected. All these tests are performed at full LOCA pressure. Tests on containment isolation valves are also performed every year.

Despite these checks, we observed some abnormal behaviors of containment pressure, due to leaks, in operation. It was decided to check the containment leaktightness on a permanent basis by installing a continuous monitoring system : the SEXTEN, working during the unit operation.

This system is called "SEXTEN 1", is used to monitor about 50 containments and its cumulated time of operation is about 250 reactor-years.

A new version of the system is now under development, it is called the "SEXTEN 2". A first prototype has been installed in an operating unit in august 1993 and a second one might be installed in the course of december 1993.

2 - FIRST TEST IN OPERATION

The first containment leakage rate tests in an operating unit were performed in 1980. They were carried out in a plant where the containment pressure had an abnormal behavior : it was influenced by the variations of the atmospheric pressure instead of beeing stable.

An instrumentation was installed inside the containment during an outage and connected to an automatic monitoring system. For measuring the containment leak rate, we used the same method as for the integrated leak rate tests performed at LOCA pressure, that is the "Absolute Method". This method depends on the measurement of the pressure, mean temperature and mean water-vapor pressure inside the containment.

The results of these tests are shown in Figure 1 :

the curve dM/M describes the modification of the dry air mass in the containment versus time. The slope of this curve represents the containment leak rate.

The curves dT/T_O, $dP/(P-H)_O$, $dH/(P-H)_O$ respectively describe the evolution of the absolute temperature, absolute pressure and water vapor pressure inside the containment, during the test.

The containment was pressurized with air to a 50 mbar (0.7 psi) overpressure. During the first phase of the test, the system recorded a decrease in the air mass corresponding to a leakage rate of 21 m^3/h STP at a 52 mbar overpressure. We then tried to localize the leak by closing valves on containment penetrations. At last, the Plant Radiation Monitoring System (PRMS) was closed and we quickly noticed a modification in the dM/M curve (end of phase 1) : the system measured a gas entrance into the containment of about 6 m^3/h STP (phase 2).

As the plant radiation system could not be isolated during a long period, we had to put it in operation again (phase 3). Then, the system measured a global leak rate of 13 m^3/h STP at a 37 mbar (0.5 psi) overpressure. The gas entrance was due to the Service Compressed Air Distribution System (SCADS) which had not been closed after the unit outage. This system was isolated and an immediate modification of the dM/M curve was observed (phase 4).

One hour later, the Plant Radiation Monitoring System was again isolated and we measured a containment leak rate of 0 m^3/h STP at a 33 mbar (0.5 psi) overpressure.

In conclusion, the system detected a leakage through the Plant Radiation Monitoring System and an undesired air inleakage into the containment through the Service Compressed Air Distribution System. This first test, therefore, demonstrated that integrated containment leakage rate could be measured during unit operation with an accuracy sufficient to detect leakage problems that may occur this type of component.

3 - STUDY AND DEVELOPMENT OF A LEAK MONITORING SYSTEM

Following this test, another containment of a different type was instrumented and measurements were recorded for approximately one year from 1981 to 1982. The same measuring method was used and 59 temperature sensors, 6 hygrometers and 1 pressure sensor were installed inside the containment. The flow rate of the Instrument Compressed Air Distribution System was also measured : the compressed air used by the air operated valves beeing released into the containment.

The containment was leaktight and the results of this test were used for studying and defining a simplified measurement instrumentation which served as a reference to build a prototype monotoring system, called SEXTEN (from the french words : "Surveillance en EXploitation du Taux de fuite des ENceintes" - In Service Monitoring of Containment Leakage Rate). Three prototypes were installed in units in order to be perfected and validated. In 1985, it was decided that all french units would be equipped with this monitoring system.

Concerning containment leaktightness testing, EDF's policy is the following :

- tests are performed at full pressure every 10 years, this interval being reduced if a major degradation of the leak rate is observed.
- the leaktightness is continuously monitored in operation, thanks to the SEXTEN system. The leak rate at 60 mbar overpressure must be below 5 Nm^3/h (900 MW plants). This criterion was agreed by our Safety Authorities.

We think that both methods are complementary, and that they cannot replace each other.

We think that continuous monitoring is necessary because EDF's experience feedback shows that a leak may occur at any time during a fuel cycle (for instance in valves which are operated during the fuel cycle).

4 - CRITERION CONCERNING LR60

A criterion concerning Lr60 was proposed. It is not based on an interpolation of the criterion used for global integrated leak rate testings, because such interpolated value depends on many parameters which we do not know (size of leak, type of flow, for instance), some check valves may be more tight at full pressure than low pressure and the possible values will be too small to be measured by the SEXTEN system.

The criterion corresponds to the role of the SEXTEN system, which is not to replace the tests at full pressure but to detect an abnormal state of the containment leaktightness due to an operator error or a failure, in operation, of a component in a system participating to the containment leaktightness. The criterion is based on the SEXTEN accuracy and on our experience concerning containment leaks in operation.

In France, in 900 MW units, the leak rate at 60 mbar overpressure (Lr60) must be below 5 m^3/h STP.

If Lr60 is in the range of 5 to 10 m^3/h, the personnel is bound to complete a leak localization procedure.

If Lr60 is above 10 m^3/h STP, the leak shall be localized and repaired within 10 days, otherwise a cold shutdown must be performed, unless the leaks are located in systems which are closed when the containment is isolated.

This criterion was agreed by our Safety Authorities and the SEXTEN System is considered as an "Important for Safety" system.

5 - SEXTEN OPERATING PRINCIPLE

SEXTEN on-line leakage detection in containments is based on the fact that the pressure inside the containment goes up and down due to the air from the Instrument Compressed Air Distribution System (ICADS) beeing consumed by the air operated valves inside the reactor building. The evolution of the pressure is of a "saw-teeth" type, one pressure cycle lasts about 20 days in french PWR and the amplitude of the pressure variation is of 100 mbar (1.5 psi).

This variation of the pressure inside the containment induces variations of the flow rate of a possible leakage through the containment.

The diagnosis of the containment leaktightness performed by the SEXTEN is based on the analysis of the evolution of the containment leak rate as a function of the containment pressure, during a pressurization cycle.

This evolution is estimated thanks to continuous periodic measurements of the containment leak rate and containment pressure. The measurement period is 24 hours in France. The diagnosis is based on the analysis of a curve presenting the measurement points (pressure, leak rate) for pressurization cycle(see figure 2).

SEXTEN calculates the slope of this curve which enables the calculation of the containment leak rate for a 60 mbar overpressure (Lr60). In EDF 900 MW units the containment leaktightness is considered adequate when Lr60 is below 5 Nm^3/h.

SEXTEN also calculates the containment leak rate when its pressure is equal to atmospheric pressure (Lr0). Then, the leak rate must be nil. In fact the measured Lr0 gives indications concerning measurements errors or abnormal gas releases inside the containment.

When a leak is detected, the SEXTEN is used as an aid for leak localization. The real-time plotting of the evolution of the gas mass inside the containment enables to see how the closing of systems or the repair of components affects the containment leakage rate (see figure 3).

The SEXTEN 1 and SEXTEN 2 use the same instrumentation. The main differences between the two systems are given into the chapter 6.

The same theoretical measuring principle is used for both systems and the measurements uncertainties are equivalent. For a 900 MW unit containment (free volume of about 50 000 m^3), the average uncertainties with the SEXTEN system are : 1,3 m^3/h STP over a 24-hour measurement period for [illegible]ntainment leak flow rate and 0,8 m^3/h STP for the assesment of Lr60 over a containmen[illegible]ure cycle.

6 - CHARACTERISTICS OF THE SEXTEN

The following instrumenta[illegible]sed :

- 1 absolute pressure tranducer,
- 10 temperature sensors,
- 2 dew point sensors,
- 1 flowmeter in the ICA[illegible]stem,
- 1 atmospheric pressure tranducer.

SEXTEN 1 is essentially a measurement device. Its accuracy is good and the problems of metrology and instrumentation are solved in a satisfactory manner. However, the possibilities of the SEXTEN 1 computer (HP 85) are limited, thus the man-machine interface is simple, and there are few possibilities of data storage and data reprocessing.

A second version of the SEXTEN system, which is called SEXTEN 2, is now under development. This system consists of a modem computer (HP VECTRA), a modem data logger (HP 75000) and a new software written in C language. The measuring instrumentation is the same as for the SEXTEN 1.

The SEXTEN 2 software will include a lot of improvements : new commands, more complete results presentation, historical records, better diagnosis functions, more performant sensor failure detection, automatic detection of a modification of the containment leak rate, data reprocessing, etc. The SEXTEN 2 is being developed according to a Quality Assurance programme.

One prototype of this SEXTEN 2 has been installed and the second one might be in the course of december 1993. But, not to wait for a long time to change the hardware of SEXTEN 1, we have developed an ADAPTED SEXTEN 1 SOFTWARE. The instrumentation (sensors) and equipment are the same as for SEXTEN 2. Only the software is different. It's written in HP IBASIC language.

7 - ADAPTED SEXTEN 1 SOFTWARE

The main functions of the ADAPTED SEXTEN 1 SOFTWARE are the following :

(24-hour period corresponds to the french measurement period)

- choice of the containment to be tested,
- automatic pre-test of the measurement part (sensors, wires, data logger, voltmeter) and the hardware (printers) before starting the SEXTEN on-line monitoring function. A written report indicates the equipment which is troubled,
- automatic periodic simplified test of the system during the continuous monitoring (every 24 hours). Written report in case of trouble,
- measurement of the containment leak rate, its uncertainty and the containment differential pressure every 24 hours. These measurements are invalidated if the uncertainty is too high,
- assessment of Lr60 and Lr0 first values and their uncertainties, after five valid "24-hour periods". These values are more precisely recalculated after each subsequent valid 24-hour period,
- automatic detection of a containment pressurization cycle end. Automatic calculation of Lr60 and Lr0 and their uncertainties. Plotting of the curve presenting the containment leak rate as a function of containment pressure,
- automatic detection of the begining of a new pressurization cycle. The calculations are reset to begin a new Lr60, Lr0 measurement cycle,
- automatic data storage on floppy disk. This function is automatically disabled or reinitiated depending on whether a floppy disk is present or not in the drive,
- automatic control of the presence of printers. An unavailable printer does not interrupt the monitoring.
- at operator request, plotting of the evolution of the air mass inside the containment for the last 30-hour period, as an aid for leakage detection,
- at operator request, measurement of the containment leak rate and the containment differential pressure during any period in the preceding 72 hours,
- at operator request, printed report of the sensor measurements,
- man-machine interface : the screen (2 lines of 40 characters) and the keyboard (complete alphanumeric keyboard with function keys) of the HP 75000 are used in a conventional way to start the system : the operator uses the keyboard to configure the system, following the instructions presented on the screen. Then the SEXTEN automatically performs leakage monitoring, no operator assistance is needed. If the operator has a request, he uses the functions keys without interrupting the continuous monitoring. This version is an improvement compared to the present SEXTEN 1 man-machine interface, which is based on printer messages, LEDs and function keys.

- data logger : HP 75000 B equipped with a HP E 1326 voltmeter, HP E 1345A relay multiplexer, IBASIC controller, 20 Mbyte hard disk and 3" 1/2 floppy disk drive.

- laser printer and inkjet printer.

When the SEXTEN 2 will be completed the following extra hardware will be necessary :

- computer HP VECTRA 386/25 equipped with 3- 1/2" floppy disk drives, 2 Mbyte RAM, parallel/serial port, DOS 6.0

- HP 82 335 A HPIB interface.

It will be very easy to reach a SEXTEN 2 from an ADAPTED SEXTEN 1.

8 - QA REQUIREMENTS

The ADAPTED SEXTEN 1 SOFTWARE has not been developed according to a QA programme. Its quality is based on the long experience we have with this software and on the tests we have performed in our premises.

The SEXTEN 2 is being developed according to a QA programme.

9 - CONCLUSIONS

The tests performed from 1980 to 1982 in some french PWR units demonstrated that the leakage rate of a containment can be measured, while the plant is in operation, with an acceptable level of uncertainty.

A continuous monitoring system of the containment leaktightness, called SEXTEN, has been developped by EDF. This system has been installed in all French PWR units. It is able to measure the containment leak rate of 900 MW units with an uncertainty of about 0.8 m^3/h STP, at the end of a 20-day containment pressurization cycle.

A criterion concerning the allowable containment leak rate in operation has been determined. The system is considered as an "Important for Safety System" by french Safety Authorities.

This system detected some leakage problems likely to occur in operation on certain systems which can provide a direct connection between the inside and outside atmosphere of the containment.

The SEXTEN System enables condition monitoring and leak diagnosis of components (mainly valves) participating to the containment leaktightness.

10 - REFERENCE DOCUMENTS

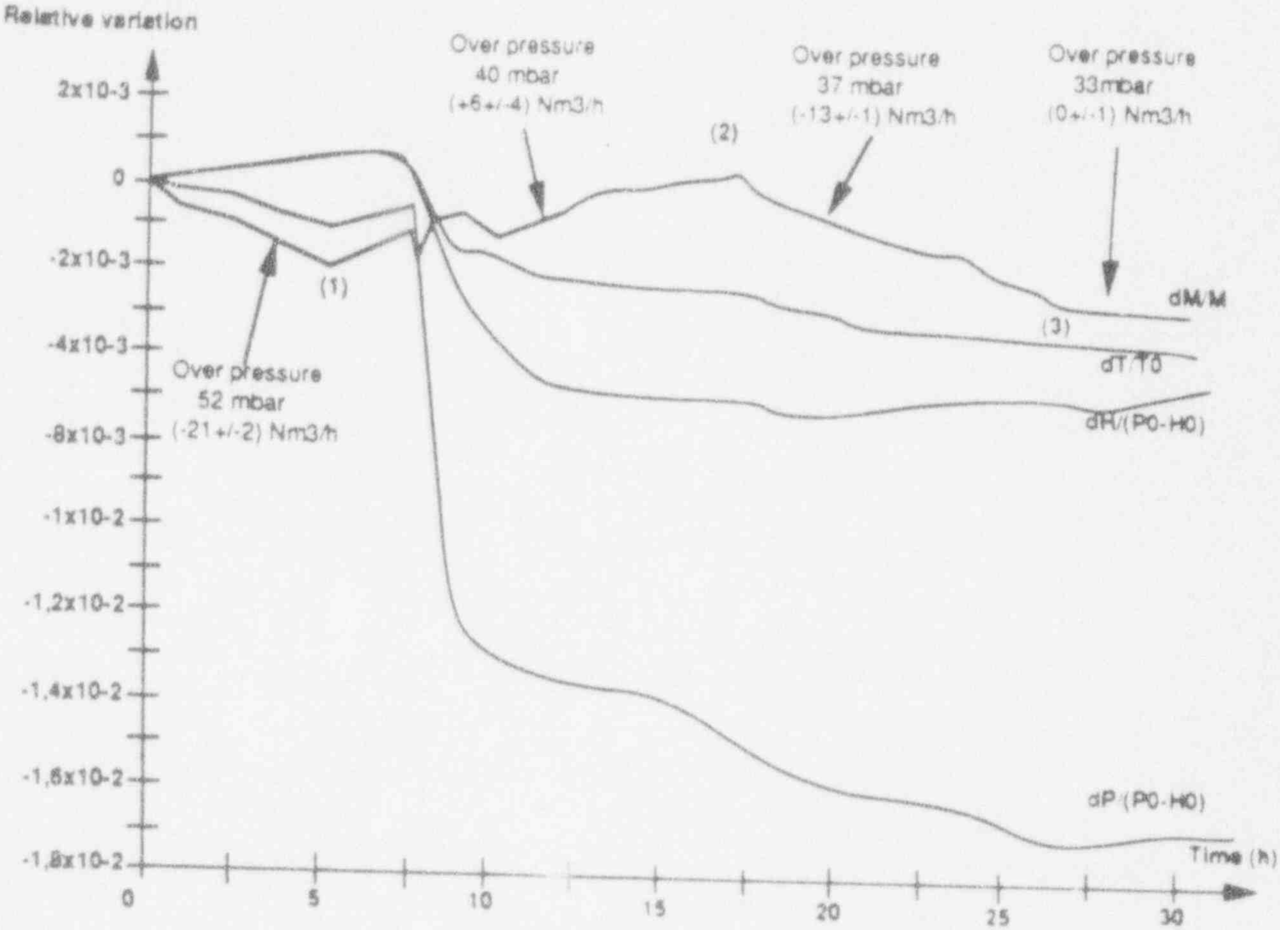
- "CONTINUOUS MONITORING OF CONTAINMENT LEAKTIGHTNESS - THE SEXTEN SYSTEM"

  MM. GERMAIN - JANNETEAU

  EDF-DER Report HP-27/92.41

- "EDF TENDER IN RESPONSE TO VATTENFALL'S INQUIRY NO F-92006"

  EDF - GSE Report



(1): Close the failed circuit

(2): Open the failed circuit

(3): Close the failed circuit and close the service compressed air distribution system.

Figure 1

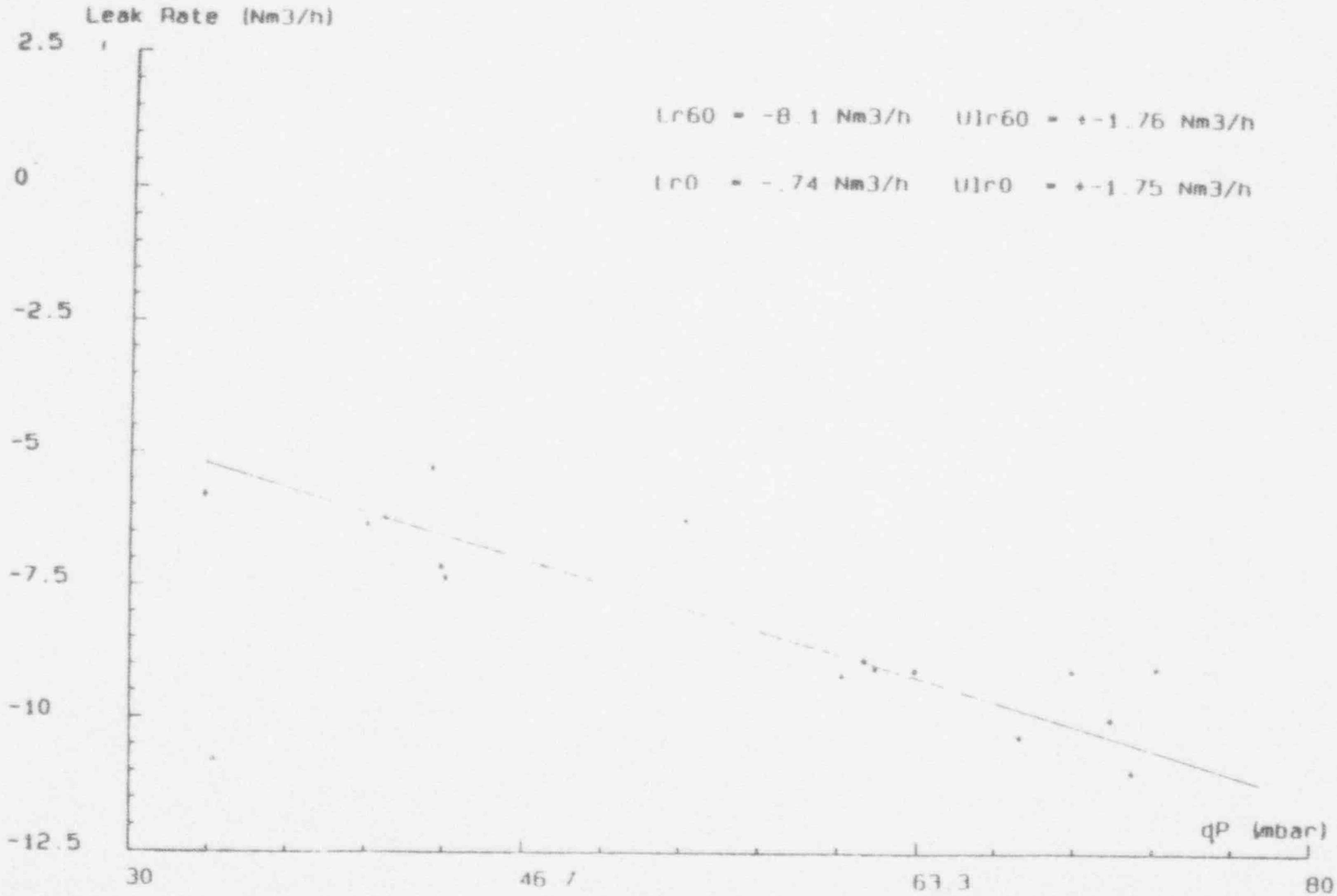

Leak Rate (Nm3/h)
Lr60 = -8.1 Nm3/h Ulr60 = +-1.76 Nm3/h
Lr0 = -.74 Nm3/h Ulr0 = +-1.75 Nm3/h
2.5
0
-2.5
-5
-7.5
-10
-12.5
30
46.7
63.3
80
qP (mbar)

Figure 2

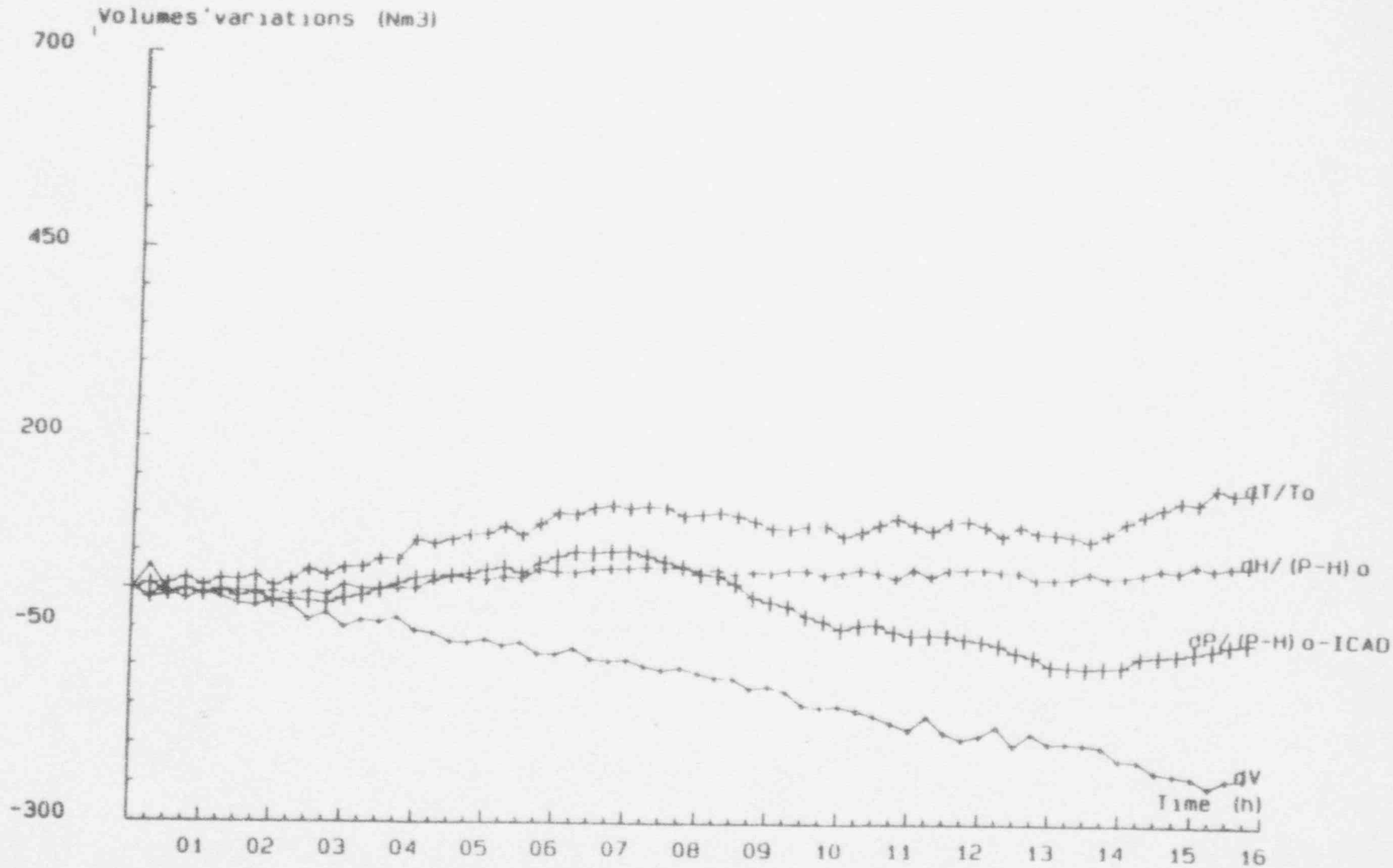
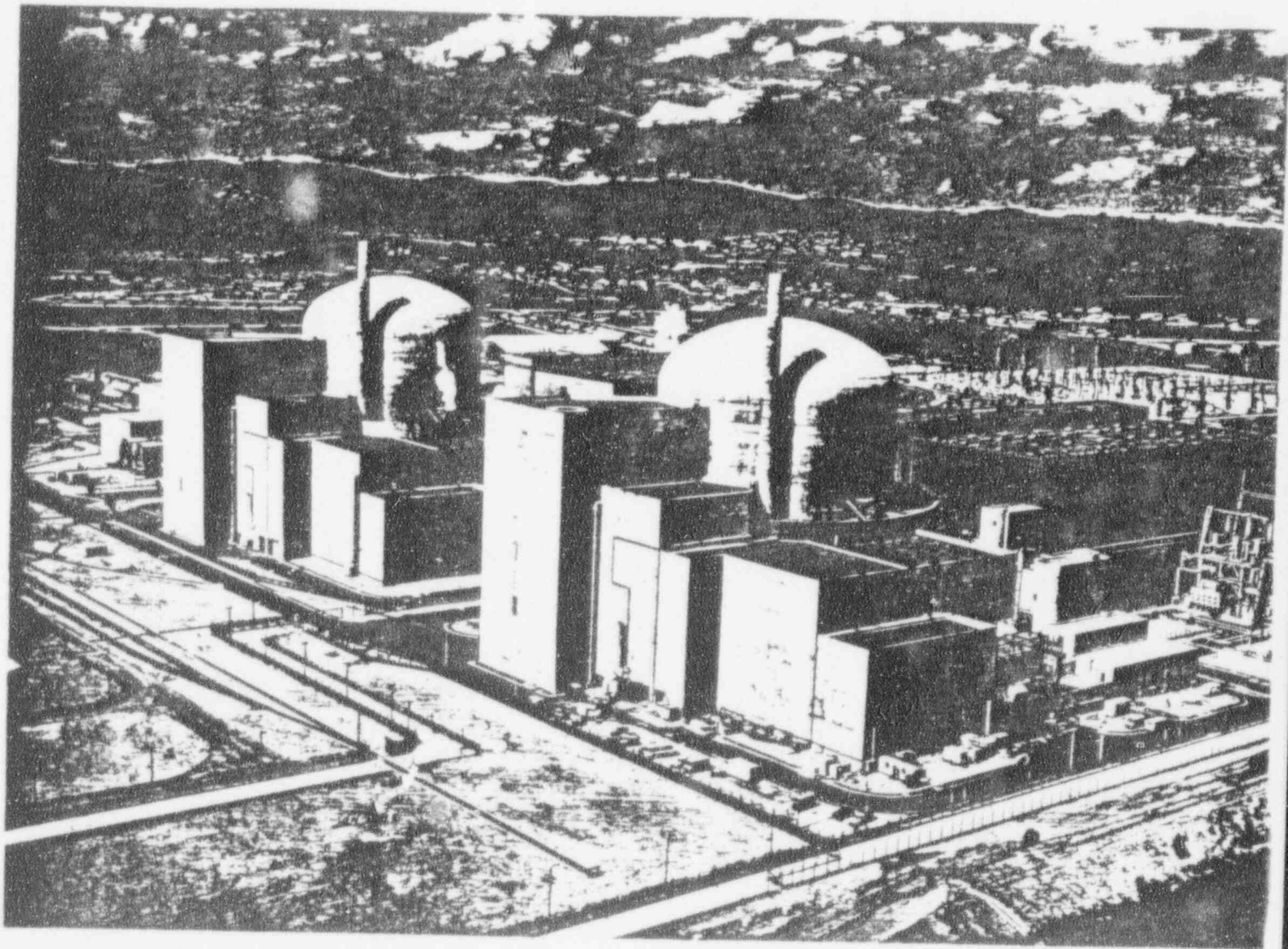

Volumes'variations (Nm3)
700
450
200
-50
-300
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
Time (h)
dT/To
dH/(P-H)o
dP/(P-H)o-ICAD
dV

Figure 3

ENCLOSURE D F

LEAKAGE RATE MEASUREMENTS IN CONTAINMENTS



EDF
Electricité de France

DTG

DEVELOPMENT, MEASUREMENT AND INDUSTRIAL CONTROLS

OVERALL LEAKAGE RATE MEASUREMENT

• Measurement principle

Measuring the overall leakage rate involves measuring the variation of the dry air mass contained in the containment at different pressures, in particular at the pressure where a primary coolant accident might take place.

The leakage rate is the relative variation of this mass per unit time. It is expressed in %/day. The dry air mass is calculated using the perfect gas equation. The partial pressure of the dry air is obtained from measurements of the total pressure and the mean partial pressure of the water vapour in the containment.

Since the containment is usually highly compartmentalized, measuring the mean temperature and mean partial pressure of the water vapour requires numerous sensors to be used. Each sensor provides a reading which represents the volume assigned to it.

The leakage rate is determined by calculating the mass of dry air contained in the containment at each reading followed by calculating the gradient of variation of these values using a least square linear interpolation. This gradient, in combination with the mean dry air mass during the period covered by the calculation, gives the required leakage rate value.

The accuracy of the measurement is of the order of 0.02 %/day.

• Resources used

The installation includes a measurement chain with over seventy high-precision sensors (two pressure meters, sixty temperature probes, ten humidity sensors). A computer, a measurement acquisition unit and a precision digital voltmeter are used to take readings from these sensors and to perform the necessary calculations. The temperature probes and the humidity sensors are distributed inside the containment, while the pressure meters, connected by piping, and other devices are assembled in a special measurement room near the control room. The sensors in the reactor building and the external devices are linked via leaktight electrical penetrations.

MEASUREMENT OF UNCOLLECTED LEAKS IN DOUBLE CONTAINMENTS

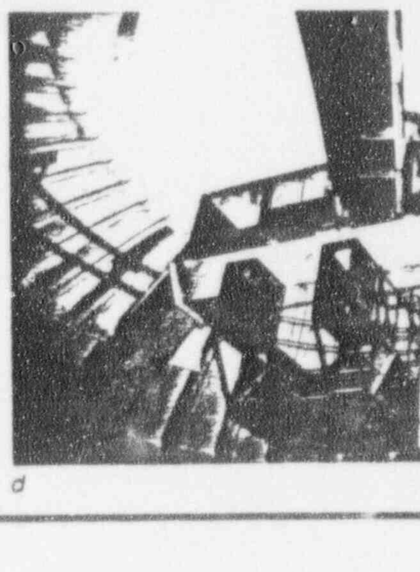
• General information on double containments

The spreading of gaseous waste in the case of an accident is prevented thanks to a second containment built around the first. The resulting space between the two is depressurized and any leaks are collected and filtered. This "double containment" principle is used in particular in the French nuclear units for 1300 and 1400 MW series plants. The overall method described above is still applied, but additions must be made to provide for the difference between collected and uncollected leaks in the inter-containment space.

• Measurement principle

Before the measurement is carried out, the inner containment is pressurized to the rated test pressure. The inter-containment space is depressurized by a tenth of a millibar relative to atmospheric pressure and the entire structure is isolated. The collected leaks coming from inner containment cause the pressure in the inter-containment space to be increased. When the difference between atmospheric pressure and the pressure in the inter-containment space becomes zero, there is, at this particular moment, no exchange with the outside. The variation of the normal air volume in the inter-containment space then represents the collected leakage flow.

c



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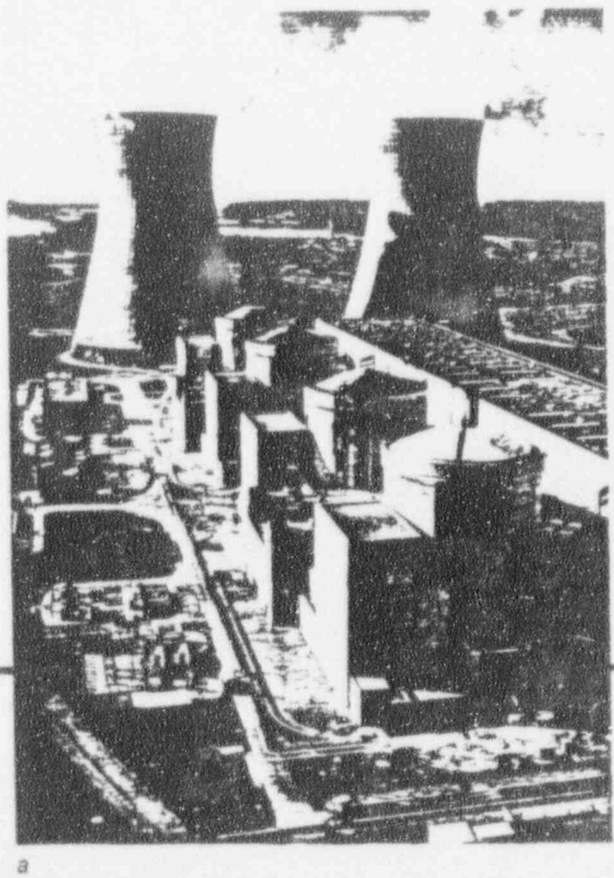
b

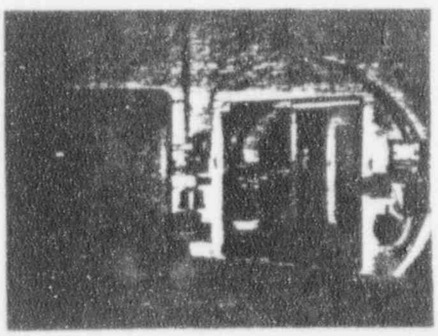


a

The overall leakage flow measurement of the inner containment and of the inter-containment space using the overall leakage rate method is carried out simultaneously and dynamically.
The uncollected leakage flows are obtained by difference.
The precision of the measurement is around 5 Nm3/h.

• Resources used

The global leakage rate in the inter-containment space is measured using similar equipment as is used to measure the overall leakage rate of the inner containment. Nevertheless, in order to account for possibly quicker parameter variations, appropriate sensors with shorter response times have been chosen along with twice as many absolute pressure measurement points in the inter-containment space. Atmospheric pressure is read at three points at 120° to each other half way up the cylindrical part of the inner containment.
A baffle system is placed on the pressure sensors so that the measurement made by the high-precision sensors installed in the measurement room is representative. The difference between atmospheric pressure and the pressure in the inter-containment space is determined with great accuracy since the sensors measuring each pressure are compared before the test and any deviations are accounted for. This value is checked after the test.



e

LEAKAGE FLOW MEASUREMENT DURING OPERATION (SEXTEN)

• Measurement principle

Two checks are made to complete the test of the overall leakage rate at accident pressure:

- regular individual tests of devices or locations liable to leaks (fittings used to cut off circuits crossing the containment, air-locks, electrical penetrations, connection of sleeves to the liner, etc.).
- continuous monitoring of the overall leakage flow in the containment for slight pressurizations which may exist in normal operation between the inside of the reactor building and the atmosphere.

The latter monitoring method is based on the fact that during operation, the air pressure in the reactor building is not equal to atmospheric pressure. The pneumatically controlled valves in the reactor building are supplied with compressed air from the outside. The operation of these devices means that air is constantly being introduced into the containment; as this slight pressurization cannot continue indefinitely, air will be rejectected periodically.
In reality, the gauge pressure of the containment varies according to a "saw-tooth" graph, with the two limit values being of the order of −40 mbar and +60 mbar; the period is around 20 days.
Any leakage ways will be revealed by the difference in pressure between the inside and outside of the reactor building thanks to leakage flow measurements similar to those used during the tests at full pressure.
In general: leaks + introduction of gas = variation of the air mass.
A computer linked to a measurement unit and sensors gives:
1) The dry air mass using the overall leakage rate measurement method.
2) The introduction of gas from elements provided by the air circuit flow meters.
The leakage flow is thence deduced by a daily analysis during a full cycle; this enables the leakage rate pressurized by 60 mbar to be estimated with an accuracy of around 2 Nm3/h.

• Resources used

Sensors identical to the ones used to measure the overall leakage rate are used, along with flow meters on the air supply circuits.
A permanent acquisition system installed on site, consisting of a measurement unit, a computer and a printer is used to restore results.

RELATED FIELDS OF EXPERTISE

- Measurement of all gas flows after collecting.
- Testing the dynamic response of pressure and temperature sensors using a non-intrusive method (POLLUX).

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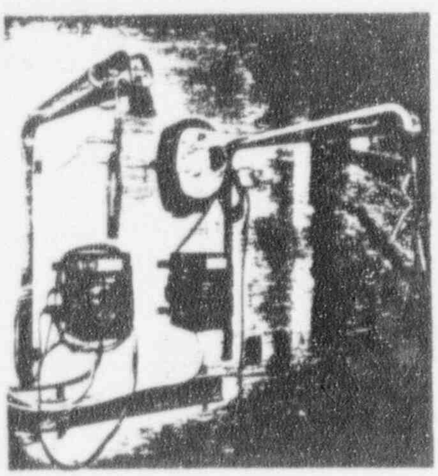

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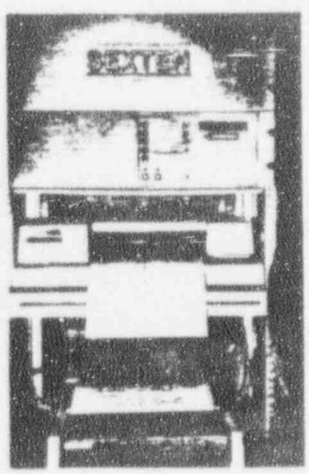

g

a: Nuclear Production Centre at Dampierre
b: Implementing an uncollected leakage measurement
c: Leakage rate measurement room
d: Instrumentation at the top of polar crane
e: Reactor building access air-lock
f: Temperature and humidity sensors
g: SEXTEN cabinet

EXPANSION

The DTG today provides services to the Production-Transport System and other EDF divisions as well as to external customers. This expansive spirit also takes the form of permanent technological exchanges with EDF's Design and Research Division and with various Universities and Scientific Associations. These exchanges also involve sharing know-how; for this purpose, the department runs training courses every year for its customers and is involved in University teaching.

HIGH-PERFORMANCE INTERVENTION RESOURCES

The DTG has a total staff of 320, including 90 engineers and 210 technicians. Because of its flexible organization, its teams can intervene from the head office at Grenoble or from the satellite offices at Lyon, Toulouse and Brive.

Engineers and technicians are people available in the field whose efficiency depends on a set of specific equipment which uses the latest technology and appropriate scientific computing equipment.
Its archives and stored data make the DTG the memory of a major company: feedback of experience and the search for innovation enable it to provide the most suitable answer to the problems arising, whatever the type of intervention.

SPECIALIZED EXPERTISE

With forty years experience in monitoring machines and structures and with fifty nuclear units in use, the experience of the DTG is widely recognized in the industrial measurement field. This renown results from both the quality and accuracy of the measurements and great flexibility
regarding the customer's requirements and restrictions.

LEAKAGE RATE MEASUREMENTS IN CONTAINMENTS

DTG reference Nr 95/1992

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ENCLOSURE E

BELGIAN POSITION ON CONTAINMENT LEAKAGE TESTING

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Authorized Inspection and Licensing Body
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CONTLEAK.DOC

SLIDE.DOT

1. Introduction

2. Tests at accident pressure

3. Tests at elevated pressure

4. Test methods

5. Tests at reduced pressure

6. Periodicity of the tests

2. Tests at accident pressure.

P_a : peak pressure in containment

Drawbacks :

- test duration
- danger
- representativeness

3. Tests at elevated pressure

$P_a / 2 \leq P_t \leq P_a$

10CFR 50, app. J :

L_t : max. allowable test leak rate at P_t

$$L_t = \frac{L_{tm}}{L_{am}} L_a \qquad L_{tm} / L_{am} \leqslant 0.7$$

$$L_t = \sqrt{\frac{P_t}{P_a}} L_a \qquad L_{tm} / L_{am} > 0.7$$

Acceptance criterion : at P_t $L_{tm} \leq 0.75 L_t$

at P_a $L_{am} \leq 0.75 L_a$

BELGIUM :

Criterion : $L_{tm} \leq 0.75 \frac{P_t}{P_a} L_a$

- independent of preoperational leak rate tests
- conservatism

Tests at elevated pressure can replace the tests at accident pressure

4. Test methods.

4.1 Use of two methods.

1. End criterion.

If both methods OK : stop after 8 hours

2. Concordance criterion.

If difference between methods less than

$$0.25\ L_t - 0.1\ L_{tm}$$

where

- $L_t = (P_t / P_a) . L_a$
- L_{tm} is average of the two measurements

no verification test (calibrated leak test)

4.2 Calibrated leak test.

ANSI/ANS-56.8 -1981 criterion

$$|L_o + L_{am} - L_c| < 0.25\ L_a$$

$0.75\ L_a < L_o < 1.25\ L_a$

modified for $P_t < P_a$

$$|L_o + L_{tm} - L_c| < 0.25\ L_t$$

$0.75\ L_t < L_o < 1.25\ L_t$

modified for $L_o < 0.75\ L_t$

$$|L_o + L_{tm} - L_c| < 0.125\ L_t + 0.125\ L_o$$

$\max(0.75\ L_{tm}, 0.1\ L_t) < L_o < 1.25\ L_t$

5. Tests at reduced pressure.

Goal : detect important leaks (misaligned valves, left open valves ,...)

On-line monitoring :
- compressed air make-up
- pressure containment
- pressure outside

Q_f versus $\sqrt{\Delta P}$ ΔP : -20 mbar -->+60mbar

Tests during operation can detect a leak of 1 cm in diameter

Plant	∅	Qf60 (Nm3/h)
T1	-	3.1
D3	-	4.3
D3	3/8"	22.5
D3	3/4"	94.7

Criterion : Qf 60 mbar ≤ 17 Nm^3/h

6. Periodicity of the tests.

Tests at elevated pressure (type A-tests) :

10 years

Tests at reduced pressure :

after each cold shutdown of more than fifteen days vinçotte

ENCLOSURE F

ESN/86/002

NEW BELGIAN POSITION ON CONTAINMENT LEAKAGE TESTING

B. De Boeck

Association Vinçotte
Sureté Nucleaire
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ABSTRACT

The containment leakage testing requirements (up to now 10 CFR 50 App. J) have recently been revaluated in Belgium. The criterion for type A tests at half the accident pressure has been strengthened, but the periodicity has been relaxed. New overall leakage test at very low overpressure have been required after each extended cold shutdown period. A few items of the procedure for type A tests have been modified. It is felt that the new requirements improve the safety but also lower the burden of the containment leakage tests.

1. INTRODUCTION

For more than ten years, the leakage tests of the Belgian containments have been made in accordance with 10 CFR 50 appendix J. With this experience, and in view of the recent developments in France and in the USA, it seemed usefull to reassess the leakage tests methodology. Therefore, a working group with representatives from the utilities, the architect engineers and the licensed organization was set up in 1984. The final report has been published in April 1986 and shows that some aspects of the present methodology can be modified and that the result offers a better compromise, combining the safety requirements and the operational ones. This paper gives the conclusions of the report.

2. TESTS AT ACCIDENT PRESSURE

Is called "accident pressure" and abbreviated Pa, the peak pressure in the containment, following a design basis accident, like mentioned in the Safety Analysis Report (definition identical to the one from 10 CFR 50).

It is felt that leakage tests at accident pressure are not warranted. The main reason is that their operational burden is not balanced by a clear safety benefit. The main drawbacks of these tests are:

- <u>Test duration</u>
  The duration of such a test is clearly larger than the one of a test realised at a lower pressure (more important preparation, longer pressurization and depressurization).

- <u>Danger</u>
  Even if such a test does not represent a dangerous loading for the containment, it is nevertheless true that it increases the risk of fires and the difficulty to fight these, and that it increases the risk of damaging equipments in the containment.

- <u>Representativeness</u>
  The Pa pressure is not representative of the real pressure in the containment after a design basis accident, on the one hand because of the margins and conservative assumptions taken in the calculation of Pa, and on the other hand because of the depressurizing effect of the containment cooling systems. Some of the type A tests performed in Belgium have shown higher leakage rates at half Pa than at Pa.

Furthermore, tests realised at a lower pressure permit to meet the safety objectives.

3. TESTS AT ELEVATED PRESSURE

Is called "elevated pressure" and abbreviated Pt, any pressure between Pa/2 and Pa, Pa and Pt being expressed in relative bars.

The 1980 edition of the 10 CFR 50 App. J, permits to do leakage tests at a pressure equal to the half of the accident pressure. The leaktightness criterion is taken from the leakage rate at full pressure and the one at reduced pressure, measured during the preoperational tests. Now, these measured leakage rates are tainted with errors being bigger when the leakage rate is lower, which is generally the case. One calculates then the ratio of the two leakage rates, and depending on the result, one uses for the criterion, either the ratio itself, either the square root of the ratio of the pressures. If the ratio of the leakage rates is used, one has seen that this ratio is not known with accuracy, but even if it were the case, then nothing indicates that it remains constant during the entire life-span of the containment. On the other hand, the square root of the ratio of the pressures does not represent the most pessimistic extrapolation law which can be obtained.

This does not imply that one should reject tests at a pressure lower than Pa, but rather that it is necessary to establish a more satisfactory criterion. The new Belgian criterion is:

$$Ltm \leq 0.75 \frac{Pt}{Pa} La$$

where - La is the leakage rate considered in the accident analysis
- 0,75 is an arbritary factor to cover the possible rise of the leakage rate in the interval between two tests
- Ltm is the 95% upper confidence limit of the measured leakage rate (appendix B of ANSI/ANS-56.8-1981 can be used to calculate this limit).

The extrapolation law of the leakage rate with the pressure, used in this criterion, is the one of the ratio of the relative pressures. This law is close to the law of the laminar flow, which gives the strongest variations of the leakage rate in function of the pressure. This law does not take into consideration the leaks with a threshold effect. Yet, the influence of such leaks is considered to be weak, as preoperational tests have shown.

To conclude, tests at elevated pressure can replace the tests at accident pressure if (1) the law of the ratio of the relative pressures is used to extrapolate the leakage rate and if (2) the test pressure is at least equal to Pa/2. There is no theoretical justification for the factor 2, but it seems desirable to test the containment at a pressure which is (1) not too different from the maximum pressure expected in the containment after accident, which (2) permits to measure the leakage rate with a reasonable accuracy, and which (3) limits the span on which the leakage rate has to be extrapolated.

4. TESTS AT REDUCED PRESSURE

4.1 Principle

In addition to the tests at elevated pressure, it is possible to perform leakage tests at a reduced pressure (i.e. lower than Pa/2), during operation. Such tests are in use in France and have been performed experimentally in Belgium. The decision has been taken to do them periodically (see § 5). The goal of these tests is not to measure accurately the leakage rate of the containment, but to detect any gross leakage path.

In normal operation, the pressure in the reactor building has a tendency to increase owing to the leakages of the compressed air system. If one measures the flow of incoming air, the pressure, the temperature and the humidity in the building, it is possible to calculate the leakage rate. For a typical test, the pressure is allowed to go from - 20 mbar to + 60 mbar. This extends on few days and measurements are taken every hour.

Symbols:

Q : flow of incoming gas (Nm^3/h)
P : absolute pressure in reactor building (mbar)
T : absolute temperature in reactor building (°K)
X : absolute humidity in reactor building (kg of water/kg of dry air)
Pv: partial pressure of water vapour (mbar)
V : quantity of dry air in reactor building (Nm^3)
Vr: free volume of reactor building (m^3)

One has:

$$Pv = \frac{P \cdot X}{0.622 + X}$$

and

$$V = Vr \cdot \frac{P - Pv}{1013} \cdot \frac{273}{T}$$

This computation is done at a regular interval delta t, and each time one computes delta V, the difference between V at time t and t - delta t. The leakage flow is then:

$$Qf = Q - \frac{\Delta V}{\Delta t}$$

At each time step one measures also delta P, the differential pressure between the reactor building and the outside. The values of Qf are then plotted in function of the square root of delta P (Qf is expected to be proportional to the square root of delta P). A straight line is then computed by the least squares method and translated to go thru the point Qf = 0 for delta P = 0. The value of Qf for delta P = 60 mbar (Qf60) is then compared with the criterion.

This criterion in Belgium is 17 Nm3/h, which corresponds to a circular hole of 1 cm in diameter. This value was chosen on the basis of the accuracy of the method used up to now, the goal being to minimize, on one hand the probability of not detecting an important leak, and on the other hand, the probability of starting a search for a non existent leak.

4.2 Experimental results

Tests have been performed in 1985 at Tihange 1 and 2, and Doel 3, to show the feasability of such tests. Some results are given below. Tests have been done with a normally isolated containment, like it is in operation, and also with different leakage paths. A few times, the leakage flow has been measured with a flowmeter installed on the leakage path.

It should be noted that for tests 8 and 9, there were head losses in the line in addition to the 3/4" flow restrictor.

TABLE 1

N°	UNIT	Ø opening	Qf60 Nm^3/h	Qf at delta P Nm^3/h	mbar
1	Tihange 1	/	3.1		
2	Doel 3	/	- 8.6		
3	Doel 3	/	4.3		
4	Doel 3	/	- 1.0		
5	Tihange 1	7 mm	11.0	11	60
6	Doel 3	3/8"	18.8		
7	Doel 3	3/8"	22.5	14 20	19 38
8	Tihange 1	0→3/4"	0,7/28.1		
9	Tihange 1	3/4"	32.5	33	60
10	Doel 3	3/4"	94.7	34	9

The conclusions of these tests are:

- small holes can be detected, the detectability limit is at around 10 Nm3/h, or a hole of 7 mmm in diameter
- the accuracy of the method is good, as can be seen from the measured leakage flows (based on the square root of the ratio of the pressures, the flow extrapolated at 60 mbar is 25 Nm3/h for test 7 and 88 Nm3/h for test 10)
- it is important to accurately measure the temperature and humidity variations in the containment during the tests.
- a pressure range from - 20 mbar to 50 mbar is to be considered as a minimum to get a good accuracy, especially for small holes.

5. PERIODICITY OF THE TESTS

It is unlikely that the containment, apart from the penetrations, will change significantly on a time scale shorter than ten years. Experience from the United States shows that when a test at elevated pressure fails, it is nearly always due to one or more leaking penetrations.

If one dissociates, for the test at elevated pressure, the function which verifies the leak tightness of the containment itself from the function which detects holes left inadvertently, then a periodicity of 10 years is acceptable for the tests at elevated pressure. The second function would then be realised on the one hand by the periodic tests of the penetrations (type B and C tests), and on the other hand by the tests at reduced pressure. These should be done when a possibility exists of having a loss of leaktightness of the containment. In Belgium, a test at reduced pressure will be done after each cold shutdown of more than fifteen days.

6. MISCELLANEOUS

6.1 Use of two measuring methods in parallel

In Belgium, the overall leakage rate tests are usually performed with the absolute method and the reference vessel method. These two methods are practically independent and their results can thus be used for mutual validation. Therefore it is not always necessary nor to pursue the test for 24 hours, nor to perform the calibrated leak test to verify the accuracy of the measures.

1. End criterion.

If both methods furnish, over a period of at least 8 hours and with at least 30 measure points, a leakage rate value which meets the criterion presented in § 3, then one may end the measurement.

2. Concordance criterion.

It is not necessary to initiate a verification test (for example: calibrated leak) if at the end of the measuring period the difference between the leakage rates measured by each of the two methods over the last 8 hours is less than:

$$0.25\ Lt - 0.1\ Ltm$$

where: - $Lt = \frac{Pt}{Pa}\ La$

- Ltm is the average of the two measurements of the leakage rate.

This criterion is largely arbitrary.
The principles which have led to its establisment are the following. The fixed term (0.25 Lt) is drawn from the success criterion of the calibrated leak test of ANSI/ANS-56.8-1981 (see § 6.2). The proportional term (0.1 Ltm) forces to a better concordance when the leakage rate is close to the maximum admissible value. In that case, it is indeed more useful to be sure that the leakage rate is correctly measured than in the case where the leakage rate is well below the criterion. In total, one obtains a concordance criterion which is consistent with the expected accuracy of the measuring methods used until now and which offers a reasonable guarantee that the leakage rate is correctly measured.

6.2 Calibrated leak test

If, during a leakage rate test at elevated pressure, only one measuring method is used, or if the concordance criterion mentioned in § 6.1 is not met, it is necessary to perform the calibrated leak test (or an equivalent test). The success criterion of this test, laid down in ANSI/ANS-56.8-1981, is only applicable in case the test pressure is equal to Pa and the superimposed leak is equal to about La.

To recall, the success criterion of this test is the following:

$$|Lo + Lam - Lc| \leq 0.25\ La$$

where
- Lo is the superimposed leakage rate
- Lam is the leakage rate measured before the calibrated leak is put into service
- Lc is the leakage rate measured after the calibrated leak is put into service

The following conditions have to be met to use this criterion:

- Pt = Pa
- 0.75 La $\leq$ Lo $\leq$ 1.25 Lt

It is easy to adapt this criterion in case Pt < Pa :

$$|Lo + Ltm - Lc| \leq 0.25\ Lt$$

where $Lt = \frac{Pt}{Pa} La$

The conditions for application are:

- Pa/2 $\leq$ Pt $\leq$ Pa (relative bars)
- 0.75 Lt $\leq$ Lo $\leq$ 1.25 Lt

If one chooses to take Lo lower than 0.75 Lt, this criterion looses its sense because it becomes too easy to meet. It is therefore necessary to adapt it. The following adaptation is proposed:

$$|Lo + Ltm - Lc| \leq 0.125\ Lt + 0.125\ Lo$$

The conditions for application are:

- Pa/2 $\leq$ Pt $\leq$ Pa (relative bars)
- max (0.75 Ltm; 0.1 Lt) $\leq$ Lo $\leq$ 1.25 Lt

This criterion has the following advantages:

- it remains simple
- it adapts itself to the value of Lo
- it is close to the ANSI criterion when Lo is close to Lt

One can note that (1) Lo may not be lower than 0.1 Lt if one wants to have a calibrated leak which remains in the measurable range, and that (2) the factor 0.125 is chosen arbitrarily equal to half the factor 0.25 of the uncorrected criterion.

6.3 Extrapolation of the leakage rate

According to the law one chooses to characterise the leaks of the containment, one obtains different relations between the leakage rate at test conditions and the leakage rate at accident conditions. The most conservative law is that of the flow of a venturi, which results in a leakage rate after accident 1.4 times higher than in test conditions (at the same pressure).

The French use, for their plants with liners, the law of the turbulent flow in a rough pipe, which is a little less conservative and gives a factor 1.35.
In France, the criterion is thus:

$$Lam \leqslant \frac{0.75}{1.35} La = 0.56 La$$

It is on the other hand useful to note that the factor 0.75 of the relation

$$Lam \leqslant 0.75 La$$

of Appendix J of 10 CFR 50 is not a factor to cover an extrapolation of the leakage rate towards accident conditions, but actually a margin to cover a possible rise of the leakage rate until the next test.

Still, in Belgium, for the calculation of the radiological consequences of a LOCA, it is supposed that the leakage rate of the containment stays at its maximum value during 24 hours and is thereafter reduced to half of that for the remaining time, whereas the pressure in the containment is rapidly brought down. Consequently one disposes here of an important conservatism.

To conclude, as long as these assumptions are conserved for the calculation of the radiological consequences, it is not necessary in the criterion of § 3, to include a supplementary factor to cover the rise of the leakage rate during accident conditions.

7. CONCLUSIONS

The establisment of a working group composed of representatives from the utilities, the architect engineers and the licenced organisation, to treat a precise technical subject, has led to the proposal of a notable improvement of the strategy applied to the overall leakage rate tests of the containment.

The main improvements are:

- shorter tests (on the condition to use two independent measuring methods)
- an increased confidence in meeting the objective of leaktightness (through the use of a criterion independent of the preoperational tests and based on a conservative extrapolation law)
- an increased confidence in maintaining the leaktightness of the containment during operation, despite a lower frequency for the tests at elevated pressure (by performing tests at reduced pressure during reactor operation).

8. REFERENCES

1 ANSI/ANS-56.8-1981, Containment System Leakage Testing Requirements

2 Proposed 10 CFR 50 App. J, Working paper D5

3 Draft Regulatory Guide MS 021-5, Containment System Leakage Testing

4 NUREG/CR-3549, Evaluation of Containment Leak Rate Testing Criteria

5 ESN/85/014, Report of the Working Group on Containment Leakage Testing

6 Containment Integrity and Leak Testing Procedures Applied and Experiences Gained in European Countries, CEC, Working Group No 1 - Ad hoc subgroup on "Containment Engineering Safeguards", (To be published)

ENCLOSURE G

NUCLEAR SAFETY
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REPORT OF THE WORKING GROUP ON CONTAINMENT LEAKAGE TESTING

I. INTRODUCTION

After ten years of operation of the first Belgian nuclear units, it seemed useful to use the accumulated experience on leakage tests of the reactor building, to revaluate the methodology in this field.

To this end, a working group composed of representatives from the utilities,the architect engineers and the licensed organization was set up around mid-1984. Six meetings have taken place between the end of 1984 and the beginning of 1986. The list of the participants is given in appendix.

Until now the American methodology has been used in Belgium. This report shows that certain aspects of this methodology can be modified and that the result offers a better compromise combining the safety requirements and the operational ones. As far as the aspects which are not treated in this report are concerned, the American methodology continues to apply. On the other hand, the group proposes to endorse the deviations accepted until now in this field.

II. TESTS AT ACCIDENT PRESSURE

Is called "accident pressure" and abbreviated Pa, the peak pressure in the containment, following a design basis accident, like mentioned in the Safety Analysis Report (definition identical to the one from 10 CFR 50).

It is not desirable to make the leakage tests realised at the Pa pressure mandatory after the start-up of a nuclear unit. They actually present drawbacks which are not balanced by evident advantages. These drawbacks are:

- Test duration
  The duration of such a test is clearly larger than the one of a test realised at a lower pressure (more important preparation, longer pressurization and depressurization).

- Danger
  Even if such a test does not represent a dangerous loading for the containment, it is nevertheless true that it increases the risk of fires and the difficulty to fight these, and that it increases the risk of damaging equipments in the containment.

- Representativeness
  The Pa pressure is not representative of the real pressure in the containment after an accident, on the one hand because of the margins and conservative assumptions taken in the calculation of Pa, and on the other hand because of the depressurizing effect of the containment cooling systems.

Furthermore, tests realised at a lower pressure permit to meet the safety objectives.

III. TESTS AT ELEVATED PRESSURE.

Is called "elevated pressure" and abbreviated Pt, any pressure between Pa/2 and Pa, Pa and Pt being expressed in relative bars.

The 1980 edition of the 10 CFR 50 App. J, permits to do leakage tests at a pressure equal to the half of the accident pressure. The leaktightness criterion is taken from the leakage rate at full pressure and the one at reduced pressure, measured during the preoperational tests. Now, these measured leakage rates are tainted with errors being bigger when the leakage rate is lower, which is generally the case. One calculates then the ratio of the two leakage rates, and depending on the result, one uses for the criterion, either the ratio itself, either the square root of the ratio of the pressures. If the ratio of the leakage rates is used, one has seen that this ratio is not known with accuracy, but even if it were the case, then nothing indicates that it remains constant during the entire life-span of the containment. On the other hand, the square root of the ratio of the pressures does not represent the most pessimistic extrapolation law which can be obtained.

This does not imply that one should reject tests at a pressure lower than Pa, but rather that it is necessary to establish a more satisfactory criterion. The proposed criterion is:

$$Ltm \leqslant 0.75 \frac{Pt}{Pa} La$$

where - La is the leakage rate considered in the accident analysis
- 0,75 is an arbitrary factor to cover the possible rise of the leakage rate in the interval between two tests
- Ltm is the 95% upper confidence limit of the measured leakage rate (appendix B of ANSI/ANS-56.8-1981 can be used to calculate this limit).

The extrapolation law of the leakage rate with the pressure, used in this criterion, is the one of the ratio of the relative pressures. This law is close to the law of the laminar flow, which gives the strongest variations of the leakage rate in function of the pressure. This law does not take into consideration the leaks with a threshold effect. Yet, the influence of such leaks is considered to be weak, as preoperational tests have shown.

To conclude, tests at elevated pressure can replace the tests at accident pressure if (1) the law of the ratio of the relative pressures is used to extrapolate the leakage rate and if (2) the test pressure is at least equal to Pa/2. There is no theoretical justification for the factor 2, but it seems desirable to test the containment at a pressure which is (1) not too different from the maximum pressure expected in the containment after accident, which (2) permits to measure the leakage rate with a reasonable accuracy, and which (3) limits the span on which the leakage rate has to be extrapolated.

IV. USE OF TWO MEASURING METHODS IN PARALLEL

In Belgium, the overall leakage rate tests are usually performed with the absolute method and the reference vessel method. These two methods are practically independent and their results can thus be used for mutual validation. Therefore it is not always necessary nor to pursue the test for 24 hours, nor to perform the calibrated leak test to verify the accuracy of the measures.

1. End criterion.

If both methods furnish, over a period of at least 8 hours and with at least 30 measure points, a leakage rate value which meets the criterion presented in § III, then one may end the measurement.

2. Concordance criterion.

It is not necessary to initiate a verification test (for example : calibrated leak) if at the end of the measuring period, the difference between the leakage rates measured by each of the two methods over the last 8 hours is less than

$$0.25\ Lt - 0.1\ Ltm$$

where: - $Lt = \frac{Pt}{Pa} La$
- Ltm is the average of the two measurements of the leakage rate.

This criterion is largely arbitrary. The principles which have led to its establisment are the following. The fixed term (0.25 Lt) is drawn from the success criterion of the calibrated leak test of ANSI/ANS-56.8-1981 (see § V). The proportional term (0.1 Ltm) forces to a better concordance when the leakage rate is close to the maximum admissible value. In that case, it is indeed more useful to be sure that the leakage rate is correctly measured than in the case where the leakage rate is well below the criterion. In total, one obtains a concordance criterion which is consistent with the expected accuracy of the measuring methods used until now and which offers a reasonable guarantee that the leakage rate is correctly measured.

V. CALIBRATED LEAK TEST

If, during a leakage rate test at elevated pressure, only one measuring method is used, or if the concordance criterion mentioned in § IV.2 is not met, it is necessary to perform the calibrated leak test (or an equivalent test). The success criterion of this test, laid down in ANSI/ANS-56.8-1981, is only applicable in case the test pressure is equal to Pa and the superimposed leak is equal to about La.

To recall, the success criterion of this test is the following :

$$|Lo + Lam - Lc| \leqslant 0.25\ La$$

where - Lo is the superimposed leakage rate
- Lam is the leakage rate measured before the calibrated leak is put into service
- Lc is the leakage rate measured after the calibrated leak is put into service

The following conditions have to be met to use this criterion:

- $Pt = Pa$
- $0.75\ La \leqslant Lo \leqslant 1.25\ La$

It is easy to adapt this criterion in case $Pt < Pa$:

$$|Lo + Ltm - Lc| \leqslant 0.25\ Lt$$

where $Lt = \frac{Pt}{Pa}\ La$

The conditions for application are :

- $Pa/2 \leqslant Pt \leqslant Pa$ (relative bars)
- $0.75\ Lt \leqslant Lo \leqslant 1.25\ Lt$

If one chooses to take Lo lower than 0.75 Lt, this criterion looses its sense because it becomes to easy to meet. It is therefore necessary to adapt it. The following adaptation is proposed:

$$|Lo + Ltm - Lc| \leqslant 0.125\ Lt + 0.125\ Lo$$

The conditions for application are:

- $Pa/2 \leqslant Pt \leqslant Pa$ (relative bars)
- $\max(0.75\ Ltm;\ 0.1\ Lt) \leqslant Lo \leqslant 1.25\ Lt$

This criterion has the following advantages:

- it remains simple
- it adapts itself to the value of Lo
- it is close to the ANSI criterion when Lo is close to Lt

One can note that (1) Lo may not be lower than 0.1 Lt if one wants to have a calibrated leak which remains in the measurable range, and that (2) the factor 0.125 is chosen arbitrarily equal to half the factor 0.25 of the uncorrected criterion.

VI. EXTRAPOLATION OF THE LEAKAGE RATE BETWEEN THE TEST CONDITIONS AND THE ACCIDENT CONDITIONS.

According to the law one chooses to characterise the leaks of the containment, one obtains different relations between the leakage rate at test conditions and the leakage rate at accident conditions. The most conservative flow is the flow of the venturi type which results in a leakage rate after accident 1.4 times higher than in test conditions (at the same pressure).

The French use, for their plants with liner, the law of the turbulent flow in a rough pipe, which is a little less conservative and gives a factor 1.35. In France, the criterion is thus :

$$Lam \leqslant \frac{0.75}{1.35} La = 0.56 La$$

It is on the other hand useful to note that the factor 0.75 of the relation

$$Lam \leqslant 0.75 La$$

of Appendix J of 10 CFR 50 is not a factor to cover an extrapolation of the leakage rate towards accident conditions, but actually a margin to cover a possible rise of the leakage rate until the next test.

Still, in Belgium, for the calculation of the radiological consequences of a LOCA, it is supposed that the leakage rate of the containment stays at its maximum value during 24 hours and is thereafter reduced to half of that for the remaining time, whereas the pressure in the containment is rapidly brought down. Consequently one disposes here of an important conservatism.

To conclude, as long as these assumptions are maintained for the calculation of the radiological consequences, it is not necessary in the criterion of § III, to include a supplementary factor to cover the rise of the leakage rate during accident conditions.

VII. TESTS AT REDUCED PRESSURE

In addition to the tests at elevated pressure, it is possible to perform leakage tests at a reduced pressure (i.e. lower than Pa/2), and where the goal isn't any more to mesure the leakage rate of the containment but to detect an important leak.

The French, for example, measure continuously the leaktightness of the reactor building, during reactor operation. The principle of this measurement is the following. In normal operation, the pressure in the reactor building has a tendency to increase owing to the leakages of the compressed air system. If one measures the flow of incoming air, the pressure, the temperature and the humidity in the building, it is possible to calculate the leakage rate. These measurements are made with the pressure varying from -40 to +60 mbar.

It is desirable to perform these tests once the temperatures in the reactor building are stabilized. Operational experience has shown that a period of two to three weeks was necessary to obtain this stabilization. It should thus be possible to obtain the result of a measurement at the latest after one month of nominal temperature and pressure in the primary circuit.

If such a test shows an unacceptable leak, the actions to be taken should also be specified. Given the importance of a leak-tight containment to reduce the consequences of a radioactive release in the reactor building, it is imperative to quickly suppress the leak or to go to cold shutdown.

On the other hand, it is necessary to have the time to find the leak, to suppress it and to redo the test, without having to face transients who themselves carry risks.

Following tests carried out in Belgium, the proposed action is : after the startup of the unit, and at the latest after two months of nominal temperature in the primary circuit, it should be shown that the leak of the containment is lower than the one resulting from a hole of 1 cm in diameter in a plate; in the opposite case the unit shall be brought to a cold shutdown at the end of the two months.

The values indicated in this action could be reviewed when the experience will be larger. The hole of 1 cm is chosen on the basis of the accuracy of the method used up to now, the goal being to minimize, on the one hand the probability of not detecting an important leak, and on the other hand, the probability of starting a search for a non existent leak.

VIII. PERIODICITY OF THE TESTS

It is unlikely that the containment, apart from the penetrations, will change significantly on a time scale shorter than ten years. Experience from the United States shows that when a test at elevated pressure fails, it is nearly always due to one or more leaking penetrations.

If one dissociates, for the test at elevated pressure, the function which verifies the leaktightness of the containment itself from the function which detects holes left inadvertently, then a periodicity of 10 years is acceptable for the tests at elevated pressure. The second function would then be realised on the one hand by the periodic tests of the penetrations (type B and C tests), and on the other hand by the tests at reduced pressure. These should be done when a possibility exists of having a loss of leaktightness of the containment. It is proposed that a test at reduced pressure should be done after each cold shutdown of more than fifteen days.

IX. CONCLUSIONS

The establisment of a working group composed of representatives from the utilities, the architect engineers and the licenced organisation, to treat a precise technical subject, has led to the proposal of a notable improvement of the strategy applied to the overall leakage rate tests of the containment.

The main improvements are:

- shorter tests (on the condition to use two independent measuring methods)

- an increased confidence in meeting the objective of leaktightness (through the use of a criterion independent of the preoperational tests and based on a conservative extrapolation law)

- an increased confidence in maintaining the leaktightness of the containment during operation, despite a lower frequency for the tests at elevated pressure (by performing tests at reduced pressure during reactor operation).

APPENDIX

LIST OF THE PARTICIPANTS OF THE WORKING GROUP ON CONTAINMENT LEAKAGE TESTING

A. BECQUAERT	(KCD)
B. CENTNER	(ELECTROBEL)
H. DE BACKER	(KCD)
B. DE BOECK	(VINCOTTE)
M. GUEBEN	(CNT)
P. HAVARD	(CNT)
P. HERNALSTEEN	(TRACTIONEL)
J.J. MONNIEZ	(CNT)
F. ROOSE	(KCD)
P. SCHUERWEGH	(KCD)

ENCLOSURE H

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SEVERE ACCIDENT RISK REDUCTION BY CONTAINMENT LEAKAGE TESTING DURING OPERATION

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It was decided in Belgium in 1986 to reduce the frequency of the type A leakage tests of the containment and to perform annual low pressure leakage tests during reactor operation. These tests require special care if a good sensitivity and thus a high probability of detecting pre-existing openings is to be achieved. The experience so far has been very satisfactory. The literature shows that the probability of pre-existing openings is relatively high. Containment leakage tests performed during reactor operation can significantly increase the probability of detecting pre-existing openings, and therefore reduce the risk of severe accidents.

1. Introduction

In 1986 the containment leakage testing requirements were modified in Belgium [1]. Type A tests will be performed every 10 years, but the integrity of the containment will be verified at least every year by a global low pressure leakage test performed during reactor operation. This test has the capability to detect leaks that correspond to a hole of 0.7 cm in diameter or more. To achieve this sensitivity it is necessary to choose the instrumentation carefully and to follow a good procedure.

Because the containment is an important factor in mitigating the consequences of a severe accident, it is necessary not only to assess its integrity after the accident has taken place, but also to ensure that it is leaktight before. Containment leakage tests performed during reactor operation have this capability. They are therefore an important step in any severe accident risk reduction scheme, because the probability of pre-existing openings, as documented up to now in the literature, is relatively high.

2. Low pressure containment leakage tests

It is now mandatory in Belgium to measure the leakage rate of the containment after each cold shutdown of more than fifteen days. This test is performed during reactor operation. Some time must be allowed to stabilise the conditions (temperature, humidity) in the reactor building, to perform the test, to correct possible problems and in that case to perform an additional test. Therefore the requirement introduced in the Technical Specifications of the plants is the following: if after two months of maintaining the primary circuit at a temperature above 260 °C, it has not been shown that the leakage rate of the containment is below 17 Nm^3/h (i.e. about 0.7%/day), the plant shall be brought to cold shutdown.

This type of requirement is unusual in the Technical Specifications because normally the frequency of the test is given and then some time is allowed for actions if the test is failed. Here the two are combined. The reason for this is to give some incentive to the utilities to perform the test as soon as possible after restart. Indeed this gives them more time for corrective measures, should the test fail.

2.1. Test methodology

In normal operation, the pressure in the reactor building has a tendency to increase owing to the leakage of the compressed air system. If one measures the flow of incoming air, the pressure, the temperature and the humidity in the building, it is possible to calculate the leakage rate [1]. The absolute method and/or the reference vessel method can be used.

For a typical test, the pressure is allowed to go from −20 mbar to +60 mbar. A least the range between 0 and 50 mbar should be covered if one wants to have a reasonable accuracy. The pressure increase rate is normally in the range of 0.5 to 1 mbar/h. A test therefore lasts for a few days. The minimum test duration should be 50 h, to be able to get enough data points. If during the test, the atmospheric pressure drops suddenly and the maximum differential pressure is reached before 50 h, the test should be performed again.

All the parameters are measured every 30 s. The values are averaged over 15 min and this gives one data point. A typical test gathers 200 to 400 data points. This is done by means of a personal computer. The data points are plotted in a graph showing the leakage rate as a function of the square root of the differential pressure between the reactor building and the auxiliary building.

During the test, care should be taken not to disturb the conditions in the reactor building. Airlock movements should be avoided as far as possible. The ventilation and the cooling of the containment should be very stable. The method takes care of temperature variations but the representativity of the temperature measurements is never perfect. Therefore any disturbances in the temperature distribution in the containment will lead to a greater spreading of the data points.

3. Results from the low pressure tests

The tests performed in Belgium use the same instrumentation as the type A tests, with the addition of the flow-meters on the compressed air system. These are thermal flow-meters which need no correction for temperature and pressure. To save a penetration, the pressure difference between the containment and the auxiliary building is not measured directly, but is computed from absolute pressure measurements. The absolute pressure in the containment is also needed to compute the mass of air.

The temperature is measured using about 30 platinum probes distributed in the containment volume so as to give the best possible average temperature. The humidity is measured by 5 to 10 lithium chloride probes. In the absolute method the air mass change in the containment during each time step is computed from the absolute pressure, the temperature and the humidity. In the reference vessel method the air mass change is computed from the absolute pressure, the pressure difference between the reference vessel and the containment, and the humidity. For both methods, the free volume of the containment must be known.

The difference between the air mass change computed from the parameters in the containment, and the air mass change measured by the flow-meters on the compressed air system, is the leakage flow of the containment. This leakage is then plotted versus the square root of the differential pressure between the reactor building and the auxiliary building.

A straight line is then computed by the least square method. Conventionally the leakage rate is expressed a the difference between the value at 60 mbar and th

Table 1
Results from the low pressure leakage tests

	Test	Absolute			Reference vessel		
		Qf0	Qf60 (N m³/h)	σ Qf60	Qf0	Qf60 (N m³/h)	σ Qf60
Doel 3	10/87	2.4	0.3	1.16			
	10/87	2.3	0.3	0.73			
	9/88	−4.9	2.1	0.84	−5.6	3.8	1.19
Doel 4	6/88	2.4	3.2	0.66	1.0	5.1	1.25
Tihange 1	1/87	−14.1	1.6	1.22	−12.9	−1.7	1.68
	1/87	−14.2	3.8	1.33			
	4/88	2.3	−0.9	0.49			
Tihange 2	4/87	−0.8	3.4	0.90			
	5/88	7.6	3.5	0.25			
Tihange 3	7/87	2.4	1.0	1.34	2.5	0.7	0.73
	8/87	3.2	−0.6	1.33	3.1	−1.6	0.43
	7/88	1.5	−0.1	0.37	1.6	−0.1	0.76

value at 0 mbar, and is noted as Qf60. The value at 0 mbar (is noted as Qf0) should theoretically be zero, but is nearly never so, for two reasons:
- the systematic errors of the instrumentation and the error on the free volume of the containment;
- an unaccounted inflow or outflow of gas, which is independent of the pressure in the containment.

The standard deviation is also computed and is a measure of the spreading of the data points. This spreading comes from the errors of the instrumentation and from lack of representativity in temperature and humidity measurements when these parameters vary. For this reason it is important to have a temperature and a humidity which are as stable as possible in the containment.

Table 1 gives the results obtained in 1987 and 1988. These results show that when the containment is leaktight, Qf60 is lower than 5 N m^3/h. Therefore if one measures a value higher than 10 N m^3/h, one is nearly sure that there is a leak. A leak of 10 N m^3/h at 60 mbar corresponds to a hole of 0.7 cm in diameter [1].

The standard deviation lies between 0 and 2 N m^3/h. One should not place too much emphasis on the value of the leakage rate, because the error is of the same magnitude as the value measured.

4. Severe accident risk reduction

To mitigate the consequences of a core meltdown, a leak-tight containment is very important. In normal operation, three barriers (the fuel rod cladding, the reactor coolant system pressure boundary, and the containment pressure boundary) protect the environment from the release of radioactive material present in the fuel. In many core meltdown accidents, the first two barriers are progressively breached and the containment represents the final barrier against releases. Therefore in severe accident analyses a great emphasis is placed on the containment behaviour [2]. Of course if the containment is to remain leaktight during the accident, it has to be leaktight at the onset of the accident. Different studies have assessed the kind of preexisting openings and calculated the unavailability of the containment.

4.1. Preexisting openings

Containment unavailability is defined as the probability that the containment will not perform its function successfully at any given time during plant life. Containment unavailability can be due to excessive valves or penetrations leakage, valves or penetrations left open after testing or power transitions, holes drilled through the containment and left unsealed, airlocks failure. The leakage area can be very small or very large (from less than 1 cm^2 to several square meters for a personnel airlock). The time it remains open may also vary widely. An airlock with both doors open will normally not remain so for long, but some leaks may go undetected until the next containment leakage test.

Table 2

	Unavailability	Leak area (in.^{2})
	0.022	0.001 to 0.01
	0.055	0.01 to 0.1
	0.033	0.1 to 1
Total	0.11	

An extensive study of the reliability of the containment was performed in NUREG/CR-4220 [3]. Licensee Events Reports (LERs) and Integrated Leak Rate Test (ILRT) reports were analysed to gather information about the containment performance. The containment unavailability was then calculated from this information. A preliminary estimate obtained from the LER data base of containment unavailability due to large leakage events (holes in the containment liner or open containment isolation valves) is in the range of 0.001 to 0.01. Containment unavailability for relatively small leaks which violate plant Technical Specifications is estimated to be 0.3.

Estimates of containment unavailability as a function of leak area were obtained using ILRT data. A first analysis using only the reports of type A tests gave the results shown in table 2 for PWR containment unavailability versus leak area.

Because type B and C tests are typically performed before an ILRT, the leak rate noted in an ILRT is smaller than the actual case. Therefore an additional review of "as found" leakages from type B and C tests was performed. The failures identified in this review were added to the previous results and the total unavailability is presented in table 3.

Table 3

	Unavailability	Leak area (in.^{2})
	0.05	0.001 to 0.01
	0.125	0.01 to 0.1
	0.075	0.1 to 1
Total	0.25	

The total unavailability is thus very close to that obtained from the LER data base (0.3). This shows that in the case of an accident, the probability that the containment will leak in excess of the Technical Specification value, is in the range of 25 to 30%.

A similar study has been performed in Belgium. LERs do not exist for Belgian plants, therefore only ILRT reports were used. Because type B and C test reports give only "as left" results, the type A test reports were used alone. Twelve ILRT reports were analysed, covering about 36 reactor years. Three tests showed a containment failure. These are:

- Doel 2, September 1986: at 0.5 bar overpressure, an open valve was discovered on the personnel air lock and was closed.
- Tihange 2, July 1981: at 2.7 bar overpressure the equipment hatch began to leak. This hatch is bolted from outside and is therefore not self-sealing. It was discovered that the torque used for the bolts was too low.
- Tihange 3, July 1984: at 0.4 bar overpressure an open line was discovered on the equipment hatch. This line had been used previously for some tests and had been inadvertantly left open.

Using the same methodology as in NUREG/CR-4220, one obtains a containment unavailability of 0.13 which is very close to the value of 0.11 obtained in that NUREG.

Ref. [4] also contains a study of pre-existing openings in technical annex 9. The study was performed in Italy by ENEA/DISP and was based on data taken from American LERs and Nuclear Power Experience Books. Data from the Italian Operating Experience were also used. The containment unavailability versus leak area obtained in this study is shown in table 4.

The total unavailability is close to the value obtained in NUREG/CR-4220, even if one subtracts the contribution from leak areas lower than 0.03 cm^2, which would not give a real containment unavailability.

Table 4

	Unavailability	Leak area (cm^2)
	0.088	lower than 0.03
	0.084	0.03 to 0.3
	0.076	0.3 to 3
	0.008	3 to 30
	0.008	larger than 30
Total	0.26	

When comparing the unavailability versus leak area from different studies, care should be taken of the formula used to compute the leak area from the mass flow rate. The Italian study uses a formula which gives results 70% higher than those of the formula used in NUREG/CR-4220. The formula chosen depends on the assumptions about the leakage path. In most cases the characteristics of the leakage path are either not known or very complex. Therefore instead of speaking of leak area, one should speak of "equivalent" leak area, corresponding to specific assumptions.

4.2. Leakage tests during operation

Section 4.1 has shown that the probability of pre-existing openings is high: a best-estimate value based on the existing literature would lie between 0.1 and 0.3. This is the probability that at any given time the leakage rate of the containment would be higher than the value given in the Technical Specifications.

Leakage tests during reactor operation, as defined in section 2, have the potential to increase the probability of detecting pre-existing openings. This is in fact their main goal. How effective are those tests in meeting that goal?

As has been shown in section 3 and in ref. [1], the detectability limit is at around 0.4 cm^2, or 0.06 $in.^2$. From the tables presented in section 4.1 it can be seen that this would reduce the unavailability of the containment by about a factor of 2. More importantly, it would be the larger holes, and thus those contributing the most to the risk, which would be taken out of the unavailability figures.

To quantify the impact of performing leakage tests during reactor operation on the risk of severe accidents, one needs a level 3 probabilistic safety assessment (PSA), which takes into account the probability of pre-existing openings versus leak area. Such a study was not available when this paper was written. In NUREG-1150 [2], for the analysis of Zion, there is a containment failure bin for pre-existing openings (failure bin 6 in table 4.3), but the probability assigned to this bind is independent of the leak area. In ref. [5], which is the detailed study for Zion done for the NUREG 1150, no information is given as to how the results of NUREG/CR-4220 have been used. Nevertheless, given the relatively high probability of having a hole exceeding the detectability limit (between 0.05 and 0.15 as shown earlier in this section), and given the large amount of radioactivity which could leak through such an opening, one can say confidently that the risk reduction would not be negligible.

5. Conclusions

Global low pressure containment leakage tests during reactor operation have been performed in Belgium for more than three years. The results have been very satisfactory. These tests allow the detection of leaks with an area of 0.4 cm^2.

Based on present international experience, the probability that at any given time the containment shows a leak with an equivalent area larger than 0.4 cm^2 has been shown to be between 0.05 and 0.15. Low pressure tests have the capability to bring this figure to zero each time they are performed.

If a severe core accident occurs when there is a hole in the containment, the radiological consequences can be very high. It is important to reduce the probability of such a hole as far as possible. Low pressure tests have this capability. They are therefore an important factor in reducing the risk of severe accidents.

References

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[3] Reliability Analysis of Containment Isolation System, NUREG/CR-4220 (1985).

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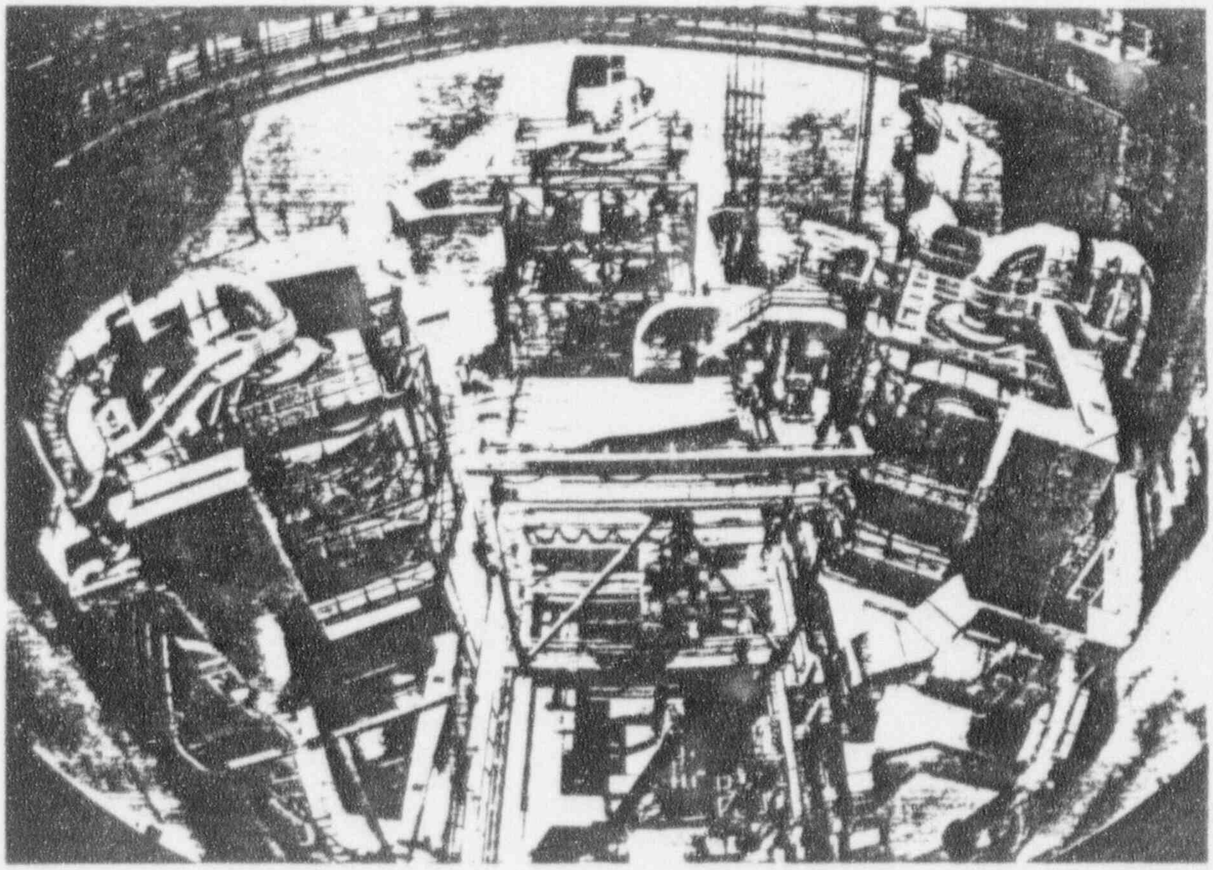
ENCLOSURE I

How tight

is your containment in operation ?



BELETEST

BELGIAN LEAK TEST

An efficient way to perform on-line containment integrated leakage rate testing

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1. Background

After ten years of Belgian PWR commercial operation, at the request of the Belgian Licensing Authority, a task force was set up to analyze the results gained from Containment Leakage Rate Testing (CLRT) experience.
This task force included representatives from:
- Licensing Authority (VINCOTTE)
- Utilities (EBES and INTERCOM)
- Architect Engineer (TRACTEBEL)

The analysis has evidenced that some aspects of the U.S. methodology, applied so far in Belgium, could be modified in order to reach a better trade-off between plant safety and operation requirements, through "on-line low pressure" tests.
Additionally, this methodology significantly reduces plant outage requirements.

It was concluded that after the containment preoperational leakage rate tests performed at peak pressure (Pa) to measure a leakage rate (Lam), it should not be considered as mandatory to perform periodic peak pressure tests in consideration of the following reasons:
- lack of representativity of the peak pressure versus the effective pressure in the containment after an accident
- risks of fire and of damaging non-safety-related components in the containment
- long time requested for pressure raising and measurements.

The 10 CFR50 - Appendix J - imposes to perform three times over ten years of operation containment integrated (type A) leak tests at a reduced pressure at least equal to half the peak pressure and to measure the leakage rate (Ltm).
*"The leakage characteristics yielded by (preoperational) measurements Ltm and Lam shall establish the maximum allowable test leakage rate Lt of not more than La x (Ltm/Lam).
In the event Ltm/Lam is greater than 0.7, Lt shall be specified as equal to La (Pt/Pa).*[1/2]"

From the test data analysis it appeared that:
- the measured values of Ltm and Lam are affected by errors which become greater as the actual leakage rate becomes smaller, which is generally the case
- the first ratio is expected to change during the containment lifetime
- the ratio $(Pt/Pa)^{1/2}$ is not conservative for laminar flow rates along the leak paths.

The US acceptance criterion was then analyzed to improve accuracy and conservatism.

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2. Belgian approach

Reduced pressure tests

• Based on an extensive testing and validation program performed with the research laboratory of the Belgian utilities LABORELEC experienced in such testing, another acceptance criterion is defined which is independent of the leakage rate measurements, deals with the laminar flow type along the leak paths and leads to the greatest leakage rate variation versus pressure changes.

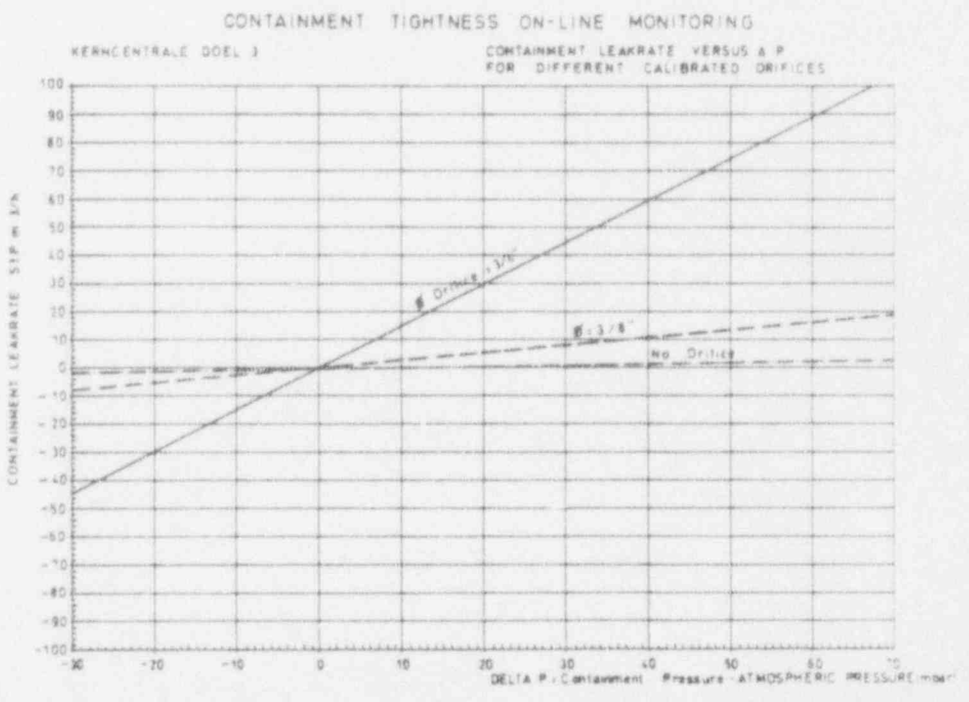
• In Belgium, containment leak tests at reduced pressure (Pt) are performed once every ten years using both absolute and comparative method (reference vessel method).
These two methods are totally independent and their results can be used for their mutual validation.

If each of both measurement techniques provides, over a period of at least 8 hours and with at least 30 consecutive measurement points, a leakage rate which meets the acceptance criterion, the test can be stopped.

Hence this approach does not require to carry on the test during 24 hours, nor to perform the calibrated leak test to verify the accuracy of the leakage rate measurement.

• If one method only is used for reduced pressure tests, or if the concordance criterion ANSI/ANS-56.8 - 1981 is not met, it is mandatory to perform a calibrated leak test (or an equivalent test).

A new acceptance criterion for this case was derived from the ANSI/ANS peak pressure test acceptance criterion to obtain the following advantages:
- easy application
- dependent upon the



calibrated leak (Lo)
- close to ANSI criterion when Lo is close to the maximum allowable leakage rate at reduced pressure (Lt).

On-line low pressure tests

Experience shows that the reactor containment liner does not give rise to tightness problems. Major sources of leaks are containment isolation valves and penetrations. These are periodically tested with a frequency consistent with 10 CRF 50 - Appendix J - requirements (types B and C tests).

Therefore, as a complement to the reduced pressure test method, another method has been developed to perform tests at very low pressures consistent with plant operation, the objective being then to detect, instead of a containment liner "natural degradation", any gross "localized" leak such as misaligned valves or left open valves, flanges or instrument connections or a faulty operation such as, for instance, an inadvertent drilling through the containment liner.

Experience shows that **these gross** localized leaks can be **evidenced** by **continuous containment on-line monitoring** during plant operation. During normal operation, the pressure in the containment building tends to increase due to compressed air leakage from pneumatically operated equipment.

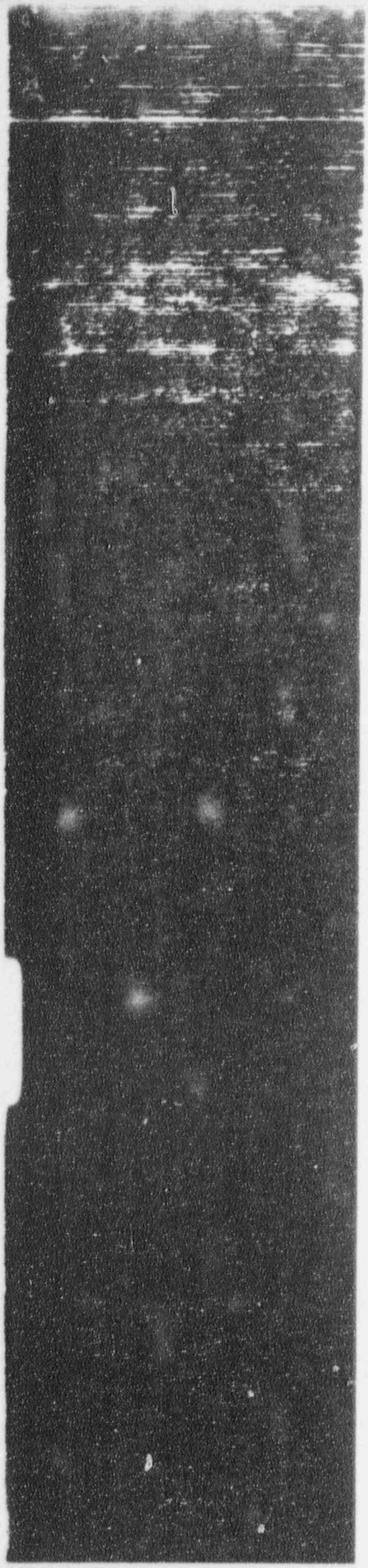
By monitoring the compressed air makeup to the containment, it is thus possible, through appropriate measurements and a calculation code, to correlate the theoretical inner pressure increase versus the measured one.
The containment leakage rate can be derived from discrepancies between these values.

The calculation code, developed for the low pressure tests takes into account the containment temperature and moisture variations during the tests. This code was validated by the experimental results.
The measurements are performed within the pressure range -40 mbars to +60 mbars.
One or both techniques (absolute method and/or reference vessel method) can be used for these tests.

After completion of the leak test, a verification test can be performed by superimposition of a leak through a calibrated orifice typically 3/8", 1/2" or 1".
Experience shows that, the detection limit is lower than 5 $STPm^3/h$ when normalized to an effective containment pressure of 60 mbars, typical values of 1 $STPm^3/h$ have been measured for tight containments.
An acceptance criterion is calculated on the basis of the characteristics of each plant.

For Belgian PWRs, a leak rate of 17 $STPm^3/h$ corresponds, at containment room temperature, to 10 times the maximum allowable leakage rate La extrapolated to 60 mbars.
Physically it also corresponds to the leak through a hole of 1 cm diameter in a thin plate at an effective pressure of 60 mbars.

The experience gained so far indicates that such tests can be easily performed in less than 72 hours.



3. BELETEST highlights

The Belgian approach to Containment Integrated Leakage Rate Testing combines two testing schemes:

- a test at reduced pressure once every ten year period instead of every three year as usual,
- a continuous on-line monitoring system.

This approach meets the concerns of both the Licensing Authority and the Utilities. The first is concerned by the **representativity** of the type A usual test prescribed by the NRC regulations and the latter are concerned by the **duration of the shutdown** necessary to raise the pressure and to perform the measurements and by the risks of damage to the non-safety-related equiments during such tests.

The **Belgian approach** does not only meet these concerns but also presents other advantages such as:

- a maximum allowable test leakage rate formula independent of the preoperational test results
- a greater confidence in the containment integrity thanks to the continuous on-line monitoring enabling to immediately detect any small aperture inadvertently left open through the containment.

A similar approach is already used in some European countries while others are also contemplating its systematic use.

The use of this approach for checking containment tightness calls for an adaptation of the methodology and the software tools in terms of the plant characteristics.
TRACTEBEL can:

- perform such an adaptation,
- bring its support during the licensing process with the Safety Authorities
- justify the representativity of the method on the basis of its experience and the Belgian validation package,
- make available the software to analyze the measurements
- assist the Utility during the first application of the new method.