Production d'énergie (hydraulique, thermique et nucléaire)

LA SURVEILLANCE CONTINUE DE L'ETANCHEITE DES ENCEINTES DE CONFINEMENT : LE SYSTEME SENTIEN

PERMANENT MONITORING OF CONTAINMENT INTEGRITY : THE SENTIEN SYSTEM

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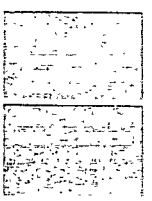

EDF
Electricité de France

Direction des Etudes et Recherches

SERVICE ENSEMBLES DE PRODUCTION
Département Surveillance Diagnostic Maintenance

1993

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EXECUTIVE SUMMARY :

Reactor containment integrity is of prime importance to the safety of PWR units. It is checked by means of tests performed at high pressure during the containment building pressure tests. These periodical tests are supplemented in France by permanent monitoring using the SEXTEN system. First feasibility tests for this system were carried out in 1980. The encouraging results obtained led to the development of a prototype, followed by an industrial system which has since been installed in all French PWR units.

This system measures the containment leak rate, with corrections for the compressed air intakes used by the air-operated valves. Leaktightness is expressed in terms of the leak rate for a 60 mbar overpressure. If the leak rate exceeds a fixed limit value, leak detection operations are initiated, using SEXTEN.

A new version of the system, known as SEXTEN 2 is being developed.

2 authors 2 figs

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SYNTHÈSE :

L'étanchéité des enceintes de confinement est primordiale pour la sûreté des tranches REP. Elle est contrôlée à l'aide de tests réalisés à forte pression, pendant les épreuves enceintes. En France, ces essais périodiques sont complétés par une surveillance en continu réalisée par un système appelé SEXTEN. Les premiers essais de faisabilité de ce type de surveillance ont été réalisés en 1980. Les résultats encourageants obtenus ont conduit à la réalisation d'un prototype, puis d'un système industriel qui a été généralisé sur toutes les tranches REP françaises.

Le système mesure le débit de fuite de l'enceinte en le corrigeant des apports de l'air comprimé consommé par les robinets pneumatiques. Il caractérise l'étanchéité en calculant le débit de fuite pour une surpression de 60 mbar. Ce débit doit rester inférieur à une valeur limite fixée, sinon des recherches de fuites doivent être réalisées avec l'aide du SEXTEN.

Une nouvelle version du système, appelée SEXTEN 2, est en cours d'étude.

EXECUTIVE SUMMARY :

Reactor containment integrity is of prime importance to the safety of PWR units. It is checked by means of tests performed at high pressure during the containment building pressure tests. These periodical tests are supplemented in France by permanent monitoring using the SEXTEN system. First feasibility tests for this system were carried out in 1980. The encouraging results obtained led to the development of a prototype, followed by an industrial system which has since been installed in all French PWR units.

This system measures the containment leak rate, with corrections for the compressed air intakes used by the air-operated valves. Leaktightness is expressed in terms of the leak rate for a 60 mbar overpressure. If the leak rate exceeds a fixed limit value, leak detection operations are initiated, using SEXTEN.

A new version of the system, known as SEXTEN 2 is being developed.

CONTINUOUS MONITORING OF CONTAINMENT LEAKTIGHTNESS THE SEXTEN SYSTEM

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ABSTRACT

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 played its part.

The containment leaktightness is usually checked before the unit is started and, then, periodically by performing integrated leakage rate tests. In France, it was decided to also check the containment leaktightness on a permanent basis by installing a continuous monitoring system : the SEXTEN, working during the unit operation.

The first studies were performed in 1980, when a containment leakage rate test was performed in an operating plant. The measurement system detected a leak through the Plant Radiation Monitoring System and an undesired air inleakage into the containment through the Service Compressed Air Distribution System.

Following these important results, a prototype of a containment leakage rate continuous monitoring system was designed and installed in two plants for an evaluation period. This system was called SEXTEN (from the French : Surveillance en EXploitation du Taux de fuite des ENceintes de confinement). The conclusions of the evaluation period were positive and it was decided that all EDF PWR plants would be equipped with this monitoring system.

The measurement of the leakage rate is based on the measurement of the average temperature, the average partial steam pressure, the absolute pressure inside the containment and the Instrument Compressed Air Distribution Sytem flow rate.

Because of the ICADS air which is released inside the containment by the air operated valves, the containment pressure slowly increases until it reaches an upper limit when a quick depressurization is performed. Generally, one containment pressure cycle lasts 20 days. The SEXTEN system uses these containment pressure cycles to perform its monitoring. It measures an average leakage rate and an average containment gauge pressure every day and analyses these measurements during one containment pressure cycle in order to calculate the containment leakage flow rate at a positive gauge pressure of 60 mbar (Lr60).

In France, in 900 MW units, the containment leaktightness is considered adequate when Lr60 is below 5 m3/h STP. For a 900 MW unit containment (free volume of about 50 000 m3), the average uncertainties with the SEXTEN system are : 1,3 m3/h STP over a 24-hour measurement period for the containment leak flow rate and 0,8 m3/h STP for the assesment of Lr60 over a containment pressure cycle.

The system operates continuously and issues measurements daily or at the end of each containment pressurization cycle. 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.

The SEXTEN system confirmed that leakages problems may sometimes occur in the containment of operating units. The leaks are generally located in the circuits running across the containment, mainly in valves. This monitoring system complements the tests performed to measure the leakage rate at the LOCA pressure, but it does not replace them. In France it has been classified as an "Important for Safety System".

A new version of the system is now under development, it is called the "SEXTEN 2". The first prototypes might be installed in operating units at the beginning of 1993, for an evaluation period.

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

A new version of the system is now under development, it is called the "SEXTEN 2". The first prototypes might be installed in operating units at the beginning of 1993, for an evaluation period.

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 were 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/TO, dP/Po-Ho, dH/Po-Ho 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 m3/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 m3/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 m3/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 Radiation Monitoring System was again isolated and we measured a containment leak rate of 0 m3/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 on this type of component.

STUDY AND DEVELOPMENT OF A LEAK MONITORING SYSTEM

Following this test, another containment of a different type was intrumented 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 monitoring 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.

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 m3/h STP.

If Lr60 is in the range of 5 to 10 m3/h, the personnel is bound to complete a leak localization procedure.

If Lr60 is above 10 m3/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.

Our opinion is that the three types of leak tests : integrated global leak test performed at full LOCA pressure every 10 years, tests on isolation valves performed every year and continuous leak rate monitoring performed in operation with the SEXTEN system enables an efficient control of the containment leaktightness.

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 diagnosis is based on the analysis of a curve presenting the measured points (pressure, leak rate) for a pressurization cycle (figure 2).

SEXTEN calculates the slope of this curve which enables the calculation of the containment leak rate for a 60 mbar (0.9 psi) overpressure (Lr60). This value is representative of the containment leaktightness in operation and an acceptance criterion concerning this value has been defined.

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

One of the problems consists in finding an instrumentation capable of accurately measuring the average temperature and the average water-vapor partial pressure, especially when these quantities have large fluctuations, which happens quite often inside the containment of an operating unit. The choice of the location of the various sensors and their weighting for the computation of average values are essential to have accurate measurements.

CHARACTERISTICS OF THE SEXTEN

The system consists of a processing unit, a data logger, a plotter and a printer. The following instrumentation is used :

- 1 absolute pressure transducer in each containment.
- 10 temperature sensors in each containment.
- 2 dew point sensors in each containment.
- 1 flowmeter in the ICAD System.
- 1 atmospheric pressure transducer.

For a 900 MW unit containment (free volume of about 50 000 m3), the average uncertainties with the SEXTEN system are :

- 1.3 m3/h STP over a 24-hour measurement period for the containment integrated leakage rate.
- 0.8 m3/h STP for the assessment of Lr60 over a pressurization cycle in the containment.

It takes approximately 4 hours to confirm the occurrence or elimination of a 5 m3/h STP leak. The system operates continuously and issues measurements daily or at the end of each pressurization cycle. 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.

The evaluation of the containment leak rate starts with a pressurization cycle. Each day, the measurements of the containment leak rate, its uncertainty and the containment over pressure are performed. These mesasurements are invalidated if the uncertainty is too high. After five valid measurements, a first calculation of Lr60 and its uncertainty is performed. These values are more precisely recalculated after each subsequent valid 24-hour period. The most precise values are obtained at the end of the pressurization cycle.

RETURN OF EXPERIENCE IN FRENCH UNITS

The installation of the SEXTEN system in all the french PWR started in the middle of the eighties. The experience which we have with the system corresponds to a cumulate time of operation of about 200 reactor-years.

The experience confirmed that leakage problems may sometimes occur in the containment of operating units. The leaks are generally located in the systems which can provide a direct connection between the inside and outside atmospheres of the primary reactor containment under normal operation, such as : the Plant Radiation Monitoring System, the Nuclear Island Vent and Drain System, the Containment Sweeping Ventilation System and the Containment Atmosphere Monitoring System. Once, a leak problem was localized in the containment access lock.

Generally the leaks are located in incorrectly-closed or leaking valves. Sometimes, leaks were due to pneumatic components (connectors, tubes). At present, all the leaks were located within the allocated time and no cold shut-down was to be performed.

Nevertheless, containment leaks in operation are rare and, more often, the measured leakage rate at 60 mbar overpressure ranges from 0 to 2 m3/h STP, so that the 5 m3/h STP criterion is very largely met. When a leak occurs, the leak rate is quite above the criterion.

THE SEXTEN 2 SYSTEM

Some equipments which were chosen to constitute the SEXTEN system are no more manufactured and a new version of the system, called SEXTEN 2, is under development.

Most of the functions of the SEXTEN 1 are maintained or improved in the SEXTEN 2 software. The main improvements are the following :

- when a new containment pressurization cycle starts, the software uses the information given by the previous cycle to perform the calculation of Lr60. This function avoids the absence of Lr60 measurements during the beginning of a new pressurization cycle.

- more performant sensor failure detection algorithms are used. Any non-vital sensor failure is automatically taken in account by the software which eliminates the defective sensor in the leak rate calculations.

- automatic detection of a modification of the containment leak rate.

- the data storage functions are improved and data reprocessing functions are available.

- increased possibilities concerning the results presentation (report, curves) are available.

- a modern man-machine interface will be used, in order to facilitate the use of the system.

It is planned to complete the prototype at the end of 1992 and to install two of them in operating units at the beginning of 1993, for a one-year evaluation period.

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 m3/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 condidered 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 (manily valves) participating to the containment leaktightness.

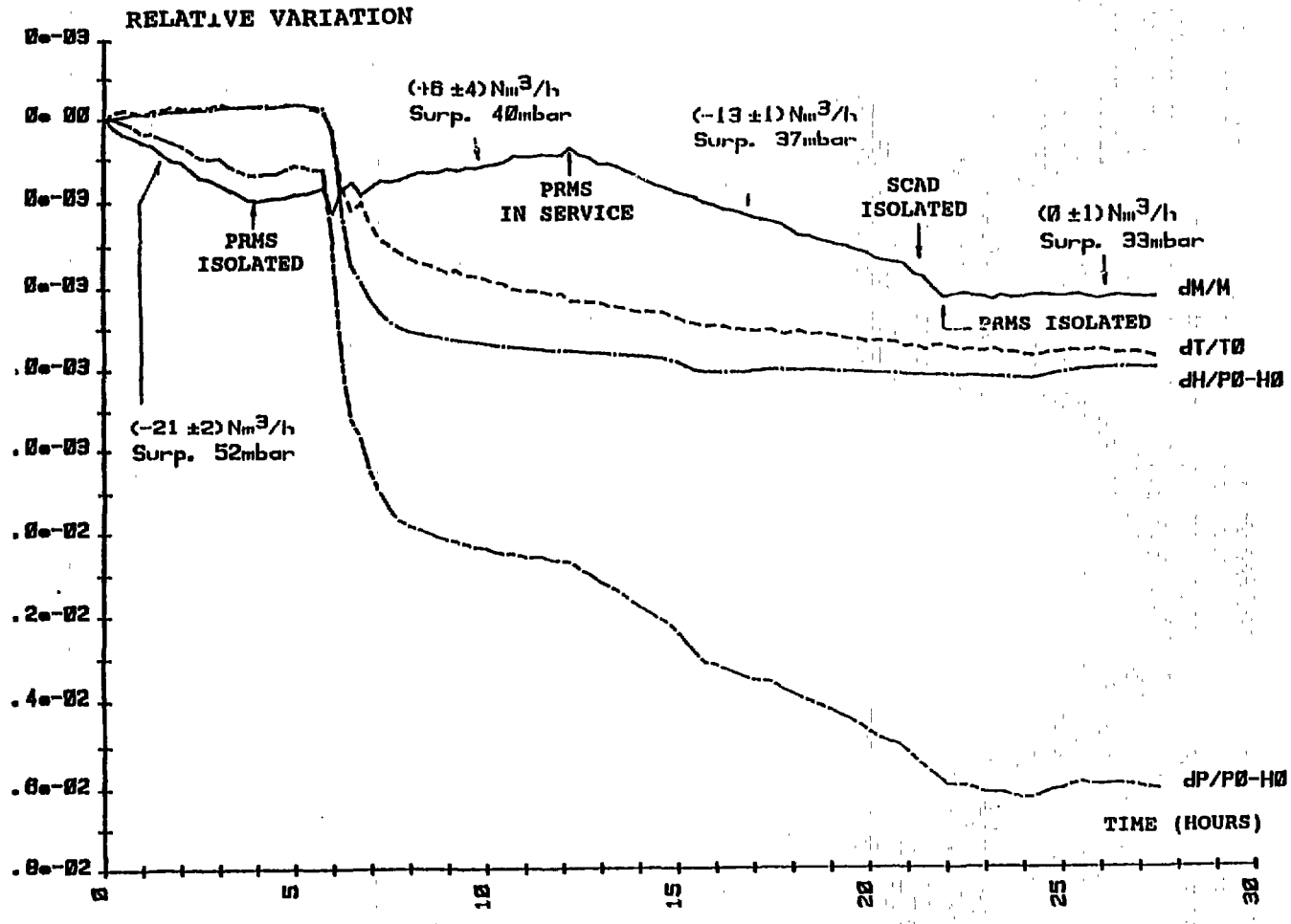

FIGURE 1 : RESULTS OF THE FIRST CONTINUOUS MONITORING OF A CONTAINMENT LEAKTIGHNESS.

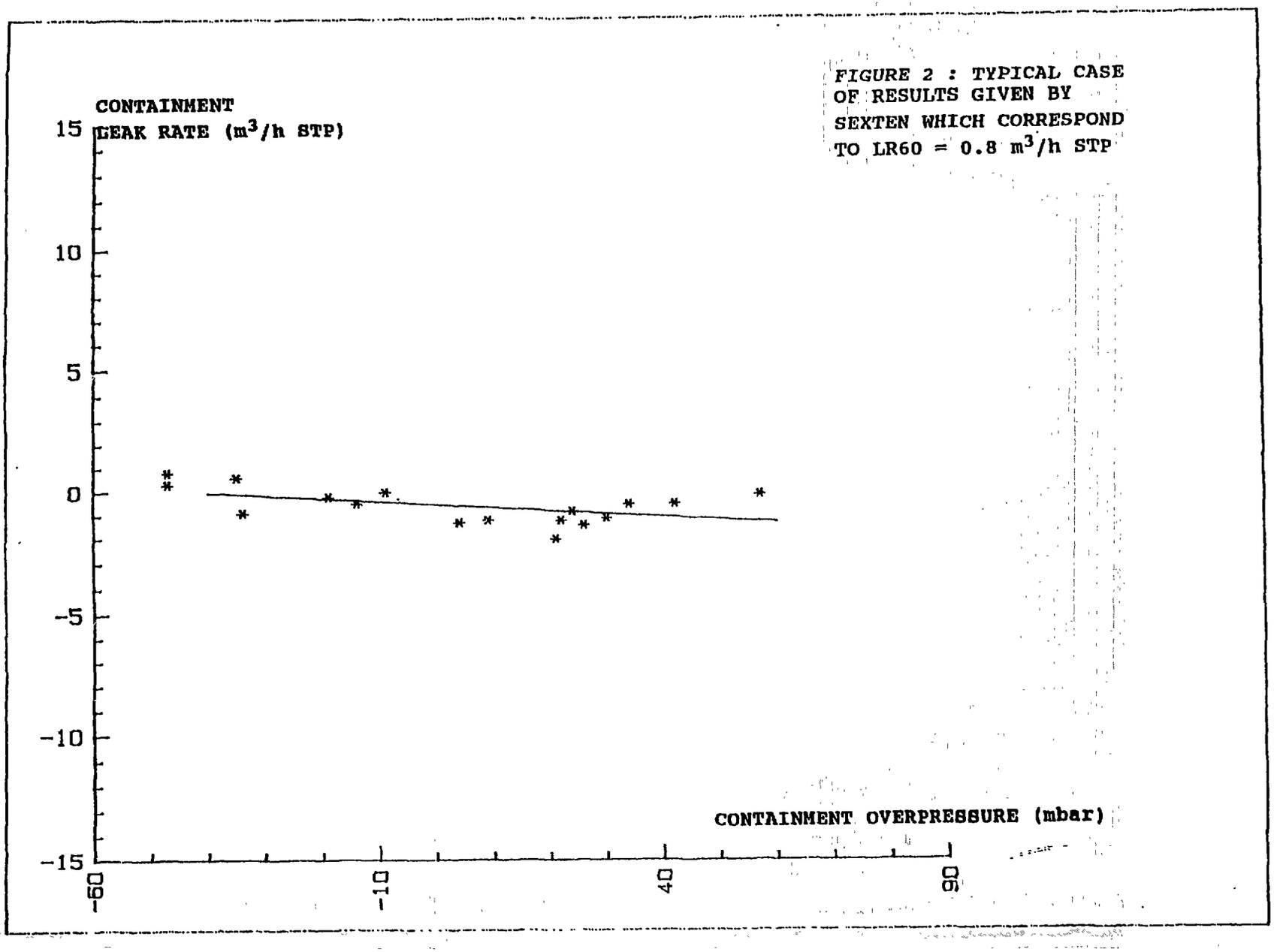

FIGURE 2 : TYPICAL CASE OF RESULTS GIVEN BY SEXTEN WHICH CORRESPOND TO LR60 = 0.8 m^3/h STP

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