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Leak Rate Measurements of Reactor Containments: Practical Experience and Analysis of Measurements

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ABSTRACT

The basic principles of leak rate measurements are provided through some official standards such as ANSI/ANS 56.8.1981 "Containment system leakage - Testing requirements" or DIN 25436 "Integrale Leckratenprüfung des Sicherheitsbehälters mit der absolute druck methode". In these standards are specified : the selective parameters of the selected instrumentation (accuracy, sensitivity, resolution, repeatability), the minimum amount of sensors and transducers to be provided, the precautions to follow during the pressurization, methods of record and statistical analysis of data, verification test and so on. It is often compulsory to go beyond these recommendations : the selected example refers to an Italian reactor steel containment vessel of 19 000 m^3 volume, lying outside for which the acceptable leakage rate was 0.03 %/day corresponding in standard atmospheric conditions to 0.53 Nm^3/Hour.

INTRODUCTION

The theoretical basis of measurement is a direct application of the perfect gases law PV = MRT where

P = dry air absolute pressure (total absolute pressure Pt less the partial pressure of water vapour Pv)
V = internal free volume of the containment devoted to the air
M = mass of the confined air
R = gas constant for air
T = mean absolute temperature of containment air

The relative variation of the air mass is given by

$$\frac{DM}{M} = \frac{DPt}{P} - \frac{DPv}{P} - \frac{DT}{T} + \frac{DV}{V} \qquad D = \text{variation conventional sign}$$

A linear regression (least squares fit) relative to the mass variation versus time enables to express the leakage rate (slope of the mass rate of change in percentage per day with its standard deviation and 95 % upper confidence level (UCL)).

INSTRUMENTATION

Taking into account the low leakage rate required (0.03 % which corresponds to a mean air temperature rate of change of 0.09°C or a pressure variation of 0.75 mbar/day) and B.V experience gained over many years, the following equipment has been used :

Temperature sensors with a platine resistance selected for their satisfactory stability and accuracy. Their location and amount depend on the internal outline of the plant and the areas where noticeable thermal changes may occur. For this vessel 33 have been installed for internal air and 13 on the steel containment itself.

Pressure transducers of high precision fitted with a quartz Bourdon tube acting as sensitive feature : they are located in the measurement room and connected through a brass-pipe to the containment vessel. Precautiously two are used for the vessel pressure and two others for atmospheric pressure (if necessary these later may record the vessel pressure).

Dew point temperature sensors of electrolytic type with lithium chloride. Six have been used, 3 of which in the annular space existing in the vessel. Two complementary sensors, of different operating principle have moreover been positioned for conformity checking.

All the instrumentation has been calibrated and certified before use through an official Bureau of Standards.

Outside these specific devices, the following precautions had to be taken with the adequate equipment :

- Dessication of the inflated air for reaching a dew point temperature of 5/6°C which has been deemed satisfactory on account of outside conditions.
- Venting of the annular space allowing an appreciable decrease of thermal rate of change in this area.
- Due to the peculiar case of this vessel subjected to high daily thermal variations, a water sprinkling system has been installed on the roof for continuous operation during day time.

All the instrumentation and equipment has worked satisfactorily.

TEST EVOLUTION

Outside the numerous preoperational checkings, the first measurements are usually carried out at atmospheric pressure for a minimum of 24 hours in order to examine all the concerned parameters : test circuit behaviour, electrical supply reliability, measurement room air conditioning, drying of inflated air, behaviour of measuring devices, software working condition and so on... These first measurements may give at first sight a rough estimate of the measurement error when the leakage rate in close to zero, but under some restrictions of those at nominal pressure. In spite of this restriction, these first measurements are essential.

Some other pressure levels (under or over the nominal pressure) are sometimes contemplated for some other reasons (for ex. : strain gauge measurements) : it shall be taken advantage of these opportunities to record leakage rate data even if the test duration is less significative :

these measurements under pressure allow a better understanding and monitoring of parameters such as temperature changes during warming up (influence of sun) or cooling down (night period), the effects of such giving unsymmetrical variations of the air temperature. The influence of volume variation (DV/V) usually neglected had to be considered in this case.

During the official test at nominal pressure, all the concerned parameters are recorded every 1/2 hour and the leakage rate is calculated simultaneously. On the graphes are plotted :

- The 8 H leakage rate which is a significative instantaneous leak : the smallest temperature changes are registered with a great sensitivity : the calculated values are usually high but the extreme values tend to decrease with time.
- The 24 H leak is partially released from daily variations.
- The 48 H leak is even more freed from the cyclic variations of DM/M.
- The 72 H leak, in this case, has been conducted until the sum of the maximum value of the 48 H leak and the instrumental error (calculated by excess) reach a satisfactory value.

ERROR ESTIMATION

The estimation of various errors, through the statistical evolution of all the data, is a very accurate and important part of the work mainly when the leakage rate is low as in this case.

There are many types of errors, more or less significative : all of them will be reviewed but a peculiar attention shall be focused on the main.

METHOD

Just as the leakage rate is calculated by linear regression on the mass variation, so are calculated similarly the slopes on the other parameters with their corresponding confidence limits, the maxima and minima of which tend to minimize according to the time elapsed. From this study it appears that the RMS (Root Mean Square) of confidence limits (CL) of every parameter is greater than the CL of the DM/M which indicates that the scattering on the DM/M is not really random but depends on the curvature of the parameters evolution. The UCL on the leak rate is a useful element of appreciation but should not be considered as an estimate of the measurements accuracy.

Random error due to temperature and pressure fluctuations resulting from either the instrumental resolution or local instabilities and is estimated from the statistical CL for which the curvature influence is the less important (in this case, resulting value : 3 % of the global error).

Precision error due mainly to the calibration conditions. Even overstimated the calculated value is low and may be disregarded (2 % of the global error).

Stability error i...e the stability vs time of various sensors. Estimated through a correlative analysis for the pressure transducers and from the electrical stability of air and dew point temperature sensors, its final value has been estimated to be of the same order of magnitude as above (5 % of the global error).

Weighted average (or representativity) error is the most crucial in the analysis and concerns only the temperature (air and dew point) sensors. The temperature variations being measured through a reduced number of devices, the result of such sampling is more or less representative of the true variations. Ar elementary volume (or area) being assigned to every sensor, the following errors may arise from the physical conditions :

- the measured temperature is different from the existing one except if the temperature gradient is linear or zero in this element.
- the heat radiation exercises an influence on the local measurement, the shell temperature being different of the air one.
- when fixing up the mean temperature, the weighted averaged volume is more or less satisfactorily determined, because the boundaries of such are discretionary and also their weight may change according to time and climatic conditions.
- at last, all the volumes are not correctly appreciated, whether they have not been instrumented or their temperature changes are different from those of the associated elementary volume. Moreover the total volume is roughly evaluated.

These unfavourable conditions are partly balanced by the following precautions :

- careful sharing out of the volume and corresponding allotment of sensors.
- use of internal venting and external water cooling system and possibility of decreasing this representativity error through a longer period of measurement.

In fact the cyclic evolution of this error is not strictly symmetrical and it has been necessary to wait 3 days for having a sufficient accuracy to be compared with the admissible leak rate test.

This error is duly linked to the temperature variations ; it overstimates the variation of mean temperature during the warming up (positively) and the cooling down (negatively) : it will be partly compensated over a 24 hours or better N x 24 hours - period.

Such error is evaluated, in a depreciatory way, through the following assumptions :

a) It is assumed than in every elementary volume the temperature scatter is equivalent to that of the whole volume and that every sensor indicates a temperature taken at random within this scattering range.

A more realistic consideration may improve this assumption : the slopes over a 72 H period show a physical stratification of the volume and the equivalent scatter considered is that of one stratum. The resulting UCL on the mean temperature proceeds from

$$2\sqrt{\sum_{j=1}^{J} C_j^2 \frac{Sj^2}{nj}}$$

where C_j = weighting coefficient of the j-stratum $\left(\frac{vj}{vo} = \frac{\text{stratum volume j}}{\text{total volume}}\right)$

Sj = standard error of the j-stratum

nj = amount of sensors in the j-stratum.

This of course applies only to the air temperature. For air hygrometry or the steel temperatures, the considered scatter is that of the whole volume which decrease drastically with time.

b) This error may be estimated by another method, considering that the elementary volumes associated to every sensor are unknown. Every volume vi is consequently modified according to a Gauss distribution of mean vi and standard error 1/2 vi i...e... the concerned volume may vary from 0 to 2 vi. By simulation, about one hundred values of leak rate have been calculated and the UCL of those is considered as weighted average error.

Such assumptions may be related to a calculation carried out only with the night data (between 21 h and 06 h) for which the influence of thermal gradients and radiation are greatly reduced.

For information, the calculations have given the following values for this error : 0.012 % per day (strata calculation) - 0.009 % (for $0 < vi < 2\ vi$) and 0.009 % (for night data). For sake of safety, the greatest one has been considered in the final value. This error represents some 90 % of the final global error and some 40 % of the admissible leak rate.

CONCLUSION

The various measurements and data calculation for determining the leak rate with the best accuracy should be made according to the following precautions :

- careful study of the plant and its appurtenances for optimal selection of amount, location and characteristics of sensors. For plants located outside, venting and cooling systems must be contemplated for temperature uniformization.

- preoperational intensive checking of the instrumentation before test and various tests of satisfactory operation of such.

- during the test itself, outside the systematic recording of parameters, a continuous survey of various sensors is compulsory for checking of reliability. In case of incident, corresponding modifications of the reocording and program data.

- during and after the test, extensive statistical handlings of data in order to determine the representativity error which entails the greatest uncertainty on the results.

From B.V. experience, gained over many years on some 30 nuclear plants, these points are essential for a rigourous estimation of a leakage rate, mainly when the admissible leak rate value is very low which was the case in the concerned example.

Test organization

The test has been organized and conducted by the technical staff of ANSALDO Div. NIRA (test management) and BELLELI (test performance), under the supervision of ENEL and ENEA-DISP (Italian Electrical Energy Agency and Nuclear Controller Agency).

All the activities involved with the test have been developed according to quality assurance program's rules for the CIRENE nuclear power plant the first result has been the certification of all the phases of the test in a detailed inspection plan. Technical procedures and specifications have been developed in a joint work by ANSALDO - BELLELI - ENEL - ENEA in order to define in advance all the activities to be performed on the vessel before, during and after the test. Particular attention was given to :

- Complete inspection of the vessel.
- The real complete containment configuration during the test in order to have a clear photography of the environmental conditions safety procedures.
- Calibration and certification of measure instruments.
- Shop staff organization.

As a conclusion, our thanks are devoted to the people whose name appear in the title and to

Mr. G.B. BOZZO (ANSALDO DIV. NIRA)
Mr. R. SALADINI (ANSALDO DIV. NIRA)
Mr. MAZZONCINI (BELLELI SPA)
Mr. D'ANDREA (BELLELI)
NIRA and BELLELI SHOP STAFF

Their technical knowledge and appreciated cooperation during the development of such test have allowed to perform satisfactory measurements and to obtain accurate results.

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