Leakage Measurements of the DR 3 Containment during Reactor Operation to Meet a Demand of Maximum 0,1% Leakage per 48 Hours

Haack, Karsten

Publication date:
1966

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Haack, K. (1966). Leakage Measurements of the DR 3 Containment during Reactor Operation to Meet a Demand of Maximum 0,1% Leakage per 48 Hours. (Denmark. Forskningscenter Risoe. Risoe-R; No. 137).

Risö Report No. 137

Risö Report No. 137

Danish Atomic Energy Commission

Research Establishment Risö

Leakage Measurements of the DR 3 Containment during Reactor Operation to Meet a Demand of Maximum 0.1% Leakage per 48 Hours

by Karsten Haack

December, 1966

Sales distributors: Jul. Gjellerup, 87, Sölvgade, Copenhagen K, Denmark
Available on exchange from: Library, Danish Atomic Energy Commission Risö, Roskilde, Denmark

December, 1966 Risö Report No. 137

Leakage Measurements of the DR 3 Containment during Reactor Operation to Meet a Demand of Maximum 0.1% Leakage per 48 Hours

by

Karsten Haack
The Danish Atomic Energy Commission
Research Establishment Risö
DR 3

Abstract

The ratio between the absolute temperature T and the partial pressure P of the atmospheric air in the hall is taken as a representative of the number of air moles present. A plot versus time gives the leak rate. The temperature is measured by means of an iron wire through the hall; the pressure is determined by projecting the mercury surface of a precision manometer onto a screen. The arrangements and the measurement equipment are described and the uncertainties of the results discussed. The experiences from six yearly tests have led to a method which is considered to be more convenient than that used previously, and yet sufficiently accurate to control the tightness of the DR 3 reactor building.

Contents

1. Introduction

The reactor hall of DR 3 was constructed and tested to have a leak rate not exceeding 0.1% of the volume per 48 hours at an inside overpressure of 4.65 m water gauge. The methods of checking the tightness of the structural parts, pipe and cable penetration, air locks, etc., and the reactor hall as a whole during the period of construction are described in Risö Report No. 12 (March, 1960). The final test showed a leakage of 0.02% per 48 hours at 4.65 m W.G.

The Danish National Health Service permitted the operation of DR 3 provided, among other things, that the hall was leak tested frequently and the leakage kept below 0.1%.

Consequently, equipment and methods have been developed to fulfil the requirement, and the tightness of the hall has been checked once a year since 1960. In order to measure a leakage of 0.1% of the volume it has been necessary to refine the measurement methods to an uncertainty of the order of 0.01%.

2. Data of Reactor Plant and Reactor Hall

DR 3 is a heavy-water-moderated and -cooled 10 MW material-testing reactor using highly enriched U^{235} fuel elements. It is placed in a containment building of cylindrical shape consisting of a 5 m high basement and an 18 m high reactor room. The diameter of the cylinder is 21 m and the volume 7600 m^3. Corrections for air locks, outside pipes and inside concrete blocks and vessels bring this figure up to 7800 m^3, which is thus the total volume inside the containment boundary.

Although the control room is placed inside the shell, a great number of electric leads penetrates the shell:

1227 leads for control of auxiliary plants;
60 coaxial cables for instrument signals;
20 power cables.

The pipes for supply of compressed air and water, for the systems of secondary cooling, air conditioning, active effluent water, sub-pressure release, external loops, fire protection, and outside instruments at the air locks and in the emergency control room penetrate the shell in a total number of 42.

The cable and pipe penetrations, the flange rubber gaskets and the valve diaphragms in the connecting pipes, the 28 m long rubber seals in the air-lock doors, and the welding seams of the 2300 m^2 surface of the steel shell are the leak possibilities to be considered in the yearly leak test.

3. The First Measurements

The methods and equipment used in the leak tests during the construction of the building were adopted for the first test undertaken by the operation group. A detailed description is to be found in Risö Report No. 12; the measurement method was briefly as follows:

The ideal gas equation is

$$P \cdot V = R \cdot T \cdot c, \qquad (1)$$

where

P = partial pressure of the gas
V = volume
R = gas constant = $8.31 \cdot 10^7$ erg/^{o}K · mol
T = temperature in ^{o}K
c = number of moles.

The volume of the DR 3 hall is split into two parts: the basement volume V_K and the reactor-room volume V_H, where

$$V_K = 0.233 \cdot V_H .$$

The total number of air molecules in the hall may then be expressed as

$$c = \frac{P_K \cdot V_K}{R \cdot T_K} + \frac{P_H \cdot V_H}{R \cdot T_H} = \frac{V_H}{R} \left(0.233 \frac{P_K}{T_K} + \frac{P_H}{T_H}\right) . \qquad (2)$$

The partial pressures P_K and P_H in the basement and reactor room respectively are obtained from the total hall pressure P and the water-vapour pressures P_{VK} and P_{VH}:

$$P_K = P - P_{VK}$$

$$P_H = P - P_{VH} .$$

By plotting the figure

$$n = 0.233 \frac{P_K}{T_K} + \frac{P_H}{T_H}, \tag{3}$$

which is proportional to the amount of air in the hall, as a function of time, the leak rate is obtained as the slope of the curve.

All measurements were carried out from outside the shell. The pressure P was found as the sum of the barometric pressure measured with a mercury barometer and the overpressure inside the building measured with a water manometer. Both manometers had engraved millimetre scales and were corrected for the thermal expansion.

The temperatures T_K and T_H were determined as the mean values of the readings from a number of thermistors in the basement (T_K) and in the reactor room (T_H).

The water-vapour pressures were measured by means of LiCl humidity elements, and mean values were again calculated from a number of elements in the basement (P_{VK}) and in the reactor room (P_{VH}).

The first leak test of the reactor hall performed by the operation group was made before the routine power operation of the reactor started. Only one man was present inside the shell at the time, watching the plant during the test; he was relieved every four hours. The measuring equipment was placed outside the shell.

The arrangement described above has several disadvantages, the most important of which are that two read-out errors are involved in the pressure measurement and that all the 60 electric connections to the humidity element and the thermistors are sensitive to contact resistance in the junction boxes where they penetrate the shell.

4. The Final Arrangement

Because of these disadvantages the measuring instruments were taken inside the shell. Thus a great number of the electric connections were avoided, and only one pressure reading had to be taken. During routine operation of the reactor several people had to be present inside the shell, so it was no complication to have the people who made the hall-test readings and calculations inside too.

The methods and the instrumentation were improved year after year until 1964, when a sufficiently good procedure was found. This procedure has been successfully used for three years and is now as follows:

The pressure is still measured by means of a mercury manometer. The desired accuracy, $\pm 0.01\%$, of about 800 mm Hg, i. e. ± 0.1 mm Hg, is obtained by an arrangement as shown in fig. 1. The manometer is suspended in a micrometer screw and a coarse-adjustment screw anchored in a mechanically stiff structure. The picture of the mercury surface is projected onto a screen in such a way that the optical axis of the system is exactly horizontal. Temperature corrections are read on a thermometer placed beside the manometer.

The measurements are made by alignment of the mercury surface picture with a line drawn on the screen horizontally through the optical axis. The mercury surface is moved by means of the micrometer screw, and the readings are taken from the scale of the latter. These readings give the deviations from the initial air pressure at the start of the leak test, which pressure is read by focusing the optical system on the engraved mm scale in the manometer glass tube and interpolating on the screen between two of the projected mm marks.

The system is parallax free and sufficiently sensitive to a relative error of ± 0.01 mm Hg as far as the micrometer screw is concerned. But the manometer tube has to be adjusted to the free mercury surface before each reading, and this adjustment incorporates an error of about ± 0.02 mm Hg. The absolute error of the P-measurement is therefore

$\Delta P = \sqrt{0.01^2 \pm 0.02^2} = 0.022$ mm Hg.

The temperature is determined from the electric resistances of two iron wires, 0.5 mm diameter, suspended through the volumes of the basement and the reactor room in such a manner that the wire length in each part of either volume is proportional to the ratio between that part volume and the total hall volume. Iron is chosen because the temperature coefficient of its electric resistance is fairly high. The wire is insulated with lacquer and suspended by means of plastic-coated clamps. Before use the two parts of the wire are thoroughly calibrated, and the calibration is checked after the hall test in order to reveal changes originating from loads and prolongations of the wires during the suspension. No changes have been found.

A diagram of the resistance measuring equipment is shown in fig. 2. A "Tinsley" potentiometer is used for the measurement of the voltage drop through a standard resistance and the two iron wires. It gives the result in 5 figures and with a relative error of 0.02%, corresponding to an absolute error in the T-measurement of 0.06°K. However, this is the mean temperature of the wires. The mean temperature of the hall is discussed in section 5.

The measuring current is 0.3 mAmps. The total iron-wire resistance is about 250 ohms. The standard cell is a Weston element, and the potentiometer is adjusted for the temperature variation of the Weston potential. The "Tinsley" potentiometer is independent of temperature, and thermoelectric powers are avoided in the instrument. In order to neutralize thermoelectric powers at the iron-wire junctions, these are connected into a single terminal row which is thermo-insulated from the surroundings.

The water-vapour pressure is determined by means of hair hygrometers and thermometers, three pairs in the basement and three pairs in the reactor room. The hair hygrometer is chosen because its reproducibility is as small as about 0.2% FSD, although the absolute error is about 2% FSD. As all the measurements in the hall test are relative, the absolute error is of minor importance, but the hygrometers are calibrated against a precision psychrometer just before the test in order to obtain an absolute error as small as possible.

The partial pressure of the water vapour is normally of the order of 10 mm Hg. As the temperature may be read with a relative error of about 0.2%, the error of the measurement of the water-vapour pressure is a little more than 0.2%, corresponding to 0.03 mm Hg.

5. Estimation of the Total Measurement Error

The number of moles of air is proportional to

$$n = 0.233 \frac{P_K}{T_K} + \frac{P_H}{T_H} \quad \text{(see eqs. (2) and (3))} .$$

Partial differentiation gives the absolute error

$$\Delta n = \sqrt{((\frac{\delta n}{\delta P_K})\ \Delta P_K)^2 + ((\frac{\delta n}{\delta T_K})\ \Delta T_K)^2 + ((\frac{\delta n}{\delta P_H}) \Delta P_H)^2 + ((\frac{\delta n}{\delta T_H}) \Delta T_H)^2}$$

$$= \sqrt{(\frac{0.233}{T_K}\ \Delta P_K)^2 + (-\frac{0.233\, P_K}{{T_K}^2}\ \Delta T_K)^2 + (\frac{1}{T_H}\ \Delta P_H)^2 + (-\frac{P_H}{{T_H}^2}\ \Delta T_H)^2}.$$

In this expression the values of the parameters are

$$T_K \simeq T_H \simeq 295^\circ K; \quad \Delta T_K = \Delta T_H = 0.06^\circ K$$

$$P_K \simeq P_H \simeq 830 \text{ mm Hg} ,$$

and as $P_K = P - P_{VK}$, it follows that

$$\Delta P_K = \sqrt{(\Delta P)^2 + (-P_{VK})^2} = \sqrt{0.022^2 + 0.03^2} = 0.037 \text{ mm Hg}$$

and accordingly $\Delta P_H = 0.037$ mm Hg .

Thus

$$\Delta n = \sqrt{\left(\frac{0.233}{295} \cdot 0.037\right)^2 + \left(-\frac{0.233 \cdot 830}{295^2} \cdot 0.06\right)^2 + \left(\frac{1}{295} \cdot 0.037\right)^2 + \left(-\frac{830}{295^2} \cdot 0.06\right)^2}$$

$$= 3.15 \cdot 10^{-4} .$$

The relative error of a single measurement is then

$$\frac{\Delta n}{n} = \frac{3.15 \cdot 10^{-4}}{3.42} = 0.92 \cdot 10^{-4} \simeq 0.01\% ,$$

where the mean value of the measurements is 3.42.

However, a systematic error is hidden in the method of the measurements. If the iron wire is not suspended in the intended way, i.e. so that every unit of volume is traversed by the same length of wire, the temperature determined by the wire resistance is not exactly the mean temperature of the hall. During steady temperature conditions this error is the same in all the measurements, and the leak rate determination is not affected. But during temperature variations outside from day to night and on weather changes, the temperature signals will not follow the pressure signals, and sinusoidal oscillations of the representative, n, of the air amount are seen.

The amplitude of these oscillations is often 0.02 - 0.03%, and one as high as 0.05% has been experienced. The influence on the leak rate determination is reduced when the measuring time is sufficiently long, e.g. about 48 hours, and when an integer of oscillations are included, starting at the maximum or the minimum of an oscillation.

Furthermore, the season of the year is important for the error just mentioned. In Denmark, October and November are the most cloudy months, with only small temperature variations from day to night; the hall leak tests are therefore mostly carried out in these months. In addition, the mean temperature outside is at that time just low enough to carry away all the heat produced in the reactor hall, thus keeping the temperature level fairly constant.

Another source of error is the use of the personnel air lock during the hall test. The pressures in the hall and the air lock are equalized by pressurizing the air lock. The difference is read with a maximum error of ± 10 mm WG. As the volume of the air lock is 34 m^3, the error of the leak rate of the hall introduced by a single sluicing is

$$\pm \frac{10}{13.6 \cdot 830} \cdot \frac{34}{8000} \cdot 10^2 = \pm 3.8 \cdot 10^{-4} \% .$$

The error is not a systematic one. Consequently, the errors will not simply be added in the case of several openings of the doors and are thus negligible.

However, the compressed air with which the air lock is pressurized is very dry, and an amount of water vapour in the hall atmosphere is therefore exchanged for an equivalent volume of air at every sluicing. On the assumption of a humidity content of the hall atmosphere of 6 g per kg air, the total increase in the amount of air in the hall caused by 11 sluicings can be calculated at about 0.014%. But this is a correction rather than an error.

Other corrections to be measured and calculated during the leak test are the contributions to the air amount in the hall by release of gases. Gas-filled experimental liners and vessels often have small leaks which can be controlled by frequent weighing of the supplying gas cylinders. Several experiments need coolants in the shape of liquid gases, which have to be weighed at the time of every measurement, e.g. once an hour. Also the carbon-dioxide cylinders for fire protection have to be checked for leakage during the test.

If the temperature changes more than about three degrees centigrade, a correction for the volume change due to the expansion of the steel wall has to be considered. In ref. 1 the correction has been calculated at 0.01% per 30°C.

The breathing of the people present in the hall during the test does not introduce any error as the number of moles of O_2 inhaled is equivalent to the number of moles of CO_2 exhaled.

6. Hall Test during Reactor Operation

The first tests were made while the reactor was shut down. The normal maintenance work and change of fuel and rigs were carried out during the tests. The arrangement was inconvenient for both the hall test group and the operation staff: the very sensitive measuring equipment was disturbed by the crowd of people working in the hall, the operation of the circular crane was restricted by the suspended iron wire, and, in spite of all precautions, the wire was broken several times, thus introducing uncontrollable corrections to the measurements.

Two alternatives were then considered. The hall test could be carried out in a prolonged shut-down period or during reactor operation. According to the experiences with this and many other research reactors, the operation period is the most "silent" time, i. e. the time when relatively little work is going on in the reactor hall.

The prolonged shut-down method was not desirable because the utilization of the plant would be reduced and the continuous four-week operation cycle would be interrupted.

Consequently, in 1963 it was attempted to make a hall test during operation of the reactor. Some aspects had to be considered beforehand. The safety evaluation of a possible accident while the hall was pressurized was treated in co-operation with the Safety Committee. The compressed air for the reactor instruments inside the shell had to be supplied by an internal compressor. The consumption and release of gases in the experiment and the reactor circuits had to be taken into account.

The feasibility of hall tests during reactor operation was demonstrated in 1963, and until now four tests have been carried out in that way. The principal difficulty was a leaky UO_2-pellet irradiation experiment which released fission gases to the hall atmosphere and caused a premature cessation of the test.

7. Results

Since 1961 the tests have been split into two parts. The first part, consisting in a soap brushing of all accessible outer surfaces of the containment at 0.1 kg/cm^2 overpressure, reveals the majority of the leaks, and these are tightened. 2 - 3 days are normally used for this work, which does not impede the reactor operation experiments, or maintenance work. The second part is the leak rate measurement, which is always limited to three days because of the restricted access to the reactor hall and the work going on in it. Often a few leaks have not yet been found when the measurements start. In these cases the final leak rate is determined on the basis of a measuring time shorter than desirable (1960, 1962, 1965).

The figures representing the amount of air in the hall are calculated once per hour during the test and plotted versus time. After the test the leak rate is calculated as a least squares fit by means of a computer, which delivers the result within the limits of error.

The plots from the years 1960, 1961, 1962, 1963, 1965, and 1966 are shown in fig. 3. The plot from 1964 is omitted because of a fault in the measuring equipment which caused large fluctuations and consequently made the result rather uncertain.

It is seen that since April 1962 the deviations have become smaller, and the day-to-night variations due to temperature variations outside are consequently less noticeable. The reason is undoubtedly that the mean temperature measurements by means of the iron wire were started in 1962.

8. Conversion of the Leak Rate. Partial Leak Tests

The leak rates have always been determined at about 0.1 kg/cm^2 overpressure in the hall. This is less than the design pressure of the hall (0.46 kg/cm^2). The conversion of the leak rate to the design pressure is a delicate problem as the leak rate is not proportional to the overpressure. As far as leaks with unchangeable dimensions are concerned, the air velocity through the hole is proportional to the square root of the overpressure if the flow is turbulent, which is certainly the case in nearly all leaks found during the tests. As the leak rate increases with the density of the air, the total dependence on the overpressure is something in between a square-root dependence and proportionality.

However, the majority of the leaks are found in gaskets and rubber seals, i.e. holes with dimensions which vary with the overpressure. According to their geometrical shape, these leaks will open or close as the pressure is increased.

Thus it is impossible to conclude anything about the leak rate at higher pressures. However, the overpressure chosen: 0.1 kg/cm^2, is realistic because higher pressures are presumed to exist only for very short periods. By means of the air cooling plant and the sprinkler system it is possible to reduce the temperature in the hall rapidly after an accident, and as the overpressure is generally due to water-vapour release, these arrangements are quite effective at reducing the overpressure.

The possibility of controlling the tightness of the hall by means of partial leak tests has been thoroughly considered. Apparently this method is suitable for a continuously operating plant, but as there are many leakage possibilities (see section 2), leak tests will be going on somewhere in the plant at almost any time of the year, and the disturbance of the operation and maintenance work will be more severe than at a total hall test. Furthermore, the manpower requirements for partial leak tests will be much greater because a lot of blank bulkheads have to be mounted and dismounted.

The present hall leak-test arrangement is considered to be the least expensive and the most convenient way of keeping the leak rate at a low level. Although it is obvious that the leak rate increases throughout the year and exceeds the specified 0.1% per 48 hours, it is valuable once a year to find and tighten the leaks and to certify that the containment is in accordance with the specifications.

9. Conclusion

The arrangement, the measuring methods and the instrumentation developed in the past six years in order to control the leak rate of the DR 3 containment are thought to be the best compromise between the Danish National Health Service's demand of a maximum leak rate of 0.1% per 48 hours and the wish of the Risö Establishment for continuous operation.

The instrumentation has a high sensitivity and reliability (mean error 0.01%) although it is simple and inexpensive.

Reactor-hall tightness tests during reactor operation at full power are a feasible and even the most convenient way of controlling the leakage from the DR 3 reactor containment.

Seven years' tightness tests have indicated that the leak rate increases again very soon after a test. A realistic estimate of the mean leak rate of the hall in the time between two tests appears to be about ten times the specified value.

10. Acknowledgements

A hall tightness test interferes with the activities of nearly every member of the operational staff of a reactor. Many are directly involved in the test, while others have to adapt their work to the restrictions in force. The work of the experimenters is also impeded.

I should like to thank all these people for their patience and indulgence during the annual tests carried out for the past seven years.

I am particularly indebted to F. Heikel Vinther, who placed his experience from the first hall tightness tests at my disposal, and to the mem-

bers of the DR 3 staff, who contributed to the elaboration of the final method and arrangement by their valuable discussions and constructive suggestions.

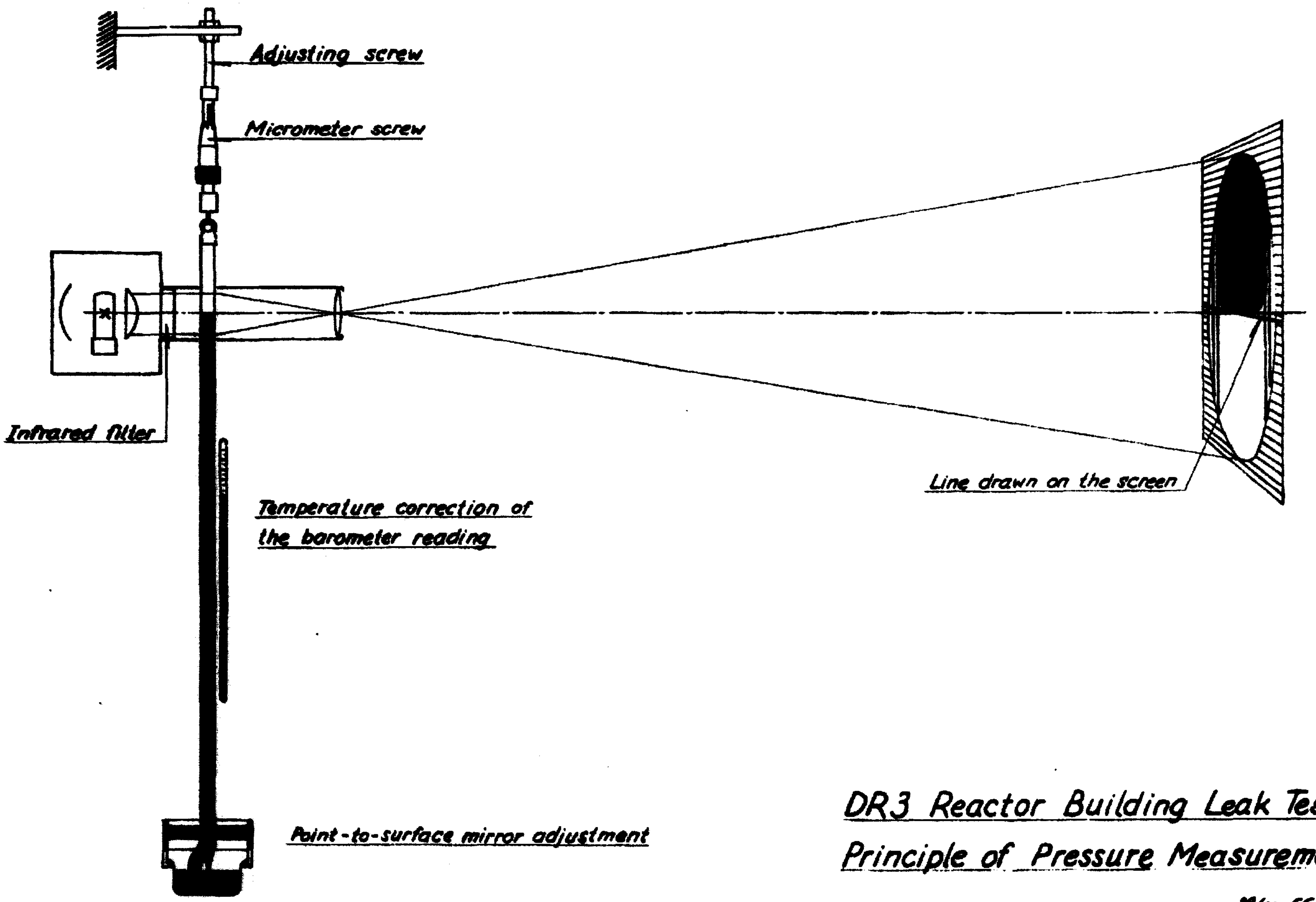
11. References

1) I. Schiellerup Petersen and F. Heikel Vinther, Leak Tests of the Buildings for the DR 2 and the DR 3 Reactors. Risö Report No. 12 (1960).

2) R. O. Brittan, Reactor Containment. ANL 5948 (1959).

3) Technischer Überwachungs-Verein Rheinland e. V., Bericht über die Dichtigkeitsprüfung der Reaktorhalle DIDO am 23-24/8 1962. TÜ -9 (1963).

4) N. A. Weil et al., Studies of Reactor Containment Structures. IITRI-578P22-9 (1964).

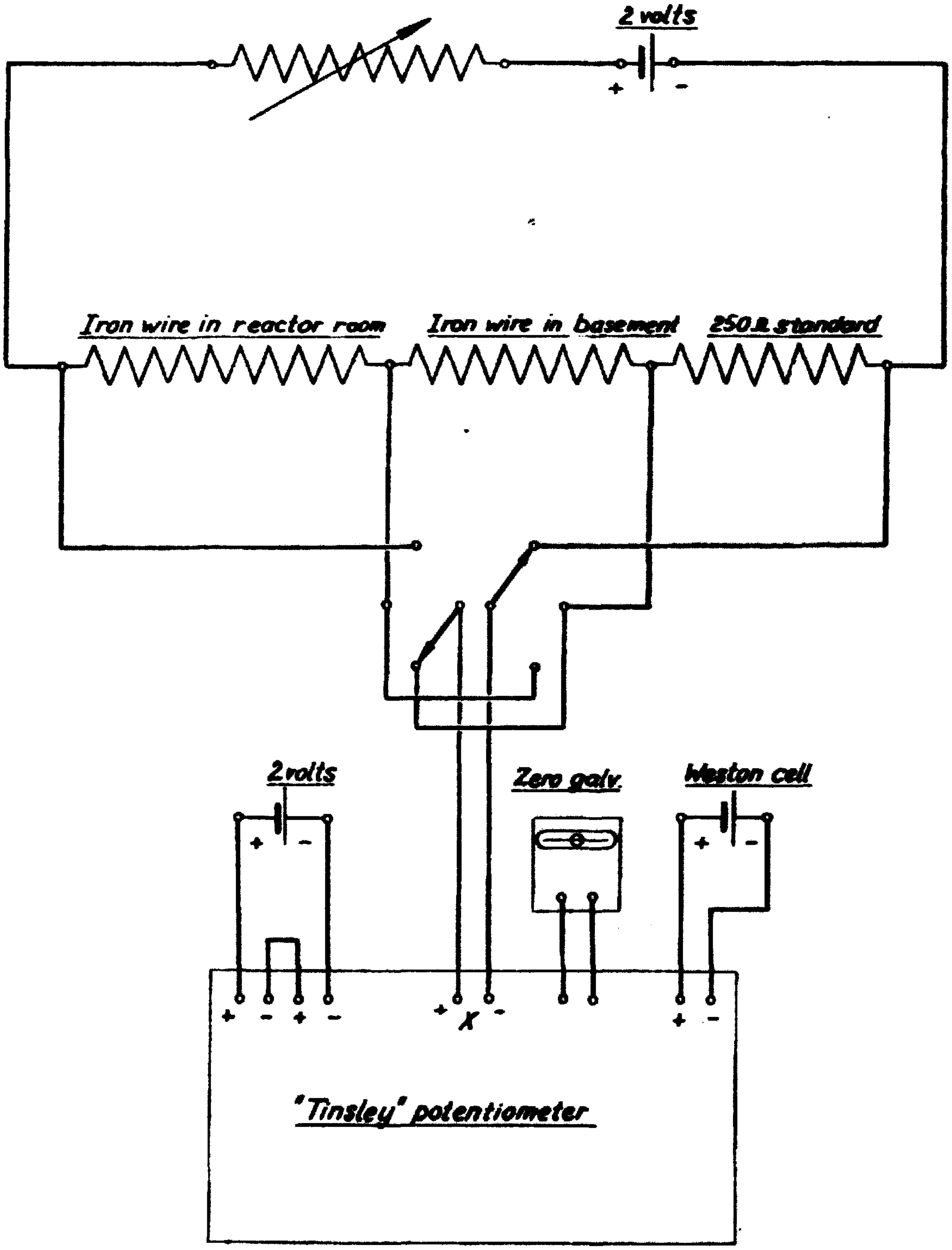


DR3 Reactor Building Leak Tests.

Principle of Pressure Measurement

29/11-66. K.H.

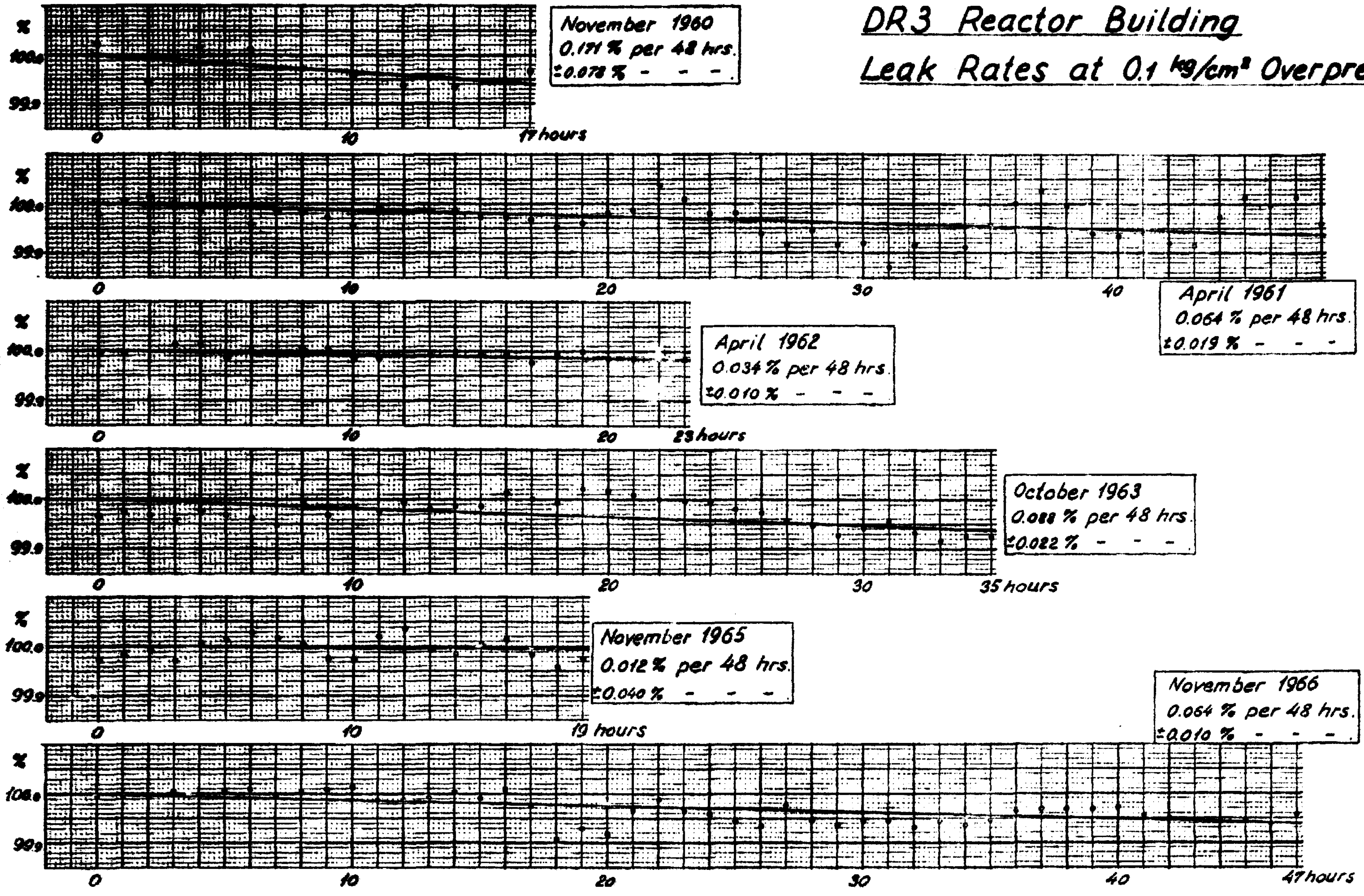
DR3 Reactor Building Leak Tests. Temperature Measurement by Means of Iron Wires



28/11-66. K.H.

Figure no.2

DR3 Reactor Building
Leak Rates at 0.1 kg/cm² Overpressure



29/11-66 KN.

Figure no. 3