REACTOR BUILDING INTEGRITY TESTING
A NOVEL APPROACH AT GENTILLY 2
PRINCIPLES AND METHODOLOGY

BY

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INTRODUCTION

In 1987, Hydro-Québec embarked on an ambitious development program to provide the Gentilly 2 nuclear power station with an effective, yet practical reactor building Integrity Test.

The Gentilly 2 Integrity Test employs an innovative approach based on the reference volume concept. It is identified as the Temperature Compensation Method (TCM) System. This configuration has been demonstrated at both high and low test pressure and has achieved extraordinary precision in the leak rate measurement. The Gentilly 2 design allows the Integrity Test to be performed at a nominal 3 kPa(g) test pressure during an (11) hour period with the reactor at full power. The reactor building Pressure Test by comparison, is typically performed at high pressure (124 kPa(g)) in a (7) day window during an annual outage.

The Integrity Test was developed with the goal of demonstrating containment availability. Specifically it was purported to detect a leak or hole in the "bottled-up" reactor building greater in magnitude than an equivalent pipe of 25 mm diameter. However it is considered feasible that the high precision of the Gentilly 2 TCM System Integrity Test and a stable reactor building leak characteristic will constitute sufficient grounds for the reduction of the Pressure Test frequency.

It is noted that only the TCM System has, to this date, allowed a relevant determination of the reactor building leak rate at a nominal test pressure of 3 kPa(g). Classical method tests at low pressure have lead to inconclusive results due to the high lack of precision.

TEMPERATURE COMPENSATION METHOD SYSTEM PRINCIPLES

General Description

The Gentilly 2 TCM System can be employed at any test pressure. In fact it also serves as the "verification" or "back-up" system to the classical method employed during the reactor building Pressure Test. This paper, however, is restricted to the low pressure Integrity Test.

The originality of the Gentilly 2 "TCM System" Integrity Test stems from the:

- low test pressure of 3 kPa(g)
- reference volume or "temperature" tubular network
- humidity sampling tubular network
- "Known leak rate" test validation procedure
- on-line computerized leak rate determination with a bounding error analysis
- extrapolation capability to allow estimation of the leak rate at 124 kPa(g)

Temperature Compensation

The extensive "tubular network" reference volume enables the determination by analogy, of the "equivalent" or "weighted" reactor building temperature. The reference volume simulates the overall reactor building behaviour and allows the leak rate determination to be independant of reactor building temperature fluctuation.

The ideal gas law can be used to show that when a confined mass of air in a leak tight reference volume is itself contained in another fixed volume of air, the differential pressure is independant of temperature. However the geometry of the reference volume must be such that the two volumes are characterized by the same temperature without delay. The appropriate reference volume was obtained at Gentilly 2 by installing a leak tight network of about a kilometer of copper tubing throughout all significant volumes of the entire reactor building.

The tubing is dimensioned and routed such that the reference volume fraction contained within each room is proportional to the volume of the room.

The differential pressure between the temperature tubular network and the reactor building constitutes the critical process variable. The reactor building leak rate is obtained from a simple linear regression of this process variable after application of several corrections. A crude test can be summarized as follows:

1. The leak tightness of the temperature tubular network is verified
2. The tubular network and the reactor building internal pressures are equilibrated and then isolated from each other.
3. Any decrease in the differential pressure can be directly related to the reactor building leakage since the tubular network continuously replicates the overall reactor building temperature.

Pressure Drop During Test

A major difficulty of a low pressure test is the extremely small pressure drop observed. During an eight hour Integrity Test performed at 2.75 kPa(g) a typical pressure drop could be 0.043 kPa(d). The equivalent pressure drop during an eight hour Pressure Test at 124 kPa(g) is 0.376 kPa(d). These figures assume a 0.5% of reactor building volume per day leak rate and 100% turbulent flow.

Vapour Partial Pressure

The precision of the TCM System is highly dependant upon the time behaviour of the reactor building vapour pressure and its spatial distribution. This is further complicated by any perturbations experienced during the test period.

Gentilly 2 uses a distributed tubular network sampling circuit with two hygrometers to obtain the "weighted" reactor building dew point measurement. The copper tubing network is sized, routed and designed with orifice flow control to insure the intake of the correct amount of air from each of the (11) reactor building zones defined for "weighting" purposes. The circuit also consists of a suction pump and flow-meters for verification of the loop calibration.

Barometric Pressure Variation

The atmospheric pressure represents an independant variable and may vary dramatically during the test period. It is possible that the positive differential pressure of the reactor building with respect to the atmosphere (which governs the leak rate) may be reduced by as much as 50% during the test as a result of a weather perturbation.

Test Validation By A "Known" Leak Rate

In order to verify each specific Integrity Test result, a post-test validation procedure was developed. A "known" leak rate of magnitude comparable to the "unknown" leak rate, is superimposed upon the latter directly upon conclusion of the "unknown" leak rate measurement. This procedure uses an artificially created "known" leak rate which, by aid of a high precision flowmeter, allows validation of the TCM System methodology and the particular test setup. The magnitude of the error between the two values of the "known" leak rate also provides a significant indication of the overall precision of the TCM System.

TCM EQUIPMENT FUNCTIONAL DESCRIPTION

TCM Leak Rate Measurement System

The temperature tubular network consists of 2473 feet of thin-walled ASTM B-68 copper tubing ranging in size from 3/16 to 1/2 inch o.d. This "brased joint" network is distributed throughout the 48,640 m^3 volume of the reactor building. The reference volume simulates the reactor building volume on a scale of 1 to 2,000,000. A low range manometer is provided to measure the differential pressure between the tubular network and the reactor building. A barometer is used to measure the absolute pressure of the network. An isolable and instrumented flowpath from the network to the outside of the reactor building permits the "known" leak rate validation procedure.

The atmospheric pressure is given by a barometer located in the service building. A medium range manometer also at the same location provides the reactor building to atmosphere differential pressure.

The humidity sampling circuit is composed essentially of a tubular network of 2200 feet of thin-walled ASTM B-68 copper tubing ranging in size from 3/8 to 3/4 inch o.d.. Thirty-two orifices are sized to proportion the flow drawn into the "Swagelok joint" network which is distributed throughout the entire reactor building volume.

The humidity sampling circuit is also equipped with a sampling pump, pressure and temperature (3 RTDs) instrumentation. Regulating valves and flowmeters are available to provide an independant calibration of the circuit and each of the 11 zone branches. Two optical dewpoint (mirror) hygrometers of the condensation type assure the humidity measurement of the air flow drawn by the sampling pump.

A reactor building instrument air tank is monitored for pressure in order to evaluate the impact of this variable. During previous Integrity Tests the Instrument Air System was temporaily modified to allow the system to pump reactor building air to the reactor building air tanks. A permanent installation is to be provided in the near future.

Data Acquisition and Processing System

An AT 386 IBM PC with a clock speed of 20 mhz, an arithmetic co-processor and a 40 MByte hard disk constitutes the heart of the system. A VGA graphics card is incorporated to ensure an effective visual interface. A colour monitor and printer form the system peripherals.

Data transmission is based on (16), "M1000 series" Metrabyte modules used for analog-to-digital conversion of each of the field instrument signals.

The TCM System building pressure test software package is identified under the acronyme "SATRAD PBR" for Reactor Building Pressurisation Data Acquisition and Processing System. The "multi-tasking" Desqview environment is required to allow data processing and acquisition in parallel.

The "PARAMS" program is used to name, initiate and terminate each test.

The "ACQUIS" program collects the field data transmitted by the Metrabyte modules at 15 second intervals.

The data processing "TRAITE" program constitutes the most complex element of "SATRAD PBR". Among other fonctions it provides data processing, data visualization,parameter specification capabilities and various data analysis algorithms.

VARIABLES CRITICAL TO THE INTEGRITY TEST

The meaningful interpretation of the minute pressure drop experienced during the test, imposes a heavy burden upon the TCM System. Hence the system and its components must be engineered to exacting precision requirements. Moreover they must maintain their performance during process perturbations due to mother nature and the reactor building environment.

The behaviour of reactor building humidity plays a major role during the Integrity Test. During the June 1989 test, under ideal conditions, the dewpoint increased from 4.5 to 5.0°C. The increase in vapour partial pressure of 0.8653 to 0.8959 kPa represents a factor of three over the test pressure drop of 0.00937 kPa. Hence a precise determination of average reactor building humidity and its variation in time and space is critical to the Integrity Test. The humidity and temperature mapping exercise conducted during the 1990 annual outage has confirmed the ability of the humidity sampling tubular network layout to adequately track reactor building humidity. A detailed error analysis indicates that the humidity sampling circuit placed 3.2% error upon the leak pressure drop.

The temperature tubular network is required to track the average reactor building temperature and its variations in time and space in order to provide a significant leak pressure drop. Field data has confirmed the temperature gradients in time and space to be negligible. Reactor building conditions, off-line, are very stable.

The (3) reactor building instrument air tanks varied in pressure between 815.86 kPa and 816.33 kPa over a 6 minute period during the 1990 test (using a special Instrument Air System configuration). The air exchange with the reactor building environment produced an error of 1.3% on the leak pressure drop.

The pressure and differential pressure measurement errors are of minor significance.

Any increase in the atmospheric pressure during a test is reflected by a decrease in the test differential pressure. A 1 kPa increase produces a 20% decrease in leak pressure drop and an amplification (a non-linear increase) of the relevant TCM System component errors.

TCM SYSTEM DATA PROCESSING

The "TRAITE" program performs an "on-line" analysis of the pressure, temperature, humidity and flow data to calculate the reactor building leak rate. The "ACQUIS" program data is collected every 15 seconds and then feeds the "TRAITE" program with the data averaged over 2 minutes. The temperature tubular network to reactor building differential pressure is first corrected for several factors. A linear regression of the corrected variable in time is then performed to yield the reactor building leak rate.

The corrections consider:

- variation of vapour partial pressure due to water vapour inside the reactor building.
- time delay in the temperature response of the temperature tubular network
- normalization of the test differential pressure to nominal conditions to account for changes in atmospheric pressure and test differential pressure over time.

A normalization routine is included to continously convert the leak rate data to the Integrity Test nominal conditions of 3.0 kPa(g).

INTEGRITY TEST LEAK RATE EXTRAPOLATION TO 124 kPa(g)

The object of this exercise is to study the possibility of deriving a meaningful leak measurement from the Integrity Test result which can be directly compared against the Pressure Test criteria (eg: 0.5% of reactor building volume per day at 124 kPa(g).

A complex non-linear extrapolation equation is required to transform a low pressure test leak rate to the equivalent result for the nominal Pressure Test conditions. This equation is heavily dependant on the "R_L" factor which represents the ratio of laminar to turbulent flow. Reactor building leakage is characterized by a combination of turbulent and laminar gas flow. This factor is dependant on the nature of the reactor building, its condition as well as the actual test and extrapolation pressures.

The leak rate extrapolation ratio between the 3 kPa and 124.0 kPa nominal test conditions varies from 8.5 for purely turbulent flow to 71.7 for purely laminar flow. The extrapolated leak rate error depends heavily on the uncertainty of the "R_L" factor. The extrapolated leak rate percentage error is roughly equivalent to the "R_L" percentage error for purely turbulent flow. However, this error ratio increases tenfold for purely laminar flow.

Data obtained during the 1990 Pressure Test at several different pressures indicates that the reactor building leakage is characterized by a predominantly turbulent flow. This would appear justificable on the basis of the new paint recently applied over 58% of the reactor building surface.

However, it remains to precisely quantify the turbulent component of "R_L" and to identify its time-dependant nature. Additional Integrity Test and Pressure Test leak rate data over a significant period of time is required.

FUTURE DEVELOPMENTS

The ultimate goal of the Integrity Test development program is to provide an "on-line" leak test capability. The TCM System has been demonstrated during annual outages. However several additionnal difficulties must be hurdled in order to prove the feasibility of the Integrity Test at full power.

Gas leakage during normal operation from the various reactor building systems will contribute to the existing water vapour partial pressure. These gases include helium, carbon dioxide and nitrogen. The resulting error must be shown to be negligible; otherwise the TCM System must incorporate the relevant parameters.

The reactor building temperature distribution "on-line". differs from the outage condition and is less uniform. However available data indicates that the temperature remains relatively stable "on-line" and should not affect the TCM System.

A detailed error analysis, over and above a simple statisfical analysis of the data, has been performed in order to demonstrate the scientific basis of the TCM System. The error band on the Integrity Test leak rate is evaluated at ± 14%. The algorithm is being incorporated to the "TRAIT" program to optimize test execution and intrepretation.

RESULTS AND CONCLUSIONS

The Gentilly 2 "TCM System" Integrity Test has been conclusively demonstrated with the reactor "off-line". It is capable of measuring the reactor building leak rate at a nominal test pressure of 3 kPa(g). The error associated with this measurement has been confirmed to lie nothin a band of ± 14% under typical test conditions. A detailed analysis of all possible random and systematic errors was performed to arrive at this conclusion. In addition the available data from the "known" leak rate validation procedure suggests that the actual error is less than ± 5%.

The original Integrity Test objective was to detect a leak corresponding to an equivalent pipe of 25 mm diameter. This objective has been attained with remankable results. The Gentilly 2 Integrity Test is able to detect a leak corresponding to a 2-3 mm diameter pipe, with high precision in a relatively short test period.

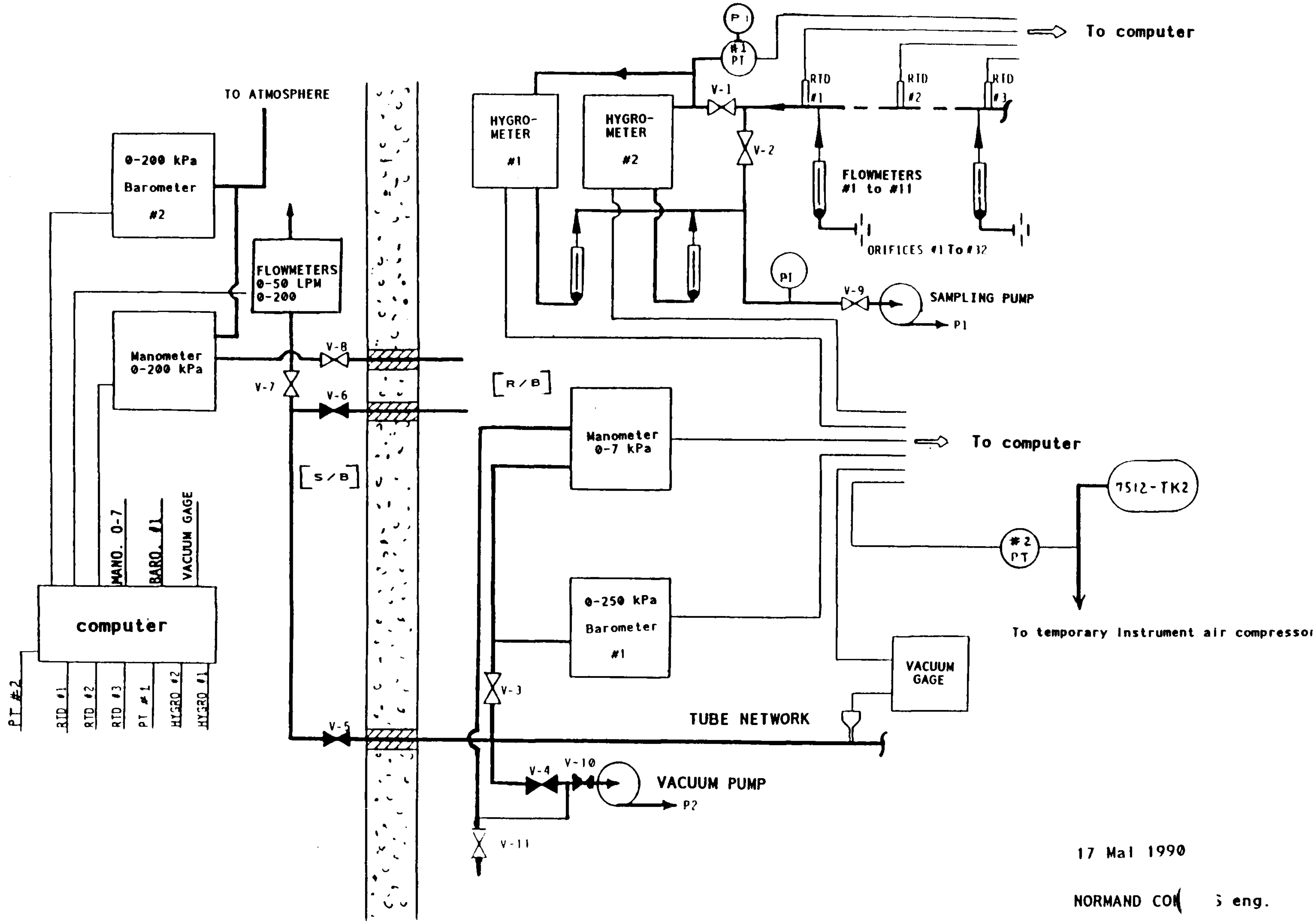
The "on-line" Integrity Test will be demonstrated during the 1991 annual outage start-up.

The merit of the Integrity Test leak rate extrapolation and its usefulness will be evaluated in due course as a sufficient bank of test data becomes available.

Acknowledgment

The authors wish to thank Mr. Denis Carrier of VFP Consultants Inc. for his work in the review and documentation of the TCM System.

R/B INTEGRITY TEST INSTRUMENTATION FLOWSHEET



17 Mai 1990

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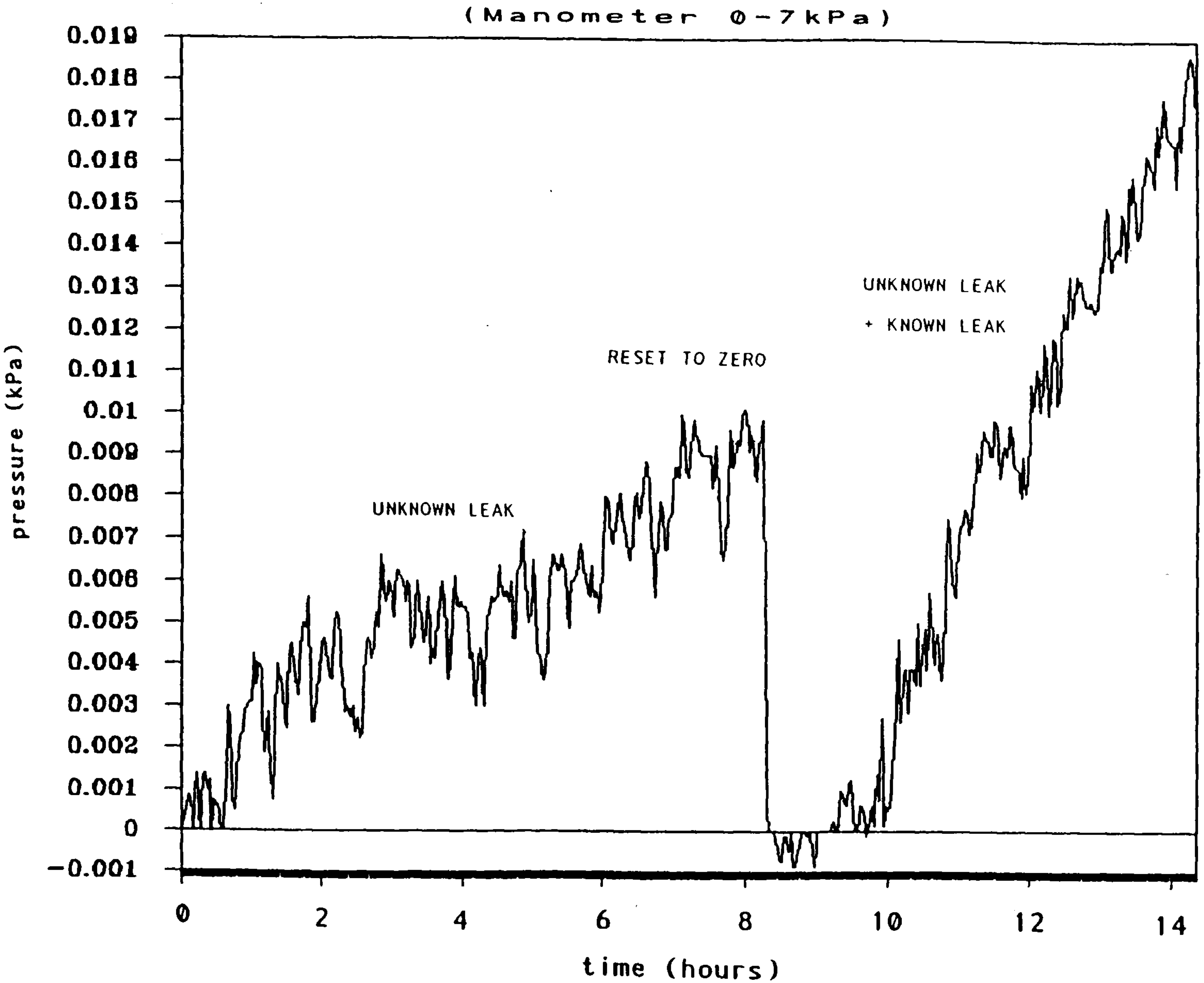
DIFFERENTIAL PRESSURE (TUBE NETWORK to R/B)



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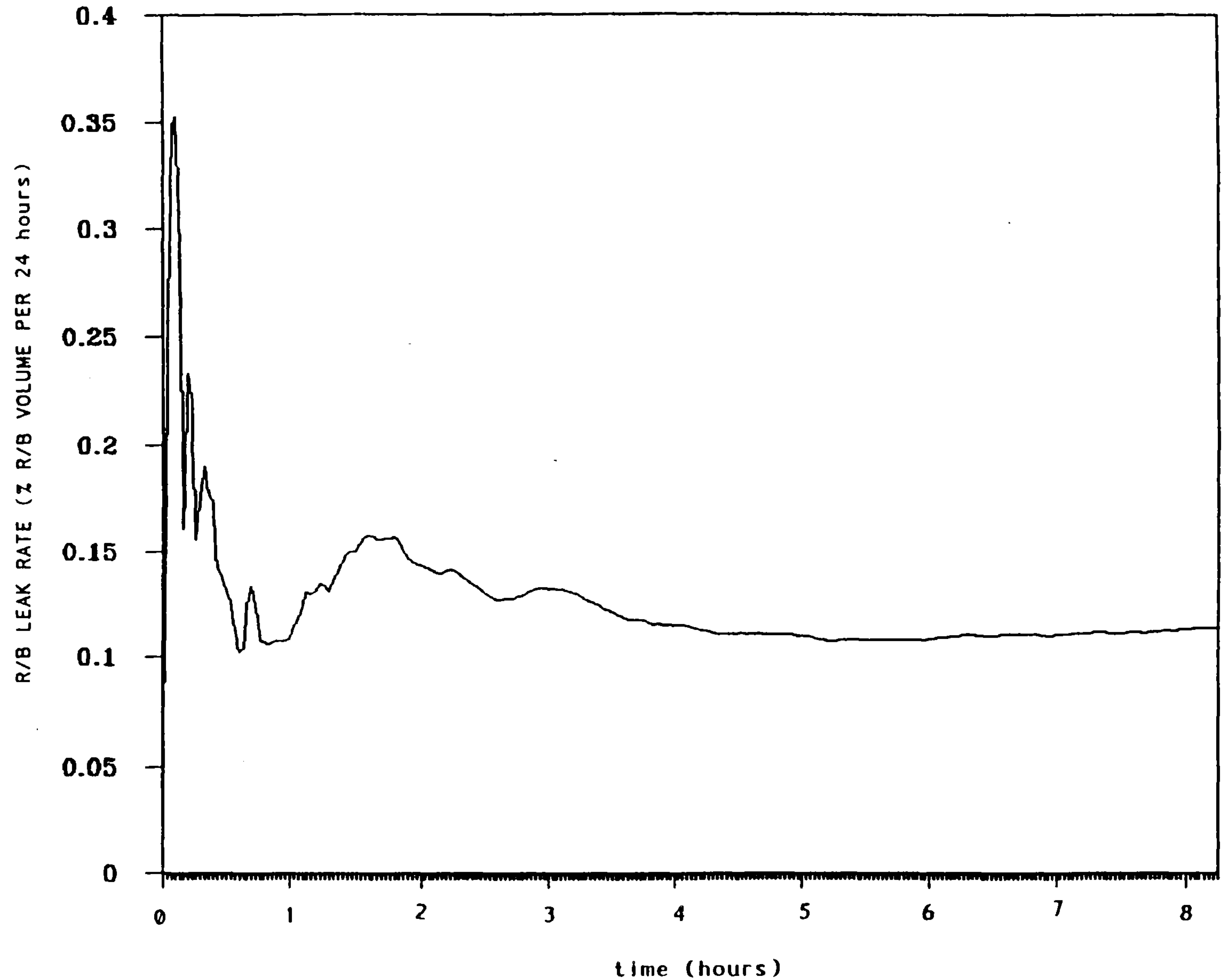
1989 R/B INTEGRITY TEST LEAK RATE (at 3 kPa(g))



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1989 R/B INTEGRITY TEST RESULTS

	LEAK RATE at 3KPa(g) (% Vol./day)	CORRESPONDING FLOW (STD LITER/min)	EQUIVALENT ORIFICE DIAMETER (mm)
UNKNOWN LEAK	0,114	39,49	3,50
UNKNOWN LEAK + KNOWN LEAK	0,162	---	---
KNOWN LEAK (TCM)	0,0483	---	---
KNOWN LEAK FLOWMETER	0,0501	16,23	2,3

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1989/1990 INTEGRITY AND PRESSURE TEST RESULTS

(USING THE TCM METHOD)