**PRTR CONTAINMENT VESSEL
LEAK RATE TEST EXPERIENCE**

D. W. HAYES

AUGUST, 1967

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LEAK RATE TEST EXPERIENCE

By

D. W. Hayes

PRTR Section
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D. W. Hayes

INTRODUCTION

This report discusses the containment vessel leak rate test on the Plutonium Recycle Test Reactor (PRTR) in November 1966. The test was conducted in accordance with the new Technical Safety Draft Guide (7.5.1 Reactor Containment Leakage Testing and Surveillance Requirements) issued by AEC Division of Safety Standards, January 15, 1965.

The PRTR is located on the Columbia River about seven miles north of the City of Richland, Washington. The containment vessel, housing the reactor, is designed to retain any gases, vapors, or liquids, within permissible limits for public health and safety, should a nuclear accident occur. To ensure that the vessel will perform its intended containment function, a program of regular inspection and testing is necessary.

The PRTR Containment Vessel was first tested for leakage in May, 1959, shortly after its construction.⁽¹⁾ The vessel was unequipped and the leakage test evaluated only the welded structure and the two personnel air locks. The measured leakage rate at that time was 0.05%/24 hr at the vessel design pressure of 15 psig.

The second leak rate test was performed in May, 1964.⁽²⁾ In the intervening five years, the vessel had been equipped; penetrations had been made for electrical, instrument, and pneumatic leads; and the containment valves and vacuum relief valves had been installed and used. A series of tests and penetration leak repairs were necessary before the leakage rate was within the acceptable limits of 1%/24 hr at the vessel design pressure of 15 psig. (Actual measured leak rate for the final test was 0.87%.) Because of the difficulty in achieving a permissible leak rate, programs were initiated or expanded upon to improve the containment system on a long-term basis.

The Operating Safety Limits for the reactor have recently been revised in conformance with the Technical Safety Draft Guide. The test requirements were changed from the former requirements in the following respects:

1. The test is conducted at the calculated peak vessel pressure for the maximum credible incident 10 psig, not the vessel design (code) pressure, 15 psig.
2. The allowable test leakage limit is determined by correcting the allowable design basis accident leakage

rate to that permissible under test conditions.

3. The allowable operation leakage limit is determined by reducing the corrected leakage rate (above) by 25%. This provides a safety margin for possible deterioration of the containment system between tests.
4. The test is performed with the containment system in an "as is" condition; without any preliminary leak detection surveys or repairs except to meet the requirements of Section 12.0* of the draft guide.
5. Closure of the containment isolation valves is accomplished by the normal mode of actuation without any preliminary exercises or adjustments.
6. The guide requires operability tests, at test pressure conditions, of the engineered safeguards systems, located in the vessel and relied upon to limit or reduce the vessel leakage under post-accident conditions.

SUMMARY

The leak rate of the Plutonium Recycle Test Reactor (PRTR) containment structure was measured, using the reference volume method, during the week of November 7, 1966. The measurement

* Section 12.0 of the draft guide provides for an annual visual inspection of all accessible parts of the containment structure and its components prior to the test, to uncover any evidence of deterioration which may affect either the containment structural integrity or leak-tightness. Any significant deterioration must be corrected in accordance with acceptable procedures prior to the conduct of the test. Such repairs are to be reported as part of the test results.

was made with the containment system in an "as is" condition at a vessel pressure of 10 psig. The accuracy of the test results was verified by superimposing a known leak rate of 0.88%/day on the existing vessel leak rate. The measured leak rate increased from 0.40% to 1.19%/day, giving a 0.79% increase, versus an expected 1.28% or 0.88% increase. The final vessel leakage rate was $0.43 \pm 0.026\%$ /day in comparison to an allowable operational leak rate of 0.678%/day.

A thorough leak check of the vessel penetrations was made while the vessel was pressurized. All the leaks detected were small and most had been previously reported. Four of the leaks were felt to be significant enough to repair. The repair methods were carefully selected on the basis that they could not increase the leak rate through the penetration. At the completion of the test, the vessel was depressurized and the repairs made. The vessel was then repressurized to 10 psig. Three of the repairs were successful and the leaks were eliminated, but only minor improvement was made in the fourth.

The mechanical closures, including the underwater fuel transfer gate (sluice gate), air lock doors, vacuum relief valves, and effluent containment valves, held very well, and only minor leaks were detected at these locations.

PREPARATIONS

The PRTR was not designed to permit containment vessel pressure tests with all systems in operating order, and extensive preparations were necessary

to prevent damage to equipment or systems by the 10 psig test pressure. Because of the loss of critical pneumatic signals for flow, levels, etc., discharge of the reactor is also usually a prerequisite to pressure testing the vessel. However, it was not necessary for this test, since the reactor had been operated only at near zero power levels since new (green) fuel elements were charged for the Batch Core experiment. Discarded shim rods and other irradiated material had been previously removed from the containment vessel storage pit.

Tanks and vessels not designed to withstand the external pressure were vented by removing rupture discs or otherwise opening the system. Heavy water drums and collection tanks were either vented, if empty, or removed from the vessel. Some of the pneumatic instrument transmitters were vented to prevent damage to the actuating bellows.

Electronic equipment and mercury vapor, fluorescent and incandescent lamps, etc., had been previously tested⁽³⁾ at external pressures up to 18 psig, and these items were left in the vessel. Television equipment and oscilloscopes were removed. Remote area monitoring radiation chambers (RAM chambers) and reactor flux chambers were left in place; however, the RAM Chamber protective aluminum housings were found to be air tight and these were vented. One of the sump pump switch floats failed an external pressure test of 10 psig and was replaced with an improved design.

The compressed air, instrument air, and breathing air lines were isolated

from the vessel. All helium supply lines to the vessel were completely valved out. The gas loop was pressurized to 10 psig with dry air but was later found to leak. It was then vented to the vessel and the air supply removed. All compressed gas cylinders were either removed from the vessel or valved out and the gauge readings recorded. Two emergency back-up air bottles for the air lock door seals were left valved in and the gauge readings recorded.

The air supply to control room pneumatic instrumentation was valved out, as was the supply to manual valve control stations. Air lines to the large pneumatic control valves were disconnected at the diaphragm chambers as a precautionary measure to prevent possible damage to the diaphragms from back pressure. Later investigation revealed that this would not have been necessary as the valves were designed for a back pressure of 20 psig.⁽⁴⁾ Two of the disconnected lines* were found to leak air from the vessel into the control room via the PRV bleed port. They were disconnected from the PRV and capped.

The primary coolant system was drained as a precautionary measure, but it was not a prerequisite for the vessel test. Because all pneumatic control valves were to be deactivated, the emergency light water injection system was blanked off to prevent ordinary water from entering the heavy water coolant piping.

* From emergency light water injection valves E-6 and E-7.

PRTR Operating Procedure XII-R covers in detail the required test preparations and performance, including a return to normal check list. Details of the test equipment design and installation are shown on H-3-14959 and in Non-Process Change 409.

Preparations required four weeks. Fabrication, installation, and leak testing of the reference vessel was the limiting item. The 200 ft section of reference vessel located in the containment vessel dome was left in place; this should help reduce preparation time for future tests.

No preliminary leak location surveys or leak repairs were made. No testing of the containment system valves or other equipment was performed other than that normally scheduled under the preventive maintenance program or routinely required by Operating Standards and/or Process Specifications. Closure of the containment system valves was accomplished by the normal mode of actuation.

METHOD AND MEASUREMENTS

METHOD

The Reference Volume Method was used to estimate the leakage rate. The development and use of this method has been extensively reported^(5,6,7) and it has been used to measure leakage rates on several containment vessels, including the PRTR vessel in 1959 and 1964.

The method involves three pressure measurements; gauge vessel pressure, barometric pressure, and the differential pressure between the vessel and the reference volume. The gauge and

barometric pressures are combined to give vessel pressure in absolute units.

The differential pressure develops during the test as the containment vessel pressure falls. These measurements can easily be made with high precision; and with ordinary care, they can be representative of large volumes.

Temperature measurements of the contents of the same large volumes were made to indicate when equilibrium condition existed. But these were not required nor used in the evaluation of the leakage rate. The changes in the partial pressure of water vapor in the vessel during the test were included in the evaluation of the leakage rate.

REFERENCE VOLUME DESIGN

The reference volume consisted of about 545 ft of 3/4 in. copper tubing with a wall thickness of 0.035 in. The reference volume tubing was installed in the vessel so that the volume of the tubing and the volume of that part of the vessel in which the tubing was located were proportional. The reference volume was also mounted as closely as possible to the central portion of each section of the vessel it served. It was thermally insulated from all wall surfaces and mounting straps supporting it. Short sections of high vacuum rubber hose thermally insulated the reference volume tubing from the servomanometer at one end and an oil seal assembly at the other end.

The use of small, thin walled, tubing and its distribution within the containment vessel was designed to minimize thermal time lags. The validity of the reference volume method of testing depended on these design features.

Before installation, the reference volume tubing was thoroughly cleaned to reduce outgassing. Also some sections were evacuated and tested prior to installation. After installation, the entire reference volume was evacuated to 9 microns of mercury and then cut off from the pumps. Over a 5 hr period, the pressure increased from 9 microns to 38 microns of mercury.

The special connection to the servomanometer was leak-checked by pressurizing it and the manometer to 3 psig with helium. Leak checking was performed with a mass spectrometer type leak detector. Operating on its most sensitive range, the leak detector will respond to a leak of about 10^{-8} cm³/min. No leaks were detected at the connector or at the cistern of the servomanometer when checked in this manner.

A remote method of equalizing the manometer was necessary because all of the reference volume and the servomanometer were located within the containment vessel. Equalization was accomplished by extending one end of the reference volume into a long cylinder which could be remotely filled with manometer oil. During pressurization of the containment vessel, the cylinder was empty and the open end of the reference volume was thus vented to the vessel atmosphere, equalizing the reference volume and containment vessel pressures. When the vessel was at test pressure, a remotely operated solenoid valve allowed oil to flow into the long cylinder, sealing that end of the reference volume.

The other end of the reference volume was coupled to the lid of the servomanometer cistern. The precision

bore tubing of the manometer was immersed in the oil in the cistern at one end and vented to vessel atmosphere at its top.

VESSEL PRESSURE

Vessel pressure was determined by summing results from a precision pressure gauge and a barometric pressure gauge mounted side by side, both equipped with mirrored rings and referenced to the same pressure. The pressure gauge was connected directly to the containment vessel wall using a spare penetration flange. It was accurate to the nearest 0.25 in. water column. The barometric pressure was read to the nearest 0.2 mbar, which is about 0.1 in. water pressure. Hence, the absolute vessel pressure was measured to about the nearest 0.4 in. water pressure.

DIFFERENTIAL PRESSURE

The differential pressure that developed between the containment vessel volume and the reference volume was determined with installed process instrumentation, a servomanometer which is normally used to measure the level of the heavy water moderator in the reactor. The device is essentially a cistern manometer with a float in a precision-bore manometer tube. As the vessel pressure decreased due to leakage, the oil level rose in the precision bore tubing, carrying the float. A linear differential transformer coil and servo system followed a small iron slug in the float.

Electrical readout was transmitted to the control room. The resolution of the instrument is 0.002 in. water.

During the test, an oil with an extremely low vapor pressure and a specific gravity of 1.00 was used, to avoid the need to consider corrections for changes in vapor pressure within the reference volume.

VAPOR PRESSURE

Vapor pressure was determined by measuring the dew point of the contained air with two transducers, which essentially were resistance temperature detectors. Their resistance had almost a linear relationship to the dew point temperature of their environment as given by a factory-supplied table relating dew point temperature to ohmic resistance of the device. Using the steam tables, a direct relationship of vapor pressure in inches water to ohmic resistance of the dew cell was prepared.

The resistance of the dew cell was determined to six places using a Wheatstone bridge with an electronic galvanometer to detect the null balance. Vapor pressure measurements to the nearest 0.025 in. water were possible, but vapor pressure was reported only to the nearest 0.1 in.

The two dew cells were checked in the shop prior to the test to determine their response to identical environments. During this test a 0.24 ohm (0.037 in. water pressure) difference was noted between cells. To normalize the reading, this difference was added to the appropriate dew cell measurement during the test. The dew cell readings were also corrected for lead resistance (i.e., the lead resistance was subtracted from the cell reading).

As a result of findings during the 1964 vessel leak rate test, added effort was made to ensure representative sampling of the vessel air and thus more accurate vapor pressure measurements. The dew cells were located in temporary 6 in. ducts, one in the reactor hall and the other in the process cell. Air was drawn from eight sample points into mixing chambers and then through the ducts with coaxial fans located at the exit of the ducts. Four of the sample points were in the reactor hall (two near the top of the dome, one in the center and one near the floor). The other four were located as follows: two in the process cell, one in the test cell, and one in the center instrument cell at the -21 ft level.

VESSEL TEMPERATURE

Temperatures were measured using six thermocouples tightly clamped onto the copper tubing reference vessel at the appropriate locations along its length. Three of the six thermocouples were located in the reactor hall. Single thermocouples were centrally located in each of the three process cells.

An ice bath reference junction, a Leeds and Northrup type K-3 potentiometer and an electronic galvanometer for null balance were used to read out the thermocouples. Each temperature measurement during the test was determined to the nearest 0.1 °F.

All thermocouple junctions were forced into intimate contact with the copper tubing and were insulated from surface drafts. Temperatures that were representative of the contents of both

the reference volume and the containment vessel could be determined with the same measurement because of the thin wall and high thermal conductivity of the reference vessel, the location of both the reference volume and the thermocouples, and the extensive recirculation of the air in the vessel during the test.

Trouble developed with the cold junction compensation during the tests. On several occasions, apparent shifts in temperature occurred on all six thermocouples following ice replacement at the cold junction. The problem was believed to be due to improper maintenance of the ice bath and contaminated mercury in the cold junction contact pools.

Although absolute temperature values could not be determined, it was felt the measurements served the needs of the test. Average vessel temperatures varied less than 2 °F between those times where apparent temperature shifts occurred.

PROCEDURES

PRESSURIZATION

The vessel was pressurized using two large compressors, each with a capacity of 200 standard cubic feet per minute (scfm). The units were equipped with oil and moisture separators and both discharged into a 2-in. line entering the vessel at a penetration normally occupied by a vacuum breaker. A tee and spool piece provided an entry point and still retained the vacuum breaker. An additional oil filter was installed in the 2-in line to assist in removing oil.

Pressurization was initially started using a 600 scfm compressor along with one 200 scfm unit. At 3 psig, it was discovered that the oil separator on the larger unit had failed and oil vapor was present in the vessel air. The vessel was depressurized, the ventilation system restored to normal and the offending oil vapor swept from the vessel. No oil film was found on any of the equipment or vessel surfaces except at the pressurization line penetration. Following this, the discharge of each compressor was checked hourly for signs of oil or water vapor. The checks were accomplished by directing the air compressor discharge against a cold metal plate, then examining the plate for signs of oil or water condensate.

There also was some concern that oil vapor in the vessel air could create an explosive hazard. This was dismissed when calculations revealed that more than 50 gal of oil, of the type used in the air compressors, would need to be added before an explosive mixture would exist at 10 psig vessel pressure.

VESSEL VENTILATION

To obtain as uniform conditions of temperature and humidity as possible within the vessel, all doors were opened and cell cover blocks were removed so the containment vessel interior would approximate one large hall. In addition, the nine recirculating ventilation blowers in the containment vessel were operated continuously during the test. The motors on the recirculating units were oversized and no reduction of air input

was necessary because of the denser air at 10 psig. The capacities of these units varied to match the heat loads in the various locations. Total capacity was 42,000 scfm. The two blowers in the reactor hall, which contains about 71% of the free space, account for 24,000 scfm of the 42,000 scfm. To ensure complete movement of air in the vessel, two Coppus blowers (capacity 1,500 scfm each) were located in the bottom of the containment vessel (-32 ft level). One blower was located in the process cell and one in the experimental cell. A plastic sleeve, approximately 12 in. in diameter and 80 ft long, was placed on each blower to direct the air from the lowest level directly up into the reactor dome within 30 ft from the top. In this manner, the containment vessel air was continuously and thoroughly mixed.

MOISTURE CONTROL

As a result of the findings by R. G. Clark and D. R. Koberg during the 1964 test ⁽²⁾ extra effort was made to provide conditions for stable vessel dew point temperatures during the test.

The compressors were equipped with oil and water separators. These units were normally used as portable fresh air sources for work requiring 100% respiratory protection. The oil and water vapor content of the compressed discharge of these units was much less than that of conventional air compressors.

The sumps were drained, dried, and covered with plastic. All water on the floors was removed and the floors dried. Openings into the process systems where

rupture discs had been removed were covered with plastic. The fuel discharge water pit was not drained; however, the cover blocks were in place and covered with a plastic sheet. All heavy water drums, unless empty, were removed from the vessel. Stable vapor pressures resulted throughout the test.

TEST EXPERIENCE

The containment vessel pressure was raised to 288 in. H₂O and the air compressors valved out. After a brief "soak" period, the reference vessel was sealed off and the vessel pressure slowly reduced to about 282 in. to bring the differential manometer well on scale. Pressure and temperature readings were started, but after a few hours it became apparent one of the compressed air supplies in the vessel was leaking.

It was felt a vessel entry at 10 psig could safely be made; and following medical examination, two engineers entered the vessel to correct the problem.* No difficulties were encountered in making the entry other than the normal "popping" of the ears during pressure equalization periods. Portable air packs were available but not needed. The vessel air was good and had only a faint odor of oil vapor.

The gas test loop piping had developed a leak and the air cylinders supplying the loop and the air lock

* Two others also took a medical examination and were on standby in the event an emergency vessel entry was necessary.

door seals were nearly depleted.* The cylinders were replaced and the air supply line to the gas loop was disconnected and capped. The loop was opened and vented to the containment vessel. An air cylinder used to hold open a diaphragm valve (to vent the boiler to the deaerator), although not leaking, was also valved out. The only pressurized line in the vessel now was to the air lock door seals.

After the test and vessel depressurization, the pressure in the two air cylinders supplying this line (to the air lock door seals) was found to have decreased from 2,000 psig to 1,785 psig, representing an air loss of about 430 standard cubic feet (scf). The air line and cylinder piping was rechecked for leaks. Two very small leaks had developed, one on a "pigtail" to one of the cylinders and the other on a fitting downstream of the pressure regulator.

The use of air from the cylinders to repressurize the air lock door seals following the vessel exit, plus the loss from the leaks, accounted for the 430 scf. Even if it is assumed all the loss was added to the vessel air during the test period, the effect on the leak rate results would be negligible.

While the engineers were inside the vessel, they made a leak check of the vessel penetrations using an ultra-

sonic leak detector. All air circulating units were turned off and the ultrasonic detector was very effective in the quiet environment. No additional leaks were found that had not been previously detected by external means.

The vessel pressure following the exit was still greater than 10 psig. Data recording and the leak rate calculations were again started without repressurizing the vessel.

FINAL TEST RESULTS

No further problems developed other than the spurious shifts in temperature noted earlier, and a 24 hr leakage rate test was made followed by a 6 hr superimposed leakage rate test. The leak rate over the 24 hr was $0.426 \pm 0.026\%$ /day. This compares favorably with an allowable test leak rate of 0.90% and an allowable operating leak rate of 0.678% /day.⁽⁸⁾ The data and final calculations are shown in Appendix E and F.

FOG SPRAY SYSTEM TEST

Following the superimposed leakage rate test and before the vessel was depressurized, the fog spray system was activated to check its operability against the 10 psig vessel pressure.* Prior to the test, the drain line to the sump was opened and the line to the spray headers was closed; thus water admitted to the system was directed to the sump. The time required to fill

* An external air supply was also tied into the air lock door seal line through a check valve and at a point inside the air lock. The pressure on the external air line was set to supply air to the seals in the event the cylinder supply became depleted.

* The fog spray system was designed to allow water to be sprayed from the top of the containment vessel dome to reduce vessel pressure and thus leakage under post-accident conditions.

the sump to a pre-determined level was essentially the same with the vessel at 10 psig as at atmosphere pressure.

COMMENTS ON TESTING

Vessel entry at 10 psig was much easier than was first thought. However, some precautions are necessary, which include:

- a. Provide means for the participants to control the pressurization and depressurization of the air lock.
- b. Ensure the vessel air remains clean and that exhaust fumes from the air compressor motors do not enter the vessel during pressurization.
- c. Provide medical examinations for the participants or otherwise ensure their respiratory system and ears will withstand the pressure changes.

Breathing of the vented calandria and storage tank into the containment vessel during the pressure cycles caused slight degradation (0.05%) of the heavy water moderator. Not all the degradation could be accounted for by the three pressure cycles during the test period; it is believed some air circulation occurred between the calandria and the vessel, perhaps via the core blanket system. Although not a problem during this test, the phenomenon can also increase the tritium concentration in the vessel air and cause a health hazard should vessel entry be required during the test.

Pressure cycles should be minimized for future tests, and venting of systems at more than one point should be avoided.

DATA ANALYSIS

The following data were taken at half hour intervals during the test:

- Vessel gage pressure
- Barometric pressure
- Vapor pressure
- Differential pressure
- Six temperatures

The data from the test instruments, all of which were located in the reactor control room, were logged on prepared formats. All computations of leakage rate were made with a desk calculator. The relationship used to determine the leakage rate was:

$$\frac{\% \text{ leakage}}{24 \text{ hr}} = 100 \frac{(24)}{(H)} \left[1 - \right.$$

$$\left. \frac{P_2 - (P_{v2} - P_{v1})}{P_1} \times \frac{P_1 + \Delta P_1}{P_2 + P_2} \right]$$

The development of this expression is given in Appendix C. The average temperatures, both inside and outside the vessel, and the vapor and differential pressures were plotted and are shown on Figure 1.

CORRECTIONS

Corrections for the minor changes in the containment vessel volume which might result from pressure or temperature variations during the testing were not considered. However, the small changes in the reference volume occurring with each change in the manometer level created a corresponding change in internal pressure in the reference volume which was extraneous to the differential pressure being measured.

As developed in Appendix D, the magnitude of the correction factor (B) expressed in terms of inches of water pressure per inch of pressure

FIGURE 1. Plot Vessel Air Temperature, Vapor and Differential Pressure

difference measured between the reference volume and the containment vessel was: $B = P_1 (0.00038)$

where

P_1 = the absolute pressure.

Hence, for a differential pressure measurement of ΔP in.,

$$B = P_1 (0.00038) \Delta P.$$

The corrected differential pressure measurement ΔP_C became

$$\Delta P_C = \Delta P + B$$

or

$$\Delta P_C = [1 + P_1 (0.00038)] \Delta P$$

where

ΔP was the measured differential pressure.

When P_1 , the absolute pressure, was at about 680 in., as it was during the test, the correction factor became about 0.26 in./in. of ΔP or about 25%. This factor was a known correction which could be precisely determined and was essentially eliminated as a factor in the results in the manner of handling the data; i.e., the values of B became small parts of two large numbers which formed a quotient (see Appendix C).

STATISTICAL ANALYSIS OF LEAKAGE RATES

Leakage rates were estimated from data obtained over 30-min intervals

using the following expression:

$$\% \text{ leakage} = \frac{\Delta P_{c2} - \Delta P_{c1}}{P_1}$$

where the symbols have the same meaning as in Appendix C. Figure 2 illustrates the results.

The average leakage rate for the 24 hr test period computed in this manner was 0.41% with an 0.048% standard deviation about the mean. The center ordinates given in inches of water, refer to the corresponding differential pressure accumulated over the 30 min intervals. When determining leakage rates in this manner, a statistical review of the results is necessary to

properly determine their precision and the amount of data that must be accumulated (length of test) in order to reach the required accuracy.

In order to produce the precision established for the test, either the data must be narrowly dispersed about the computed mean, or a sufficient sampling must be completed.

From the test, Table I summarizes the statistical analysis completed for the leakage rates computed from pressure measurements determined over 30 min intervals. The data were arbitrarily assumed to follow a normal distribution.

FIGURE 2. Leakage Rates and Differential Pressures from 30 min. Periods

TABLE I. Summary of Statistical Analysis of Leakage Rates

Time Interval (24 hr Clock)	No. of Samples	Average Leak Rate, %/day $\bar{X}$	Standard Deviation, σ (a)	95% Confidence Level, 1.96σ (b)	Error 95% Confidence
1700-2000	6	0.52	0.04	0.036	$\pm 6.8\%$
1700-2200	10	0.49	0.10	0.061	$\pm 12.6\%$
1700-2400	14	0.47	0.09	0.047	$\pm 10.1\%$
1700-0200	18	0.45	0.09	0.041	$\pm 9.2\%$
1700-0400	22	0.44	0.09	0.036	$\pm 8.8\%$
1700-0600	26	0.43	0.09	0.036	$\pm 8.6\%$
1700-0800	30	0.42	0.09	0.035	$\pm 8.4\%$
1700-1000	34	0.41	0.09	0.032	$\pm 7.8\%$
1700-1200	38	0.41	0.09	0.029	$\pm 7.2\%$
1700-1400	42	0.41	0.09	0.027	$\pm 6.8\%$
1700-1600	46	0.41	0.09	0.026	$\pm 6.2\%$

$$(a) \sigma \text{ (of any observation)} = \sqrt{\frac{(X - \bar{X})^2}{n-1}} .$$

$$(b) \sigma \text{ (of the running average)} = \sqrt{\frac{(X - \bar{X})^2}{n(n-1)}} .$$

NOTE: The sigma (σ) for the standard deviation column was computed differently than for the 95% confidence column. The first column is intended to show when data scatter reached equilibrium about the mean, and the second to show the amount of data that must be accumulated to obtain the required accuracy. It may be noted further that sufficient data were accumulated within the first three hours to assure that the leakage rate was less than the allowable under Technical Safety Draft Guide 7.5.1.

Dispersion about the mean reached an equilibrium after about five hours as indicated by the standard deviation. It was noted the dispersion about the mean, at equilibrium, was about the same for this test as the 1964 test. This may suggest the test precision is limited by the instrumentation and method of data taking.

CHECKING THE METHOD

The method of measuring the leakage rate was tested by superimposing a

measured leakage rate on the containment vessel for the last 6 hr of the test. The superimposed leakage rate was measured with a calibrated rotameter which monitored the air flow from a fixed orifice established with a valve and 3/8 in. copper tubing at a spare 2 in. vessel penetration. The leakage rate computed for the 6 hr immediately prior to the test is compared to that for the 6 hr in which the known leak was added.

Leakage rate for the preceding 6 hr, 10:30 a.m. to 4:30 p.m., on 11-15-66 determined by the equation developed in Appendix C

0.40%

Leakage rate for 6 hr from 5:00 p.m. to 11:00 p.m. on 11-15-66

1.19%

Difference, due to superimposed leakage rate

0.79%

During the 6 hr superimposed leak rate test, the measured flow rate was recorded every 10 min. The average outflow was 5,904 standard cubic feet per day (scfd). From this, the leakage rate of 0.88%/day was determined. The correspondence of results provide assurance in the method and in the installed equipment used in the test.

VESSEL LEAK LOCATION

Four separate leak surveys were made of the vessel penetrations while the vessel was pressurized to 10 psig. One of the surveys was made from the inside of the vessel. Table II summarizes the results. Appendix B lists all the vessel penetrations and their service. Since all the detected leaks were small and the measured vessel leak rate was below the allowable operating leak rate, it would have been incorrect to attempt leak repairs unless there was positive assurance that the leak could be improved and not made worse. Four of the leaks could be repaired with this assurance; and following the leak rate test, the repairs were made. See Table III. The vessel was then repressurized and the penetrations rechecked; three of the repairs were successful and the leaks eliminated, but only minor improvement was made on the fourth.

TABLE II. Leak Survey Results - Vessel Pressure >10 psig

<u>Penetration</u>	<u>Estimated Leak Rate</u>
SO-1	about 150 scfd
SO-2	about 150 scfd
SO-10	about 100 scfd (after repairs - 0 scfd)
P-6	about 25 scfd (after repairs - 0 scfd)
P-7	very small (pinhole in weld seam)
P-15	about 170 scfd
P-23	about 15 scfd (after repairs - 0 scfd)
Vessel vacuum relief valves	
West unit	0
East unit	about 2 scfd
Sluice gate	about 245 scfd
Ventilation containment valves (2)	unmeasured, but very small
Airlock doors	less than 5 scfd
Effluent containment valves	less than 10 scfd
Wire runs including primary pump leads	unmeasured, but individually very small. Total estimated at less than 1000 scfd.

LEAK DETECTION METHOD

Three local leak detection methods were used during the test. They were "C leak" (soap bubbles), volume displacement, and ultrasonic leak detector. The volume displacement method was used where possible, because it not only indicated the leak but provided an accurate method of measuring the leak rate. Examples of volume displacement methods include:

TABLE III. Vessel Leak Repairs

Penetration No.	Leaks Observed	Repairs	Estimated Leak Rate	
			Before	After
P-6	Leaking at bottom of penetration. Appears small void developed in potting compound which did not set up hard.	Forced "Dercon" plastic steel into void by caulking penetration from the inside, then pressurizing vessel.	25 scfd	0
P-23	Leaking through threads on pipe cap.	Added thread sealant and replaced cap.	15 scfd	0
SO-1	Leaking on top and near outside edge. Appears to be a hole resulting from pipe mounted on penetration edge to protect wiring from sharp edge.	Increased depth of potting compound to cover leak point; pressurized vessel to force epoxy into voids.	150 scfd	small improvement
SO-10	Leakage through gasket at right back corner	Replaced gasket and increased backup plate thickness from 1/4 in. to 1/2 in.	100 scfd	0

- Measurement of the water displaced in the discharge water pit (i.e., leakage through the sluice gate seal).
- Sealing a large plastic bag over a penetration or over the end of a pipe downstream of its containment valve.

Leakage past the sluice gate seal, vessel vacuum relief valves, aqueous containment valves (W-44, W-46, W-47, S-29 and S-70), fog spray drain line valve (SW-39), flash tank and boiler relief line valve (S-75), main air lock door seal, and spare penetration No. 23 were measured in this manner.

The ultrasonic leak detector was used as a quick-scanning device over a

large number of wire runs and instrument tubing fittings where the escaping air had some minimum sound frequency detectable with the translator, but inaudible to the human ear. The unit was particularly effective when used in a quiet environment but could not detect leaks diffusing through porous wire insulation or in multiwire cables.

The soap bubble technique was useful around mechanical seals and around electrical conductors which were imbedded in the epoxy potting-compound-filled penetration trays. It also was used, where possible, to verify leaks located with the ultrasonic leak detector.

ACKNOWLEDGMENTS

The preparations, method, and procedure of measuring the vessel leak rate were the same as those used in 1964 and reported by R. G. Clark and D. R. Koberg.⁽²⁾ This author borrowed liberally from their report, in many cases changing only those parts necessary to adapt it to the current test.

The assistance provided by R. G. Clark during the test and the technical review of this report by the Nuclear Safeguards and Engineering Section, and H. E. Hanthorn of that section, are gratefully acknowledged.

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7. R. F. Brittain. Reactor Containment, ANL-5948. Argonne National Laboratory, May, 1959.
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APPENDIX A

INSTRUMENTATION

APPENDIX A

INSTRUMENTATION

Pressure Gage - Wallace and Tiernan, Model No. FA-145, Serial No. HH-11878, Range 0-408 in. Custom ordered for 0-415 in.

Barometric Pressure - Wallace and Tiernan, Model No. FA-112, Serial No. GG-09978, Range 450-1030 mbars.

Dew Point - Five Dial Wheatstone Bridge, Leeds and Northrup Catalog No. 4735, Serial No. 1660433; 1 1/2 V Eveready Telephone Battery; Galvanometer, Leeds and Northrup; Dew Cell, Dew Probe Sensor, SS-129-B, Minneapolis-Honeywell Regulator Company.

Temperature - Six Iron-Constantan Thermocouples. Potentiometer, Type K-3, Serial No. 75535, Leeds and Northrup Company, Philadelphia. Electronic Galvanometer, Leeds and

Northrup, D. C. Microvolt Amplifier, Catalog No. 9885, Serial No. 1321179. Standard Cell, The Eppley Laboratory, Inc., No. 406266. Battery, Willard, 2 V wet cell. Ref. junction, Dewar flask, ice bath. Calibration Thermometer - Taylor Instrument Co., style EL-3, Serial No. LI-145.

Differential Pressure - Servomanometer, Exactel Servomanometer, 0-120 in. Model C S1201 D, Serial No. 628.

Flow Meters - Fischer-Porter, Series 10A2700, Flowrator Meters, Tube FP-1-35-G-10, Float 1-GSVT-64.

Leak Detectors - C-Leak, Chemical Sundries Inc., Chicago, Illinois. Ultrasonic Translator, Delcon Corporation, Palo Alto, California. Mass Spectrometer Leak Detector, General Electric, Type M-60.

APPENDIX B

CONTAINMENT VESSEL PENETRATIONS

APPENDIX B

CONTAINMENT VESSEL PENETRATIONS

Penetration			Penetration		
No. *		Contents	No.		Contents
New	Old		New	Old	
SO-1	1	480 V Main power conductors	P-25	36	Spare, not in use
SO-2	2	480 V Main power conductors	P-26	35	Spare, not in use
SO-3	3	Miscellaneous control wires	P-27	34	Spare, not in use
SO-4	4	Multiconductor cables	P-28	41	Multiconductor cables
SO-5	5	Miscellaneous control wires	P-29	40	Spare, not in use
SO-6	6	Instrument air tubing	P-30	39	Spare, not in use
SO-7	7	Spare penetration not in use	P-31	38	Spare, not in use
SO-8	8	FERTF heater leads	P-32	42	Gas loop thermocouple and control wires
SO-9	9	Miscellaneous control wires	P-33	43	Gas loop thermocouple wires
SO-10	10	Abandoned and sealed	P-34	44	Spare, not in use
SO-11	11	Spare, not in use	P-35	45	Spare, not in use
P-1	17	Communication wire runs	S-29	S-29	Excess secondary coolant line
P-2	16	Communication wire runs	S-70	S-70	Flash tank drain line
P-3	15	2400 V power conductors	S-71	S-71	Flash tank vent line
P-4	14	2400 V power conductors	S-75	S-75	Flash tank - HX-1 relief line
P-5	13	2400 V power conductors	S-81	S-81	Steam export line
P-6	12	2400 V power conductors	W-33	W-33	Waste line to holdup tank
P-7	19	Instrument air lines	W-34	W-34	Waste line to holdup tank
P-8	20	480 V main power conductors, misc. wires	W-44	W-44	Drain line
P-9	21	Television camera cable	W-46	W-46	Drain line
P-10	22	2400 V power conductors	Emergency Air Lock		
P-11	23	Communication wire runs	Main Air Lock		
P-12	24	Communication wire runs	Freight Door		
P-13	25	Area Radiation Monitoring signal leads, misc. wires	Vessel Vacuum Relief Valves (2)		
P-14	26	Multiconductor cables	Flash Tank and HX-1 Relief Line		
P-15	27	Multiconductor cables	Bellows		
P-16	28	Multiconductor cables	Twenty-six inch Steam Line Bellows		
P-17	29	Coaxial cables	Flash Tank Drain Line Bellows		
P-18	30	Multiconductor cables	Flash Tank Vent Line Bellows		
P-19	31	Large single conductor cable	Sluice Gate		
P-20	32	Large single conductor cable	Ventilation Valves (2)		
P-21	33	Miscellaneous individual control wires	Rupture Loop and Gas Loop Penetrations (Valves RL-4A, RL-9, RL-41B, RL-41C, RL-89 and GL-V-63)		
P-22	33	Miscellaneous individual control wires	Pneumatic Facility Penetration		
P-23	18	Spare, not in use	Spare Flanged Penetration, North Tunnel		
P-24	37	D20 addition piping	Spare Flanged Penetration, Basin Area		

* The penetrations were renumbered in 1964. Both the old and new numbers are given here for easy reference.

APPENDIX C

DEVELOPMENT OF THE EXPRESSION FOR LEAKAGE RATE

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DEVELOPMENT OF THE EXPRESSION
FOR LEAKAGE RATE

The development of the expressions for determining the leakage rate by the reference volume method has been given in considerable detail elsewhere (5 & 6). The following summarizes the method, which starts with the perfect gas laws. Reference vessel parameters are given with a prime and the subscripts one and two are used to denote the same parameter after a lapse of time.

For the reference volume,

$$P_1' V_1' = W_1' RT_1',$$

$$P_2' V_2' = W_2' RT_2',$$

and for the containment vessel,

$$P_1 V_1 = W_1 RT_1,$$

$$P_2 V_2 = W_2 RT_2.$$

Note that in the above V' , W' , V and R may be assumed constants, i.e.,

$$V_1' = V_2' = V',$$

$$W_1' = W_2' = W',$$

$$V_1 = V_2 = V,$$

and R is a universal constant (for both systems). (However, see derivation of correction factor, Appendix D.)

Initially, the difference in pressures between the vessels is:

$$\Delta P_1 = P_1' - P_1,$$

$$\Delta P_1 = R \left(\frac{W' T_1'}{V'} - \frac{\Delta P_1}{V} \right).$$

from which:

$$W_1 = \frac{V}{T_1} \left(\frac{W' T_1'}{V'} - \frac{\Delta P_1}{R} \right).$$

Similarly:

$$W_2 = \frac{V}{T_2} \left(\frac{W' T_2'}{V'} - \frac{\Delta P_2}{R} \right).$$

Then,

$$\frac{W_1 - W_2}{W_1} = \frac{P_1' T_1}{P_1 T_1'} \left(\frac{T_1'}{T_1} - \frac{T_2'}{T_2} \right) + \frac{T_1}{P_1} \left(\frac{\Delta P_2}{T_2} - \frac{\Delta P_1}{T_1} \right), \quad (1)$$

where $\frac{W_1 - W_2}{W_1}$ is the fractional leakage during the period of the test.

$\frac{W_1 - W_2}{W_1} \times 100$ gives the leakage rate in percent.

Referring to Equation (1), if it is assumed that the temperatures in the reference volume and the vessel are equal to each other initially and again (if not continuously) at the end of the test, the first term becomes zero and

$$\frac{W_1 - W_2}{W_1} = \frac{T_1}{P_1} \left(\frac{\Delta P_2}{T_2} - \frac{\Delta P_1}{T_1} \right) \quad (2a)$$

$$\text{or} \quad \frac{W_1 - W_2}{W_1} = \frac{\Delta P_2}{P_1} \left(\frac{T_1}{T_2} - \frac{\Delta P_1}{P_1} \right) \quad (2b)$$

$$\text{or} \quad \frac{W_1 - W_2}{W_1} = \frac{1}{P_1} \left(\Delta P_2 \frac{T_1}{T_2} - \Delta P_1 \right). \quad (2c)$$

Equations (2a), (2b), and (2c) include a temperature measurement or at least knowledge that the temperature in the vessel at two different times is identical.

However, Equation (1) can be handled algebraically by substituting the term $(\Delta P_1 + P_1)$ for P_1' , then dividing numerator and denominator by $(\Delta P_2 + P_2)$, and without making any assumptions the following expression can be developed.

$$\frac{W_1 - W_2}{W_1} = 1 - \frac{P_2}{P_1} \left(\frac{P_1 + \Delta P_1}{P_2 + \Delta P_2} \right) \left(\frac{T_1}{T_1'} \times \frac{T_2'}{T_2} \right). \quad (3)$$

In Equation (3) above, if it is assumed that, at the time of the measurement of the other parameters, the temperatures in the two volumes are equal; i.e., $T_1 = T_1'$ initially and $T_2 = T_2'$ later, then the reference volume method yields an expression independent of temperature.

$$\frac{W_1 - W_2}{W_1} = 1 - \frac{P_2}{P_1} \left(\frac{P_1 + \Delta P_1}{P_2 + \Delta P_2} \right).$$

The above expression, when a correction for vapor pressure (Pv) is included, is written as:

$$\frac{W_1 - W_2}{W_1} = 1 - \frac{P_2 - (Pv_2 - Pv_1)}{P_1} \times \frac{P_1 + \Delta P_1}{P_2 + \Delta P_2}.$$

It is interesting to note that the expression for the leakage rate with

the Absolute Method using the same development is:

$$\frac{W_1 - W_2}{W_1} = 1 - \frac{P_2 - (Pv_2 - Pv_1)}{P_1} \times \frac{T_1}{T_2}.$$

Thus $\frac{T_1}{T_2}$ and $\frac{P_1 + \Delta P_1}{P_2 + \Delta P_2}$ function identically, and the reference volume, properly installed, serves as an averaging gas thermometer. Pressure (P) and differential pressure (ΔP) can easily be measured to the precision and accuracy required with single measurements, which are representative of the entire volumes, whereas representative temperatures cannot be measured to the same precision as easily.

APPENDIX D

CORRECTION FACTOR FOR THE OBSERVED

DIFFERENTIAL PRESSURE

APPENDIX D

CORRECTION FACTOR FOR THE OBSERVED
DIFFERENTIAL PRESSURE

The correction factor for the differential pressure, made necessary by the change in volume of the reference volume, is developed as follows. All parameters refer only to the reference volume. Assume that the temperature of the contents of the reference volume remains constant for this development. Then the difference in pressure in the reference volume at two different times, T_1 and T_2 , due only to a change in volume, is ΔP_x and will be referred to as B, thus:

$$\Delta P_x = B = P_1 - P_2 = WRT \left(\frac{1}{V_2} - \frac{1}{V_1} \right).$$

Dividing both sides by P_1 or its equivalent,

$$\frac{WRT}{P_1} \cdot \frac{B}{P_1} = V_1 \left(\frac{1}{V_1} - \frac{1}{V_2} \right)$$

$$B = P_1 \left(1 - \frac{V_1}{V_2} \right).$$

V_1 = Volume of the reference vessel
= 2379 in.³.

Assume that V_2 is greater than V_1 by a 1 in. rise in the manometer leg. For the reference system used in this test, an increase in volume resulting from a rise in the precision bore

(0.750 in.) manometer leg results in a volume change of:

$$\frac{\pi D^2 L}{4}.$$

Since a similar change in oil level also occurs in the oil seal pot, this value must be doubled* thus:

$$\begin{aligned} V_2 &= V_1 + 2 \times \frac{D^2 L}{4} \\ &= 2379 + 2 \times \frac{(0.75)^2 \times 1}{4} \\ &= 2379 + 0.9. \end{aligned}$$

Hence:

$$\begin{aligned} B &= P_1 \left(1 - \frac{V_1}{V_2} \right) = P_1 \left(1 - \frac{2379}{2379.9} \right) \\ &= P_1 (1 - 0.99962) / \text{in. of} \\ &\quad \text{differential pressure change.} \end{aligned}$$

Thus, the correction (B) for each inch of change in manometer level (ΔP) as measured, is:

$$\frac{B}{\Delta P} = P_1 (0.00038).$$

The corrected differential pressure valve (ΔP_c) for each differential pressure measurement ΔP is:

$$\begin{aligned} \Delta P_c &= \Delta P + B \\ \Delta P_c &= \Delta P (1 + 0.00038 P_1). \end{aligned}$$

* Assumes I.D. of the "Tee" in the oil seal assembly is 0.75 in.; actually it was slightly smaller.

APPENDIX E

DATA SHEETS

APPENDIX E

DATA SHEET

Date	Time Clock (24 hr)	Barometer,		Vessel Pressure, in. H ₂ O (gage)	Vessel Pressure, in. H ₂ O (absolute)	Differential Pressure,		Vapor Pressure, in. H ₂ O (average)
		mbars	in. H ₂ O			in. H ₂ O (uncorrected)	in. H ₂ O (corrected)	
11-14-66	1630	996	399.89	278.8	678.69	3.990	5.0190	4.92
	1700	996	399.89	278.8	678.69	4.079	5.1309	4.92
	1730	996	399.89	279.2	679.09	4.136	5.2033	4.92
	1800	996.5	400.09	279.0	679.09	4.203	5.2873	4.95
	1830	996.4	400.05	279.2	679.25	4.267	5.3683	4.95
	1900	996.1	399.90	279.4	679.30	4.328	5.4450	4.95
	1930	996.2	399.97	279.3	679.27	4.391	5.5244	4.95
	2000	995.6	399.73	279.7	679.43	4.449	5.5972	4.95
	2030	995.8	399.81	279.7	679.51	4.482	5.6393	4.95
	2100	995.2	399.57	279.8	679.37	4.537	5.7079	4.97
	2130	995.0	399.49	279.8	679.29	4.574	5.7547	4.97
	2200	995.0	399.49	279.9	679.39	4.627	5.8212	4.95
	2230	995.3	399.61	279.8	679.41	4.672	5.8781	4.95
	2300	996.0	399.89	279.6	679.49	4.720	5.9387	4.95
	2330	996.2	399.97	279.5	679.47	4.767	5.9978	4.95
	2400	995.8	399.81	279.6	679.41	4.812	6.0539	4.94
11-15-66	0030	995.0	399.49	280.0	679.49	4.864	6.1199	4.94
	0100	995.9	399.85	279.7	679.55	4.902	6.1676	4.94
	0130	996.3	400.0	279.4	679.40	4.940	6.2153	4.95
	0200	996.8	400.21	279.3	679.51	4.988	6.2759	4.95
	0230	996.8	400.21	279.3	679.51	5.030	6.3288	4.96
	0300	996.9	400.26	279.2	679.46	5.065	6.3727	4.95
	0330	997.0	400.30	279.2	679.50	5.120	6.4420	4.94
	0400	995.5	400.09	279.25	679.34	5.178	6.5144	4.96
	0430	996.6	400.13	279.3	679.43	5.205	6.5488	4.95
	0500	996.2	399.97	279.3	679.27	5.243	6.5962	4.95
	0530	996.4	400.05	279.3	679.35	5.298	6.6656	4.96
	0600	996.7	400.17	279.20	679.37	5.338	6.7157	4.99
	0630	997.2	400.38	278.8	679.18	5.374	6.7609	4.98
	0700	997.5	400.5	278.80	679.30	5.426	6.8264	5.0

DATA SHEET (cont.)

Date	Time Clock (24 hr)	Barometer,		Vessel Pressure, in. H ₂ O (gage)	Vessel Pressure, in. H ₂ O (absolute)	Differential Pressure,		Vapor Pressure, in. H ₂ O (average)
		mbars	in. H ₂ O			in. H ₂ O (uncorrected)	in. H ₂ O (corrected)	
11-15-66	0730	997.4	400.46	278.6	679.06	5.458	6.8663	4.99
	0800	998.4	400.86	279.40	679.26	5.489	6.9057	5.0
	0830	998.4	400.86	278.4	679.26	5.539	6.9687	5.0
	0900	998.2	400.70	278.6	679.30	5.575	7.0139	4.99
	0930	998.2	400.7	278.6	679.30	5.611	7.0593	5.0
	1000	998.4	400.86	278.4	679.26	5.664	7.1258	5.0
	1030	998.7	400.98	278.3	679.28	5.707	7.1801	5.0
	1100	998.7	400.98	278.4	679.38	5.756	7.2416	5.01
	1130	998.8	401.02	278.4	679.42	5.789	7.2836	5.02
	1200	998.3	400.82	278.4	679.22	5.830	7.3347	5.02
	1230	997.8	400.62	278.6	679.22	5.890	7.4102	5.01
	1300	997.4	400.46	278.5	679.96	5.926	7.4549	5.01
	1330	998.4	400.86	278.4	679.26	5.970	7.5109	5.02
	1400	998.4	400.86	278.4	679.26	6.008	7.5586	5.02
	1430	997.3	400.42	278.7	679.12	6.050	7.6112	5.01
	1500	997.5	400.5	278.7	679.20	6.100	7.6744	5.02
	1530	997.3	400.42	278.7	679.12	6.138	7.7220	5.01
	1600	997.2	400.38	278.6	678.98	6.184	7.7794	5.02
	1630	996.8	400.22	278.6	678.82	6.232	7.8395	5.02
	1700	996.9	400.26	278.6	678.86	6.272	7.8895	5.03
	1730	996.9	400.26	278.4	678.66	6.407	8.0593	5.03
	1800	996.1	399.93	278.6	678.53	6.546	8.2342	5.04
	1830	995.8	399.81	278.6	678.41	6.682	8.4053	5.05
	1900	995.8	399.81	278.4	678.21	6.819	8.5776	5.04
	1930	995.4	399.65	278.3	677.95	6.947	8.7386	5.05
	2000	995.2	399.57	278.3	677.87	7.081	8.9072	5.04
	2030	995.0	399.49	278.4	677.89	7.213	9.0732	5.04
	2100	994.2	399.17	278.3	677.47	7.336	9.2279	5.05
	2130	994.2	399.17	278.2	677.37	7.474	9.4015	5.04
	2200	993.0	398.69	278.6	677.29	7.592	9.5499	5.02
	2230	992.2	398.37	278.6	676.97	7.730	9.7235	5.03
	2300	991.8	398.21	278.6	676.81	7.862	9.8840	5.04
	2330	991.2	398.97	278.8	676.77	7.923	9.9663	5.04

DATA SHEET TEMPERATURES

<u>Time Clock, (24 hr)</u>	<u>T/C #1 °F</u>	<u>T/C #2 °F</u>	<u>T/C #3 °F</u>	<u>T/C #4 °F</u>	<u>T/C #5 °F</u>	<u>T/C #6 °F</u>	<u>Average °F</u>
11-14-66							
1400	67.9	68.7	68.9	69.5	70.0	71.4	69.0
1500	67.8	69.0	68.3	69.7	70.0	70.8	69.2
1600	67.6	69.0	68.2	68.8	69.6	70.0	68.9
1700	67.5	69.2	67.7	68.7	69.1	69.5	68.6
1800	67.7	67.6	68.2	68.6	69.1	71.5	68.8
1900	68.2	68.5	68.0	68.4	68.8	69.8	68.6
2000	72.9	73.6	73.0	72.5	73.6	74.0	73.4
2100	73.6	74.1	73.5	73.9	73.7	74.3	73.8
2200	72.7	73.1	72.8	72.9	73.0	73.6	73.0
2300	72.5	73.4	72.6	73.2	72.9	73.3	72.9
2400	72.5	73.5	72.9	73.4	73.2	73.9	73.7
11-15-66							
0100	72.7	72.9	72.4	72.8	72.5	73.3	72.7
0200	72.7	73.2	73.1	73.1	72.8	73.8	73.1
0300	72.9	73.8	73.1	73.2	73.2	73.1	73.2
0400	72.1	72.5	72.3	72.3	72.3	76.2	72.9
0500	72.4	72.7	72.1	73.1	72.5	73.8	72.7
0600	72.4	73.0	71.4	71.3	71.7	72.6	71.9
0700	71.9	73.0	72.2	72.6	72.0	72.5	72.3
0800	72.8	74.3	73.1	73.4	72.4	73.1	73.2
0900	72.5	73.7	72.9	73.1	72.0	73.2	72.9
1000	71.9	72.8	72.1	72.2	71.7	72.8	72.3
1100	72.6	74.0	72.6	72.7	72.4	73.5	73.0
1200	72.9	73.2	73.1	73.2	72.7	73.3	73.1
1300	72.2	73.4	73.0	72.9	72.3	73.5	72.9
1400	67.6	68.8	68.5	68.4	68.0	69.2	68.4
1500	67.3	68.2	68.2	68.1	67.8	69.3	68.2
1600	68.1	68.6	68.5	67.9	67.5	68.7	68.2
1700	68.0	68.5	68.2	67.8	67.5	69.2	68.2
1800	69.0	70.7	70.0	69.2	68.8	70.7	69.7
1900	68.3	68.8	69.0	68.4	68.0	69.4	68.6
2000	68.1	69.1	68.8	68.2	67.8	69.1	68.5
2100	67.9	68.8	68.5	68.7	67.9	68.6	68.4
2200	69.0	69.0	68.7	68.4	67.5	69.5	68.5
2300	73.9	74.8	74.1	73.9	74.0	74.3	74.1

Above tabulation includes corrections.

Ice bath changes were made about every four hours including changes at 1910 (11-14-66), 1310 (11-15-66) and 2215 (11-15-66).

APPENDIX F

LEAKAGE RATE CALCULATIONS

APPENDIX F

LEAKAGE RATE CALCULATIONS

The following calculations were made for the leak test completed November 15, 1966.

The initial time was 4:30 pm, November 14, 1966. The pressure measurements were corrected to inches of water column at 4 °C. The data were:

$$P_{B1} = 996 \text{ mbars} \times 0.4015 \text{ in. H}_2\text{O} \\ = 399.89 \text{ in.}$$

$$P_{G1} = 278.80 \text{ in. H}_2\text{O}$$

$$P_1 = 678.69 \text{ in.}$$

$$P_{V1} = 4.92 \text{ in.}$$

$$\Delta P_{C1} = 5.01902 \text{ in.}$$

The final time was 4:00 pm, November 15, 1966. The data were:

$$P_{B2} = 996.8 \text{ mbars} \\ = 400.22 \text{ in.}$$

$$P_{G2} = 278.6 \text{ in.}$$

$$P_2 = 678.82 \text{ in.}$$

$$P_{V2} = 5.02 \text{ in.}$$

$$\Delta P_{C2} = 7.83944 \text{ in.}$$

$$\frac{\% \text{ Leakage}}{24 \text{ hr}} = 100 \left[1 - \frac{P_2 - (P_{V2} - P_{V1})}{P_1} \right. \\ \left. \times \frac{P_1 + \Delta P_{C1}}{P_2 + \Delta P_{C2}} \right]$$

$$\frac{P_2 - (P_{V2} - P_{V1})}{P_1} = \frac{678.82 - (5.02 - 4.92)}{678.69}$$

$$= \frac{678.72}{678.69}$$

$$= 1.000044$$

$$\frac{P_1 + \Delta P_{C1}}{P_2 + \Delta P_{C2}} = \frac{678.69 + 5.01902}{678.82 + 7.83944}$$

$$= \frac{678.70902}{686.65944}$$

$$= 0.99570$$

$$100 (1 - 1.000044 \times 0.9957) = 100 (1 - 0.99574) \\ = 0.426$$

$$\frac{\text{Leakage}}{24 \text{ hr}} = 0.43\% \text{ at } 278.6 \text{ in.}$$

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