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VLA ELECTRONICS MEMORANDUM NO. 199

VACUUM TESTS ON SOME VLA FRONT END DEWARS

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1. INTRODUCTION

The following is a report on some recent vacuum measurements carried out on two aluminium VLA front end dewars, and the implication of these measurements on the ability of the cryogenic system to recover after unscheduled system power shutdowns.

The aims of the measurements were to determine to what extent the dewar pressure and temperature would rise after long periods of operation subsequent to a power shutdown, estimate the duration of a power shutdown which could be tolerated before rough pumping on the dewar was necessary, and also to estimate what maximum leak rate was allowable that would enable the vacuum and cryogenic systems to recover to operating temperature and pressure in the shortest possible time after the restoration of power.

2. GENERAL DISCUSSION

Previous work on this subject has investigated the leak rate parameters for cryogenic receiver dewars (Refs. 1, 2, and 3) including VLA and VLA-like dewars such as the 140' Cassegrain receiver dewar, and some of the proposals and recommendations contained therein bear some discussion at this stage.

2.1 Leak Rate Specifications

VLA Memorandum No. 106 (Ref. 1) indicates that the highest tolerable leak rate for a VLA dewar operating for a maximum time of one year between scheduled warm-ups would be of the order of 2×10^{-1} std. cc/min (2.5×10^{-4} torr litre/sec. - see Appendix 1 for conversion factors between leak rate units). This figure appears to have been based on the time taken to saturate the charcoal trap (~1 year for 10^4 std. cc.). If operated under these conditions, the dewar would certainly require rough pumping after any sort of warm-up during the one year operating period, and would probably require baking of the charcoal trap as well to insure that all the absorbed contamination had been driven out.

To avoid this situation the final proposal in Ref. 1 was for the dewar to maintain 50 microns for one year giving an implied leak rate of 5 x 10^{-6} std. cc/min. or 6.3 x 10^{-8} torr litre/sec. (for a 40 litre volume). This would have the advantage that the dewar would never need rough pumping after warming-up even after operating for periods up to a year after initial cooldown.

The leak rate obtained by Brockway (Ref. 2) for the 140' Cassegrain dewar of 56 x 10^{-6} torr litre/sec was about five times better than the 2 x 10^{-2} std. cc/min. specification in Ref. 1 so that this dewar would have taken about five years to reach the charcoal trap saturation limit.

It should be pointed out however, that the leak rate of the Cassegrain dewar was an order of magnitude greater than that of most of the Green Bank dewars measured by Brundage (Ref. 3). Brockway attributed this to possible distributed leakage past the many feet of O-ring seals (~20 ft) used on the dewar, although measurement of this was complicated by long time constants due to the O-rings not being vented to the atmosphere or the vacuum.

The implication is, then, that the initial specification of 2.5 x 10^{-4} torr litre/sec can be comfortably met, but that the 6.3 x 10^{-8} torr litre/sec specification may be more difficult to achieve because of distributed leakage past the O-ring seals.

In addition to this, it is instructive to examine the leak rate one might expect from permeation of air and water vapour through the O-rings. Brockway has estimated a leak rate of about 30 x 10^{-8} torr litre/sec for air permeation through the seals of the Cassegrain dewar. Compare this with the leak rate of 6.3 x 10^{-8} torr litre/sec necessary to maintain the VLA dewar at 50 microns for one year as proposed in Ref. 1. Given that the VLA dewar has an overall O-ring seal length equivalent to the Cassegrain dewar (and possibly more), it seems doubtful that the 50 micron/year leak rate proposal could ever be acheived in practice because the permeation rate appears to be significantly greater than the required total leak rate from permeation and all other sources as well.

2.2 Recovery

In the period immediatly following a power shutdown, whether or not the system will recover to its normal operating temperature will be largely determined by how rapidly the dewar pressure will rise due to the evaporation of frozen contaminants on the refrigerator cold surfaces. Because of the low specific heat of the metals attached to the second stage (when at low temperatures) this mass will warm up rapidly once the refrigerator has stopped, causing the contamination frozen to these surfaces (mostly N_2 and O_2) to begin to evaporate. Water vapour, mainly from outgassing, will not be liberated until much later and at much higher temperatures.

If the degree of contamination is high (e.g. if due to a leaky dewar or a long operation time) then the pressure rise will be rapid, and once into the 10^{-3} torr (1 micron) region, will begin to fully load the cold surfaces by gas conduction. This further accelerates the temperature rise which in turn increases the evaporation rate. This will ultimately lead to the need for rough pumping of the dewar before the system can be recooled.

This in itself is not a major problem in the VLA system, as the roughing pump is automatically set to begin pumping once the dewar pressure has risen to ~60 microns (60×10^{-3} torr). However it does mark the beginning of a new sequence of events requiring the automatic operation of vacuum pumps and solenoid valves according to preset timing and vacuum level settings, and for this reason adds further complexity to the reliability question.

Consequently, a highly desirable feature of the vacuum system would be the ability to maintain a dewar pressure of <60 microns for as long a period as is possible after the power has gone off. Of course, the stringent leak rate of Ref. 1 (6.3×10^{-8} torr litres/sec) would achieve this, but as has already been pointed out, this is a very difficult specification to meet.

Realistically then, the best one can do is ensure that the minimum possible leak rate is obtained for each VLA dewar system. In this way, both the contamination build up and the subsequent pressure rise when the refrigerator stops, can be kept to a minimum, in the short term at least.

2.3 Recovery and the Vac-Ion Pump

Brockway has shown how the recovery time of a refrigeration system can be reduced by the use of a Vac-Ion pump.

This comes about because the ion pump is most effective when pumping on background leaks and contaminants during the phase prior to cryopumping. As this also coincides with the period when the gas load is high (i.e. pressures of 10^{-3} to 10^{-4} torr), any method of effectively reducing dewar pressures in this range will shorten the cooldown time significantly.

Once the cryopumping phase has commenced, however, the greater relative pumping speed of the cold cryosurfaces will result in the majority of the leak contaminants being deposited there. Over a long operational period then, sufficient contamination will build up on the cryosurfaces so that when a power shutdown does occur the rise in dewar pressure could be sufficient to shut the Vac-Ion pump off in the protect mode, when the power was restored. This would occur at dewar pressures in excess of 1 micron (or 10^{-3} torr).

This situation then poses the problem of remote control or automatic operation of the Vac-Ion pump power supplies. Without modification, these would all need to be reset manually after power shutdowns long enough to allow the dewar pressure to increase to the point where the ion pump gas load is excessive.

It does seem then to be essential to have the ion pump power supplies modified so that they will reset automatically at dewar pressures <1 micron and be operating during the time when they are most useful, i.e. during the recovery cooldown.

3. TEST RESULTS

Two sets of measurements were performed on dewars with known "good" vacuum performance, (a) to determine what sort of vacuum decay rate had been achieved, and (b) to determine the vacuum behaviour of the dewar during simulated power shutdowns after known quantities of air had been leaked into the system.

3.1 Observed Vacuum Decay Rate

This test was carried out on the aluminium dewar in front end rack A-11 which was available in the lab for a scheduled refrigerator retrofit. This front end had been in operation at cryogenic temperatures for at least six months without the dewar having been opened to the atmosphere so that it could be safely assumed that all outgassing of dewar walls and components had taken place.

Before the dewar was opened for the retrofit, the system was rough pumped for approximately 12 hours at a pressure of 1 micron (10^{-3} torr) and the cold station heater then turned on for about 6 hours to thoroughly bake out the charcoal trap. After further rough pumping the final dewar pressure achieved was 1.3 micron. The roughing pump was then valved off and the dewar pressure monitored for a period of 48 hours using the Hastings gauge fitted to the system. The results are shown in Fig. 1.

Unfortunately, some retrofit work was begun on the front end power supply system during the final 28 hours of the test which may explain the discontinuity in the pressure vs. time curve.

The pressure decay rate for the first 21 hours of the measurement was 0.3 micron/hr. Note the absence of an initial high rate of vacuum decay in the first few hours of the test - this is an indication of outgassing and the absence of this feature implies that the indicated decay rate is a result of the true background leak.

The latter 27 hours indicate a pressure decay rate of 0.55 micron/hr, and as pointed out earlier, this may have been due to something that was done during the retrofit work.

The leak rates equivalent to the observed pressure decay rates can be found from the expression,

$$Q = V \frac{dP}{dT} \quad \text{torr litres/unit time}$$

where Q is the leak rate, dP/dT is the pressure decay rate in torr/unit time and V is the enclosed volume in litres.

Taking 40 litres as the enclosed volume of the VLA dewars, the observed pressure decay rates (0.3 and 0.55 micron/hr) give leak rates of 3.3×10^{-6} and 6.1×10^{-6} litres/sec respectively.

These leak rates are comparable to those of the Green Bank dewars measured by Brundage (Ref. 3) and about an order of magnitude better than the leak rate measured by Brockway for the 140 ft Cassegrain dewar (Ref. 2).

Subsequent measurements made with the Veeco leak detector on the dewar in front end rack A-11, indicated a small detectable leak at the base of the dewar which had a very long time constant. The actual magnitude of the leak was difficult to determine because of the long time constant involved and the fact that it was indeed quite a small leak. A very rough estimate would put it in the vicinity of 10^{-8} torr litres/sec.

Based on the premise that a detectable leak was found and that it has been possible to construct complete dewar systems where no detectable leaks were found it is reasonable to suggest that a maximum pressure decay rate standard of 10 micron/day be used as an upper limit for testing of all VLA dewars. This corresponds to a leak rate of 4.63×10^{-6} torr litre/sec.

It should be kept in mind that this decay rate should be due to the background leak only, and that the effects of outgassing components should be taken into account in any measurements done to determine the ultimate dewar leak rate.

3.2 Vacuum System Behaviour During Warm-up

These tests were performed on the aluminium dewar in front end rack A-24 and consisted mainly of dewar pressure and second-stage temperature measurements as a function of time, at different levels of leak contamination.

The first test was run after the system had been operating for about four days at a temperature of 15 K. The refrigerator was shut down and the dewar pressure and second-stage temperature measured at regular time intervals until the second-stage temperature reached approximately 80 K, as measured by the built-in temperature monitor.

The refrigerator was then restarted and cooled back down to 18 K, whereupon 25 std. cc of air was leaked into the dewar. The refrigerator was again stopped and the dewar pressure and second-stage temperature monitored until a temperature of approximately 70 K was reached.

The refrigerator was again cooled and a further 100 std. ccs of air was leaked into the system, a third and final set of pressure and temperature measurements were taken until the second-stage temperature reached approximately 120 K.

All the dewar pressure measurements $<10^{-3}$ torr were made using a Varian Ionisation Gauge Model NRC 840 with an NRC 563-P gauge tube. For pressures greater than 10^{-3} torr the Hastings thermocouple gauge was used.

The second-stage temperature was monitored using the platinum resistor thermometer built into the cryogenics monitoring system.

The results of these tests are shown; in Fig. 2, dewar pressure vs time after refrigerator shutdown, Fig. 3, dewar pressure vs second-stage temperature and Fig. 4, second-stage temperature vs time after refrigerator shutdown. In all these results, curve #1 corresponds to the system behaviour after four days running, curve #2 after 25 std. cc of air was bled into the dewar, and curve #3 after 125 std. cc of air had been added.

In addition to these tests, the dewar was thoroughly leak checked using a Veeco mass spectrometer leak detector with the result that no detectable leak could be found down to a level of 3×10^{-9} std. cc/sec.

4. DISCUSSION OF THE TEST RESULTS

4.1 Gas Inflow Estimates

The basic usefulness of the pressure decay measurements on the dewar in A-11 lies mainly in establishing some sort of standard by which to judge the behaviour of the dewar in A-24.

Having previously specified a leak rate of 4.6 x 10^{-6} torr litre/sec as a reasonable upper limit based on the observed leak rates of A-11, we can now estimate the time required to accumulate the amount of air bled into the dewar in the A-24 tests. It should be kept in mind that these time estimates will be minimum times, and should be significantly longer in practice provided the maximum leak rate specification is comfortably met.

Consequently, based on the fact that 10^{-6} torr litre/sec is equivalent to 0.114 std. cc/day, the 4.6 x 10^{-6} torr litre/sec leak would require 25/46 x 0.114 = 48 days to leak 25 std. cc of air into the dewar. Similarly, the total of 125 std. cc of air leaked into the dewar is equivalent to 240 days or ~8 months operation. Finally, at the end of one year, the maximum total leak inflow would be approximately 190 std. cc of air.

4.2 Vacuum Behaviour After Shutdown

Perhaps the most striking feature in the dewar pressure curves of Figures 2 and 3 is the manner in which the dewar pressure rises to a maximum about seven minutes after the refrigerator is shut down. It then proceeds to fall to less than 1 micron, staying that way for some considerable time until it finally begins to rise again as the refrigerator second-stage temperature reaches into the 60-70 K region.

This behaviour occurred at all three levels of contamination in the A-24 tests, with the time taken to reach the peak pressure (~7 min), and the second-stage temperature at which the peak pressure occurs (30-40 K), being relatively unaffected by the degree of contamination. What is affected of course, is the pressure at the peak, and the final minimum pressure to which it falls. These all become progressively higher as the level of contamination increases.

This behaviour of the vacuum system in the early part of the shutdown is thought to be due to the rapid evaporation of frozen contamination and its subsequent removal by the activated charcoal trap attached to the second-stage cold station.

It has been pointed out earlier, that immediately the refrigerator is stopped, the second-stage cryosurfaces begin to warm up very rapidly and the consequent evaporation of frozen contaminants on these surfaces begins to raise the dewar pressure fairly quickly (as indicated in the initial phases of the curves in Figures 2 and 3).

The activated charcoal trap however is still very effective as a sorption pump, particularly in the temperature ranges involved at this stage (approximately 30 to 50 K). As a result the charcoal trap will pump away on the evaporating cryosurface contaminants (mainly N_2 and O_2) thereby reducing the dewar pressure to quite a low level (<1 micron in all three tests).

The rate at which the charcoal trap will pump on the background pressure is difficult to estimate because of variations in the sorption rates of the various types of activated charcoal available, and a lack of data on sorption rates at temperatures below 77 K and specifically in the region 30→50 K.

However, from curves in Dushman[4] and Scott[5] it is possible to estimate that a sorption trap cooled to 90 K (-183°C) pumping on a background pressure of 10^{-4} torr (0.1 micron) will absorb ~1 std. cc of air (or N_2) per gram of charcoal. We expect though, that the VLA trap will do better than this, because of its lower operating temperature.

The quantity of charcoal within the VLA trap has been roughly estimated to be ~20 grams, so that at 10^{-4} torr the total volume of gas that could be readily absorbed is roughly 20 std. cc. If however, the pressure were to rise to ~10^{-2} torr (or 10 microns), the volume of gas that could be absorbed would be 60→70 times this value i.e. almost 1.4 std. litres of air.

Thus it is possible to see how effectively the charcoal trap could pump the dewar background pressure back to a reasonable level after it had risen due to cold surface evaporation. All this depends, of course, on the charcoal trap temperature not rising too quickly to 77 K and above.

The time for which the vacuum system is held below 1 micron appears to be largely a matter of how long it takes the refrigerator second-stage to warm up to the 60-70 K range. It is in this range of temperatures that all the dewar pressures, regardless of the contamination level, start to show signs of increasing again. The subsequent rate of dewar pressure rise is of course strongly related to the contamination level and will rise more rapidly for a heavily contaminated system.

4.3 Temperature Behaviour After Shutdown

The curves in Fig. 4 (second-stage temperature vs time after shutdown) indicate that the time taken to warm up to a given temperature is also significantly dependent on the contamination level, and not surprisingly, everything warms up faster when these levels are high. This probably reflects an increased gas conduction component in the thermal loading of the cooled surfaces brought about by the inability of the charcoal trap to quickly remove evaporated contamination generated during the initial part of the warming-up period.

4.4 Operational Significance of the Vacuum Tests

It is probably useful now to look at some of the test results and see how they could apply to actual cryogenic systems operating at the VLA.

A singularly significant result is that which indicates the length of time the system can remain down before critical vacuum levels are reached in the dewar.

For example, dewar pressures of 1 micron and 60 microns are significant, because these are the points where (a) the Vac-Ion pump will turn off on overload (~1 micron), and (b) the roughing vacuum pump will turn on (~60 microns) when in automatic control. The latter of these could be used as a guide by which to judge the vacuum and recovery performance of a dewar, and the CTI refrigeration system has a known capacity to recover to operating temperature, starting with a roughing vacuum of 60 microns and a second-stage temperature of 60→80 K.

Referring to Fig. 2 then, we see that our dewar with the prescribed 4.6 x 10^{-6} torr litre/sec leak rate, after having been operating for eight months would turn off the Vac-Ion pump on overload when system power was restored after a power shutdown of ~2 min duration. However, a power shutdown of ~2 hour duration could occur before the roughing vacuum pump would turn on automatically when the system power was restored. It is felt that this performance will still hold for systems that have been operating for even longer periods (up to 12 months) if a smaller leak rate than that specified can be achieved, e.g. a factor 2 improvement in leak rate should double the operating time for which a 2 hour shutdown could be tolerated.

As mentioned earlier in the report, however, the Vac-Ion pump would need to be restarted, either manually or automatically, once the dewar vacuum fell below 1 micron.

The ability of the vacuum systems to survive a long power shutdown is illustrated in Table 1. These are the results of vacuum and temperature measurements made on all operating front ends after scheduled power shutdowns on 1 and 2 August, 1979 and lasting for at least 1 hour.

Of the 18 front-ends operating, 9 had high dewar temperatures (>100 K) and bad dewar vacuums (>60 micron) when the power was restored. The remaining 9 all had satisfactory dewar pressures (<10 micron), and second-stage temperatures in the expected range 60→80 K (see Fig. 4 for t >60 min). It is interesting to note that of these 9, 7 had been very carefully leak checked before installation. Front ends A-17, A-18, A-19, A-20 and A-21 (newly constructed systems) and A-10 and A-12 (retrofitted systems), were carefully examined with the Veeco leak detector down to the 10^{-8} std cc/sec level. Of the 2 remaining systems, one, A-11, is the subject of the pressure decay rate measurements earlier in this report and was seen to have fairly "good" vacuum properties. Its acceptable performance under shutdown conditions therefore indicated the value of having these good vacuum properties.

One final point for discussion concerns the system recovery time after a power shutdown. Unfortunately, during the lab tests, the recovery time back to operating temperature was only measured for the first shutdown test - essentially only after 4 days running time. The measurements indicated a recovery time of 80 minutes after the system had been off for 120 minutes, i.e. the cooldown time was shorter than the warm-up time. However it should be kept in mind that the dewar pressure at the start of the recovery period was of the order of 10^{-5} torr (0.01 micron), so that the gas conduction component in the refrigerator thermal load would be very small. The subsequent tests indicated much higher initial dewar pressures in the recovery phase i.e. $>10^{-4}$ torr for the second shutdown test and $>10^{-3}$ (1 micron) for the third test. This would certainly imply a longer cooldown time due to thermal loading by gas conduction.

Under operational conditions then it would seem that, provided the dewar vacuum held up during a long shutdown (say <60 microns) the recovery time would be roughly equivalent to the duration of the power shutdown. This time would of course be significantly reduced by the use of a Vac-Ion pump.

5. CONCLUSIONS

The first conclusion one can make is that considerable effort should be put into obtaining as low a leak rate as is possible in each completed front-end dewar. Now perhaps this is not a very original statement to make and has all been said before but it is worth repeating here with emphasis as it does have considerable bearing on the VLA front-end reliability problem. As the cryogenics reliability has steadily improved with the introduction of CTI refrigerators it is now imperative to match this with improved vacuum reliability and perhaps the best way to do this is to set a leak rate standard to which all VLA dewars should comply.

Consequently, a maximum total leak rate of 4.6×10^{-6} torr litre/sec (10 microns/day pressure rise) is being suggested as the standard for all completed VLA dewar systems. On the basis of the tests conducted in this work, operation times in excess of 8 months at this leak rate would still see the cryogenic systems being able to recover from power shutdowns of between 1 to 2 hours without the need for rough pumping. It is doubtful that interruptions to critical power would last this long, even allowing for sequential load switching when operating on emergency power.

Crucial to achieving this performance is the role played by the activated charcoal trap in the VLA dewar. It is this device which enables the dewar vacuum to be maintained during the period that the power is off by pumping the evaporating cryodeposits from the cold metallic surfaces. In this way the dewar pressure is kept to a minimum so that when power is restored, the system has the best chance of quickly recovering to operating temperature. However, this pumping action is limited to about 2 hours or the time it takes the charcoal trap temperature to reach the 70→80 K range. It is at this point that dewar pressures begin to rise again due to increased evaporation.

The time taken for the system to recover to operating temperature is estimated to be about the same as the shutdown time, provided the dewar pressure is less than 60 microns at the time the power is restored. This of course can be significantly reduced if a Vac-Ion pump were used when dewar pressures get below 1 micron (10^{-3} torr). However, some sort of automatic sensing will be necessary for the Vac-Ion power supplies in order to ensure that the pump is turned on once the dewar pressure has dropped below the 1 mircon level.

Finally, the results of some scheduled power shut-downs of duration in excess of 1 hour show that front-end dewars recently installed which had been carefully leak checked before installation, survived the shutdown successfully with dewar pressures generally <10 micron and temperatures between 60→80 K. This is convincing evidence that the effort involved in obtaining the minimum possible leak rate for each dewar system will result in improved vacuum performance and hence more reliable cryogenics operation for the VLA front-end.

ACKNOWLEGEMENTS

Thanks are due to the members of the VLA Cryogenics Section for obtaining vacuum data on all cryogenic dewars installed in antennas after the power shutdowns of the 1st and 2nd of August, 1979.

Further thanks are due to S. E. McCrary for leak testing and pressure decay rate measurements on both the dewars tested in this report.

REFERENCES

1. VLA Electronics Memorandum No. 106, January 1973. "Leaks in Dewars, Pressurized Waveguide and Helium Refrigerator Lines", D. L. Thacker.
2. NRAO Memorandum, May 1975. "140-foot Cassegrain Receiver Vacuum and Cryogenics Considerations", Charles J. Brockway.
3. NRAO Memorandum, January 1974. "Measurements of Vacuum Integrity and Outgassing for Several Receiver Dewars", W. Brundage.
4. "Scientific Foundations of Vacuum Technique", Saul Dushman. John Wiley & Son, page 457.
5. "Cryogenic Enigneering", Russell B. Scott. Van Nostrand Co. Inc., page 163.
6. "Vacuum Technology", A. Roth. North-Holland Publishing Co., 1976, pages 42-43; 66-67 and 430.

TABLE 1.

VACUUM AND CRYOGENIC PARAMETERS AFTER SCHEDULED SHUTDOWNS: 1 AND 2 AUGUST 1979

Southeast Arm: Power off: 0830-0930 (1 hour)

Antenna #	Dewar Pressure	Temperature	Comments
3	atmospheric	200 K	Rough pumped
10	5 micron	65 K	OK
7	200 micron	100 K	Rough pumped
11	0 micron	75 K	OK
13	200 micron	?	Cold station thermometer failed - also rough pumped
12	1 micron	75 K	OK
16	200 micron	90 K	Rough pumped

North Arm: Power off: 0915-1030 (1 hour 15 minutes)

Antenna #	Dewar Pressure	Temperature	Comments
18	3 micron	70 K	OK
19	0 micron	60 K	OK
20	11 micron	80 K	OK

Southwest Arm: Power off: (1 hour 24 minutes)

Antenna #	Dewar Pressure	Temperature	Comments
4	atmospheric	160 K	Rough pumped
6	70 micron	125 K	Rough pumped
2	110 micron	150 K	Rough pumped
8	80 micron	260 K	Rough pumped
14	5 micron	75 K	OK
15	150 micron	125 K	Rough pumped
17	2 micron	75 K	OK
21	1 micron	75 K	OK

APPENDIX

VACUUM UNITS AND CONVERSION FACTORS

Useful reference tables of vacuum units (pressure and leak rate) and conversion factors between them, can be found in "Vacuum Technology" by A. Roth[6], pages 42-43 and 66-67.

Also, on page 430 a table is found giving leak rate specifications including pressure decay rates, times for given pressure rises, gas inflow and equivalent openings, all as a function of leak rate.

The following tables summarize several of these units and their conversion factors.

(i) Pressure Units

1 atmosphere = 760 mm of Hg

1 torr = 1 mm of Hg (1.316×10^{-3} atmos)

1 micron = 10^{-3} torr (1.316×10^{-6} atmos)

(ii) Leak Rate Units

Two units referred to in this work.

(a)	standard cc/sec standard cc/min standard cc/day	Expressed as a gas inflow at the rate of 1 cc at STP/unit time.
(b)	torr litre/sec	Expressed as a pressure rise in a given volume/unit time.

(iii) Pressure Decay Rates and Conversion Factors To Leak Rate Units

The most obvious indication of a leaking vacuum system is the rate at which the dewar pressure rises after the pumping system is removed. The leak rate of the system can then be inferred if the rate of pressure increase and the system enclosed volume is known. However, care must be used in interpreting the dewar pressure rise, as it will be a combination of background leak and outgassing in the initial stages of evacuation. Several days of rough pumping may be necessary to remove the majority of the outgassing products.

The leak rate equivalents to several pressure decay rates are:

(V_s = system enclosed volume in litres)

1 micron/min = $1.67\ V_s\ 10^{-5}$ torr litre/sec

($=6.7 \times 10^{-4}$ torr litre/sec for V_s = 40 litres)

1 micron/hr = $2.78\ V_s \times 10^{-7}$ torr litre/sec

($=11.12 \times 10^{-6}$ torr litre/sec for V_s = 40 litres)

1 micron/day = $1.16\ V_s \times 10^{-8}$ torr litre/sec

($= 4.6 \times 10^{-7}$ torr litre/sec for V_s = 40 litres)

(iv) Leak Rate Conversion Factors

(a) 1 std. cc/sec = 0.76 torr litre/sec

1 std. cc/min = 12.7×10^{-3} torr litre/sec

1 std. cc/day = 8.8×10^{-6} torr litre/sec

(b) 1 torr litre/sec = 1.32 std. cc/sec

1 torr litre/sec = 79 std. cc/min

1 torr litre/sec = 11.4×10^{4} std. cc/day

(v) Some Leak Rate Examples

(a) 50 micron/year proposal (Ref. 1)

Leak rate $Q = 5 \times 10^{-6}$ std. cc/min

$= 5 \times 10^{-6} \times 12.7 \times 10^{-3}$ torr litre/sec

$\therefore \quad Q = 6.35 \times 10^{-8}$ torr litre/sec

Alternatively

$$50 \text{ micron/yr} = 50 \times \frac{1.16}{365} \times 40 \times 10^{-8} \text{ torr litre/sec}$$

$$= 6.4 \times 10^{-8} \text{ torr litre/sec}$$

(b) 10 Micron/day Proposal

$10 \text{ micron/day} = 10 \times 1.16\ V_s \times 10^{-8}$ torr litre/sec

$= 4.6 \times 10^{-6}$ torr litre/sec if $V_s = 40$ litre

Converting to the std. cc/unit time units:

$Q = 1.32 \times 4.6 \times 10^{-6}$ std. cc/sec

$\therefore \quad = 6.1 \times 10^{-6}$ std. cc/sec

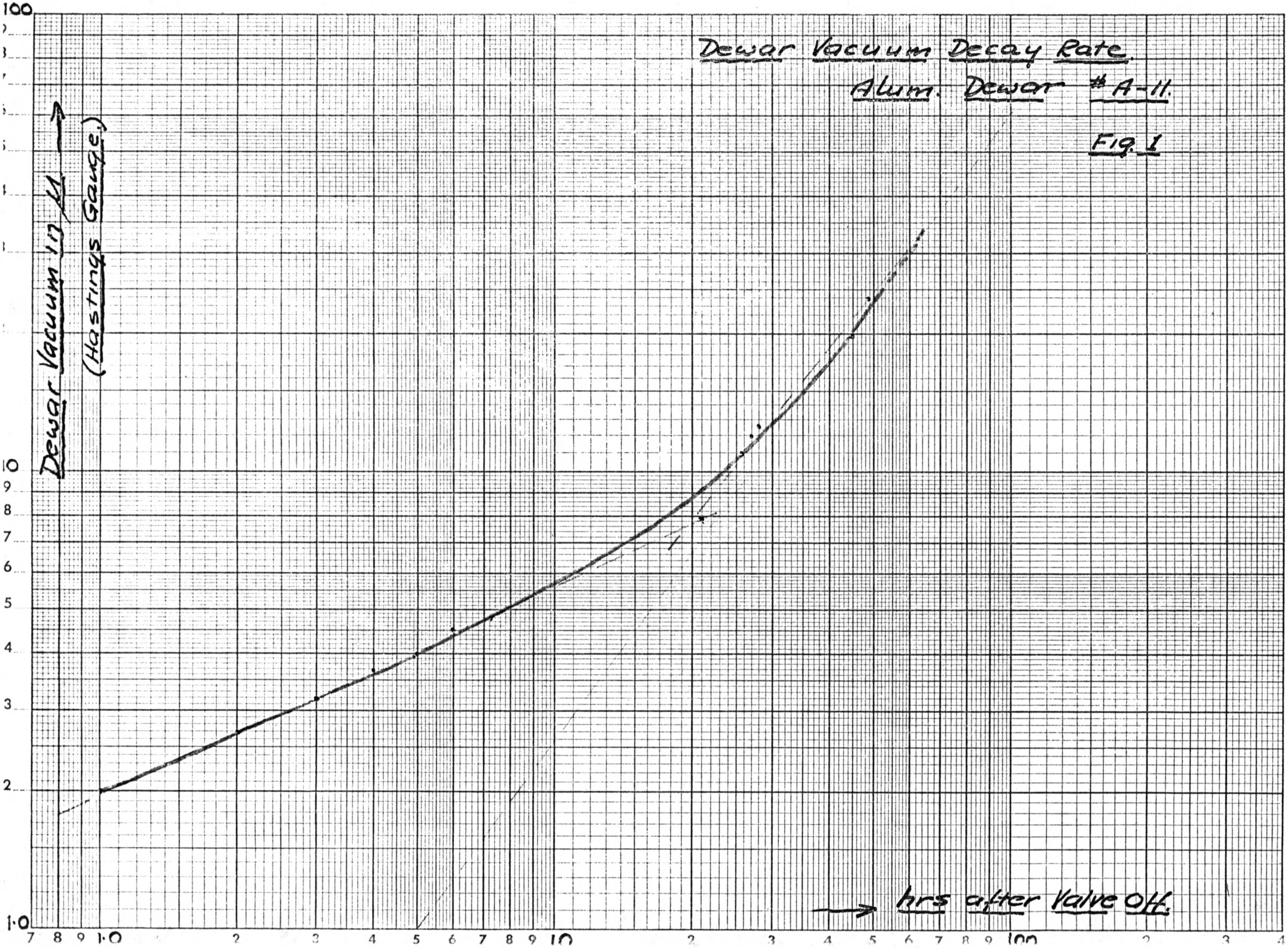
$= 79 \times 4.6 \times 10^{-6}$ std. cc/min

$= 3.63 \times 10^{-4}$ std. cc/min

$= 11.4 \times 4.6 \times 10^{-6} \times 10^{4}$ std. cc/day

$= 0.52$ std. cc/day

So after six months operation ~95 std. cc has leaked into the dewar, and after twelve months ~190 std. cc has leaked in.

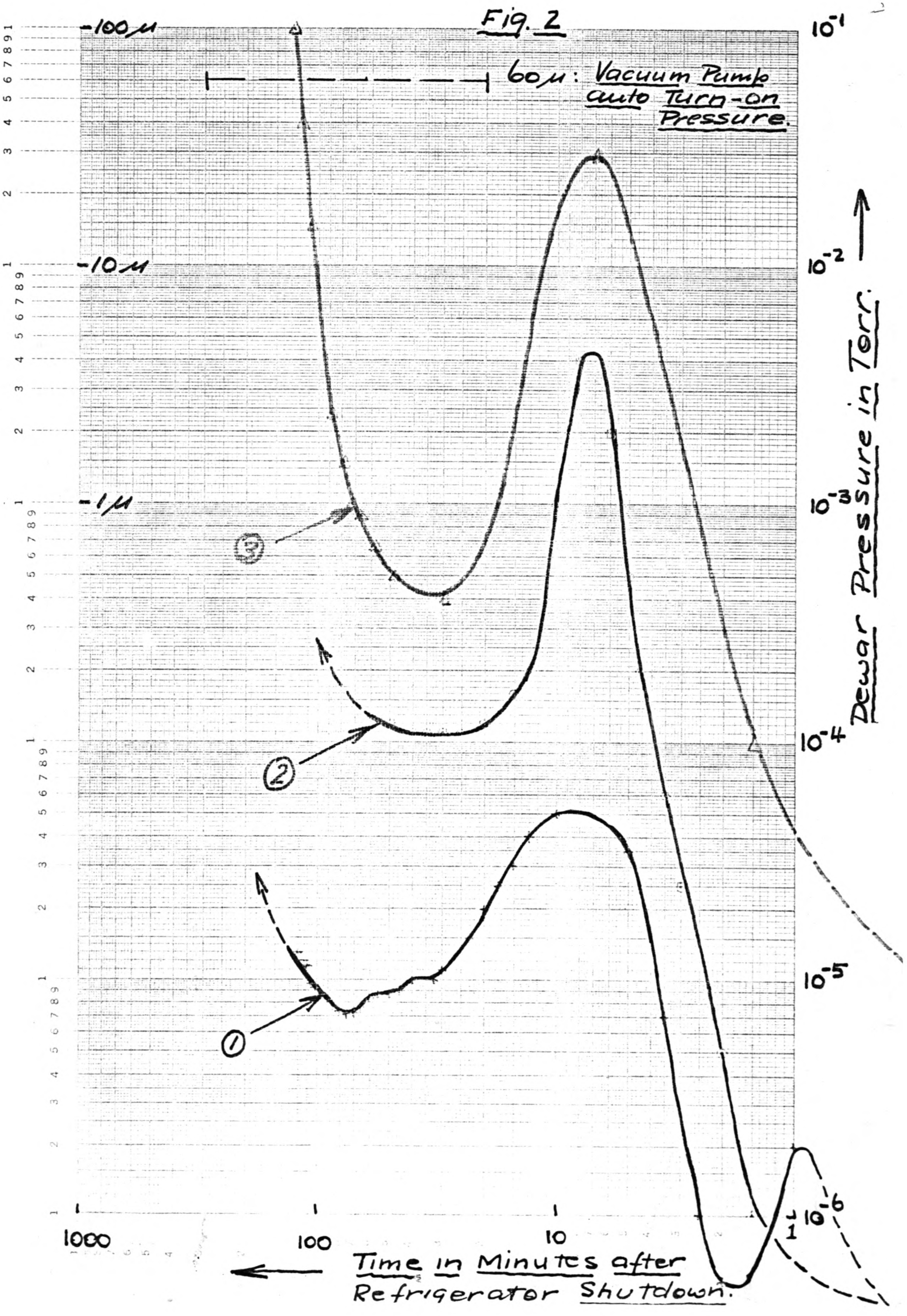


Dewar Vacuum Decay Rate.

Alum. Dewar #A-11.

Fig. I

Fig. 2



-100μ
-10μ
-1μ
60μ: Vacuum Pump auto Turn-on Pressure.
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
Dewar Pressure in Torr.
1000
100
10
1
Time in Minutes after Refrigerator Shutdown.
③
②
①

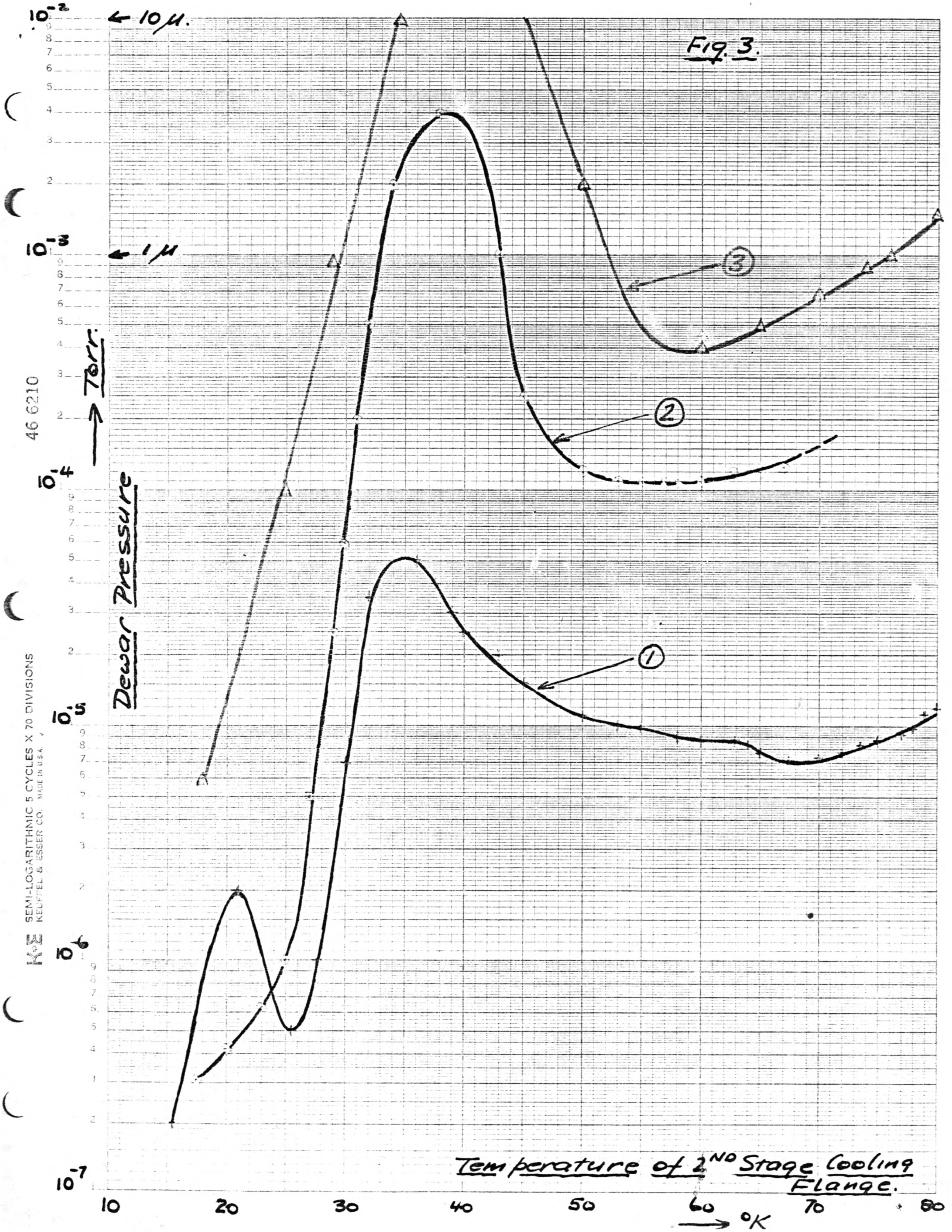
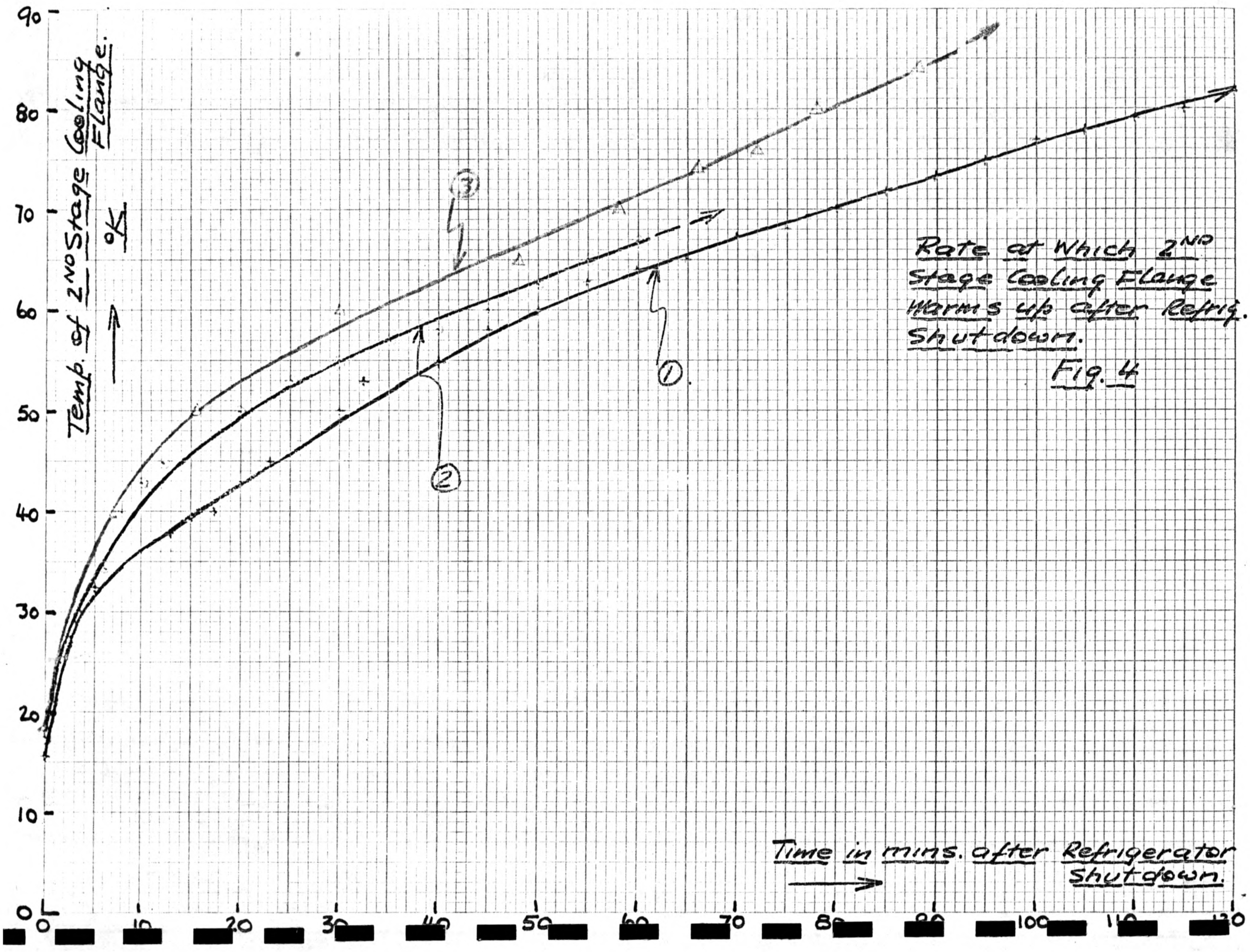


Fig. 3.

10^{-2} ← 10 μ.
10^{-3} ← 1 μ
10^{-4}
10^{-5}
10^{-6}
10^{-7}
→ Torr.
Dewar Pressure
③
②
①
10
20
30
40
50
60
70
80
→ °K
Temperature of 2ND Stage Cooling Flange.
KE SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210



Rate at Which 2ND Stage Cooling Flange Warms up after Refrig. Shutdown.

Fig. 4