UC-38
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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE		CODE TF0200	SERIAL M5569 B	PAGE 1 OF 31
AUTHOR R. BYRNS/G. NEWELL	DEPARTMENT MECHANICAL	LOCATION BERKELEY	DATE AUGUST 27, 1980	

PROGRAM — PROJECT — JOB
NEUTRAL BEAM SYSTEM TEST FACILITY - TFTR

CRYOGENIC TESTS

TITLE
DIVERTER VALVE AND OPERATION

A Revision 10/7/80
B Revision 3/11/81

INDEX PAGE

CROSS REFERENCE: Engineering Note M5378B First Cooldown and Operation 1979
Operation 1980

DISTRIBUTION
R. Byrns
G. Newell
A. Paterson
K. Berkner
K. Lou

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE		CODE TFO-200	SERIAL M5569 B	PAGE 2. OF
AUTHOR G. Newell/R. Byrns	DEPARTMENT Mechanical	LOCATION Berkeley	DATE September 5, 1980	
PROGRAM — PROJECT — JOB NEUTRAL BEAM SYSTEM TEST FACILITY - TFTR				
CRYOGENIC TESTS				
TITLE DIVERTER VALVE, HEAT LEAK, CRYOPUMP SPEED				

Comp. clock 1379 hrs
Warm eng. 1300
dry " 1079

Summary

Diverter valve tests August 26, 27, 1980 were made on the NBSTF- TFTR prototype in Bldg. 6. Performance of the valve action was excellent. Regen Cycle time on H_2 was 60 minutes, D_2 was 90 minutes. With practice these times can probably be cut in half. The cryopanel liquid was pushed back into the LHe dewar and held for controlled release. Cooldown, circulation, and regen modes all were OK. The tank base pressure seemed improved by about a decade after the de-rime operation.

Heat leak for a single panel was about 4 liters/hour (~4 watts). This compares well with V. Garzotto's measurement the previous week at PPPL of 5 liters/hour for a single cryopanel. Thus total heat load would be 30/40 watts for the 8 panels and another 30/40 watts for the LHe dewar and xsfer lines; total 60/80 watts (~same as 7/79 or slightly less.)

"Apparent" cryopump speeds at the duct end, IG-1, were 13.9 Mℓ/s for H_2; 18.4 Mℓ/s for D_2. At the neutralizer, IG-12; 1.53 Mℓ/s H_2; 1.3 Mℓ/s D_2 measurements were made without beam, turbo pump and duct target tank isolated, ion gage factor of 2.4 for H_2, and possible 20% error between IG-1 and IG-12. Conductance between the baffles separating the tank makes the pumping speed definition and analysis complex. It is of more interest to know the base pressure with beam on in the different tank areas.

Discussion

Diverter valve test results are shown on the accompanying graphs. LHe dewar level, vacuum tank pressure and cryopanel temperatures are shown versus time in minutes. Hydrogen was the first test. The panels were well loaded initially (approx. 5,000 Torr. liters), the turbo pump closed off and the diverter valve put in the REGEN mode; (Foot valve closed and "D" valve set

@ 10 psi back pressure.) LN supply was closed off.

Response was slow at first, but after about 12 minutes the pressure rose rapidly, tripped the Ion Gages @ 10^{-4} and the panels warmed fast and LN dumped (violently). A turbo pump was attempted restart, but the pressure was too high, so the rough pump was put on; then the Turbo pump. By then both top and bottom of the panels was approaching 60°K. After tank vac. pressure was pretty well down, the foot valve was cracked to feed LHe to the panels, then later opened full.

The H_2 test went well for a first time, and for the D_2 test we were able to anticipate better. 3000 T-l D_2 was loaded onto panels (The previous eve. H_2 was put on.) It took almost 57 minutes before the ion gage tripped off, but we got the turbo pump on faster and it caught without roughing. We also cracked the LHe dewar foot valve sooner and the panel temps didn't rise as high (49° and 55°K). Happily enough LHe (30%) in the dewar to continue the test.

The refrigerator stopped (broken valve rocker arm support.) just prior to the D_2 test. The graph shows the compressor suction pressure and also the recovery of the LHe gas from the recooling of the panels. Vac. tank pressure is sensitive to compressor suction pressure, as the vapor pressure of LHe affects the temperature and the v.p. of H_2 and D_2.

Cycle time can be reduced by practice and anticipation. Initial time to trip the IG can be reduced by continuing to feed large H_2 bursts. Heat transfer between the 80°K LN panel and the LHe panel begins to move in the thermocouple gage linear range of 1 to 1000 micron. Tank pressure and panel temp can be closely controlled by playing the proper tune on the turbo pumps and the foot valve/diverter valve.

Heat load was estimated from decay of panel temp and dry out of LHe at the end of the D_2 run with the refer off. After 3 hours the panels still had LHe and extrapolating the temp/time curve would be ~~dry~~ MT after 4.5 hours. A panel holds 16 liters. Therefore $\frac{16 \text{ liters}}{4 \text{ hours}}$ = 4 liters/hour $\approx$ 3 watts/panel

Pump Speed

Panel loading from gas source pulses with pressure and time is shown in the log book data sheets. Tests were with 8 active cryopanels in the NBSTF, target tank turbopump and duct valved off, no beam, 10-100 sec pulses for H_2, ion gage factor between 2.2 and 2.6 (100 sec pulses for D_2) use 2.4.

The gas load pulse is a calibrated amount from earlier information on the sphere in Bldg. 16. H_2 pulses of 12T-liters/s, 22 T-liters/s and 40 T-liters/s were used, at varied times and duration. IG-1 reads tank pressure at the duct end and IG-12 reads at the neutralizer. There is a possible variation of 20% between the two ion gages as noted at steady state. Baffles and conductance within the tank make the analysis complex, for gas load distribution and speed. Beam on and pressure distribution is more important and plans call for multiple ion gage locations in future.

Pumping speed values were taken from the data -

ie on H_2 Q = 40 T-liters/sec for 50 sec and 100 sec

IG-1 (DUCT) $\Delta P = 1.2 \times 10^{-6}$ Torr (2.4) = 2.88×10^{-6} T

$$S = \frac{Q}{\Delta P} = \frac{40 \text{ T-liters/sec}}{2.88 \times 10^{-6} \text{ T}} = 13.9 \times 10^{6} \text{ liters/sec}$$

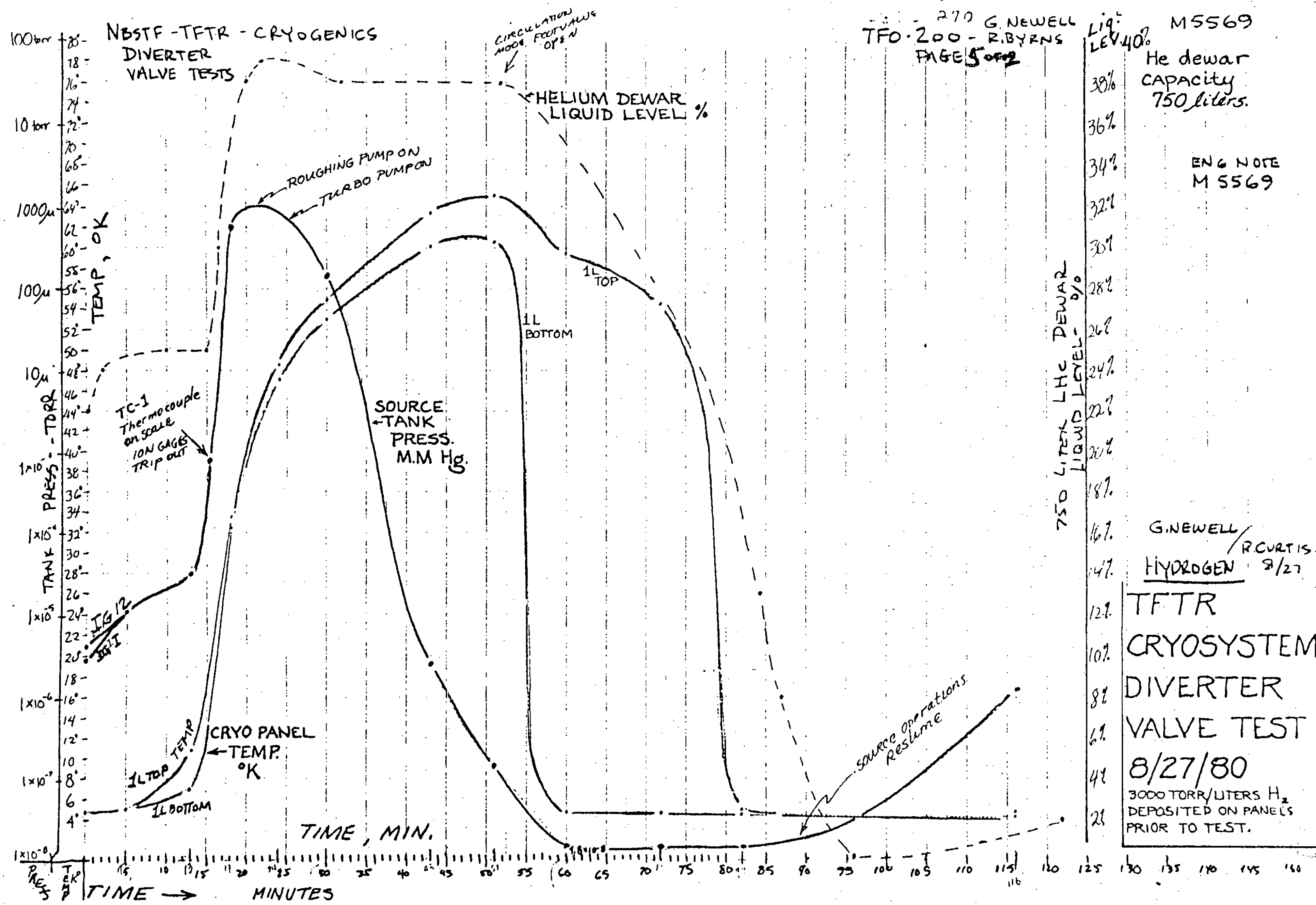
IG-12 (Neutralizer)

$$\Delta P = 10.9 \times 10^{-6} \text{ Torr } (2.4) = 26.2 \times 10^{-6} \text{ T}$$

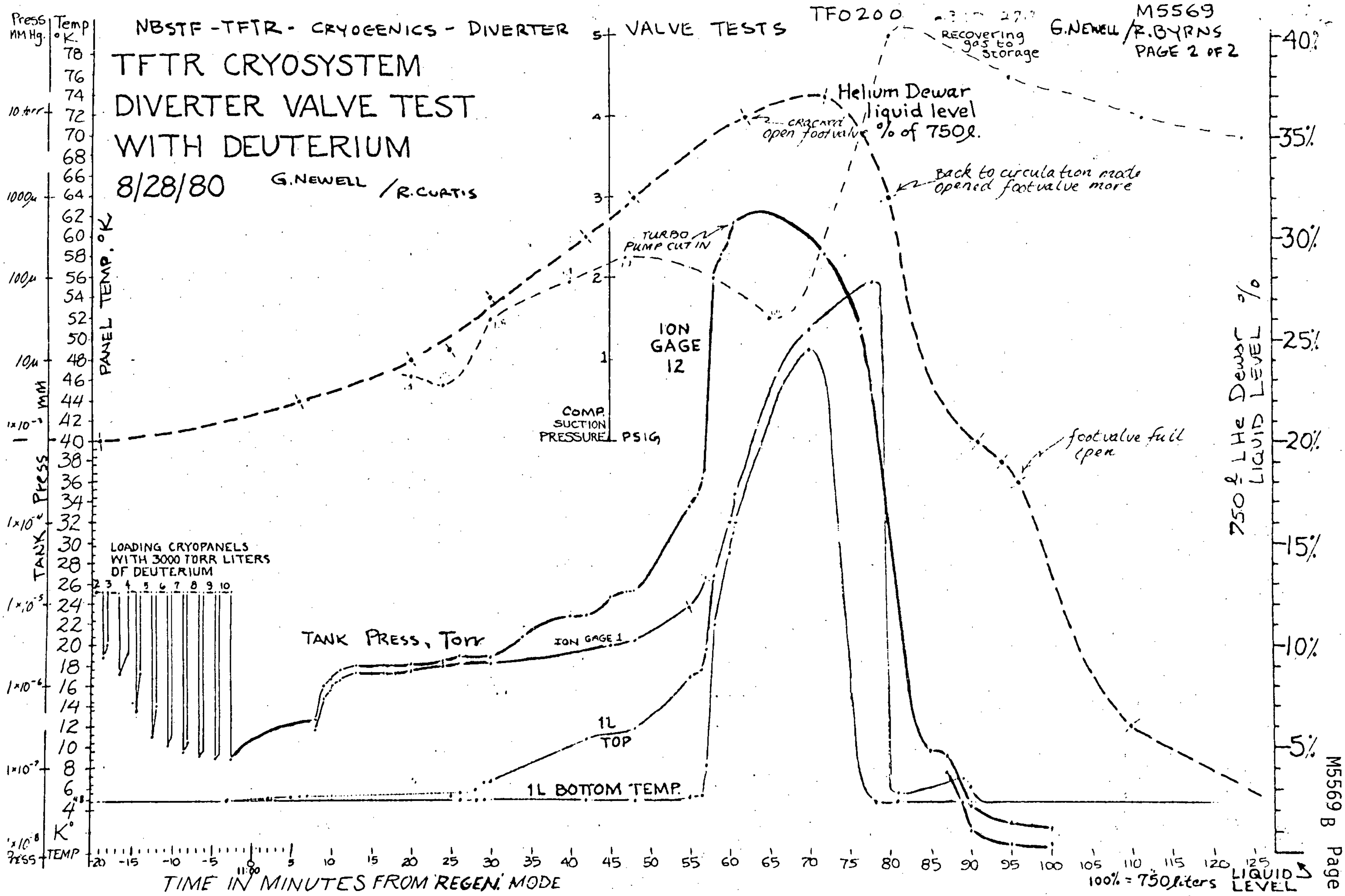
$$S = \frac{Q}{\Delta P} = \frac{40 \text{ T-}\ell/\text{sec}}{26.2 \times 10^{-6} \text{ T}} = 1.53 \times 10^{6}\ \ell/\text{s}$$

9-23 - Test with D_2 - very slow to respond - after ~2 HRS - added H_2
Then Regen mode reached Temp → ~ 40°K.
Total time ~ 2.5 hrs.

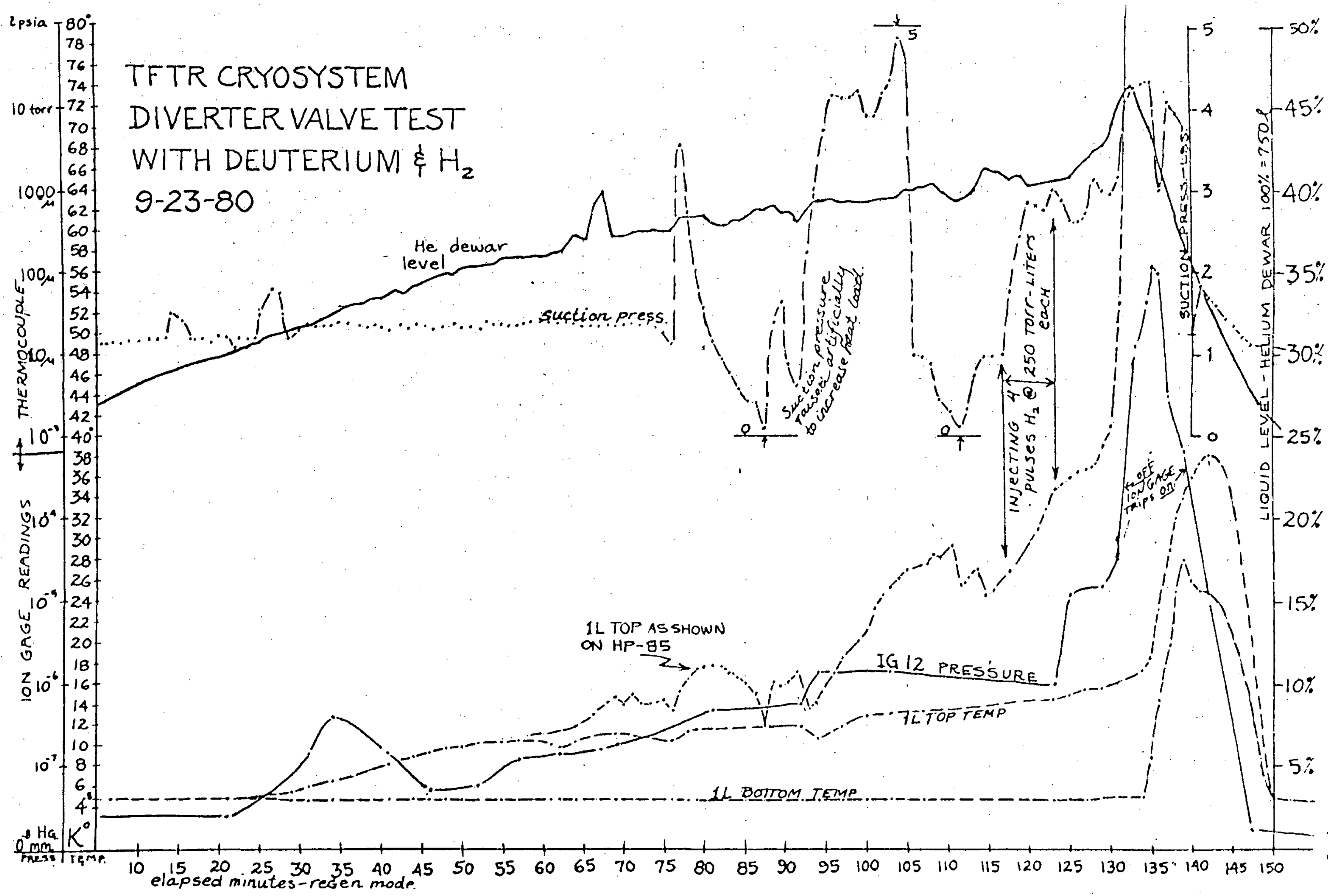
9-24 Test @ D_2 deposit 45,000 T-ℓ D_2
no H_2 added, just wait,
Temp → 40°K
Total time ~ 4 hrs.



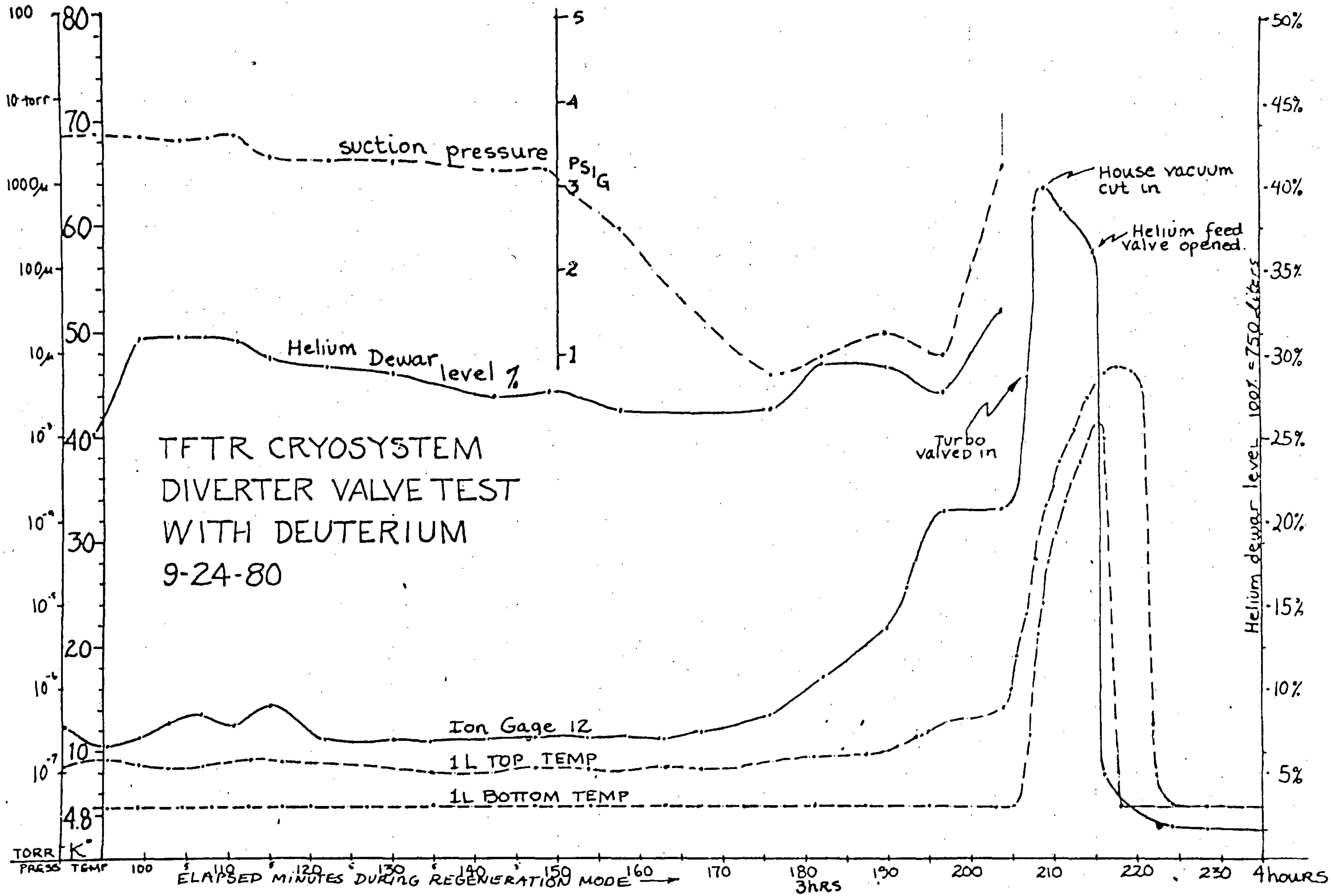
NBSTF - TFTR - CRYOGENICS
DIVERTER VALVE TESTS
TFO · 200 - R. BYRNS
G. NEWELL
PAGE 5 of 12
M5569
He dewar capacity 750 liters.
ENG NOTE M5569
CIRCULATION MODE, FOOT VALVE OPEN
HELIUM DEWAR LIQUID LEVEL %
ROUGHING PUMP ON
TURBO PUMP ON
1L TOP
1L BOTTOM
SOURCE TANK PRESS. M.M Hg.
TC-1 Thermocouple on scale
ION GAGES TRIP OUT
IG 12
CRYO PANEL TEMP. °K
1L TOP TEMP
1L BOTTOM
TIME, MIN.
Source operations Resume
TANK PRESS. - TORR
TEMP, °K
750 LITER LHe DEWAR LIQUID LEVEL - %
TIME → MINUTES
G. NEWELL / R. CURTIS 8/27
HYDROGEN
TFTR CRYOSYSTEM DIVERTER VALVE TEST
8/27/80
3000 TORR/LITERS H_2 DEPOSITED ON PANELS PRIOR TO TEST.

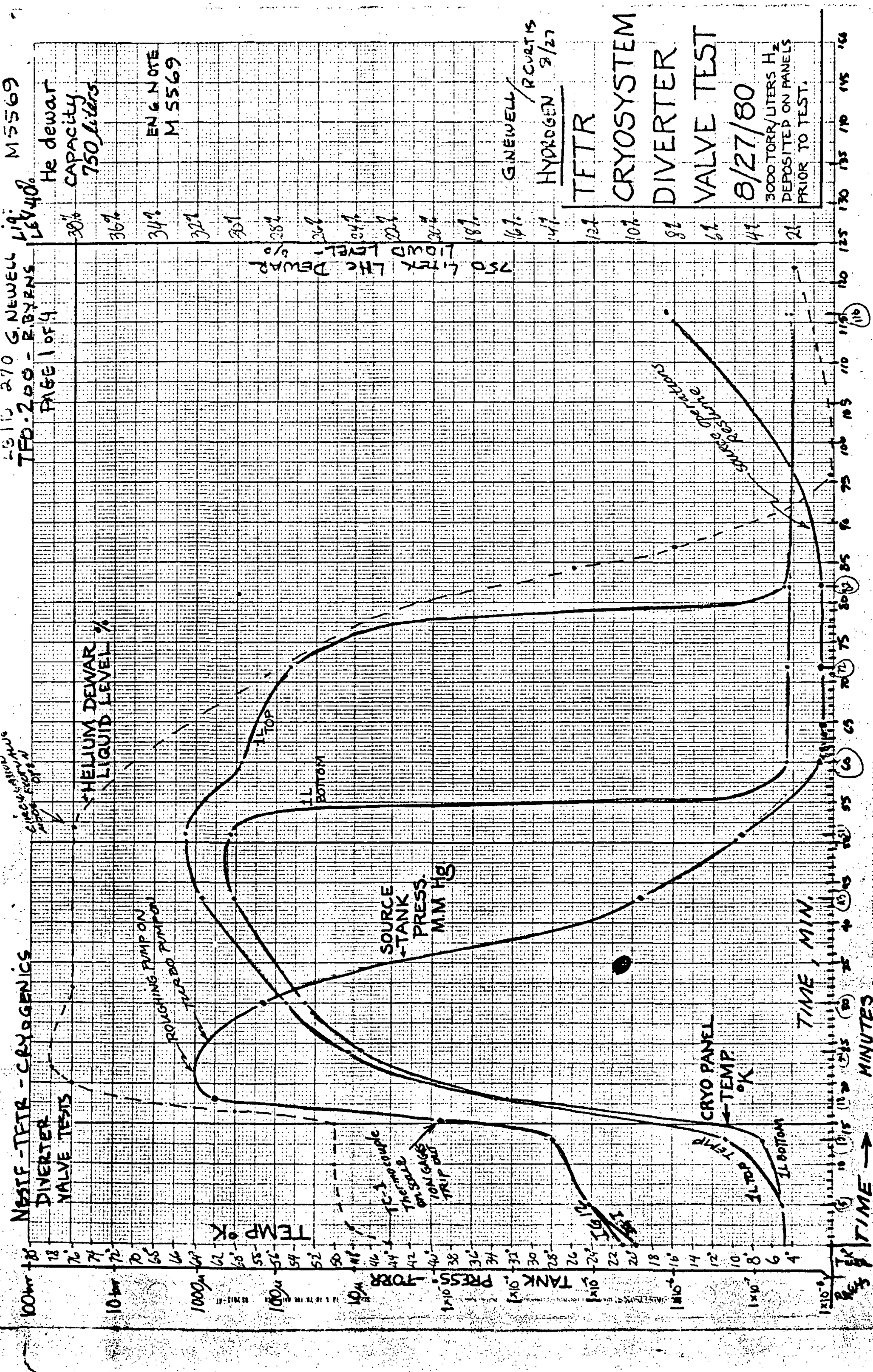


NBSTF - TFTR - CRYOGENICS - DIVERTER VALVE TESTS
TF0200
M5569
G.NEWELL / R.BYRNS
PAGE 2 OF 2
TFTR CRYOSYSTEM
DIVERTER VALVE TEST
WITH DEUTERIUM
8/28/80
G.NEWELL / R.CURTIS
Press MM Hg.
Temp °K.
PANEL TEMP. °K
TANK Press MM
Recovering gas to storage
Helium Dewar liquid level % of 750l.
CRACKED open footvalve
Back to circulation mode opened footvalve more
TURBO PUMP CUT IN
ION GAGE 12
COMP. SUCTION PRESSURE PSIG
footvalve full open
750 l LHe Dewar % LIQUID LEVEL
LOADING CRYOPANELS WITH 3000 TORR LITERS OF DEUTERIUM
TANK PRESS, Torr
ION GAGE 1
1L TOP
1L BOTTOM TEMP.
TIME IN MINUTES FROM REGEN. MODE
100% = 750 liters
LIQUID LEVEL

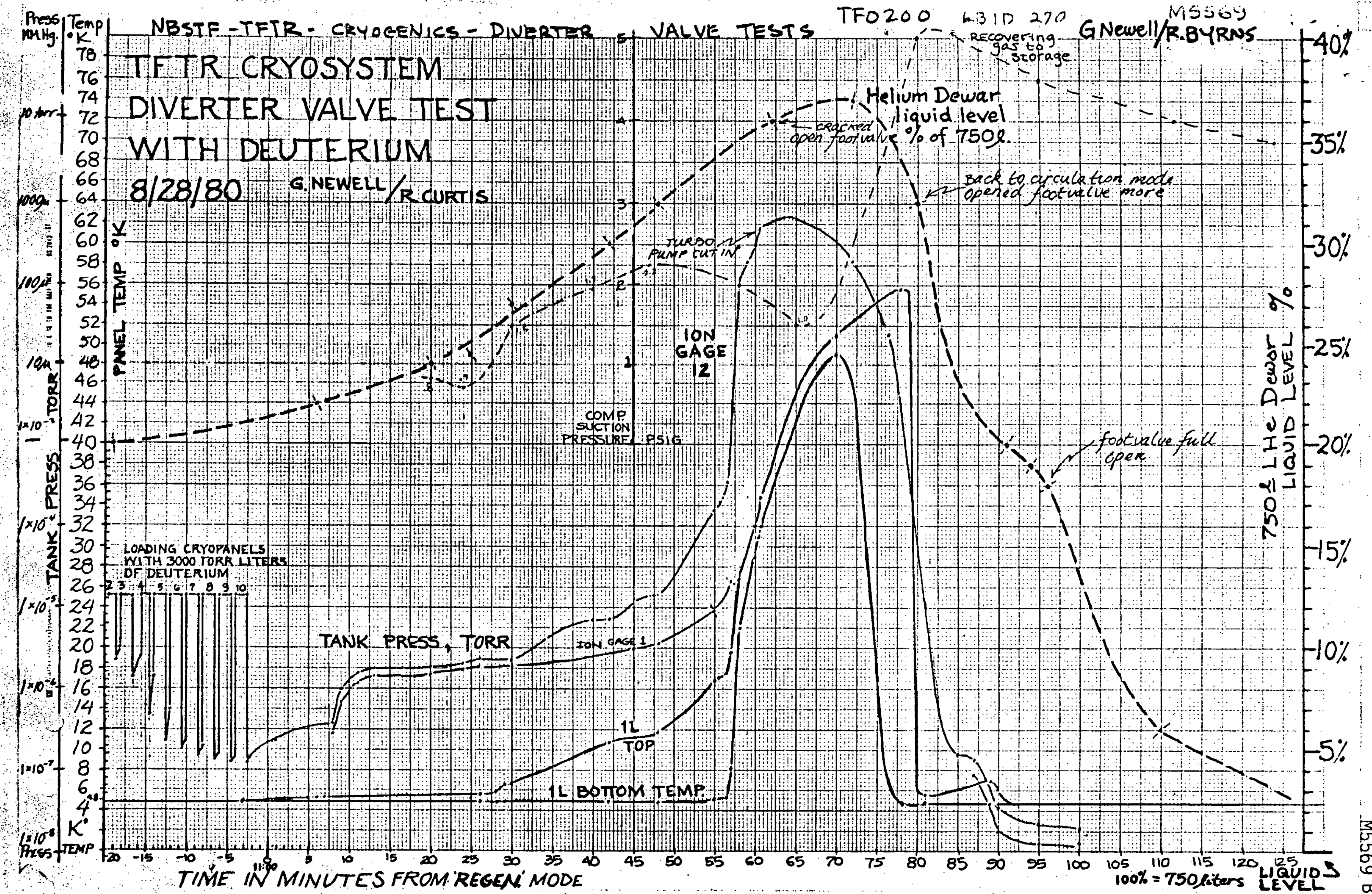


M5569 B page 7

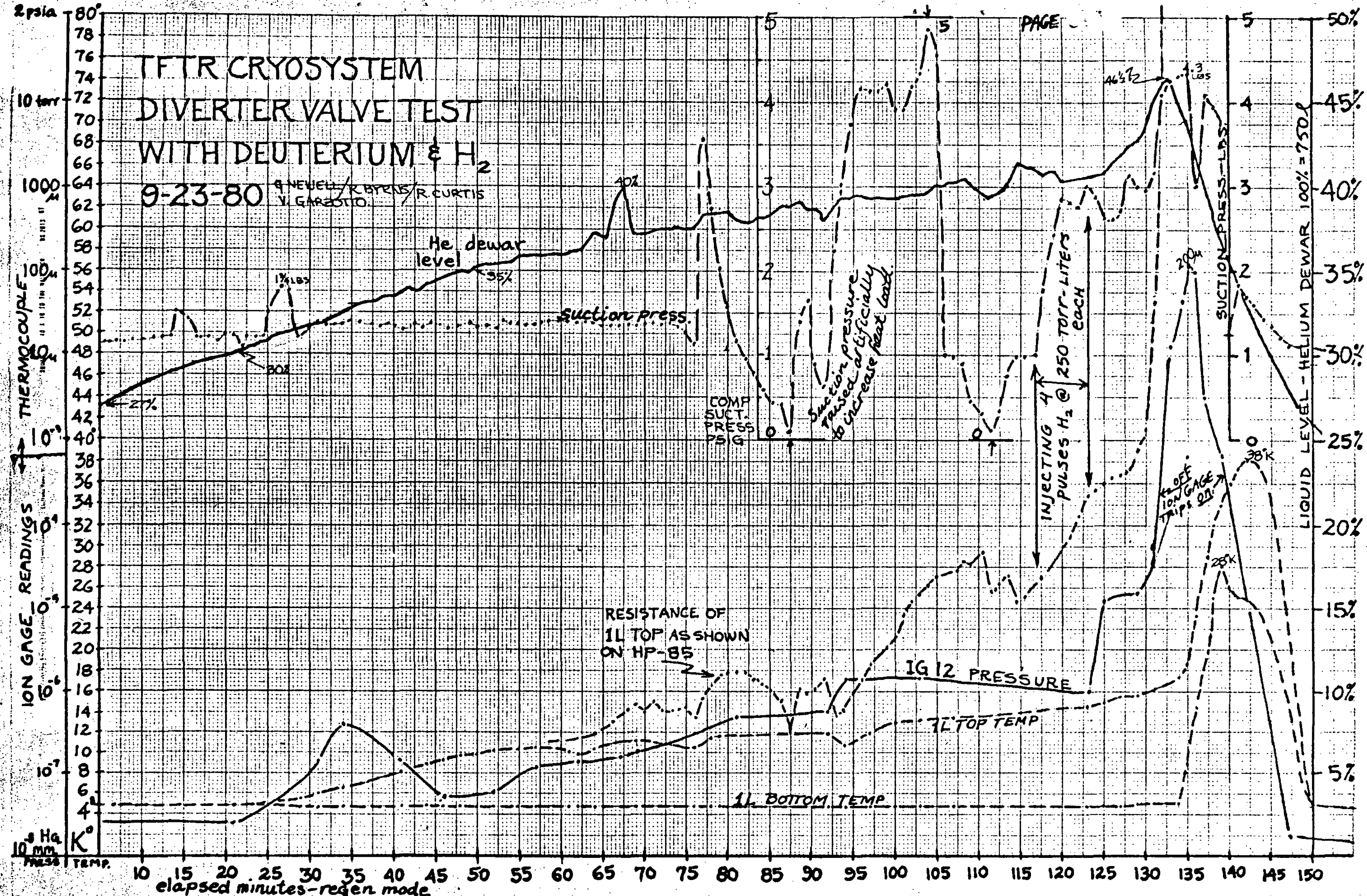

TFTR CRYOSYSTEM
DIVERTER VALVE TEST
WITH DEUTERIUM
9-24-80
suction pressure
PSIG
Helium Dewar level %
House vacuum cut in
Helium feed valve opened.
Turbo valved in
Ion Gage 12
1L TOP TEMP
1L BOTTOM TEMP
Helium dewar level 100% = 750 liters
ELAPSED MINUTES DURING REGENERATION MODE
3hrs
4hours
TORR PRESS
K° TEMP
10 torr
1000μ
100μ
10μ
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%



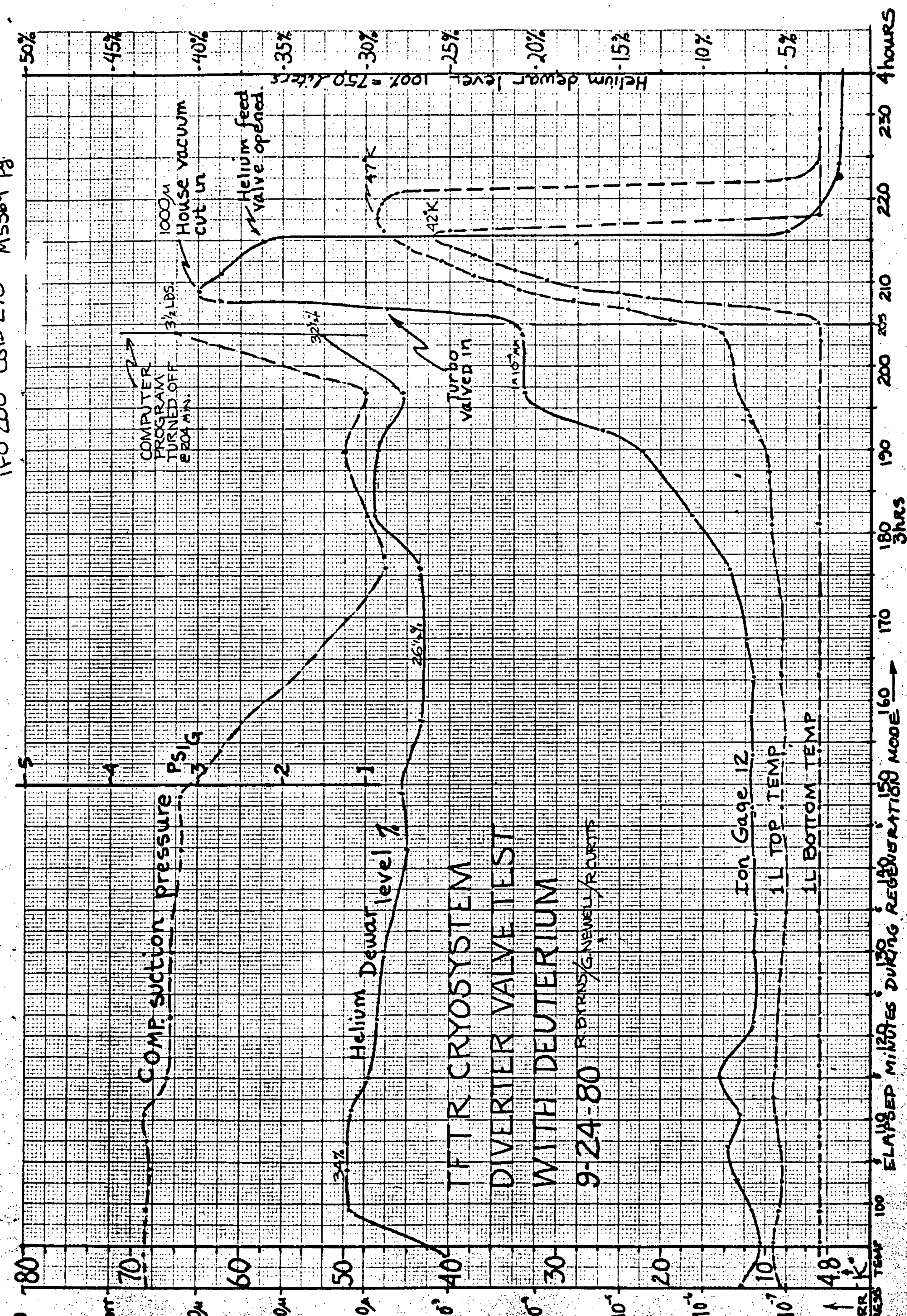
NESIF - TFTR - CRYOGENICS
DIVERTER VALVE TESTS
LSIC 270 G. NEWELL
TFD. 200 - R. BYRNS
PAGE 1 OF 4
M5569
He dewar capacity 750 liters
ENG NOTE M5569
G. NEWELL / R. CURTIS 8/27
HYDROGEN
TFTR
CRYOSYSTEM
DIVERTER
VALVE TEST
8/27/80
3000 TORR/LITERS H2 DEPOSITED ON PANELS PRIOR TO TEST.
HELIUM DEWAR LIQUID LEVEL %
750 LITER LHe DEWAR LIQUID LEVEL - %
SOURCE TANK PRESS. M.M Hg
CRYO PANEL TEMP °K
TEMP °K
TANK PRESS - TORR
ROUGHING PUMP ON
TURBO PUMP ON
ION GAGE TRIP OUT
TC-1 Thermocouple on scale
1L TOP
1L BOTTOM
SOURCE DIVERTER POSITIONS
TIME, MIN.
TIME → MINUTES

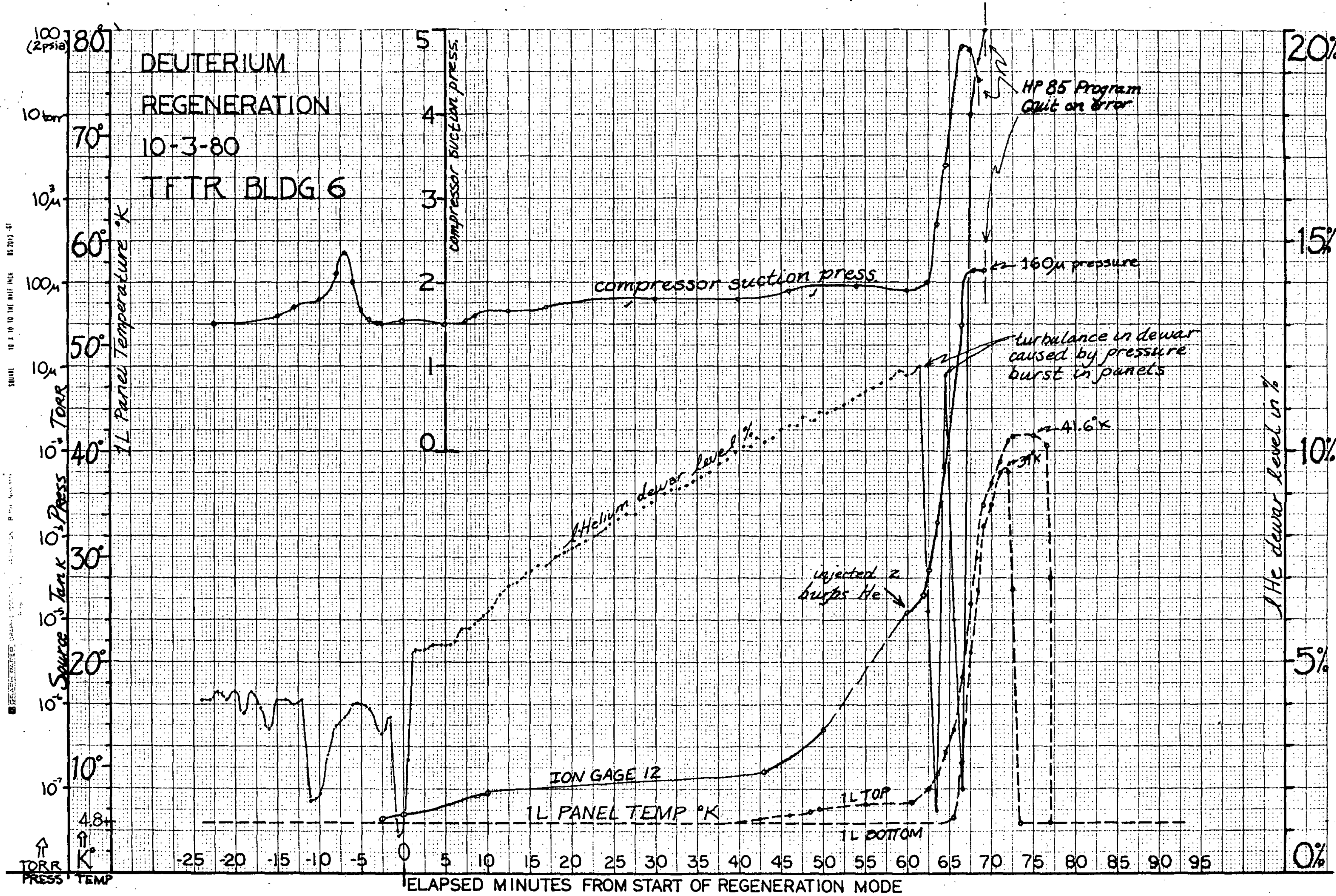

NBSTF - TFTR - CRYOGENICS - DIVERTER VALVE TESTS
TF0200
M5569
G Newell/R.BYRNS
TFTR CRYOSYSTEM
DIVERTER VALVE TEST
WITH DEUTERIUM
8/28/80
G. NEWELL/R. CURTIS
Helium Dewar liquid level % of 750l.
cracked open footvalve
Recovering gas to storage
Back to circulation mode opened footvalve more
TURBO PUMP CUT IN
ION GAGE 2
COMP SUCTION PRESSURE PSIG
footvalve full open
PANEL TEMP °K
TANK PRESS - TORR
750l LHe Dewar % LIQUID LEVEL
LOADING CRYOPANELS WITH 3000 TORR LITERS OF DEUTERIUM
TANK PRESS, TORR
ION GAGE 1
1L TOP
1L BOTTOM TEMP.
Press mm Hg.
Temp °K
K° TEMP
TIME IN MINUTES FROM 'REGEN' MODE
100% = 750 liters
LIQUID LEVEL
40%
35%
30%
25%
20%
15%
10%
5%

TFO 200 LBID 270 M5561



M5569 B page 11


TFO 200 LBID 270 M5569 P3
TFTR CRYOSYSTEM
DIVERTER VALVE TEST
WITH DEUTERIUM
9-24-80 R.BYRNS/G.NEWELL/R.CURTIS
COMP. suction pressure
PSIG
Helium Dewar level %
Ion Gage 12
1L TOP TEMP
1L BOTTOM TEMP
Helium dewar level 100% = 750 liters
COMPUTER PROGRAM TURNED OFF @204 MIN.
Turbo valved in
1000μ House vacuum cut in
Helium feed valve opened.
3½ LBS.
32½%
26½%
34%
42K
47K
ELAPSED MINUTES DURING REGENERATION MODE
3hrs
4hours
TORR PRESS
TEMP °K



M5569 B page 12A

8-26-80
8/26/80

AL
CH
GEORGE NEWELL

CRYO TEST (HYDROGEN)

NBSTF-3 102
aug 26, 1980

10 sec. pulses

TIME	H_2 FLOW	ΔP1	IG 1 (○) BEFORE	IG 1 DURING	IG 1 AFTER	IG 12 (X) BEFORE	IG 12 DURING	IG 12 AFTER	ΔP12
15:18	1# 12 TL/s	1.1	5.3×10^{-6}	6.4×10^{-5}	5.3×10^{-6}	6.9×10^{-6}	1.0×10^{-5}	6.9×10^{-6}	3.1
15:27			5.7			7.6			
15:30		1.1	6.1×10^{-6}	7.0×10^{-6}	5.7×10^{-6}	7.7×10^{-6}	1.1×10^{-5}	7.1×10^{-6}	3.6
15:38		1.0	5.3×10^{-6}	6.3×10^{-6}	5.4 ×	6.9×10^{-6}	1.0×10^{-5}	7.0×10^{-6}	[illegible]
15:40		.5	5.4×10^{-6}	6.0×10^{-6}	4.9×10^{-6}	7.0×10^{-6}	1.0×10^{-5}	6.0×10^{-6}	[illegible]
15:40		.7	5.5×10^{-6}	6.2×10^{-6}	5.2×10^{-6}	7.0×10^{-6}	1.0×10^{-5}	6.4×10^{-6}	[illegible]
15:42		.6	6.1×10^{-6}	6.7×10^{-6}	5.5×10^{-6}	7.7×10^{-6}	1.0×10^{-5}	6.8×10^{-6}	[illegible]
15:43		.6	5.7×10^{-6}	6.3×10^{-6}	5.4×10^{-6}	7.3×10^{-6}	1.0×10^{-5}	6.6×10^{-6}	[illegible]
				7.9/6.4					
15:44	5# 22 TL/s	0.9	6.4×10^{-6}	7.3×10^{-6}	5.7×10^{-6}	8.1×10^{-6}	1.3×10^{-5}	7.0×10^{-6}	4.9
15:47		1.0	7.0×10^{-6}	8.0×10^{-6}	5.9×10^{-6}	8.9×10^{-6}	1.4×10^{-5}	7.1×10^{-6}	5.1
15:49		0.7	4.8×10^{-6}	5.5×10^{-6}	4.1×10^{-6}	6.1×10^{-6}	1.1×10^{-5}	5.0×10^{-6}	4.9
15:50		.8	4.5×10^{-6}	5.3×10^{-6}	4.2×10^{-6}	5.7×10^{-6}	1.1×10^{-5}	5.2×10^{-6}	5.3
15:51	15# 40 TL/s	1.3	4.4×10^{-6}	5.7×10^{-6}	4.1×10^{-6}	5.7×10^{-6}	1.7×10^{-5}	5.0×10^{-6}	11.3
15:53		1.2	6.0×10^{-6}	7.2×10^{-6}	5.4×10^{-6}	7.5×10^{-6}	1.8×10^{-5}	6.6×10^{-6}	10.5
15:54		1.1	6.5×10^{-6}	7.6×10^{-6}	6.4×10^{-6}	8.0×10^{-6}	1.9×10^{-5}	7.9×10^{-6}	11.0
15:56		1.3	7.6×10^{-6}	8.8×10^{-6}	7.0×10^{-6}	9.4×10^{-6}	2.0×10^{-5}	8.6×10^{-6}	10.6
		1.0	8.0×10^{-6}	9.0×10^{-6}	7.3×10^{-6}	8.0×10^{-6}	2.0×10^{-5}	9.2×10^{-6}	12.0
15:58	50 sec Pulse 200	1.2 } 1.3	7.8×10^{-6}	9.0×10^{-6} 8.1	6.8×10^{-6}	9.7×10^{-6}	2.0×10^{-5} 2.0	8.5×10^{-6}	10.3 } 11.5
16:04	100 sec 400	1.2	7.3×10^{-6}	8.5×10^{-6}	7.3×10^{-6}	9.1×10^{-6}	2.0×10^{-5}	9.0×10^{-6}	10.9

Deuterium 8/27/80

NBS 3/180
Aug 27, 80
8 panels
no beam
100 sec pulses
Gage Factor 2.4

Turbo pump. Duct Target Tank off.

Shut down to deposit D_2 on the cryo panels to repeat tests as per yesterday. (3000 ~~TL~~ TL will be deposited by setting up (15 # D_2 = 30 TL/s) – 10 pulses at 99.9 seconds

PULSE #	ΔP	IG 1 ($\times 10^{-6}$) BEFORE	DURING	AFTER (~2 sec)	ΔP	IG 12 ($\times 10^{-6}$) BEFORE	DURING	AFTER (~2 sec)	ΔP
1		7.7	5.1 (3.3)	5.3	−2.6	9.0	18.0 (6)	6.6	9
2		5.4	2.2 (1.6)	3.7	−3.2	6.7	14 (14)	4.9	7.3
3		3.7	1.5 (1.1)	1.7	−2.2	4.9	14 (14)	2.8	9.1
4		1.7	0.9	0.6	−0.8	2.8	13	1.3	10.2
5		0.8	0.9	0.2	+0.3	1.3	13	0.7	11.7
6		0.2	0.8 (.76)	0.12	+0.6	0.7	13 (13)	0.44	12.3
7		0.12	0.76 (.76)	0.07	+0.64	0.44	13 (13)	0.28	12.6
8		0.07	0.75	0.055	+0.68	0.28	13	0.20	12.7
9		0.055	0.73	0.04	+0.68	0.20	13	0.15	12.8
10		0.04	0.72	0.03	+0.68	0.15	13	0.10	12.8

Started waiting 30 seconds after pressure started to drop (after pulse) to take after reading.

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
TF0200	M5569 B	15 1 OF

AUTHOR	DEPARTMENT	LOCATION	DATE
R. Byrns	Mechanical	Berkeley	7/17/80

PROGRAM — PROJECT — JOB

NBSTF-TFTR

CRYOGENICS

TITLE

DIVERSION VALVE

INTRODUCTION

The requirements for the divertor valve were originally set up by PPPL in meetings with LLL. These parameters were also probably tied in to joint committee thinking regarding the 750 ℓ LHe dewar. Generally, I suspect that the dewar was specified to provide some 6 or 7 hours of liquid storage for refrigerator outage. This is redundant if one considers a 2000 gallon LHe central storage and supply. The radioactivity required remote handling and disassembly, and also was probably the reason for the co-axial bayonet transfer lines.

The Divertor valve originally had 2 functions specified; the cooldown mode and the circulating mode, with remote operation capability. Both of these functions have been shown to work satisfactorily. The REGENERATION mode (or derime) was added as a later thought to the specified function. This was because of some concern with the possible problems connected with heavy D_2 or H_2 ice build-up. (and T_2 handling capacity)

Based on bubble chamber work with H_2 and D_2 in the middle 50's there may be undue concern with the H_2 ice problem. However general PPPL guidelines for diversion valve "Regen" mode are: once a week use with cycle time of a few hours - not to exceed 4, preferably much less.

The "Regen" mode has an upper valve at the top of the cryopanel - and a lower valve for liquid supply from the dewar bottom to the bottom of the panel.

The upper valve is supposed to seal tight and function as a back pressure or relief valve set at 10 psig. (It leaks presently.) The lower or "foot" valve is supposed to seal tight at 1 psig, pass LHe from panels, and prevent LHe from the dewar supplying the cryopanel. (It leaks.) 7-17-80 With both valves closed the heat load is supposed to boil out the LHe either back into the dewar or out the 10 psi valve as gas (GHe). The temperature of the panel should come up and evaporate the frozen H_2 or HD.

For the Regen mode at least one of the two valves must seal tight. If the upper valve, then the build up of gas pressure should push the LHe back into the dewar, or if the "foot" valve closes tight, then the gas He should pass out freely thru the divertor valve, even in the "circulation" mode.

The other criteria is to have this happen in reasonably short time. An estimated target temperature for "derime" is 8-10°K.

Hydrogen Vapor Pressure: (Approx.) pg. 326 - Adv. Cryogenics, C.M. Bailey

P	1mm	100μ	1μ	5×10^{-5}	10^{-6}	10^{-7}
T	10°K	8°K	6°K	5°K	4.2°K	4°K

<u>A panel</u> 4' x 12' ≃ $3.5m^2$ (one side) ≃ <u>$7m^2$ total</u>

Holds ≃ 15-20 liters LHe

Weighs ≃ 200 lbs. stainless steel

Assume warm-up occurs by radiation only -

Assume 1 watt/m^2 ≃ <u>7 watts total</u>

∴ $20\ \ell\ \text{LHe}\ 0.7\ \frac{\text{w h}}{\ell} = 14$ watt hours - time to dry = 2 HRS

Specific heat stainless steel - page 85 C.D.B.

est. @ 4°K $\simeq 0.1\ \frac{\text{watt sec}}{\ell\text{b}\ {}^\circ\text{K}} = C_p$

@ 20°K $\simeq 1$

Time to heat to 8°K - 10°K from 5°K.

$$0.1\ \frac{\text{watt sec}}{\ell\text{b}\ {}^\circ\text{K}}\ (200\ \ell\text{bs.})\ (5^\circ\text{K})\ \frac{\text{min}}{60\ \text{sec}} = 1.5\ \text{watt min}$$

7 watts available ———— 0.2 min ≃ 12 sec.

∴ 2 HRS to boil dry ~ seconds to raise panel temp using avail. radiant heat load; faster and more controllable with external heater applied or some method to transfer LHe out of panel.

Conclusions and Recommendations to PPPL

1. For minimum mechanical work, omit trying to get divertor valve to work in "Regen" mode - just be sure it works in Cooldown and Circulation (REGEN).
2. Fix foot valve so it really seals tight! Use a much stiffer valve rod, more closing force and possibly even a soft seat.
3. Wrap 50 watt heater wire (nichrome) on lower LHe cryopanel pipe for external control.

Reference Drawing Lists

19Q0102
19Q0112
19Q0092
19Q0123
19E5623A
19Q0133
19Q0082
19E7073B
19E5643A
19E5704A
19E7164A
19E5694A
19E5684A
19E7174A
19E7874B
19E7245A

79-104956 2 of 6 - 19N1186
78-119734 12 of 14 - 19N2536
77-111682 19E8076A
77-111202 19E7854

SUBJECT

NAME

DATE

REGENERATION REQUIREMENT.

Each source has a cold gas flow of ≈ 30 torr-l/sec. This gas is essentially all pumped by the cryopumps. The internal volume of the beamline is grossly 50,000 liters. Equipment within displaces a volume estimated as follows:

$$\text{Cryopumps: } 200\,l\ (He) + 250\,l\ (LN_2) + \frac{13{,}000\ lb}{18.3\ lb/liter} \leftarrow \text{Typ. SS}$$

$$= 1160 \text{ liters}$$

Magnet and stand, etc $20{,}000\ lb/18.3 = 1100\ l.$

Calorimeter & Ion Dump $\sim 1100\ l.$

Available volume within the beamline is thus $\gtrsim 45{,}000$ liters.

With 12 torr-l/liter of room temp. D_2 as an administrative limit, the total quantity of D_2 which can be injected between regeneration cycles is

$$Q = 12 \times 45{,}000 = 540{,}000 \text{ torr } l.$$

Thus for ½ second pulses, the total number of source shots allowed between regenerations is

$$\frac{540{,}000 \text{ torr-l}}{30 \frac{\text{t-l}}{\text{sec}} \times \frac{1}{2} \text{ sec}}$$

= 36,000 source shots.

For the NBSTF with one source, and 5 minute intervals 16 hours per day, 5 days per week the time between regenerations is

$$\frac{36{,}000 \text{ shots}}{12 \frac{\text{shots}}{\text{hour}} \times 16 \frac{\text{hours}}{\text{day}} \times \frac{5 \text{ day}}{\text{week}}} = \underline{37.5 \text{ weeks}}$$

For TFTR (non Tritium operation) with 3 sources, the limit is reached in $\underline{12\frac{1}{2} \text{ weeks}}$

For TFTR with T_2 operation, regeneration must be done every week (after 96 T_2 machine pulses) to limit T_2 accumulation in the NBL.

(A) TIME FOR He PANEL TO BOIL DRY
(FEED SHUT OFF, NO SYPHONING)

For a vertical section of the panel 1 cm wide and x cm height above the bottom,

$$\underset{\text{INTO LIQUID}}{\dot{Q}(x)} = \dot{q}'' x = \frac{30.8}{345800} x = 8.9\times10^{-5} x$$

The mass flow out by vaporization

$$-\dot{M}(x) = \frac{\dot{Q}(x)}{\lambda} = \frac{8.9\times10^{-5}}{18.56} x = 4.8\times10^{-6} x$$

At $t=0$, $X=L$ at $t=t$, $X=X$

$$-\frac{dM(x)}{x} = 4.8\times10^{-6}\, dt$$

But $M(x) = M(L)\frac{x}{L} = \frac{20\ell\ (118\ g/\ell)}{110\times340} x = .0631\,x$

$$\int_L^x -\frac{.0631\,dx}{x} = \int_0^t 4.8\times10^{-6}\,dt$$

$$-.0631 \ln x/L = 4.8\times10^{-6}\,t$$

$$x/L = \exp\left(-\frac{4.8\times10^{-6}}{.0631}t\right) \equiv \exp(-t/\tau)$$

So $\tau = \frac{.0631}{4.8\times10^{-6}} = 13{,}146$ sec $= 3.65$ hours.

The effect of residual gas conduction should not be apparent until the last 5-10% only of the panel remains cold.

SUBJECT

NAME

DATE

(B) SYPHONING.

The panel exit is valved off. The feed is shut but with a ≈ 5 psi check valve. The panels self pressurize to syphon the liquid back into the dewar.

The pressure in the panels will remain constant at $1.28 + 5/14.7 \approx 1.6$ ATM.

4.5K operating

The heat rate into the liquid is $30.8 \frac{x}{L}$ watts where x is the liquid height.

The heat rate into the gas is $30.8 \left(\frac{L-x}{L}\right) + 15.3 + 4.0 + 0.5 = 30.8(L-x) + 19.8$ watts.

If the gas temperature remains at saturation (4.76 K), then the mass of gas created by boiling (λ = 15.88 j/gm) divided by its density (2.915×10^{-2} g/cm^3) gives the volume of liquid expelled. The heat input into the gas must also appear as a heat load on the liquid to maintain saturation.

If the gas is stratified (as expected) and is at some average temperature $T_g > 4.76$ K, its density will be less than saturation density and thus occupy more volume. The syphon rate should be even faster.

SUBJECT

NAME

DATE

CONSERVATIVE CALCULATION

Gas remains at saturation but no account taken of heat load on the gas. This should give the slowest emptying rate for the panels.

TIME FOR INITIAL PRESSURIZATION TO 1.6 ATM.

assume Panels 90% by weight full of liquid at 4.5K.

$$P_0 = 1.28 \text{ ATM} \qquad \rho_0 = \frac{.1189(.9) + (2.213\times10^{-2})(0.1)}{1}$$

$$= .1092 \text{ gm/cm}^3$$

We have a total volume (including lines) of 200 liters

so $M_{TOT} = 200\times10^3 \times .1092 = 21844.6 \text{ gm}$

$M_{L10} = 19,660 \text{ g} \qquad M_g = 2184.4 \text{ gm}$

$$u_{INITIAL} = \frac{u_L M_L + u_g M_g}{M_L + M_g} = \frac{10.16(19660) + 23.94(2184.4)}{21844.6}$$

$$= 11.54 \text{ j/gm}$$

The heat load is 50.6 watts.

At $P = 1.6$ atm, $\rho = .1092$ gm/cm^3, $u = 12$ j/gm
(using P vs U diagram in NBS 111)

$$\Delta u = 12 - 11.54 = 0.46 \text{ j/gm}$$

$$\Delta U = (0.46)\,21844.6 = 10048 \text{ joule}$$

or $t = \Delta U/\dot{Q} \approx 200$ sec. (3.3 min)

AFTER INITIAL PRESSURIZATION

At this point we are at saturation with

$P = 1.6$ atm, $\rho_L = .1113$ $\rho_g = .02915$ and

$(u = 12\ j/gm.)$ $(u_L = 11.64$ $u_g = 23.42)$

$$-(\rho_g) M_L/\rho_L + -(\rho_g) M_g/\rho_g = -200{,}000(\rho_g)$$

$$M_L + M_g = 21{,}845$$

$$M_L(1 - \rho_g/\rho_L) = 21845 - 200{,}000(.02915)$$

$$M_L = \frac{16015}{1 - \rho_g/\rho_L} = 21{,}697 \text{ grams}$$

$$M_g = 21845 - 21697 = 147 \text{ grams}$$

So we are essentially full of saturated liquid at 1.6 K

SUBJECT

CALCULATE TIME CONSTANT FOR SYPHON

NAME

DATE

$$dQ_{IN} = \dot{Q}\,dt = 30.8\frac{x}{L}\,dt$$

$$dV_{OUT} = \frac{dQ}{\lambda \rho_g} = \frac{30.8\frac{x}{L}\,dt}{\lambda \rho_g}$$

$$-\frac{dx}{L} = \frac{dV_{OUT}}{160{,}000} = \frac{30.8\,x}{L\lambda\rho_g\,160{,}000}\,dt$$

$$-\frac{dx}{x} = \frac{30.8\,dt}{\lambda\rho_g(160{,}000)}$$

at $t=0,\ x=L$
$t=t\ \ x=x$

$$\int_L^x \frac{dx}{x} = -\frac{30.8}{\lambda\rho_g(160{,}000)}\int_0^t dt$$

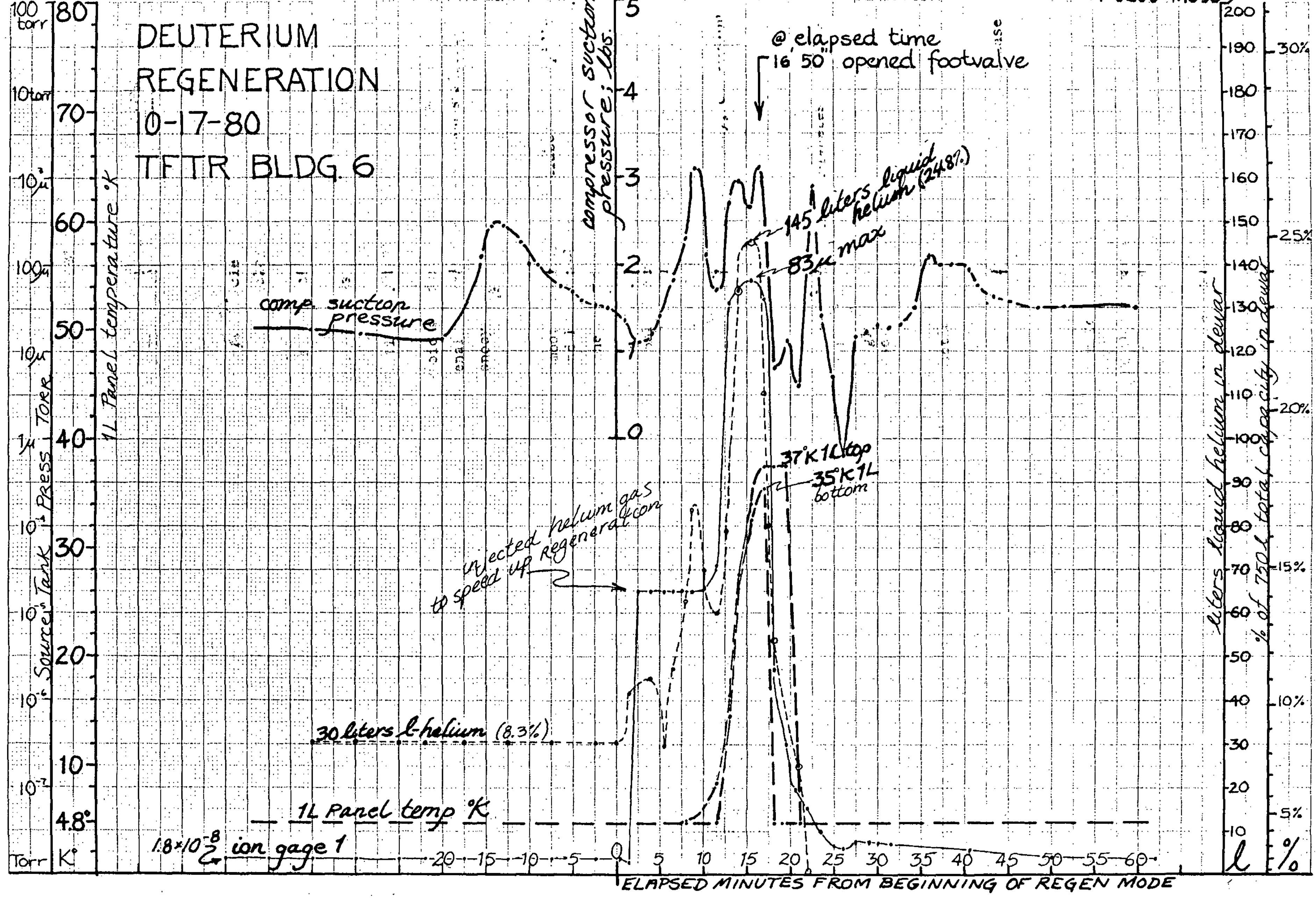
$$\ln\frac{x}{L} = \frac{-30.8}{\lambda\rho_g\,160(3)}\,t$$

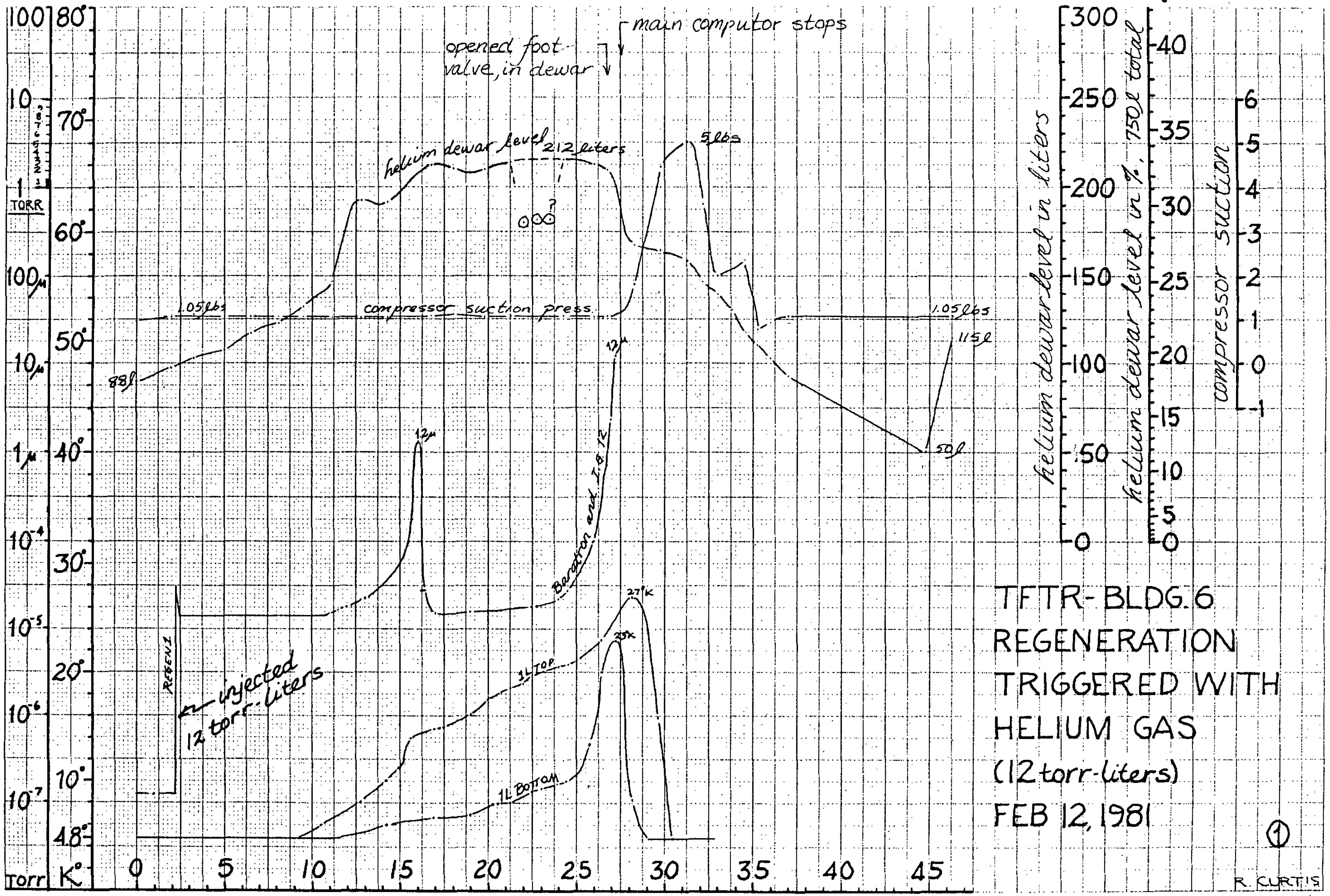
$$\frac{x}{L} = \exp\left[-\frac{30.8\,t}{\lambda\rho_g\,160(3)}\right]$$

$$\frac{j/s}{J/gm\ \cancel{\frac{gm}{cm^3}}\ \cancel{cm^3}} = s^{-1}$$ ✓

$$\tau = \frac{160(3)\,\lambda\,\rho_g}{30.8} = 2810 = 0.78\text{ hours}$$ ✓

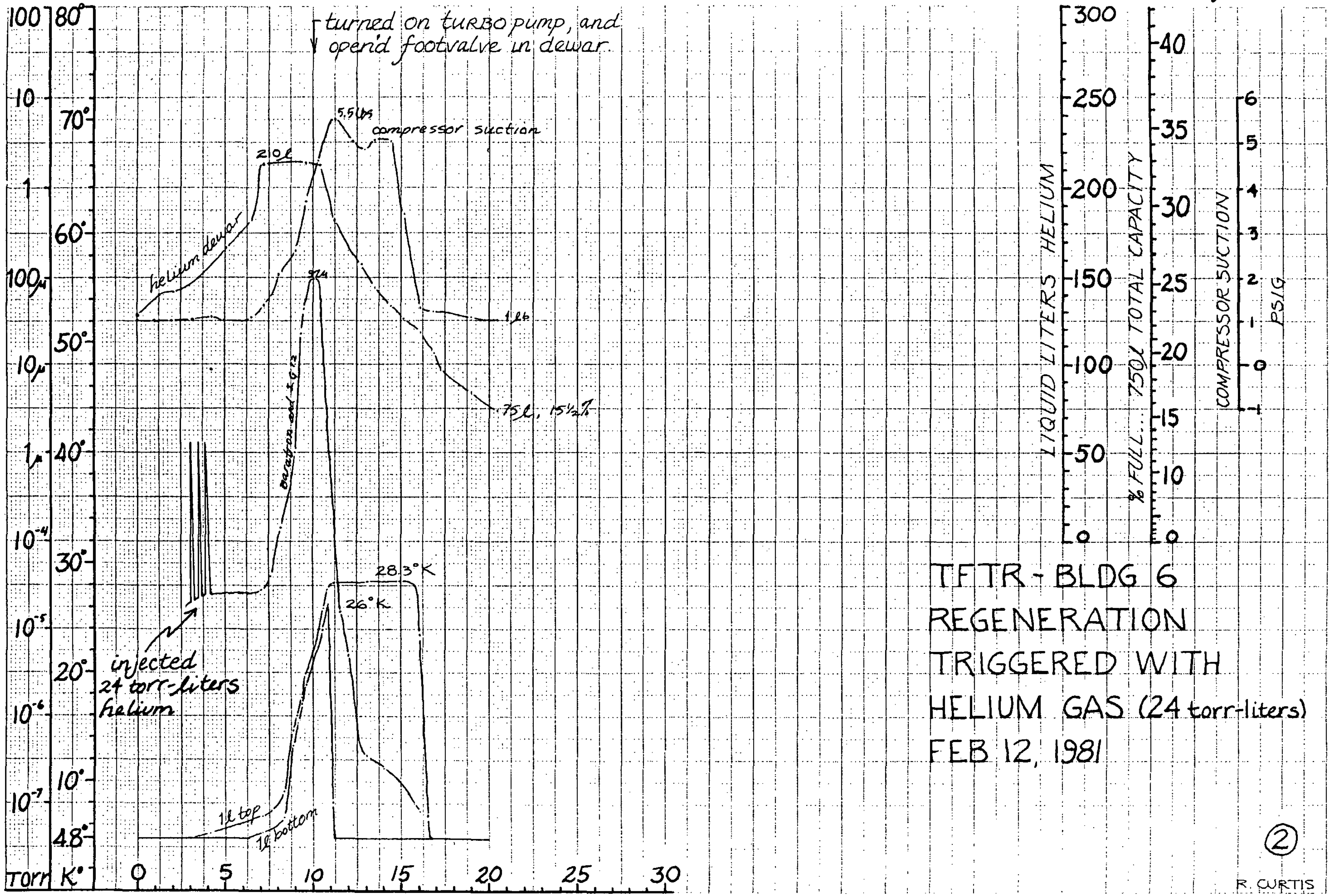
This is faster than the "boil out" method by a factor of $3.65/0.78 = \underline{4\,2/3}$. After $3\tau \approx 140$ minutes, only 5% of the liquid will be left.

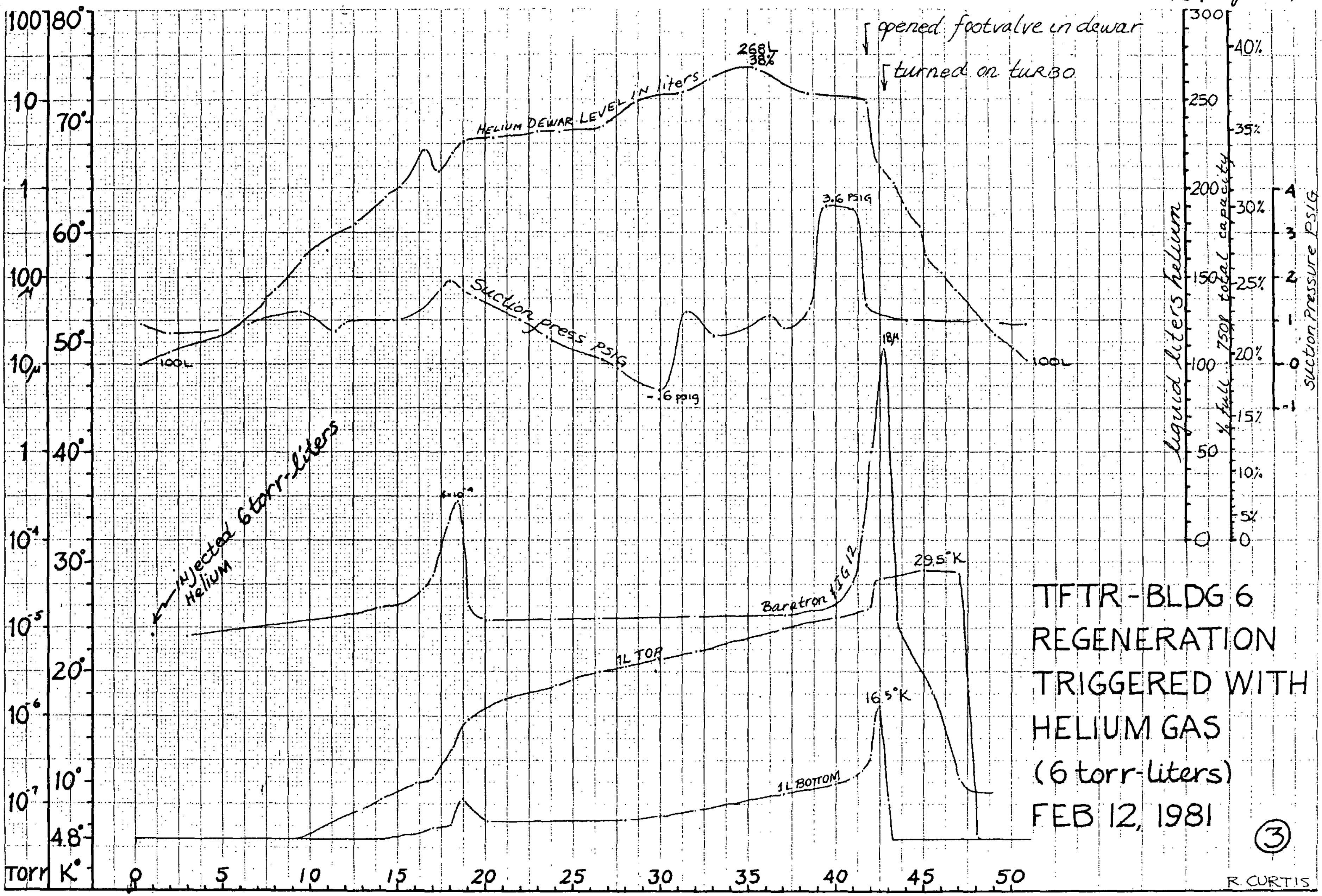

DEUTERIUM
REGENERATION
10-17-80
TFTR BLDG. 6
@ elapsed time
16' 50" opened footvalve
comp. suction pressure
145 liters liquid helium (24.8%)
83μ max
37°K 1L top
35°K 1L bottom
injected helium gas to speed up Regeneration
30 liters l-helium (8.3%)
1L Panel temp °K
1.8×10^-8 ion gage 1
Source's Tank Press. TORR
1L Panel temperature °K
compressor suction pressure; lbs.
liters liquid helium in dewar
% of 750 l total capacity in dewar
ELAPSED MINUTES FROM BEGINNING OF REGEN MODE
Torr
K°
l
%

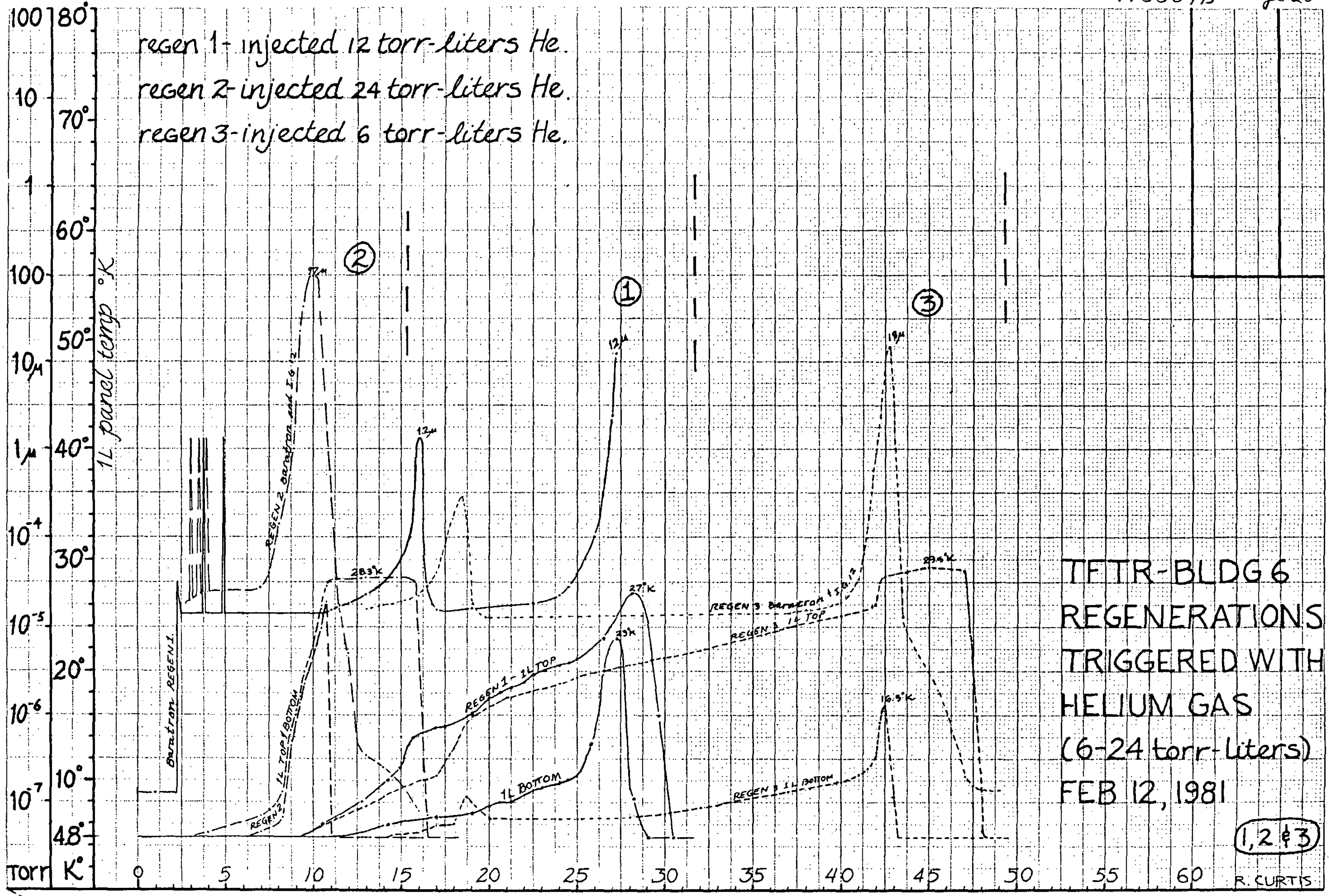


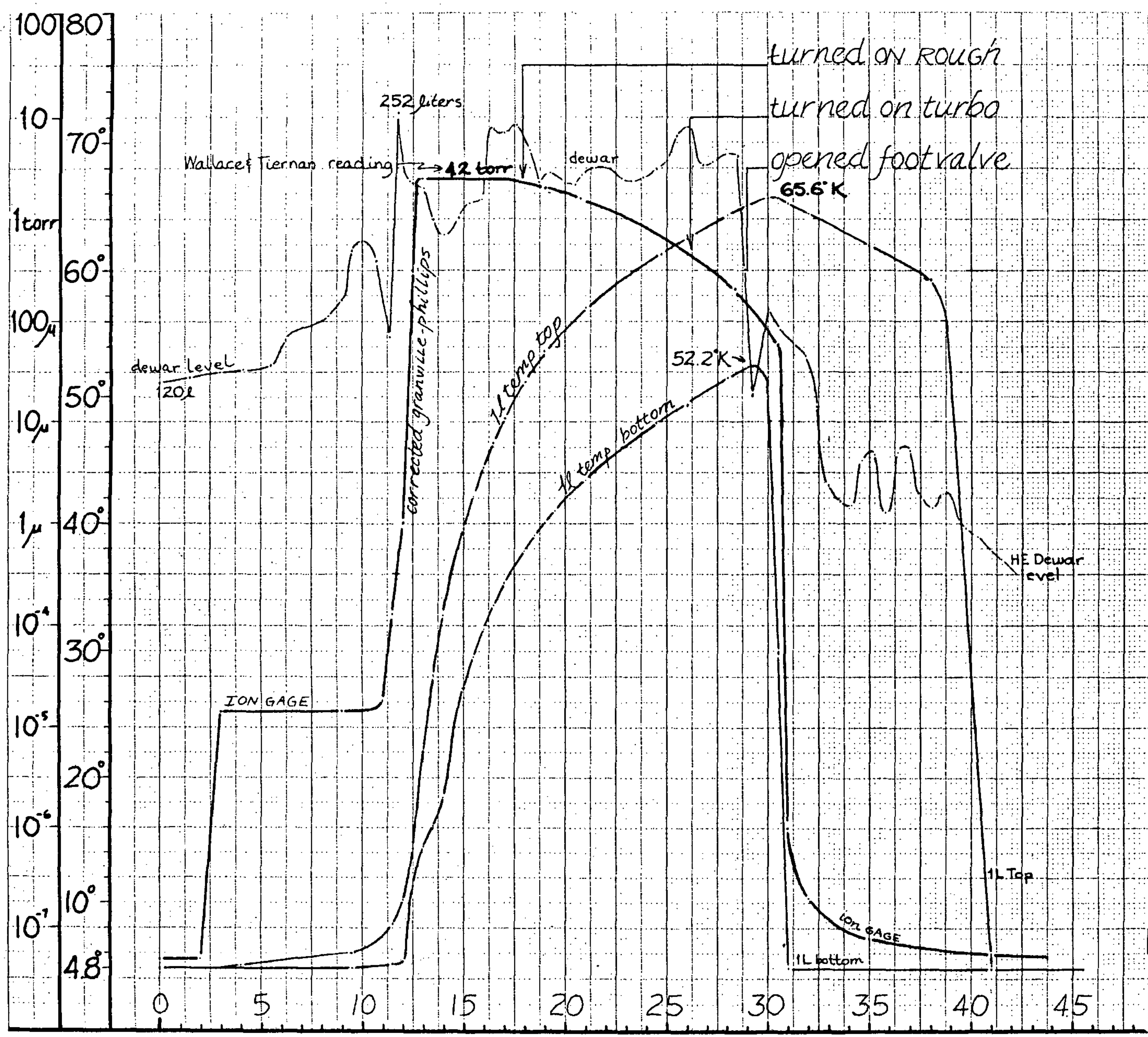
TFTR-BLDG. 6
REGENERATION
TRIGGERED WITH
HELIUM GAS
(12 torr-liters)
FEB 12, 1981

①


turned on TURBO pump, and opend footvalve in dewar
5.5 lbs
compressor suction
210 l
helium dewar
1 lb
75 l, 15½%
injected 24 torr-liters helium
28.3°K
26°K
1 l top
1 l bottom
Torr
K°
LIQUID LITERS HELIUM
% FULL... 750 l TOTAL CAPACITY
COMPRESSOR SUCTION PSIG
TFTR - BLDG 6
REGENERATION
TRIGGERED WITH
HELIUM GAS (24 torr-liters)
FEB 12, 1981
2
R. CURTIS


opened footvalve in dewar
turned on TURBO
268L
38%
HELIUM DEWAR LEVEL IN liters
100L
100L
3.6 PSIG
Suction press PSIG
-.6 psig
18μ
injected 6 torr-liters Helium
Baratron VIG 12
29.5°K
1L TOP
16.5°K
1L BOTTOM
liquid liters helium
% full 750l total capacity
suction pressure PSIG
Torr
K°
0
5
10
15
20
25
30
35
40
45
50
100
10
1
100μ
10μ
1
10^{-4}
10^{-5}
10^{-6}
10^{-7}
80°
70°
60°
50°
40°
30°
20°
10°
4.8°
300
250
200
150
100
50
0
40%
35%
30%
25%
20%
15%
10%
5%
0
4
3
2
1
0
-1
TFTR - BLDG 6
REGENERATION
TRIGGERED WITH
HELIUM GAS
(6 torr-liters)
FEB 12, 1981
3
R. CURTIS


regen 1- injected 12 torr-liters He.
regen 2- injected 24 torr-liters He.
regen 3- injected 6 torr-liters He.
TFTR-BLDG 6
REGENERATIONS
TRIGGERED WITH
HELIUM GAS
(6-24 torr-Liters)
FEB 12, 1981
1,2 & 3
R. CURTIS
1L panel temp °K
Torr
K°
100
10
1
100
10μ
1μ
10^{-4}
10^{-5}
10^{-6}
10^{-7}
80°
70°
60°
50°
40°
30°
20°
10°
4.8°
0
5
10
15
20
25
30
35
40
45
50
55
60
②
①
③
Baratron REGEN 1
REGEN 2 Baratron and I.G. 12
1L TOP & BOTTOM
REGEN 2
28.3°K
12μ
27°K
23°K
REGEN 1 - 1L TOP
1L BOTTOM
REGEN 3 Baratron & I.G. 12
REGEN 3 1L TOP
REGEN 3 1L BOTTOM
16.5°K
29.4°K



TFTR-BLDG. 6
ADMINISTRATIVE
LIMIT-REGENERATN
OF DEUTERIUM...
(13 torr @ 0°C)...USING
12 torr-liters of Helium
FEB 26, 1981
JOST FEIST, G. NEWELL, R. CURTIS Dr.

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