CAA
58392
08-059-00701
107

LEYDEN L&C

1980 THRU 1989

FILE B

PSC 039644

BR HOLLOMBAUGH
RESERVOIR ENG
11/1/88

# 1988 LEYDEN L&U

APPARENTLY NO L&U HAS BEEN ACOUNTED FOR SINCE 1986. THE LAST L&U ACCOUNTED FOR WAS THRU JULY, 1986 & WAS REPORTED PER A 12/3/86 MEMO.

THE 12/1/87 MEMO STATES THAT LEYDEN L&U IS UNDER FURTHER REVIEW & IF L&U IS REVEALED, IT WILL BE REPORTED IN 1988.

→ THE L&U REPORTED FOR 1988 (GIVEN TO BILL VOING ON 10/31/88) WAS 22,000 MCF. THIS L&U IS BASED ON A TIME PERIOD FROM JAN 87 TO JAN 88. THIS TIME PERIOD WAS CHOSEN BECAUSE OF PRESSURE DATA: THE CAVERN WAS SHUT IN FOR MANY DAYS & WAS FAIRLY CLOSE TO A STABILIZED PRESS. THE CAVERN PRESSURE WAS EXTRAPOLATED TO 150 DAYS FROM KNOWN PRESS DATA (FIG 1 & FIG 2).

METHOD 1: DETERMINED (1) CAV PRESS & (2) MEASUREMENT VOLUME FOR BOTH PERIODS IN TIME. USED PRESSURE FACTOR TO COMPARE VOLUMES, THIS GAVE L&U.

FIG 1 & 2

ALSO LOOKED AT SEPT 1988 CONDITIONS. PER SAME METHOD, GOT THE FOLLOWING.

| | | |
|---|---|---|
| L&U | JAN 87 TO SEPT 88 | 59450 MCF |
| L&U | JAN 88 TO SEPT 88 | 84152 MCF |

THIS WOULD INDICATE THAT THERE IS MORE L&U FROM JAN 88 TO SEPT 88 THAN THERE IS FROM JAN 87 TO SEPT 88. THIS CAN NOT BE! THEREFORE THE METHOD IS SUSPECT. NOTE THAT PRESS WAS NOT VERY STABILIZED IN SEPT 88.



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METHOD 2: ALSO ATTEMPTED TO ESTIMATE LEU BY FOLLOWING METHOD

1. GET $P_{STAB}/Z$ BEFORE DRAWDOWN (state 1)
2. GET BOOK (MEASURED) WITHDRAWN VOLUME = $V_W$
3. GET $P_{STAB}/Z$ AFTER DRAWDOWN (state 2)
4. CALC $V_W/\Delta P/Z$
5. CALC $V_{TS}$ FROM $P_2$ & STEP 4
6. COMPARE $V_{TS}$ FROM STEP 5 TO BOOK VOLUME TOT STOR
7. DIFFERENCE IS LEU

FIGURE 3

PROBLEMS WITH THIS METHOD. DRAW CAVERN DOWN REAL LOW & IT IS DIFFICULT TO ESTIMATE A GOOD STABILIZED STATE 2 PCAV. LEU ESTIMATE PER THIS METHOD IS SOMEWHERE BETWEEN 135,900 MCF & 631,503 MCF. THIS LEU REPRESENTS ALL LEU WHICH HAS NOT BEEN PREVIOUSLY ACCOUNTED FOR, IT DOES NOT REPRESENT THE LEU BETWEEN TWO POINTS IN TIME AS DID METHOD 1.

I WOULD ESTIMATE THAT THE CURRENT BOOK VOLUME (TOTAL IN STORAGE PER MGAS REPORT) IS ABOUT 500,000 MCF HIGHER THAN IT SHOULD BE. THERE HAVE BEEN MANY YEARS WHICH NO LEU HAS BEEN WRITTEN OFF.

NEED TO INVESTIGATE LEYDIGI LEU MUCH FURTHER!

SUMMARY $C = VOL/PSI$

REPORTED 1988 LEU 22,000 MCF

$C_{STAB}$ ESTIMATED BETWEEN 10.4 & 12.3 MMCF/PSIA/Z (WITHDRAWAL)

$C_{DYNAMIC}$ = 8.6 MMCF/PSIG FROM 2/15/88 TO 4/2/88

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$C_{DYNAMIC}$ STATE 1 2/15/88 $P_{SURFACE}$ = 243.6 PSIG

WITHDRAWAL = 1624 955 MCF

STATE 2 4/2/88 $P_{SURFACE}$ = 55 PSIG

$\Delta P$ = 188.6 PSIG

$C_{DYNAMIC}$ = 1624.955 MMCF / 188.6 PSIG = 8.6 MMCF/PSIG

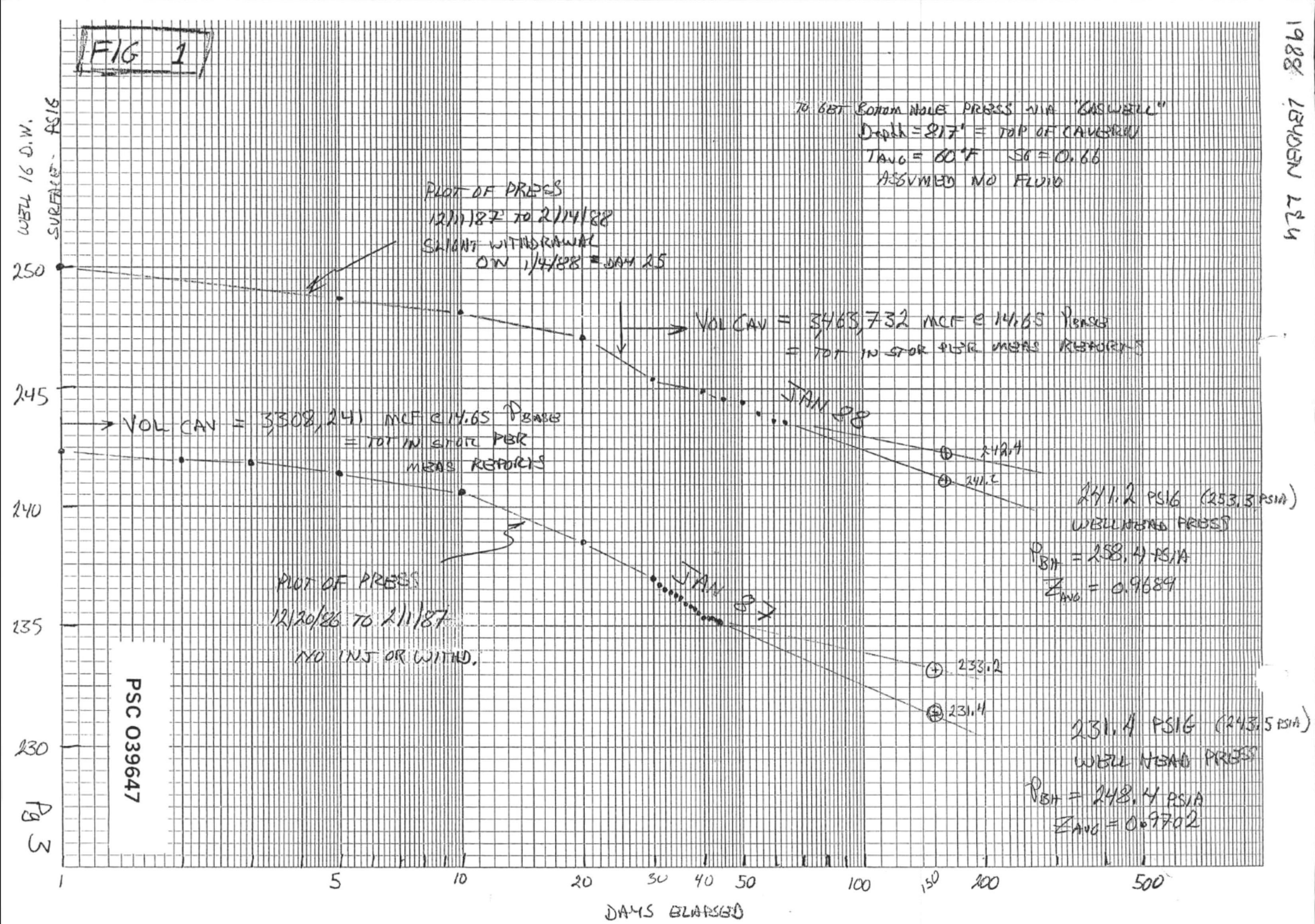
FIG 1
WELL 16 D.W. SURFACE - PSIG
250
245
240
235
230
1
5
10
20
30
40
50
100
150
200
500
DAYS ELAPSED
TO GET BOTTOM HOLE PRESS W/A "GASWELL"
Depth = 817' = TOP OF CAVERN
TAVG = 60°F SG = 0.66
ASSUMED NO FLUID
PLOT OF PRESS
12/11/87 TO 2/14/88
SLIGHT WITHDRAWAL
ON 1/4/88 = DAY 25
VOL CAV = 3463,732 MCF @ 14.65 PBASE
= TOT IN STOR PER MEAS REPORTS
JAN 88
242.4
241.2
241.2 PSIG (253.3 PSIA)
WELLHEAD PRESS
PBH = 258.4 PSIA
ZAVG = 0.9689
VOL CAV = 3308,241 MCF @ 14.65 PBASE
= TOT IN STOR PER
MEAS REPORTS
PLOT OF PRESS
12/20/86 TO 2/1/87
NO INJ OR WITHD.
JAN 87
233.2
231.4
231.4 PSIG (243.5 PSIA)
WELL HEAD PRESS
PBH = 248.4 PSIA
ZAVG = 0.9702
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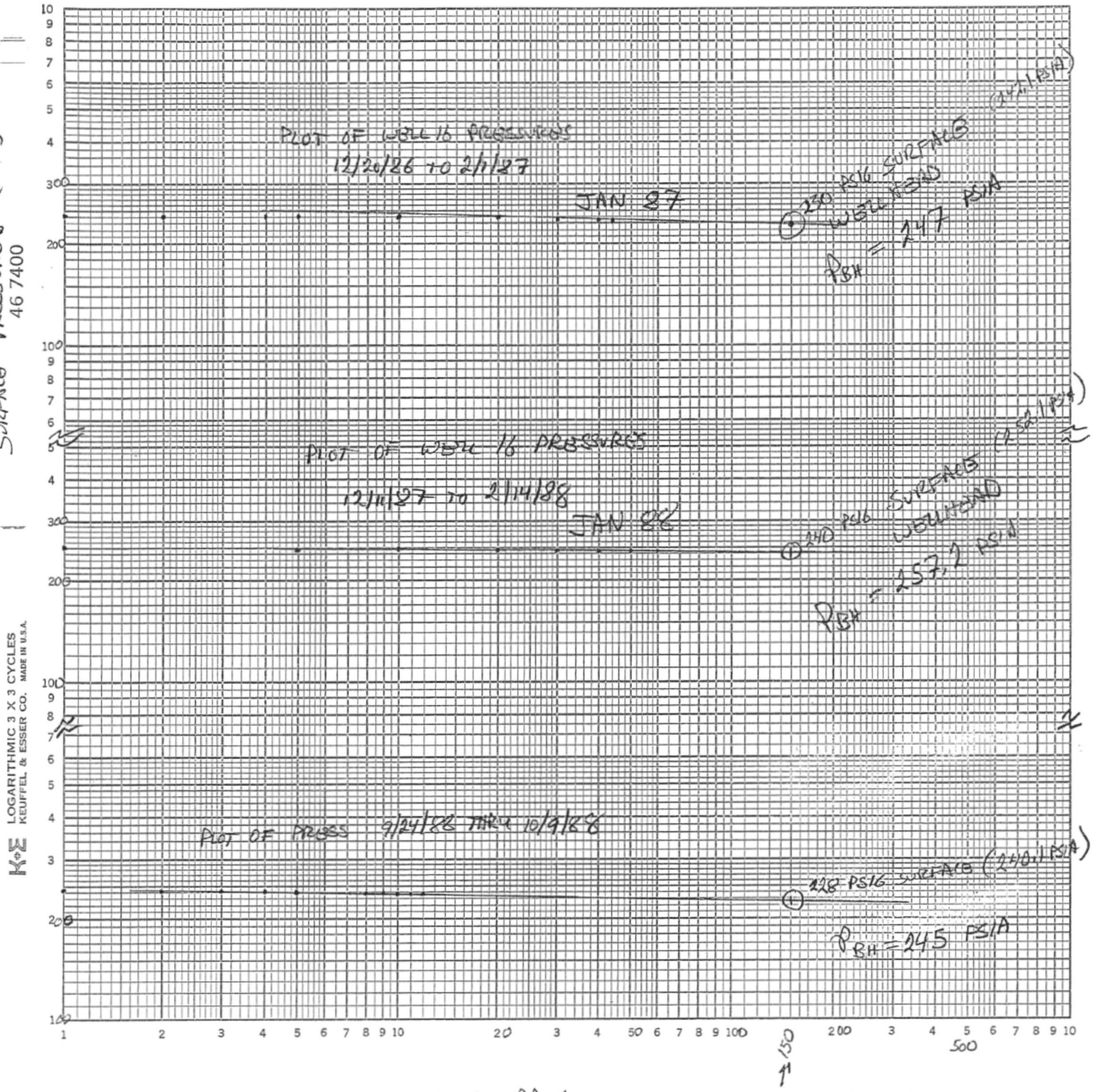
Pg 3
1988 LOWER 254

FIG 2

1988 LEYDEN LEY




ELAPSED DAYS

EXTRAPOLATE TO 150 DAYS

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1988 LEYDEN LEU

JAN 87

$P_{CAV.} = 248.4$ PSIA

$Z_{AVG} = 0.9702$

$VOL = 3\,308.241$ MCF

$\frac{3\,308.241 \text{ MMCF}}{248.4 \text{ PSIA}} = 13.32 \frac{\text{MMCF}}{\text{PSIA}}$

JAN 88

$P_{CAV} = 258.4$ PSIA

$Z_{AVG} = 0.9689$

$VOL = 3\,463\,732$ MCF

$\frac{3\,463.732 \text{ MMCF}}{258.4 \text{ PSIA}} = 13.4 \frac{\text{MMCF}}{\text{PSIA}}$

IGNORE Z FOR THESE TWO PRESSURES WHEN COMPARING TO EACH OTHER. EFFECTS OF Z ARE NEGLIGIBLE WHEN COMPARED TO EXTRAPOLATION ACCURACY WHEN GETTING STABILIZED CAV PRESS.

258.4 PSIA JAN 88
− 248.4 PSIA JAN 87
10 PSIA DIFFERENCE × 13.32 MMCF/PSIA = 133 200 MCF EXPECTED DIFF

3463 732 MCF JAN 88
− 3308 241 MCF JAN 87
155 491 MCF ACTUAL DIFFERENCE
− 133 200 MCF EXPECTED DIFFERENCE
22 291 MCF LEU

OR CONVERT JAN 88 VOL TO A VOL WHICH WOULD OCCUR IF IT WERE AT JAN 87 PRESSURE:

$V = 3463732 \frac{248.4}{258.4} = 3329\,687$ MCF
− 3308.241 MCF VOL JAN 87 PER MEAS REPORTS
21 446 MCF LEU

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SEPT 1988

| DATE | Pow well 16 SRF | DAY |
|---|---|---|
| 9/24 | QUIT INJECTING | |
| 25 | | |
| 26 | 242.0 | 1 |
| 27 | 241.5 | 2 |
| 28 | 241.5 | 3 |
| 29 | 240.6 | 4 |
| 30 | 240.1 | 5 |
| 10/1 | – | 6 |
| 10/2 | – | 7 |
| 3 | 239.0 | 8 |
| 4 | 238.7 | 9 |
| 5 | 0238.2 | 10 |
| 6 | 238.1 | 11 |
| 7 | 237.7 | 12 |
| 8 | – | 13 |
| 9 | – | 14 |

EXTRAPOLATED TO 150 DAYS PER FIG 2 &

$P_{BH}$ = 245 PSIA

NOTE THAT THIS PRESSURE IS PROBABLY NOT VERY STABILIZED. THAT QUIT INJECTING ON THE 23 OF SEPT & I ONLY HAD 16 DAYS OF PRESS DATA TO PLOT.

$P_{CAV}$ = 245 PSIA

VOL = 3,204,323 MCF PER GAS MEAS REPORT

SEPT 88 COMPARE TO JAN 87 = CONVERT TO VOL @ 248.4 PSIA (JAN 87 PRESS)

$$3\,204\,323 \frac{248.4}{245} = 3\,248\,791 \text{ MCF EXPECTED @ JAN 87 PRESS}$$

3 308 241 MCF PER MEAS REPORT JAN 87

59 450 MCF L&U SINCE JAN 87

SEPT 88 COMPARE TO JAN 88 – CONVERT TO VOL @ 258.4 PSIA (JAN 88 PRESS)

$$3204\,323 \frac{258.4}{245} = 3\,379\,580 \text{ MCF EXPECTED @ JAN 88 PRESS}$$

3 463 732 MCF PER MEAS REPORT JAN 88

84 152 MCF L&U SINCE JAN 88

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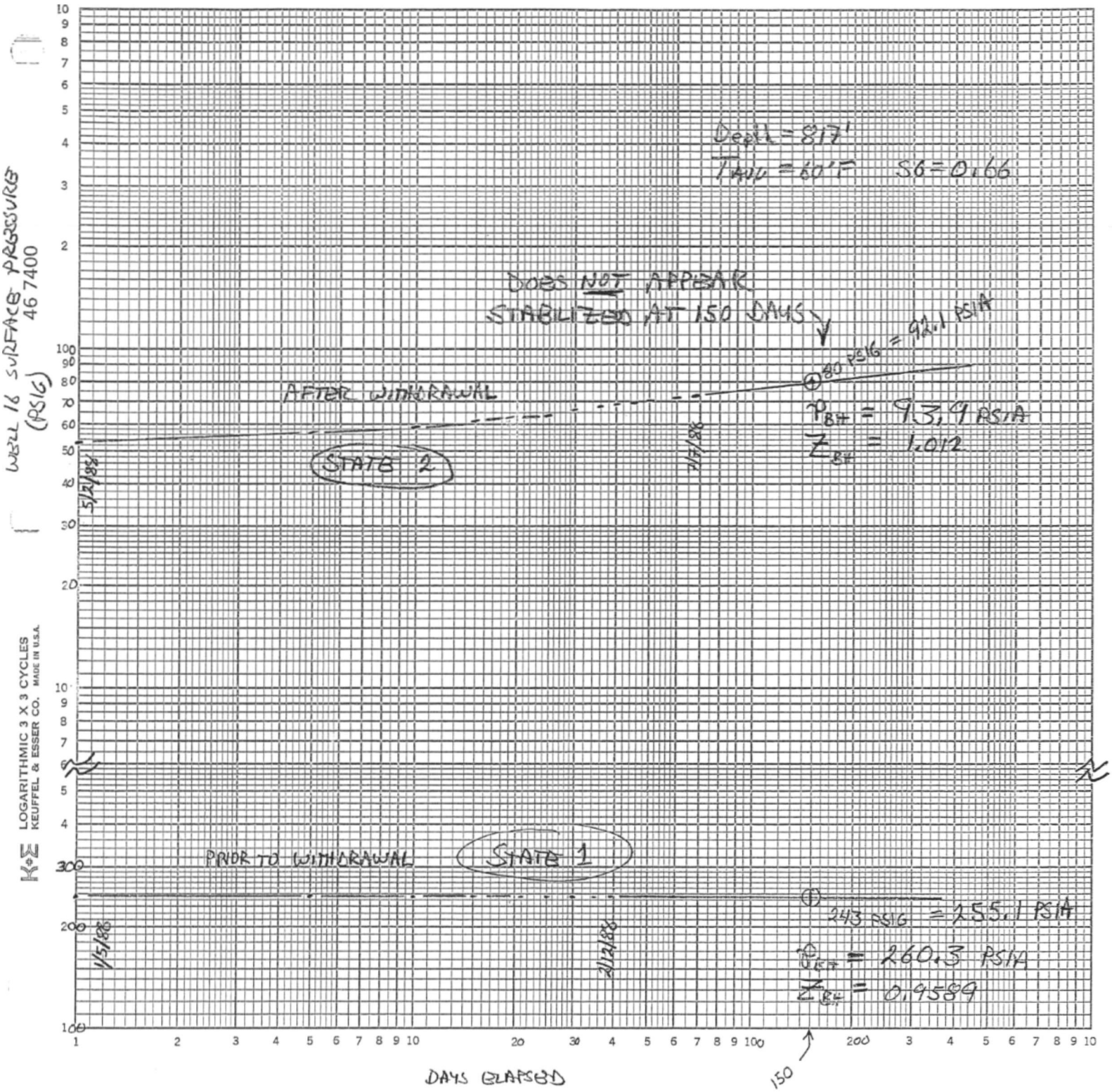
FIGURE 3

1988 LEMBEN LEU

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Pg 6

PER FIGURE 3

STATE 1 $P/Z = \frac{260.3}{0.9589} = 271.46$ PSIA

STATE 2 $P/Z = \frac{93.9}{1.012} = 92.79$ PSIA (120)

151.46

$\Delta P = 178.67$ PSIA

VOLUME WITHDRAWN FROM STATE 1 TO STATE 2 = 1,856,608 MCF
(PER GAS MEAS. REPORTS)

12.26

INDICATED PRESENT CAVERN CAPACITY = $\frac{1856608 \text{ MCF}}{178.67 \text{ PSIA}}$ = 10,391 MCF/PSIA
= 10.39 MMCF/PSIA

STATUS ON 7/7/88 – EXTRAPOLATED (ESTIMATED) $P_{CAV}$ = 93.9 PSIA (120)

CALCULATED GAS IN PLACE = 10.39 MMCF/PSIA X 93.9 PSIA = 975,621 MCF
BOOK VOLUME – TOTAL IN STORAGE – PER MEAS REPORT = 1607124 MCF
INDICATED LEU = 631,503 MCF

THIS SEEMS QUITE HIGH. THE "STATE 2" EXTRAPOLATED CAVERN PRESSURE DOES NOT LOOK STABILIZED. THE CAVERN WAS LOWERED TO ≈ 45 # DURING DRAWDOWN & PROBABLY TAKES A LONG TIME TO STABILIZE.

RE-FIGURE LEU & ASSUME THE ACTUAL STATE 2 STABILIZED CAVERN PRESSURE TO BE 120 PSIA (ESTIMATED) INSTEAD OF 92.79 PSIA ∴ $\Delta P$ = 151.46 PSIA,
& $V/\Delta P$ = 12.26 MMCF/PSIA & $P_2 \times V/\Delta P$ = 120 x 12.26 MMCF/PSIA = 1,471,200 MCF
BOOK VOL. 1607124 MCF
INDICATED LEU = 135,900 MCF

NOT SURE WHAT THE TRUE STATE 2 STAB CAV PRESS IS.



Bud Hilbert

LEBANON DEC 87

| DATE (1987) | INJECT (MCF) | WITHDRAWAL (MCF) | Pwell 16 SURF PSIG | VOL CAVERN |
|---|---|---|---|---|
| DEC 1 | | | 246.1 | |
| 2 | | | 246.0 | |
| 3 | | | 245.8 | |
| 4 | 757 | | 245.7 | |
| 5 | 135 | | | |
| 6 | | | | |
| 7 | | | 245.7 | |
| 8 | | | 245.3 | |
| 9 | 19,027 | | 245.3 | |
| 10 | 19,980 | | 249.8 | |
| 11 | | | 250.0 | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | 248.7 | |
| 15 | | | 248.7 | |
| 16 | | | 248.5 | |
| 17 | | | 248.5 | |
| 18 | | | 248.4 | |
| 19 | | | | |
| 20 | | | | |
| 21 | | | 248.1 | |
| 22 | | | 247.8 | |
| 23 | | | 247.8 | |
| 24 | | | 247.5 | |
| 25 | | | | |
| 26 | | | | |
| 27 | | | | |
| 28 | | | | |
| 29 | | | 247.1 | |
| 30 | | | 247.1 | |
| 31 | | | 247.1 | |

PSC 039653

# L 18BN JAN 1988

| | DATE (1988) | INJECT MCF | WITHDRAWAL MCF | VOL CAVERN | $P_{well}$ 16 PSIG | $P_{well}$ 16 PSIA BOTT HOLE |
|---|---|---|---|---|---|---|
| F | 1/1/88 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| M | 4 | | 7644 | | 246.1 | |
| | 5 | | | 1 | 245.6 | |
| | 6 | | | | 245.5 | |
| | 7 | | | | 245.6 | |
| F | 8 | | | | 245.6 | |
| | 9 | | | 5 | 245.4 | |
| | 10 | | | | 245.4 | |
| M | 11 | | | | 245.7 | |
| | 12 | | | | 245.5 | |
| | 13 | | | | 245.4 | |
| | 14 | | | 10 | 245.0 | |
| F | 15 | | | → | 245.1 | 262.46 (250.32 PSIG) |
| | 16 | | | | 245.1 | |
| | 17 | | | | 245.1 | |
| M | 18 | | | | 245.1 | |
| | 19 | | | 15 | 244.9 | |
| | 20 | | | | 244.9 | |
| | 21 | | | | 244.8 | |
| F | 22 | | | → | 244.6 | 256.74 PSIG 261.95 |
| | 23 | | | | | |
| | 24 | | | | | |
| M | 25 | | | 21 | 244.5 | |
| | 26 | | | | 244.3 | |
| | 27 | | | | 244.3 | |
| | 28 | | | → | 244.3 | 256.44 PSIG 261.64 |
| F | 29 | | | 25 | 244.4 | |
| | 30 | | | | | |
| | 31 | | | | | |

PSC 039654

FOR WELL 16, TO GET BOTTOM HOLE PRESS, USED GASWELL COMPUTER PROG.
DEPTH = 817' = TOP OF CAVERN
$T_{AVG}$ = 60°F, SG = 0.66, ASSUMED NO FLUID.

# LEBON FEB 1988

| | DATE | INJECT | WITHDRAWAL MCF 14.65 PSIA | VOL CAVERN | PRESS 16 PSIG | BOTTOM HOLE PSIA |
|---|---|---|---|---|---|---|
| M | 2/1/88 | | | | 244.4 | |
| | 2 | | | | 244.1 | |
| | 3 | | | | 244.0 30 | |
| | 4 | | | | 244.0 | |
| F | 5 | | | | → 243.9 255.04 PSIA | 261.23 |
| | 6 | | | | – | |
| | 7 | | | | – | |
| M | 8 | | | | 243.7 35 | |
| | 9 | | | | 243.8 36 | |
| | 10 | | | | 243.7 37 | |
| | 11 | | | | 243.7 38 | |
| F | 12 | | — | START PLOT HERE WEEK = 1 → | 243.6 255.74 | 260.93 39 |
| | 13 | | | | – | |
| | 14 | | | | – | |
| M | 15 | | 404 | | – | |
| | 16 | | 53 890 | 254,320 | 242.0 | |
| | 17 | | 68 176 | | 230.3 | |
| | 18 | | 63 612 | TOTAL IN STORAGE = X - 254,320 = 3,209,412 | 219.8 | |
| F | 19 | | 68 238 | | 2 → 210.1 222.24 | 226.73 |
| | 20 | | 61 474 | | – | |
| | 21 | | 54 764 | | – | |
| M | 22 | | 38 421 | 270,989 | 189.0 | |
| | 23 | | 25 849 | | – | |
| | 24 | | 27 533 | | 185.7 | |
| | 25 | | 29 253 | | 183.4 | |
| F | 26 | | 33 695 | | 3 → 180.3 192.44 | 196.31 |
| | 27 | | 28 058 | | – | |
| | 28 | | 30 303 | | – | |
| M | 29 | | 29 192 | | 172.0 | |
| | | FEB SUM | 612,862 | | | |

PER MEASUREMENT REPORT
CUSHION GAS 794,000 MCF (14.65)
WORKING GAS 2,669,732 MCF
X = TOTAL IN STORAGE = 3,463,732 MCF

PSC 039655

LB40: MAR 1988

| DATE | WITHDRAWAL MCF 14.65 | VOL CAV | P well 16 SURF (PSIG) | BH (PSIA) | |
|---|---|---|---|---|---|
| 3/1/88 | 27,466 | | 168.9 | | |
| 2 | 29,196 | 210,591 | 165.4 | | |
| 3 | 32,521 | | 162.9 | | |
| 4 | 33,855 | | 159.1 | 174.67 | Z=0.979 |
| 5 | 30,626 | | — 171.24 PSIA | | |
| 6 | 30,844 | | — | | |
| 7 | 27,212 | | 149.2 | | |
| 8 | 22,838 | 198,505 | 146.2 | | |
| 9 | 28,936 | | 144.2 | | |
| 10 | 28,910 | | 140.4 | | |
| 11 | 29,339 | | 137.7 | 152.84 | 0.982 |
| 12 | 32,827 | | — 149.84 | | |
| 13 | 28,874 | | — | | |
| 14 | 44,159 | | 126.7 | | |
| 15 | 31,330 | 213,095 | 120.8 | | |
| 16 | 26,980 | | 118.2 | | |
| 17 | 20,858 | | 116.0 | | |
| 18 | 28,287 | | 114.5 | 129.17 | |
| 19 | 29,295 | | — 126.64 | | |
| 20 | 27,385 | | — | | |
| 21 | 24,355 | 222,631 | 104.9 | | |
| 22 | 32,233 | | 102.6 | | |
| 23 | 38,330 | | 97.1 | | |
| 24 | 35,989 | | 93.1 | | |
| 25 | 35,044 | | 88.1 | 102.23 | 0.988 = Z |
| 26 | 25,198 | | — 100.24 | | |
| 27 | 19,381 | | — | | |
| 28 | 36,019 | | 80.7 | | |
| 29 | 46,857 | | 74.3 | | |
| 30 | 47,943 | | 66.3 | | |
| 31 | 34,772 | | 59.3 | | |
| MAR SUM | 967,437 | | | | |

PSC 039656

LEYDI 1 APRIL 1988

≈ 9100 ATM PRESS

| | DATE | WITHDRAWAL MCF 14.65 | VOL CAV | WELL 16 WELLHEAD PSIG | WELL 16 BOTTOM HOLE PSIA | WELL 12 WELLHEAD PSIG | WELL 12 BOTT HOLE PSIA |
|---|---|---|---|---|---|---|---|
| | 4/1/88 FRI | 30,146 | 240,314 | → 8 53 ?* 65.14 PSIA | 66.43 | | |
| | 2 SAT | 14,510 | | 55.6 | | | |
| | 3 SUN | | | 59.9 | | | |
| M | 4 | | | 63.3 | | | |
| | 5 | | | 65.7 | | | |
| | 6 | | | 67.6 | | | |
| | 7 | | | 69.3 | | | |
| F | 8 | | | → 9 70.7 82.84 | 84.48 | | |
| | 9 | | | – | | | |
| | 10 | | | – | | | |
| M | 11 | 8,466 | | 73.5 | | | |
| | 12 | 4,192 | 499 | 72.3 | | | |
| | 13 | 2,857 | 371 | 72.4 | | | |
| | 14 | 10,145 | | 73.2 | | | |
| F | 15 | 11,839 | | → 10 71.7 83.84 | 85.50 | | |
| | 16 | | | – | | | |
| | 17 | | | – | | | |
| M | 18 | 25,615 | | 68.2 | | | |
| | 19 | 20,185 | 101,014 | 65.1 | | | |
| | 20 | 19,159 | | 62.5 | | | |
| | 21 | 14,755 | | 60.0 | | 120 | |
| F | 22 | 21,306 | | → 11 57.8 69.94 | 71.32 | 117 129.14 PSIA | 132.62 |
| | 23 | | | – | | 115 | |
| | 24 | | | – | | 117 | |
| M | 25 | 20,597 | | 58.5 | | 116 | |
| | 26 | 21,325 | 93,140 | 54.7 | | 115 | |
| | 27 | 20,927 | | 51.4 | | 115 | |
| | 28 | 20,299 | | 48.8 | | 113 | |
| F | 29 | 9,992 | TOTAL IN STORAGE = 1,607,124 MCF | → 12 46.5 58.64 | 59.80 | 112 124.14 | 127.48 |
| | 30 | | | – | | | |

APR TOT 276,309

* GUESS FROM CHART, ETC

FOR WELL 12, TO GET BOTTOM HOLE PRESS, USED "GASWELL" W/ DEPTH = 1100, TEMP = 60°F, SG = 0.66 ASSUMED NO FLUID.

PSC 039657

LEADS MAY 1988

| | DATE | WITHDRAWN MCF 14.65 | VOL CAV. | P well 16 wellhead PSIG | | P well 16 Bottom Hole | P well 12 WELLHEAD PSIG | | P well 12 BOTTOM PSIA |
|---|---|---|---|---|---|---|---|---|---|
| | 5/1/88 | No INJ OR WITHDRAWAL | | – | | | | | |
| M | 2 | | 1 | 52.7 | | | 110 | | |
| | 3 | | | 53.8 | | | 111 | | |
| | 4 | | | 54.7 | | | 113 | | |
| | 5 | | | 55.6 | | | 114 | | |
| F | 6 | | 5 | 13 → 56.6 | 68.74 PSIA | 70.10 | 115 | 127.14 | 130.57 |
| | 7 | | | – | | | 115 | | |
| | 8 | | | – | | | 115 | | |
| M | 9 | | | 58.1 | | | 115 | | |
| | 10 | | | 58.5 | | | 116 | | |
| | 11 | | 10 | 59.0 | | | 116 | | |
| | 12 | | | 59.6 | | | 116 | | |
| F | 13 | | | 14 → 60.0 | 72.14 | 73.57 | 118 | 130.14 | ~~134.67~~ Guess e 133 |
| | 14 | | | – | | | 118 | | |
| | 15 | | | – | | | 118 | | 133.65 |
| M | 16 | | 15 | 61.3 | | | 118 | | |
| | 17 | | | 61.7 | | | 119 | | |
| | 18 | | | 62.1 | | | 118 | | |
| | 19 | | | 62.5 | | | 117 | | |
| F | 20 | | 19 | 15 → 62.8 | 74.94 | 76.42 | 116 | 128.14 | 131.59 |
| | 21 | | | – | | | 118 | | |
| | 22 | | | – | | | 119 | | |
| M | 23 | | | 63.7 | | | 119 | | |
| | 24 | | | – | | | 120 | | |
| | 25 | | | 64.3 | | | 120 | | |
| | 26 | | 25 | 64.7 | | | 120 | | |
| F | 27 | | | 16 → 65.0 | 77.14 | 78.67 | 120 | 132.14 | 135.70 |
| | 28 | | | – | | | 121 | | |
| | 29 | | | – | | | 121 | | |
| M | 30 | | | – | | | 121 | | |
| | 31 | TOT IN STORAGE = 1607.124 | 30 | 66.3 | | | 121 | | |

PSC 039658

LEAGUE JUNE 1988

THERE WAS NO INJECT OR WITHDRAWAL IN JUNE

| | DATE | Vol Cavern | | P well 16 wellhead PSIG | | P well 16 Bottom Hole | P well 12 wellhead PSIG | | P well 12 Bottom PSIA |
|---|---|---|---|---|---|---|---|---|---|
| W | 6/1/88 | | | 66.4 | | | 121 | | |
| T | 2 | | | 66.6 | | | 121 | | |
| F | 3 | | 17 → | 66.8 | 78.94 PSIA | 80.50 | 122 | 134.14 | 137.76 |
| | 4 | | | — | | | 122 | | |
| | 5 | | | — | | | 122 | | |
| M | 6 | 36 | | 67.7 | | | 123 | | |
| | 7 | | | 67.7 | | | 124 | | |
| | 8 | | | 68.1 | | | 124 | | |
| | 9 | | | 68.2 | | | 124 | | |
| F | 10 | 40 | 18 → | 68.5 | 80.64 | 82.24 | 124 | 136.14 | 139.81 |
| | 11 | | | — | | | 125 | | |
| | 12 | | | — | | | 124 | | |
| M | 13 | | | 69.2 | | | 123 | | |
| | 14 | | | 69.3 | | | 124 | | |
| | 15 | 45 | | 69.6 | | | 124 | | |
| | 16 | | | 69.8 | | | 125 | | |
| F | 17 | | 19 → | 70.0 | 82.14 | 83.77 | 125 | 137.14 | 140.84 |
| | 18 | | | — | | | 125 | | |
| | 19 | | | — | | | 125 | | |
| M | 20 | 50 | | 70.5 | | | 125 | | |
| | 21 | | | 70.7 | | | 126 | | |
| | 22 | | | 70.9 | | | 126 | | |
| | 23 | | | 71.1 | | | 126 | | |
| F | 24 | | 20 → | 71.2 | 83.34 | 85.00 Z=0.94 | 126 | 138.14 | 141.87 |
| | 25 | | | — | | | 126 | | |
| | 26 | | | — | | | 125 | | |
| M | 27 | | | 71.6 | | | 126 | | |
| | 28 | | | — | | | 127 | | |
| | 29 | Total in storage 1,607,124 MCF | | — | | | 126 | | |
| THUR | 30 | | 60 | 72.0 | | | 126 | | |

PSC 039659

LB4DB JULY 1988

| | DATE | INJECTION MCF | P well 16 wellhead PSIG | | Bottom hole | P well 12 wellhead PSIG | | Bottom hole PSIA | Vol CAV |
|---|---|---|---|---|---|---|---|---|---|
| = | 7/1/88 | | → 21 | 72.4 | 86.22 | 126 | 138.14 | 141.87 | |
| | 2 | | | — 84.54 PSIA | | 126 | | | |
| | 3 | | | — | | 126 | | | |
| n | 4 | | | — | | 126 | | | |
| | 5 | | 65 | 72.5 | | 128 | | | |
| | 6 | START INJECTION | 66 | 73.2 | | 129 | | | |
| | 7 | | 67 | 73.2 | | 128 | | | |
| = | 8 | ? | → 22 | 73.3 | 87.13 | 127 | 139.14 | 142.89 | |
| | 9 | | | — 85.44 | | 130 | | | $\Delta P = 55.76$ |
| | 10 | | | — | | 134 | | | |
| n | 11 | | | 90.3 | | 136 | | | |
| | 12 | | | 95.2 | | 140 | | | |
| | 13 | | | 98.8 | | 141 | | | |
| | 14 | | | 102.7 | | 144 | | | |
| = | 15 | | → 23 | 107.1 | 121.62 | 146 | 158.14 | 162.42 | $\Delta P = 40.8$ |
| | 16 | | | — 119.24 | | 147 | | | |
| | 17 | | | — | | 148 | | | |
| n | 18 | | | 118.2 | | 150 | | | |
| | 19 | | | 122.6 | | 152 | | | |
| | 20 | | | 126.4 | | 155 | | | |
| | 21 | | | 129.4 | | 158 | | | |
| = | 22 | | → 24 | 133.2 | 148.24 | 164 | 176.14 | 180.92 | $\Delta P = 32.68$ |
| | 23 | | | — 145.34 | | 165 | | | |
| | 24 | | | — | | 165 | | | |
| n | 25 | | | 141.3 | | 165 | | | |
| | 26 | | | 142.9 | | 167 | | | |
| | 27 | | | 144.6 | | 169 | | | |
| | 28 | | | 143.2 | | 168 | | | |
| = | 29 | | → 25 | 145.8 | 161.10 | 169 | 191.14 | 186.05 | $\Delta P = 24.95$ |
| | 30 | | | — 157.94 | | | | | |
| | 31 | | | — | | | | | |

PSC 039660

well 16 Sub Pressure

| | | | | | |
|---|---|---|---|---|---|
| | 235.4 | 192 | 43.4 | 43.4 | 0 |
| | 236.7 | 192 | 44.7 | 44.7 | 0 |
| | 238.3 | 192 | 46.3 | 46.3 | 0 |
| | 239.6 | 192 | 47.6 | 47.6 | 0 |
| | 240.8 | 192 | 48.8 | 48.8 | 0 |
| | 242.2 | 192 | 50.2 | 50.2 | 0 |
| | 242.6 | 192 | 50.6 | 50.6 | 0 |
| | 241.9 | 192 | 49.9 | 49.9 | 0 |
| | 241.3 | 192 | 49.3 | 49.3 | 0 |
| | 240.7 | 192 | 48.7 | 48.7 | 0 |
| | 240.2 | 192 | 48.2 | 48.2 | 0 |
| | 241.7 | 192 | 49.7 | 49.7 | 0 |
| | 243.7 | 192 | 51.7 | 51.7 | 0 |
| | 244.5 | 192 | 52.5 | 52.5 | 0 |
| | 244.9 | 192 | 52.9 | 52.9 | 0 |
| | 245.2 | 192 | 53.2 | 53.2 | 0 |
| | 246.1 | 192 | 54.1 | 54.1 | 0 |
| 12/1/86 | | | | | 1283.2 1283.2 0 |
| 1/86 | 246.9 | 192 | 54.8 | 54.8 | 0 INSERTION ENDS |
| | 246.2 | 192 | 54.2 | 54.2 | 0 |
| | 245.9 | 192 | 53.8 | 53.8 | 0 |
| | 245.4 | 192 | 53.4 | 53.4 | 0 |
| | 245.2 | 192 | 53.2 | 53.2 | 0 |
| | 244.9 | 192 | 52.9 | 52.9 | 0 |
| | 244.7 | 192 | 52.7 | 52.7 | 0 |
| | 244.6 | 192 | 52.6 | 52.6 | 0 |
| | 244 | 192 | 52 | 52 | 0 |
| | 243.8 | 192 | 51.8 | 51.8 | 0 |
| | 243.6 | 192 | 51.6 | 51.6 | 0 |
| | 243.1 | 192 | 51.1 | 51.1 | 0 |
| | 242.7 | 192 | 50.7 | 50.7 | 0 |
| | 242.2 | 192 | 50.2 | 50.2 | 0 |
| | 241.7 | 192 | 49.7 | 49.7 | 0 |
| | 241.2 | 192 | 49.2 | 49.2 | 0 |
| | 240.9 | 192 | 48.9 | 48.9 | 0 |
| | 242.3 | 192 | 50.3 | 50.3 | 0 |
| | 242.7 | 192 | 50.7 | 50.7 | 0 |
| 1 12/20 | 242.3 | 192 | 50.3 | 50.3 | 0 |
| 2 | 242 | 192 | 50 | 50 | 0 |
| 3 | 241.9 | 192 | 49.9 | 49.9 | 0 |
| 4 | 241.9 | 192 | 49.9 | 49.9 | 0 |

PSC 039661

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 241.4 | 192 | 49.4 | 49.4 | 0 | | | |
| | 241.2 | 192 | 49.2 | 49.2 | 0 | | | |
| | 241.1 | 192 | 49.1 | 49.1 | 0 | | | |
| | 240.8 | 192 | 48.8 | 48.8 | 0 | | | |
| | 240.7 | 192 | 48.7 | 48.7 | 0 | | | |
| 10 | 240.6 | 192 | 48.6 | 48.6 | 0 | | | |
| | 240.3 | 192 | 48.3 | 48.3 | 0 | | | |
| | 240.2 | 192 | 48.2 | 48.2 | 0 | | | |
| | | | | | | 1574.2 | 1574.2 | 0 |
| 1/1/87 | 239.9 | 192 | 47.9 | 47.9 | 0 | | | |
| | 239.7 | 192 | 47.7 | 47.7 | 0 | | | |
| | 239.3 | 192 | 47.3 | 47.3 | 0 | | | |
| | 239.3 | 192 | 47.3 | 47.3 | 0 | | | |
| | 239.3 | 192 | 47.3 | 47.3 | 0 | | | |
| | 239 | 192 | 47 | 47 | 0 | | | |
| | 238.8 | 192 | 46.8 | 46.8 | 0 | | | |
| 20 | 238.5 | 192 | 46.5 | 46.5 | 0 | | | |
| | 238.4 | 192 | 46.4 | 46.4 | 0 | | | |
| | 238.1 | 192 | 46.1 | 46.1 | 0 | | | |
| | 238.1 | 192 | 46.1 | 46.1 | 0 | | | |
| | 238 | 192 | 46 | 46 | 0 | | | |
| | 237.7 | 192 | 45.7 | 45.7 | 0 | | | |
| | 237.5 | 192 | 45.5 | 45.5 | 0 | | | |
| | 237.4 | 192 | 45.4 | 45.4 | 0 | | | |
| | 237.3 | 192 | 45.3 | 45.3 | 0 | | | |
| | 237.1 | 192 | 45.1 | 45.1 | 0 | | | |
| 30 | 236.9 | 192 | 44.9 | 44.9 | 0 | | | |
| | 236.7 | 192 | 44.7 | 44.7 | 0 | | | |
| | 236.5 | 192 | 44.5 | 44.5 | 0 | | | |
| | 236.4 | 192 | 44.4 | 44.4 | 0 | | | |
| | 236.3 | 192 | 44.3 | 44.3 | 0 | | | |
| | 236.2 | 192 | 44.2 | 44.2 | 0 | | | |
| | 235.9 | 192 | 43.9 | 43.9 | 0 | | | |
| | 235.8 | 192 | 43.8 | 43.8 | 0 | | | |
| | 235.7 | 192 | 43.7 | 43.7 | 0 | | | |
| | 235.6 | 192 | 43.6 | 43.6 | 0 | | | |
| 40 | 235.3 | 192 | 43.3 | 43.3 | 0 | | | |
| | 235.3 | 192 | 43.3 | 43.3 | 0 | | | |
| | 235.3 | 192 | 43.3 | 43.3 | 0 | | | |
| | 235.2 | 192 | 43.2 | 43.2 | 0 | | | |
| | | | | | | 1404.5 | 1404.5 | 0 |

PSC 039662

2/1/87

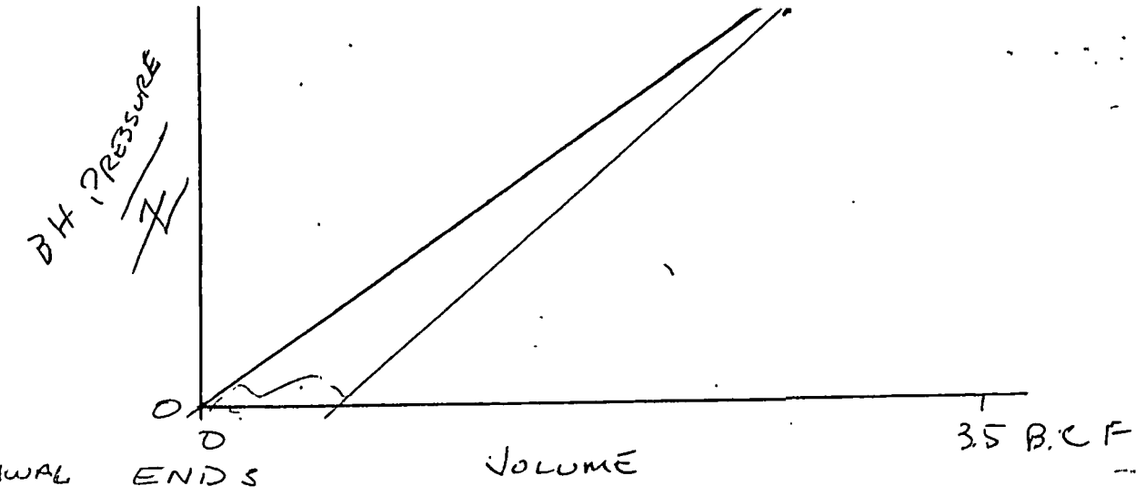
| | | | | | | |
|---|---|---|---|---|---|---|
| 1/87 | 44 | 235.2 | 192 | 43.2 | 43.2 | 0 |
| | | 235.2 | 192 | 43.2 | 43.2 | 0 — SMALL INJECTION |
| | | 236.2 | 192 | 44.2 | 44.2 | 0 |
| | | 236 | 192 | 44 | 44 | 0 |
| | | 235.7 | 192 | 43.7 | 43.7 | 0 |
| | | 235.5 | 192 | 43.5 | 43.5 | 0 |
| | | 235.4 | 192 | 43.4 | 43.4 | 0 |
| | | 235.5 | 192 | 43.5 | 43.5 | 0 |
| | | 235.6 | 192 | 43.6 | 43.6 | 0 |
| | | 235.6 | 192 | 43.6 | 43.6 | 0 |
| | | 235.5 | 192 | 43.5 | 43.5 | 0 |
| | | 235.4 | 192 | 43.4 | 43.4 | 0 |
| | | 235.3 | 192 | 43.3 | 43.3 | 0 |
| | | 235.5 | 192 | 43.5 | 43.5 | 0 |
| | | 235.4 | 192 | 43.4 | 43.4 | 0 |
| | | 235.4 | 192 | 43.4 | 43.4 | 0 |
| | | 235.3 | 192 | 43.3 | 43.3 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | | 235 | 192 | 43 | 43 | 0 |
| | 24 | 234.9 | 192 | 42.9 | 42.9 | 0 |
| | 25 | 234.3 | 192 | 42.3 | 42.3 | 0 — WITHDRAWAL STARTS. |
| | 26 | 232.9 | 192 | 40.9 | 40.9 | 0 |
| | 27 | 230.8 | 192 | 38.8 | 38.8 | 0 |
| | 28 | 230.8 | 192 | 38.8 | 38.8 | 0 |
| | | | | | 1201.4 | 1201.4 | 0 |
| 1/87 | | 226.3 | 192 | 34.3 | 34.3 | 0 |
| | | 221.7 | 192 | 29.7 | 29.7 | 0 |
| | | 230.2 | 192 | 38.2 | 38.2 | 0 |
| | | 230.1 | 192 | 38.1 | 38.1 | 0 |
| | | 230.2 | 192 | 38.2 | 38.2 | 0 |
| | | 230.3 | 192 | 38.3 | 38.3 | 0 |
| | | 230.4 | 192 | 38.4 | 38.4 | 0 |
| | | 230.3 | 192 | 38.3 | 38.3 | 0 |
| | | 230.2 | 192 | 38.2 | 38.2 | 0 |
| | | 230.3 | 192 | 38.3 | 38.3 | 0 |
| | | 228.8 | 192 | 36.8 | 36.8 | 0 |
| | | 221.7 | 192 | 29.7 | 29.7 | 0 |

PRESSURE 1 (high) ⇒ 234.3 psig
VOLUME 1 (high) ⇒ ?

BOOK VOLUME @ FEB 24 / 14.6 > psia

280

PSC 039663




| | | | | | |
|---|---|---|---|---|---|
| | [illegible] | 192 | 23.6 | 23.6 | 0 |
| | 312.2 | 192 | 24.2 | 24.2 | 0 |
| | [illegible] | 192 | 23.5 | 23.5 | 0 |
| | [illegible] | 192 | 22.1 | 22.1 | 0 |
| | 315.9 | 192 | 19.9 | 19.9 | 0 |
| | 185.1 | 192 | 3.1 | 3.1 | 0 |
| | 192.2 | 192 | 0.2 | 0.2 | 0 |
| | 136.9 | 192 | -5.1 | 0 | -5.1 |
| | 136.[illegible] | 192 | -11.3 | 0 | -11.3 |
| | [illegible] | 192 | -12.5 | 0 | -12.5 |
| | [illegible] | 192 | -13.5 | 0 | -13.5 |
| | 131.[illegible] | 192 | -11.9 | 0 | -11.9 |
| | 131.[illegible] | 192 | -12.[illegible] | 0 | -12.[illegible] |
| | 152 | 192 | -10 | 0 | -10 |
| | 182.7 | 192 | -9.3 | 0 | -9.3 |
| | 183.2 | 192 | -9.8 | 0 | -9.8 |
| | 183.5 | 192 | -9.5 | 0 | -9.5 |
| | 184 | 192 | -8 | 0 | -8 |
| | 184.2 | 192 | -7.7 | 0 | -7.7 |
| 4/1/87 | | | | 426.5 | 545.2 | -118.5 |
| 4/2/87 | 184.6 | 192 | -7.4 | 0 | -7.4 |
| | 184.7 | 192 | -7.3 | 0 | -7.3 |
| | 185.2 | 192 | -6.8 | 0 | -6.8 |
| | 185.4 | 192 | -6.6 | 0 | -6.6 |
| | 185.6 | 192 | -6.4 | 0 | -6.4 |
| | 185.8 | 192 | -6.2 | 0 | -6.2 |
| | 185.9 | 192 | -6.1 | 0 | -6.1 |
| | 186.4 | 192 | -5.6 | 0 | -5.6 |
| | 186.4 | 192 | -5.6 | 0 | -5.6 |
| | 186.6 | 192 | -5.4 | 0 | -5.4 |
| | 186.8 | 192 | -5.2 | 0 | -5.2 |
| | 187 | 192 | -5 | 0 | -5 |
| | 187.1 | 192 | -4.9 | 0 | -4.9 |
| | 187.1 | 192 | -4.9 | 0 | -4.9 |
| | 187.3 | 192 | -4.7 | 0 | -4.7 |
| 4/16 | 187.6 | 192 | -4.4 | 0 | -4.4 |
| | 187.6 | 192 | -4.4 | 0 | -4.4 |
| | 187.7 | 192 | -4.3 | 0 | -4.3 |
| | 187.8 | 192 | -4.2 | 0 | -4.2 |
| | 187.8 | 192 | -4.2 | 0 | -4.2 |
| | 187.7 | 192 | -4.3 | 0 | -4.3 |

WITHDRAWAL ENDS

PSC 039664

# Interoffice Memo

WestGas™
Western Gas Supply Company

Date Dec. 1, 1987

To Jim Gerrity, Supervisor Office Funtions

From Bill Uding, Supervisor Resv. & Storage Eng.

Attn.

Subj. L & U from Storage Fields

The Reservoir and Storage Engineering Unit has completed its annual review of storage field gas in storage inventories and reports the following:

Roundup
L & U = 8900 Mcf @ 14.73 Psia. This loss occurred during the drilling, completion, and testing of the new well, #28, and during workovers on wells #24 and #18.

Asbury and Fruita
No change in volumes of gas in storage for these fields.

Leyden
A volumetric analysis of Leyden did not conclusively indictate lost gas. The data is under further review at this time. In the event that a determination shows lost gas, the volumes will be reported in 1988.

If you have any questions regarding this information, please call me on 572-4151.

Bill Uding

Bill Uding

FORM 798-22-4892

PSC 039665

Aug-Nov

# Water Withdrawal 86-87

| Aug 86 | Sept | Oct | Nov | Dec |
|---|---|---|---|---|
| 84,100 | 215,800 | 3,400 | 321,800 | 42,700 |
| 68,200 | 135,500 | 168,500 | 22,000 | 22,000 |
| 69,800 | 164,300 | 60,300 | 22,000 | 16,200 |
| 82,900 | 149,200 | 67,000 | 22,000 | 22,000 |
| 62,800 | 159,100 | 102,000 | 22,000 | 628,100 |
| 95,500 | 23,500 | 50,300 | 66,000 | 22,000 |
| 69,200 | 54,500 | 46,000 | 44,000 | 22,000 |
| 315,000 | 57,000 | 22,500 | 22,000 | 22,000 |
| 115,900 | 27,700 | 22,000 | 211,500 | 22,000 |
| 70,000 | 27,233 | 22,000 | 138,400 | 66,000 |
| 153,100 | 22,933 | 22,100 | 224,300 | 22,000 |
| 90,600 | 22,934 | 22,000 | 22,000 | 22,000 |
| 54,900 | 183,500 | 22,000 | 22,000 | 22,000 |
| 39,000 | 36,600 | 22,000 | 22,000 | 22,000 |
| 30,600 | 20,300 | 22,000 | 66,000 | 22,000 |
| 114,150 | 25,400 | 66,000 | 217,600 | 22,000 |
| 114,150 | 42,100 | 22,000 | 137,200 | 50,400 |
| 383,300 | 22,900 | 22,000 | | 22,000 |
| 169,200 | 23,000 | 22,000 | 1,602,800 | 191,100 |
| | 19,700 | 22,000 | | |
| 2,822,400 | 28,400 | 22,000 | | 1,289,500 |
| | 5,000 | 22,000 | | |
| | 107,000 | 22,000 | | |
| | 100,000 | 22,000 | | |
| | 55,500 | 22,000 | | |
| | 1,729,100 | 938,100 | | |

Jan 87

125,500
22,000
44,000
22,000
128,400
22,400
22,000
22,000
44,000
22,000
22,000
22,000
22,000
66,000 19th
22,000 20
22,000 21
22,000 1/22/87

672,300

Total 9,045,200 Gal

divide by 7.48
to get CF of water

197.2 - point of interest

X pressure divided by 14.65

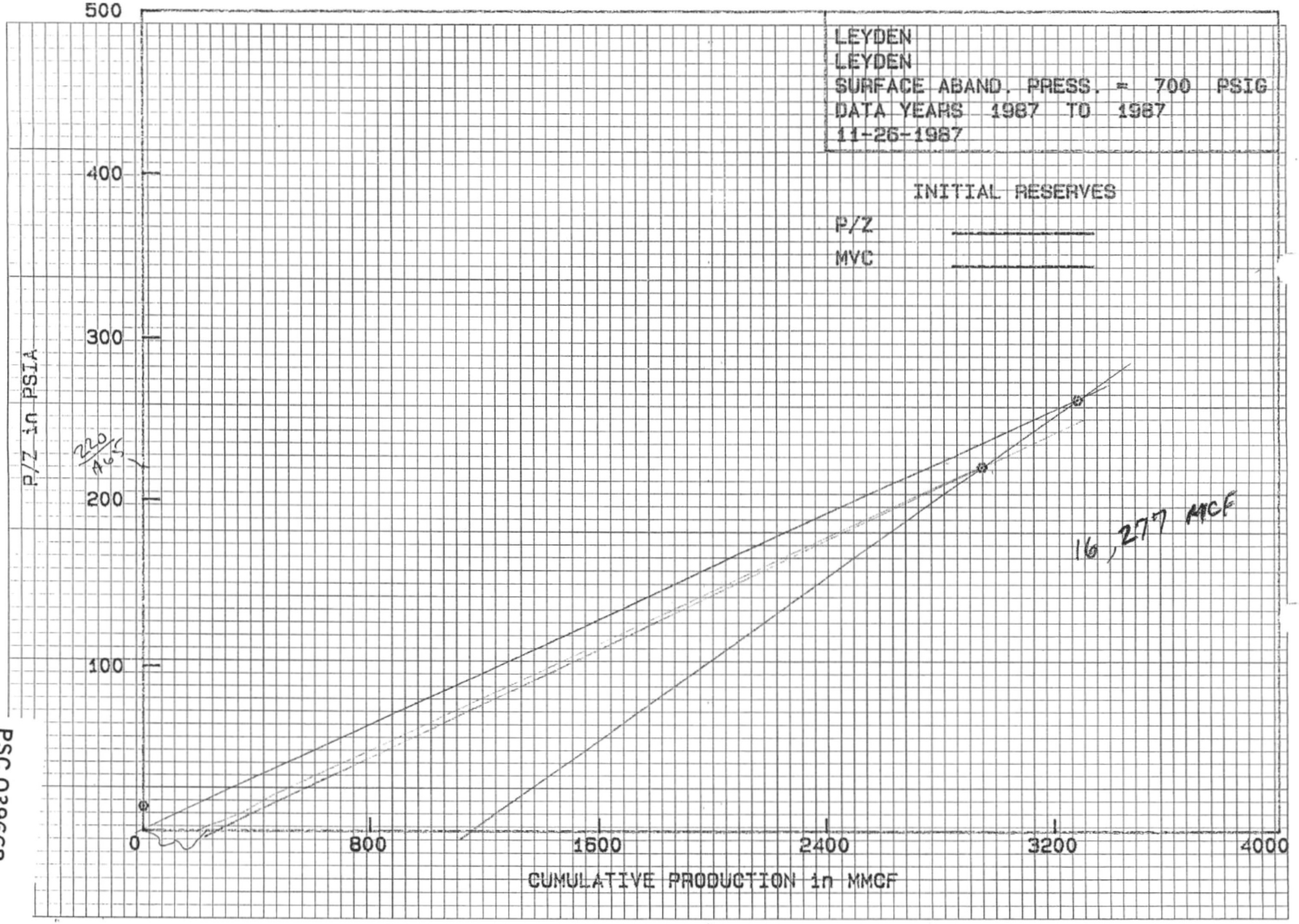
16,277 MCF

PSC 039667

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 0700

15,036




265 MMCF

PSC 039668

Reported per 12/3/86 memo

1986 L+U Calculations

A plot of R/Z vs. Volume showed that the difference between book volume + gas in place was 60,000 MCF. Water withdrawal between 11/15/85 - 8/1/86 was 1,596,123 Cu ft, or 1596 MCF.

60,000 - 1600 = 58400 MCF L+U

APPARENTLY THIS COVERS L&U ... THRU JULY, 1986

Water withdrawn from 11/15/85 - 81/1/86
11,939,000 gals = 1,596,123 cu ft

| Nov 85 | Dec | Jan 86 | Feb | March |
|---|---|---|---|---|
| 39,700 | 181,200 | 72,000 | 619,000 | 56,000 |
| 113,400 | 3,700 | 28,000 | 209,300 | 59,300 |
| 38,700 | 23,100 | 28,000 | 216,400 | 28,000 |
| 30,000 | 57,800 | 28,000 | 41,800 | 28,000 |
| 71,000 | | 66,600 | 44,800 | |
| 41,100 | 265,800 | 113,300 | 121,300 | 171,300 |
| 39,400 | | 38,300 | 47,600 | |
| 38,600 | | 41,100 | 37,200 | |
| | | 40,500 | 10,800 | |
| 181,900 | | 42,200 | 175,200 | |
| | | 123,600 | 39,700 | |
| | | 174,500 | 36,700 | |
| | | 210,100 | | |
| | | 218,000 | 1,599,800 | |
| | | 207,500 | | |
| | | 1,431,700 | | |

58400 MCF

| April | May | June | July |
|---|---|---|---|
| 16,200 | 20,800 | 472,100 | 84,500 |
| 19,600 | 22,400 | 168,400 | 144,000 |
| 5000 | 53,300 | 166,300 | 111,900 |
| 20,700 | 20,700 | 165,600 | 208,300 |
| 43,500 | 21,700 | 164,900 | 125,000 |
| 20,000 | 20,700 | 309,100 | 92,300 |
| 20,300 | 20,700 | 159,400 | 122,900 |
| 5,000 | 63,100 | 166,600 | 147,700 |
| 20,000 | 8,500 | 153,200 | 262,300 |
| 60,900 | 42,200 | 161,200 | 49,300 |
| 20,300 | 181,000 | 54,300 | 31,900 |
| 20,300 | 181,000 | 151,100 | 68,200 |
| 20,500 | 119,000 | 268,200 | 27,200 |
| 21,600 | 119,000 | 150,700 | 63,200 |
| 58,900 | 163,700 | 220,400 | 27,400 |
| 21,300 | 165,900 | 110,100 | 20,300 |
| 21,600 | 166,400 | 151,300 | 10,000 |
| | 178,600 | 117,900 | 29,200 |
| 415,700 | 166,300 | 151,200 | 88,200 |
| | 166,000 | 107,500 | 53,100 |
| | 166,300 | | 49,900 |
| | | 3,569,500 | 169,200 |
| | 2,067,300 | | |
| | | | 1,936,000 |

8/1/86

PSC 039671

Leyden Pound Days

| Date | Pressure | Constant | Pound Days | Pound Days High | Pound Days Low | Total Pound Days | Total Pound Days High | Total Pound Days Low |
|---|---|---|---|---|---|---|---|---|
| 09/01/85 | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.6 | 192 | -31.4 | 0 | -31.4 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.7 | 192 | -31.3 | 0 | -31.3 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.9 | 192 | -31.1 | 0 | -31.1 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | | | |
| | 160.8 | 192 | -31.2 | 0 | -31.2 | -936.1 | 0 | -936.1 |
| 10/01/85 | 160.8 | 192 | -31.2 | 0 | -31.2 | — injection | | |
| | 165.9 | 192 | -26.1 | 0 | -26.1 | | | |
| | 170 | 192 | -22 | 0 | -22 | | | |
| | 174.3 | 192 | -17.7 | 0 | -17.7 | | | |
| | 177.2 | 192 | -14.8 | 0 | -14.8 | | | |
| | 183 | 192 | -9 | 0 | -9 | | | |
| | 186 | 192 | -6 | 0 | -6 | | | |
| | 189.4 | 192 | -2.6 | 0 | -2.6 | | | |
| | 192.7 | 192 | 0.7 | 0.7 | 0 | | | |
| | 196.1 | 192 | 4.1 | 4.1 | 0 | | | |
| | 199.9 | 192 | 7.9 | 7.9 | 0 | | | |
| | 202.4 | 192 | 10.4 | 10.4 | 0 | | | |
| | 207.2 | 192 | 15.2 | 15.2 | 0 | | | |
| | 209.7 | 192 | 17.7 | 17.7 | 0 | | | |
| | 212.9 | 192 | 20.9 | 20.9 | 0 | | | |
| | 216.2 | 192 | 24.2 | 24.2 | 0 | | | |
| | 219.4 | 192 | 27.4 | 27.4 | 0 | | | |
| | 222.4 | 192 | 30.4 | 30.4 | 0 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 224.7 | 192 | 32.7 | 32.7 | 0 | | | | |
| | 229.2 | 192 | 37.2 | 37.2 | 0 | | | | |
| | 231.5 | 192 | 39.5 | 39.5 | 0 | | | | |
| | 233.8 | 192 | 41.8 | 41.8 | 0 | | | | |
| | 235.4 | 192 | 43.4 | 43.4 | 0 | | | | |
| | 235.9 | 192 | 43.9 | 43.9 | 0 | | | | |
| | 236.5 | 192 | 44.5 | 44.5 | 0 | | | | |
| | 237.1 | 192 | 45.1 | 45.1 | 0 | | | | |
| | 238.1 | 192 | 46.1 | 46.1 | 0 | | | | |
| | 238.8 | 192 | 46.8 | 46.8 | 0 | | | | |
| | 241.1 | 192 | 49.1 | 49.1 | 0 | | | | |
| | 243.4 | 192 | 51.4 | 51.4 | 0 | | | | |
| | 245.7 | 192 | 53.7 | 53.7 | 0 | Shutin | 604.7 | 734.1 | -129.4 |
| 11/01/85 | 247.2 | 192 | 55.2 | 55.2 | 0 | drop in pressure | | | |
| | 246.7 | 192 | 54.7 | 54.7 | 0 | | | | |
| | 246.1 | 192 | 54.1 | 54.1 | 0 | | | | |
| | 245.5 | 192 | 53.5 | 53.5 | 0 | | | | |
| | 245.6 | 192 | 53.6 | 53.6 | 0 | | | | |
| | 244.9 | 192 | 52.9 | 52.9 | 0 | | | | |
| | 244 | 192 | 52 | 52 | 0 | | | | |
| | 243.9 | 192 | 51.9 | 51.9 | 0 | | | | |
| | 243.7 | 192 | 51.7 | 51.7 | 0 | | | | |
| | 243.5 | 192 | 51.5 | 51.5 | 0 | | | | |
| | 243.3 | 192 | 51.3 | 51.3 | 0 | | | | |
| | 242 | 192 | 50 | 50 | 0 | injection | | | |
| | 241.6 | 192 | 49.6 | 49.6 | 0 | Shut in | | | |
| | 245 | 192 | 53 | 53 | 0 | drop in pressure | | | |
| 1 | 249.3 | 192 | 57.3 | 57.3 | 0 | | | | |
| | 248.8 | 192 | 56.8 | 56.8 | 0 | | | | |
| | 248.4 | 192 | 56.4 | 56.4 | 0 | | | | |
| | 248.1 | 192 | 56.1 | 56.1 | 0 | | | | |
| 5 | 247.3 | 192 | 55.3 | 55.3 | 0 | | | | |
| | 246.9 | 192 | 54.9 | 54.9 | 0 | | | | |
| | 246.6 | 192 | 54.6 | 54.6 | 0 | | | | |
| | 246.2 | 192 | 54.2 | 54.2 | 0 | | | | |
| 10 | 245.9 | 192 | 53.9 | 53.9 | 0 | | | | |
| | 245.7 | 192 | 53.7 | 53.7 | 0 | | | | |
| | 245.4 | 192 | 53.4 | 53.4 | 0 | | | | |
| | 245 | 192 | 53 | 53 | 0 | | | | |
| 15 | 244.8 | 192 | 52.8 | 52.8 | 0 | | | | |
| | 244.6 | 192 | 52.6 | 52.6 | 0 | | | | |
| | 244.4 | 192 | 52.4 | 52.4 | 0 | | | | |
| | 244.2 | 192 | 52.2 | 52.2 | 0 | 1604.6 | 1604.6 | 0 | |

Leyden Pound Days

| Date | Pressure | Constant | Pound Days | Pound Days High | Pound Days Low | Total Pound Days | Total Pound Days High | Total Pound Days Low |
|---|---|---|---|---|---|---|---|---|
| 12/01/85 | 244 | 192 | 52 | 52 | 0 | | | |
| 20 | 243.8 | 192 | 51.8 | 51.8 | 0 | | | |
| | 243.5 | 192 | 51.5 | 51.5 | 0 | | | |
| | 243.2 | 192 | 51.2 | 51.2 | 0 | | | |
| | 242.9 | 192 | 50.9 | 50.9 | 0 | | | |
| | 242.8 | 192 | 50.8 | 50.8 | 0 | | | |
| 25 | 242.8 | 192 | 50.8 | 50.8 | 0 | | | |
| | 242.8 | 192 | 50.8 | 50.8 | 0 | | | |
| | 242.8 | 192 | 50.8 | 50.8 | 0 | | | |
| | 242.3 | 192 | 50.3 | 50.3 | 0 | | | |
| | 242.1 | 192 | 50.1 | 50.1 | 0 | | | |
| 30 | 242 | 192 | 50 | 50 | 0 | | | |
| | 241.9 | 192 | 49.9 | 49.9 | 0 | | | |
| | 241.6 | 192 | 49.6 | 49.6 | 0 | | | |
| | 241.4 | 192 | 49.4 | 49.4 | 0 | | | |
| | 241.1 | 192 | 49.1 | 49.1 | 0 | | | |
| 35 | 241.2 | 192 | 49.2 | 49.2 | 0 | | | |
| | 241 | 192 | 49 | 49 | 0 | | | |
| | 240.9 | 192 | 48.9 | 48.9 | 0 | | | |
| | 240.8 | 192 | 48.8 | 48.8 | 0 | | | |
| | 240.7 | 192 | 48.7 | 48.7 | 0 | | | |
| 40 | 240.6 | 192 | 48.6 | 48.6 | 0 | | | |
| | 240.5 | 192 | 48.5 | 48.5 | 0 | | | |
| | 240.3 | 192 | 48.3 | 48.3 | 0 | | | |
| | 240 | 192 | 48 | 48 | 0 | | | |
| | 239.8 | 192 | 47.8 | 47.8 | 0 | | | |
| 45 | 239.9 | 192 | 47.9 | 47.9 | 0 | | | |
| | 239.8 | 192 | 47.8 | 47.8 | 0 | | | |
| | 239.7 | 192 | 47.7 | 47.7 | 0 | | | |
| | 239.6 | 192 | 47.6 | 47.6 | 0 | | | |
| | 239.4 | 192 | 47.4 | 47.4 | 0 | 1533.2 | 1533.2 | 0 |
| 01/01/86 | 239.3 | 192 | 47.3 | 47.3 | 0 | | | |
| 50 | 239.2 | 192 | 47.2 | 47.2 | 0 | | | |
| | 239.2 | 192 | 47.2 | 47.2 | 0 | | | |
| | 239.1 | 192 | 47.1 | 47.1 | 0 | | | |
| | 239.1 | 192 | 47.1 | 47.1 | 0 | | | |
| 55 | 239 | 192 | 47 | 47 | 0 | | | |
| | 238.6 | 192 | 46.6 | 46.6 | 0 | | | |
| | 238.5 | 192 | 46.5 | 46.5 | 0 | | | |
| | 238.6 | 192 | 46.6 | 46.6 | 0 | | | |
| | 238.5 | 192 | 46.5 | 46.5 | 0 | | | |
| 60 | 238.5 | 192 | 46.5 | 46.5 | 0 | | | |
| | 238.4 | 192 | 46.4 | 46.4 | 0 | | | |
| | 238.4 | 192 | 46.4 | 46.4 | 0 | | | |
| | 238.3 | 192 | 46.3 | 46.3 | 0 | | | |
| | 238.3 | 192 | 46.3 | 46.3 | 0 | | | |
| 65 | 238.1 | 192 | 46.1 | 46.1 | 0 | | | |
| | 238 | 192 | 46 | 46 | 0 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 237.9 | 192 | 45.9 | 45.9 | 0 | | | |
| | 237.9 | 192 | 45.9 | 45.9 | 0 | | | |
| | 237.8 | 192 | 45.8 | 45.8 | 0 | | | |
| 70 | 237.7 | 192 | 45.7 | 45.7 | 0 | | | |
| | 237.6 | 192 | 45.6 | 45.6 | 0 | | | |
| | 237.6 | 192 | 45.6 | 45.6 | 0 | | | |
| | 237.5 | 192 | 45.5 | 45.5 | 0 | | | |
| | 237.4 | 192 | 45.4 | 45.4 | 0 | | | |
| 75 | 237.2 | 192 | 45.2 | 45.2 | 0 | | | |
| | 237.1 | 192 | 45.1 | 45.1 | 0 | | | |
| | 237 | 192 | 45 | 45 | 0 | | | |
| | 236.7 | 192 | 44.7 | 44.7 | 0 | | | |
| | 236.7 | 192 | 44.7 | 44.7 | 0 | | | |
| 02/01/86 80 | 236.5 | 192 | 44.5 | 44.5 | 0 | 1427.7 | 1427.7 | 0 |
| | 236.4 | 192 | 44.4 | 44.4 | 0 | | | |
| | 236.4 | 192 | 44.4 | 44.4 | 0 | | | |
| | 236.3 | 192 | 44.3 | 44.3 | 0 | | | |
| | 236.2 | 192 | 44.2 | 44.2 | 0 | | | |
| 85 | 236 | 192 | 44 | 44 | 0 | | | |
| | 235.9 | 192 | 43.9 | 43.9 | 0 | | | |
| | 235.8 | 192 | 43.8 | 43.8 | 0 | | | |
| | 235.8 | 192 | 43.8 | 43.8 | 0 | | | |
| | 235.8 | 192 | 43.8 | 43.8 | 0 | | | |
| 90 | 235.8 | 192 | 43.8 | 43.8 | 0 | | | |
| | 235.5 | 192 | 43.5 | 43.5 | 0 | | | |
| | 235.4 | 192 | 43.4 | 43.4 | 0 | | | |
| | 235.5 | 192 | 43.5 | 43.5 | 0 | | | |
| | 235.4 | 192 | 43.4 | 43.4 | 0 | | | |
| 95 | 235.4 | 192 | 43.4 | 43.4 | 0 | | | |
| | 235.3 | 192 | 43.3 | 43.3 | 0 | | | |
| | 235.2 | 192 | 43.2 | 43.2 | 0 | | | |
| | 235.1 | 192 | 43.1 | 43.1 | 0 | | | |
| 2/20/86 | 235.2 | 192 | 43.2 | 43.2 | 0 | | | |
| 100 | 231.8 | 192 | 39.8 | 39.8 | 0 | | | |
| | 220.4 | 192 | 28.4 | 28.4 | 0 | | | |
| | 210.7 | 192 | 18.7 | 18.7 | 0 | | | |
| | 203.5 | 192 | 11.5 | 11.5 | 0 | | | |
| | 195.9 | 192 | 3.9 | 3.9 | 0 | | | |
| | 192.2 | 192 | 0.2 | 0.2 | 0 | | | |
| | 189.6 | 192 | -2.4 | 0 | -2.4 | | | |
| | 187.9 | 192 | -4.1 | 0 | -4.1 | | | |
| | 184.4 | 192 | -7.6 | 0 | -7.6 | 918.8 | 932.9 | -14.1 |

* withdrawal

Leyden Pound Days

| Date | Pressure | Constant | Pound Days | Pound Days High | Pound Days Low | Total Pound Days | Total Pound Days High | Total Pound Days Low |
|---|---|---|---|---|---|---|---|---|
| 03/01/86 | 180.9 | 192 | -11.1 | 0 | -11.1 | | | |
| | 179.1 | 192 | -12.9 | 0 | -12.9 | | | |
| | 174.9 | 192 | -17.1 | 0 | -17.1 | | | |
| | 172.9 | 192 | -19.1 | 0 | -19.1 | | | |
| | 170.7 | 192 | -21.3 | 0 | -21.3 | | | |
| | 167.8 | 192 | -24.2 | 0 | -24.2 | | | |
| | 164.8 | 192 | -27.2 | 0 | -27.2 | | | |
| | 162.9 | 192 | -29.1 | 0 | -29.1 | | | |
| | 161.4 | 192 | -30.6 | 0 | -30.6 | | | |
| | 157.6 | 192 | -34.4 | 0 | -34.4 | | | |
| | 154.1 | 192 | -37.9 | 0 | -37.9 | | | |
| | 150.9 | 192 | -41.1 | 0 | -41.1 | | | |
| | 147 | 192 | -45 | 0 | -45 | | | |
| | 145.1 | 192 | -46.9 | 0 | -46.9 | | | |
| | 142.8 | 192 | -49.2 | 0 | -49.2 | | | |
| | 139.9 | 192 | -52.1 | 0 | -52.1 | | | |
| | 136.7 | 192 | -55.3 | 0 | -55.3 | | | |
| | 133.9 | 192 | -58.1 | 0 | -58.1 | | | |
| | 130 | 192 | -62 | 0 | -62 | | | |
| | 129 | 192 | -63 | 0 | -63 | | | |
| | 126.4 | 192 | -65.6 | 0 | -65.6 | | | |
| | 121.9 | 192 | -70.1 | 0 | -70.1 | | | |
| | 125.9 | 192 | -66.1 | 0 | -66.1 | | | |
| | 119.4 | 192 | -72.6 | 0 | -72.6 | | | |
| | 117.2 | 192 | -74.8 | 0 | -74.8 | | | |
| | 115 | 192 | -77 | 0 | -77 | | | |
| | 112.5 | 192 | -79.5 | 0 | -79.5 | | | |
| | 109.7 | 192 | -82.3 | 0 | -82.3 | | | |
| | 106.9 | 192 | -85.1 | 0 | -85.1 | | | |
| | 104.6 | 192 | -87.4 | 0 | -87.4 | | | |
| | 104.8 | 192 | -87.2 | 0 | -87.2 | -1585.3 | 0 | -1585.3 |
| 04/01/86 | 105.5 | 192 | -86.5 | 0 | -86.5 | | | |
| | 107.3 | 192 | -84.7 | 0 | -84.7 | | | |
| | 108.3 | 192 | -83.7 | 0 | -83.7 | | | |
| | 109.3 | 192 | -82.7 | 0 | -82.7 | | | |
| | 109.9 | 192 | -82.1 | 0 | -82.1 | | | |
| | 110.7 | 192 | -81.3 | 0 | -81.3 | | | |
| | 111.2 | 192 | -80.8 | 0 | -80.8 | | | |
| | 111.7 | 192 | -80.3 | 0 | -80.3 | | | |
| | 112.3 | 192 | -79.7 | 0 | -79.7 | | | |
| | 112.8 | 192 | -79.2 | 0 | -79.2 | | | |
| | 113.4 | 192 | -78.6 | 0 | -78.6 | | | |
| | 113.7 | 192 | -78.3 | 0 | -78.3 | | | |
| | 114 | 192 | -78 | 0 | -78 | | | |
| | 114.4 | 192 | -77.6 | 0 | -77.6 | | | |
| | 114.7 | 192 | -77.3 | 0 | -77.3 | | | |
| | 115.1 | 192 | -76.9 | 0 | -76.9 | | | |
| | 115.6 | 192 | -76.4 | 0 | -76.4 | | | |

1 5 10 15

Shutin

Build in pressure

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 115.7 | 192 | -76.3 | 0 | -76.3 | | | |
| 20 | 116 | 192 | -76 | 0 | -76 | | | |
| | 116.2 | 192 | -75.8 | 0 | -75.8 | | | |
| | 116.5 | 192 | -75.5 | 0 | -75.5 | | | |
| | 116.7 | 192 | -75.3 | 0 | -75.3 | | | |
| | 117 | 192 | -75 | 0 | -75 | | | |
| 25 | 117.2 | 192 | -74.8 | 0 | -74.8 | | | |
| | 117.6 | 192 | -74.4 | 0 | -74.4 | | | |
| | 117.8 | 192 | -74.2 | 0 | -74.2 | | | |
| | 118 | 192 | -74 | 0 | -74 | | | |
| | 118.2 | 192 | -73.8 | 0 | -73.8 | | | |
| | 118.5 | 192 | -73.5 | 0 | -73.5 | | | |
| 30 | 118.6 | 192 | -73.4 | 0 | -73.4 | -2336.1 | 0 | -2336.1 |
| 05/01/86 | 118.8 | 192 | -73.2 | 0 | -73.2 | | | |
| | 119 | 192 | -73 | 0 | -73 | | | |
| | 119.2 | 192 | -72.8 | 0 | -72.8 | | | |
| 35 | 119.5 | 192 | -72.5 | 0 | -72.5 | | | |
| | 119.7 | 192 | -72.3 | 0 | -72.3 | | | |
| | 119.8 | 192 | -72.2 | 0 | -72.2 | | | |
| | 120.1 | 192 | -71.9 | 0 | -71.9 | | | |
| | 120.2 | 192 | -71.8 | 0 | -71.8 | | | |
| 40 | 120.4 | 192 | -71.6 | 0 | -71.6 | | | |
| | 120.5 | 192 | -71.5 | 0 | -71.5 | | | |
| | 120.7 | 192 | -71.3 | 0 | -71.3 | | | |
| | 120.8 | 192 | -71.2 | 0 | -71.2 | | | |
| | 120.9 | 192 | -71.1 | 0 | -71.1 | | | |
| 45 | 121.1 | 192 | -70.9 | 0 | -70.9 | | | |
| | 121.1 | 192 | -70.9 | 0 | -70.9 | | | |
| | 121.3 | 192 | -70.7 | 0 | -70.7 | | | |
| | 121.4 | 192 | -70.6 | 0 | -70.6 | | | |
| | 121.4 | 192 | -70.6 | 0 | -70.6 | | | |
| 50 | 121.5 | 192 | -70.5 | 0 | -70.5 | | | |
| | 121.7 | 192 | -70.3 | 0 | -70.3 | | | |
| | 121.8 | 192 | -70.2 | 0 | -70.2 | | | |
| | 121.9 | 192 | -70.1 | 0 | -70.1 | | | |
| | 122 | 192 | -70 | 0 | -70 | | | |
| 55 | 122.1 | 192 | -69.9 | 0 | -69.9 | | | |
| | 122.2 | 192 | -69.8 | 0 | -69.8 | | | |
| | 122.3 | 192 | -69.7 | 0 | -69.7 | | | |
| | 122.4 | 192 | -69.6 | 0 | -69.6 | | | |
| | 122.4 | 192 | -69.6 | 0 | -69.6 | | | |
| 60 | 122.5 | 192 | -69.5 | 0 | -69.5 | | | |
| | 122.7 | 192 | -69.3 | 0 | -69.3 | | | |
| | 122.8 | 192 | -69.2 | 0 | -69.2 | -2197.8 | 0 | -2197.8 |

Leyden Pound Days

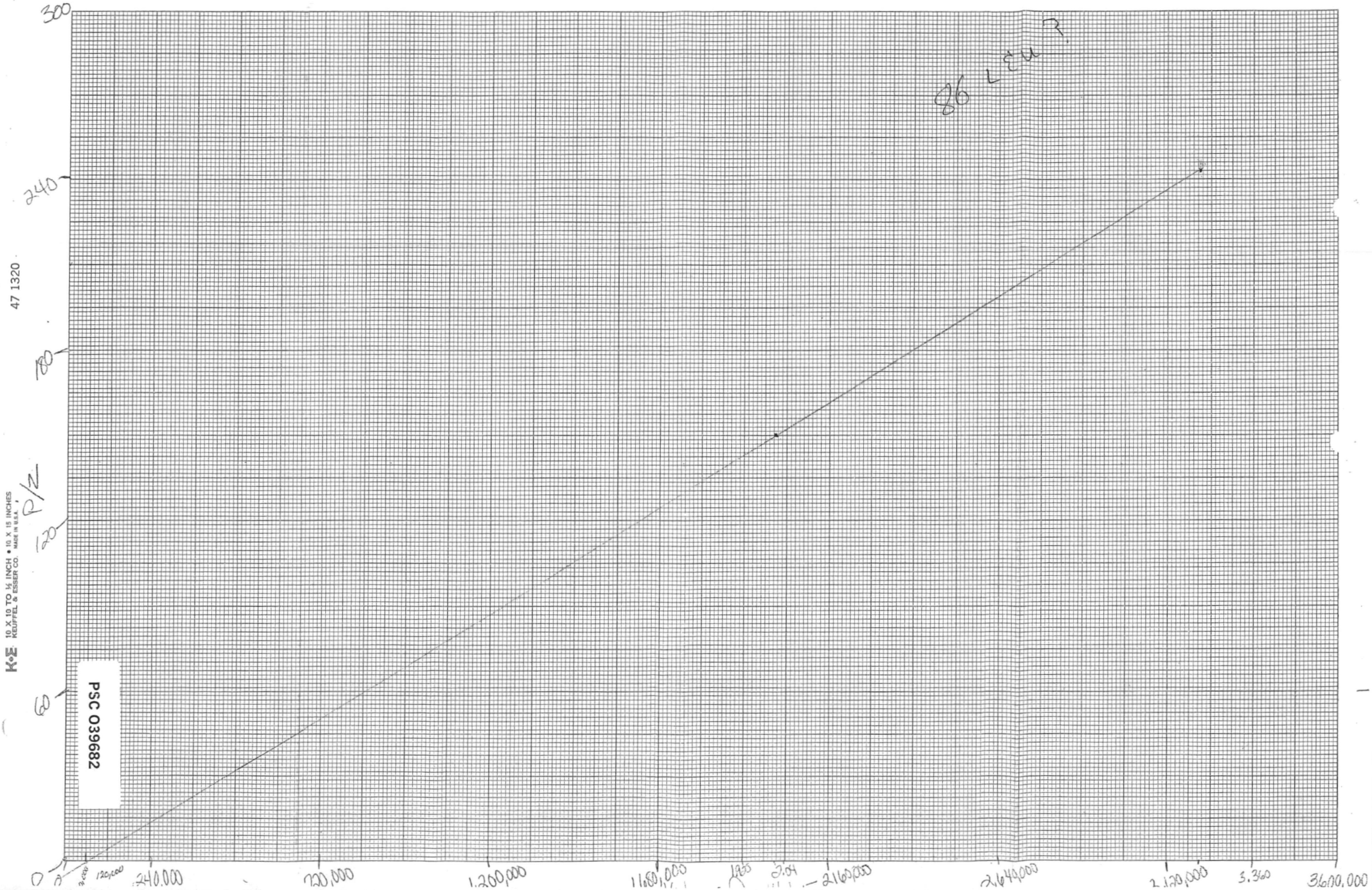
| Date | Pressure | Constant | Pound Days | Pound Days High | Pound Days Low | Total Pound Days | Total Pound Days High | Total Pound Days Low |
|---|---|---|---|---|---|---|---|---|
| 06/01/86 | 122.8 | 192 | -69.2 | 0 | -69.2 | | | |
| | 122.9 | 192 | -69.1 | 0 | -69.1 | | | |
| | 123 | 192 | -69 | 0 | -69 | | | |
| 65 | 123.1 | 192 | -68.9 | 0 | -68.9 | | | |
| | 123.2 | 192 | -68.8 | 0 | -68.8 | | | |
| | 123.2 | 192 | -68.8 | 0 | -68.8 | | | |
| | 123.3 | 192 | -68.7 | 0 | -68.7 | | | |
| 70 | 123.5 | 192 | -68.5 | 0 | -68.5 | | | |
| | 123.6 | 192 | -68.4 | 0 | -68.4 | | | |
| | 123.6 | 192 | -68.4 | 0 | -68.4 | | | |
| | 123.7 | 192 | -68.3 | 0 | -68.3 | | | |
| | 123.7 | 192 | -68.3 | 0 | -68.3 | | | |
| 75 | 123.7 | 192 | -68.3 | 0 | -68.3 | | | |
| | 123.8 | 192 | -68.2 | 0 | -68.2 | | | |
| | 123.9 | 192 | -68.1 | 0 | -68.1 | | | |
| | 124 | 192 | -68 | 0 | -68 | | | |
| | 123.1 | 192 | -68.9 | 0 | -68.9 | | | |
| 80 | 123.7 | 192 | -68.3 | 0 | -68.3 | | | |
| | 124.3 | 192 | -67.7 | 0 | -67.7 | | | |
| | 124.3 | 192 | -67.7 | 0 | -67.7 | | | |
| | 124.3 | 192 | -67.7 | 0 | -67.7 | | | |
| | 124.4 | 192 | -67.6 | 0 | -67.6 | | | |
| 85 | 124.4 | 192 | -67.6 | 0 | -67.6 | | | |
| | 124.5 | 192 | -67.5 | 0 | -67.5 | | | |
| | 124.6 | 192 | -67.4 | 0 | -67.4 | | | |
| | 124.7 | 192 | -67.3 | 0 | -67.3 | | | |
| | 124.7 | 192 | -67.3 | 0 | -67.3 | | | |
| 90 | 124.8 | 192 | -67.2 | 0 | -67.2 | | | |
| | 124.8 | 192 | -67.2 | 0 | -67.2 | | | |
| | 124.9 | 192 | -67.1 | 0 | -67.1 | -2043.5 | 0 | -2043.5 |
| 07/01/86 | 124.9 | 192 | -67.1 | 0 | -67.1 | | | |
| | 124.9 | 192 | -67.1 | 0 | -67.1 | | | |
| 95 | 125 | 192 | -67 | 0 | -67 | | | |
| | 125 | 192 | -67 | 0 | -67 | | | |
| | 125.1 | 192 | -66.9 | 0 | -66.9 | | | |
| | 125.2 | 192 | -66.8 | 0 | -66.8 | | | |
| | 125.3 | 192 | -66.7 | 0 | -66.7 | | | |
| 100 | 125.3 | 192 | -66.7 | 0 | -66.7 | | | |
| | 125.4 | 192 | -66.6 | 0 | -66.6 | | | |
| | 125.5 | 192 | -66.5 | 0 | -66.5 | | | |
| | 125.6 | 192 | -66.4 | 0 | -66.4 | | | |
| | 125.6 | 192 | -66.4 | 0 | -66.4 | | | |
| 105 | 125.6 | 192 | -66.4 | 0 | -66.4 | | | |
| | 125.6 | 192 | -66.4 | 0 | -66.4 | | | |
| | 125.7 | 192 | -66.3 | 0 | -66.3 | | | |
| | 125.8 | 192 | -66.2 | 0 | -66.2 | | | |
| | 125.8 | 192 | -66.2 | 0 | -66.2 | | | |
| 110 | 125.9 | 192 | -66.1 | 0 | -66.1 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 125.9 | 192 | -66.1 | 0 | -66.1 | | | |
| | 126 | 192 | -66 | 0 | -66 | | | |
| | 126.1 | 192 | -65.9 | 0 | -65.9 | | | |
| | 126 | 192 | -66 | 0 | -66 | | | |
| 115 | 126.1 | 192 | -65.9 | 0 | -65.9 | | | |
| | 126.2 | 192 | -65.8 | 0 | -65.8 | | | |
| | 126.2 | 192 | -65.8 | 0 | -65.8 | | | |
| | 126.2 | 192 | -65.8 | 0 | -65.8 | | | |
| | 126.3 | 192 | -65.7 | 0 | -65.7 | | | |
| | 126.4 | 192 | -65.6 | 0 | -65.6 | | | |
| | 126.4 | 192 | -65.6 | 0 | -65.6 | | | |
| | 126.5 | 192 | -65.5 | 0 | -65.5 | | | |
| | 126.5 | 192 | -65.5 | 0 | -65.5 | -2054 | 0 | -2054 |
| 08/01/86 | 126.5 | 192 | -65.5 | 0 | -65.5 | in section | | |
| | 130.5 | 192 | -61.5 | 0 | -61.5 | | | |
| | 134.5 | 192 | -57.5 | 0 | -57.5 | | | |
| | 138.5 | 192 | -53.5 | 0 | -53.5 | | | |
| | 139 | 192 | -53 | 0 | -53 | | | |
| | 140.9 | 192 | -51.1 | 0 | -51.1 | | | |
| | 141.8 | 192 | -50.2 | 0 | -50.2 | | | |
| | 143.1 | 192 | -48.9 | 0 | -48.9 | | | |
| | 144.3 | 192 | -47.7 | 0 | -47.7 | | | |
| | 145.5 | 192 | -46.5 | 0 | -46.5 | | | |
| | 146.8 | 192 | -45.2 | 0 | -45.2 | | | |
| | 148.1 | 192 | -43.9 | 0 | -43.9 | | | |
| | 148.6 | 192 | -43.4 | 0 | -43.4 | | | |
| | 148.9 | 192 | -43.1 | 0 | -43.1 | | | |
| | 149.9 | 192 | -42.1 | 0 | -42.1 | | | |
| | 150.8 | 192 | -41.2 | 0 | -41.2 | | | |
| | 152.1 | 192 | -39.9 | 0 | -39.9 | | | |
| | 154.6 | 192 | -37.4 | 0 | -37.4 | | | |
| | 155.4 | 192 | -36.6 | 0 | -36.6 | | | |
| | 156.6 | 192 | -35.4 | 0 | -35.4 | | | |
| | 157.2 | 192 | -34.8 | 0 | -34.8 | | | |
| | 158.3 | 192 | -33.7 | 0 | -33.7 | | | |
| | 159.2 | 192 | -32.8 | 0 | -32.8 | | | |
| | 160.2 | 192 | -31.8 | 0 | -31.8 | | | |
| | 161.1 | 192 | -30.9 | 0 | -30.9 | | | |
| | 162.3 | 192 | -29.7 | 0 | -29.7 | | | |
| | 163 | 192 | -29 | 0 | -29 | | | |
| | 163.7 | 192 | -28.3 | 0 | -28.3 | | | |
| | 164.6 | 192 | -27.4 | 0 | -27.4 | | | |
| | 165.7 | 192 | -26.3 | 0 | -26.3 | | | |
| | 166.9 | 192 | -25.1 | 0 | -25.1 | -1273.4 | 0 | -1273.4 |

Leyden Pound Days

| Date | Pressure | Constant | Pound Days | Pound Days High | Pound Days Low | Total Pound Days | Total Pound Days High | Total Pound Days Low |
|---|---|---|---|---|---|---|---|---|
| 09/01/86 | 168 | 192 | -24 | 0 | -24 | | | |
| | 169.1 | 192 | -22.9 | 0 | -22.9 | | | |
| | 168.8 | 192 | -23.2 | 0 | -23.2 | | | |
| | 169.5 | 192 | -22.5 | 0 | -22.5 | | | |
| | 170.2 | 192 | -21.8 | 0 | -21.8 | | | |
| | 170.7 | 192 | -21.3 | 0 | -21.3 | | | |
| | 171.5 | 192 | -20.5 | 0 | -20.5 | | | |
| | 172.4 | 192 | -19.6 | 0 | -19.6 | | | |
| | 173.1 | 192 | -18.9 | 0 | -18.9 | | | |
| | 173.4 | 192 | -18.6 | 0 | -18.6 | | | |
| | 173.5 | 192 | -18.5 | 0 | -18.5 | | | |
| | 174.1 | 192 | -17.9 | 0 | -17.9 | | | |
| | 174.6 | 192 | -17.4 | 0 | -17.4 | | | |
| | 175.1 | 192 | -16.9 | 0 | -16.9 | | | |
| | 175.8 | 192 | -16.2 | 0 | -16.2 | | | |
| | 179.3 | 192 | -12.7 | 0 | -12.7 | | | |
| | 181.9 | 192 | -10.1 | 0 | -10.1 | | | |
| | 185.1 | 192 | -6.9 | 0 | -6.9 | | | |
| | 187.2 | 192 | -4.8 | 0 | -4.8 | | | |
| | 189.1 | 192 | -2.9 | 0 | -2.9 | | | |
| | 191.9 | 192 | -0.1 | 0 | -0.1 | | | |
| | 193.5 | 192 | 1.5 | 1.5 | 0 | | | |
| | 192.3 | 192 | 0.3 | 0.3 | 0 | | | |
| | 192.8 | 192 | 0.8 | 0.8 | 0 | | | |
| | 192.6 | 192 | 0.6 | 0.6 | 0 | | | |
| | 192.9 | 192 | 0.9 | 0.9 | 0 | | | |
| | 193 | 192 | 1 | 1 | 0 | | | |
| | 193 | 192 | 1 | 1 | 0 | | | |
| | 193.1 | 192 | 1.1 | 1.1 | 0 | | | |
| | 192.5 | 192 | 0.5 | 0.5 | 0 | -330 | 7.7 | -337.7 |
| 10/01/86 | 192.7 | 192 | 0.7 | 0.7 | 0 | | | |
| | 195.6 | 192 | 3.6 | 3.6 | 0 | | | |
| | 196.9 | 192 | 4.9 | 4.9 | 0 | | | |
| | 197.5 | 192 | 5.5 | 5.5 | 0 | | | |
| | 198.9 | 192 | 6.9 | 6.9 | 0 | | | |
| | 200 | 192 | 8 | 8 | 0 | | | |
| | 201.2 | 192 | 9.2 | 9.2 | 0 | | | |
| | 202.4 | 192 | 10.4 | 10.4 | 0 | | | |
| | 203.4 | 192 | 11.4 | 11.4 | 0 | | | |
| | 204.6 | 192 | 12.6 | 12.6 | 0 | | | |
| | 205.9 | 192 | 13.9 | 13.9 | 0 | | | |
| | 206.9 | 192 | 14.9 | 14.9 | 0 | | | |
| | 208.5 | 192 | 16.5 | 16.5 | 0 | | | |
| | 209.3 | 192 | 17.3 | 17.3 | 0 | | | |
| | 210.2 | 192 | 18.2 | 18.2 | 0 | | | |
| | 211 | 192 | 19 | 19 | 0 | | | |
| | 212.2 | 192 | 20.2 | 20.2 | 0 | | | |
| | 213.3 | 192 | 21.3 | 21.3 | 0 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 214.3 | 192 | 22.3 | 22.3 | 0 | | | |
| | 215.4 | 192 | 23.4 | 23.4 | 0 | | | |
| | 216.3 | 192 | 24.3 | 24.3 | 0 | | | |
| | 216.9 | 192 | 24.9 | 24.9 | 0 | | | |
| | 218.4 | 192 | 26.4 | 26.4 | 0 | | | |
| | 219.2 | 192 | 27.2 | 27.2 | 0 | | | |
| | 220.3 | 192 | 28.3 | 28.3 | 0 | | | |
| | 221.3 | 192 | 29.3 | 29.3 | 0 | | | |
| | 222.4 | 192 | 30.4 | 30.4 | 0 | | | |
| | 223.5 | 192 | 31.5 | 31.5 | 0 | | | |
| | 224 | 192 | 32 | 32 | 0 | Shut in | | |
| | 225.1 | 192 | 33.1 | 33.1 | 0 | | | |
| | 224.3 | 192 | 32.3 | 32.3 | 0 | 579.9 | 579.9 | 0 |
| 11/01/86 | 223.8 | 192 | 31.8 | 31.8 | 0 | Dick | | |
| | 223.3 | 192 | 31.3 | 31.3 | 0 | | | |
| | 222.8 | 192 | 30.8 | 30.8 | 0 | | | |
| | 222.4 | 192 | 30.4 | 30.4 | 0 | | | |
| | 222.1 | 192 | 30.1 | 30.1 | 0 | | | |
| | 222 | 192 | 30 | 30 | 0 | | | |
| | 225.2 | 192 | 33.2 | 33.2 | 0 | | | |
| | 226.7 | 192 | 34.7 | 34.7 | 0 | | | |
| | 228.1 | 192 | 36.1 | 36.1 | 0 | | | |
| | 229.5 | 192 | 37.5 | 37.5 | 0 | | | |
| | 230.2 | 192 | 38.2 | 38.2 | 0 | | | |
| | 230.8 | 192 | 38.8 | 38.8 | 0 | | | |
| | 230.5 | 192 | 38.5 | 38.5 | 0 | | | |
| | 235.4 | 192 | 43.4 | 43.4 | 0 | | | |
| | 236.7 | 192 | 44.7 | 44.7 | 0 | | | |
| | 238.3 | 192 | 46.3 | 46.3 | 0 | | | |
| | 239.6 | 192 | 47.6 | 47.6 | 0 | | | |
| | 240.8 | 192 | 48.8 | 48.8 | 0 | | | |
| | 242.2 | 192 | 50.2 | 50.2 | 0 | | | |
| | 242.6 | 192 | 50.6 | 50.6 | 0 | | | |
| | 241.9 | 192 | 49.9 | 49.9 | 0 | | | |
| | | | | | | 822.9 | 822.9 | 0 |


300
240
180
120
60
0
86 L&U
P/N
120,000
240,000
720,000
1,200,000
1,680,000
2.04
2160000
2,640,000
2,120,000
5,360
3600,000
47 1320
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PSC 039682

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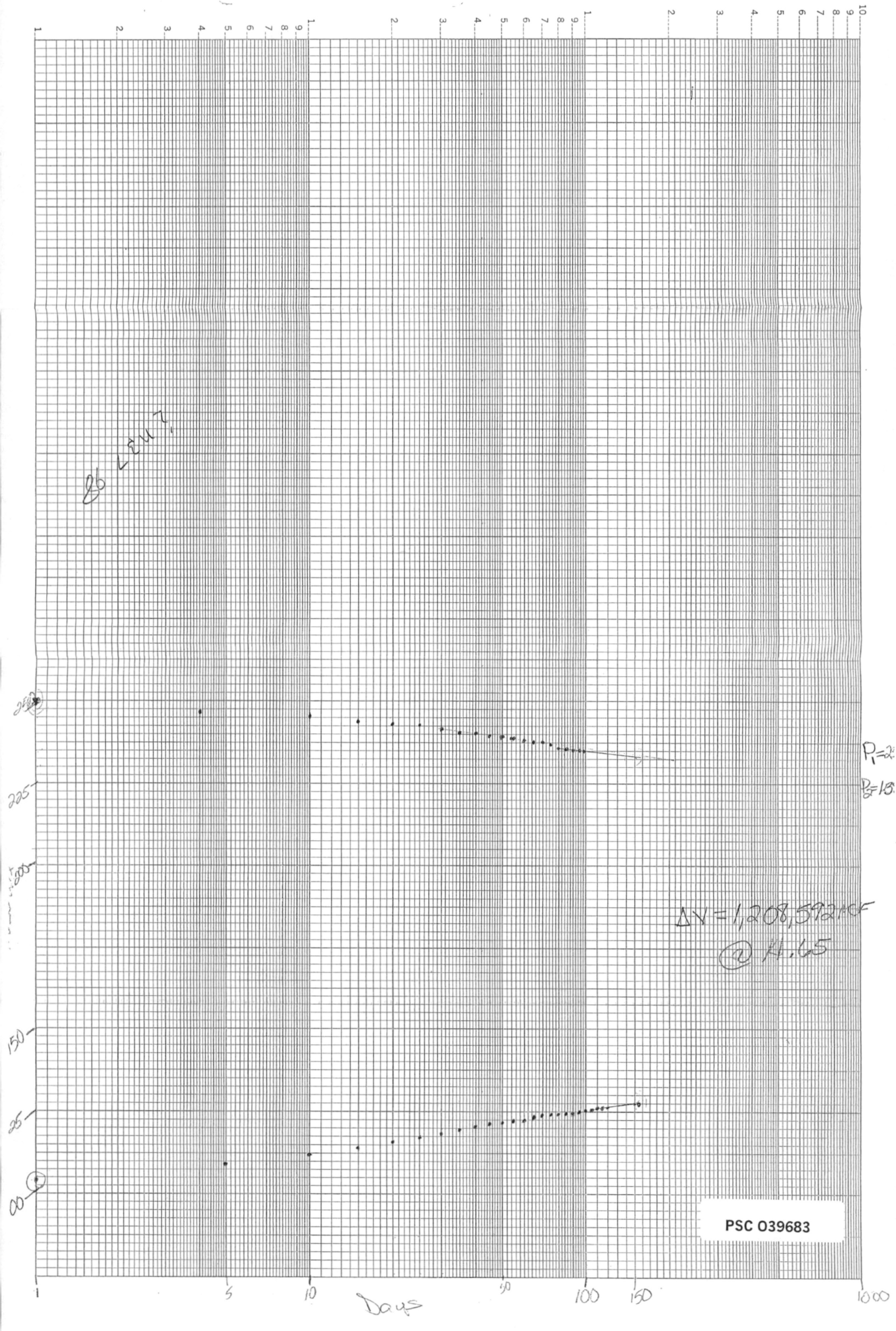
47 5490



INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE December 30, 1981

TO Vic Coleman — General Accounting DEPARTMENT OR DIVISION

FROM Jim Gerrity — Western Slope Gas Company DEPARTMENT OR DIVISION

ATTN.

SUBJ. Gas Underground Storage Inventory Adjustment

After careful review by Western's Reservoir Engineering section, it has been estimated that the Fruita underground storage facility has 12,100 Mcf less natural gas than currently booked. Leyden, on the other hand, is estimated to have 50,000 mcf more natural gas than currently booked. Both the Roundup and Ashury inventories are unchanged.

Please contact me with any questions regarding this matter.

Jim

Jim Gerrity

cc: John Kasprzak
Pete Hilbert
Steve Banks
Chuck Becker
Bill Udig
Kent Watanabe
Jerry Kilpatrick

Bennitt's

"Leyden, on the other hand, is estimated to have 50,000 mcf more natural gas than currently booked"

PSC 039684

FORM (A) 401-16-1458

PAGE
FOLIO

# SUMMARY OF GAS DELIVERED

Gas Delivered To Leyden Storage Project at Leyden

For Period From November 1, 1984 To November 30, 1984

| | | |
|---|---|---|
| Volume in MCF For | 14.65# | 12.37# |
| Injection | 45,510 | 53,897 |
| Withdrawal | - | - |
| *Additional MCF | 50,000 | 59,215 |
| Net Injection | 95,510 | 113,112 |
| Storage as of Midnight | | |
| Cushion Gas | 794,000 | 940,334 |
| Working Gas | 2,315,826 | 1,742,638 + 2,742,6 |
| Total in Storage | 3,109,826 | 3,682,972 |

Cost payable to interest holders:

Mcf x $0.0195147 = $

* Additional working gas per Jim Gerrity's memo Dec. 30, 1983.

+ additional working was per Jim Gerrity's memo Dec 30 1985

PSC 039685

LEYDEN 83 L & U

| 82.9# | | BHP | BHP/Z |
|---|---|---|---|
| STABLIZED LOW PRESS. | 82.9 PSIG | 96.46 | 98.12 |
| STABLIZED HIGH PRESS = | 234.1 PSIG | 240.09 | ~~250.63~~ 261.74 |

CHANGE OF VOLUME = 1,710,790 MCF -

TOTAL INVENTORY PER POUND

83 LOW 1,089,809 / 98.12 = 11,107
HIGH 2,800,599 / ~~[illegible]~~ 261.74 = ~~11,174~~ 10,700

| | | | BHP | BHP/Z |
|---|---|---|---|---|
| 82 | STABLIZED LOW PRESS | 82.8 PSIG | 96.36 | 98.02 |
| | STABLIZED HIGH PRESS | 232.5 PSIG | 248.63 | 259.96 |

ΔVOLUME = 1,632,774

Low
High 2,731,056 / 259.96 = 10506

83 INCREMENTAL INVENTORY PER POUND
1,710,790 / (~~261.74~~ 163.62 - 98.12) = ~~11,117~~ 10,456

82 INCREMENTAL
1,632,774 / 161.94 10,083

191,405 NOV. INJ.
1,519,385 OCT INJ.
1,710,790 MCF

APRIL 23
OCT 3

| | |
|---|---|
| 10 | 31 |
| 31 | 30 |
| 30 | 15 |
| 31 | 45 |
| 31 | |

PSC 039686

| | | |
|---|---|---|
| 82 | TOTAL INV. /# | 10,506 |
| 83 | TOTAL INV/# | 10,700 |

| | | |
|---|---|---|
| 82 | INCREMENTAL INV/# | 10,083 |
| 83 | INCROMENTAL INV/# | 10,456 |

TOTAL $\frac{10700}{10506} = 1.0185$ 5

INCREM. $\frac{10,456}{10,083} = 1.037$

+ 50,000

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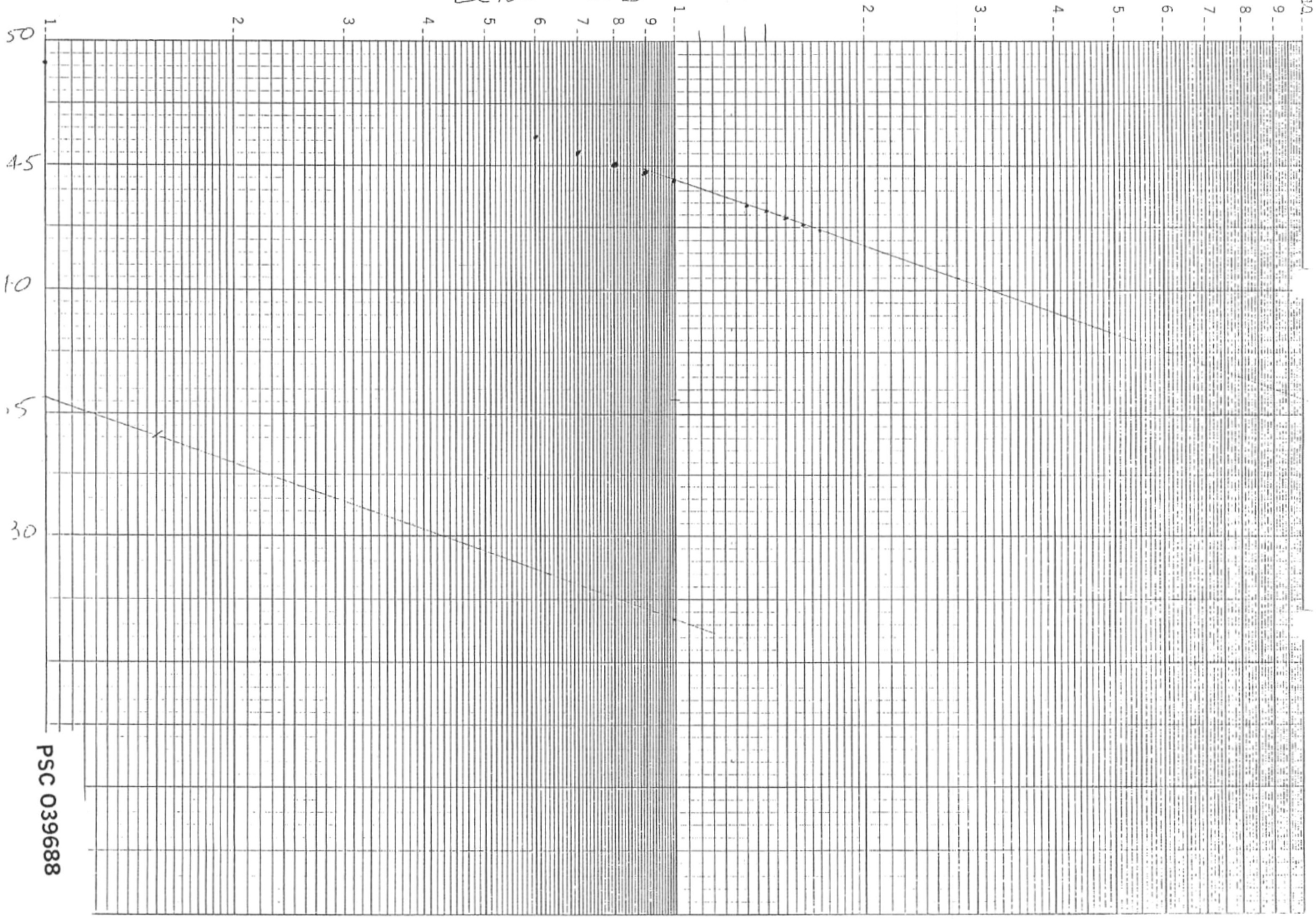
LEYDEN STAB PRESSURE 83-84




PSC 039688

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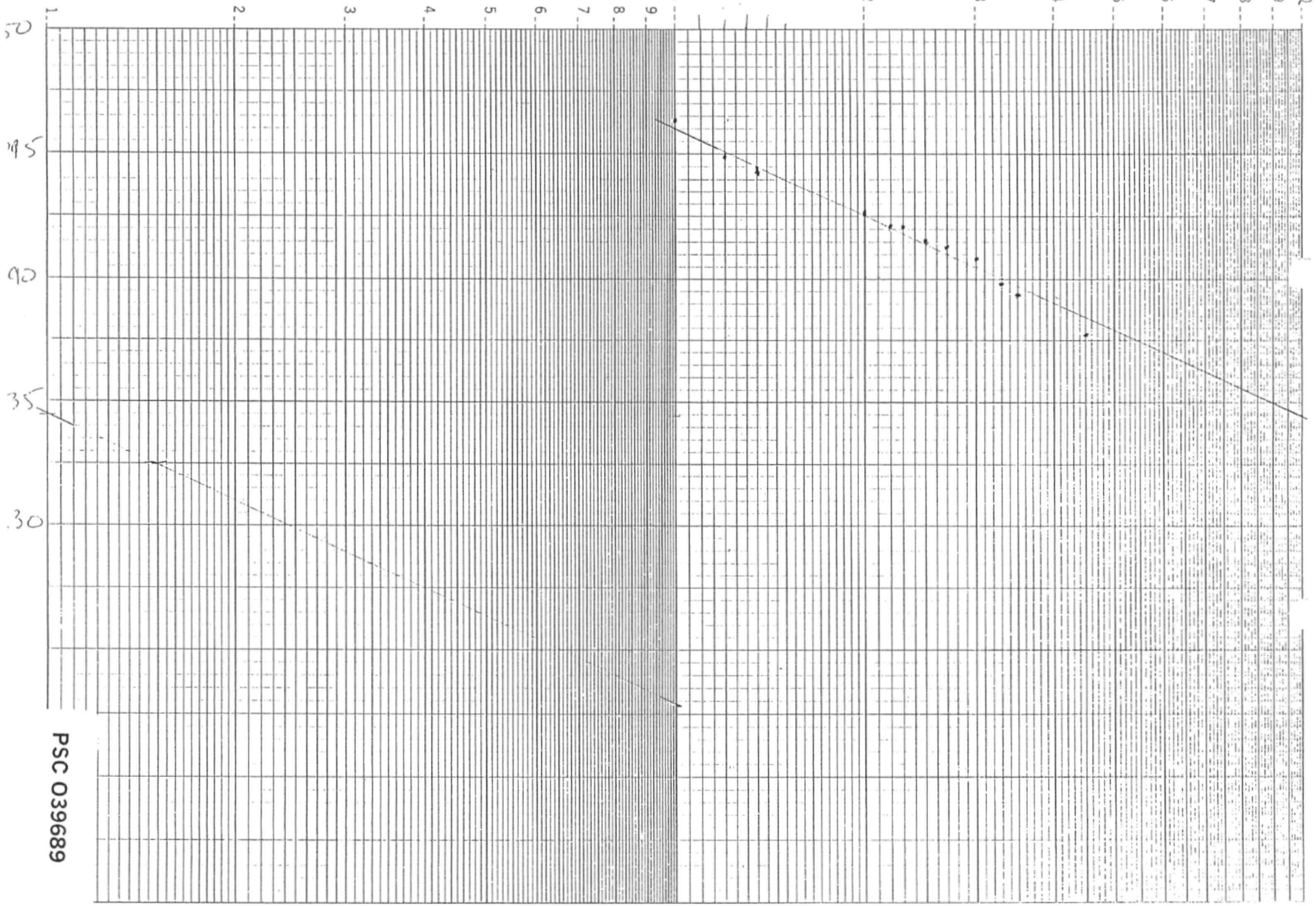
46 4970

LEYDEN STAB PRESSURE 82-83




PSC 039689

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE December 1, 1982

TO Mr. Victor L. Coleman, Supervisor — General Books (DEPARTMENT OR DIVISION)

FROM Kristen Larson, Special Projects Engineer — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. Account 1823-18 Gas Losses

It is recommended that no gas be written off as Lost and Unaccounted for Gas in the Underground Storage Operations for 1982.

Kristen Larson
Kristen Larson

KL:cp

CONCURRENCE:

Ken Hooker 12/2/82
Kenneth Hooker, Jr.
Gas Supply Manager

Donald E. Lancaster
Donald E. Lancaster, Manager
Fuel Supply Development

The Total Volume Equation for the 1982-83 season is derived below:

1. The initial cavern pressure on 12/10/81 was 249.9 psig. While shut in for 27 days from 12/10/81 until 1/6/82, the pressure dropped to 246.5 psig. Extrapolating this pressure-time relationship graphically for 150 days, the pressure was determined to be 238 psig. (See Figures 1A & 1B).

2. Following a major withdrawal period, the cavern pressure is 64.0 psig on 5/13/82. While shut in from 5/13/82 through 8/3/82, the pressure rose to 83.3 psig. Again graphically extrapolating for 150 days, the pressure rose to 91.0 psig. (See Figures 2A & 2B).

3. From 12/10/81 until 8/3/82, 1,716,850 MCF at 14.65 was withdrawn from the Leyden Mine.

4. The stabilized cavern pressures of 238 and 91 psig must be converted to Absolute Bottom Hole Pressures.

$$P = 238.0 \text{ psig} = (238.0 + 12.29) = 250.29 \text{ psia}$$

$$P_{\text{bottom hole}} = 250.29 \exp\left[\frac{(0.01878)(0.6394)(790)}{(0.96)(530)}\right]$$

$$P_{\text{bottom hole}} = 255.62 \text{ psia}$$

Correcting for supercompressibility

$$\frac{255.62}{Z} = \frac{255.62}{0.96} = 266.3 \text{ psia}$$

Similarly, for P = 91 psig,

$$P = 91 \text{ psig} = (91.0 + 12.29) = 103.29 \text{ psia}$$

$$P_{\text{bottom hole}} = 103.29 \text{ psia} \exp\left[\frac{(0.01878)(0.6394)(790)}{(0.96)(530)}\right]$$

$$P_{\text{botttom hole}} = 105.1 \text{ psia}$$

Correcting for supercompressibility

$$\frac{105.1}{0.98} = 107.3 \text{ psia}$$

| Gauge Pressure | Bottom Hole/Z Pressure |
|---|---|
| 91.0 | 107.3 psia |
| 238.0 | 266.3 |
| 250.0 | 278.2 |
| 0.0 | 12.29 |

5. If the gas withdrawn from Leyden is divided by the difference in stabilized cavern pressure, a constant defining the relationship between the stabilized cavern pressure and the volume is determined.

$$\frac{1{,}716{,}850 \text{ MCF}}{(266.3 - 107.3) \text{ psia}/\bar{z}} = 10798 \frac{\text{MCF}}{\text{psia}/\bar{z}}$$

The Total Volume Equation is

Total Volume = (Botttom hole cavern pressure/$\bar{Z}$)(10798 $\frac{\text{MCF}}{\text{psia}/\bar{z}}$)

or TV = (10798)(CP/$\bar{Z}$)

6. In order that the total volume equation can be used with gauge pressures, it must be modified as follows:

$$(10798 \frac{\text{MCF}}{\text{psia}/\bar{z}})\ (278.2) = 3{,}004{,}004 \text{ MCF}$$

$$(10798 \frac{\text{MCF}}{\text{psia}/\bar{z}})(12.29) = 132{,}707 \text{ MCF}$$

$$3{,}004{,}004 - 132{,}707 = 2{,}871{,}297 \text{ MCF}$$

$$\frac{2{,}871{,}297 \text{ MCF}}{(250 - 0) \text{ psig}} = 11{,}485 \frac{\text{MCF}}{\text{psig}}$$

PSC 039692

K.D.L.
12/2/82

Calculation of Lost and Unaccounted for Gas in 1982

1. From the 1982-83 Total Volume Equation (based on the previous year's data) the volume of gas in place on July 26, 1982 can be determined.

   A. On July 26, 1982 the cavern pressure was 82.3 psig. The corresponding stabilized cavern pressure is 91.0 psig. The bottom hole pressure corrected for supercompressibility is 107.3 psia/z.

   B. The total volume equation is

$$TV = (10798 \frac{MCF}{psia/z})CP/Z$$

$$TV = (10798)(107.3 \text{ psia/z}) = 1,158,625 \text{ MCF}$$

   From this equation, the volume in place in the cavern is 1,158,625 MCF (at 14.65 psia).

2. From the Summary of Gas Delivered Reports the total MCF in storage is 1,106,327 at 14.65 psia.

3. Based on the above, the total volume equation predicts in excess of 52,298 MCF of the value documented in the Summary of Gas Delivered Reports.

4. It is the recommendation of this author that no L & U gas be written off for 1982. The excess gas predicted by the total volume equation (52,298 MCF) could be gas that is migrating back into the cavern.

   During the summer of 1980 the mine pressure was held high, not allowing the gas to migrate back into the cavern. Therefore, gas that usually returns to the cavern was not allowed to do so.

   In the summer of 1981 the pressure in the cavern was decreased to 59.4 psig, allowing gas to migrate back into the cavern. In September of 1981 a pound day balance was initiated. The pound day balance is an attempt to recover lost and unaccounted for gas by allowing the mine to equalize the number of days and the magnitude of their pressure above aquifer pressure with the number of days below aquifer pressure.

   Due to the work being done on well No. 15, the refill of the mine was delayed and the mine was held at a low pressure longer than desirable, if the number of pound days low were to equal the number of pound days high. Therefore, the number of pound days low and the magnitude of their pressure is greater than the number and magnitude of pound days high. This further allows gas to migrate back into the cavern.

   The recovery of 52,298 MCF is explained by the high shut in pressure of 1980 followed by the low cavern pressure of 1981 and 1982 coupled by the pound day balance. Based on the total volume equation and supported by the three summer shut in pressures previously mentioned, this author recommends no L & U gas be written off for 1982.

**PSC 039693**

K.D.L.
12/2/82

Calculation of Lost and Unaccounted for Gas in 198?

1. From the 1982-1983 Total Volume Equation (based on the previous years data) the volume of gas in place on July 26, 1982 can be determined.

A. On July 26, 1982 the cavern pressure was 82.3 psig. The corresponding stabalized cavern pressure is 91.0 psig. The bottomhole pressure corrected for supercompressibility is 107.3 psia/z

B. The total volume equation is

$$TV = \left(10798 \frac{MCF}{psia/z}\right) CP/z$$

$$TV = (10798)(107.3\ psia/z) = 1{,}158{,}625\ MCF$$

From this equation, the volume on place in the cavern is 1,158,625 MCF (at 14.65 PSIA)

2. From the Summary of Gas Delivered Reports the Total MCF in Storage is 1,106,327 at 14.65 PSIA.

3. Based on the above, the total volume equation predicts in excess of 52,298 MCF of the value documented in the Summary of Gas Delivered Reports.

PSC 039694

4. It is the recomendation of this author that no L+U gas be written off for 1981. The excess gas predicted by the total volume equation (52,298 MCF) could be gas that is migrating back into the cavern.

During the summer of 1980 the mine pressure was held high, not allowing the gas to migrate back into the cavern due to the high cavern pressure. Therefore, gas that usually returns to the cavern was not allowed to do so due to the high cavern pressure.

In the summer of 1981 the pressure in the cavern was decreased to 59.4 psig allowing gas to migrate back into the cavern. In September of 1981 a pound day balance was initiated. The pound day balance is an attempt to recover lost and unaccounted for gas by allowing the mine to equalize the number of days and the magnitude of their pressure above aquifer pressure with the number of days below aquifer pressure.

PSC 039695

Due to work being done on well #15, the refill of the mine was delayed and the mine was held at a low pressure longer than desireable if the number of lb days low were to equal the number of lb days high. Therefore, the number of lb days low and the magnitude of their pressure is greater than the number and

magnitude of 15 days high. This further allows gas to migrate back into the cavern

The recovery of 52,298 MCF is explained by the high shut in pressure of 1980 followed by the low cavern pressures of 1981 and 1982 coupled by the pound day balance. Based on the Total Volume Equation and supported by the three summer shut-in pressures previously mentioned. this author recomends no L+U gas be written off for 1981.

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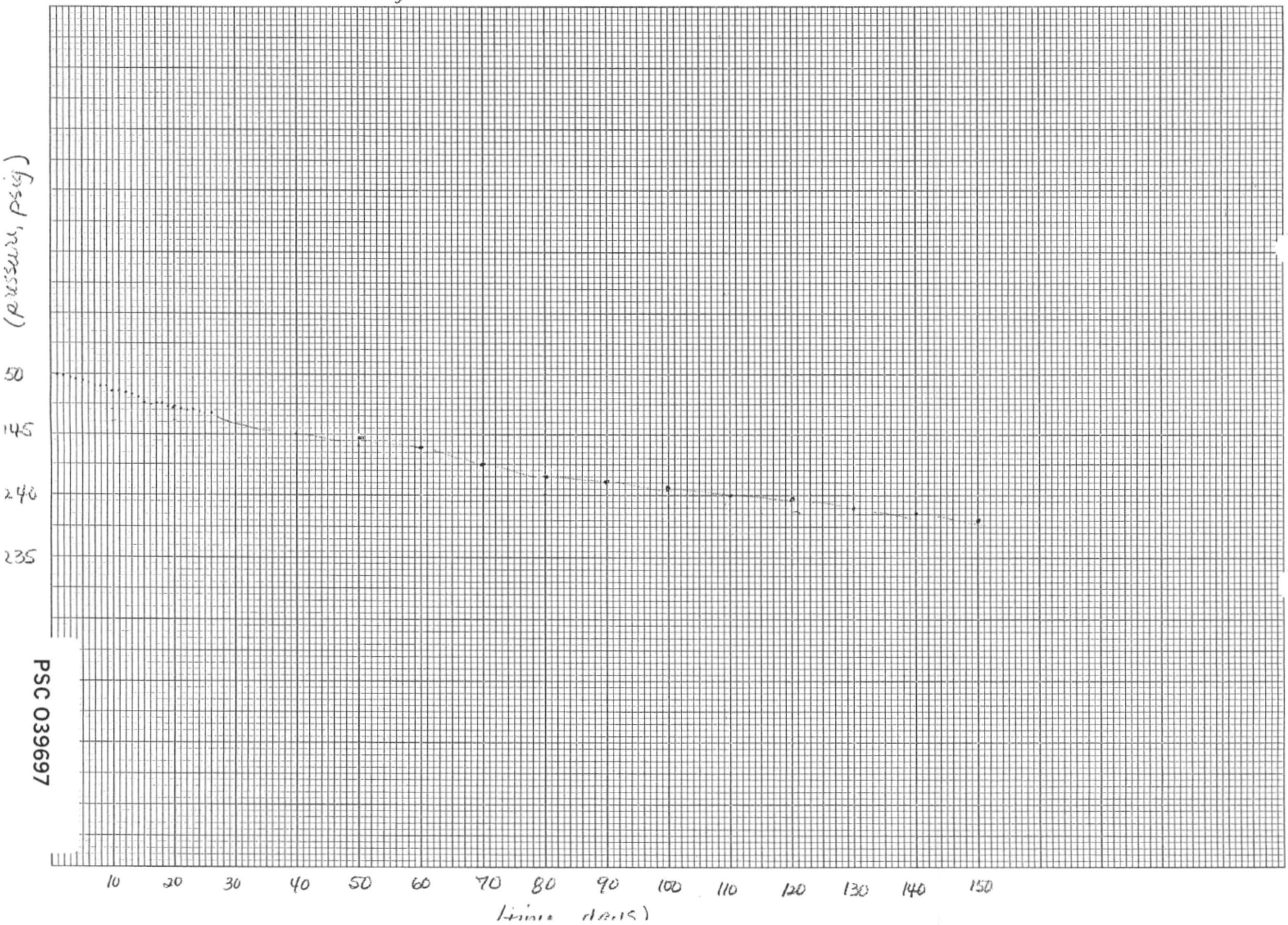
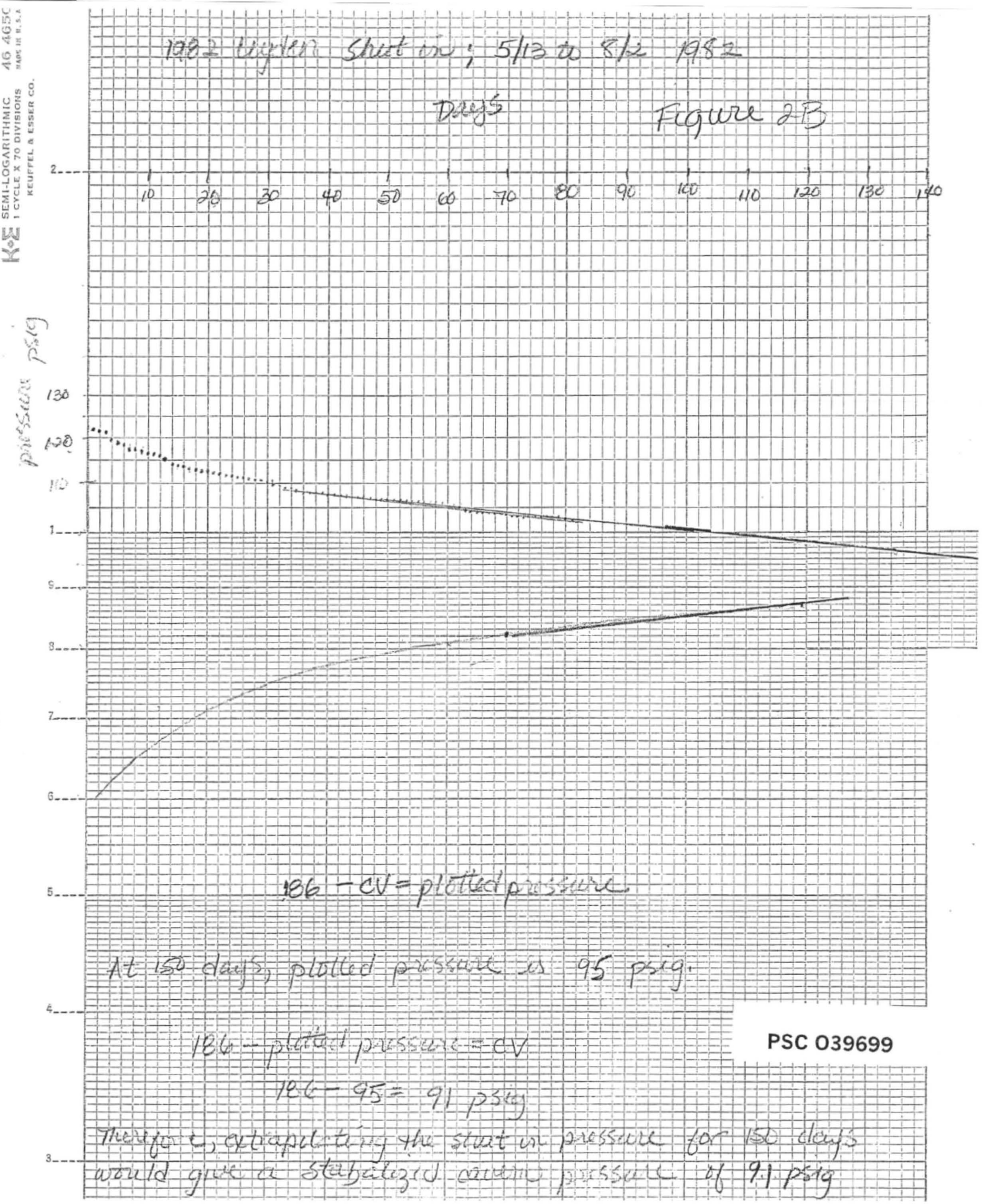
46 1320

Figure 1A

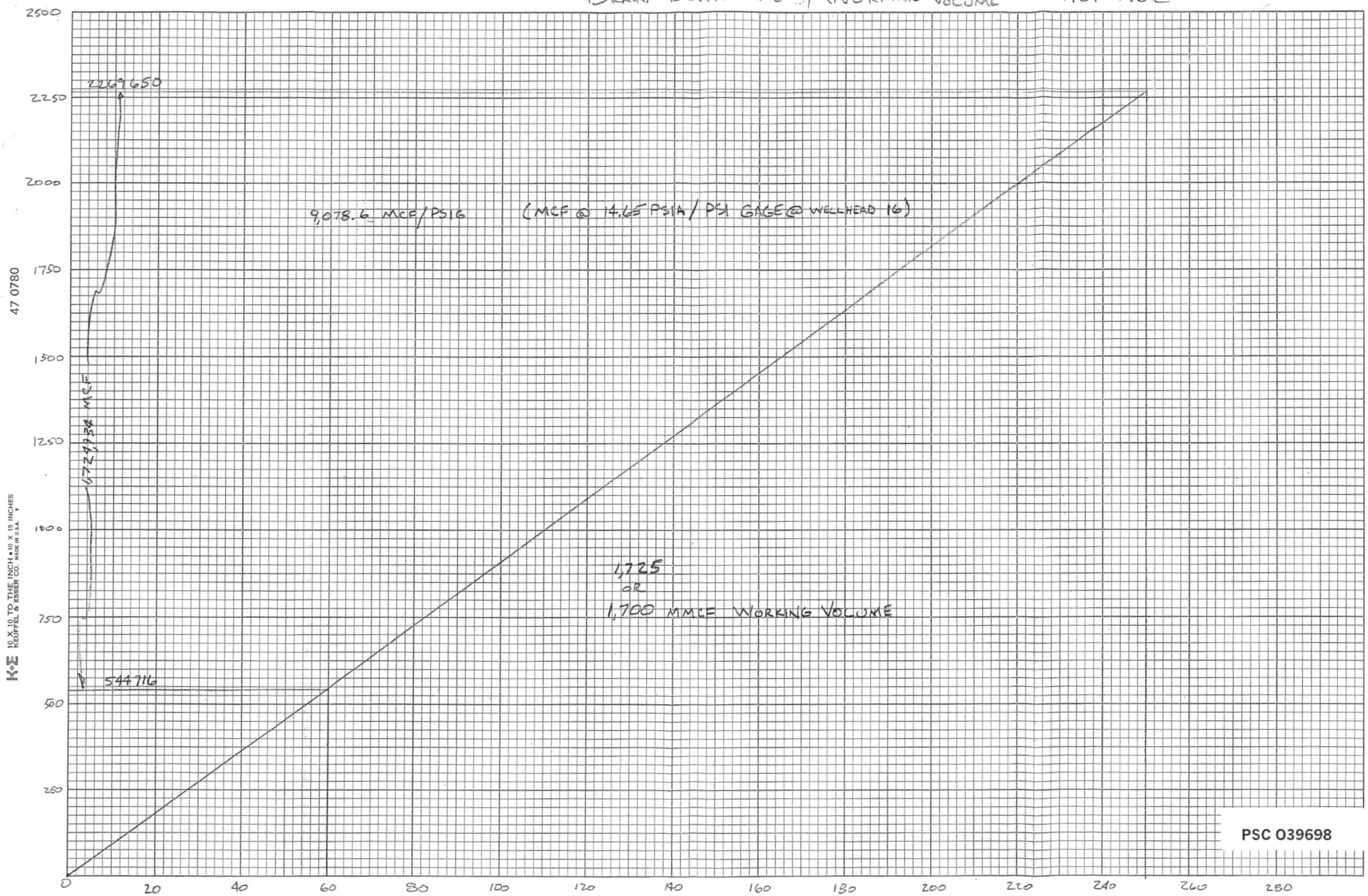



PSC 039697


1982 Upper Shut in; 5/13 to 8/2 1982
Days
Figure 2B
pressure psig
10 20 30 40 50 60 70 80 90 100 110 120 130 140
130
120
110
186 - CV = plotted pressure
At 150 days, plotted pressure is 95 psig.
186 - plotted pressure = CV
186 - 95 = 91 psig
Therefore, extrapolating the shut in pressure for 150 days would give a stabilized casing pressure of 91 psig

PSC 039699

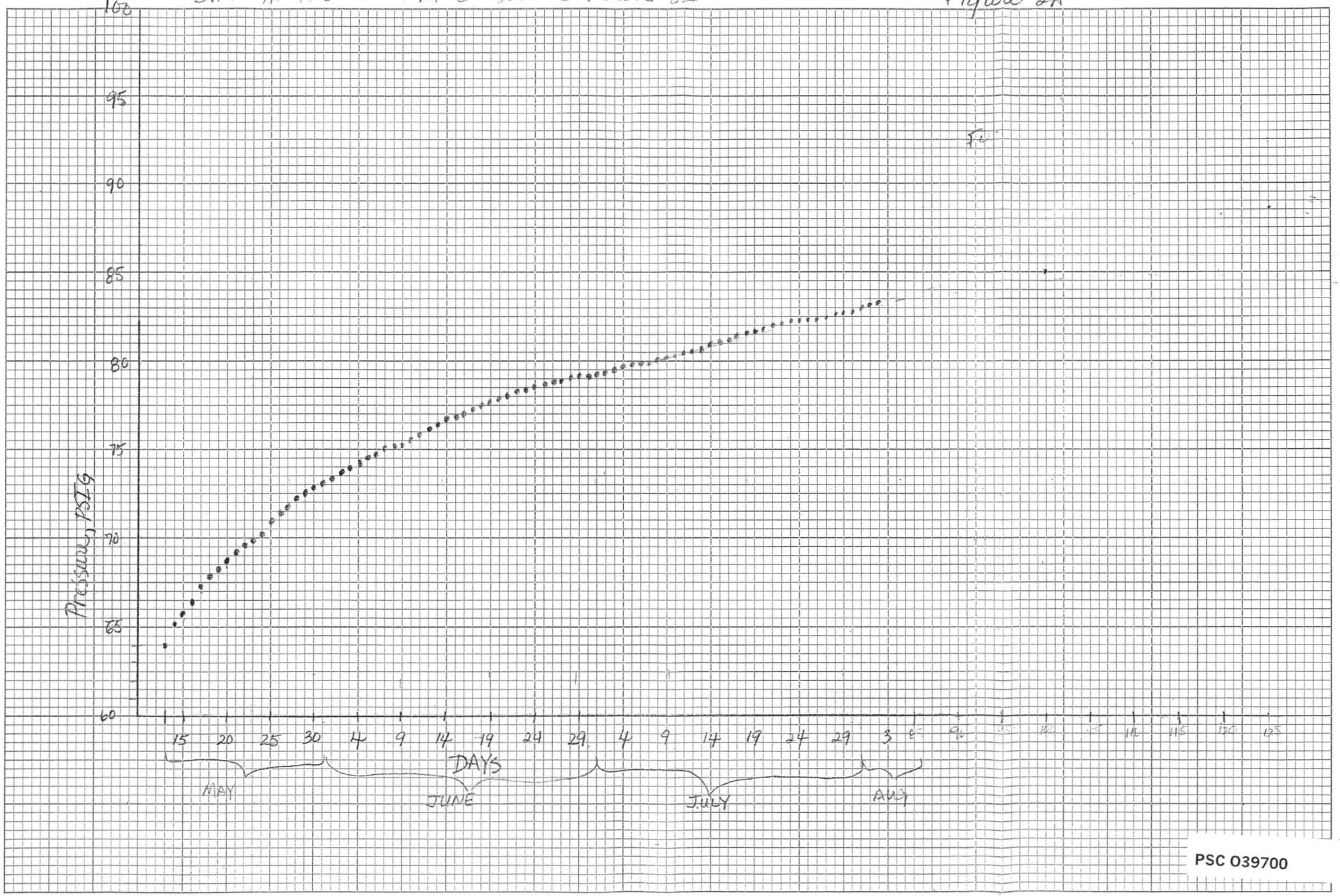
DRAWN DOWN RATE .../WORKING VOLUME 1981-1982




PSC 039698

SHUT IN PRESSURE AT LEYDEN SUMMER '82

Figure 2A




PSC 039700

47 0780
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INTER-DEPARTMENT MEMO - PUBLIC SERVICE COMPANY OF COLORADO

DATE November 3, 1982

TO Mr. R. C. Engebrit, Superintendent, Leyden Gas Storage

FROM Mr. R. D. Reeves, General Accounting Manager

ATTN

SUBJ Review of Specific Accounts and Amounts for Year-End Closing

We are again at the time of year when certain accounts should be carefully reviewed for the year-end closing.

At September 30, 1982, our records show balances in the following accounts for which you have responsibility:

1823-18 Gas Losses

*Are we to anticipate an inventory adjustment representing the cost of gas lost or unaccounted for in underground storage operations?

Please review the above accounts and submit a report regarding the items to Vic Coleman, Room 520, on or before November 26, 1982. If you have any questions please call Vic on 571-7969.

R. D. Reeves

R. D. Reeves

RDR/bdp

PSC 039702

FORM 980-22-2904 INTER–DEPARTMENT MEMO – FUEL RESOURCES DEVELOPMENT CO.

DATE February 24, 1982

TO Mr. Bill Uding, Special Projects Engineer, Fuel Supply Development
DEPARTMENT OR DIVISION

FROM Mr. D. F. Cook, Engineering & Production Manager, Fuelco
DEPARTMENT OR DIVISION

ATTN.

SUBJ. SHUT-IN PRESSURE FOR LEYDEN

In reply to your memo of January 27, 1982, Fuelco has nothing to add to your plan to lower cavern pressure to shut-in pressure of 70 psig.

We are in the process of running GR-Neutron logs on the Leyden wells and expect to be finished by February 27th.

D. F. Cook

DFC/b

PSC 039703

FORM 22 0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE January 20, 1982

TO Mr. William E. Brackett, Coordinator — Regulatory Analysis (DEPARTMENT OR DIVISION)

FROM Mr. Bill Uding, Engineer — Special Projects (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. Cushion Gas at Leyden

The reservoir study of the Leyden Storage Project revealed that a change in the reported cushion gas volume is in order. I recommend that the old figure of 537,000 MCF be changed to 794,000 MCF.

There are two reasons for the increased volume. One is the use of the total volume equation in place of the drawdown rate equation and the other is a net change in the cavern volume itself.

A new method to determine total gas volumes in storage has been developed which uses a calculated stablized pressure instead of actual cavern pressure following a drawdown. This method accounts for gas that has migrated beyond the cavern during high pressure intervals and returns during low pressure shut-ins.

My recommended cushion gas definition is the total gas volume remaining at depletion pressure. The old figure (537,000) was produced using the drawdown equation from 0. to 60. PSIG. It did not account for gas in the surrounding formation or in the cavern at 0 PSIG.

A second correction to be applied to the old figure is to account for a change in the cavern volume. The calculated volume of the cavern grew from 92.7 $M^2CF$ in 1979 to 98.2 $M^2CF$ in 1981. Some 7 $M^2CF$ of water was withdrawn during this interval. As the size of the cavern increased, the gas volume to fill the mine to 60 PSIG also increased.

Bill

Bill Uding

PSC 039704

The Leyden Storage operating and maintenance costs for which this department is responsible are as follows:

Lost and Unaccounted for Gas, Account No. 5920-21-16

The lost and unaccounted for gas for 1981 will be the difference between the total gas metered in and metered out of Leyden Storage from November 1, 1980 through October 31, 1981. The L and U gas for 1978 and 1979 was 130,404 MCF and 155,530 MCF at 14.65 psia respectively. It is recommended that a budgeted volume of 150,000 MCF be used along with the budgeted annual cost of gas to calculate the budget estimate for the 1981 Leyden L and U gas cost.

Gas and Water Royalties, Account No. 5930-67-14

The landowners were paid royalties totaling $34,236 in January 1980 and July 1980 for gas withdrawals made from Leyden during the period of July 1979 through June 1980. This amount was substantially lower than those gas royalties paid in January 1979 and July 1979 totaling $82,608. The reduction between 1979 and 1980 royalties was due to the elimination of the 1980 spring drawdown. However, it is uncertain at this time whether or not a spring drawdown will be initiated during 1981. Therefore, the withdrawals during the 1978-79 heating season, which were close to the design cold weather year, are a good indication of the withdrawals which will be experienced if the 1980-81 heating season is about 20% colder than normal and a spring drawdown is initiated. Water royalty payments in recent years have totaled approximately $200 annually. Therefore, it is recommended that an estimate of $84,000 be budgeted for 1981 gas and water royalties.

Lease Rental, Account No. 5920-51-13

The annual lease rental payments are stipulated in the agreements with the landowners and will total $50,414.11 each year through 1989. It is recommended that an estimate of $50,500 be included in the 1981 O & M Budget.

Well Operation and Maintenance, Account Nos. 5920-66-16 and 5920-66-17

It is recommended that $60,000 in 1980 dollars be budgeted for costs necessary to operate and maintain the water, observation and gas wells and shaft seals during 1981.

It is recommended that trending be used for the above expenses for years 1981 through 1985.

The Leyden Storage Capital Construction Budget items and estimates have been reviewed with System Planning and are described on the attached program analysis

sheets. It is recommended that the Leyden remedial work be budgeted as a planned item for 1981, the downhole safety valves and the drilling and completion of one additional gas well be budgeted as contingent items for 1983 and that the Leyden remedial work be budgeted as contingent for 1982. The Leyden Storage expansion to 215 $M^2CFD$ should be budgeted as contingent for 1984.

John A. Shealy

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE August 28, 1981

TO Mr. R. D. Carnesi — Gas Budget & Statistics (DEPARTMENT OR DIVISION)

FROM Mr. E. E. Ellis, Solar Coordinator — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. 1982 Leyden Reservoir O & M Budget

Please use the following dollar estimates for the 1981 base for the 1982 Leyden Reservoir Operations and Maintenance Budget.

| FPC Account | Account Name | 1981 Dollars |
|---|---|---|
| 910-01816-11 | Wells Expense (Oper.) | $30,000 |
| 910-01832-11 | Mtc. of Wells (Mtce.) | $30,000 |

Please escalate these estimates using the rates provided in the 1982 Corporate Goals and Planning Guidelines.

For Leyden Lost and Unaccounted for gas please use 150,000 MCF at 14.65 psia per year. Please use the cost of gas figures from the September 17, 1980 Brackett to Hooker Cost of Gas memo.

Edward E. Ellis

Edward E. Ellis

EEE:sr

PSC 039708

| | | |
|---|---|---|
| 360 X 12 = | 4320 | FUELCO |
| 25000 X 1.1 = | 27500 | LOGING |
| | 30 000 | LABOR |
| TOTAL | 61 820 | |

(11) ello

| | (16) OPER 1816 | (17) MTCE 1832 |
|---|---|---|
| 72 | 6702 | 14682 |
| 73 | 9417 | 13048 |
| 74 | 12098 | 17157 |
| 75 | 17863 | 10109 |
| 76 | 42599 | 63503 |
| 77 | 30616 | 38,762 |
| 78 | 21447 | 52,126 |
| 79 | 45124 | 19,717 |
| 80 | 50963 | 24,140 |
| mo. 81 | 28420 | 2,120 |

( T CENTER HOW CHARGED CODE

REPORT NO. 5553

FUEL SUPPLY DEVELOPMENT 5920 - GAS SUPPLY MANAGER

| HOW CHARGED | FPC ACCOUNT / ACCOUNT CODE | ACCOUNT NAME | ACCOUNT GROUP |
|---|---|---|---|
| 14 | 910-01825-11 | STORAGE WELL ROYALTIES | GAS UNDERGROUND STORAGE - OPE |
| 15 | 910-01871-11 | DISTR LOAD DISPATCHING | GAS DISTRIBUTION - OPER. |
| 16 | 910-01816-11 | WELLS EXPENSES | GAS UNDERGROUND STORAGE - OPE |
| 17 | 910-01832-11 | MTCE OF WELLS | GAS UNDERGROUND STORAGE - MTC |
| 35 | 930-01871-11 | DISTR LOAD DISPATCHING | GAS DISTRIBUTION - OPER. |
| 55 | 910-00955-11 | UNDISTR GENER SUPV EXP | CLOSING ACCOUNTS |
| 58 | 910-00958-11 | UNDISTR GAS SUPPLY EXP | CLOSING ACCOUNTS |
| 65 | 098-01851-11 | SYSTEM CONT & LOAD DISP | GAS TRANSMISSION - OPER. |
| 85 | 910-00932-82 | MTCE GEN PLT-OFF FURN EQ | ADMIN. AND GENERAL - MTCE. |
| 90 | 910-00962-11 | TXS OTHER THAN INC | CLOSING ACCOUNTS |
| 96 | 910-00426-51 | OTHER INC DED-OTHER DED | OTHER INCOME AND DEDUCTIONS |
| 97 | 910-00926-19 | EMPL BENEFITS - MISC | ADMIN. AND GENERAL - OPER. |
| 98 | 910-00926-28 | EMPL BENE - LOST TIME | ADMIN. AND GENERAL - OPER. |

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE November 24, 1981

TO Mr. Victor Coleman, Supervisor — General Books (DEPARTMENT OR DIVISION)

FROM Mr. Bill Uding, Special Projects Engineer — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. Account 1823-18 - Gas Losses

It is recommended that 131,089 MCF at 14.65 PSIA (155,251 Mcf at 12.37 psig) be written off at the end of 1980 as Lost and Unaccounted For Gas in the Underground Storage Operations.

Bill Uding

BU:sr

CONCURRENCE:

Kenneth Hooker, Jr.
Gas Supply Manager

Donald E. Lancaster, Manager
Fuel Supply Development

PSC 039712

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

~~EDC~~ Bill

DATE October 26, 1981

TO R. C. Engebrit — Supt. Leyden Gas Storage (DEPARTMENT OR DIVISION)

FROM R. D. Reeves, General Accounting Manager (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. Review of Specific Accounts and Amounts for Year-End Closing

We are again at the time of year when certain accounts should be carefully reviewed for the year-end closing.

At September 30, 1981, our records show balances in the following accounts for which you have responsiblility:

1823-18 Gas Losses

*Are we to anticipate an inventory adjustment representing the cost of gas lost or unaccounted for in underground storage operations?

Please review the above accounts and submit a report regarding the balance to Vic Coleman, Room 520, on or before November 26, 1981. If you have any question please call Vic on Extension 571-7969.

R. D. Reeves

R. D. Reeves

RDR/bdt

Ken
would you take care of this?
Thanks, Ray Engebrit

PSC 039713

L & U, TOTAL STORAGE FOR, FALL 81

INTIAL STABILIZED PRESSURE

(1) STARTING NOV 22, UNTIL DEC 29
PRESSURE DROPS FROM 250.0 TO 247.8
STABILIZED PRESSURE EQUALS 242.7# (SEE GRAPH #1)

(2) INJECTIONS AND WITHDRAWS FROM NOV 22 UNTIL JULY 26

- 1829005

(3) FINAL CAVERN PRESSURE 76.1 PSIG.
ENDING STABLIZED PRESSURE = 85# (SEE GRAPH #2)

| GAGE PRESSURE | BOTTOM HOLE CORRECTED PSIA/Z | |
|---|---|---|
| 242.7# | 270.45 | (271.25) |
| 85# | 100.01 | (100.29) |
| 250 | 278.2 | |
| 0 | 12.2 | |

$$\frac{1829005}{170.44}$$

10731 MCF/PSIA/Z

10731 MCF/PSIA/Z × 278.2 PSIA/Z = 2985,364

2,985,

10731 × 12.2 = 130 919

285 444.6 / 250 11.418 M²CF/PSI

B

3

793,834

PSC 039714

$$96.97 \cdot e^{\left(\frac{.01877}{.988}\right)\left(\frac{.65}{520}\right)(790)}$$

$$\frac{98.8}{.988} \qquad 100$$

$$\frac{254.67\, e^{\left(\frac{.01877}{.96}\right)\left(\frac{.65}{520}\right)(790)}}{.96} \qquad 270.45$$

$$\frac{261.97\, e^{\frac{.01877}{.96}\left(\frac{.65}{520}\right)(790)}}{96} \qquad 278.2$$

$$\frac{11.97\, e^{\frac{.01877}{(1)}\left(\frac{.65}{520}\right)(790)}}{1}$$

FROM LAST INVENTORY SEPT 14/80

BEGINNING CORRECTED VOLUME = 2,786,704 MCF

TOTAL INJECTION AND WITHDRAWS METERED = 1829 005
143 920

VOLUME AS OF 7/26 ON BOOKS → 1,101,619

COMPUTED VOLUME ON 7/26

85 × 11,418 = 970 530

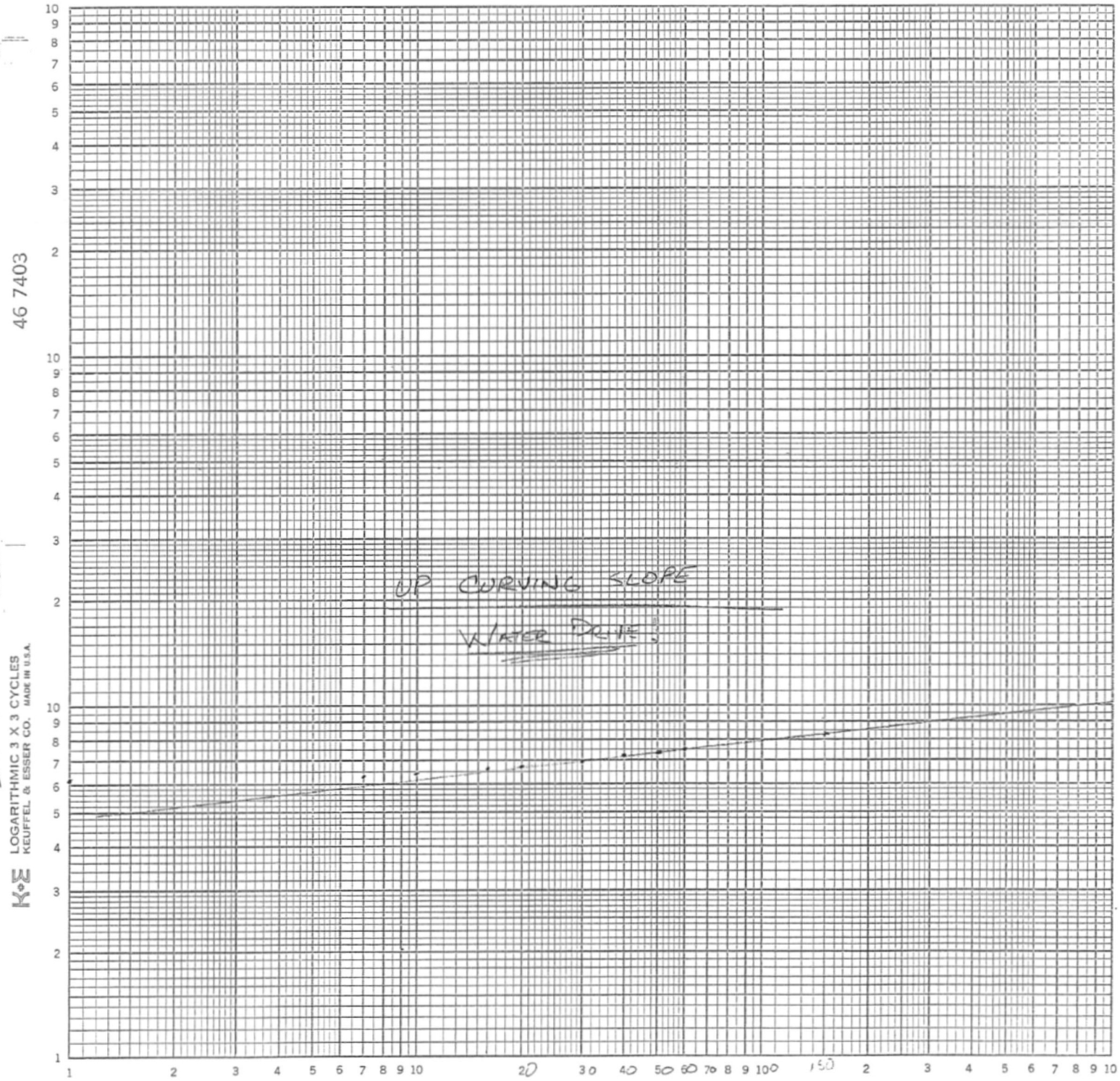
1,101,619
970 530

LOST & UNACCOUNTED FOR. 131,089 MCF

GRAPH #2

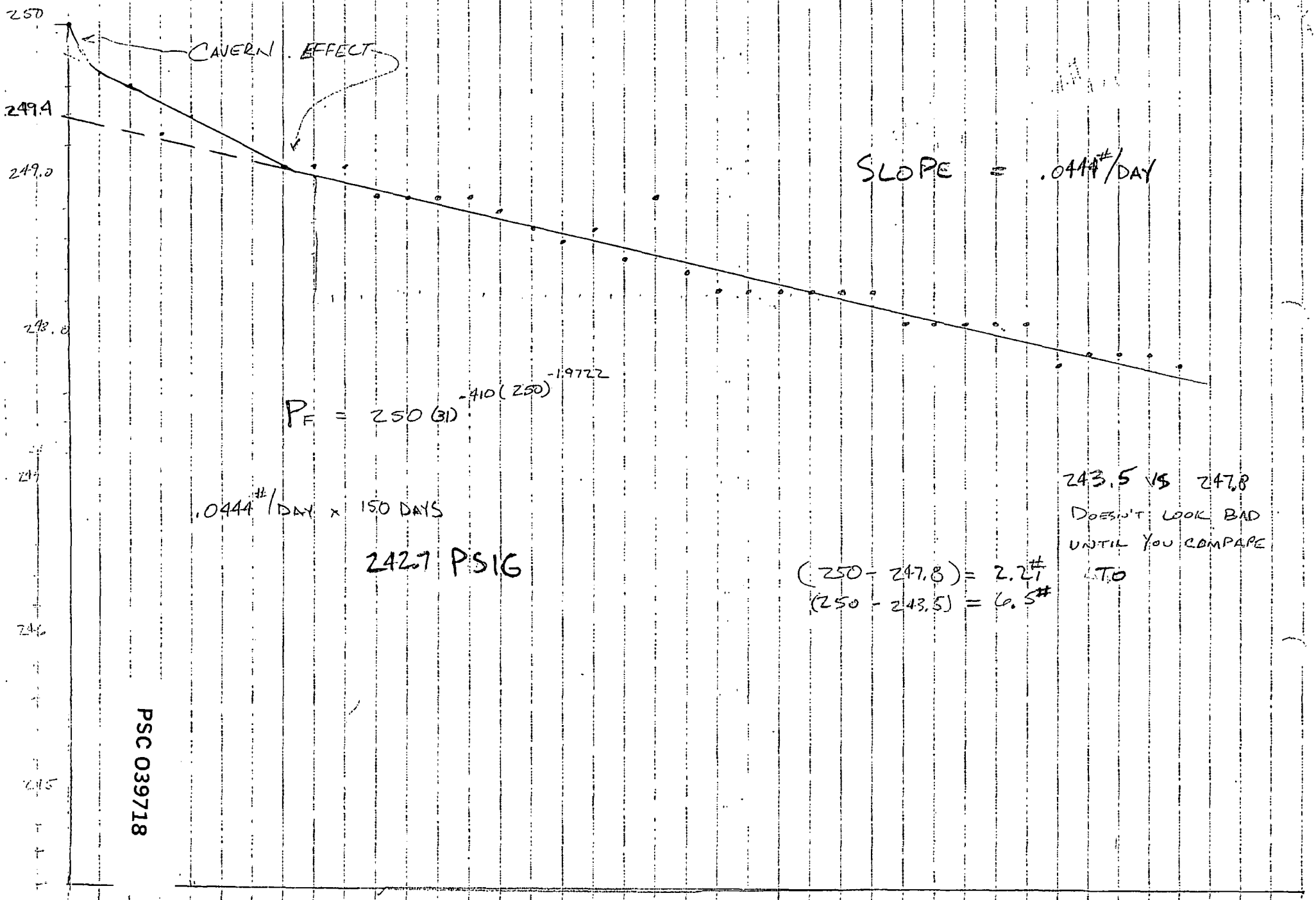
PRESSURE VS. TIME

1981 SUMMER SHUTIN




PSC 039717

# GRAPH #1




PSC 039718

162 15

BASED SOLELY ON SPRING DRAW DOWN 1981

MARCH 25 1959 PSI 2000 MMCF
APRIL 23 55.2 PSI 9,

VOLUME = 1 748 448 1136
- 530 465 70

= 1,217,983 MCF

2270

55.2 PSIG 67.17 PSIA
195.9 207.87 PSIA

$$\frac{67.17\ e^{\left(.01877\ \frac{6x}{ZT}\right)}}{Z \rightarrow (.97)} = 69.13$$

300
200
700
700
900

$$\frac{207.87\ e^{\left(.01877\ \frac{6x}{ZT}\right)}}{Z \rightarrow (.97)} = 211.88$$

$$\frac{1,217,983}{211.88 - 69.13} = 8532.2 \text{ MCF/PSIA}$$

250 PSIG 261.97

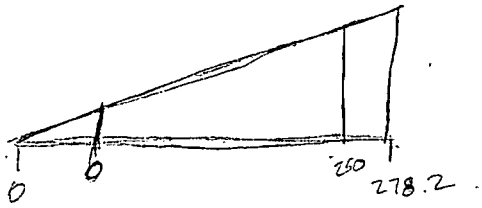
2375,000

$$\frac{261.97\ e^{\left(.01877\ \frac{6x}{ZT}\right)}}{Z \rightarrow .96} \quad 278.2$$

10.61

$$11.97\ e^{\left(\frac{.01877\ 6x}{T}\right)} = 12.19$$

PSC 039719




8532.2 ( 278.2 ) - 12.19

$$\frac{2,269,650.5}{250}$$

9,078.6 MCF/PSIG

2269,650
544,716

1,724.934

WORKING VOLUME = 1,725,000

John — Ele file.

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE March 5, 1980 X-7942

TO Mr. R. R. Midwinter, Controller

FROM Lynn W. Wilkinson, Gas Supply Manager — DEPARTMENT OR DIVISION: Fuel Supply Development

ATTN.

SUBJ. Leyden Storage Cushion and Working Gas Volumes

The Leyden Storage performance test conducted in the spring of 1979 indicated that the total gas in storage is 2,236,175 MCF at 14.65 PSIA when the cavern is at its full pressure of 250 PSIG. Of this total amount, 537,000 MCF is cushion gas and 1,699,175 MCF is working gas.

As outlined in your December 31, 1975 memo, the cushion gas volume was recently reduced from 834,000 MCF to 537,000 MCF because the design working gas depletion pressure was reduced from 100 PSIG to 60 PSIG. The installation of compressor units in 1976, which are capable of operating at a suction pressure of 60 PSIG, allowed for the increase in working volume and this corresponding decrease in cushion gas.

It has been noted that the total gas in Leyden Storage shown in the Summary of Gas Delivered Reports is erroneously high by 421,706 MCF. A review of past reports has revealed that this error has existed for many years. Please consider what steps need to be taken to correct the working gas inventory. In the meantime, the 1980 Leyden Storage spring performance test will be conducted. Although there may be a small change in the total storage volume due to differing water encroachment and dewatering rates, the performance test is expected to confirm the total volume of 2,236,175 MCF. You will be contacted in early April to discuss the latest test results and how to correct the inventory records.

Lynn

Lynn W. Wilkinson

LWW:cp

cc: J. A. Shealy
N. Brenner

PSC 039721

FORM 850-22-0058 INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE February 7, 1980

TO Mr. Lynn W. Wilkinson, Gas Supply Manager — Fuel Supply Development (DEPARTMENT OR DIVISION)

FROM John A. Shealy, Special Projects Engineer — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. Accumulated Measurement Error for Leyden

As of October 31, 1979, Chart Processing and the Accounting Department show total gas in storage* of 2,752,682 MCF at 14.65 psia for the Leyden Storage facility. Subtracting out the 1979 L & U of 155,530 MCF at 14.65 psia gives Chart Processing and Accounting a new total gas in storage* of 2,597,152 MCF @ 14.65 psia.

According to the 1979 spring performance test, at a maximum pressure of 250 psig, the cavern has a maximum total gas in storage* of 2,236,175 MCF @ 14.65 psia. To determine our total gas in storage* on October 31, 1979, we use the pressure volume relationship derived in the spring performance test. We first select a period of time when the pressure in the cavern has been allowed to stabilize.

On November 1, 1978, the pressure stabilized at 247.9 psig. From the performance test, this pressure corresponds to a total gas in storage* of 2,217,391 MCF @ 14.65 psia. From November 1, 1978 to October 31, 1979

| | | |
|---|---|---|
| Injections total | = | 3,984,448 MCF @ 14.65 psia |
| Withdrawals total | = | 3,870,863 MCF @ 14.65 psia |
| L & U for the year 1979 | = | 155,530 MCF @ 14.65 psia |

Therefore, on October 31, 1979 we should have a total gas in storage* of

| Pressure-Volume Calculations | + | Injections | - | Withdrawals | - | L & U for 1979 | = |
|---|---|---|---|---|---|---|---|
| 2,217,391 MCF | | 3,984,448 | | 3,870,863 | | 155,530 | |
| | | | | | | | 2,175,446 MCF @ 14.65 psia |

Total gas in storage* from pressure-volume calculations = 2,175,446 MCF @ 14.65 psia.
Total gas in storage* from Chart Processing and Accounting records = 2,597,152 MCF @ 14.65 psia.

Therefore, if we assume that our pressure-volume calculations (from performance test) are correct, then Chart Processing and the Accounting Department need to write-off 421,706 MCF @ 14.65 psia as an accumulated measurement error over the last 20 years. In looking back over previous Summary of Gas Delivered Reports, it was found that an error was present even then.

| | | |
|---|---|---|
| January 31, 1976 | Total Gas in Storage | 2,718,226 MCF |
| September 30, 1973 | Total Gas in Storage | 2,639,503 MCF |
| January 31, 1972 | Total Gas in Storage | 2,686,476 MCF |
| January 31, 1971 | Total Gas in Storage | 3,492,676 MCF |

| | | |
|---|---|---|
| December 31, 1969 | Total Gas in Storage | 3,001,134 MCF |
| January 31, 1968 | Total Gas in Storage | 3,004,494 MCF |
| December 31, 1965 | Total Gas in Storage | 2,811,634 MCF |
| November 31, 1964 | Total Gas in Storage | 2,733,228 MCF |

From the 1979 performance test the maximum total gas in storage* at 250 psig is 2,236,175 MCF @ 14.65 psia. This is the largest total gas in storage* ever calculated from a perfornace test, and at no time can we ever have more gas in the cavern than thermodynamically or physically possible.

In determining what actually caused this error, it can only be assumed that inherent meter inaccuracies and inaccurate chart readings (due to recorder failures, smudges, improper interpretation and other chart related problems) over a 20 year period have caused this accumulated measurement error to occur. This error cannot be detected in an L & U report because the L & U report never relates total gas in storage at the end of a year to a corresponding pressure related volume at the end of a year.

To prevent this from occurring in the future, once each year the Fuel Supply Development Division will calculate a yearly L & U report and correct the total amount of gas in storage for Chart Processing and Accounting.

Do we want to write-off this error now or wait for the 1980 performance test to verify this figure?

* - Working volume plus cushion gas

John A. Shealy

John A. Shealy

JAS:cp

INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE December 31, 1979

TO Mr. O. D. Davis, Property Accounting Director
DEPARTMENT OR DIVISION

FROM R. R. Midwinter, Controller
DEPARTMENT OR DIVISION

ATTN.

SUBJ. Change in Volume of Cushion Gas at Leyden

Mr. Lynn Wilkinson has advised me that the design of the Leyden Underground Gas Storage facility was modified prior to 1979 from 100 pounds depletion pressure to 60 pounds depletion pressure. Accordingly, more gas is now recoverable from the storage facility and the corresponding reduction in the volume of Cushion Gas should be recognized.

Per my discussion with Mr. Wilkinson last week, the amount of "Cushion Gas" should be reduced from 834,000 MCF to 537,000 MCF.

Please set up the necessary entries to reflect the reduction in Cushion Gas. Also record the salvage value of the reclassified gas as an addition to account number 81-164-11, Gas Stored Underground - Current, at its value for tax purposes to avoid creating an insignificant book-tax difference in the Inventory Account. (The Cushion Gas is being depreciated for book purposes whereas it is being amortized for tax purposes)

R R Midwinter

RRM/c
cc: D. D. Brunkhardt
Lynn Wilkinson
F. W. Beier

PSC 039724

# LEYDEN GAS STORAGE FACILITY

Pressure-Volume Relationships

And

The Effects of Cavern Pressure
on Lost and Unaccounted for Gas

By

John A. Shealy
Special Projects Engineer

August 26, 1980

PSC 039725

Each year a pressure-volume relationship is derived for the Leyden Underground Storage facility. This relationship is used in dispatching and operating guidelines for:

1. Determining the working volume available, given the daily cavern pressure.
2. Determining the amount of gas required to refill the cavern from one pressure to another.
3. Determining the amount of lost and unaccounted for gas to be reported annually.
4. Determining the total storage, total working volume and total cushion volume.

This relationship is always calculated toward the end of the heating season when a substantial drawdown can be initiated. This generates the three primary sources of information used in calculating the pressure-volume relationship which are:

1. The beginning shut-in pressure before the drawdown.
2. The amount of gas withdrawn during the drawdown.
3. The final shut-in pressure after the drawdown.

After both pressures are corrected for bottom hole pressure, temperature and supercompressibility, the pressure-volume relationship is determined by dividing the amount of gas withdrawn ($M^2CF$) by the change in corrected pressure (psig). (See Appendix I.) This gives the pressure-volume relationship required for the operating and dispatching guideline purposes previously mentioned.

However, this relationship is not an actual pressure-volume relationship; it is better described as a drawdown rate. This drawdown rate is very useful in determining the amount of working volume which can be withdrawn between two given pressures, the amount of gas that will be required to refill the cavern and for estimating the amount of working volume available for peak loads during the heating season. However, the use of this drawdown rate for calculating the total storage volume, the total cushion volume and the annually reported lost and unaccounted for gas volumes is in error.

The reason this drawdown rate cannot be used to calculate total cushion and storage volume or for L and U calculations is because the beginning and ending

pressures were not stabilized. In order to determine a true pressure-volume relationship, stabilized cavern pressure must be used. These stabilized cavern pressures take into account all the pressure variations not accounted for in the calculation of the drawdown rate. These pressure variations are as follows:

1. The Pressure Drawdown Gradient Effect
   After a period of substantial drawdown, the storage field must be shut-in for a period of 7 to 15 days to allow sufficient time for a substantial pressure equalization between wells and for removal of most of the pressure drawdown gradient set up during production from the wells.

2. Gas Migration Effect
   During the course of the heating season, the cavern is maintained at a high cavern pressure to insure deliverability for possible peak day demand. During this period, high pressure gas migrates into various formations surrounding the cavern. As the cavern is drawndown to a low pressure and shut-in, some of this high pressure gas migrates back into the cavern and eventually stabilized with the cavern pressure. From actual data the time period involved in this stabilization has been shown to be approximately 120 to 150 days.

3. Water Level Effects
   During the course of a shut-in period, the water levels in the cavern will rise and fall to various levels. The total water level increase or decrease observed during this shut-in period corresponds to a pressure change in the cavern which must be attributed to water level movement and not gas migration or the drawdown gradient.

Taking into account all of these pressure variations, an appropriate pressure-volume relationship can be derived. This derivation is based on the same principles as those used in the calculation of the drawdown rate. However, the difference is that stabilized cavern pressures are now used. (See Appendix II.)

From Appendix I it was found that the drawdown rate associated with the Leyden Gas Storage facility was 8.4667 $M^2CF$/psig. Therefore, during the 1980-81 heating season, with a cavern pressure of 250 psig, a working volume of 1608 $M^2CF$ and a drawdown rate of 8.4667 $M^2CF$/psig can be expected. This is a smaller drawdown rate than was derived for the 1979-80 heating season (8.9447 $M^2CF$/psig; working volume = 1699 $M^2CF$). However, it should be noted that this drawdown rate does not remain constant. This is due to such variables as permeability, porosity, presence of connate water and surrounding formation thickness.

From Appendix II it was found that the pressure-volume relationship for the Leyden Gas Storage facility was 11.6258 $M^2CF$/psig. However, since this pressure-volume relationship was derived from actual stabilized cavern pressures, an actual stabilized cavern pressure must be known before the pressure-volume calculation can be done.

However, there are certain periods during the normal heating season when the cavern cannot be shut-in to allow for pressure stabilization. For that reason the need exists to develop an equation (based on past years' data) which can accurately predict a final stabilized cavern pressure, given any daily cavern pressure. Once this is known, then the amount of gas in storage can be easily calculated. (See Appendix III.)

From Appendix III it was found that for initial shut-in pressures below 215 psig the cavern pressure increases with time. Theoretically, this signifies the migration of high pressure gas from the surrounding formations back into the cavern. For shut-in pressures of 237 psig or more, the cavern pressure decreases with time. This signifies the migration of high pressure cavern gas back into the surrounding formations. It has been assumed that when high pressure gas migrates into the surrounding formations and later migrates back into a low pressure cavern, some of this gas is left behind and eventually is lost. If the cavern pressure can be maintained at a null point (226 psig), then theoretically this indicates a stabilization point where no gas is lost or returned from the surrounding formations. This then will reduce the annual amount of L and U gas occurring from gas migration and will also protect the integrity of the reservoir. In actuality, maintaining a cavern pressure of 226 psig allows the L and U gas to be <u>minimized</u> and the cavern pressure or working volume to be <u>maximized</u>. However, maintaining a cavern pressure of 226 psig during the heating season versus 250 psig means a loss in available working volume of approximately 205 MMCF.

It is recommended that an experimental period be chosen (preferably during a summer shut-in period when no well rework or maintenance is scheduled) when the cavern pressure can be held at 226 psig. This will allow for determination of actual dollar savings available in reduced L and U expense and time for further information to be gathered concerning the supply and demand situation for PSCo.'s future natural gas sales. If gas supplies are great enough to allow for a reduction in Leyden working volume and the experimental program indicates a substantial saving in L and U expenses, then it will be recommended that the maximum cavern pressure for the Leyden Gas Storage facility be changed from 250 psig to 226 psig.

Remaining Volume Curve
Drawdown Rate

Data:

Pressure Base = 11.97 psi

$P_1$ = 242.8 psig shut-in pressure before drawdown (4/10/79)

$P_2$ = 80.1 psig shut-in pressure after drawdown (5/11/79)

$Q_T$ = 1333.818 ($M^2CF$ @ 14.65) total withdrawal (4/10/79 - 5/11/79)

X = 790 ft. (well No. 16 depth)

G = 0.6530 gravity

T = 60° + 460° = 520° Rankin (average well bore temperature)

$P_3$ = 250 psig (maximum design cavern pressure)

$P_4$ = 60 psig (minimum design cavern pressure)

To find the bottom hole pressure using the Fowler's Simplified Method, whereas

$$P_A = P_B e^{\left(.01877 \frac{GX}{T}\right)}$$

Where:

$P_A$ = Bottom hole pressure

$P_B$ = Top hole pressure

G = Gravity

e = 2.71828

X = Well depth (feet)

$e^{\left(.01877 \frac{GX}{T}\right)}$ is bottom hole correction factor

$$e^{\left(\frac{(.1877)(.653)(790)}{520}\right)} = e^{.01862} = 1.0188$$

$P_{A_1}$ = 242.8 (1.0188) = 247.36 Bottom hole corrected

$P_{A_2}$ = 80.1 (1.0188) = 81.61 Bottom hole corrected

$P_{A_3}$ = 250.0 (1.0188) = 254.70 Bottom hole corrected

$P_{A_4}$ = 60.0 (1.0188) = 61.13 Bottom hole corrected

## Correction for Supercompressibility

$$Z = 1/(F_{PV})^2$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $P_1$ | = | 247.36 | $F_{(PV)}$ | = | 1.02003 | $Z$ | = | .9611 |
| $P_2$ | = | 81.61 | $F_{(PV)}$ | = | 1.00653 | $Z$ | = | .9871 |
| $P_3$ | = | 254.70 | $F_{(PV)}$ | = | 1.0206 | $Z$ | = | .9601 |
| $P_4$ | = | 61.13 | $F_{(PV)}$ | = | 1.0047 | $Z$ | = | .9907 |

## PSIA/Z Calculations (Bottom Hole Corrected)

1. $\frac{247.36 + 11.97}{.9611} = 269.83$

2. $\frac{81.61 + 11.97}{.9871} = 94.80$

3. $\frac{254.7 + 11.97}{.9601} = 277.75$

4. $\frac{61.1 + 11.97}{.9907} = 73.75$

The theoretical pressure volume curve was constructed by using the theoretical pressure decline curve. The curve is plotted as gas volume in the cavern versus P/Z, where P is the bottom hole pressure (PSIA) and Z is the compressibility factor. The theoretical pressure decline curve is a straight line equation in the form

$$Y = Mx + b$$

Where:

b is the intercept and equals zero (0)

M is the slope defined by

$M = \frac{\Delta Y}{\Delta X}$ Where: $\Delta Y$ is the change in pressure for the drawdown period.
$\Delta X$ is the change in volume ($M^2CF$) for the drawdown period.

$$M = \frac{269.83 - 94.80}{1333.818} = 0.13122$$

or $\frac{1}{M} = 7.6206$

$$Y = M(x) \quad \text{or} \quad X = \frac{1}{M}(Y)$$

Therefore:

$$X = 7.6206(Y)$$

Solving for X at the four (4) bottom hole pressures gives

$X_1$ = 269.83 (7.6206) = 2056.266 $M^2CF$
$X_2$ = 94.80 (7.6206) = 722.433 $M^2CF$
$X_3$ = 277.75 (7.6206) = 2116.622 $M^2CF$
$X_4$ = 73.75 (7.6206) = 562.019 $M^2CF$

PSIG/Z Top Hole

The stored volume is defined as $X_3$ which is equal to 2116.622 $M^2CF$ @ 250 psig.

Therefore:

$$M = \frac{\Delta Y}{\Delta X} = \frac{250 - 0}{2116.622\ M^2CF} = 0.11811$$

or $\frac{1}{M} = 8.4667$

Therfore: $X = 8.4667(Y)$

$X_1$ = 250 (8.4667) = 2116.622 $M^2CF$

$X_2$ = 60.0 (8.4667) = 508.002 $M^2CF$

Then the working volume is = $X_1 - X_2$

= 2116.622 - 508.002

= 1608.620 $M^2CF$

Therefore, for 190 pounds of working pressure (250 - 60), and a total working volume of 1,608.493 $M^2CF$, expect to have an 8.4667 $M^2CF$/psi drawdown rate.

Calculations for Determining the Pressure-Volume Relationship Associated with the Leyden Gas Underground Storage Facility

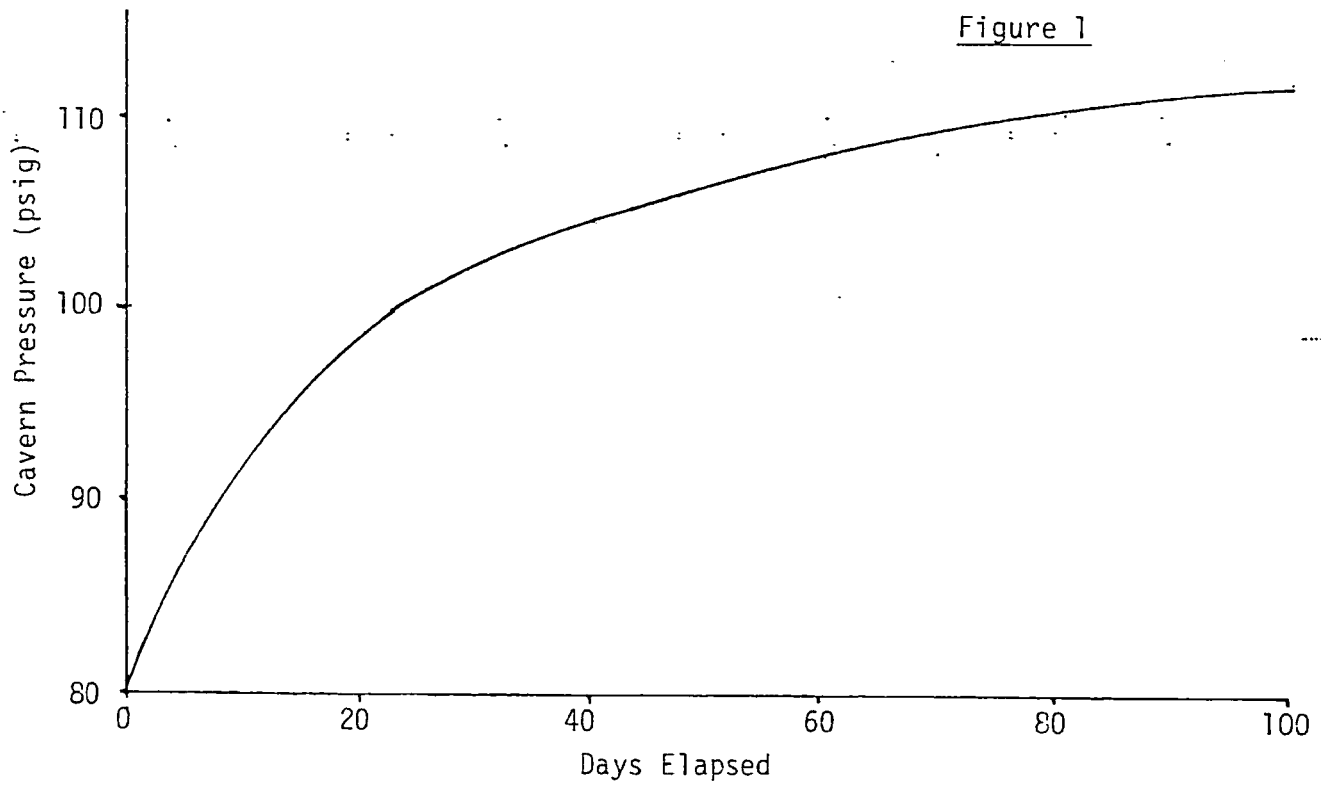
A. Four variables must be known before a pressure-volume relationship can be derived. They are as follows:

1. A beginning stabilized pressure.
2. A final stabilized pressure.
3. The pressure increase or decrease caused by water levels increasing or decreasing.
4. A known volume which was injected or withdrawn between the two stabilized pressures.

1. A Beginning Stabilized Pressure

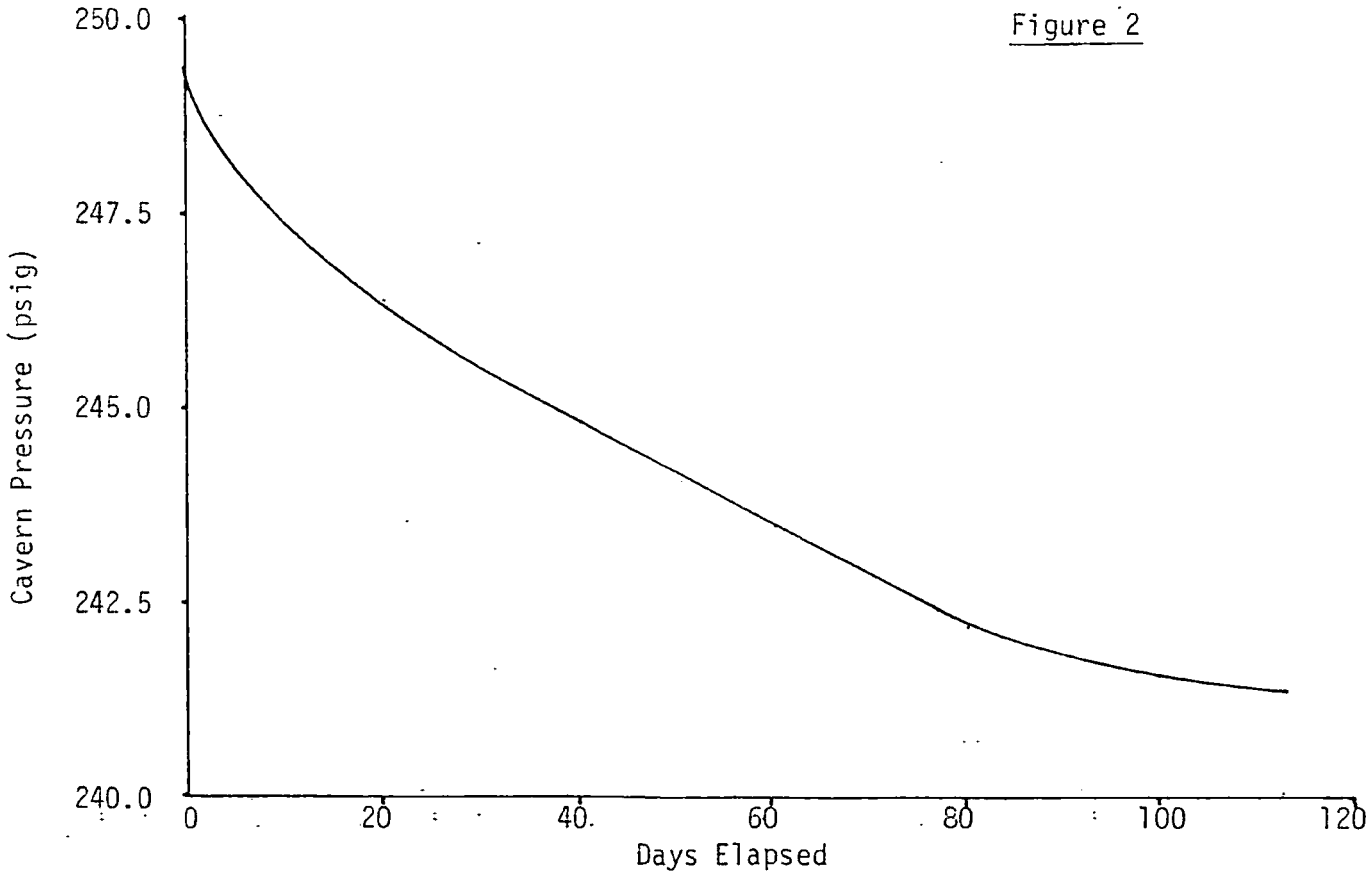
On May 11, 1979 the cavern was shut-in at 80.1 psig. After 101 days the cavern pressure had increased to 111.7 psig. From Figure 1 it can be seen that this pressure was very close to stabilization.

Figure 1




2. The Final Cavern Pressure

On March 27, 1980 the cavern was shut-in at 249.6 psig. After 113 days the cavern pressure had dropped to 241.4 psig. From Figure 2 it can be seen that the cavern pressure has not yet stabilized. By extending the curve it can be predicted that the cavern will eventually stabilize at approximately 241 psig.




3. Pressure Effects Caused by Varying Water Levels

During the high cavern pressure shut-in period the water level measured at well No. 16 had dropped approximately 9 feet (from 781 feet to 790 feet). To convert this 9 feet of water to an appropriate pressure the following calculation is performed.

The specific gravity (S.G.) of water at STP is 62.2598 $\frac{lb}{ft^3}$

Pressure change = $(S.G.)(h_2 - h_1)$

Pressure change = $62.2598 \frac{lb}{ft^3} (790' - 781') = 560.34 \frac{lb}{ft^2}$

Pressure change = 3.9 psig

Therefore, since the shut-in cavern pressure had dropped from 249.6 psig to 241 psig, an 8.6 psig decrease, about 3.9 psig of this drop can be attributed to the decrease in water level. This leaves a 4.7 psig drop which can be attributed to high pressure gas migrating into the various low pressure formations surrounding the cavern. Therefore, the actual cavern gas pressure went from 249.6 psig to 244.9 psig. $P_1$ = 244.9 psig

Since no water level readings were taken during the low pressure shut-in period, it will be assumed that the pressure increase caused by the changing water level

will be equal to 3.9 psig. Therefore, during the low pressure shut-in period the actual cavern gas pressure went from 80.1 psig to 107.8 psig.

$P_2$ = 107.8 psig

4. Volume

The net injection of gas from May 11, 1979 to July 13, 1980 was 1,550,302 MCF at 14.65 psia.

B. Calculations of Pressure-Volume Relationship

Data:

Pressure Base = 11.97

$P_1$ = 244.9 psig final stabilized cavern pressure

$P_2$ = 107.8 psig beginning stabilized cavern pressure

$Q_T$ = 1,550.302 ($M^2CF$ @ 14.65) total injection (May 11, 1979 → July 17, 1980)

X = 790 ft (well No. 16 depth)

G = 0.6530 gravity

T = 60° + 460° = 520° Rankin (average well bore temperature)

$P_3$ = 250 psig (maximum design cavern pressure)

$P_4$ = 60 psig (minimum design cavern pressure)

To find the bottom hole pressure using Fowler's Simplified Method, whereas:

$$P_A = P_B \, e^{\left(.01877 \frac{Gx}{T}\right)}$$

Where:

$P_A$ = Bottom hole pressure

$P_B$ = Top hole pressure

G = Gravity

X = Well depth (feet)

$e^{\left(.01877 \frac{Gx}{T}\right)}$ is the bottom hole correction factor

$$\therefore e^{\left(\frac{.01877(.6530)(790)}{520}\right)} = e^{.01862} = 1.0188$$

Therefore, correcting the pressures gives

$P_{A_1}$ = 244.9(1.0188) = 249.50 Bottom hole corrected

$P_{A_2}$ = 107.8(1.0188) = 109.83 Bottom hole corrected

$P_{A_3}$ = 250.0(1.0188) = 254.70 Bottom hole corrected

$P_{A_4}$ = 60.0(1.0188) = 61.1 Bottom hole corrected

## Corrections for Supercompressibility

$$Z = 1/(F_{(PV)})^2$$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $P_1$ | = | 249.5 | $F_{(PV)}$ | = | 1.02019 | $Z$ | = .9608 |
| $P_2$ | = | 109.83 | $F_{(PV)}$ | = | 1.00886 | $Z$ | = .9825 |
| $P_3$ | = | 254.70 | $F_{(PV)}$ | = | 1.0206 | $Z$ | = .9600 |
| $P_4$ | = | 61.1 | $F_{(PV)}$ | = | 1.0047 | $Z$ | = .9907 |

## PSIA/Z Calculations (Bottom Hole Corrected)

1. $\frac{249.50 + 11.97}{.9608} = 272.138$

2. $\frac{109.83 + 11.97}{.9825} = 123.967$

3. $\frac{254.70 + 11.97}{.9600} = 277.781$

4. $\frac{61.1 + 11.97}{.9907} = 73.756$

The pressure (PSIA/Z) - volume curve is assumed to be a straight line relationship due to the assumption of constant well bore temperature.

$$Y = MX + b$$

Where:

b is the intercept and equals zero (0).

M is the slope defined by

$$M = \frac{\Delta Y}{\Delta X}$$

Where $\Delta Y$ is the change in cavern pressure

$\Delta X$ is the change in volume in $M^2CF$

$$M = \frac{272.138 - 123.969}{1{,}550.302\ M^2CF} = 0.095574$$

or $\frac{1}{M} = 10.4631$

Therefore $X = 10.4631(Y)$

Solving for X at the four bottom hole pressures

$X_1 = 272.138(10.4631) = 2{,}847.407\ M^2CF$

$X_2 = 123.967(10.4631) = 1{,}297.100\ M^2CF$

$X_3 = 277.781(10.4631) = 2{,}906.450\ M^2CF$

$X_4 = 73.756(10.4631) = 771.716\ M^2CF$

Then the working volume is defined as $X_3 - X_4$

$X_3 - X_4 = 2{,}906.450 - 771.716 = 2{,}134.734\ M^2CF$

PSIG/Z Top Hole

The stored volume is as stated 2,906.450 $M^2CF$ @ 250 psig and the intercept is zero (0).

Therefore:

$$M = \frac{\Delta Y}{\Delta X} = \frac{250 - 0}{2{,}906.450} = 0.086016$$

or

$$\frac{1}{M} = 11.6258$$

Therefore: $X = 11.6258Y$

$X_1 = 250(11.6258) = 2{,}906.450\ M^2CF$

$X_2 = 60(11.6258) = 697.548\ M^2CF$

Then the working volume is $X_1 - X_2$

$= 2{,}906.450 - 697.548$

$= 2{,}208.902\ M^2CF$

These volumes are based on stabilized cavern pressures which were achieved after approximately 200 days of shut-in time. Therefore, this pressure-volume relationship (11.6258 $M^2CF$/psig) cannot be used as the actual drawdown rate needed for operating purposes. However, if this pressure volume relationship is used in conjunction with a stabilized cavern pressure, then the amount of gas in storage can be accurately determined for accounting purposes.

## Calculations for Determining a Stabilized Cavern Pressure

To determine the amount of gas in storage the equation X = 11.6258Y is used, where X equals the amount of gas in storage in $M^2CF$ @ 14.65 and Y equals the stabilized cavern pressure. Therefore, in order to accurately calculate the amount of gas in storage, the cavern must be shut-in and the pressure allowed to stabilize. However, there are certain times during the normal heating season when the cavern cannot be shut-in to allow for pressure stabilization. For that reason the need exists to develop an equation which can accurately predict the final stabilized cavern pressure, given any daily cavern pressure. Once this is known, then the amount of gas in storage can easily be calculated for any day of the year.

From previous years' data it has been found that the pressure in the cavern during shut-in periods either rises or falls, depending on the initial shut-in pressure. At a high initial shut-in pressure the cavern pressure decreases to a lower stabilized pressure, and at a low initial shut-in pressure the cavern pressure increases to a higher stabilized pressure. Table I shows some previous years' initial shut-in pressures, the final stabilized pressures and the time duration involved between initial and final pressures.

TABLE I

| Date | Initial Shut-In Pressure | Days Elapsed | Final Stabilized Shut-In Pressure |
|---|---|---|---|
| 1972 | 106.2 psig | 117 Days | 132.5 psig |
| 1973 | 161.5 psig | 123 Days | 174.7 psig |
| 1974 | 87.7 psig | 107 Days | 120.0 psig |
| 1975 | 93.3 psig | 91 days | 123.7 psig |
| 1976 | 87.8 psig | 86 Days | 110.2 psig |
| 1977 | 77.5 psig | 102 Days | 113.9 psig |
| 1978 | 92.4 psig | 130 Days | 122.0 psig |
| 1979 | 80.1 psig | 101 Days | 111.7 psig |
| 1980 | 249.6 psig | 113 Days | 241.3 psig |

Figures I and II show the actual daily cavern pressure for two different shut-in periods. From these graphs it can be seen that the actual curve on which the pressure follows during the shut-in period is similar to the curve generated by a exponential equation.

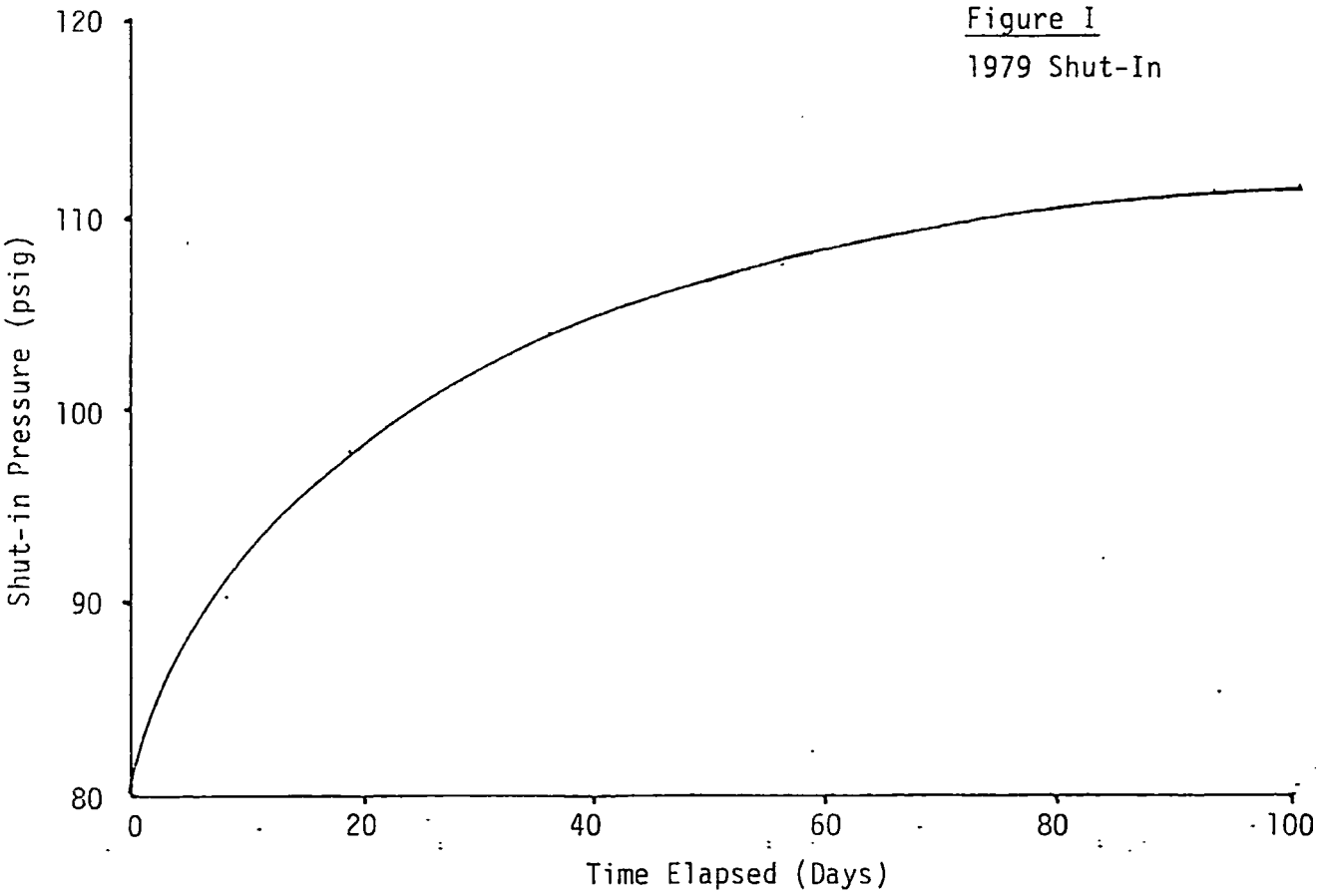


Figure I
1979 Shut-In
Shut-in Pressure (psig)
120
110
100
90
80
0
20
40
60
80
100
Time Elapsed (Days)

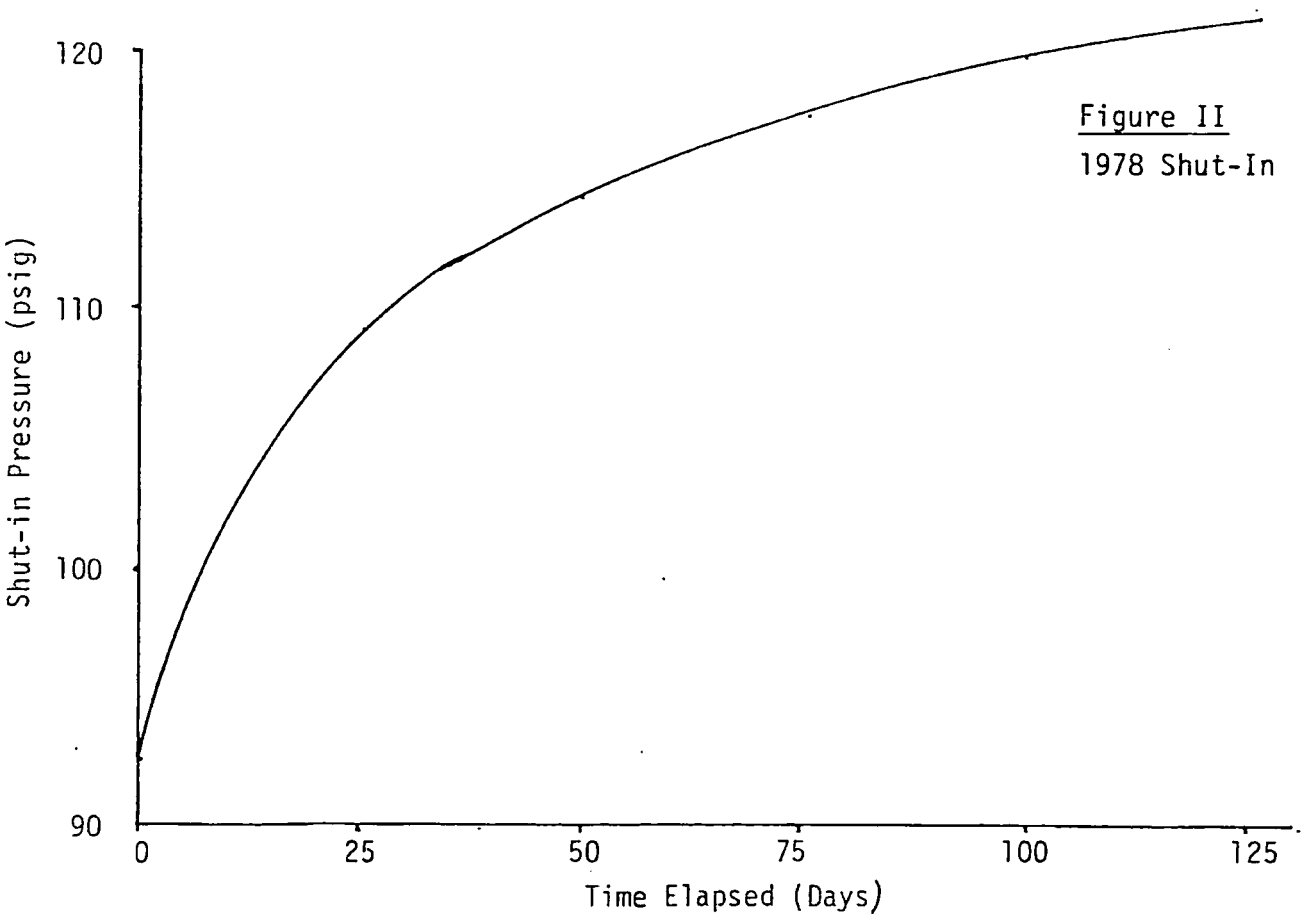
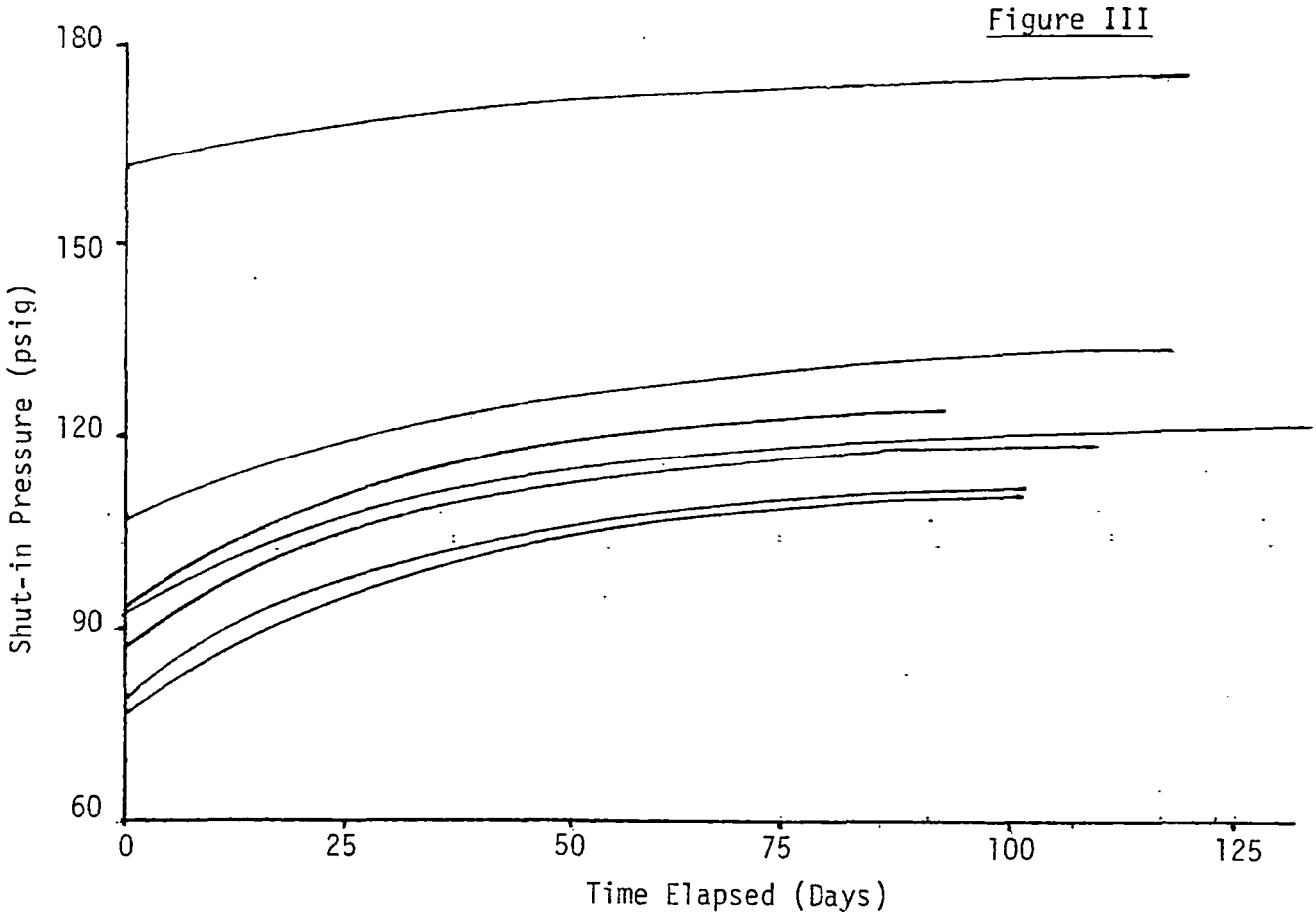


Figure II
1978 Shut-In
Shut-in Pressure (psig)
120
110
100
90
0
25
50
75
100
125
Time Elapsed (Days)

If it is assumed that all past years' shut-in pressures followed along the same similar type of exponential curve as those periods shown in Figures I and II, then an appropriate graphical solution can be derived. Plotting the initial shut-in pressures, final shut-in pressures and days elapsed between pressures for each year shown in Table I, an appropriate curve can be drawn from each year's data.

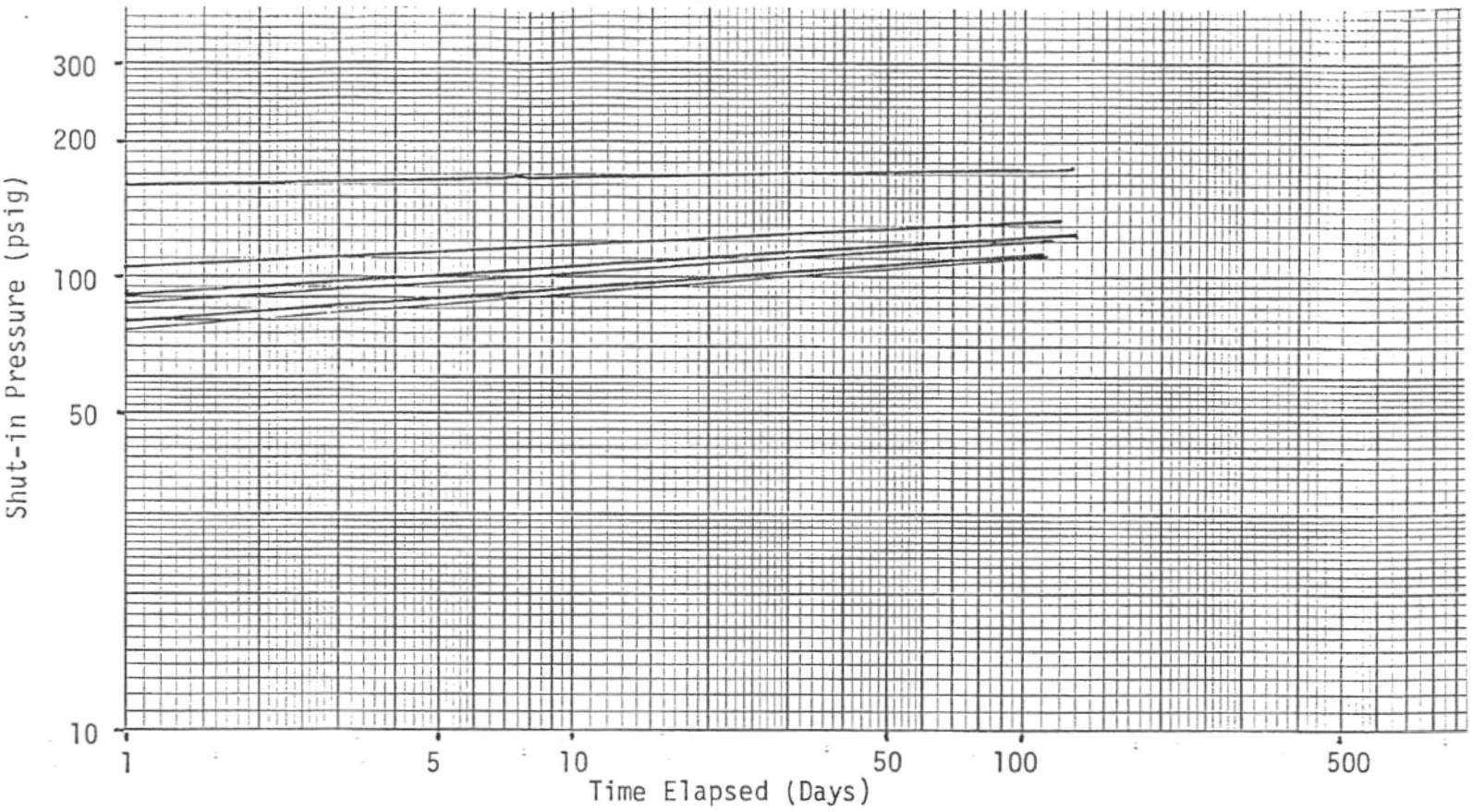
Figure III




As can be seen in Figure III, the exponential shape changes depending on the initial shut-in pressure. This is to be expected. As the initial shut-in pressure becomes higher, the harder it becomes for high pressure gas to migrate back into the cavern and, therefore, creating a smaller difference between the initial and final shut-in pressures.

Plotting these curves on Log-Log paper generates a straight line for each shut-in period. From Figure IV it can be seen that these lines vary in slope and intercept depending on the initial shut-in pressures.

Figure IV




The equation which describes these lines is of the form $Y = CX^N$.

Where:

Y = The final cavern pressure

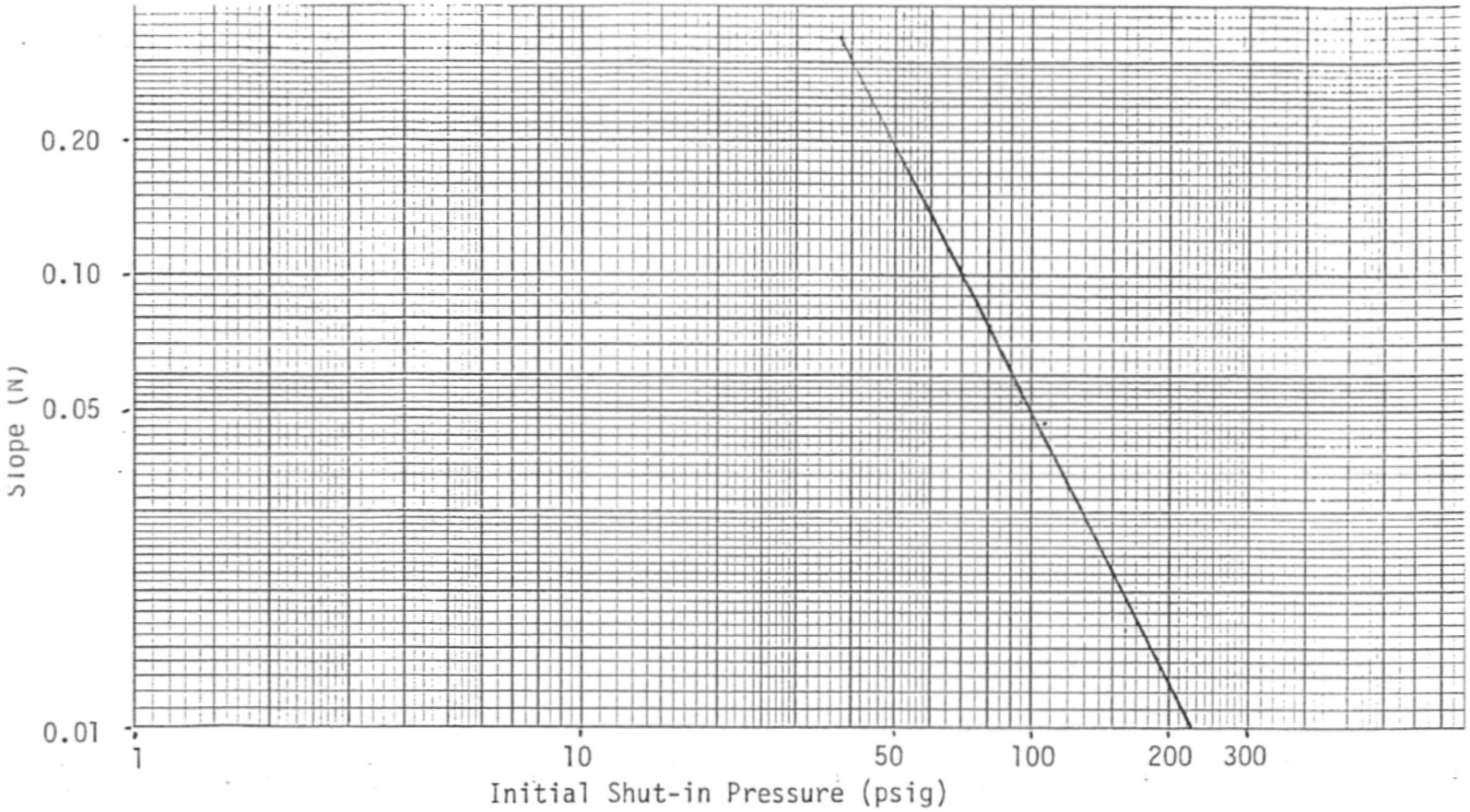
C = The initial cavern pressure

X = The number of shut-in days

N = The slope of the line

From Figure IV it was found that "C" and "N" vary depending on the initial shut-in pressure. However, "C" will always be equal to the initial shut-in pressure which will always be a known quantity. If the slope of each line is plotted against the initial shut-in pressure, it also appears as a straight line on Log-Log paper. (See Figure V.)

Figure V




Therefore, the equation which best predicts the value of "N", given the initial shut-in pressure, is:

$$N = 410\ (P_i)^{-1.9722}$$

Where:

$P_i$ = The initial shut-in pressure

Plugging this value back into the initial equation for predicting the final stabilized cavern pressure gives

$$Y = CX^{[410\ (P_i)^{-1.9722}]}$$

Where:

C is equal to the initial shut-in pressure which can also be written as $P_i$.

X is equal to the number of days the cavern is shut-in and can also be written as t.

Y is equal to the final shut-in pressure which can also be written as $P_F$.

This gives:

$$P_F = P_i\ (t)^{[410\ (P_i)^{-1.9722}]}$$

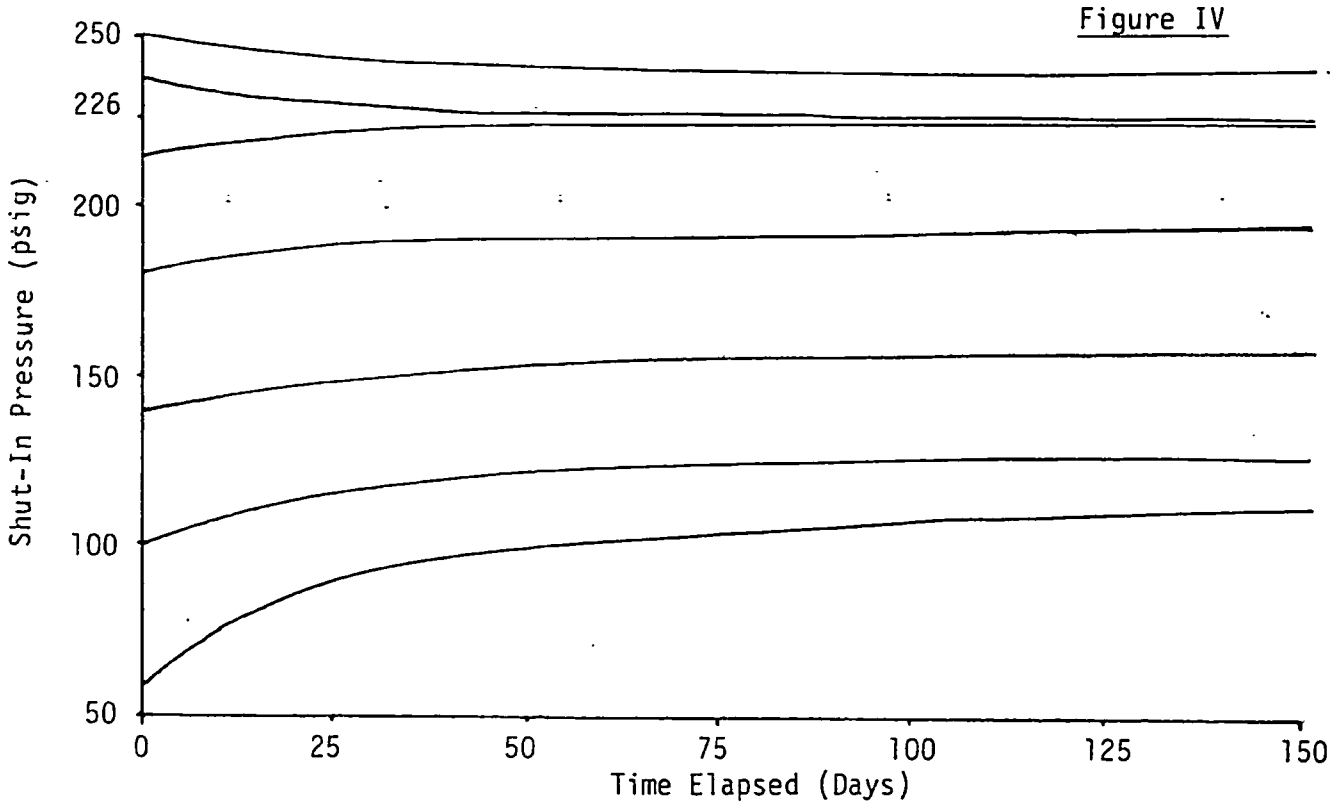
However, this equation only applies to low cavern pressures which will increase with time. For high cavern pressures which decrease with time, the power function $[410\ (P_i)^{-1.9722}]$ becomes negative due to the negative slope.

Therefore, for high cavern pressures the equation becomes

$$P_F = P_i(t)^{-[410\ (P_i)^{-1.9722}]}$$

In order to clearly define the actual boundaries associated with these two equations, both equations are plotted in Figure VI.

Figure IV




From Figure VI it can be seen that both the positive slope and the negative slope approach zero (0) change at approximately 226 psig. Therefore, plugging 226 psig into both equations as the $P_F$ value and solving for both limits on $(P_i)$ at time equal to 150 days gives:

$$226 \text{ psig} = P_i(150)^{+[410\ (P_i)^{-1.9722}]}$$

and

$$226 \text{ psig} = P_i(150)^{-[410\ (P_i)^{-1.9722}]}$$

From a trial and error solution, the limits are as follows:

1. For cavern pressure of 237 psig or more, the equation for predicting the stabilization pressure is

$$\underline{P_F = P_i(t)^{-[410\ (P_i)^{-1.9722}]}}$$

2. For cavern pressure of 215 psig or less, the equation for predicting the stabilization pressure is

$$\underline{P_F = P_i(t)^{+[410\ (P_i)^{-1.9722}]}}$$

3. For cavern pressures between 237 psig and 215 psig, the stabilized cavern pressure can best be determined by graphical interpolation.

To determine the accuracy of these equations, the actual stabilized cavern pressures, shown in Table I, are compared with the equation calculated stabilized cavern pressures as shown in Table II.

TABLE II

| Date | Initial Shut-In Pressure | Days Elapsed | Actual Final Stabilized Pressure | Calculated Final Stabilized Pressure | Percent Error |
|---|---|---|---|---|---|
| 1972 | 106.2 psig | 117 | 132.5 psig | 129.34 psig | 2.39 |
| 1973 | 161.5 psig | 123 | 174.7 psig | 176.20 psig | 0.85 |
| 1974 | 87.7 psig | 107 | 120.0 psig | 116.28 psig | 3.10 |
| 1975 | 93.3 psig | 91 | 123.7 psig | 118.72 psig | 4.02 |
| 1976 | 87.8 psig | 86 | 110.2 psig | 114.81 psig | 4.02 |
| 1977 | 77.5 psig | 102 | 113.9 psig | 110.67 psig | 2.80 |
| 1978 | 92.4 psig | 130 | 122.0 psig | 120.45 psig | 1.27 |
| 1979 | 80.1 psig | 101 | 111.7 psig | 111.76 psig | 0.06 |
| 1980 | 249.6 psig | 113 | 241.3 psig | 240.78 psig | 0.21 |

The accuracy of these equations ranges from an average of 1.64% above to 2.38% below the actual.

Table III shows the discrepency involved when calculating a total volume in storage using a given daily cavern pressure versus a calculated stabilized cavern pressure.

TABLE III

| Date | Actual Cavern Pressure | Volume @ 11.6258 $M^2CF/psi$ ($M^2CF$) | Calculated Stabilized Cavern Pressure (Using 150 Days) | Volume @ 11.6258 $M^2CF/psi$ ($M^2CF$) | Actual Volume* ($M^2CF$) | Percent** Improved (%) |
|---|---|---|---|---|---|---|
| 3-27-80 | 249.6 psig | 2,901.799 | 240.18 psig | 2,792.359 | 2,812.084 | 454.8 |
| 2-19-80 | 249.9 psig | 2,905.287 | 240.28 psig | 2,793.447 | 2,757.223 | 408.7 |
| 1-28-80 | 201.7 psig | 2,344.924 | 213.85 psig | 2,486.177 | 2,540.638 | 259.4 |
| 11-29-79 | 183.6 psig | 2,134.497 | 197.00 psig | 2,290.290 | 2,461.771 | 190.9 |
| 5-11-79 | 80.1 psig | 931.226 | 115.00 psig | 1,337.007 | 1,417.312 | 605.3 |
| 12-31-78 | 167.4 psig | 1,946.159 | 182.16 psig | 2,117.810 | 2,192.205 | 330.7 |
| 12-3-78 | 183.8 psig | 2,136.822 | 197.18 psig | 2,292.439 | 2,527.439 | 166.2 |
| 9-30-78 | 251.2 psig | 2,920.401 | 241.84 psig | 2,811.612 | 2,685.735 | 186.4 |
| 5-1-78 | 92.4 psig | 1,074.223 | 121.39 psig | 1,411.259 | 1,514.662 | 426.1 |
| 2-26-78 | 248.8 psig | 2,892.499 | 239.36 psig | 2,782.730 | 2,818.775 | 204.5 |
| 1-17-78 | 228.2 psig | 2,653.007 | 227.00 psig | 2,639.056 | 2,675.563 | -61.7 |
| 12-12-77 | 241.9 psig | 2,812.281 | 236.00 psig | 2,743.688 | 2,853.122 | -267.9 |
| 12-9-77 | 198.5 psig | 2,307.721 | 210.85 psig | 2,451.402 | 2,577.896 | 213.6 |
| 10-24-77 | 248.2 psig | 2,885.523 | 238.73 psig | 2,775.507 | 2,785.440 | 1007.5 |
| 5-22-77 | 77.5 psig | 900.999 | 114.01 psig | 1,325.456 | 1,402.056 | 654.0 |

* - Actual volumes as reported by the Accounting Department and the Summary of Gas Delivered Report.

** - $\frac{\text{Actual cavern pressure X 11.6258 } M^2CF/psi \text{ - Actual volume*}}{\text{Calculated cavern pressure X 11.6258 } M^2CF/psi \text{ - Actual volume*}}$ X 100

From Table III it can be seen that all pressure volume calculations, except for those pressures in or near the uncertainty zone (237 psig to 215 psig), are more accurate.

PSC 039745

INTER-DEPARTMENT MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE November 12, 1980

TO Mr. Kenneth Hooker, Jr., Gas Supply Manager — Fuel Supply Development (DEPARTMENT OR DIVISION)

FROM John A. Shealy, Special Projects Engineer — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. 1979-80 Leyden Lost and Unaccounted for Gas

The annual lost and unaccounted for (L & U) gas volumes for the Leyden Underground Storage facility have always been calculated for the time period November 1st through October 31st. To calculate this L & U volume, cavern pressures on the above dates are recorded, a pressure-volume (P-V) relationship is utilized and injection-withdrawal records are summarized. However, in past years the P-V relationship used was not a true P-V relationship, but instead a drawdown rate. The drawdown rate is the ratio between the amount of gas withdrawn and the corresponding immediate drop in cavern pressure. A true P-V relationship is the ratio between the amount of gas withdrawn and the corresponding stabilized drop in cavern pressure. When the cavern is at a pressure ($P_1$) and an amount of gas is withdrawn (V), the cavern pressure will drop to a lower pressure ($P_2$). The calculated drawdown rate is then equal to $V/(P_1 - P_2)$. However, if no activity is initiated after this withdrawal, the pressure ($P_2$) will begin to stabilize at a substantially different pressure ($P_3$). The calculated P-V relationship is then equal to $V/(P_1 - P_3)$. This stabilization effect is caused by pressure drawdown gradient effects, gas migration effects and water level changes within the cavern. For the year 1980-81, the drawdown rate was calculated as 8.4667 $M^2CF/PSIG$, while the P-V relationship was 11.6258 $M^2CF/PSIG$. (See attached report.)

Since the P-V relationship is derived from stabilized cavern pressures, stabilized cavern pressures must be known before a P-V calculation can be performed. Therefore, to accurately calculate the annual L & U, stabilized cavern pressures must be used for the beginning and ending dates of the calculation period. The best stabilized cavern pressures are obtained at the end of the summer shut-in period, and, therefore, it is recommended that the annual L & U calculation be based on summer ending pressures versus November 1st and October 31st pressures.

Some examples of erroneous L & U calculations, based on unstable cavern pressures, and the accurate L & U calculation for 1979-80 are shown below:

Example 1 -- September 12, 1979 - unstable cavern pressure = 241.8 PSIG
October 31, 1979 - unstable cavern pressure = 241.2 PSIG
Injections = 281,852 MCF
Withdrawals = 41,407 MCF

Since pressures equal like volumes, then the injections minus the withdrawals should be equal to the change in cavern pressure. Any difference thereafter will be written off as L & U. Howver, due to the unstability of the cavern pressures, the following was calculated as L & U:

Injections - withdrawals = (change in pressure)(P-V relationship) + L & U

OR

L & U = (injections - withdrawals) - (change in pressure)(P-V relationship)

L & U = (281,852 - 41,407)MCF - (241.2 - 241.8)PSIG (11,625.8)MCF/PSIG

L & U = 247,420 MCF over a 49 day period

Example 2 -- August 20, 1979 - stabilized cavern presssure = 111.7 PSIG
October 31, 1979 - unstabilized cavern pressure = 241.2 PSIG
Injections = 1,376,774 MCF
Withdrawals = 41,407 MCF

L & U = (injections - withdrawals) - (changes in pressure)(P-V relationship)

L & U = (1,376,777 - 41,407)MCF - (241.2 - 111.7)PSIG (11,625.8)MCF/PSIG

L & U = -170,171 MCF

It is very difficult to explain a negative L & U. However, it does indicate that other sources, besides pressures and volumes, are effecting the L & U calculations. Those other sources are those effects on pressure stabilization mentioned earlier (pressure gradient, gas migrating and changes in water levels).

L & U Calculation for 1979-80

Stabilized cavern pressure on August 20, 1979 = 111.7 PSIG
Stabilized cavern pressure on September 14, 1980 = 239.7 PSIG

Injections from 8/20/79 → 9/14/80 = 3,266,527 MCF
Withdrawals from 8/20/79 → 9/14/80 = 1,711,846 MCF

L & U = (3,266,527 - 1,711,846)MCF - (239.7 - 111.7)PSIG (11,625.8)MCF/PSIG

L & U = 66,616 MCF

John A. Shealy

JAS:cp
Attachment

1/3/80.

MATHMATICAL ERROR WAS DISCOVERED IN CHART PROCESSING RECORDS FROM DEC, 1978 TO JAN 1979 THE L&U AMOUNT FOR 1978 WAS NOT WRITTEN OFF IN THE JANUARY 1979 SUMMARY OF GAS DELIVERED REPORT. THE AMOUNT NOT WRITTEN OFF TOTALED TO 130,404 MCF @ 14.65 #.

STILL HAVING PROBLEMS IN JUSTIFYING WHY OUR P-V CALCULATIONS SHOWS LESS GAS IN STORAGE THAN OUR SUMMARY OF GAS DELIVERED REPORTS. ONE PROBLEM IS WE ARE USING OUR ORIFICE METERS TO CALCULATE OUR TOTAL GAS IN STORAGE, OUR L&U, AND OUR TOTAL WORKING GAS; WHILE OUR ORIFICE METER ARE GENERATING THE % ERROR INVOLVED. HOW CAN YOU USE A PROBLEM TO TRY AND CORRECT A PROBLE? TWO WRONGS DONT MAKE A WRITE.

PSC 039748

AS OF 10/31/79 CHART PROCESSING SHOWS

2,752,682 MCF AS TOTAL GAS IN STORAGE.

AS OF 10/31/79 ACCOUNTING DEPT. SHOWS

2,752,682 MCF AS TOTAL GAS IN STORAGE.

NOW SUBSTRACT OUT NEW YEARS A+U FOR LEYDEN.

155,530 MCF.

AS OF MIDNIGHT 10/31/79 CHART PROCESSING + ACCOUNTING SHOW.

2,597,152 MCF AS TOTAL GAS IN STORAGE
- 537,000 MCF CUSHION GAS

2,060,152 MCF WORKING GAS

ACCORDING TO P-V. CALCULATIONS WE SHOW THAT ON 10/31/79 WE SHOULD HAVE

2,175,446 MCF (TOTAL GAS IN STORAGE)
- 537,000 MCF CUSHION GAS

1,638,446 MCF

DIFFERENCE BEING. -

421,706 MCF @ 14.65 #s

PSC 039749

ON NOV 1, 1978 THE PRESSURE WAS 247.9 psig. THIS CORRESPONDS TO A ~~[illegible]~~ TOTAL GAS STORAGE OF 2,217,391 MCF @ 14.65#

FROM 11/1/78 TO 10/31/79

INJECTIONS TOTAL 3,984,448 MCF
WITHDRAWALS TOTAL 3,870,863 MCF

TAKE INITIAL VOLUME + SUB. WITHDRAWALS, ADD INJECTIONS.

2,217,391 + 3,984,448 − 3,870,863

= 2,330,976 MCF

NOW SUBSTRACT OUT L+U FOR 79.
(155,530 MCF)

= 2,330,976 − 155,530 MCF

= 2,175,446 MCF (TOTAL GAS IN STORAGE)

− 536,682 MCF (1979 CUSHION GAS)

1,638,764 MCF. (WORKING GAS)

PSC 039750

DEC 31, 1978.

ACCOUNTING SHOWS TOTAL WORKING VOLUME OF

1,358,205 MCF (TOTAL WORKING STORAGE)

+ 834 000 MCF (CUSHION)

2,192,205 MCF (TOTAL STORAGE GAS)

INJECTIONS FROM

12/31/78 → 10/31/79 = 2,827,900 MCF

WITHDRAWLS = 2,267,423 MCF

SO ON (10/31/79) ACCOUNTING SHOWS.

2,192,205 + 2,827,900 − 2,267,423

= 2,752,682 MCF.

NOW SUBSTRACT OUT THIS YEARS L&U.
(155,530)

2,752,682 − 155,530 =

| | | |
|---|---|---|
| TOTAL | | 2,597,152 MCF |
| CUSHION | − | 536,682 MCF |
| WORKING | − | |
| | | 2,060,470 MCF |

DIFFERENCE = 421,206 MCF

PSC 039751

TABLE IV

| Date | Actual Stabilized Cavern Pressure (PSIG) | Calculated Total Volume @ 11.6258 $M^2CF$/PSIG ($M^2CF$) | Actual Total Volume ($M^2CF$) | Difference ($M^2CF$) |
|---|---|---|---|---|
| 7/13/80 | 241.4 | 2,806,468 | 2,812.084 | 5.616 |
| 8/20/79 | 111.7 | 1,298.602 | 1,417.312 | 118.710 |
| 9/08/78 | 122.0 | 1,418.348 | 1,514.662 | 96.314 |
| 9/01/77 | 113.9 | 1,324.179 | 1,402.056 | 77.877 |
| 8/12/76 | 110.2 | 1,281.163 | 1,328.663 | 47.500 |
| 7/31/75 | 123.7 | 1,438.111 | 1,521.526 | 83.415 |
| 8/28/74 | 120.0 | 1,395.096 | 1,499.386 | 104.290 |
| 9/01/73 | 174.7 | 2,031.027 | 2,094.408 | 63.381 |
| 9/14/72 | 132.5 | 1,540.419 | 1,671.014 | 130.595 |

J.A.S.
8/13/80

PSC 039752

ON OCTOBER 31, 1979 CAVERN PRESSURE = 241.2 PSIG

NET INJECTION FROM

10/31/79 → 11/1/80 = 325,109 MCF

ON OCTOBER 1, 1980 CAVERN PRESSURE WAS @ 250.0 PSIG

FROM 3/27/80 (249.6 PSIG)

TO 9/15/80 (239.7 PSIG) ← 172 DAY ELAPSED

THEORETICALLY DECLINE – 239.9 PSIG

FROM 9/15 → 9/29 – 105,798 MCF INJECTED

ON 10/1/80 CAVERN PRESSURE = 250 PSIG

ON 10/27/80 CAVERN PRESSURE = 247.8 PSIG

1ST METHOD 248,378 MCF

2ND METHOD 41,387 MCF

PSC 039754

OCT 31, 1979 → NOVEMBER 1, 1980.

OCT 31, 1979 CROWN PRESSURE = 241.2 psig

OCT 24, 1980 ACTUAL - 247.8 psig.
PROJECTED NOV 1, 1980 - 246.0 psig.

TOTAL IN STORAGE - 2,922,261

NET INJECTION - 325,109 MCF

76,730 FROM 241.2 → 247.8

2,922,261
- 2,859,947 M²CF.

62,314

97,191.6 125,087

240.6

24 hr ← TUESDAY EVENING

SUNDAY MORNING → ← 11/1 -

PSC 039755

| | + | − | NET |
|---|---|---|---|
| 8/1/80 - 8/30/80 | 4,379 | — | + 4,379 |
| 9/1/80 - 9/30/80 | 105,798 | — | + 105,798 |
| 10/1/80 - 10/31/80 | — | 2,135 | - 2,135 |
| | 3,372,325 | 1,715,981 | 1,658,344 |

STABILIZED CAVERN PRESSURE ON 10-1

10/31/80 = 247.3 psig → 247.1 →

247.0

(5-1)

LEU = 81,885 →

FROM 8/20/79 → 10/31/80

PSC 039756

ON 5/15/79 THE CAVERN PRESSURE WAS 72.3 psig.
ON 6/23/80 THE CAVERN PRESSURE WAS 241.9 psig

FROM 5/15/79 → TO DATE

| INJECTIONS TOTALS | WITHDRAWAL TOTALS |
|---|---|
| 3,262,148 MCF | 1,711,846 |

NET INJECTION OF

1,550,302 MCF

PRESSURE ROSE FROM 72.3 TO 241.9 psig

A PRESSURE INCREASE OF 169.3 psig

OR BY ASSUMING 8.9447 M²CF/psig

THIS WOULD REQUIRE 1,517,021 MCF

THEREFORE L+U = 1550302
- 1517021

33,281 MCF

PSC 039758

Assuming 8.9447 m²cf/psig.

72. psig

8/20/79 - pressure = 111.7 psig  6/23/80 - 241.9 psig

| | INJECTIONS + | WITHDRAWALS − |
|---|---|---|
| 8/20/79 corrected to ~~[illegible]~~ | - ~~582,300~~ | 111.7 - 241.9 |
| August | - 610,935 | |
| Sept | - 698,012 | |
| Oct | - 67,830 | 41,407 |
| Nov | - 271,306 | 692,621 |
| Dec | - 843,305 | 286,286 |
| Jan | - 75,473 | 611,540 |
| Feb | - 595,582 | 35,148 |
| Mar | - 99,705 | 42,802 |
| Apr. | - — | 2,042 |
| May | — 130.2 | — |
| June | — | |
| June 23 corrected to 176.8 psig | | ~~582,300~~ |
| | 3,844,448 | 2,294,146 |

1,550,302 MCF  Now?

PSC 039759

NOV 1, 1978.

247.9 psig.

+ 3984448 − 3,870,863.

NET INJECTION IF 113,585 = 12.69 psig.

59,929

Oct 31, 1979

241.2 psig.

OR -6.7 psig DECREASE.

+ 172,000 MCF

117,056. MCF

— 55,552 INCREASE

72 psig → 241.9 psig. 8.9447

A NET INJECTION OF ~~1,519,704 MCF~~

1,550,302 MCF

62.5

~~64%~~

↑ 30,598 MCF

10.79

PSC 039760

SEPT 14, 1989 PRESSURE - 248.5 psig.

ASSUME NOV 1, 1980 PRESSURE - 241.7 psig.

| | | INJECTIONS | WITHDRAWALS |
|---|---|---|---|
| 9/14/79 | CORRECTED TO 248.1 psig<br>248.5 psig | | ~~30,412~~ |
| SEPT. | | 113,689 | |
| OCT | | 67,830 | 41,407 |
| NOV. | | 271,306 | 692,621 |
| DEC | | 843,305 | 286,286 |
| JAN | | 75,473 | 611,540 |
| ~~FEB~~ | | ~~595,582~~ | ~~35,148~~ |
| MAR | | 99,705 | 42,802 |
| APR. | | | 2,042 |
| | 241.7 | | |
| NOV 1, 1980 | CORRECTED TO 245.1 | ~~30,412~~ | |
| | | 2,097,302 | 1,742,258 |

355,044

PSC 039761

Nov. 1, 80 – 2 Assuming 8.9447 cf/psig.

Sept 14, 89 – 248.5

8/20/79 – 111.7 psig.  6/23/80 – 241.9 psig

| CNV | WITH |
|---|---|
| 3262148 | 1711846 |
| | + 999122 |
| | 2710968 |
| 551,180 | |

PSC 039762

M 850-22-0058 INTER-DEPARTMENTAL MEMO – PUBLIC SERVICE COMPANY OF COLORADO

DATE November 12, 1980

TO Mr. Kenneth Hooker, Jr., Gas Supply Manager — Fuel Supply Development (DEPARTMENT OR DIVISION)

FROM John A. Shealy, Special Projects Engineer — Fuel Supply Development (DEPARTMENT OR DIVISION)

ATTN.

SUBJ. 1979-80 Leyden Lost and Unaccounted for Gas

The annual lost and unaccounted for (L & U) gas volumes for the Leyden Underground Storage facility have always been calculated for the time period November 1st through October 31st. To calculate this L & U volume, cavern pressures on the above dates are recorded, a pressure-volume (P-V) relationship is utilized and injection-withdrawal records are summarized. However, in past years the P-V relationship used was not a true P-V relationship, but instead a drawdown rate. The drawdown rate is the ratio between the amount of gas withdrawn and the corresponding immediate drop in cavern pressure. A true P-V relationship is the ratio between the amount of gas withdrawn and the corresponding stabilized drop in cavern pressure. When the cavern is at a pressure ($P_1$) and an amount of gas is withdrawn (V), the cavern pressure will drop to a lower pressure ($P_2$). The calculated drawdown rate is then equal to $V/(P_1 - P_2)$. However, if no activity is initiated after this withdrawal, the pressure ($P_2$) will begin to stabilize at a substantially different pressure ($P_3$). The calculated P-V relationship is then equal to $V/(P_1 - P_3)$. This stabilization effect is caused by pressure drawdown gradient effects, gas migration effects and water level changes within the cavern. For the year 1980-81, the drawdown rate was calculated as 8.4667 $M^2CF/PSIG$, while the P-V relationship was 11.6258 $M^2CF/PSIG$. (See attached report.)

Since the P-V relationship is derived from stabilized cavern pressures, stabilized cavern pressures must be known before a P-V calculation can be performed. Therefore, to accurately calculate the annual L & U, stabilized cavern pressures must be used for the beginning and ending dates of the calculation period. The best stabilized cavern pressures are obtained at the end of the summer shut-in period, and, therefore, it is recommended that the annual L & U calculation be based on summer ending pressures versus November 1st and October 31st pressures.

Some examples of erroneous L & U calculations, based on unstable cavern pressures, and the accurate L & U calculation for 1979-80 are shown below:

Example 1 -- September 12, 1979 - unstable cavern pressure = 241.8 PSIG
October 31, 1979 - unstable cavern pressure = 241.2 PSIG
Injections = 281,852 MCF
Withdrawals = 41,407 MCF

Since pressures equal like volumes, then the injections minus the withdrawals should be equal to the change in cavern pressure. Any difference thereafter will be written off as L & U. However, due to the unstability of the cavern pressures, the following was calculated as L & U:

Injections - withdrawals = (change in pressure)(P-V relationship) + L & U

OR

L & U = (injections - withdrawals) - (change in pressure)(P-V relationship)

L & U = (281,852 - 41,407)MCF - (241.2 - 241.8)PSIG (11,625.8)MCF/PSIG

L & U = 247,420 MCF over a 49 day period

Example 2 -- August 20, 1979 - stabilized cavern presssure = 111.7 PSIG
October 31, 1979 - unstabilized cavern pressure = 241.2 PSIG
Injections = 1,376,774 MCF
Withdrawals = 41,407 MCF

L & U = (injections - withdrawals) - (changes in pressure)(P-V relationship)

L & U = (1,376,777 - 41,407)MCF - (241.2 - 111.7)PSIG (11,625.8)MCF/PSIG

L & U = -170,171 MCF

It is very difficult to explain a negative L & U. However, it does indicate that other sources, besides pressures and volumes, are effecting the L & U calculations. Those other sources are those effects on pressure stabilization mentioned earlier (pressure gradient, gas migrating and changes in water levels).

L & U Calculation for 1979-80

Stabilized cavern pressure on August 20, 1979 = 111.7 PSIG
Stabilized cavern pressure on September 14, 1980 = 239.7 PSIG

Injections from 8/20/79 → 9/14/80 = 3,266,527 MCF
Withdrawals from 8/20/79 → 9/14/80 = 1,711,846 MCF

L & U = (3,266,527 - 1,711,846)MCF - (239.7 - 111.7)PSIG (11,625.8)MCF/PSIG

L & U = 66,616 MCF

John A. Shealy

JAS:cp
Attachment

markedly
for comparative look.

| | L&U Reported | Revised calculation |
|---|---|---|
| 1973-74 | 125,527 | 143,789 |
| 1974-75 | 114,748 | 84,454 |
| 1975-76 | 23,392 | 90,037 |
| 1976-77 | 132,508 | 195,035 |
| 1977-78 | 130,204 | 151,467 |
| 1978-79 | 127,230 | 152,799 |
| Total | 684,127 | 837,583 |

PSC 039764