0011

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Attachment I General Equations

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ATTACHMENT I
GENERAL EQUATIONS

[SLUG TEST RESULTS]

ATTACHMENT I

A. General Equation for the Residual Head in a Well

Theis (1935) presented the equation for the drawdown in an instantaneous vertical line source.[1] The equation provides a useful method for estimating the transmissivity of a formation in the vicinity of a well, which is a physical approximation of the theoretical vertical line source. Ideally, a "slug" of water is injected into a fully developed well at time t=0. The well theoretically penetrates the full length of the aquifer in question, a condition met by each well, 10-2 and 11-2. The equation for the residual head is then written as:

$$s = \frac{Q \exp(-r^2S/4Tt)}{4\pi Tt} \qquad [1]$$

where

- s = residual water level after injection of the water, measured with respect to the original water table.
- r = distance from the injection well to an observation point
- t = time since injection of the slug
- Q = volume of the slug
- T = aquifer transmissivity
- S = aquifer storativity

Generally, only a small volume of water is injected into a well. For this reason, the reaction to the injected slug usually is not measurable in the aquifer beyond the immediate vicinity of the well. Therefore, the water-level measurements are made only in the injection well; the distance is then the radius of the well. For values of r as small as the well radius, especially where S is small (as for artesian aquifers), the argument of the exponential in equation 1 approaches zero as t becomes large and the value of the exponential terms approaches unity. Then, for a consistent set of units, transmissivity can be represented as:

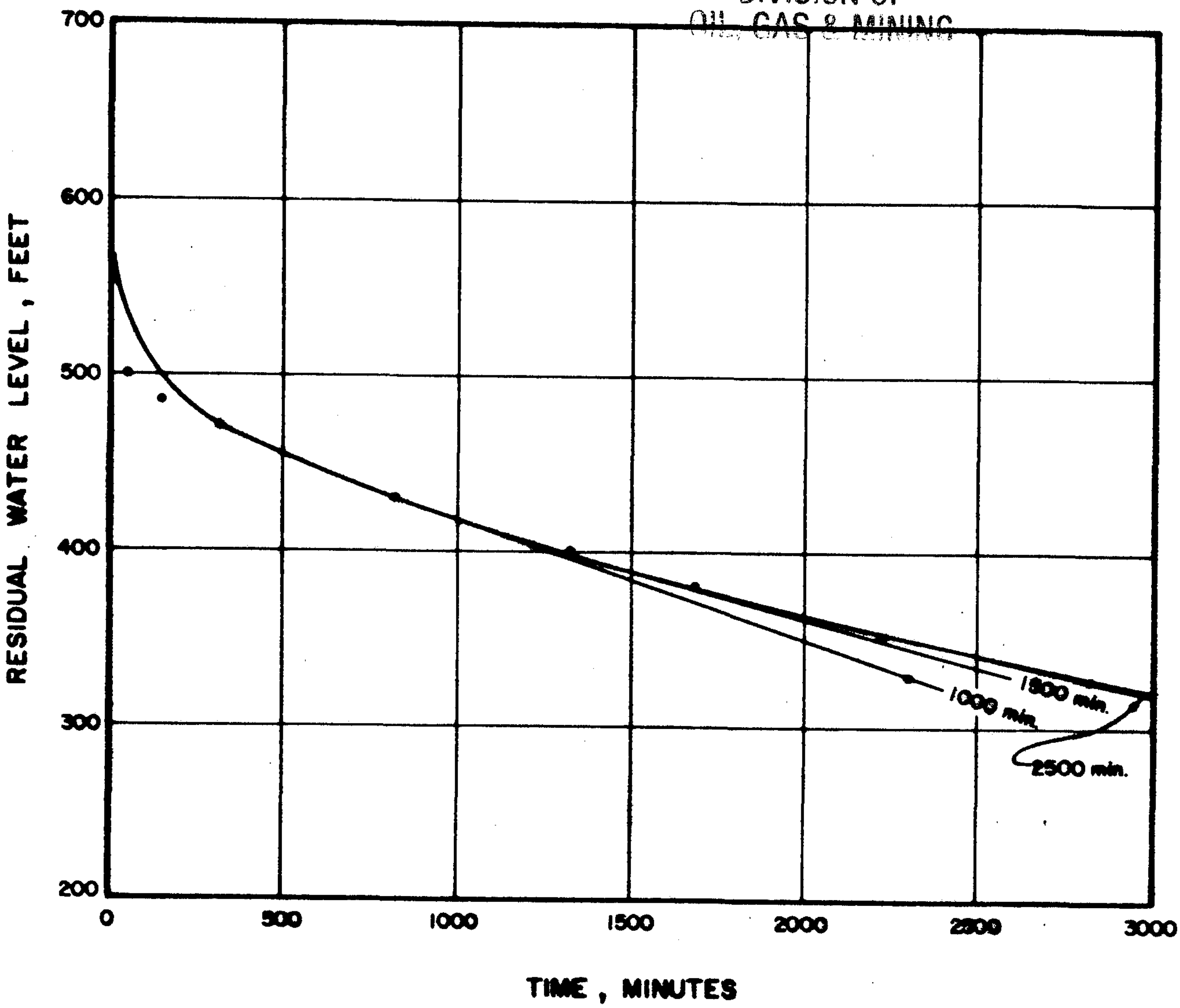
$$T = \frac{Q}{4\pi st} \qquad [2]$$

A plot of s versus 1/t should be a straight line which passes through the origin. Any coordinate of the line should thus yield a value for T.

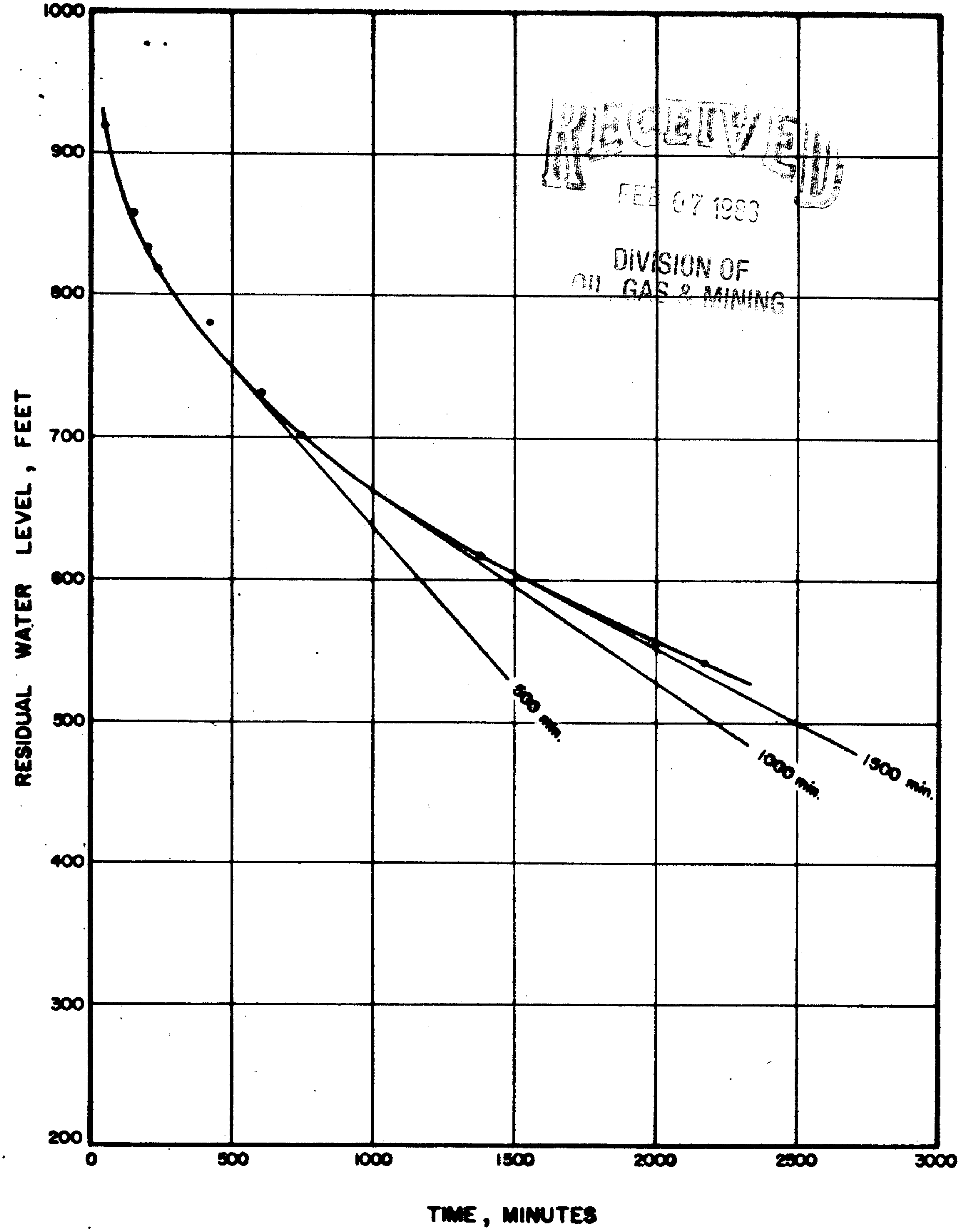
B. Specific Technique for Transmissivity Determination from test Data of Wells 11-2 and 10-2

Observed data for wells 11-2 and 10-2 did not plot on a straight line, nor was there a trend for any of the locally straight segments on either plot to pass through the origin. This may be attributed

[1] Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Amer. Geophys. Union Trans., 16th Ann. Mtg., pt.2, p. 519-524



Wahler Associates	SUNEDCO COAL COMPANY	RESIDUAL HEAD VS. TIME, WELL 10-2	
	PALO ALTO • NEWPORT BEACH • DENVER	PROJECT NO.: SED-102A	DATE: NOVEMBER 1982	FIGURE NO.: 1-1



Wahler Associates	SUNEDCO COAL COMPANY	RESIDUAL HEAD VS. TIME, WELL 11-2	
	PALO ALTO • NEWPORT BEACH • DENVER	PROJECT NO. SED-102A	DATE NOVEMBER 1982
		FIGURE NO. 1-2	

to poor well construction techniques. The water levels in both wells were asymptotic not to the original static level, but to levels more than 200 feet higher. WA has speculated that all of the additional excess head was indeed necessary to force water into the formation and to overcome head loss associated with the perforations in the casing. At later time, the residual excess head in the well was not great enough to overcome severe head loss, through the perforations, thus causing a relatively slow decline in the water level and a correspondingly low apparent transmissivity.

Assuming that the water levels were displaced by some constant value due to well inefficiency during the tests, WA has employed a differential form of equation 2 to determine transmissivity from the graphs of Figures I-1 and I-2, which represent time-residual head data for wells 10-2 and 11-2 respectively. The key to the analysis is that T is determined from the predicted rate of fall of the water level rather than its actual position at various times during the test. Consequences of the analysis is that the apparent transmissivity of the formation is found at various points in time, with the gradual decrease being attributed more and more to poor well completion. In addition, the trend for the water table not to return to static is removed from the analysis.

Equation 2 is rearranged as:

$$T = \frac{-Q}{4\pi(ds/dt)t^2} \qquad [3],$$

and the slope of the time-residual head curve (always negative) is measured at various values of time, t. Table 1 summarizes the values of transmissivity for the Price River formation as obtained by equation 3. Using 1000 as a time during the test for which T is representative, the transmissivity of the Price River formation aquifer is approximately 1 gpd/ft.

C. Coal Transmissivities as Derived from Well 5-1 Data

An estimate of the transmissivity of the coal members of the Blackhawk formation is possible by applying Darcy's law to the observed data for well 5-1. This is done by calculating the volume of water lost to the formation from the well over a given time, and dividing it by the average gradient in the immediate vicinity of the well during the time period. As water is not likely to have penetrated too far radially into the formation, the assumption that the formation gradient is equal to the average excess head during the time period of interest is reasonable. Therefore,

$$T = Q/i\Delta t\pi d \qquad [4],$$

where:

Q = volume of water lost to formation during time Δt

i = average excess head during time Δt

πd = the "width" of well screen, if unfolded, normal to the flow.

For well 5-1, use $i = 280.2$ ft/ft between times of 2 and 1922 minutes. Then $\Delta t = 1.33$ days, and $Q = 4.5$ feet (7.48 gallons/ft^3) ($\pi d^2/4$), or 4.6 gallons. Then:

$$T = 4.6 \text{ gallons}/(280.2)(1.33 \text{ days})\ \pi(.417 \text{ ft})$$
$$T = 0.009 \text{ gpd/ft}$$

TABLE I-1

SUMMARY OF TRANSMISSIVITY VALUES FROM PRICE RIVER FORMATION AQUIFER TESTS

A. Well 10-2*

time t (min)	slope ds/dt (ft/min)	transmissivity T (gpd/ft)***
1000	90/1300	1.04
1500	30/550	0.59
2500	42/1000	0.27

B. Well 11-2**

time t (min)	slope ds/dt (ft/min)	transmissivity T (gpd/ft)***
500	110/500	2.19
1000	40/300	0.91
1500	30/300	0.54

*Volume of slug = Q = $(\pi d^2/4)$(initial excess head)(7.48 gal/ft^3)
= 627 gallons

**Volume of slug = Q = $(\pi d^2/4)$(initial excess head)(7.48 gal/ft^3)
= 1053 gallons

***$T = 114.6Q/(ds/dt)t^2$, for units used.

ATTACHMENT II

FIELD TEST DATA

FIELD PERMEABILITY TEST

FALLING HEAD

PROJECT SAGE POINT / DUGOUT CANYON TESTED BY JOEL SIEGEL DATE 11-4-82
PROJECT NO. SED102A CALCULATED BY Joel Siegel DATE 11-9-82
BORING NO. 5-1 CHECKED BY ______ DATE ______

DIAMETER OF BORING N/A
DIAMETER OF CASING 5 INCH PERMEABILITY, K ______
HEIGHT OF CASING (REF. LEVEL)
ABOVE GROUND SURFACE 2.6 FT. PUMPING FROM: ______ TO ______
PERFORATED CASING FROM: ______ TO ______
TYPE OF PERFORATION: ______
DEPTH TO GROUND WATER
FROM TOP OF CASING (STATIC) 304.9 FT. PUMPING RATE: ______ gpm

	DATE AND TIME	ELAPSED TIME (MIN)	DEPTH TO WATER (ft)	S.W.L.-DEPTH TO WATER(ft) H	H/Ho**	INVERSE TIME (MIN⁻¹)
11-4-82	13:41	0	304.9 *	—	—	—
	13:51	0	11.9	293.0	—	—
	13:53	2	22.5	282.4	1	50× 10⁻²
	13:53:30	2.5	23.5	281.4	0.99	40× 10⁻²
	13:55	4	23.7	281.2	0.99	25× 10⁻²
	13:58	7	23.8	281.1	0.99	14.3 × 10⁻²
	14:02	11	23.9	281.0	0.99	9.1 × 10⁻²
	14:17	26	24.0	280.9	0.99	3.85× 10⁻²
	14:41	50	24.0	280.9	0.99	2.00 × 10⁻²
	21:53	482	24.9	280.0	0.99	0.21× 10⁻²
11-5-82	08:24	1113	25.9	279.0	0.99	0.09 × 10⁻²
	21:53	1922	27.0	277.9	0.98	0.05× 10⁻²
			END	OF TEST.		

COMMENTS: *STATIC LEVEL

FIELD PERMEABILITY TEST

FALLING HEAD

PROJECT SAGE POINT/DUGOUT CANYON
PROJECT NO. SED102A
BORING NO. 10-2

TESTED BY JOEL SIEGEL DATE 11-3-82
CALCULATED BY Joel Siegel DATE 11-9-82
CHECKED BY ______ DATE ______

DIAMETER OF BORING N/A
DIAMETER OF CASING 5 INCH
HEIGHT OF CASING (REF. LEVEL) ABOVE GROUND SURFACE 2.3 FT.
PERFORATED CASING FROM: ______ TO ______
TYPE OF PERFORATION: ______
DEPTH TO GROUND WATER FROM TOP OF CASING (STATIC) 715.8 FT

PERMEABILITY, K ______
PUMPING FROM: ______ TO ______
PUMPING RATE: ______ gpm

	DATE AND TIME	ELAPSED TIME (MIN)	DEPTH TO WATER (ft)	S.W.L.-DEPTH TO WATER(ft) H	H/Ho	INVERSE TIME (MIN⁻¹)
11-3-82	8:31	0	715.8 *	—	—	—
	9:06	0	101.0	614.8	1	—
	9:09	3	125.4	590.4	.96	33.3×10⁻²
	9:11	5	139.6	576.2	.94	20.0×10⁻²
	9:13	7	146.5	569.3	.93	14.3×10⁻²
	9:15	9	149.7	566.1	.92	11.1×10⁻²
	9:18	12	150.8	565.0	.92	8.33×10⁻²
	9:23	17	182.6	533.2	.87	5.88×10⁻²
	9:27	21	195.3	520.5	.85	4.76×10⁻²
	9:39	33	212.4	503.4	.82	3.03×10⁻²
	9:47	41	213.8	502.0	.82	2.44×10⁻²
	10:00	54	215.8	500.0	.81	1.85×10⁻²
	10:34	88	220.6	495.2	.81	1.14×10⁻²
	11:12	126	225.2	490.6	.80	0.79×10⁻²
	11:39	153	229.5	486.3	.79	0.65×10⁻²
	12:03	177	231.1	484.7	.79	0.56×10⁻²
	12:41	215	235.0	480.8	.78	0.46×10⁻²
	13:19	253	238.8	477.0	.78	0.39×10⁻²
	14:26	320	245.1	470.7	.77	0.31×10⁻²
	15:18	372	249.8	466.0	.76	0.27×10⁻²
	20:13	667	273.2	442.6	.72	0.15×10⁻²
	22:49	823	284.1	431.7	.70	0.12×10⁻²
11-4-82	07:14	1328	315.6	400.2	.65	0.075×10⁻²
	13:12	1686	335.0	380.8	.62	0.059×10⁻²

COMMENTS: *STATIC LEVEL.

FIELD PERMEABILITY TEST

FALLING HEAD

PROJECT SAGE POINT/DUGOUT CANYON
PROJECT NO. SED102A
BORING NO. 10-2

TESTED BY JOEL SIEGEL DATE 11-3-82
CALCULATED BY Joel Siegel DATE 11-9-82
CHECKED BY ______ DATE ______

DIAMETER OF BORING N/A
DIAMETER OF CASING 5 INCH
HEIGHT OF CASING (REF. LEVEL)
ABOVE GROUND SURFACE 2.3 FT.
PERFORATED CASING FROM: ______ TO ______
TYPE OF PERFORATION: ______
DEPTH TO GROUND WATER
FROM TOP OF CASING ______

PERMEABILITY, K ______
PUMPING FROM: ______ TO ______
PUMPING RATE: ______ gpm

	DATE AND TIME	ELAPSED TIME (MIN)	DEPTH TO WATER (ft)	S.W.L.-DEPTH TO WATER(ft) H	H/Ho	INVERSE TIME (MIN⁻¹)
11-4-82	22:10	2224	361.0	354.8	.58	0.045×10^{-2}
11-5-82	08:11	2825	386.9	328.9	.53	0.035×10^{-2}
	21:36	3630	417.0	298.8	.49	0.027×10^{-2}
			END OF	TEST.		

COMMENTS:

FIELD PERMEABILITY TEST

FALLING HEAD

PROJECT SAGE POINT/DUGOUT CANYON
PROJECT NO. SED102A
BORING NO. 11-2

TESTED BY JOEL SIEGEL DATE 11-4-82
CALCULATED BY [signature] DATE 11-9-82
CHECKED BY ____ DATE ____

DIAMETER OF BORING N/A
DIAMETER OF CASING 5 INCH
HEIGHT OF CASING (REF. LEVEL) ABOVE GROUND SURFACE 2.4 FT.
PERFORATED CASING FROM: ____ TO ____
TYPE OF PERFORATION: ____
DEPTH TO GROUND WATER FROM TOP OF CASING (STATIC) 1127.6 FT

PERMEABILITY, K ____
PUMPING FROM: ____ TO ____
PUMPING RATE: ____ gpm

	DATE AND TIME	ELAPSED TIME (MIN)	DEPTH TO WATER (ft)	S.W.L.-DEPTH TO WATER(ft) H	H/Ho	INVERSE TIME (MIN⁻¹)
11-4-82	7:40	0	1127.6 *	—	—	—
	8:53	0	95.3	1032.3	1	—
	8:56	3	119.2	1008.4	.98	33.3×10^{-2}
	9:01	8	130.0	997.6	.97	12.5×10^{-2}
	9:02	9	143.4	984.2	.95	11.1×10^{-2}
	9:06	13	172.1	955.5	.93	7.69×10^{-2}
	9:09	16	184.1	943.5	.91	6.25×10^{-2}
	9:15	22	187.9	939.7	.91	4.55×10^{-2}
	9:21	28	193.7	933.9	.90	3.57×10^{-2}
	9:28	35	198.9	928.7	.90	2.86×10^{-2}
	9:41	48	208.0	919.6	.89	2.08×10^{-2}
	10:00	67	221.3	906.3	.88	1.49×10^{-2}
	10:22	89	234.0	893.6	.87	1.12×10^{-2}
	10:45	112	247.9	879.7	.85	0.89×10^{-2}
	11:25	152	270.6	857.0	.83	0.66×10^{-2}
	11:48	175	281.3	846.3	.82	0.57×10^{-2}
	12:16	203	294.2	833.4	.81	0.49×10^{-2}
	12:40	227	303.5	824.1	.80	0.44×10^{-2}
	12:58	245	309.7	817.9	.79	0.41×10^{-2}
	15:00	427	348.3	779.3	.75	0.23×10^{-2}
	16:53	480	372.1	755.5	.73	0.21×10^{-2}
	18:52	599	397.1	730.5	.71	0.17×10^{-2}
	21:23	750	425.5	702.1	.68	0.13×10^{-2}
11-5-82	07:53	1380	512.3	615.3	.60	0.072×10^{-2}
	21:08	2175	584.6	543.0	.53	0.046×10^{-2}

COMMENTS: * STATIC LEVEL.

END OF TEST