REFERENCE 4

Strosnider

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March 3, 1981

Mr. Milton Vagins
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission
Mail Station 1130 SS
Washington, D.C. 20555

Dear Milt:

Subject: Parametric Analysis of Rancho Seco Overcooling Accident

The fracture-mechanics parametric analysis that you requested for the Rancho Seco overcooling accident (March 20, 1978) has been completed, and the results and a discussion thereof follow.

According to information we received from NRC on December 5, 1980 (letter from Fabic to Serpan, November 25, 1980), the Rancho Seco transient condition started with a spike in primary-system pressure and a rapid rise in cold-leg-coolant temperature as shown in Fig. 1. By ~1 min after the spike the pressure was decreasing gradually from ~2150 psi, and the temperature was rising slowly above 585°F. At 9 min into the transient both the pressure and temperature started dropping rather rapidly. Up to this point the transients would have had little effect on the vessel.

In a later communique (letter from Strosnider to Cheverton, January 30, 1981), the information in Table 1 and Fig. 2 was made available to us. Time zero in these two sources of transient data is assumed to be consistent with a time of ~9 min in Fig. 1. Figure 2 indicates that the initial major drop in pressure (t = 9 min, Fig. 1; t = 0, Fig. 2) extended down to ~1500 psi in ~15 min. Following this, there was an irregular series of ups and downs with a net increase to ~2100 psi within ~35 min, and this in turn was followed by a gradual decrease to ~1900 psi over a 50-min period. This is the end of a 100-min period that we were requested to analyze.

The pressure vs time curve that we used in our analysis is the smooth curve in Fig. 2, which was suggested and drawn through the pressure peaks by NRC. Pressure and temperature curves reproduced by us from the data in Table 1 and Fig. 2 are shown in Fig. 3, and corresponding tabulated data used as input to OCA-I is shown in Table 2.

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It should be pointed out that at t = 100 min (Fig. 2) the wall temperatures are still substantially higher than the coolant temperature and thus the material toughness will continue to decrease for some time, the amount depending upon the temperature of the coolant thereafter. Since the pressure is still high and eventually goes even higher (Fig. 2) a continued decrease in wall temperature may be of concern. However, our analysis has covered only that part of the transient requested (Δt = 100 min).

The analysis of Rancho Seco was performed using OCA-I with all of the built-in (default) input data (refer to OCA-I draft report, February 9, 1981), a heat-transfer coefficient of 330 Btu/hr·ft^2·°F and an initial wall temperature of 570°F. Parameters varied in the analysis and specific values considered are shown in Table 3. As indicated, the analysis included variations in copper content, initial RTNDT ($RTNDT_o$) and inner-surface fluence (F_o). The analysis also included two variations in the ASME Section XI toughness curves other than RTNDT: one variation constituted the use of no upper shelf and the other constituted the inclusion of an upper shelf of 400 ksi $\sqrt{in.}$ for both K_{Ic} and K_{Ia}.

Detailed results of the analysis are presented in tabular form (microfiche) for both the heat-transfer and fracture-mechanics analyses. In addition, results of the fracture-mechanics analysis are summarized in the form of K_I VS time and a/w curves (Fig. 4), critical-crack-depth curves for the cases involving $K_I \geq K_{Ic}$, and two summary tables. As indicated by the critical-crack depth curves (Figs. 5 through 19), conditions for warm prestressing exist, and WPS mitigates the consequences of the transient. This comes about because during the 100-min portion of the transient analyzed both the thermal and pressure loads first increase with time and then decrease. This is indicated by the temperature and pressure transients in Fig. 3 and by the K_I vs time and a/w curves in Fig. 4. It should be noted that the WPS curve is the same for all cases calculated because the WPS curve is dependent only on the transient condition, not on fracture toughness.

Let us now narrow our discussion to the case of no upper shelf. An examination of Figs. 5 through 19 and Table 4 indicates that if WPS is ignored, and if crack initiation takes place, which it does for the cases represented by the figures, then for some but not all initiating crack depths the crack will jump more than 90% of the way through the wall, and the corresponding initial crack depths (a/w) range upward from ~0.03 (0.25 in.). Furthermore, the threshold fluence for crack initiation for the most severe case ($RTNDT_o$ = 40°F and Cu = 0.35%) is ~0.75 x10^{19} n/cm^2 (~6 years). If WPS is included, the threshold fluence is increased to ~1.7 x10^{19} n/cm^2 (~14 years).

For some cases in Table 4 the maximum crack penetration $[(a_c/w)_a]$ is less than or equal to 0.9, indicating that the vessel would not fail prior to accumulating the corresponding fluence. It must be remembered, however, that OCA-I does not include a failure mode associated with simple rupture of the uncracked ligament as a result of excessive internal pressure. If the pressure is near normal operating pressure, the threshold crack depth for rupture is ~0.7.

With this in mind the results in Table 4 can be further condensed to simply reveal the useful life of the vessel for the particular accident analyzed. Such a summary is shown in Table 5.

If we assume that WPS is effective, the data in Figs. 5 through 19 indicate that the deepest crack that will initiate will correspond to $a/w \cong 0.5$. With reference to Fig. 4 we see that $a/w = 0.5$ corresponds to a maximum K_I value of ~250 ksi $\sqrt{in.}$, which is probably below the upper shelf. This implies that the analysis for flaw depths at least up to ~0.5 is reasonably correct. However, K_I values for deeper flaws are greater and may exceed the upper shelf, in which case an analysis that ignores the upper shelf would be in error. The effective upper-shelf toughness for a large structure such as a pressure vessel is not known. However, an arbitrary value of 400 ksi $\sqrt{in.}$ for K_{Ic} and K_{Ia} was used for a second complete set of Rancho Seco-1 calculations in order to get a feel for the effect of an upper shelf. Critical-crack-depth curves for these cases are presented in Figs. 20 through 55. As indicated in these figures and as reasoned above, the introduction of the particular upper shelf affects only the very deep flaws ($a/w > 0.5$), allowing them to initiate (tear). However, WPS prevents shallow cracks from becoming sufficiently deep for initiation at upper-shelf toughness. Thus, the introduction of an upper shelf of 400 ksi $\sqrt{in.}$ does not substantially change the results obtained without an upper shelf.

Note that Fig 4-55 are not included in this copy

Sincerely,

Dick

R. D. Cheverton

RDC:spf
Attachments

cc: S. K. Iskander
R. W. Klecker, DOR-NRC
F. R. Mynatt
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TABLE 1. MARCH 20, 1978, RANCHO SECO OVER-COOLING TRANSIENT TEMPERATURE TIME HISTORY

TIME INTO TRANSIENT (min)	TEMPERATURE (°F)
0	590
24	385
48	300
72	280
96	310

TABLE 2. TEMPERATURE AND PRESSURE TRANSIENTS USED IN OCA-I FOR RANCHO SECO-I ANALYSIS

TIME (min)	TEMPERATURE (°F)	PRESSURE (psi)
0	590	1500
10	490	1710
20	412	1880
30	356	2020
40	318	2110
50	296	2130
60	282	2100
70	280	2050
80	284	2000
90	299	1950
100	320	1900

TABLE 3. PARAMETERS VARIED IN THE RANCHO SECO ANALYSIS AND THE VALUES CONSIDERED

$RTNDT_o$ (°F)	20, 40
Copper (%)	0.1, 0.25, 0.35
F_o (10^{19} n/cm^2)	0.6, 0.8, 1.0, 2.0, 3.0, 4.0

TABLE 4. RANCHO SECO-1 CRITICAL CRACK DEPTHS FOR INITIATION AND ARREST ASSUMING NO UPPER SHELF FOR TOUGHNESS CURVES

f_0 ([illegible] n/cm^2)	APPROXIMATE FULL-POWER TIME (years)	NEGLECTING WPS $(a_c/w)_i$	NEGLECTING WPS $(a_c/w)_a$	INCLUDING WPS $(a_c/w)_i$	INCLUDING WPS $(a_c/w)_a$	NEGLECTING WPS $(a_c/w)_i$	NEGLECTING WPS $(a_c/w)_a$	INCLUDING WPS $(a_c/w)_i$	INCLUDING WPS $(a_c/w)_a$
		RT_{NDT_0} = 20°F, Cu = 0.10%				RT_{NDT_0} = 40°F, Cu = 0.10%			
0.6	4.8	*				*			
0.8	6.4	*				*			
1.0	8	*				*			
2.0	16	*				*			
3.0	24	*				*			
4.0	32	*				*			
		RT_{NDT_0} = 20°F, Cu = 0.25%				RT_{NDT_0} = 40°F, Cu = 0.25%			
0.6	4.8	*	*	*	*	*	*	*	*
0.8	6.4	*	*	*	*	*	*	*	*
1.0	8	*	*	*	*	*	*	*	*
1.50						Threshold			
1.80		Threshold							
2.0	16	0.06-0.18	0.38→0.9	*	*	0.04-0.30	0.34→0.9	*	*
2.25								Threshold	
2.85				Threshold					
3.0	24	0.04-0.44	0.33→0.9	0.05-0.18	0.33-0.38	0.04-0.66	0.33→0.9	0.04-0.23	0.33-0.47
4.0	32	0.03-0.72	0.39→0.9	0.04-0.29	0.39-0.52	0.03→0.9	0.38→0.9	0.03-0.34	0.38-0.64
		RT_{NDT_0} = 20°F, Cu = 0.35%				RT_{NDT_0} = 40°F, Cu = 0.35%			
0.6	4.8	*	*	*	*	*	*	*	*
0.75						Threshold			
0.8	6.4	*	*	*	*	0.08-0.15	0.5→0.9	*	*
1.0	8	*	*	*	*	0.06-0.32	0.5→0.9	*	*
1.20		Threshold							
1.70								Threshold	
2.0	16	0.05→0.9	0.59→0.9	*	*	0.04→0.9	0.6→0.9	0.06-0.20	0.6-0.65
2.50				Threshold					
3.0	24	0.04→0.9	0.68→0.9	0.05-0.23	0.68-0.80	0.03→0.9	0.7→0.9	0.03-0.35	0.7-0.90
4.0	32	0.03→0.9	0.78→0.9	0.04-0.33	0.78→0.9	0.03→0.9	0.8→0.9	0.03-0.5	0.8→0.9

*No initiation.

TABLE 5. USEFUL FULL-POWER LIFE OF VESSEL BASED ON SPECIFIC 100-MIN TRANSIENT (years)

Cu (%)	$RTNDT_{0}$, °F: -20		40	
	WPS	W/O WPS	WPS	W/O WPS
0.1	>32	>32	>32	>32
0.25	>32	14	>32	12
0.35	20	10	14	6

Incipient crack initiation

FIGURE 3 /

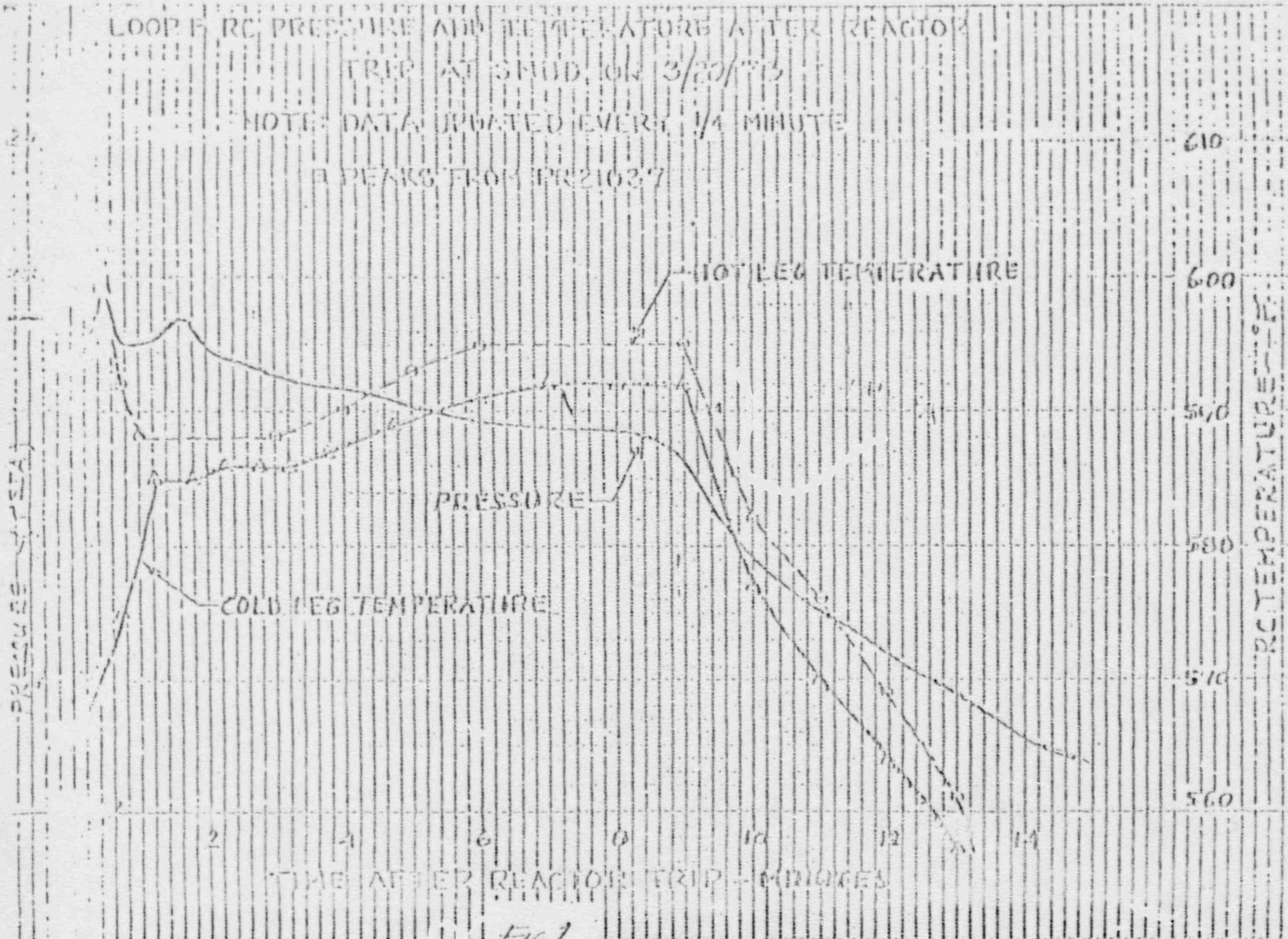

Fig 1

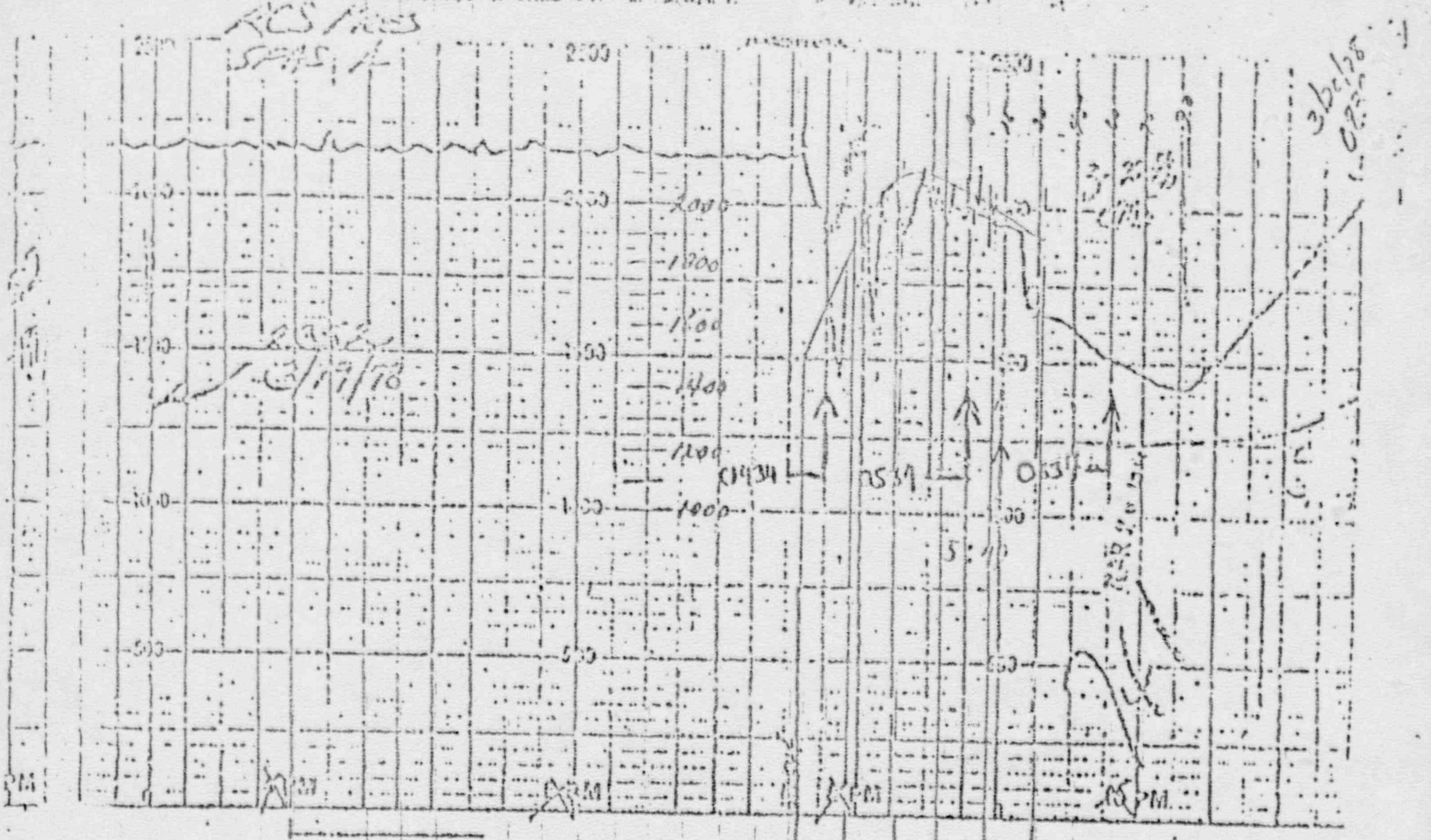

FIG 2 RECORDING OF PRESSURE TRANSIENT (RANCHO SECO, MARCH 20, 1978)

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