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ANALYSIS OF UNREPAIRED FLAW INDICATIONS AT BRUNSWICK STEAM ELECTRIC PLANT UNIT 2

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1.0 INTRODUCTION

This report summarizes analyses performed by NUTECH to evaluate unrepaired flaws in the recirculation system at Carolina Power and Light Company's Brunswick Steam Electric Plant Unit 2 (Brunswick 2). The flaw indications were originally detected with ultrasonic (UT) examination near 11 welds during the October-November 1983 inspection. At that time, fracture mechanics evaluations showed that the 11 welds did not require repair because acceptable design safety margins existed for at least the next six months (the time until the next scheduled refueling outage).

These 11 welds were ultrasonically re-examined during the Spring, 1984 inspection. A comparison of the results of the two inspections is given in Table 1.0. This information was provided to NUTECH in Reference 1. All flaws were detected in type 304 stainless steel.

Table 1.0

Weld No.	Thru-Wall (%) 1983	Thru-Wall (%) 1984	Length (IN) 1983	Length (IN) 1984	Orientation	Location
2-B32-28"-A-8	6.0+	13.0+	1.0	0.625	45° Skewed	Elbow
2-B32-28"-A-14	8.0	9.0	0.5	0.5	Circumferential	Elbow
2-E11-20"-A-2	16.0	*	0.95	*	-	-
2-B32-28"-A-4	9.0	2.0	1.0	0.75	Circumferential	Pipe
	15.0	13.0	1.5	0.625	Circumferential	Elbow
2-B32-28"-B-4	11.0	7.0	1.0	0.875	Circumferential	Elbow
2-B32-28"-B-5	4.5	11.0	2.375	2.25	Circumferential	Upstream
	15.0+	20.0+	3.0	3.5	Circumferential	Upstream
	4.5	9.0	1.5	1.75	Circumferential	Upstream
2-B32-28"-B-3	10.0	5.0	0.7	0.75	Circumferential	Elbow
	10.0	5.0	0.8	4.5	Circumferential and Axial	Elbow
2-B32-22"-AM-5	20.0+	14.0+	11.5 (Int.)	0.5	Circumferential and Skewed	Pipe
2-B32-22"-BM-1	15.0	13.0	1.2	1.75	Circumferential	End Cap
2-B32-28"-A-13	12.0	6.0	0.5	0.9	Circumferential	Pipe
2-B32-28"-B-9	17.6	8.0	1.0	0.875	Skewed	Pipe

Note: Comparison of sizing using 60° transducer unless otherwise noted.
+ Comparison of sizing using 45° transducer.
* No indication found during 1984 inspection.

2.0 UNREPAIRED FLAW EVALUATION

UT re-evaluation of the 11 welds previously identified at Brunswick Unit 2 has revealed reportable indications in 10 of these welds. Weld 2E11-20"-A2 was found not to have reportable indications during the Spring, 1984 inspection. Eight of the welds with flaws are in the 28" recirculation piping and two are in the 22" recirculation piping.

Flaw depths used in calculating crack growth were those reported during the Spring, 1984 inspection.

2.1 28" Recirculation Piping

Eight welds in the 28" recirculation piping have reportable flaw indications. The geometries of the welds with indications include pipe-to-pipe, pipe-to-valve, and pipe-to-elbow. The flaws are characterized in Table 1.

The prediction of crack growth for each of the existing UT flaw indications requires several inputs:

1) Steady state applied stress
2) Weld residual stress
3) Flaw characterization
4) Crack growth model
5) Crack growth law

The steady state applied stress is equal to the sum of the pressure, deadweight, thermal, and overlay shrinkage stresses. The pressure and deadweight stresses are upper bound values found in Reference 2 and thermal and shrinkage stresses are found in Reference 3.

Weld residual stresses are obtained from standard NUTECH curves (Reference 4).

The crack growth model is a linear interpolation between an inside diameter (I.D.) cracked cylinder and an edge-cracked plate. The model assumes a 360° crack. The magnification factors for both an I.D. cracked cylinder with a wall thickness to outside radius ratio of 0.1 and an edge-cracked plate were obtained from Reference 5.

Two crack growth laws were used to analyze each flaw indication. Crack Growth Law 1 (CGL-1) is similar to the law used by the NRC in their confirmatory analyses. Crack Growth Law 2 (CGL-2) is the correlation which was used in the previous evaluation of these flaws (Reference 6). These two laws are presented below.

<u>CGL-1</u>

$$\frac{da}{dT} = 3.59 \times 10^{-8} K^{2.161}$$

<u>CGL-2</u>

$$\frac{da}{dT} = 1.2 \times 10^{-6} e^{.11k}$$

where:

$\frac{da}{dT}$ = Crack growth rate (inches/hour)

K = Stress intensity factor (ksi in)

The allowable end-of-cycle crack depth was obtained from Reference 7 and NRC Generic Letter 84-11, "Inspections of BWR Stainless Steel Piping." The NRC letter requires taking 2/3 of the allowable depth found in Reference 7. By these criteria, the calculated allowable depth becomes equal to 50% of the through-wall thickness for all eight flaw indications. This method of determining allowable flaw depth is the same as that used in Reference 6, and meets the requirements of Generic Letter 84-11.

The predicted crack growth of each of the eight flaw indications (in the case of multiple flaws on one weld, the most severe was used) was calculated using the NUTECH computer program NUTCRAK (Reference 5). The predicted crack depth versus time for each weld is plotted in Figures 2.1 to 2.8.

2.2 22" Recirculation Piping

Two welds (22-AM-5 and 22-BM-1) in the 22" recirculation piping have reportable flaw indications. Weld 22-AM-5 is a cross-to-pipe weld and weld 22-BM-1 is an end cap-to-pipe weld. The majority of the flaw indications are circumferential and all are tabulated in Table 1.0. The allowable end-of-cycle crack depth is 2/3 of the Reference 7 value, in accordance with Generic Letter 84-11.

The crack growth of the UT flaw indications in these welds was predicted using the method presented in Section 2.1. Crack growth versus time for these two welds is presented in Figures 2.9 and 2.10.

2.3 20" RHR Piping

As previously mentioned, weld 2E11-20"-A2 had no reportable indications in the Spring, 1984 inspection.

However, an analysis was still performed using data from the October-November inspection when indications were found. The indications are tabulated in Table 1, and the allowable end-of-cycle crack depth is 50% from References 6 and 7.

Crack growth predictions for the UT flaw indications in this weld were made using the methods presented in Section 2.1. Predicted crack growth versus time is presented in Figure 2.11.

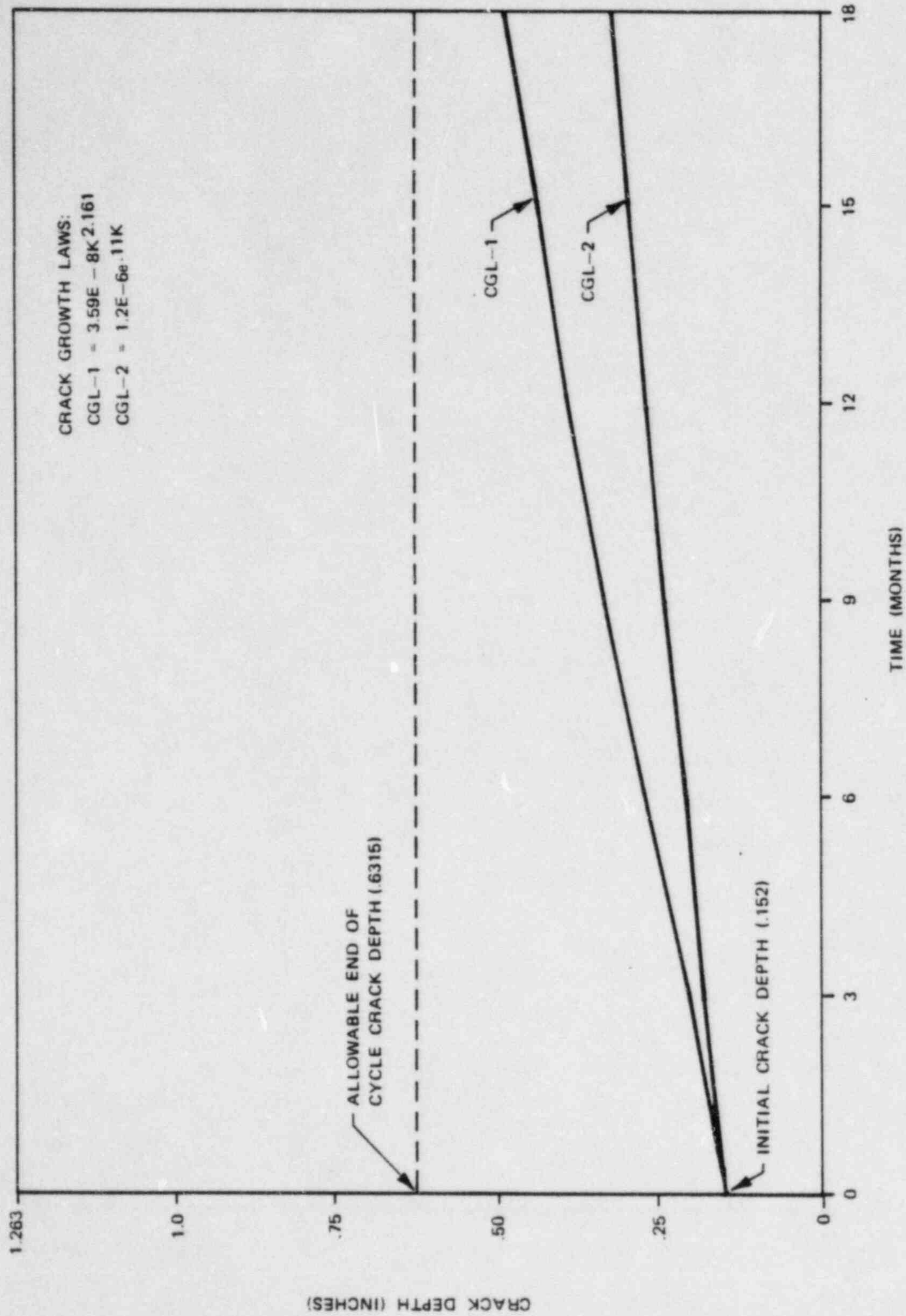

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Figure 2.1
CRACK GROWTH - VS - TIME, WELD 28A4
(BRUNSWICK 2)

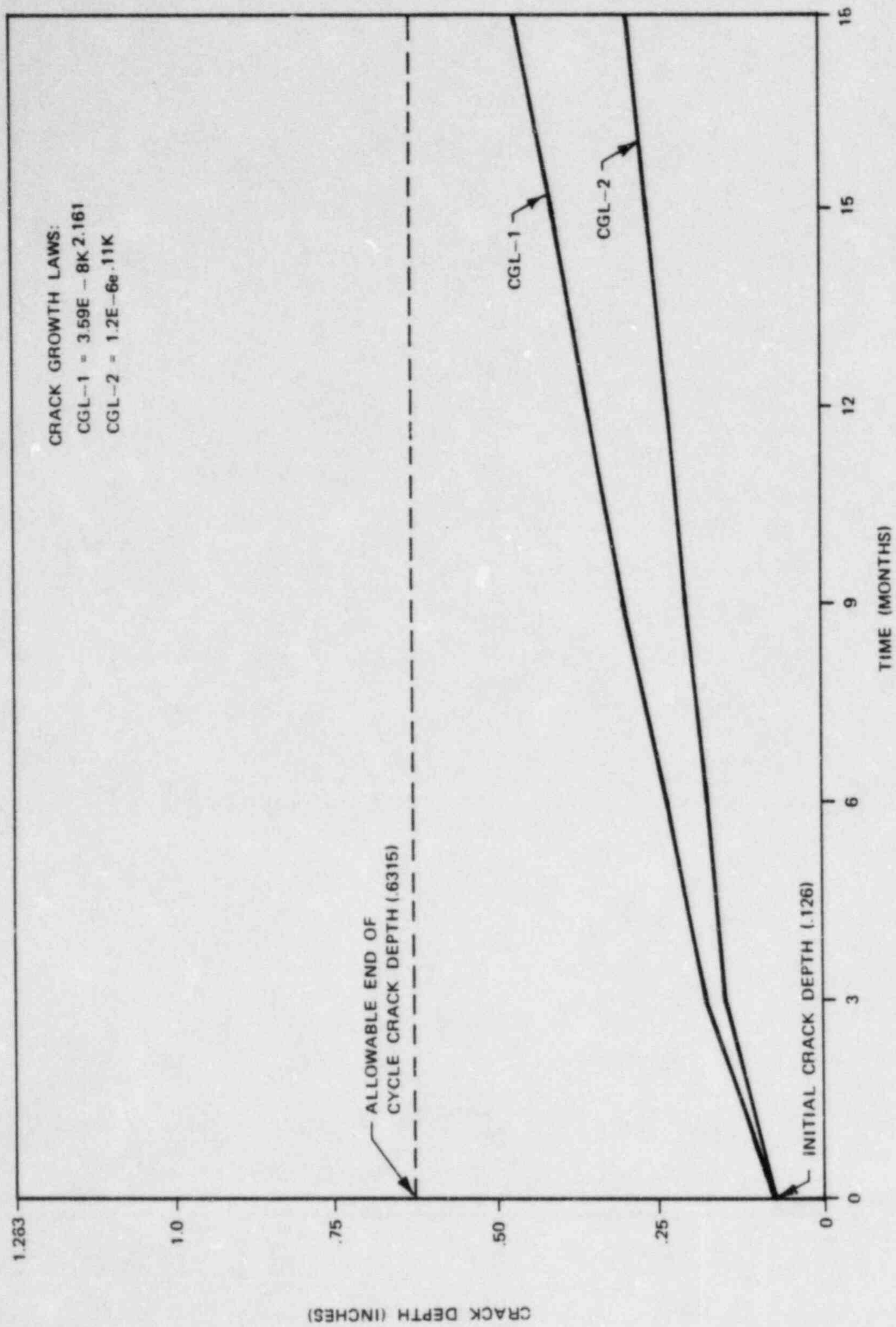

Figure 2.2

CRACK GROWTH - VS - TIME, WELD 28A14 (BRUNSWICK 2)

CCPL84.01-10

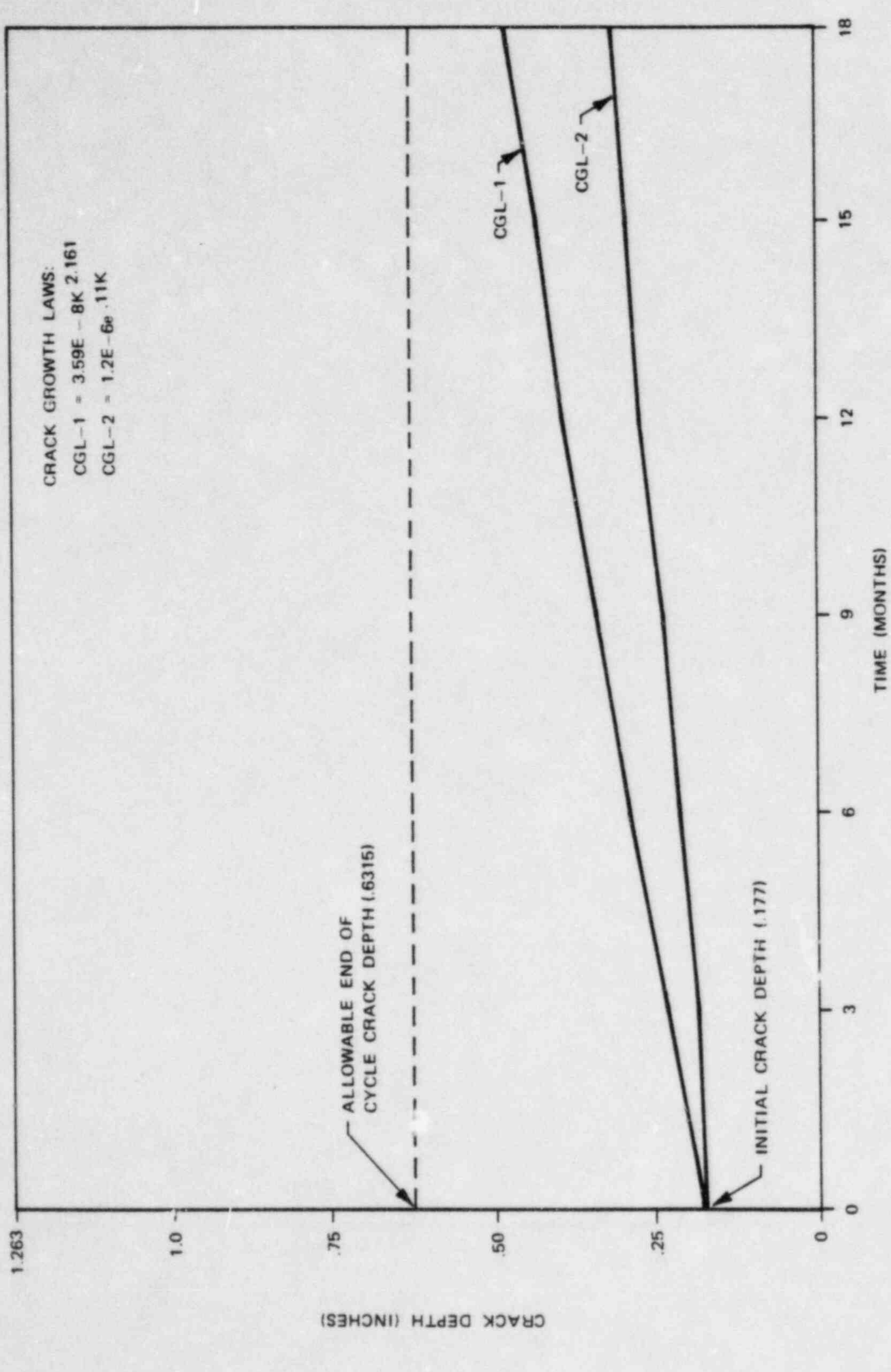

Figure 2.3

CRACK GROWTH - VS - TIME, WELD 28A8
(BRUNSWICK 2)

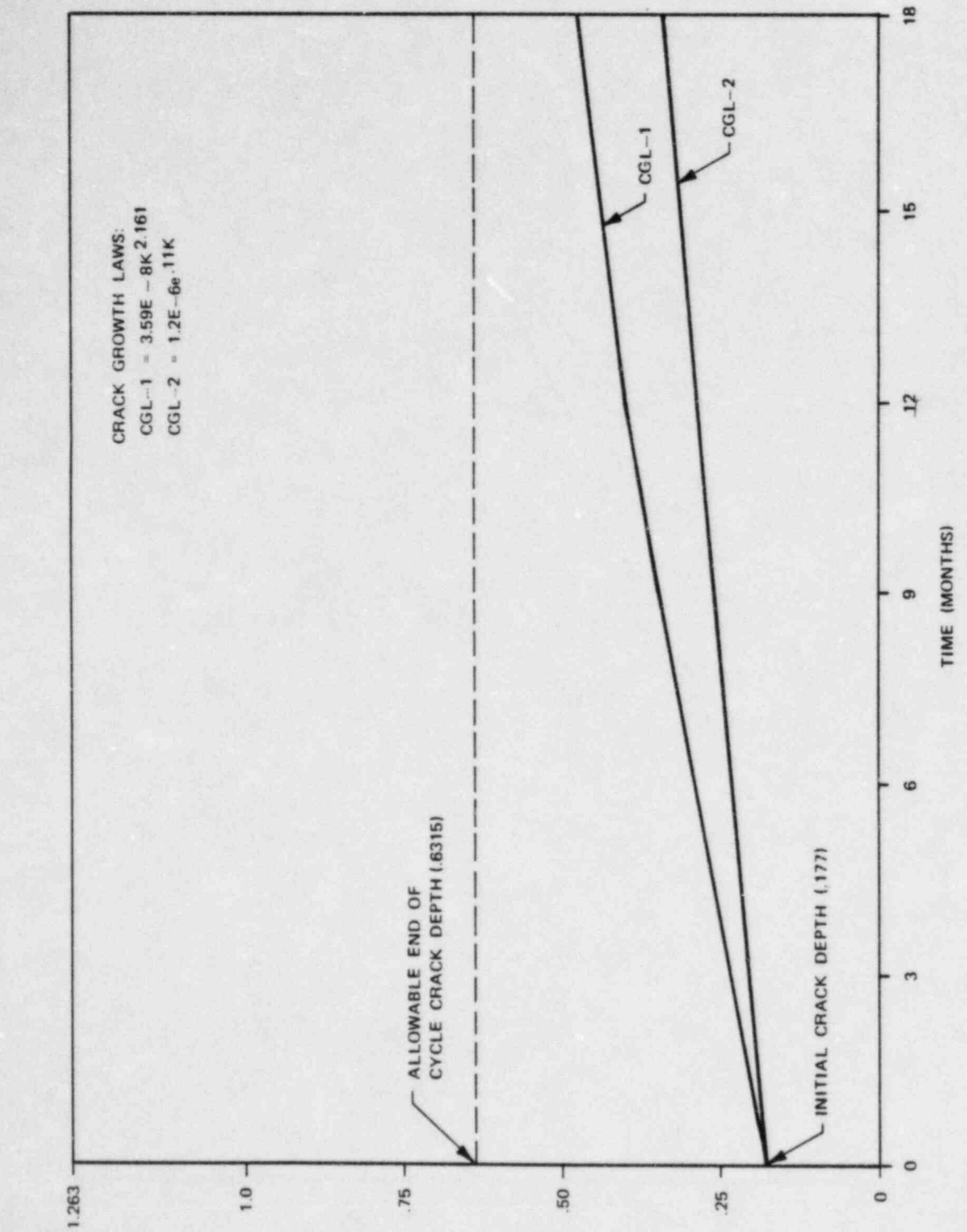

Figure 2.4

CRACK GROWTH - VS - TIME, WELD 28B3 (BRUNSWICK 2)

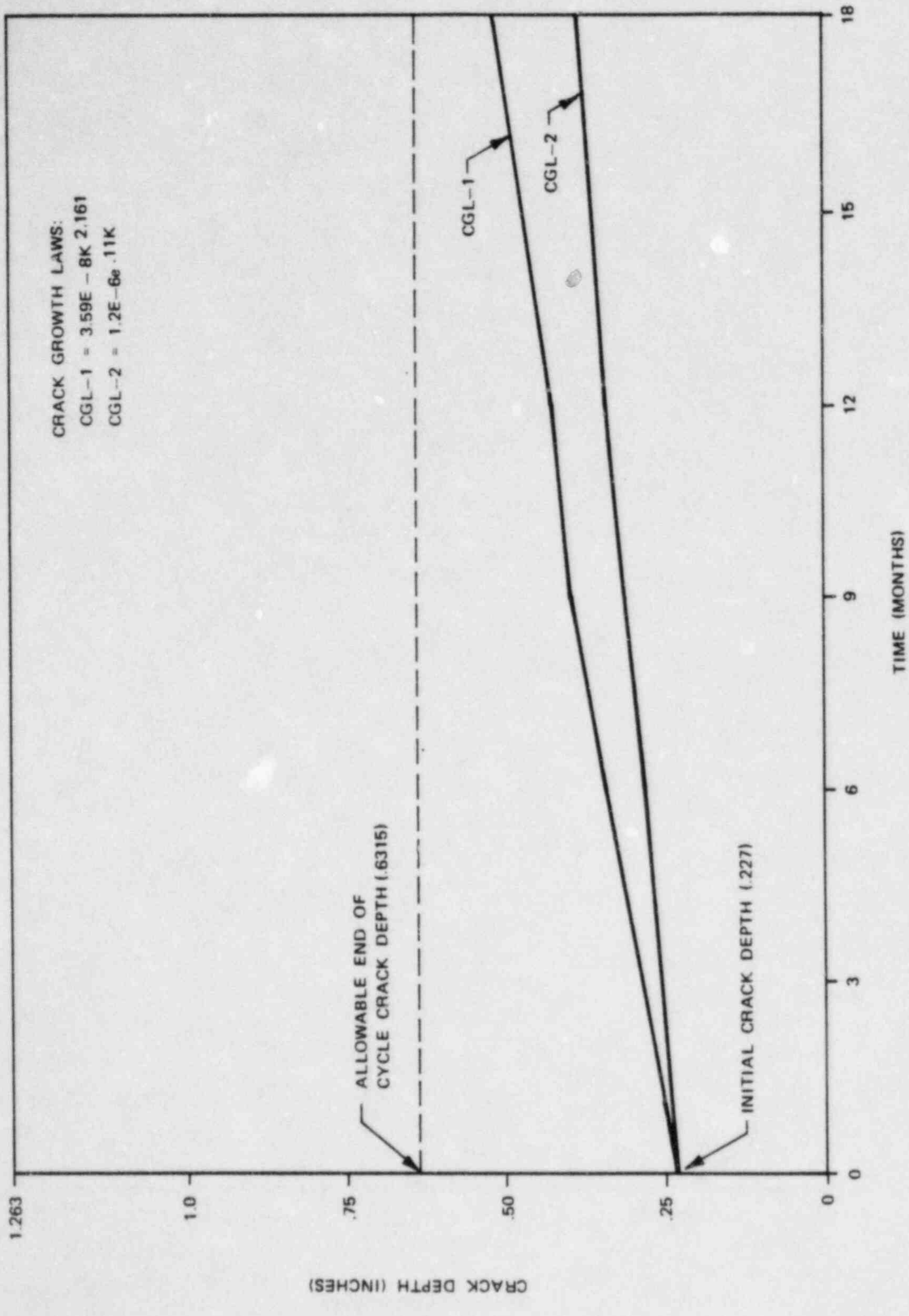

Figure 2.5

CRACK GROWTH - VS - TIME, WELD 28B9 (BRUNSWICK 2)

CCPL84.01-06

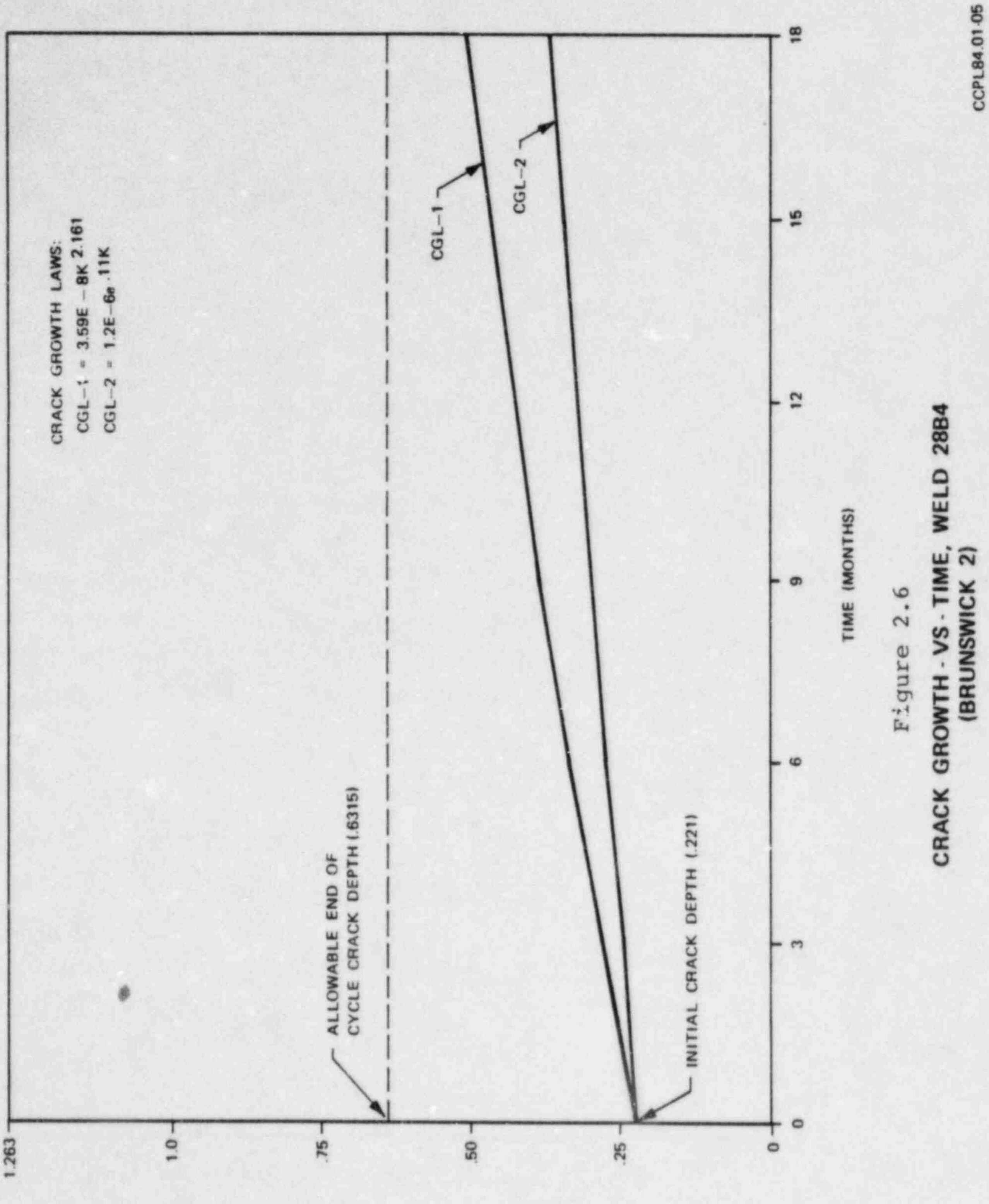

Figure 2.6

CRACK GROWTH - VS - TIME, WELD 28B4 (BRUNSWICK 2)

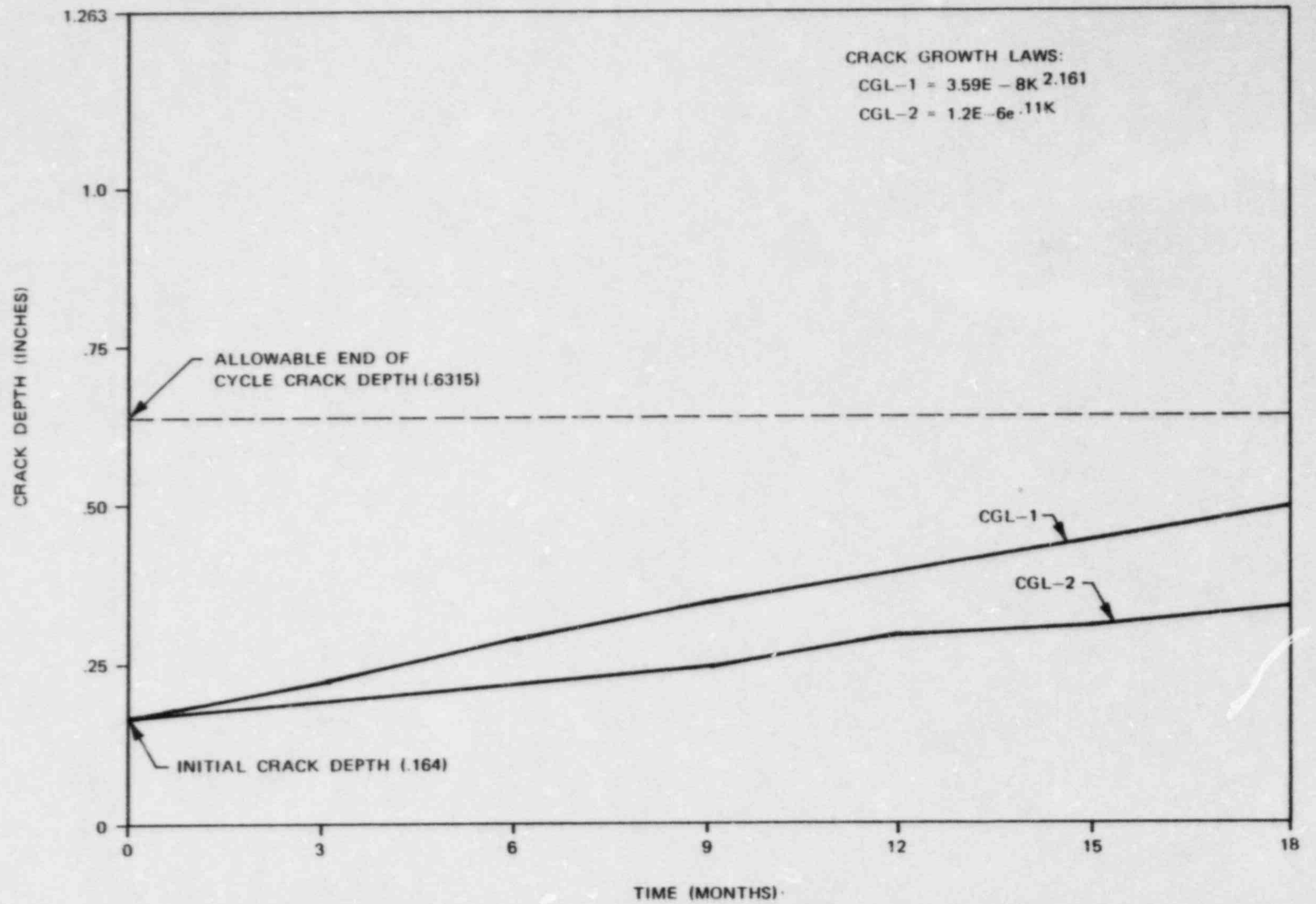

Figure 2.7

CRACK GROWTH - VS - TIME, WELD 28A13
(BRUNSWICK 2)

CCPL84.01-04

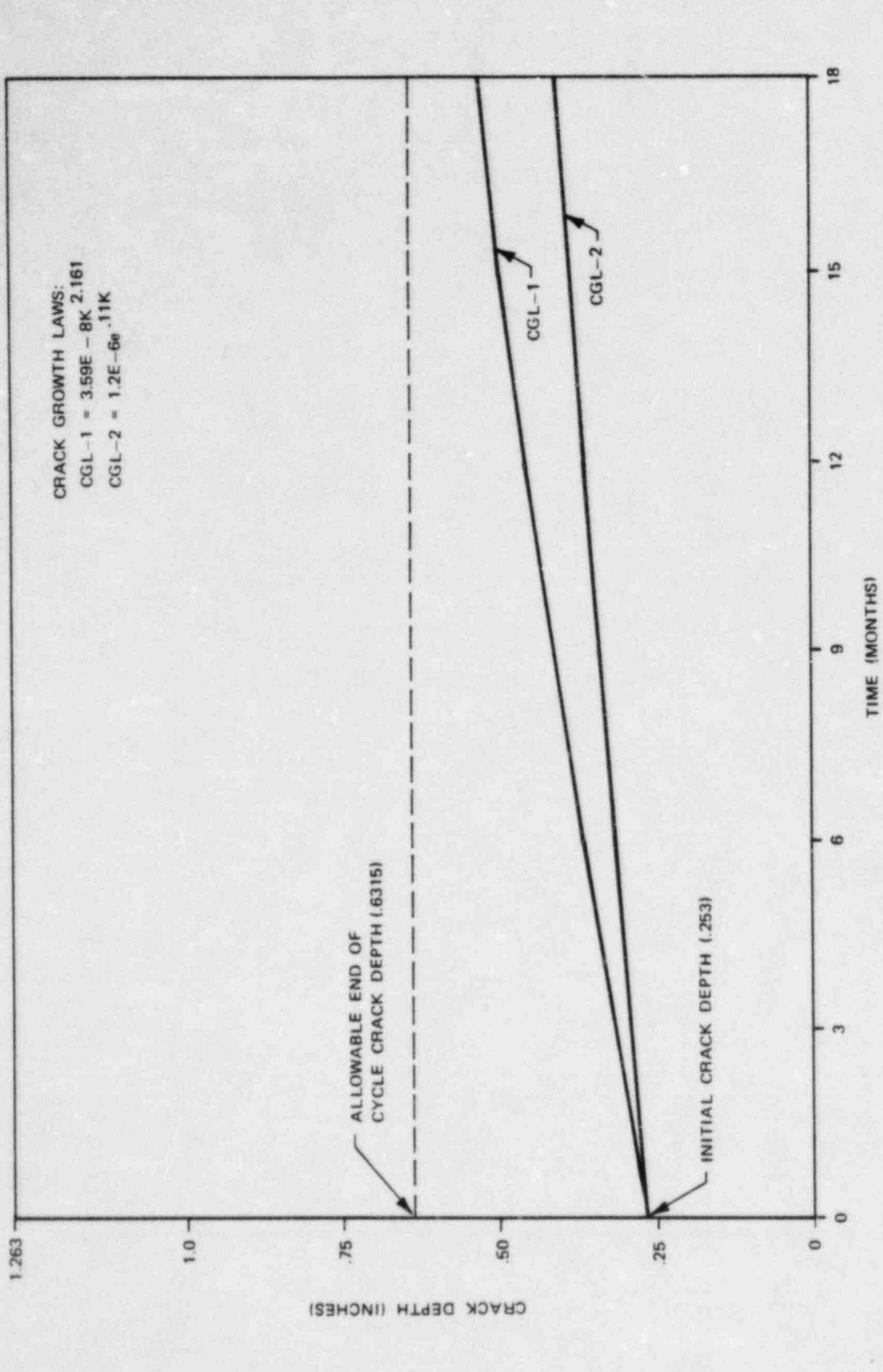

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Figure 2.8

CRACK GROWTH - VS - TIME, WELD 28B5 (BRUNSWICK 2)

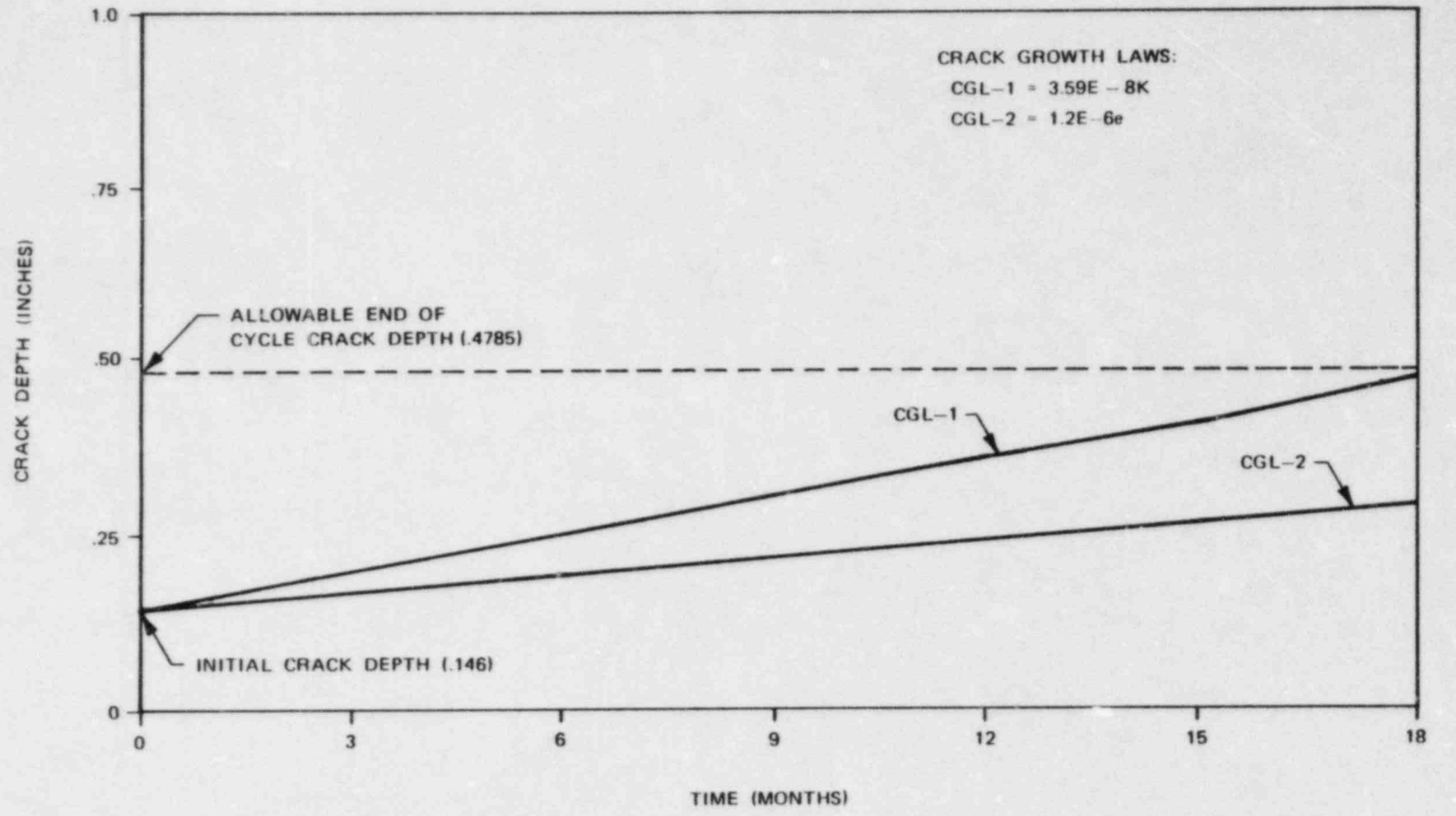

Figure 2.9

CRACK GROWTH - VS - TIME, WELD 22AM5
(BRUNSWICK 2)

CCPL84.01-07

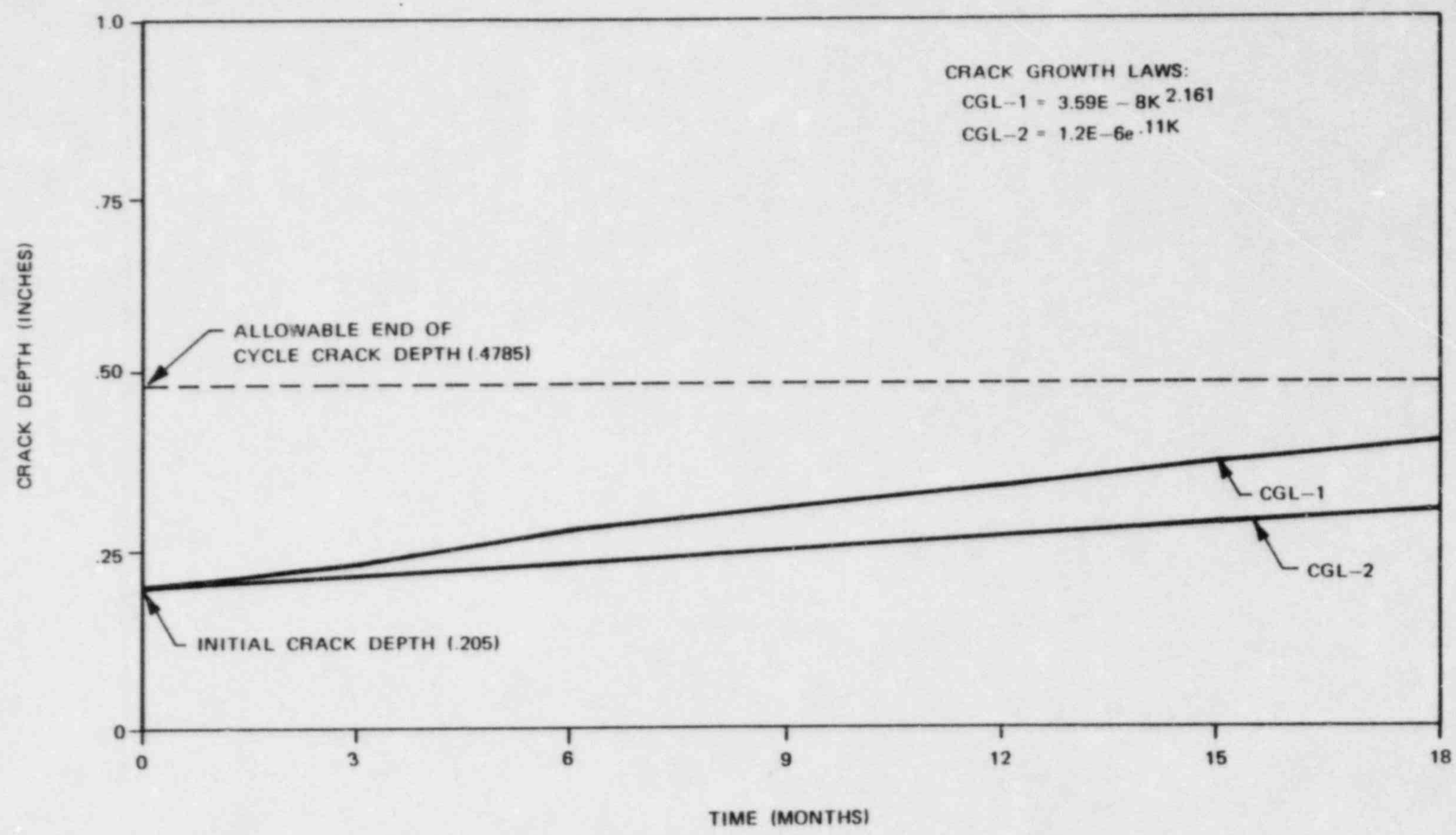

Figure 2.10

CRACK GROWTH - VS - TIME, WELD 22BM1
(BRUNSWICK 2)

CCPL84.01-01

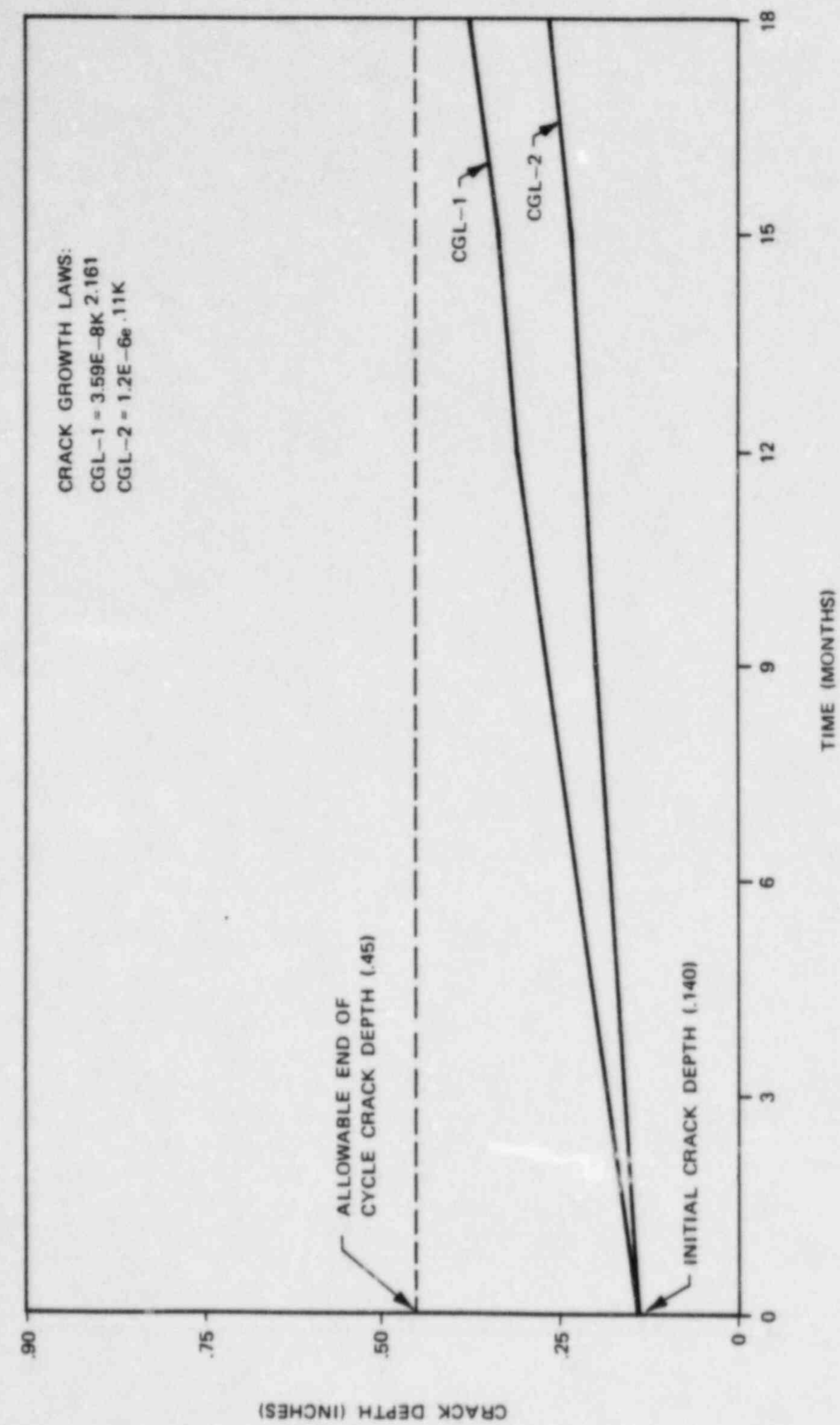

Figure 2.11
CRACK GROWTH - VS - TIME, WELD 20A2
(BRUNSWICK 2)

CCPL84.01-11

3.0 COMPARISON WITH PREVIOUS CRACK GROWTH PREDICTION

Because of the uncertainty inherent in ultrasonic testing procedures, data on flaw indications is often called into question. However, if we assume that indications that appeared to grow did indeed grow, some comparison can be made between the previously predicted crack growth and the actual crack growth. Since the 60° transducer is better for depth sizing than the 45° transducer, the 60° results will be used in the comparison.

Among the 60° transducer indications that appeared to grow, the flaw that apparently grew the most was on weld 28-B-5 (6.5% growth in 6 months). If the deepest flaw indication grew at this rate over the next 18 months, it would still not exceed the allowable end-of-cycle depth.

This observation compares well with the crack growth prediction of Reference 8 (summarized in Reference 6), where the deepest crack was expected to grow approximately 4% in 6 months.

4.0 CONCLUSIONS

The evaluation of the flaw indications in the recirculation system piping reported herein shows that IGSCC will not cause flaw indications to grow beyond acceptable levels for at least the next 18 months.

5.0 REFERENCES

1. Letter from C. R. Dietz of CP&L to Howard Sund of NUTECH Engineers, dated May 3, 1984, NUTECH File #CPL019.0004.

2. "Load Calculations for Analyses of Recirculation, RHR, and RWCU Pipes," NUTECH File #CPL013.0306.

3. "Weld Overlay Analyses - Thermal Expansion Analysis," NUTECH File #CPL009.0302.

4. NUTECH Internal Memo HLG-84-001, Dated 1/10/84.

5. NUTECH Computer Program NUTCRAK, Version 2.0.2.

6. "Design Report for Weld Overlay Repairs at Brunswick Steam Electric Plant Unit 2," Rev. 1, December 1983, NUTECH File #CPL013.0104.

7. ASME Boiler and Pressure Vessel Code, Section XI, 1983 Edition, Winter, 1983 Addenda, Paragraph IWB-3600.

8. "IGSCC Crack Growth Analysis for Recirculation, RHR, and RWCU Flawed Pipes," NUTECH File #CPL013.0312.

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