UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 17 1982

SUBJECT: SUMMARY OF MEETING WITH PWR INDUSTRY REPRESENTATIVES ON June 9, 1982 CONCERNING THE PRESSURIZED THERMAL SHOCK (PTS) ISSUE

Introduction

This was a meeting in Bethesda, MD on June 9, 1982 with the PWR Industry representatives including representatives from the B&W Owners Group (B&WOG), the Combustion Engineering Owners Group (CEOG), the Westinghouse Owners Group (WOG), the eight licensees who received the letter dated August 21, 1981, the Atomic Industrial Forum (AIF), Babcock & Wilcox (B&W), Combustion Engineering (CE), and Westinghouse (W). The meeting was requested by the staff for the purpose of presenting and discussing the current NRC staff considerations of possible recommendations for PTS requirements. The list of attendees are provided in Enclosure 1. Enclosure 2 provides the agenda of the meeting. The staff's material for presenting the possible recommendations for PTS requirements is provided in Enclosure 3. The material which CEOG used in their discussion is provided in Enclosure 4.

Discussion

In the staff's view the principal object of the meeting was to establish a dialogue with the industry and obtain some feedback in order to identify areas of agreement and disagreement, to narrow the gap in these differences and to ultimately go to the Commission with recommendations for requirements to resolve the PTS issue.

Highlights of these discussions provide by group are identified in the following.

NRC Staff Comments

The principal difference between the staff and the industry is the staff's consideration of establishing a RT_{NDT} limit. The staff does not accept the industry's point that operators can be relied upon to limit the pressure during a PTS event. The criteria of failure is a transient induced stress sufficient to initiate a crack. Warm prestressing is not considered. The probabilistic approach is based on the experience to date. Although the industry analyses of a number of transients have generally indicated the vessels are acceptable for operation to the end-of-life (EOL), the operational data base indicates problems. The staff rejects the design basis approach to identifying the critical transient as being not sufficiently severe considering the cooldown effects of transients experienced to date involving multiple failures. The staff considers a generic approach to solving the problem more proper than a plant specific or vendor plant approach.

CEOG Comments

The CEOG doesn't agree with the conservatisms of the staff's transient and the crack initiation criteria. The transient would result in a much higher limit of RT_{NDT} (300° if the duration time is 30 min., 290° if the duration time is 60 min. and 280° if the duration time is 90 min.). They suggested that the difference was partially the result of using a different heat transfer coefficient. (Staff considered 330 BTU/sq. ft./hr./°F; CEOG considered 300 BTU/sq. ft./hr./°). Even if the RT_{NDT} value would be exceeded, CE contends that the vessel would not fail. The vessel could tolerate larger stresses, up to and beyond yield for the outer membrane. CE maintains that data shows that crack arrest would occur. CE contends that a transient characterized by low temperature and high pressure has a nil probability of occurring. It doesn't represent what can realistically occur. A plant cannot hold pressure up when the temperature reduces and if the pressure does increase the temperature increases. To choose a common transient for all plants is not right. A plant specific approach is more appropriate. Some significant design differences in plants preclude the capability of a transient characterized by a low temperature and high pressure.

WOG Comments

The WOG response considered the staff approach arbitrary and the staff's transient too severe. WOG believes some events taken from the staff's data base would not be applicable to W plants. If these events were not considered for W plants it would result in an event for W plants of a temperature of 300° at a probability of 10^{-2}. This is consistent with the WOG May 28, 1982, report. The May 28, 1982 report indicated a probability of 4×10^{-3} for a transient resulting in 290° temperatures. The WOG believes that the differences of the different vendor plants should be considered in the final approach to solving the problem. It is wrong for the NRC to take a generic approach which does not consider plant specific differences.

B&W Comments

B&W believes the approach should be plant specific. The plant specific submittals should be reviewed. The NRC should place more emphasis on nondestructive examination activity. The improvement of procedures and training is the single most effective activity to solve the PTS issue.
Each plant should be given the opportunity to review the staff's report before implementation of requirements.

Omaha Public Power District Comments

Much effort and several submittals have been made and it doesn't apprear that the staff has considered the information to develop the proposed position. The staff's proposed position is too conservative. No credit has been given operator action, plant specific information has not been considered, the crack initiation criteria is not justified and the limit on RT_{NDT} should be established on a technical basis-not an arbitrary basis.

Conclusions

The Commission desires a resolution to the PTS issue. Some plants will need to make changes before the EOL. The proposed RT_{NDT} limit is not yet fixed. The staff is still formulating the limit. The staff will provide two weeks for the industry to submit comments in order for the staff to consider industry views in the determination of a staff position. The staff does not subscribe to the view that the industry cannot be held to a standard and the staff doesn't believe it is necessary to consider each plant on a plant specific basis. It is the staff's view that a limit will be established. The comments from the industry should consider the following:

1. The severity and frequency of the proposed transient. Resolve the difference between operating data and frequency calculated by PRA studies.

2. The physical possibility of a plant condition that prevents for example a high pressure and low temperature from occurring at the same time.

3. The staff's correct use of data, i.e., assumed β (transient time constant) should different? Can plants tolerate transients which have occurred to EOL for all plants?

4. Resolution of differences between staff and industry assumptions in the areas of material properties and fluence.

5. Resolution of failure criteria - crack initiation versus crack arrest. Specify what, if any, are the differences in the methods for prediction of initiation and arrest. Identify what methods should be used, i.e., LEFM or EFPM.

6. The properly conservative acceptance criteria to be used. NRC needs to develop this.

7. The proper heat transfer coefficient to be used in the development of a position. This may vary for different conditions, for example RCPs running vs. tripped.

8. The understanding of the damage function through the vessel wall.

9. The use of the best-estimate values versus conservative values of RT_{NDT} in formulating the regulation.

10. Other differences which should be considered.

Original Signed By:

Guy S. Vissing, Project Manager
Operating Reactors Branch #4
Division of Licensing

Enclosures:
1. Attendance List
2. Agenda
3. Staff's Material & Possible Recommendations
4. CEOG Discussion Material

cc w/enclosures: See next page

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SURNAME ▶	GVissing/cb						
DATE ▶	6/17/82						

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MEETING SUMMARY DISTRIBUTION

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BGrimes, DEP
SSchwartz, DEP
SRamos, EPDB
FPagano, EPLB

Meeting Participants Fm. NRC: See Enclosure 1, Column 1

D. Eisenhut
G. Lainas
R. Vollmer

W. Hazelton

T. Murley
H. Thompson

L. Shao
R. Bernero

G. Zech
J. Roe

C. Serpan
L. Shotkin
W. Johnston
A. Spano

J. Strosnider

G. Knighton
J. Austin

B. D. Liaw
M. Vagins
D. Ziemann

C. Johnson

E. Abbott
R. Johnson
E. Goodwin

Enclosure 1

ATTENDANCE LIST FOR MEETING WITH PWR INDUSTRY REPRESENTATIVES ON JUNE 9, 1982

CONCERNING PRESSURIZED THERMAL SHOCK ISSUE

NRC

R. Woods
M. J. Virgilio
L. Connor
B. Sheron
T. Speis
B. Newlin
T. Dunning
E. Rossi
F. Rosa
J. Buzy
J. Clifford
C. Morris
D. L. Basdekas
T. Novak
E. Igne
W. Bock
A. M. Rubin
F. Schroeder
N. Anderson
W. A. Paulson
S. J. Bhatt
P. C. Wagner
T. M. Lee
P. N. Randall
R. W. Klecker
F. B. Litton
J. Strosnider
N. Lauben
E. D. Throm
L. Lois
G. Glines
T. Cox
B. Elliot
R. Mattson
L. S. Rubenstein
G. S. Vissing
S. Hanauer
H. Denton

EDS Nuclear

R. Gamble

CE

J. Pfeifer
J. M. Westhoven
D. A. Peck
J. J. Herbst
G. Menzel
D. Earler
D. J. Ayres
S. T. Byrne

OPPD

K. J. Morris
J. K. Gasper

Maine Yankee

H. F. Jones
W. J. Metevia

EPRI

B. Chexal
J. Berga

GPU Nuclear

J. Delezenski

INPO

G. B. Fader

Consumers Power Co.

R. Huston
G. F. Pratt

MPR Associates (BG&E)

J. Nestell

BG&E

M. D. Patterson

Southern California Edison Company

W. G. Flourney
A. C. Llorens

B&W

J. H. Taylor

Duke Power Co.

R. L. Gill

Arkansas Power & Light

D. F. Spond

Westinghouse

B. King
S. Dean
R. Sero
K. Balkey
J. Rumancik
M. A. Weaver
J. D. McAdoo

Southern Co. Services

W. M. Andrews

Northeast Utilities

T. Starr
M. Kupinski

Pacific Gas & Electric

Owen H. Davis

Arizona Public Service

M. J. Winsor

Public Service Elec. & Gas (NJ)

M. O. Banderia

AIF

P. Higgins

NUTECH

A. Oxfurth
S. Cooley

Stone & Webster

C. Ader

Florida Power & Light Co.

R. Kaminsky
R. Uhrig
V. T. Chilson

Bechtel Power

J. Bezila

Con. Edison of NY

D. M. Speyer

Carolina Power & Light

D. C. Woods

Scandpower

D. Pomeroy

PNL

F. Simonen

Rochester Gas & Electric

R. Elias

Enclosure 2

AGENDA

FOR

MEETING WITH PWR INDUSTRY

JUNE 9, 1982

CONCERNING

THE STAFF'S POSSIBLE RECOMMENDATIONS

FOR

PTS REQUIREMENTS

I.	Discussion of possible NRC recommendations for PTS requirements.	S. Hanauer
II.	Industry's identification of areas where they believe the bases for the staff's proposed position are in error, why our position is in error, and (if possible) a quantitative estimate of how much difference results from each item.	Industry Representatives

#1

Current NRC Staff Consideration of Possible Recommendations for PTS Requirements

June 3, 1982 (ACRS)
June 8, 1982 (PNL)
June 9, 1982 (Industry Rep)

Summary of Actual Plant Events

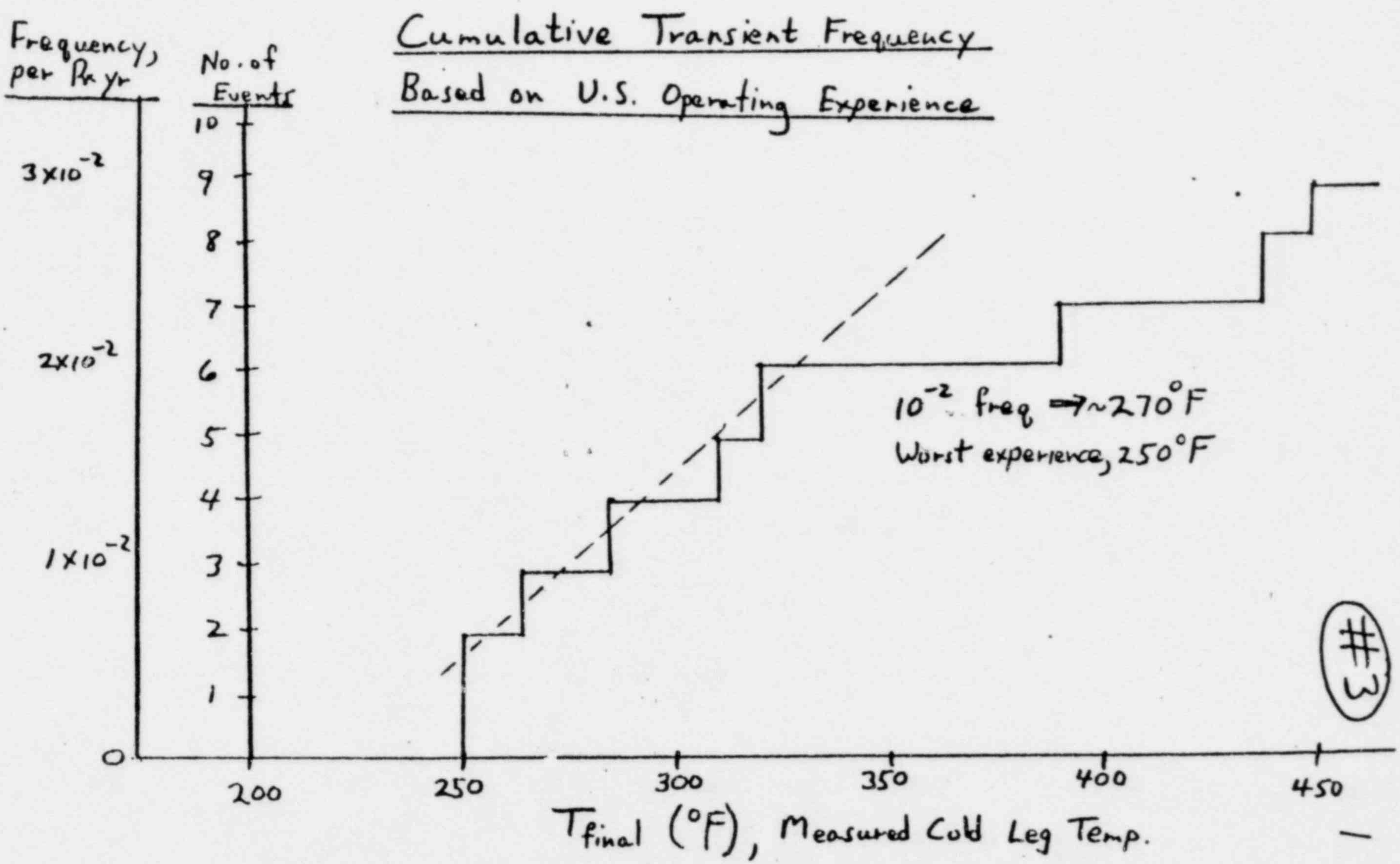
NSSS	Plant Description	Date	Beta (1/m)	T-final (deg F)	Duration	T-init. (deg F)	Pressure (psig)	Comments
W	Robinson 2 Pre-op small SLB	04/28/72	0.097	320.	1 hr	530.	2050.	
W	Robinson 2 Stuck S.G. Valve	11/05/72	0.043	389.	2 hr	550.	1700.	P-reading off scale
B+W	Rancho Seco Loss of NNI/ICS	03/20/78	0.104	285.	1 hr	600.	2000.	
W	Robinson 2 RCP seal SBLOCA	05/01/78	0.172	310.	30 m	450.	1000.	P-reading off scale
B+W	Three Mile-2 PORV SBLOCA	03/28/79	0.098	250.	1 hr	450.	1800.	3-4 hrs in transient
B+W	Crystal River-3 Loss of NNI/ICS	02/26/80	?	250.	?	560.	2300.	T-range 100 -400 deg F
W	Ginna SGTR/Stuck PORV	01/25/82	0.127	285.	45 m	550.	1400.	Coldest T-measured.
CE	Ft. Calhoun			440				
CE	ANO-2			450				

#2

Foreign experience is not included in our data base. Example of experience not included:

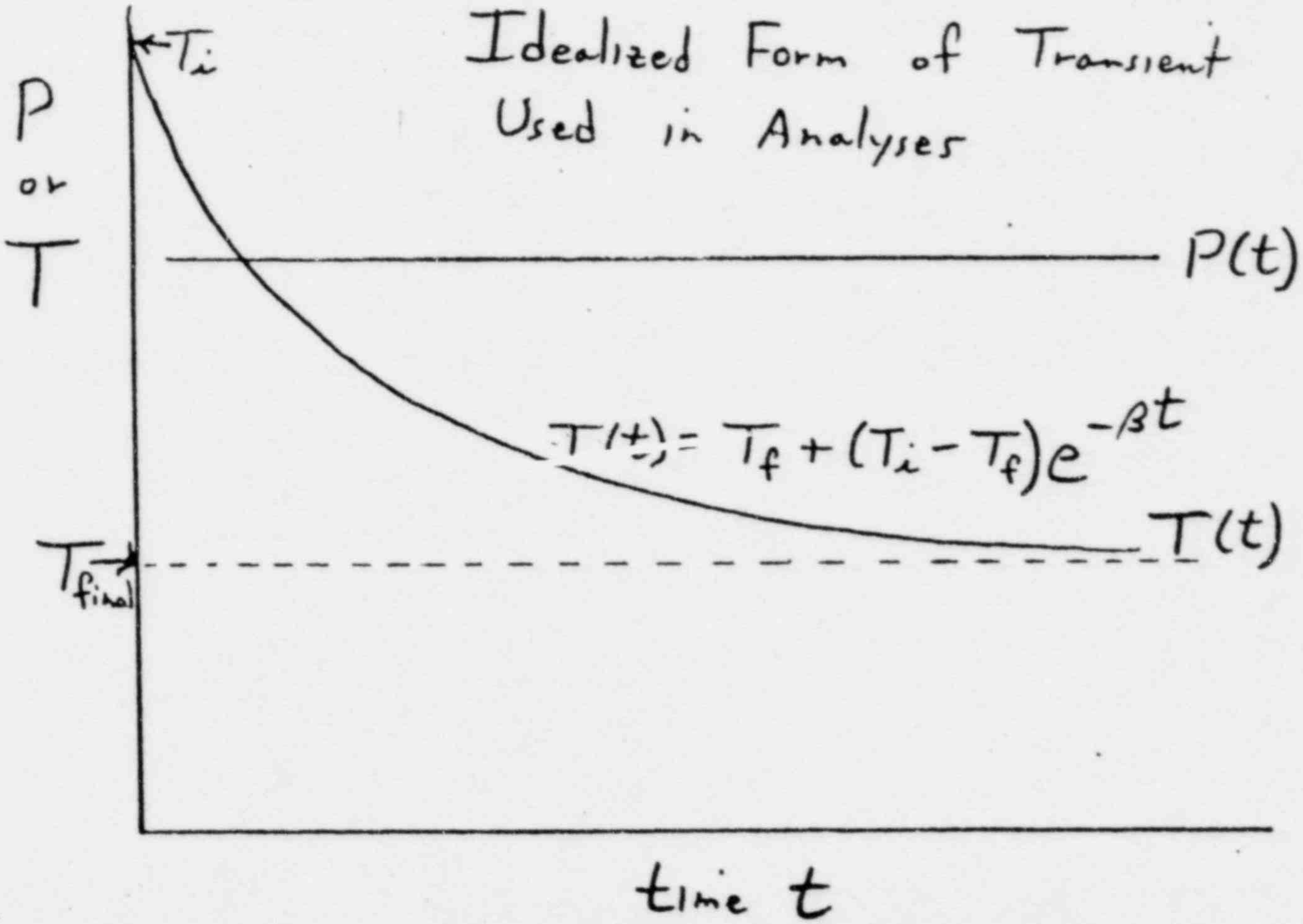
W	Borselle S.G. Blowdown	03/02/81	0.253	285.	45 m	440.	2100.	2-loop PWR European

Totals: 4 W 2 CE 3 B+W (9 Total)



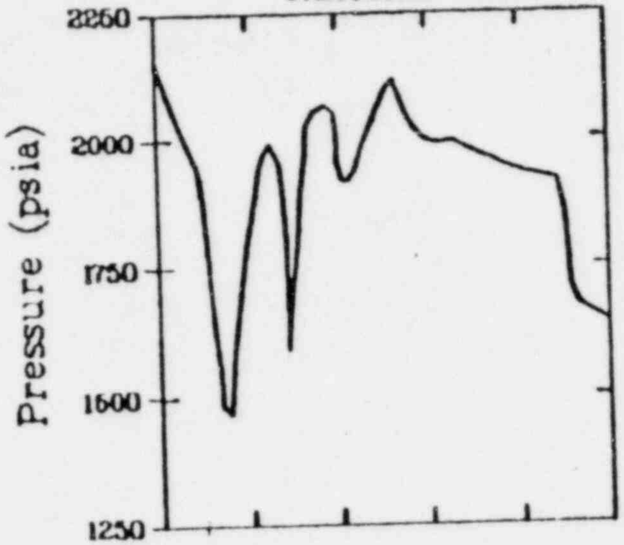
Cumulative Transient Frequency
Based on U.S. Operating Experience
Frequency, per Rx yr
No. of Events
3x10^-2
2x10^-2
1x10^-2
0
10
9
8
7
6
5
4
3
2
1
10^-2 freq → ~270°F
Worst experience, 250°F
200
250
300
350
400
450
T_final (°F), Measured Cold Leg Temp.
#3

Idealized Form of Transient Used in Analyses



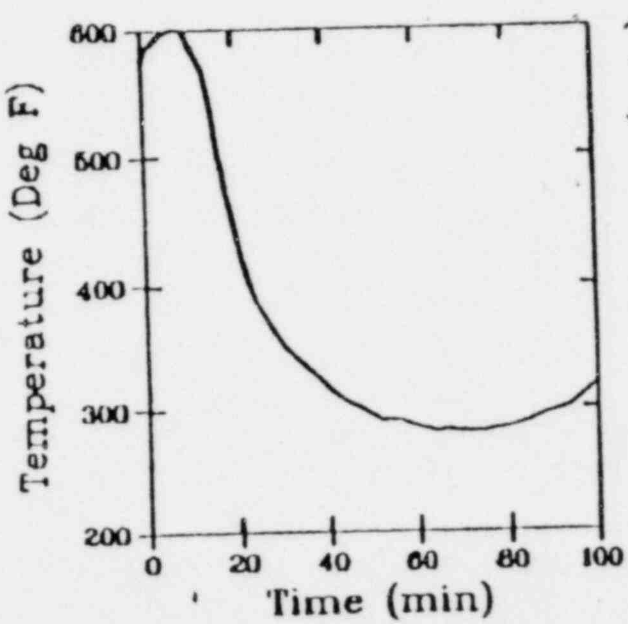
#4

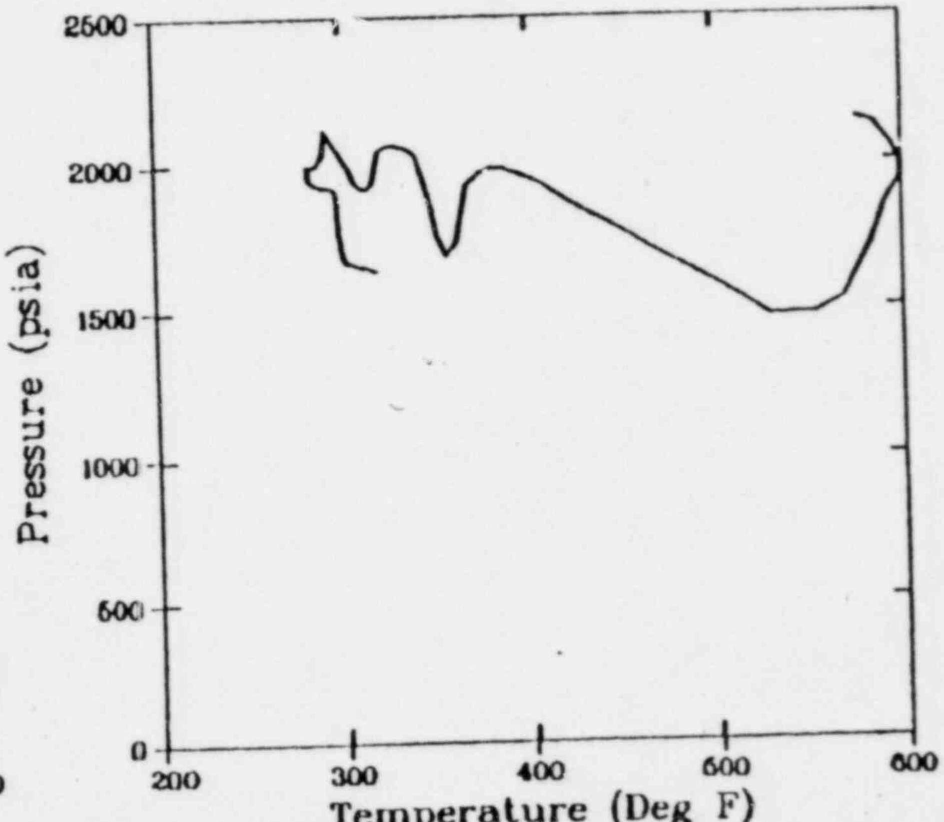
Rancho Seco 1 03/20/78 Overcooling Transient



NOTES:

- B&W NSSS
- Loss of NNI/ICS Indicators
- SG refill with MFW
- Pressure Controlled with SI





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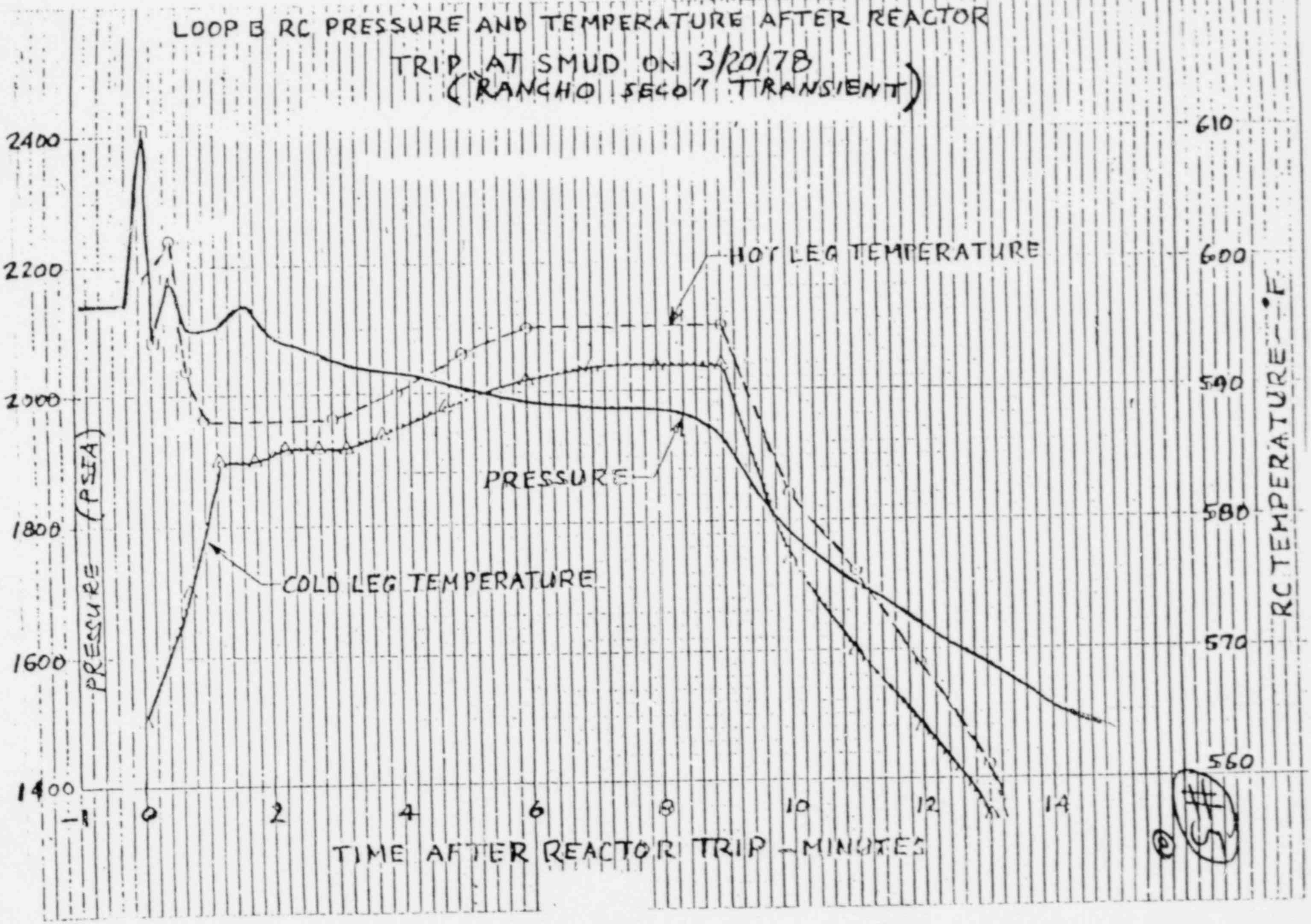
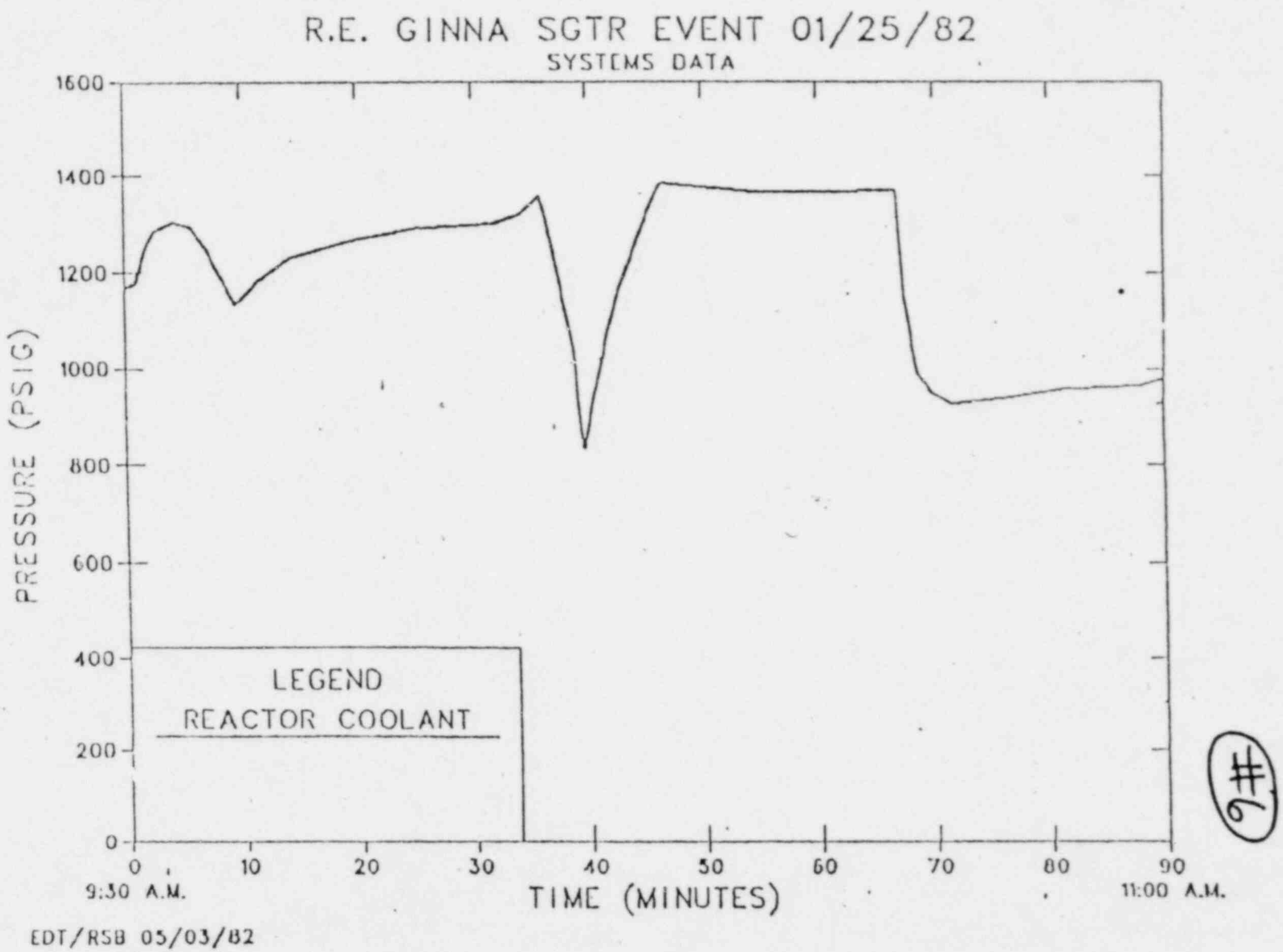
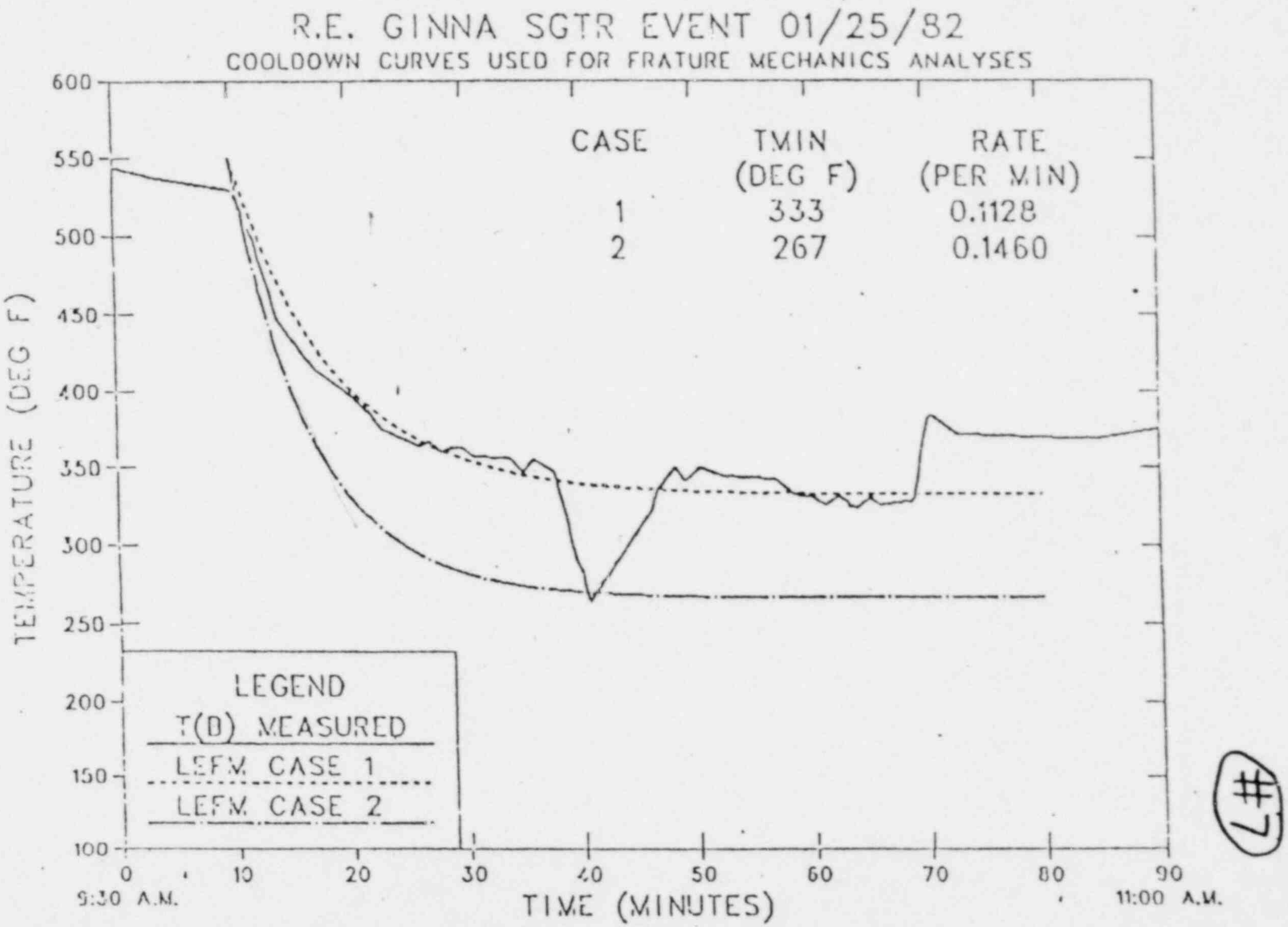
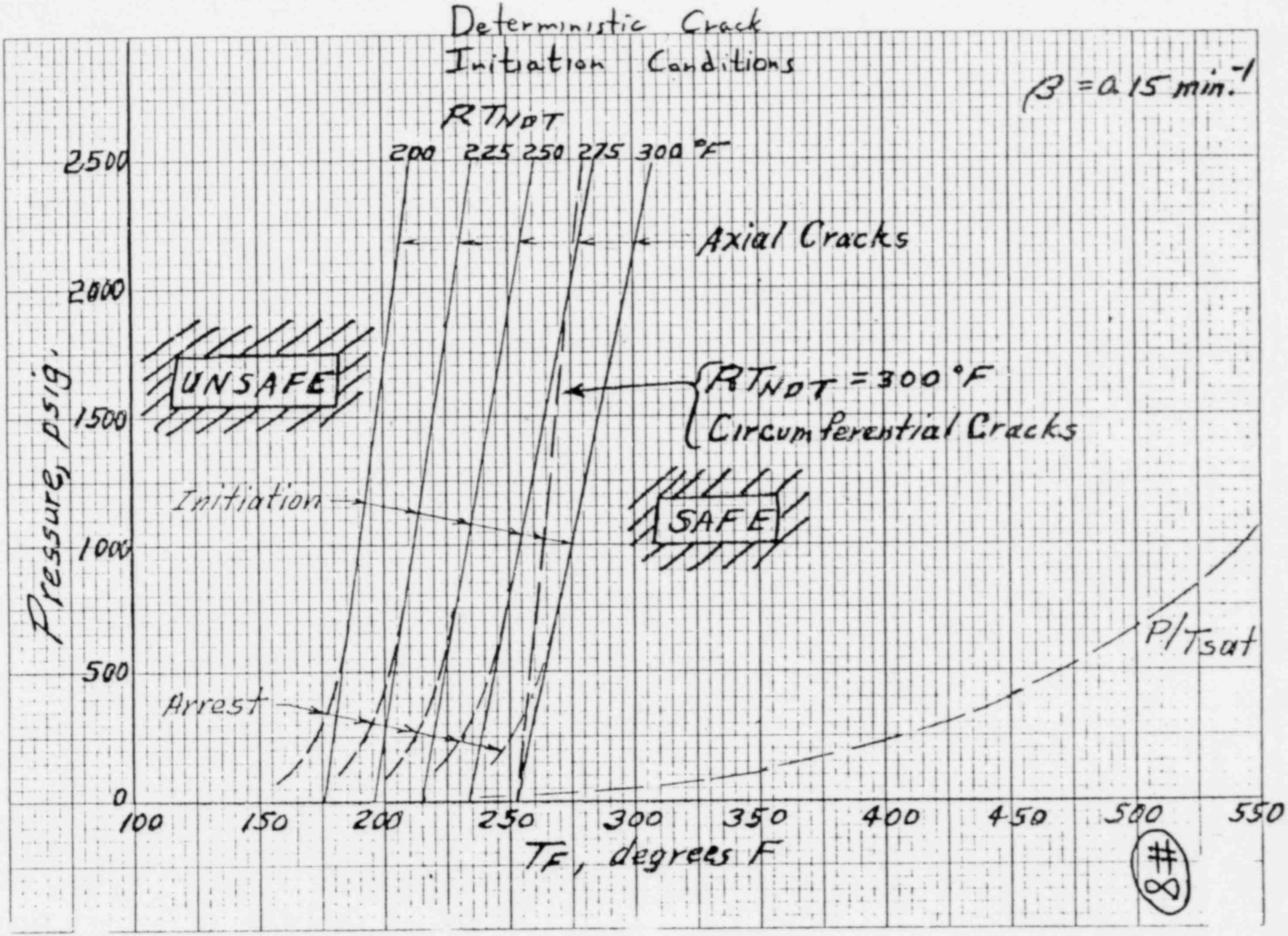


LOOP B RC PRESSURE AND TEMPERATURE AFTER REACTOR
TRIP AT SMUD ON 3/20/78
("RANCHO SECO" TRANSIENT)
HOT LEG TEMPERATURE
PRESSURE
COLD LEG TEMPERATURE
PRESSURE (PSIA)
2400
2200
2000
1800
1600
1400
RC TEMPERATURE - °F
610
600
590
580
570
560
-1
0
2
4
6
8
10
12
14
TIME AFTER REACTOR TRIP - MINUTES
#5


R.E. GINNA SGTR EVENT 01/25/82
SYSTEMS DATA
PRESSURE (PSIG)
1600
1400
1200
1000
800
600
400
200
0
LEGEND
REACTOR COOLANT
0
10
20
30
40
50
60
70
80
90
9:30 A.M.
TIME (MINUTES)
11:00 A.M.
EDT/RSB 03/03/82
#9

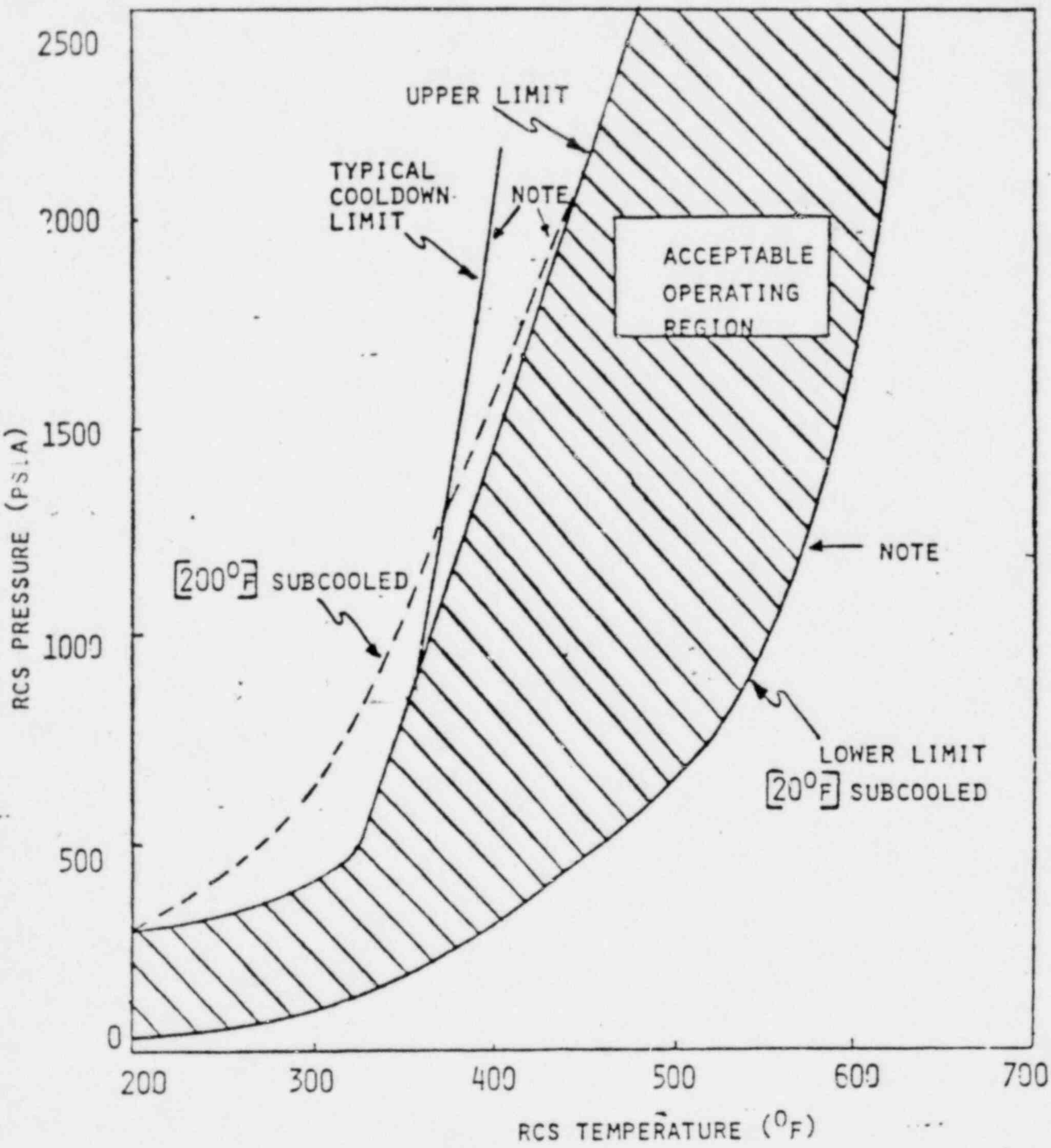


EDT/RSB 05/03/82

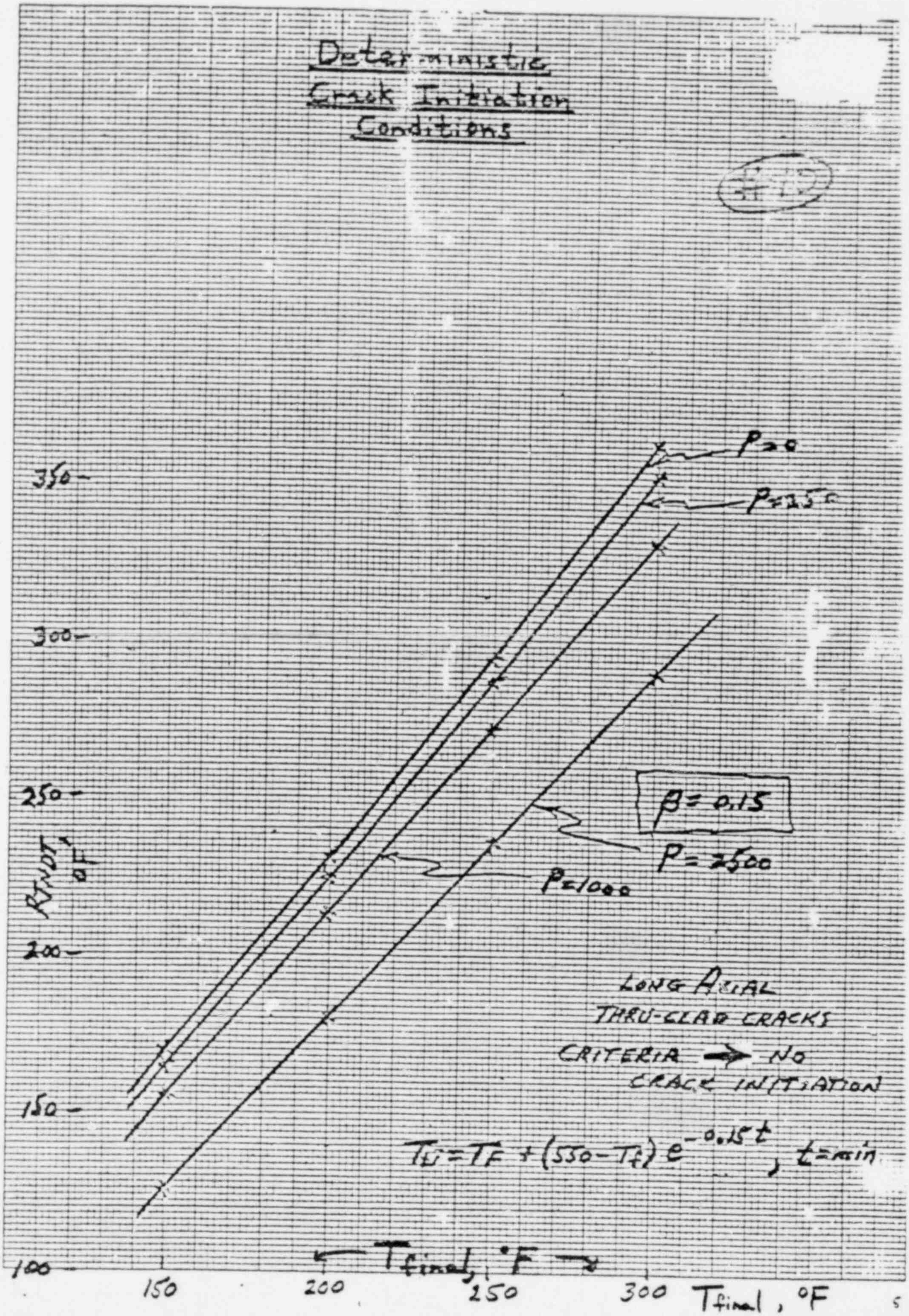

Deterministic Crack
Initiation Conditions
β = 0.15 min.⁻¹
RTNDT
200 225 250 275 300 °F
Axial Cracks
UNSAFE
RTNDT = 300 °F
Circumferential Cracks
SAFE
Initiation
Arrest
P/Tsat
Pressure, psig.
2500
2000
1500
1000
500
0
100 150 200 250 300 350 400 450 500 550
TF, degrees F
#8

POST ACCIDENT RCS PT LIMIT CURVES

#9



(Provided to NRC by CEOG at 3/3/82 meeting)



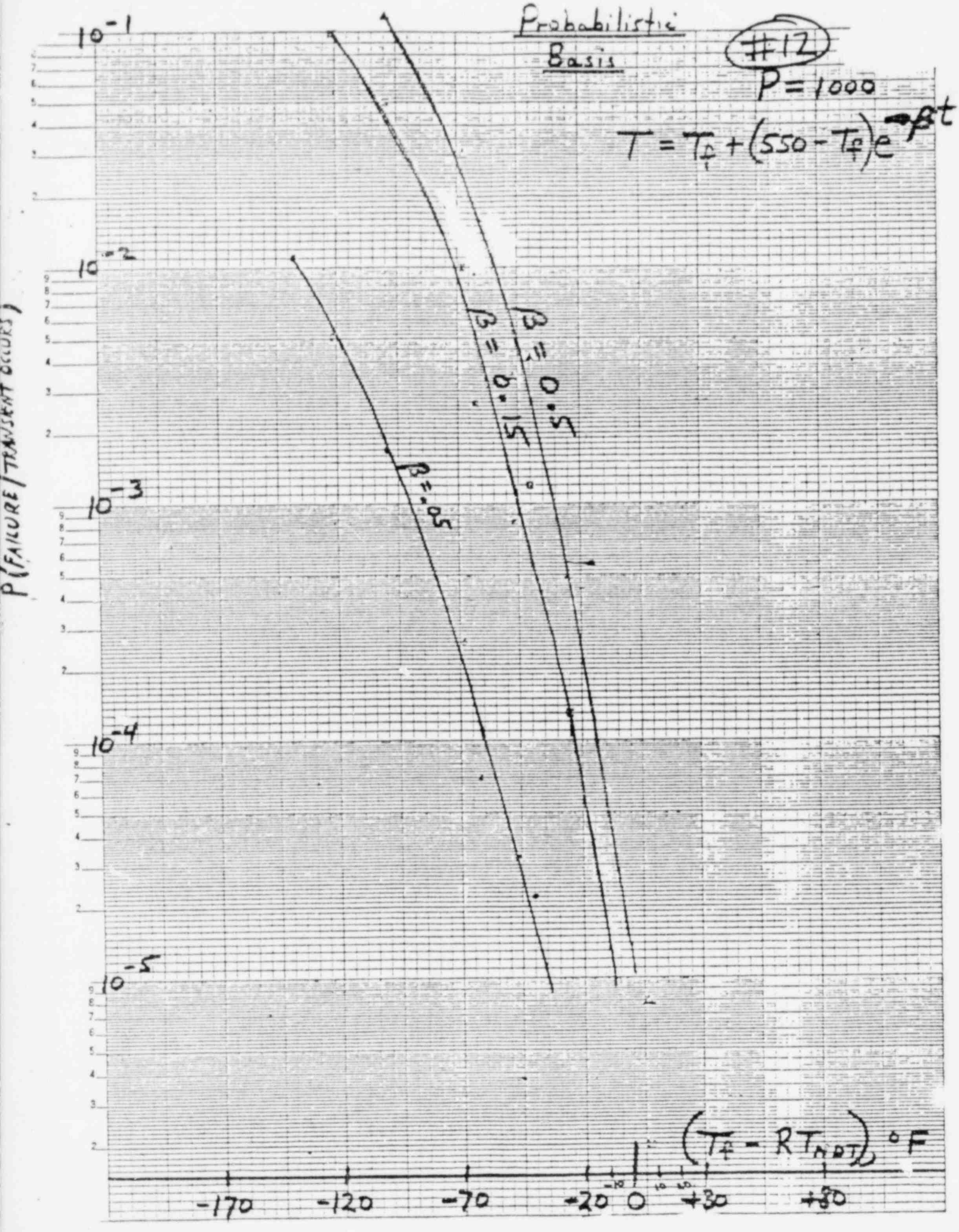
Deterministic Crack Initiation Conditions
P=0
P=250
β = 0.15
P = 2500
P=1000
LONG AXIAL THRU-CLAD CRACKS
CRITERIA → NO CRACK INITIATION
$T_W = T_F + (550 - T_F)e^{-0.15t}$, t=min
RTNDT, °F
350
300
250
200
150
100
← Tfinal, °F →
150
200
250
300
Tfinal, °F

#11

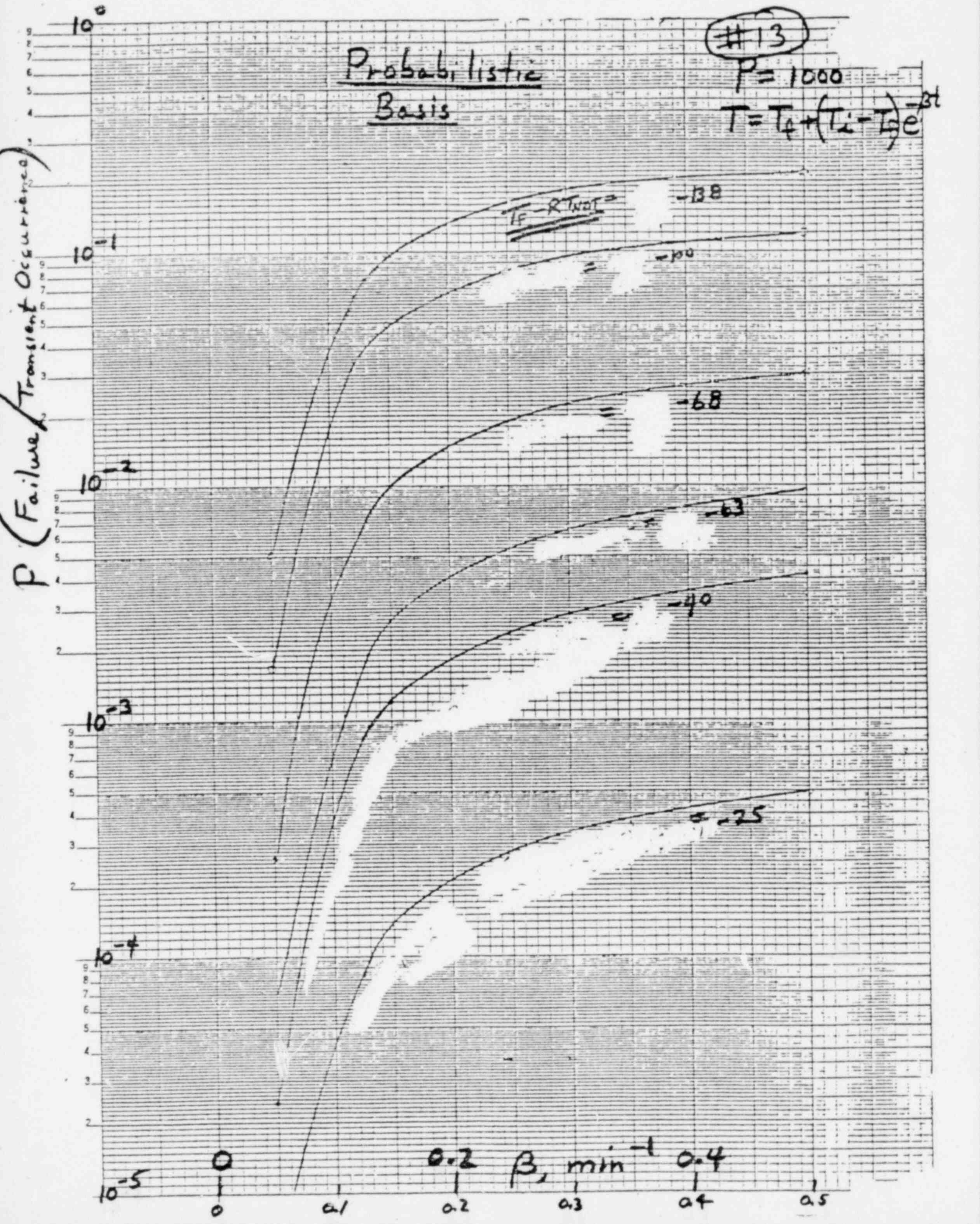
Deterministic Method for Crack Initiation

(based on transient with $T_{final} = 250°F$ and $\beta = 0.15\ min^{-1}$)

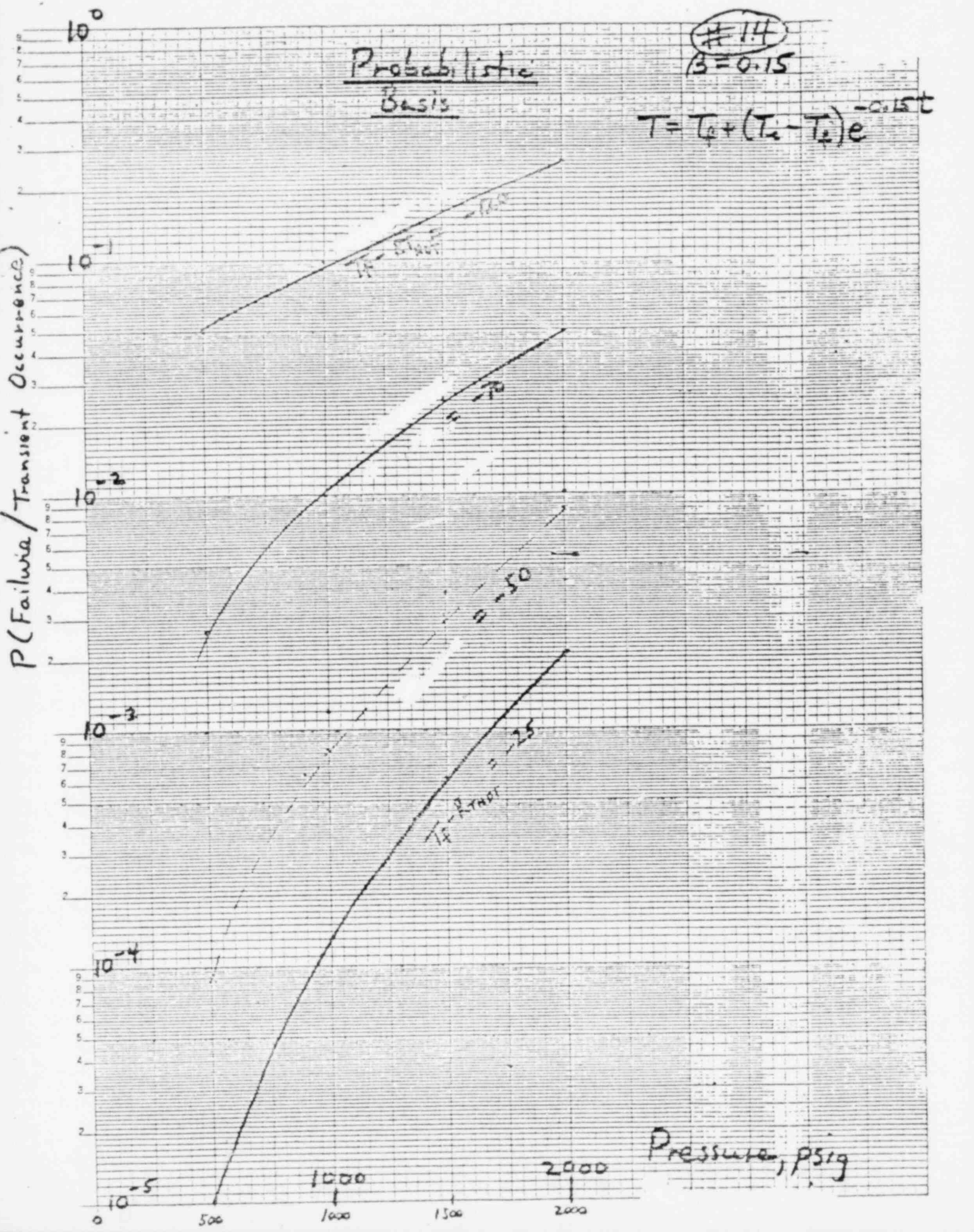
RT_{NDT}, °F	Pressure, psig
230	> 2500
275	< 1000
295	< 300



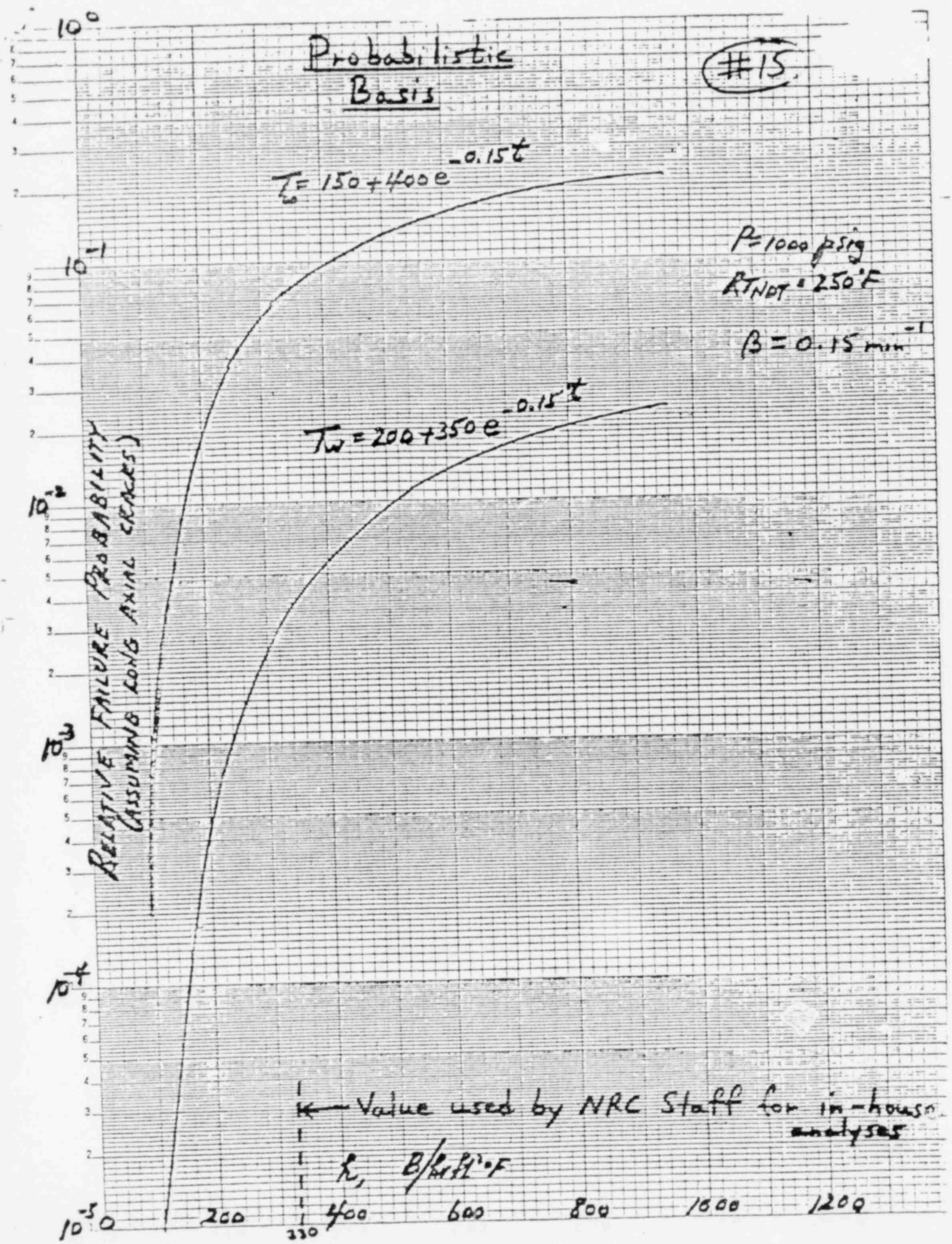
Probabilistic Basis
#12
P = 1000
$T = T_f + (550 - T_f)e^{-\beta t}$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
P (FAILURE / TRANSIENT OCCURS)
β = 0.5
β = 0.15
β = .05
$(T_f - RT_{NDT})$, °F
-170
-120
-70
-20
0
+30
+80



#13
Probabilistic Basis
P = 1000
T = Tf + (Ti - Tf) e^-βt
Tf - RTNDT =
-138
-100
-68
-63
-40
-25
P (Failure / Transient Occurrence)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
0
0.2
β, min^-1
0.4
0
0.1
0.2
0.3
0.4
0.5



Probabilistic Basis
#14
β=0.15
$T = T_f + (T_i - T_f)e^{-0.15t}$
P(Failure / Transient Occurrence)
Pressure, psig
1000
2000
0
500
1000
1500
2000


Probabilistic Basis
#15
$T_w = 150 + 400e^{-0.15t}$
$T_w = 200 + 350e^{-0.15t}$
P = 1000 psig
RT_{NDT} = 250°F
$\beta = 0.15 \, min^{-1}$
Relative Failure Probability (Assuming Long Axial Cracks)
← Value used by NRC Staff for in-house analyses
h, B/hr ft² °F
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
200
330
400
600
800
1000
1200

#16

Deterministic Method for Crack Initiation

(based on transient with $T_{final} = 250°F$ and $\beta = 0.15\ min^{-1}$)

RT_{NDT}, °F	Pressure, psig	*P(failure/trans)*
230	> 2500	10^{-5} to 10^{-4}
275	< 1000	10^{-4} to 10^{-3}
295	< 300	10^{-4} to 10^{-3}

* Probability of vessel failure given occurrence of the transient described and with vessel RT_{NDT} shown

(#17)

RT_{NDT} Limits Under Consideration

- Using deterministic curves, with $\beta = 0.15$, $T_f = 250$:

  for full pressure capability, then

  RT_{NDT} (Actual) = 230°F for longitudinal welds

  RT_{NDT} (Actual) = 255°F for circumferential welds

- Using probabilistic curves for above β, T_f, and RT_{NDT}:

  P (failure / transient occurrence) = $\sim 10^{-5}$

  P (transient occurrence) = $\sim 10^{-2}$

  $\therefore$ P (failure) (For the given transient) = $\sim 10^{-7}$

  Note, however, that the total failure probability would be higher to account for all transients including those with $T_f < 250°F$ and/or $\beta > 0.15 \text{ min}^{-1}$

#18

Determination of RT_{NDT}

- Limit under consideration was derived assuming actual RT_{NDT} is known

- How should RT_{NDT} be determined for regulation?
  - "Best Estimate" value
  - Conservative value

#19

Unquantified Uncertainties

- Local temperature in downcomer vs. measured temp.
- Changes being made:
  - better instrumentation (bus seperation in B&W plnt)
  - interim training and procedure modifications
- Consequences of vessel failure
- Failure criteria
- Heat transfer coefficient
- Cladding effects (increases K_{IC} but may inhibit growth)
- Use of K_{IC} 200 ksi $\sqrt{in}$ for crack arrest
- Best estimate vs. lower bound K_{IC}
- Method used to determine RT_{NDT}
- More severe transients may occur
- We used normal distributions with "tails" that may not exist in reality
- Assumed crack shape, size, and probability

(#20)

Possible Actions for Plants that Do Not Currently Meet Criteria

- Justification of lower RT_{NDT}, for example through lower initial RT_{NDT}
- Operations improvements
  - licensee would have to prepare and justify
  - licensees would have to show that no other safety problems were created
- Instrumentation improvements for use by operator
- Credit for pressure limiting control system
  - licensee would have to design reliable system
  - licensee would have to determine and justify that system would not create safety problems
- Full volumetric NDE of vessel
- [redacted] shutdown for annealing

(#21)

Flux Reduction Considerations

- Are we willing to accept EOL RT_{NDT} equal to limit for many older operating plants?
- Does this mean limiting RT_{NDT} should be lowered?
- Should we require flux reduction methods to slow down toughness degradation?
- We propose that these questions should be answered when the safety goal is finalized.

#22

Defense in Depth

Should we require:

- upgraded operator procedures and training at all plants

- improved instrumentation at some RT_{NDT} threshold

- hardware improvements at some RT_{NDT} threshold:
  - Auto Pressure Control
  - Warmer Feedwater
  - Warmer ECCS Water

- required flux reduction at some RT_{NDT} threshold

CEOG COMMENTS

NRC/INDUSTRY PTS MEETING
(6/9/82)

- CONSERVATISMS IN NRC LEFM ANALYSES

- CHARACTERISTICS OF NRC TRANSIENT

- PROBABILITY OF NRC TRANSIENT

CONSERVATISMS IN NRC LEFM ANALYSES

- ANALYSIS OF NRC TRANSIENT

- CRACK INITIATION CRITERION

  CRACK ARREST

  LEFM / EPFM

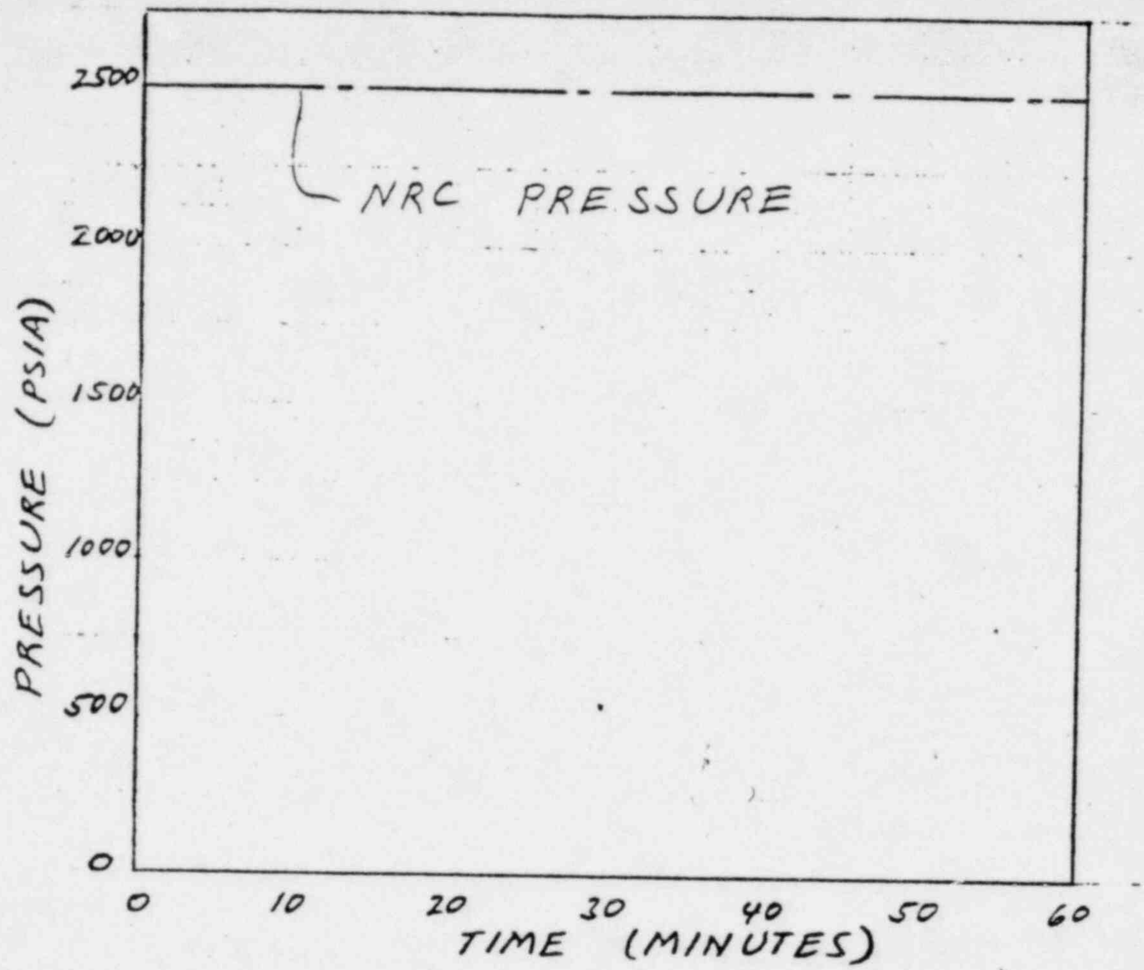
ANALYSIS OF NRC TRANSIENT

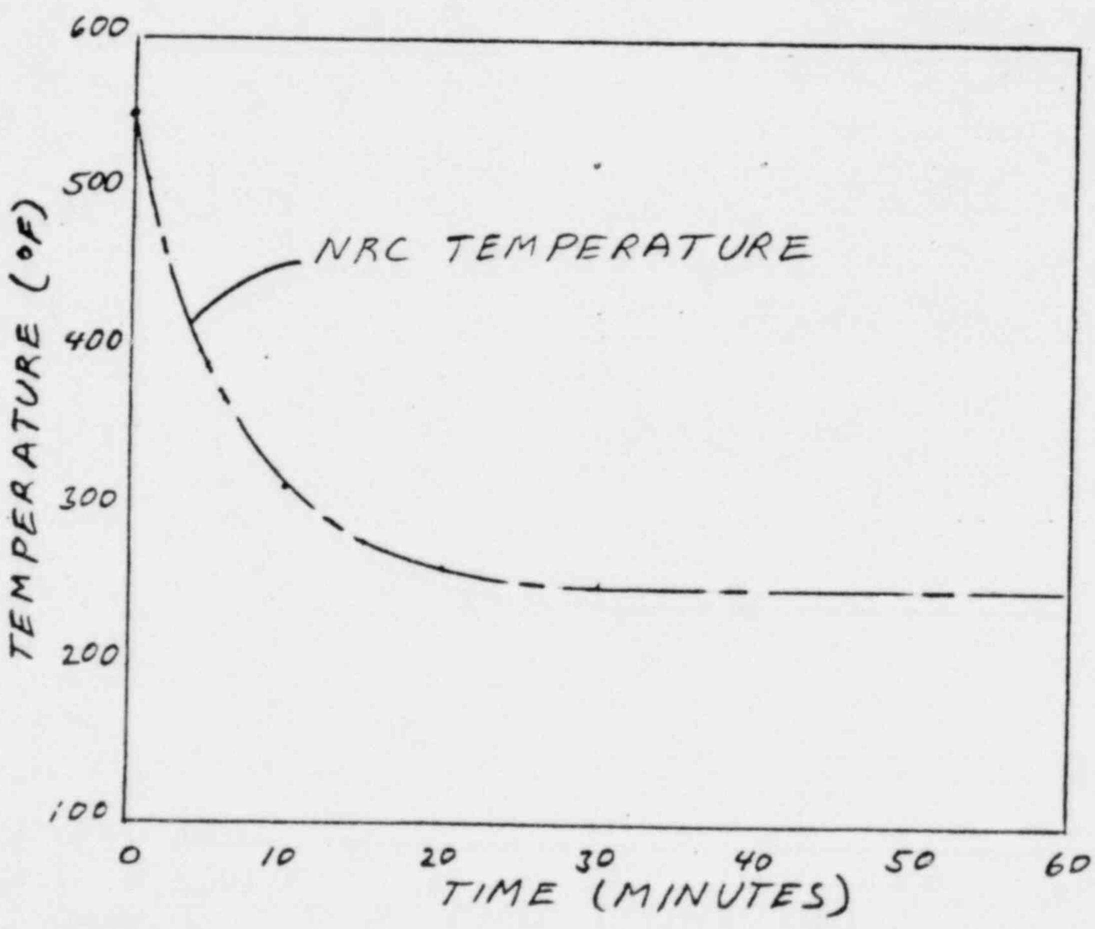
DURATION OF TRANSIENT (MINUTES)	RT_{NDT} AT INITIATION (°F)
30	320
60	290
90	280

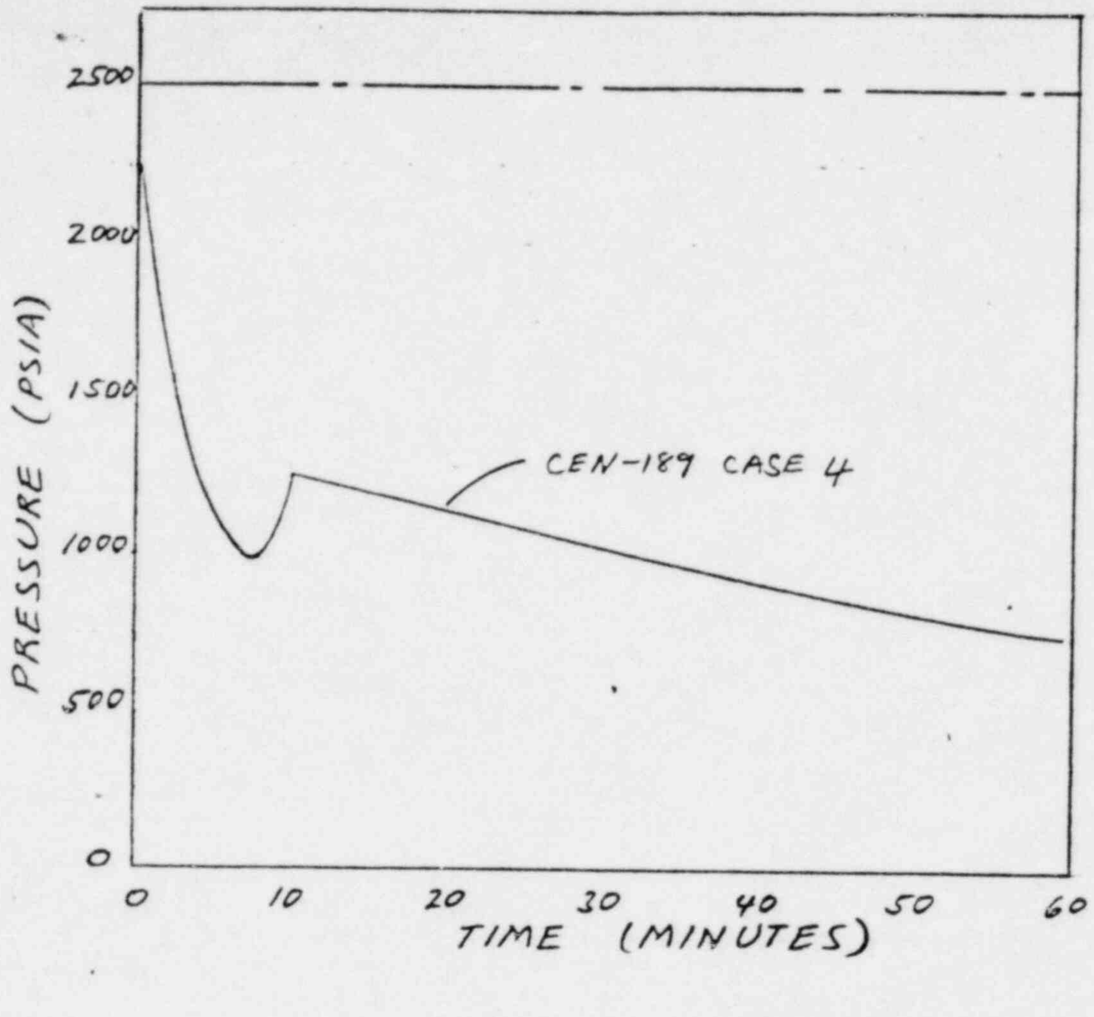
CHARACTERISTICS OF NRC TRANSIENT

- CONSTANT HIGH PRESSURE WHILE TEMPERATURE RAPIDLY DECREASES

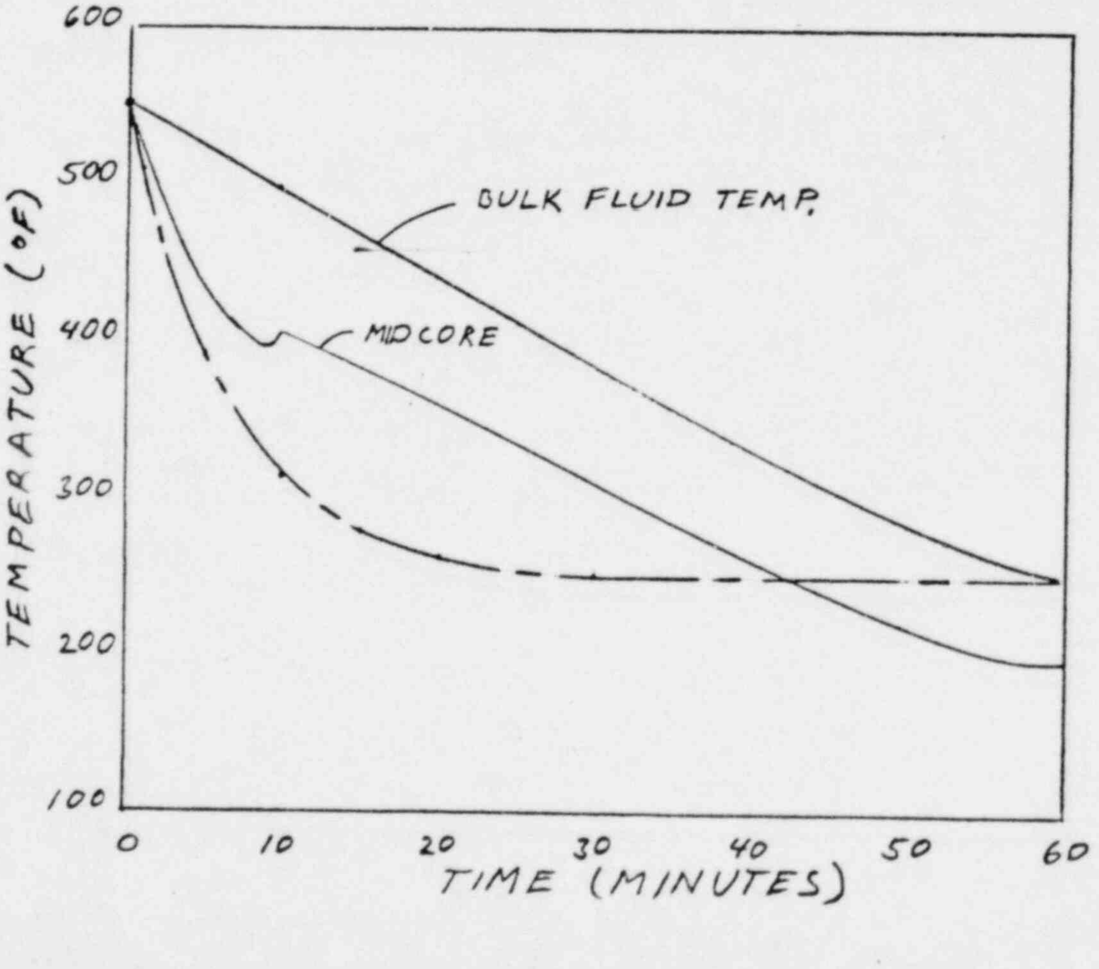
- RAPID COOLDOWN TO CONSTANT LOW TEMPERATURE


2500
2000
1500
1000
500
0
PRESSURE (PSIA)
NRC PRESSURE
0
10
20
30
40
50
60
TIME (MINUTES)

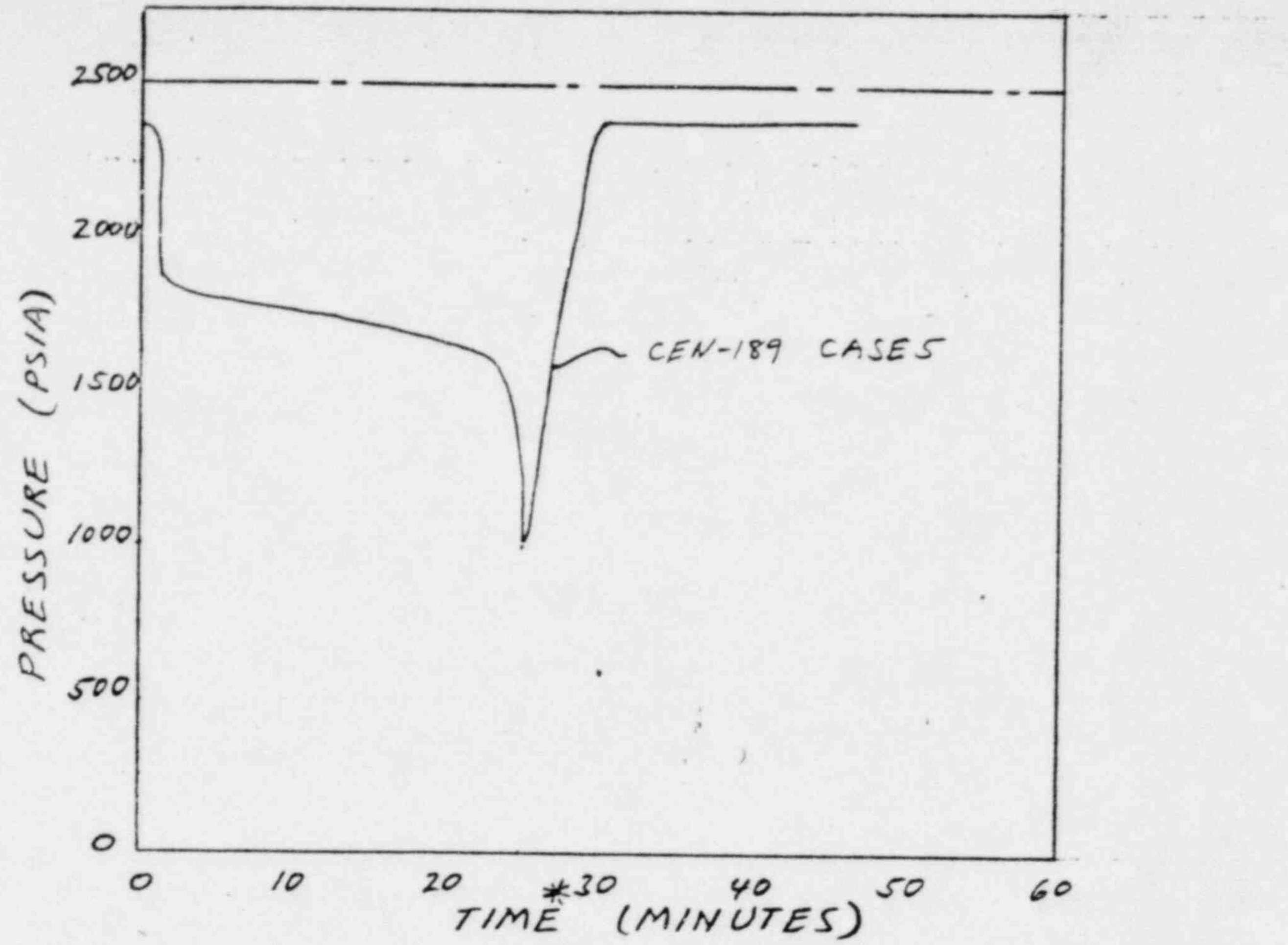

600
500
400
300
200
100
TEMPERATURE (°F)
NRC TEMPERATURE
0
10
20
30
40
50
60
TIME (MINUTES)

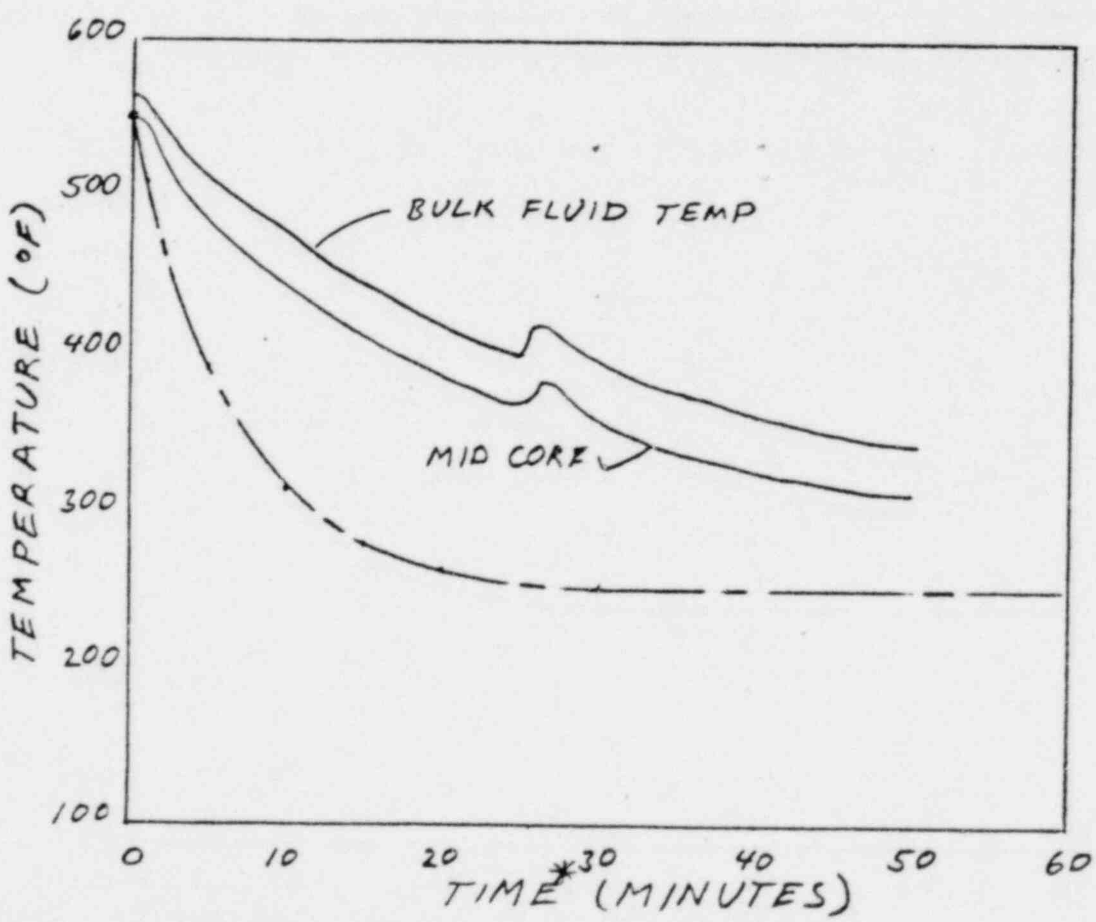


2500
2000
1500
1000
500
0
PRESSURE (PSIA)
CEN-189 CASE 4
0
10
20
30
40
50
60
TIME (MINUTES)

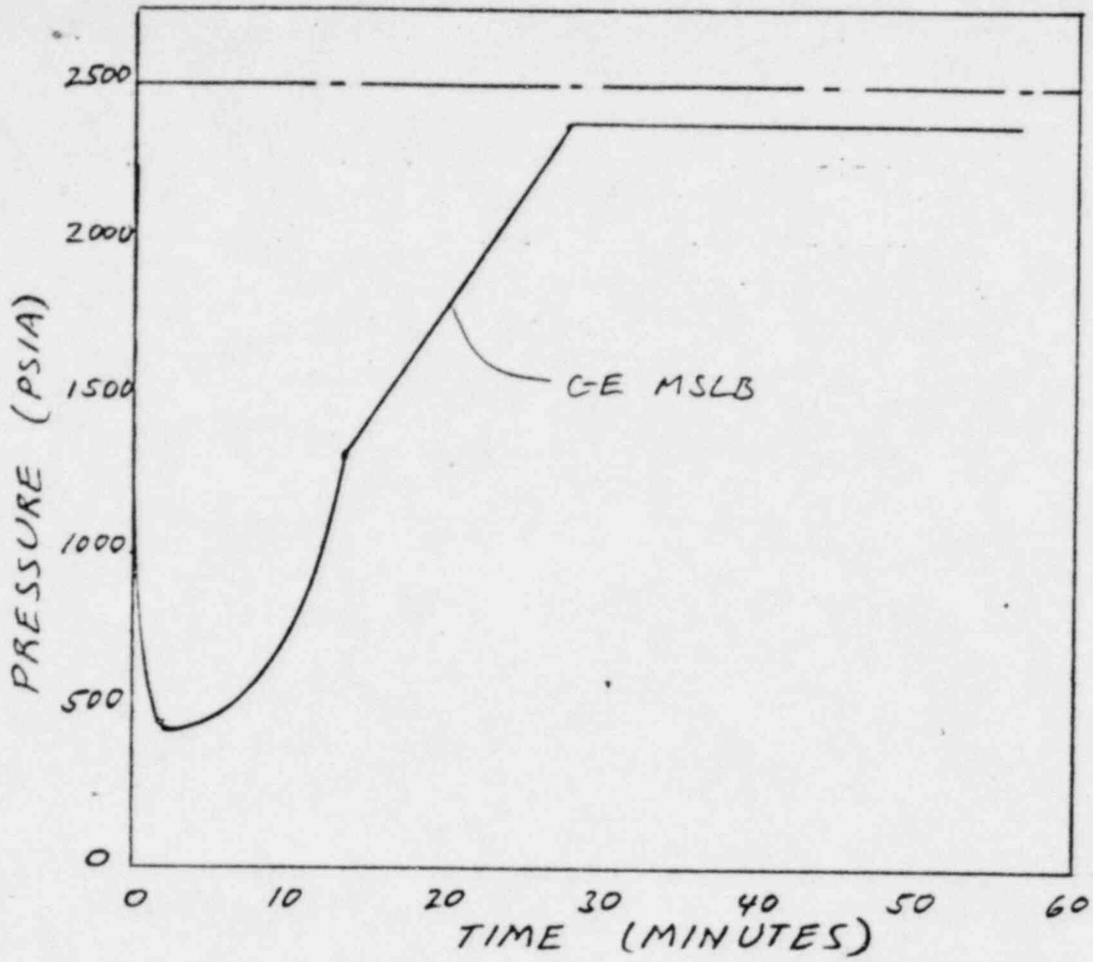


600
500
400
300
200
100
TEMPERATURE (°F)
BULK FLUID TEMP.
MIDCORE
0
10
20
30
40
50
60
TIME (MINUTES)

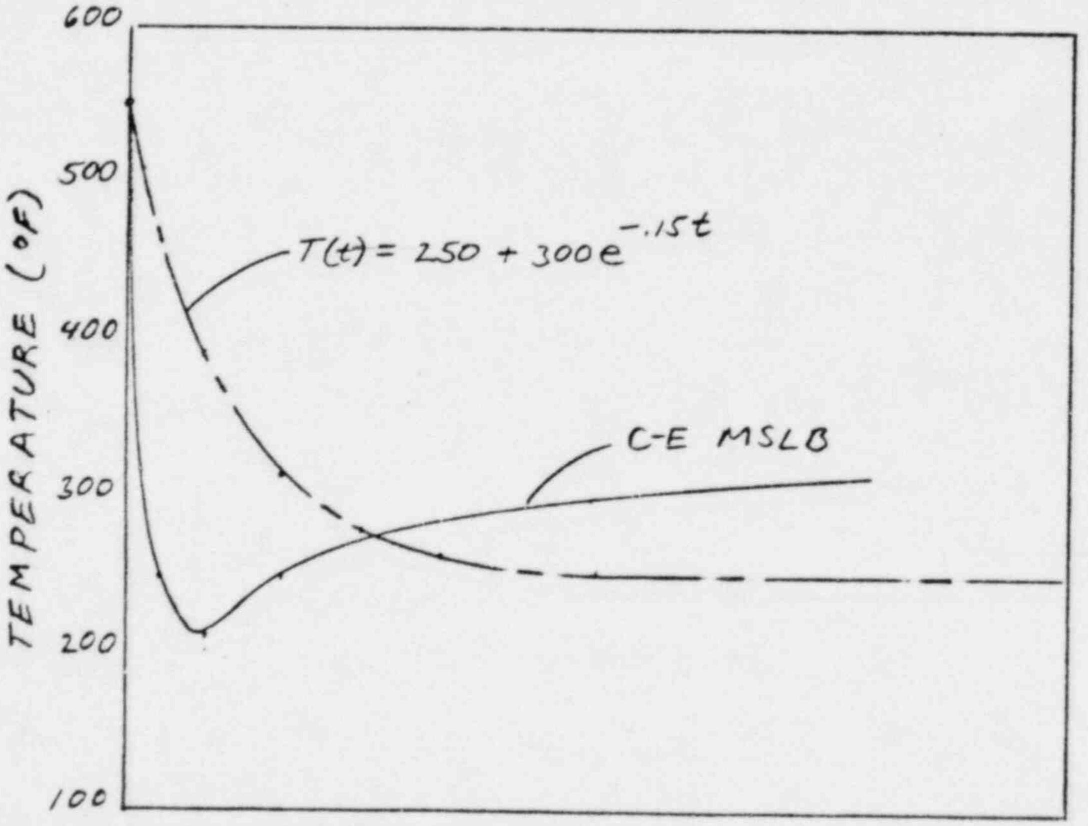




* TIME AFTER FEEDWATER RESTORATION



2500
2000
1500
1000
500
0
PRESSURE (PSIA)
C-E MSLB
0
10
20
30
40
50
60
TIME (MINUTES)



600
500
400
300
200
100
TEMPERATURE (°F)
T(t) = 250 + 300e^-.15t
C-E MSLB
0
10
20
30
40
50
60
TIME (MINUTES)

CONCLUSIONS OF COMPARISONS OF NRC TRANSIENT AND SYSTEM RESPONSES

- PRESSURE CANNOT REMAIN HIGH WHILE TEMPERATURE DECREASES RAPIDLY

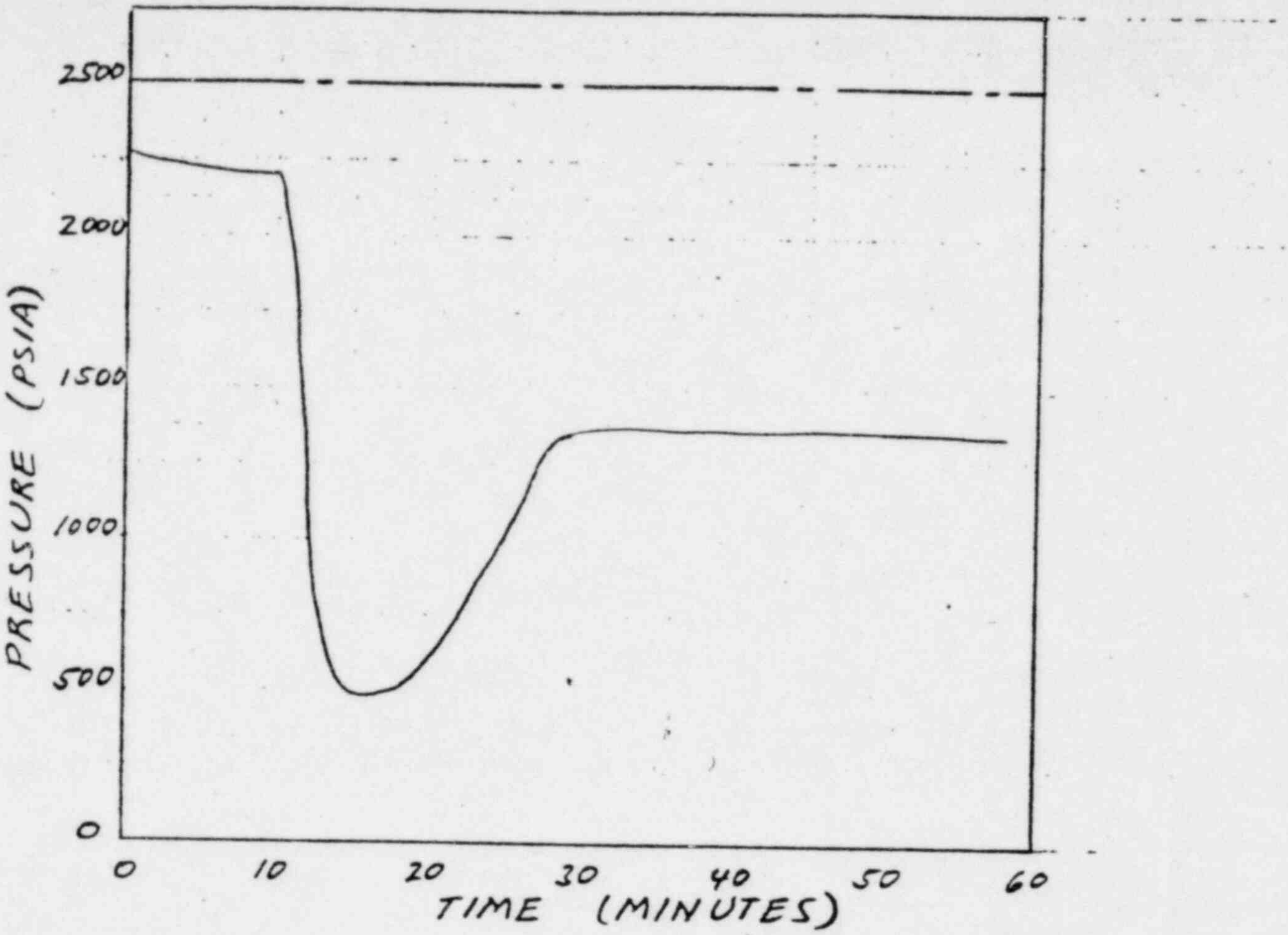
- TEMPERATURE DOES NOT REMAIN LOW FOR CASES OF REPRESSURIZATION AFTER A RAPID INITIAL COOLDOWN

PROBABILITY OF NRC TRANSIENT

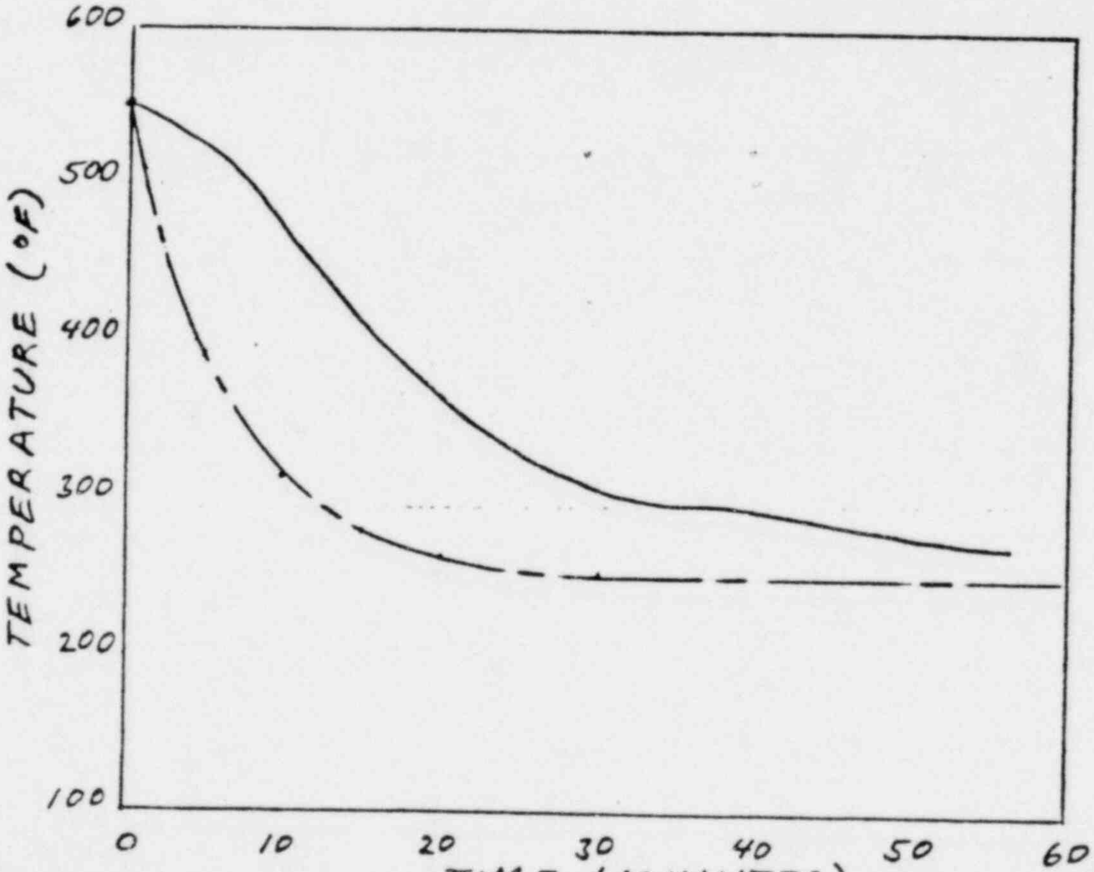
- PROBABILITY OF SIMULTANEOUS OCCURRENCE OF NRC PRESSURE <u>AND</u> TEMPERATURE IS NIL

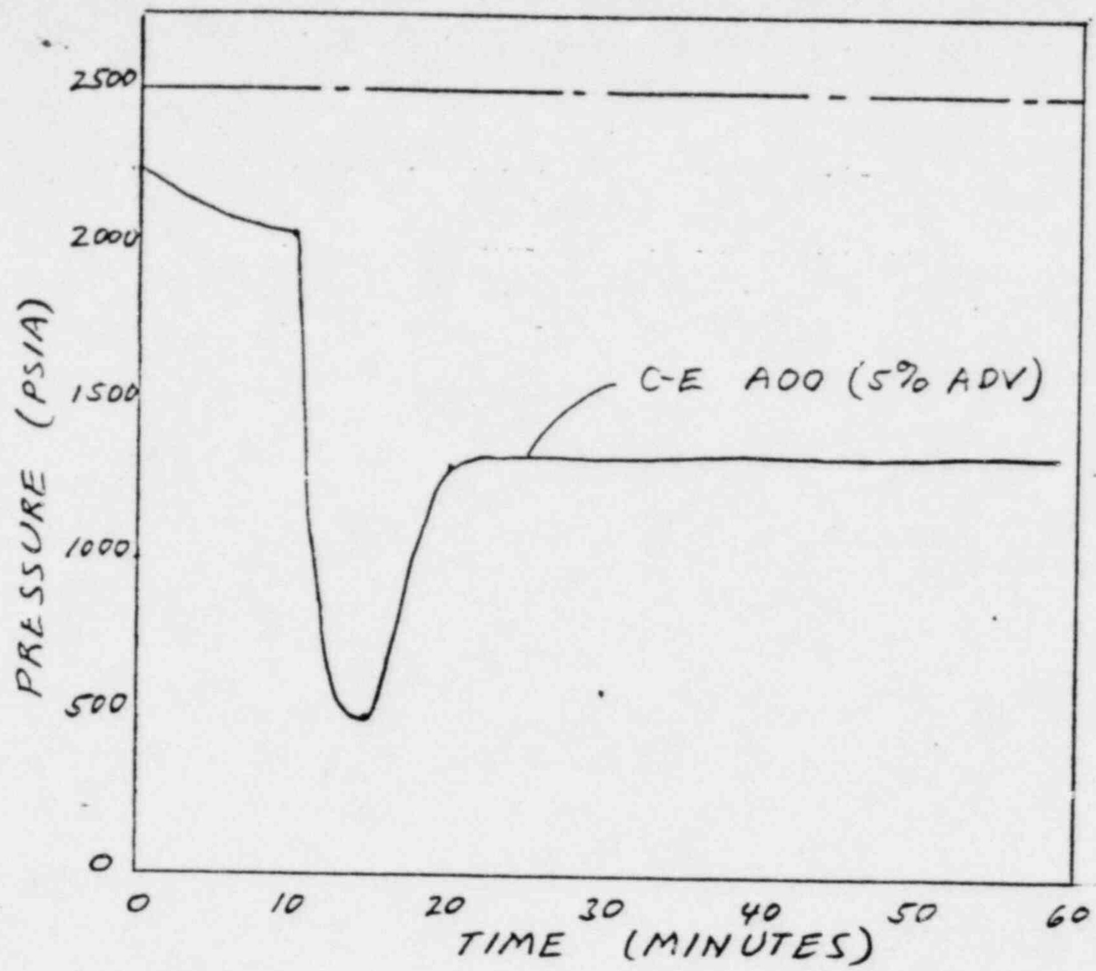
- PROBABILITY OF SEQUENCES OF EVENTS NECESSARY TO PRODUCE NRC TEMPERATURE TRANSIENT ARE VERY LOW

- TRANSIENTS RESULTING FROM 10^{-2}/YR EVENTS ARE MUCH LESS SEVERE THAN NRC TRANSIENT

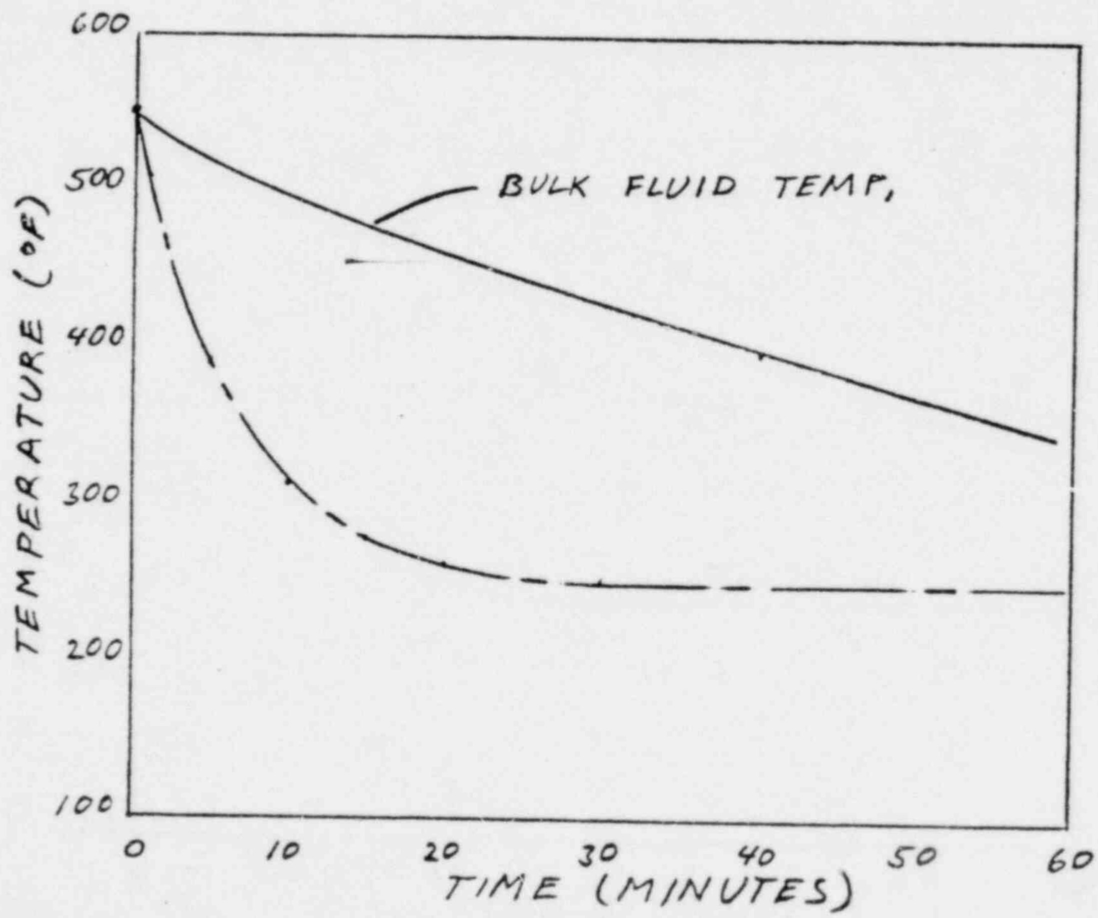


MSSV FAILURE + FAILURE TO ISOLATE AFW





2500
2000
1500
1000
500
0
PRESSURE (PSIA)
C-E AOO (5% ADV)
0
10
20
30
40
50
60
TIME (MINUTES)



600
500
400
300
200
100
TEMPERATURE (°F)
BULK FLUID TEMP,
0
10
20
30
40
50
60
TIME (MINUTES)

OCA-1 ANALYSIS

INPUT

1. HEAT TRANSFER COEFFICIENT

300 BTU/HRFT^2 °F

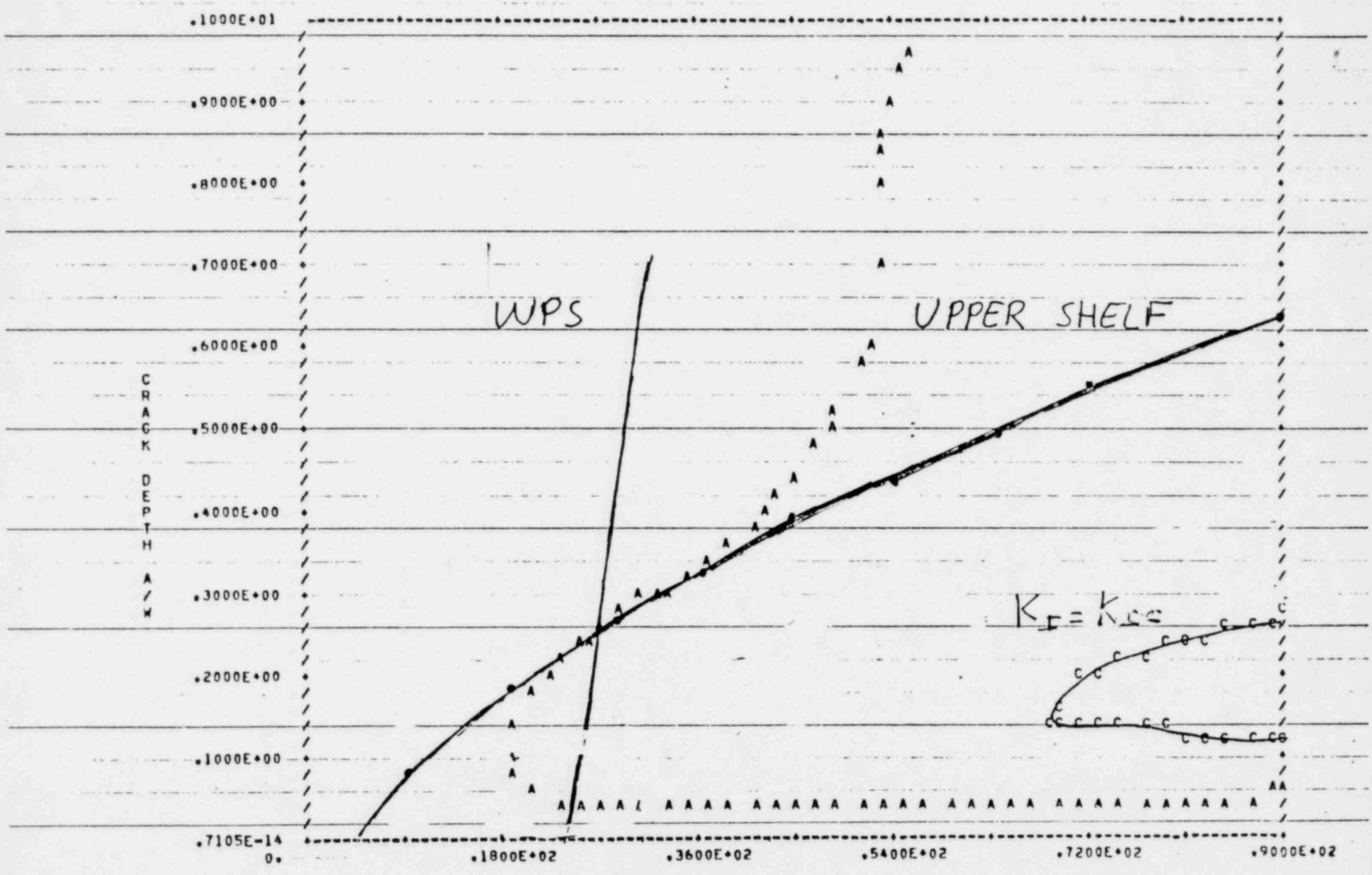
2. MATERIAL PROPERTIES

	250F	550 F
E	29.25×10^6	27.7×10^6
α	6.89×10^{-6}	8.16×10^{-6}
$\frac{E\alpha}{1-\nu}$	285	323

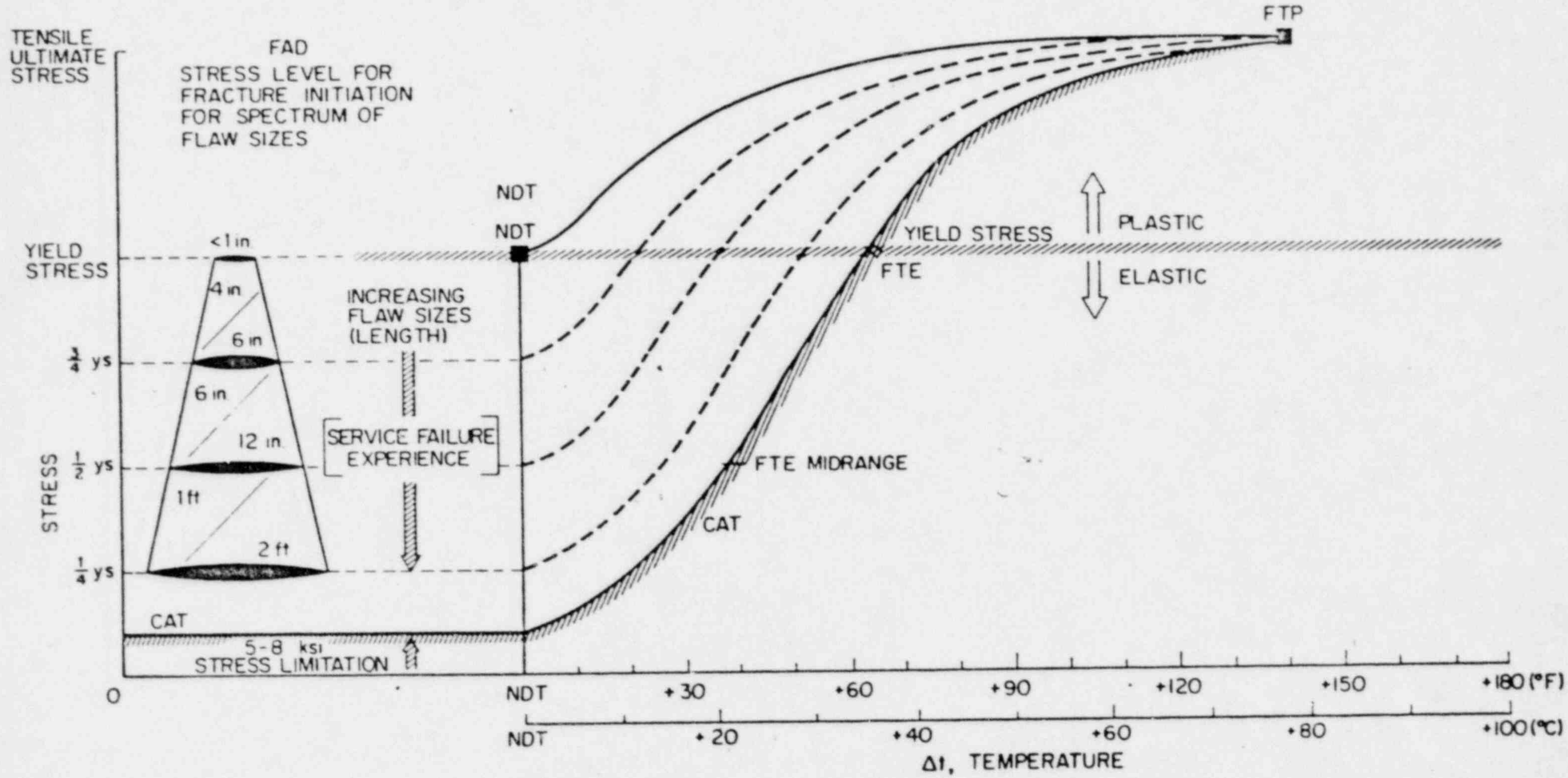
IN ANALYSIS

$$\frac{E\alpha}{1-\nu} = 304$$

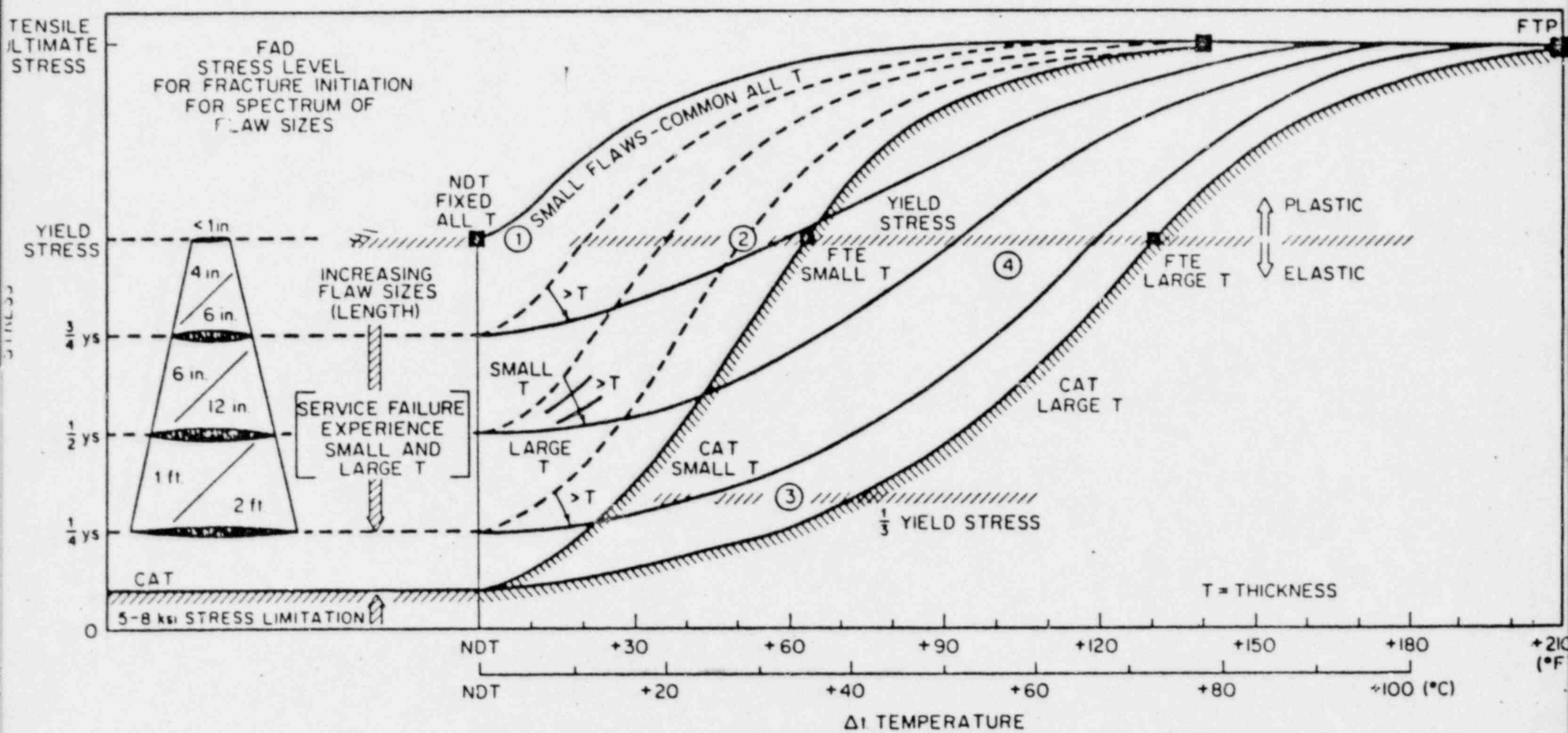
CRITICAL CRACK DEPTH VS. TIME



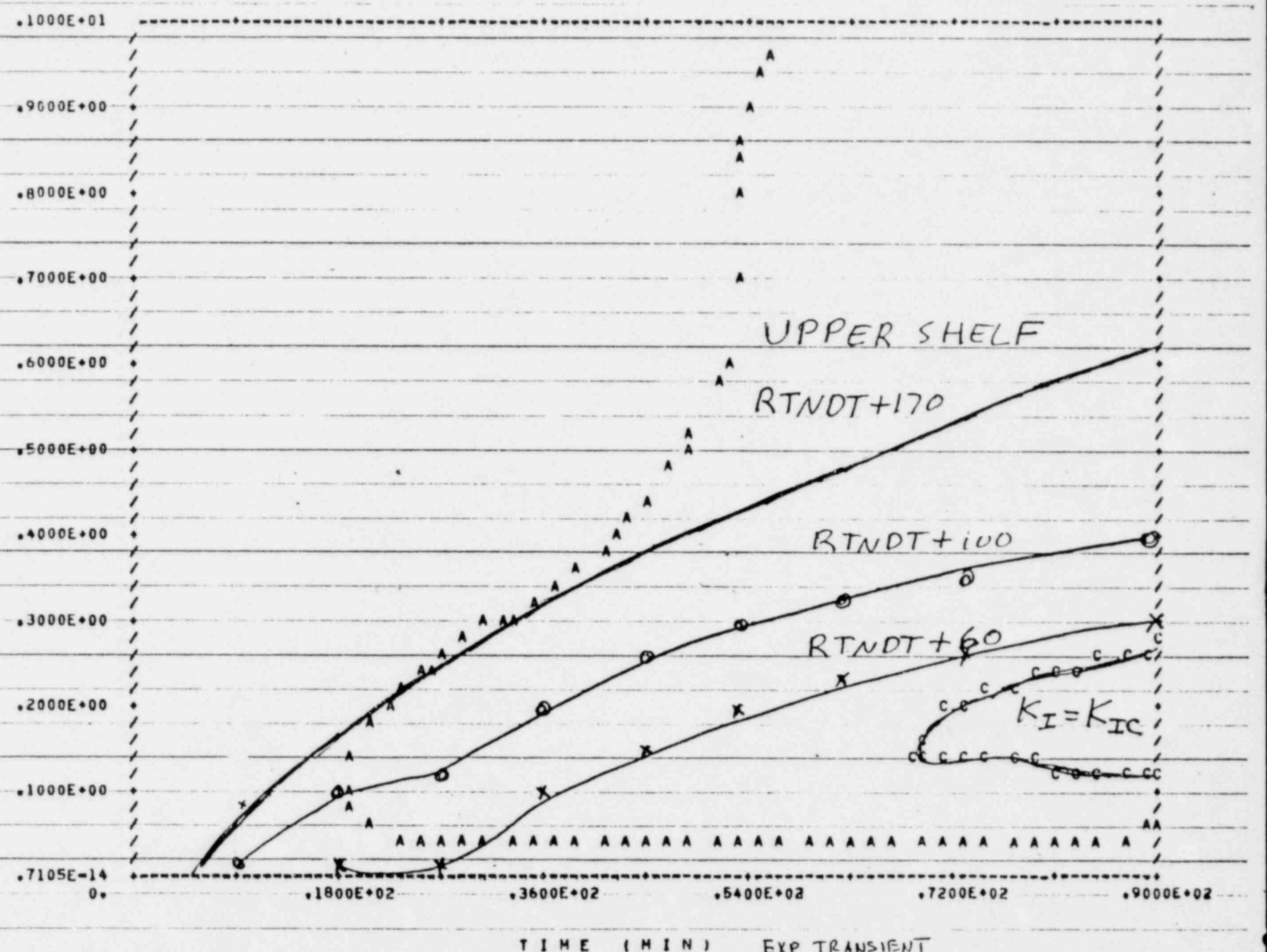
FLUENCE = .10E+20 N/SQ. CM
INITIAL RTNDT = -20. DEG. F
PCT. CU = .35



TENSILE ULTIMATE STRESS
FAD
STRESS LEVEL FOR FRACTURE INITIATION FOR SPECTRUM OF FLAW SIZES
FTP
NDT
NDT
YIELD STRESS
<1 in
4 in
6 in
3/4 ys
6 in
12 in
1/2 ys
1 ft
2 ft
1/4 ys
STRESS
INCREASING FLAW SIZES (LENGTH)
SERVICE FAILURE EXPERIENCE
CAT
5-8 ksi
STRESS LIMITATION
YIELD STRESS
FTE
PLASTIC
ELASTIC
FTE MIDRANGE
CAT
0
NDT
+30
+60
+90
+120
+150
+180 (°F)
NDT
+20
+40
+60
+80
+100 (°C)
Δt, TEMPERATURE


TENSILE
ULTIMATE
STRESS
FAD
STRESS LEVEL
FOR FRACTURE INITIATION
FOR SPECTRUM OF
FLAW SIZES
FTP
SMALL FLAWS - COMMON ALL T
NDT
FIXED
ALL T
YIELD
STRESS
< 1 in.
4 in.
6 in.
6 in.
12 in.
1 ft.
2 ft.
INCREASING
FLAW SIZES
(LENGTH)
SERVICE FAILURE
EXPERIENCE
SMALL AND
LARGE T
3/4 ys
1/2 ys
1/4 ys
CAT
5-8 ksi STRESS LIMITATION
0
SMALL
T
LARGE
T
> T
YIELD
STRESS
FTE
SMALL T
FTE
LARGE T
PLASTIC
ELASTIC
CAT
SMALL T
CAT
LARGE T
1/3 YIELD STRESS
T = THICKNESS
NDT
+30
+60
+90
+120
+150
+180
+210 (°F)
NDT
+20
+40
+60
+80
+100 (°C)
Δt TEMPERATURE

CRITICAL CRACK DEPTH VS. TIME



FLUENCE = .10E+20 N/SQ. CM
INITIAL RTNDT =-20. DEG. F
PCT. CU = .35
PCT. P = .012
SURFACE RTNDT 280

X T - RTNDT = 60 °F
o T - RTNDT = 100 °F