LOAD-TIME HISTOGRAM AND ELASTIC ANALYSIS OF CRBRP HEAT TRANSPORT SYSTEM PIPING

SUMMARY

The CRBRP heat transport system piping was designed and analyzed for the operating and load conditions as specified in the Piping Design Specification. The various types of design loading conditions have been categorized into design, normal, upset, emergency and faulted conditions, and organized into a load histogram. Using the thermal transient defined for each condition and the histogram, a set of load cycles was constructed using the 863 startup-shutdown conditions. The stress analysis of the piping was performed on the basis of the thermal transients and loadings resulting from the loading categories and the histogram.

The ELTEMP computer program was used to perform the elastic ASME Code compliance analysis. The input required to perform the Code evaluation included the pipe cross-section geometry, component type (elbow, tee, straight, etc.), the forces and moments output data from the flexibility analyses, average temperature, linear temperature gradients, non-linear temperature gradients, pressure, etc. This information was used to calculate the primary, primary-plus-secondary, and primary-plus-secondary-plus peak stress intensities according to the rules of Subsection NB-3650 of Section III. The calculated primary stress intensities were then compared with the corresponding allowable limits in Section III and Code Case 1592 for Class 1 components in elevated temperature service. In addition, the secondary and peak stresses were used within ELTEMP to evaluate ratchetting limits and to determine creep-fatigue damage in accordance with the elastic procedures specified in Code Case 1592.

DOE-PNC Specialist Meeting on
High Temperature Piping Design and Analysis

R. M. Mello - ARD

DISCLAIMER

The following pages are an exact representation of what is in the original document folder.

HTS PIPING STRUCTUAL DESIGN CRITERIA & REQUIREMENTS

Criteria

- ASME B & PV Code, 1974, Section III, Nuclear Power Plant Components
- ASME Code Case Interpretation 1592-7
- RDT Standard E15-2NB-T, Nuclear Components
- RDT Standard F9-4T

Requirements

- Seismic Category I
- ASME Code Class 1
- CRBRP Design Duty Cycle & Histogram

0850-3
S663-3

PRIMARY PIPING DESIGN DUTY CYCLE AND HISTOGRAM

- Dry Heatup, Sodium Fill, Sodium Drain and Dry Cooldown Operations
- Umbrella Thermal Transients Resulting From the Normal, Upset, Emergency and Faulted Conditions
- Seismic Disturbances
- Service Life of 30 Years With Availability Factor of 0.85
- Operating Cycles-863 Startup/Shutdowns
- Sequence of Cycles-Undefined

0850-20

LOAD-TIME HISTOGRAM AND ELASTIC ANALYSIS OF CRBRP PRIMARY PIPING

R.M. MELLO
Westinghouse Advanced Reactors Division

DOE-PNC Specialist Meeting on High
Temperature Piping Design and Analysis

ARD-Madison, Pennsylvania
March 26-30, 1979

0850-21

DESIGN TRANSIENTS FOR PRIMARY 36-INCH AND 24-INCH HOT LEG PIPING

State Pairs		Number Of Occurrences	Applicable Transients	Comments
Initial	Final			
1	2	13	PRP-1N	Dry Heatup
2	1	13	PRP-2N	Dry Cooldown
2	3	13	Part of PRP-1N	Sodium Fill
3	2	13	Part of PRP-2N	Sodium Drain
3	5	140	PRP-3N	Normal Startup From Refueling
4	5	723	PRP-4N (50),PRP-5N (673)	Normal Startup From Hot Standby
5	3	60	PRP-6N	Normal Shutdown to Refueling
5	4	284	PRP-7N (260), PRP-9U (24)	Normal and Upset Shutdowns to Hot Standby
5	7	10629	PRP-8N (10619),PRP-5U (10)	Normal and Upset Loading
7	5	10110	PRP-9N	Normal Unloading
6	7	46500	PRP-10N	Normal (Up Power) Fluctuations
7	6	46500	PRP-11N	Normal (Down Power) Fluctuations
7	7	30×10^6	PRP-12N	Steady State Temperature Fluctuations
7	4	439	PRP-1U (238), PRP-2U (146) PRP-3U (14), PRP-8U (5), PRP-11U (21), PRP-12U (10), PRP-13U (5)	Upset Shutdowns to Hot Standby
7	3	79	PRP-1U (30), PRP-2U (42), PRP-E (7)[1]	Non-Normal Shutdowns to Refueling
7	3	1	SSE	Faulted Event
4	4	20	PRP-4U	Upset Shutdown During Startup
4	3	1	PRP-2F (1)	Faulted Activation of DHRS

Note: 1. When Evaluating Event PRP-2E Substitute Condition 8 for Condition 7.

0850-22

STEADY STATE CONDITIONS FOR PRIMARY 36-INCH AND 24-INCH HOT LEG PIPING

Condition Designation	Condition	T(°F)	Pressure (psig) PRP(A)*	PRP (B)	Flow (10^6 1bm/hr)
1	Room Temperature, Drained	70	0.0	0.0	0.0
2	Refueling Temperature, Drained	400	0.0	0.0	0.0
3	Refueling Conditions	400	9.1	14.4	1.4
4	Hot Standby	600	8.9	14.3	1.4
5	40% Power (130 MW Per Loop, Thermal/Hydraulic Design)	910	8.2	34.0	4.9
6	80% Power (299 MW Per Loop, Stretch)	975	6.9	115.0	11.2
7	Full Power (373.7 MW Per Loop, Stretch)	1015	6.0	168.0	14.0
8	66.7% Power, Two Loop (373.7 MW Per Loop, Stretch)	1015	6.0	168.0	14.0

*PRP(A) is the Designation Used for the 36-Inch Primary Hot Leg Piping Between the RV and Primary Pump and PRP (B) is the Designation Used for the 24-Inch Primary Hot Leg Piping Between the Primary Pump and IHX.

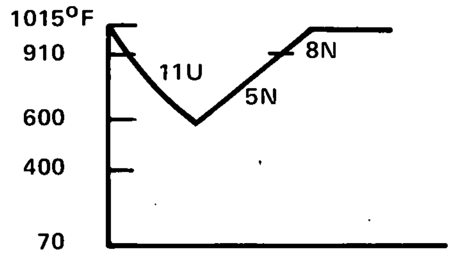
0850-23

LOAD HISTOGRAM

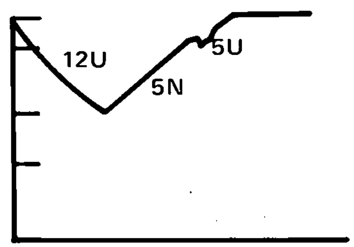
- Code Requirements Regarding The Establishment Of Loading History For Deformation-Controlled Limits Are Not Clearly Defined, Except For Fatigue Analysis.
- Load Cycles Are Defined That Use All The Plant Transients (Uniform History).
- Stress Cycle For Each Load Cycle Defined By The Two Stress Extremes For The Load Cycle (Extremes Are Identified As Load Cases).
- Ratchetting And Creep Damage Evaluated For Each Specified Stress Cycle.
- Fatigue Stress Cycles Constructed Within ELTEMP Using All Possible Combinations Of The Extremes (Or Load Cases) For The Load Cycles.
- Minor Cycles Defined.

0850-10
S663-10

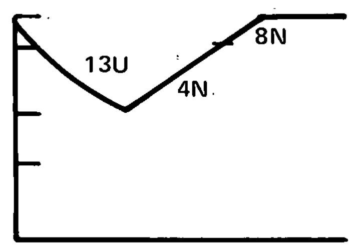
DEFINED LOAD CYCLES (TYPICAL EXAMPLES)



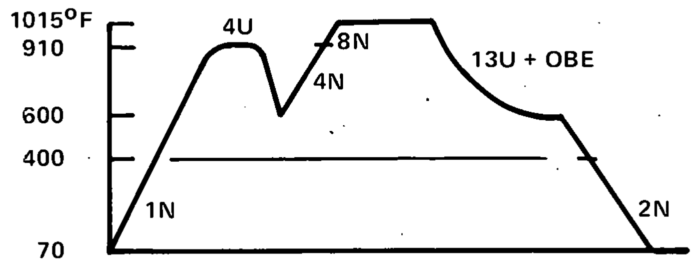
21 CYCLES



14. 10 CYCLES



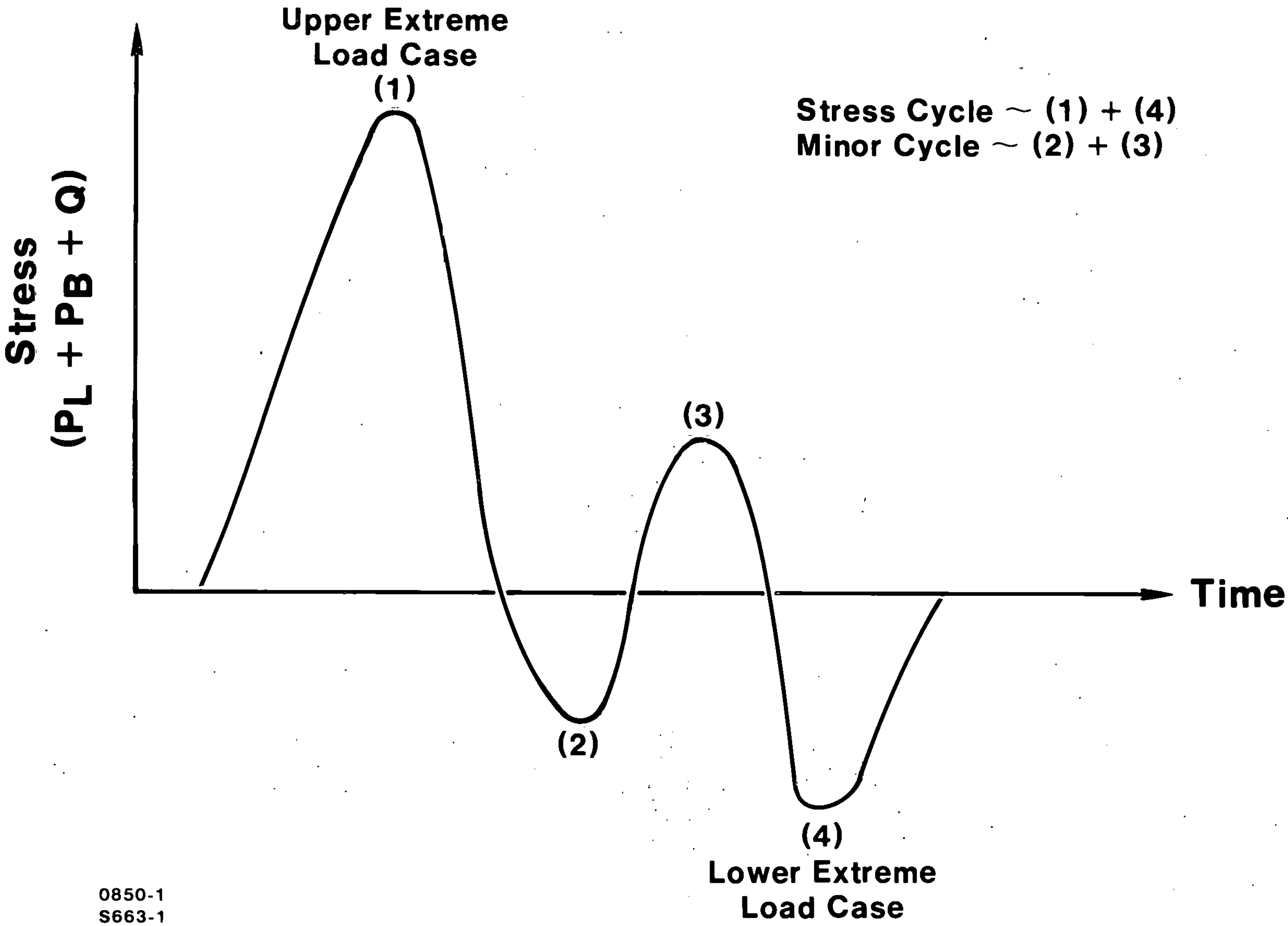
15. 4 CYCLES



16. 1 CYCLE

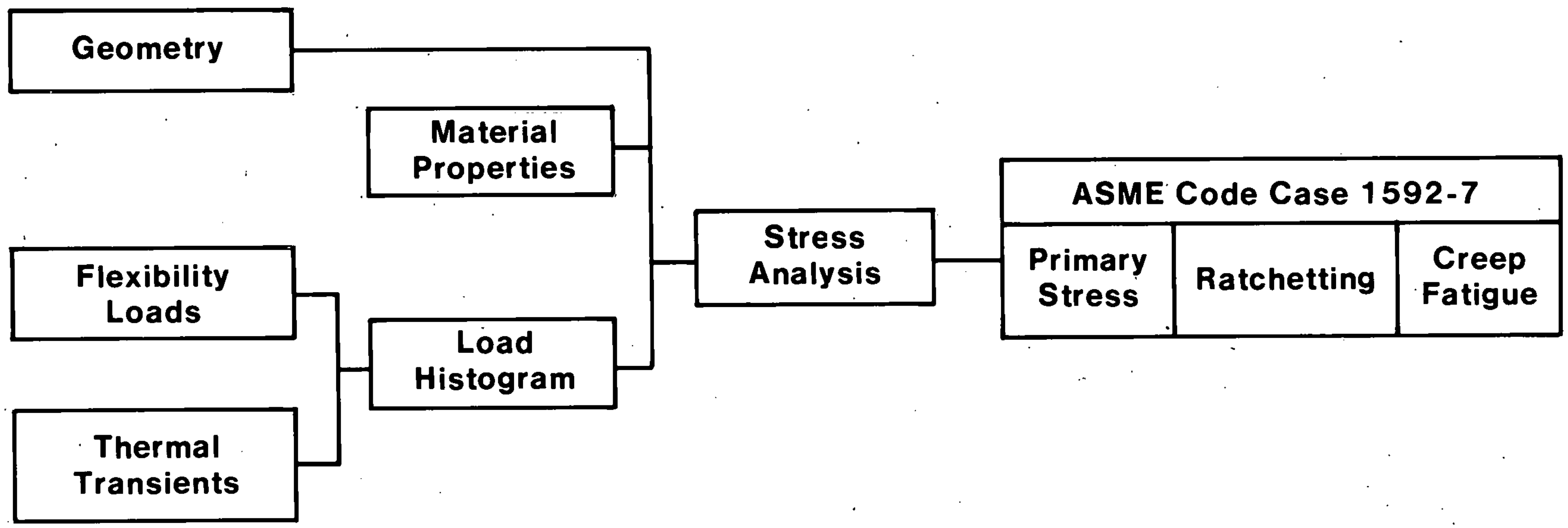
0850-2
S663-2

STRESS HISTORY FOR A GIVEN LOAD CYCLE



0850-1
S663-1

ELASTIC
STRUCTURAL EVALUATION CRITERIA
ELTEMP (CRBRP — Code Case 1592-7)



0850-9
S663-9

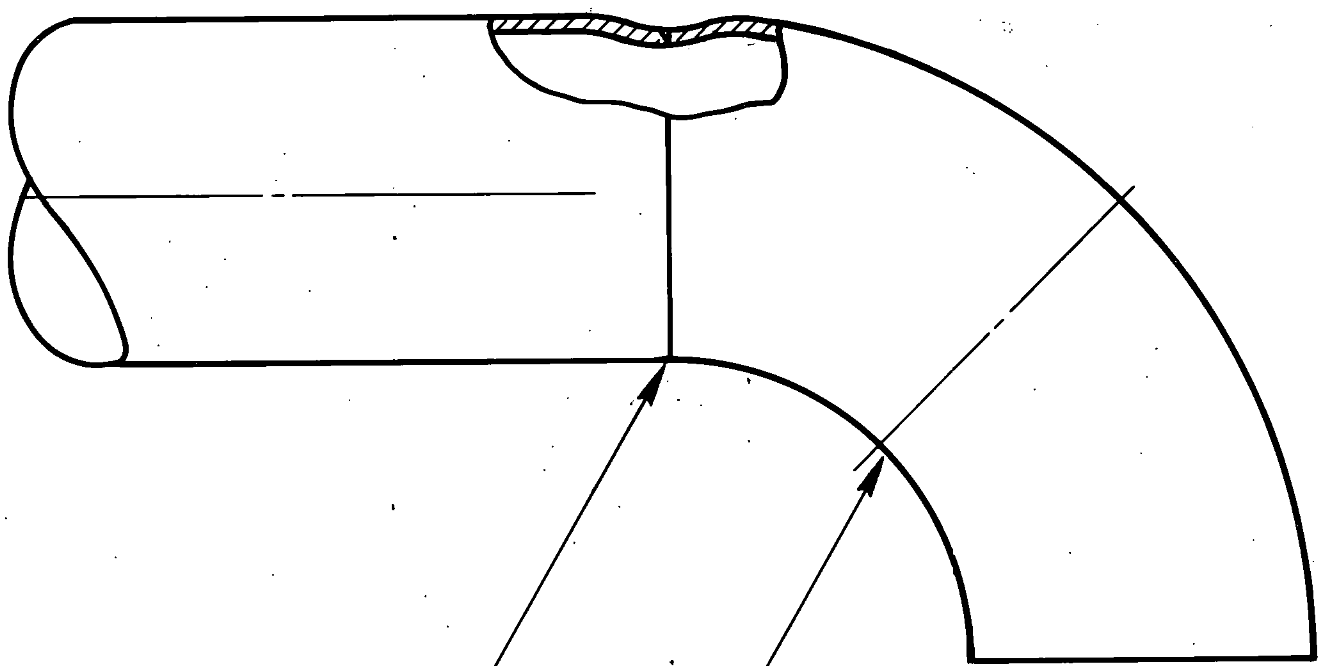
FLEXIBILITY ANALYSIS

- Deadweight, Thermal Expansion
- Seismic

  (1) Response Spectrum Modal Method
  (2) Piping/HTS Equipment Composite Model
  (3) Stiffness of Clamp/Pipe, Snubber, Support Steel & Building at Support Point
  (4) Decoupling of Piping Legs & Branch Lines

0850-35

STRESS EVALUATION



(1) Elbow Mid-Section

(2) Elbow/Straight Pipe Girth Welds

- Girth Weld Shrinkage
- Elbow Ovalization Carry-Thru @ Joint

(3) Nozzle/Straight Pipe Girth Welds

0850-4
S663-4

CODE EVALUATION

- Criteria Written In Terms Of Code Subarticle -3200
- Stress Indices And Stress Equations Of Code Subarticle NB-3600 Used To Determine Pipe Stress Intensities Such As $(P_L + P_b)$, $(P_L + P_b + Q)$, Etc.
- Example

$$(P_L + P_b) = \frac{B_1 P D_o}{2t} + \frac{B_2 D_o M_i}{2I}$$

0850-13
S663-13

LOAD-CONTROLLED CODE EVALUATION

Condition	General Primary Membrane (1592 And F9-4)	Primary Membrane — Plus — Blending (1592)	Primary Membrane — Plus — Blending (F9-4)
Design	$P_m \leq S_o$	$(P_L + P_b) \leq 1.5\ S_o$	
Normal	$P_m \leq S_{mt}$	$(P_L + P_b) \leq \begin{cases} 1.5\ S_m \\ K_t S_t \end{cases}$	$(P_L + P_b) \leq KS_m$ $(P_L + P_b/K_t) \leq S_t$
Upset	$P_m \leq S_{mt}$	$(P_L + P_b) \leq \begin{cases} 1.5\ S_m \\ K_t S_t \end{cases}$	$(P_L + P_b) \leq KS_m$ $(P_L + P_b/K_t) \leq S_t$
Emergency	$P_m \leq 1.2\ S_m$ $P_m \leq S_t$	$(P_L + P_b) \leq \begin{cases} 1.8\ S_m \\ K_t S_t \end{cases}$	$(P_L + P_b) \leq 1.2\ KS_m$ $(P_L + P_b/K_t) \leq S_t$
Faulted	$P_m \leq 1.5\ S_m$ $P_m \leq 1.2\ S_t$	$(P_L + P_b) \leq \begin{cases} 3.0\ S_m \\ 1.2\ K_t S_t \end{cases}$	$(P_L + P_b/K_t) \leq 1.2\ S_t$

0850-16
S663-16

DEFORMATION-CONTROLLED CODE EVALUATION

Ratchetting

- Test 1, 2 And 3 (O'Donnell-Porowsky Method) ~ Code Case 1592-7
- Test 4 (Minor Exposure To Elevated Temperature)

  $P_L + P_b + Q \leqslant 3\, S_m$ (Eq. 10)

  Or

  $Q_{TE} \leqslant 3\, S_m$ (Eq. 12) And (Eq. 13)
- Bree Full Relaxation Method, $\Sigma(\Delta\epsilon)_k$
- Paragraph 6.2 Of RDT F9-5T

Creep-Fatigue

$$\Sigma\left(\frac{\Delta T}{T_D}\right)_k + \Sigma\left(\frac{n}{N_D}\right)_k$$

0850-11
S663-11

ELASTIC CREEP-DAMAGE EVALUATION

- $S_K = \text{Min.} \begin{cases} 1.25\ S_{Y/K} \\ (P_{m/K} + 0.5\ S_{r/K}) > (P_L + P_b + Q)_{SS} \end{cases}$

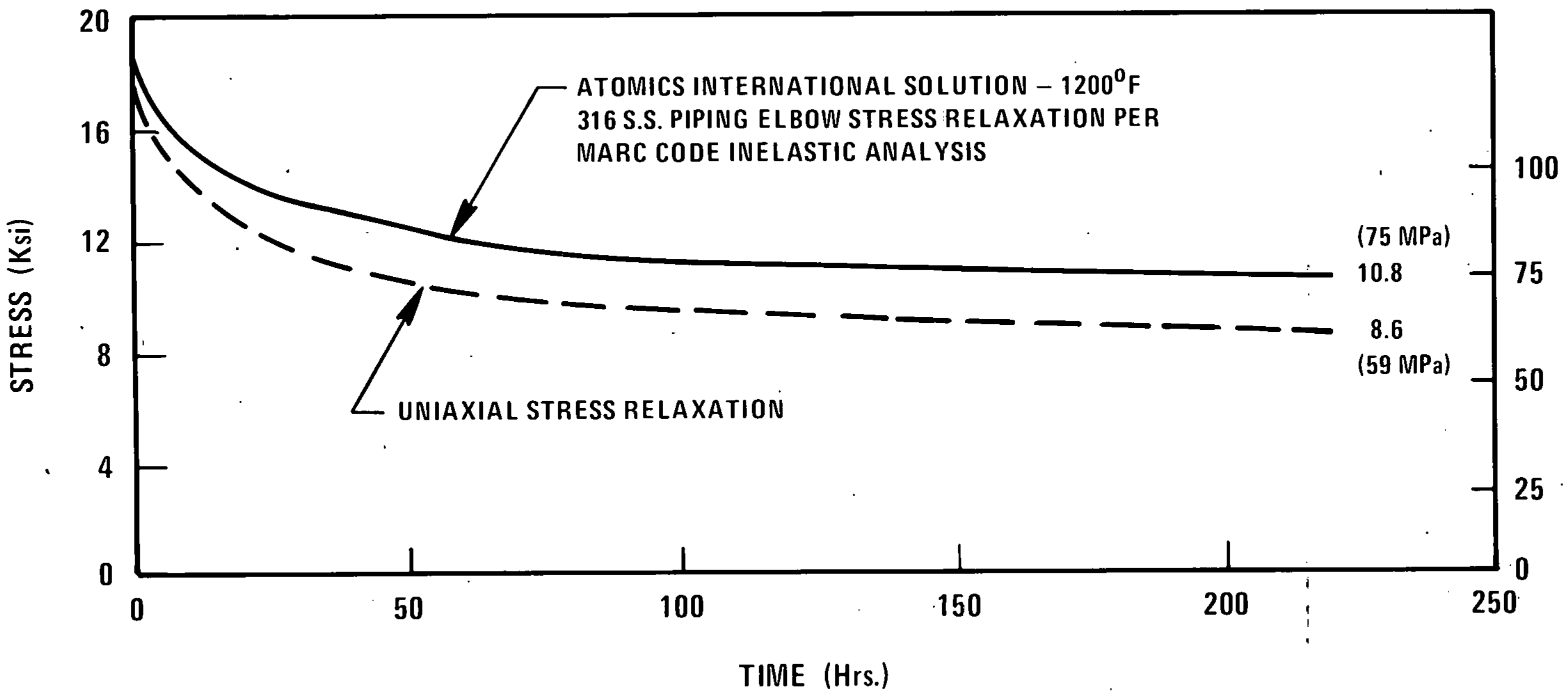
  Or $\quad \text{Min.} \begin{cases} 1.25\ S_{Y/K} \\ (P_L + P_b + Q)_{SS} \end{cases}$

- Creep-Damage

$$\Sigma \frac{\Delta T_i}{T_D(S_K/K^1)}$$

0850-14
S663-14

COMPARISON OF PIPING STRESS RELAXATION TO UNIAXIAL RELAXATION AT 1200°F



0850-8
S663-8

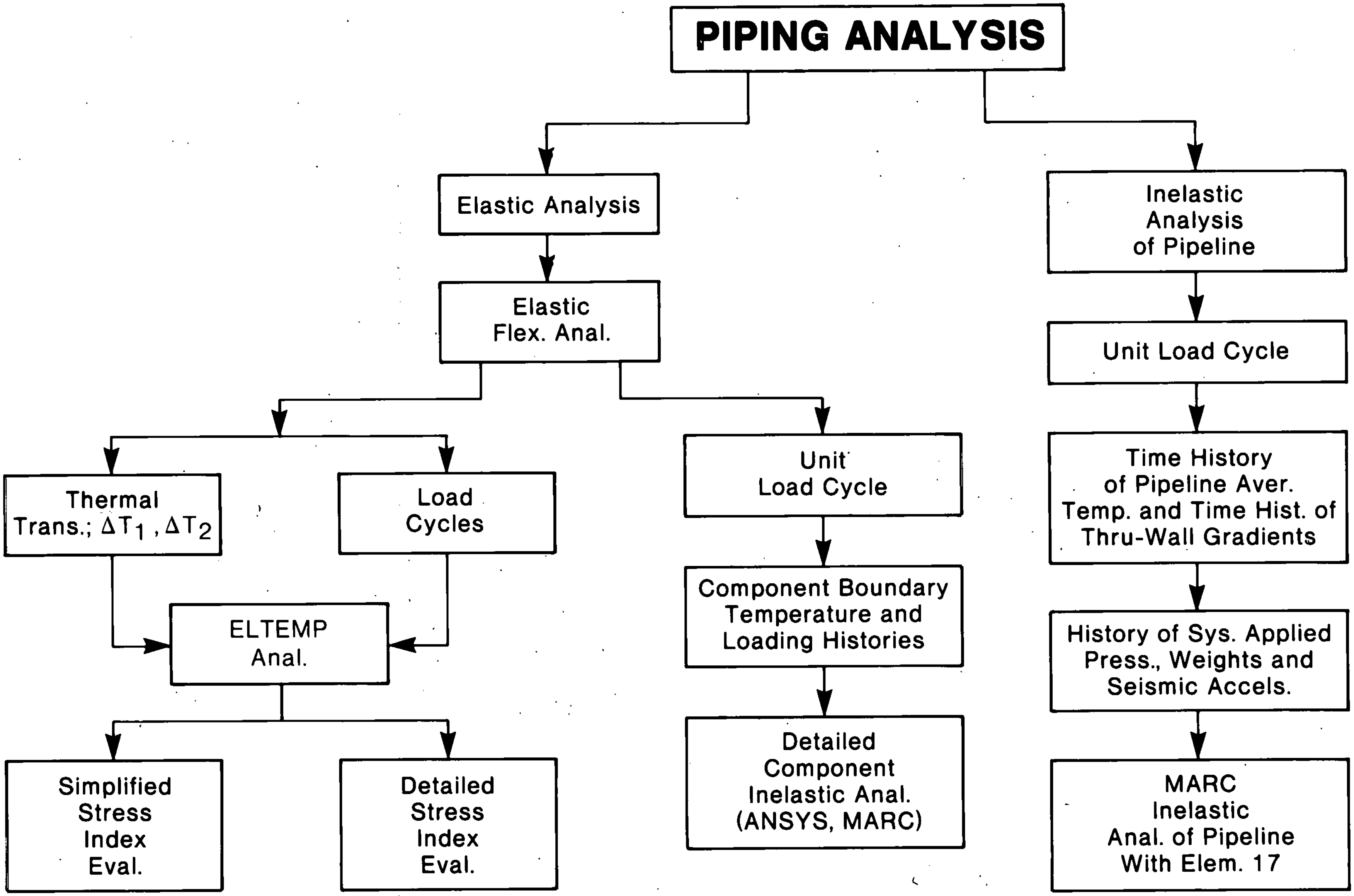
ELASTIC FATIGUE EVALUATION

- Equation 7 Of Code Case 1592-7

  $\epsilon_T = K_E \epsilon_e + K_E^2 \epsilon_P + K_T \epsilon_F$

  Where ϵ_T Is Defined For A Load Case
- Strain Range $\epsilon_t = \epsilon_T^{(1)} - \epsilon_T^{(2)}$
- In ELTEMP ϵ_e, ϵ_P And ϵ_F Calculated As Strain Ranges And ϵ_T Used As ϵ_t
- Stress Analysis Of Piping In Terms Of Stress Intensities Without Sign.

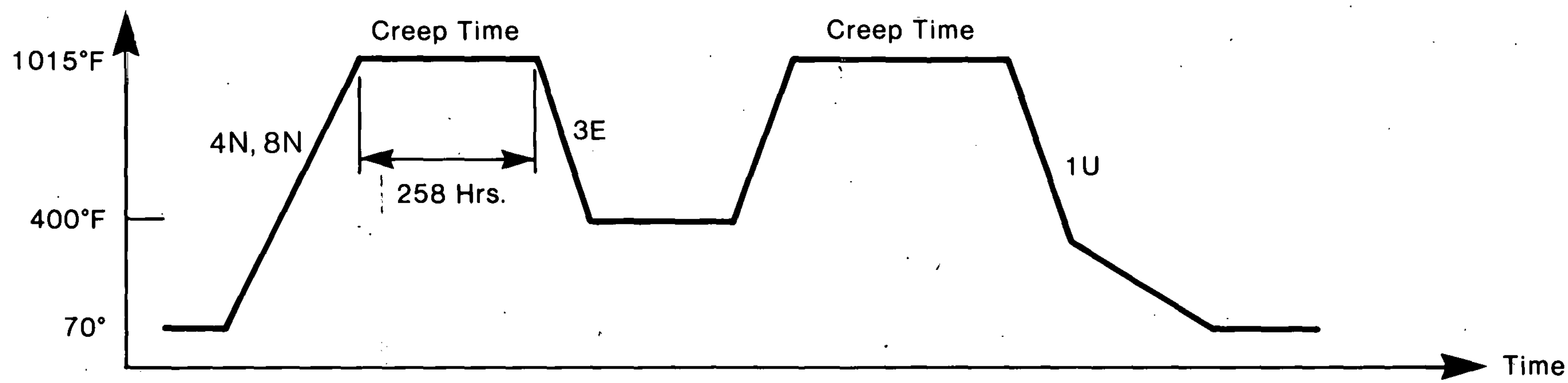
0850-15
S633-15


PIPING ANALYSIS
Elastic Analysis
Elastic Flex. Anal.
Thermal Trans.; ΔT1 , ΔT2
Load Cycles
ELTEMP Anal.
Simplified Stress Index Eval.
Detailed Stress Index Eval.
Unit Load Cycle
Component Boundary Temperature and Loading Histories
Detailed Component Inelastic Anal. (ANSYS, MARC)
Inelastic Analysis of Pipeline
Unit Load Cycle
Time History of Pipeline Aver. Temp. and Time Hist. of Thru-Wall Gradients
History of Sys. Applied Press., Weights and Seismic Accels.
MARC Inelastic Anal. of Pipeline With Elem. 17

0850-24

APPLICATION OF DESIGN TRANSIENTS TO INELASTIC STRUCTURAL ANALYSIS OF PIPING COMPONENTS

Specified Transient Events	Occurrences	Load Histogram Event	Occurrences
Startups			
(1) 3N-8N,4N-8N, 5N-8N	863	4N	864
Shutdowns			
(1) Normal (6N,7N)	320		
(2) Upset	535	1U,6N,7N	432
(3) Emergency	7	3E,U	432
(4) Faulted	1		



Unit Load Cycle (Use 432 Cycles as Given)

0850-25

CONCLUSIONS

- Elastic Analysis-Histogram is Defined That Uses All the Umbrella Transients (Uniform History)
- Piping Evaluated in Accord With the Elastic Methods and Rules of Code Case 1592-7 With ELTEMP
- Failure of Elastic Limits
  (1) Inelastic Component Analysis
  (2) Inelastic Flexibility Analysis

0850-26

CONF-790363--3

LOAD-TIME HISTOGRAM AND ELASTIC ANALYSIS OF CRBRP HEAT TRANSPORT SYSTEM PIPING

SUMMARY
ABSTRACT

The CRBRP heat transport system piping was designed and analyzed for the operating and load conditions as specified in the Piping Design Specification. The various types of design loading conditions have been categorized into design, normal, upset, emergency and faulted conditions, and organized into a load histogram. Using the thermal transient defined for each condition and the histogram, a set of load cycles was constructed using the 863 startup-shutdown conditions. The stress analysis of the piping was performed on the basis of the thermal transients and loadings resulting from the loading categories and the histogram.

The ELTEMP computer program was used to perform the elastic ASME Code compliance analysis. The input required to perform the Code evaluation included the pipe cross-section geometry, component type (elbow, tee, straight, etc.), the forces and moments output data from the flexibility analyses, average temperature, linear temperature gradients, non-linear temperature gradients, pressure, etc. This information was used to calculate the primary, primary-plus-secondary, and primary-plus-secondary-plus peak stress intensities according to the rules of Subsection NB-3650 of Section III. The calculated primary stress intensities were then compared with the corresponding allowable limits in Section III and Code Case 1592 for Class 1 components in elevated temperature service. In addition, the secondary and peak stresses were used within ELTEMP to evaluate ratchetting limits and to determine creep-fatigue damage in accordance with the elastic procedures specified in Code Case 1592.

DOE-PNC Specialist Meeting on
High Temperature Piping Design and Analysis

R. M. Mello - ARD