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LaRC DESIGN ANALYSIS REPORT FOR NATIONAL TRANSONIC FACILITY FOR 9% NICKEL TUNNEL SHELL

FATIGUE ANALYSIS

VOL. 6

BY

JAMES W. RAMSEY, JR., JOHN T. TAYLOR, JOHN F. WILSON, CARL E. GRAY, JR., ANNE D. LEATHERMAN, JAMES R. ROOKER, AND JOHNNY W. ALLRED

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Formal Documentation of Design Analyses to Obtain Code Approval of Fabricated National Transonic Facility

16. Abstract This report contains the results of extensive computer (finite element, finite difference and numerical integration), thermal, fatigue, and special analyses of critical portions of a large pressurized, cryogenic wind tunnel (National Transonic Facility). The computer models, loading and boundary conditions are described. Graphic capability was used to display model geometry, section properties, and stress results. A stress criteria is presented for evaluation of the results of the analyses. Thermal analyses were performed for major critical and typical areas. Fatigue analyses of the entire tunnel circuit is presented.

The major computer codes utilized are: SPAR - developed by Engineering Information Systems, Inc. under NASA Contracts NAS8-30536 and NAS1-13977; SALORS - developed by Langley Research Center and described in NASA TN D-7179; and SRA - developed by Structures Research Associates under NASA Contract NAS1-10091; "A General Transient Heat-Transfer Computer Program for Thermally Thick Walls" developed by Langley Research Center and described in NASA TM X-2058.

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NTF TUNNEL SHELL

NASA LaRC

FATIGUE ANALYSIS

9% Ni

SEPTEMBER 1976

VOLUME 6

LaRC CALCULATIONS

FOR THE

NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

DATE: SEPTEMBER, 1976

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This report is one volume of a Design Analysis Report prepared by LaRC on portions of the pressure shell for the National Transonic Facility. This report is to be used in conjunction with reports prepared under NASA Contract NAS1-13535(c) by the Ralph M. Parsons Company (Job Number 5409-3 dated September 1976) and Fluidyne Engineering Corporation (Job Number 1060 dated September 1976). The volumes prepared by LaRC are listed below:

1. Finite Difference Analysis of Cone/Cylinder (9% Ni), Vol. 1, NASA TM X73956-1.
2. Finite Element Analysis of Corners #3 and #4 (9% Ni), Vol. 2, NASA TM X73956-2.
3. Finite Element Analysis of Plenum Region Including Side Access Reinforcement, Side Access Door and Angle of Attack Penetration (9% Ni), Vol. 3, NASA TM X73956-3.
4. Thermal Analysis (9% Ni), Vol. 4, NASA TM X73956-4.
5. Finite Element and Numerical Integration Analyses of the Bulkhead Region (9% Ni), Vol. 5, NASA TM X73956-5.
6. Fatigue Analysis (9% Ni), Vol. 6, NASA TM X73956-6.
7. Special Studies (9% Ni), Vol. 7, NASA TM X73956-7.

NTF DESIGN CRITERIA
FOR 9% NICKEL

GENERAL

THE DESIGN OF THE PRESSURE SHELL REFLECTED IN THIS REPORT SATISFIES THE DESIGN REQUIREMENTS OF THE ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 1. SINCE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN, ADDITIONAL ANALYSES WERE PERFORMED IN AREAS HAVING COMPLEX CONFIGURATIONS SUCH AS THE CONE CYLINDER JUNCTIONS, THE GATE VALVE BULKHEADS, THE BULKHEAD-SHELL ATTACHMENTS, THE PLENUM ACCESS DOORS AND REINFORCEMENT AREAS, THE ELLIPTICAL CORNER SECTIONS, AND THE FIXED REGION (RING S8) OF THE TUNNEL. THE DIVISION 1 DESIGN CALCULATIONS, THE ADDITIONAL ANALYSES AND THE CRITERIA FOR EVALUATION OF THE RESULTS OF THE ADDITIONAL ANALYSES TO ENSURE COMPLIANCE WITH THE INTENT OF DIVISION 1 REQUIREMENTS ARE CONTAINED IN THE TEXT OF THIS REPORT. THE DESIGN ANALYSES AND ASSOCIATED CRITERIA CONSIDERED BOTH THE OPERATING AND HYDROSTATIC TEST CONDITIONS.

IN CONJUNCTION WITH THE DESIGN, A DETAILED FATIGUE ANALYSIS OF THE PRESSURE SHELL WAS ALSO PERFORMED UTILIZING THE METHODS OF THE ASME CODE, SECTION VIII, DIVISION 2.

MATERIAL

THE PRESSURE SHELL MATERIAL SHALL BE ASME, SA-553-1 FOR PLATE AND SA-522 FOR FORGINGS. THE MATERIAL PROPERTIES AT TEMPERATURES EQUAL TO OR BELOW 150°F ARE AS FOLLOWS:

(A) PLATE, 2.0 INCHES OR THINNER

YIELD = 85.0 KSI
ULTIMATE = 100 KSI

(B) WELDS (AUTOMATIC AND SEMIAUTOMATIC)

YIELD = 52.5 KSI
ULTIMATE = 95.0 KSI

(C) WELDS (HAND)

YIELD = 58.5 KSI
ULTIMATE = 95.0 KSI

OPERATING, DESIGN AND TEST CONDITIONS

THE OPERATING, DESIGN AND TEST CONDITIONS FOR THE TUNNEL PRESSURE SHELL AND ASSOCIATED SYSTEMS AND ELEMENTS ARE SUMMARIZED BELOW:

1. OPERATING MEDIUM

   ANY MIXTURE OF AIR AND NITROGEN

2. DESIGN TEMPERATURE RANGE

   MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT, EXCEPT IN THE REGION OF THE PLENUM BULKHEADS AND GATE VALVES INSIDE A 23-FOOT, 4-INCH DIAMETER, FOR WHICH THE TEMPERATURE RANGE IS MINUS 320 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

3. PRESSURE RANGE

	TUNNEL CONFIGURATION	OPERATING PRESSURE RANGE, PSIA	DESIGN PRESSURES PSID
A.	CONDITION I - PLENUM ISOLATION GATES OPEN AND TUNNEL OPERATING:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	PLENUM (PLENUM PRESSURE IS LIMITED TO .4 TO 1 TIMES THE REMAINDER OF THE TUNNEL CIRCUIT	3.3 to 130	A. 15 EXTERNAL B. 119 INTERNAL
	BULKHEAD		56 (EXTERNAL TO PLENUM)
B.	CONDITION II - PLENUM ISOLATION GATES OPEN AND TUNNEL SHUTDOWN:		
	ENTIRE TUNNEL CIRCUIT	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	BULKHEAD		0

C. CONDITION III - PLENUM ISOLATION GATES AND ACCESS DOORS CLOSED:		
TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
PLENUM (PLENUM OPERATING PRESSURE CAN EXCEED THE PRESSURE IN THE REMAINDER OF THE TUNNEL CIRCUIT BY 24 PSI, BUT DOES NOT EXCEED THE 130 PSIA MAXIMUM OPERATING PRESSURE)	0 to 130	A. 15 EXTERNAL B. 119 INTERNAL
BULKHEAD		A. 25 (INTERNAL TO PLENUM) B. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *C. 110.5 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

D. CONDITION IV - PLENUM ISOLATION GATES CLOSED AND ACCESS DOORS OPEN:		
TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
PLENUM	14.7	0
BULKHEAD		A. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *B. 110.5 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

4. HYDROSTATIC TEST DESIGN CONDITIONS

THE PRESSURE SHELL WAS DESIGNED FOR HYDROSTATIC TEST IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASME CODE, SECTION VIII, DIVISION 1. THE TEST PRESSURES SHALL BE AS FOLLOWS. PRESSURE SHELL TEMPERATURE SHALL BE EQUAL TO OR BELOW 100°F DURING HYDROSTATIC TESTS.

CONDITION (1) - MAXIMUM INTERNAL PRESSURE CONDITION FOR THE ENTIRE TUNNEL CIRCUIT

PH_1 = 1.5 (119) + HYDROSTATIC HEAD
= 178.5 PSI + HYDROSTATIC HEAD

CONDITION (2) - MAXIMUM DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

PH_2 = 1.5 (119) + HYDROSTATIC HEAD
= 178.5 + HYDROSTATIC HEAD

PH_2* = 1.5 (111.5) $\left(\frac{23.7}{22.2}\right)$ + HYDROSTATIC HEAD

= 178.5 + HYDROSTATIC HEAD

*TUNNEL OPERATION LIMITATIONS PRECLUDE PRESSURE DIFFERENTIALS ACROSS BULKHEADS IN EXCESS OF 110.5 PSI FOR BULKHEAD AND GATE TEMPERATURES IN EXCESS OF 150°F.

CONDITION (3) - MAXIMUM REVERSE DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

PH_3 = 1.5 (25) = 37.5 PSI

THE PRESSURE SHELL EXCEPT FOR THE PLENUM SHALL BE PRESSURIZED TO 141 PSIG. THE PLENUM SHALL BE PRESSURIZED TO 178.5 PSIG.

PRESSURE SHELL STRESS EVALUATION CRITERIA

THIS CRITERIA ESTABLISHES THE BASIS FOR ANALYSIS AND DESIGN OF THE PRESSURE SHELL SO IT WILL MEET OR EXCEED ALL OF THE REQUIREMENTS OF SECTION VIII, DIVISION 1 OF THE ASME BOILER AND PRESSURE VESSEL CODE AND CAN BE STAMPED WITH A DIVISION 1 "U" STAMP.

1. SECTION VIII, DIVISION 1, DIRECT APPLICATION

A. THE MAXIMUM ALLOWABLE STRESS (S)

S = 23.7 KSI (-320°F TO +150°F)

S = 22.2 KSI (-320°F TO +200°F)

(B) PRIMARY BENDING PLUS PRIMARY MEMBRANE STRESSES

THE LOCAL MEMBRANE STRESSES ARE NOT GENERALLY CONSIDERED IN SECTION VIII, DIVISION 1 DESIGNS. HOWEVER, FOR THE PURPOSE OF DESIGNING LOCAL REINFORCEMENT AT BRACKETS, RINGS OR PENETRATIONS NOT COVERED BY DESIGN BASED ON STRESS ANALYSIS, THE LOCAL SHELL MEMBRANE STRESS SHALL BE:

$$P_b + P_m \leq 1.5\ SE$$

NOTE: E IS JOINT EFFICIENCY

2. IN REGIONS OF THE PRESSURE SHELL WHERE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN (REF. U-2(g)), ADDITIONAL ANALYSES WERE PERFORMED UTILIZING THE GUIDELINES OF THE ASME CODE, SECTION VIII, DIVISION 2, APPENDIX 4, "DESIGN BASED ON STRESS ANALYSIS." THE BASIC STRESS CRITERIA FOR DIVISION 2 IS REPRESENTED IN FIGURE 4-130.1 AND RESTATED BELOW INDICATING ANY MODIFICATIONS OR EXCESS REQUIREMENTS APPLIED TO IT TO REMAIN WITHIN THE INTENT OF DIVISION 1 AND TO OBTAIN A DIVISION 1 STAMP.

A. GENERAL PRINCIPAL MEMBRANE STRESS

MAXIMUM ALLOWABLE STRESS

S = 23.7 KSI (-320°F TO +150°F)

S = 22.2 KSI (-320°F TO +200°F)

MAXIMUM ALLOWABLE STRESS INTENSITY

S_m = 31.7 KSI (-320°F TO +200°F)

B. PRIMARY GENERAL MEMBRANE STRESS INTENSITY

$$P_m \leq S_m$$

AND IN ORDER TO COMPLY WITH DIVISION 1, THE MAXIMUM PRINCIPAL MEMBRANE STRESS MUST BE:

$$P_m^* \leq S$$

NOTE: THE * IS USED TO DENOTE THAT MAXIMUM PRINCIPAL STRESSES ARE TO BE COMPUTED FOR THE GIVEN LOADING CONDITION. THE INTENT IS TO DETERMINE THE STRESSES WHICH REPRESENT THE HOOP STRESSES AND MERIDIONAL STRESSES WHICH ARE THE STRESSES USED IN DIVISION 1 COMPUTATIONS.

C. DESIGN LOADS, PRIMARY LOCAL MEMBRANE STRESS INTENSITY

$$P_L \leq 1.5\ S_m$$

NOTE: LOCAL MEMBRANE STRESS INTENSITY IS DEFINED IN ACCORDANCE WITH DIVISION 2, APPENDIX 4-112(i). THE TOTAL MERIDIONAL LENGTH IS CONSIDERED TO BE 1.0 $\sqrt{RT}$.

D. DESIGN LOADS, PRIMARY LOCAL MEMBRANE PLUS PRIMARY BENDING STRESS INTENSITY

$$P_L + P_b \leq 1.5\ S_m$$

E. OPERATING LOADS, PRIMARY PLUS SECONDARY STRESS INTENSITY

$$P_L + P_b + Q \leq 3\ S_m$$

F. COMMENT

BECAUSE OF THE LOW YIELD STRENGTH EXPECTED AT THE WELDS AS COMPARED TO THE YIELD STRENGTH OF THE PLATE, STRESS INTENSITIES COMPUTED IN (A), (B), (C), (D), OR (E) SHALL NOT EXCEED THE YIELD STRENGTH OF THE MATERIAL AT EITHER WELD OR PLATE LOCATIONS.

3. A FATIGUE ANALYSIS WAS CONDUCTED IN ACCORDANCE WITH SECTION VIII, DIVISION 2 WITHOUT MODIFICATION.

4. HYDROSTATIC TEST CONDITION DESIGN CONSIDERATIONS

A. PRESSURE SHELL

IN ACCORDANCE WITH DIVISION 1 OF THE ASME CODE, DESIGN ANALYSIS OF THE PRESSURE SHELL FOR THE HYDROSTATIC TEST CONDITION IS NOT REQUIRED. HOWEVER, IN ORDER TO PROVIDE A SATISFACTORY ENGINEERING DESIGN FOR THE PRESSURE SHELL THE FOLLOWING CRITERIA WAS USED:

(a) THE MAXIMUM GENERAL MEMBRANE STRESS PERPENDICULAR TO A WELD LINE WAS LIMITED TO THE LESSER OF:

$$P_m{}^* \leq 0.8 \text{ WELD YIELD STRESS}$$

OR

$$P_m{}^* \leq 0.5 \text{ WELD ULTIMATE STRESS}$$

(b) THE GENERAL PRINCIPAL MEMBRANE STRESS IN THE PLATE (NOT AT A WELD) WAS LIMITED TO THE LESSER OF:

$P_m * \leq 0.8$ PLATE YIELD STRESS

$P_m * \leq 0.5$ PLATE ULTIMATE STRESS

(*) THE STRESSES SATISFYING THIS CRITERIA ARE BASED ON MAXIMUM MEMBRANE STRESSES RATHER THAN INTENSITY CRITERIA.

NTF 9% Ni

FATIGUE ANALYSIS

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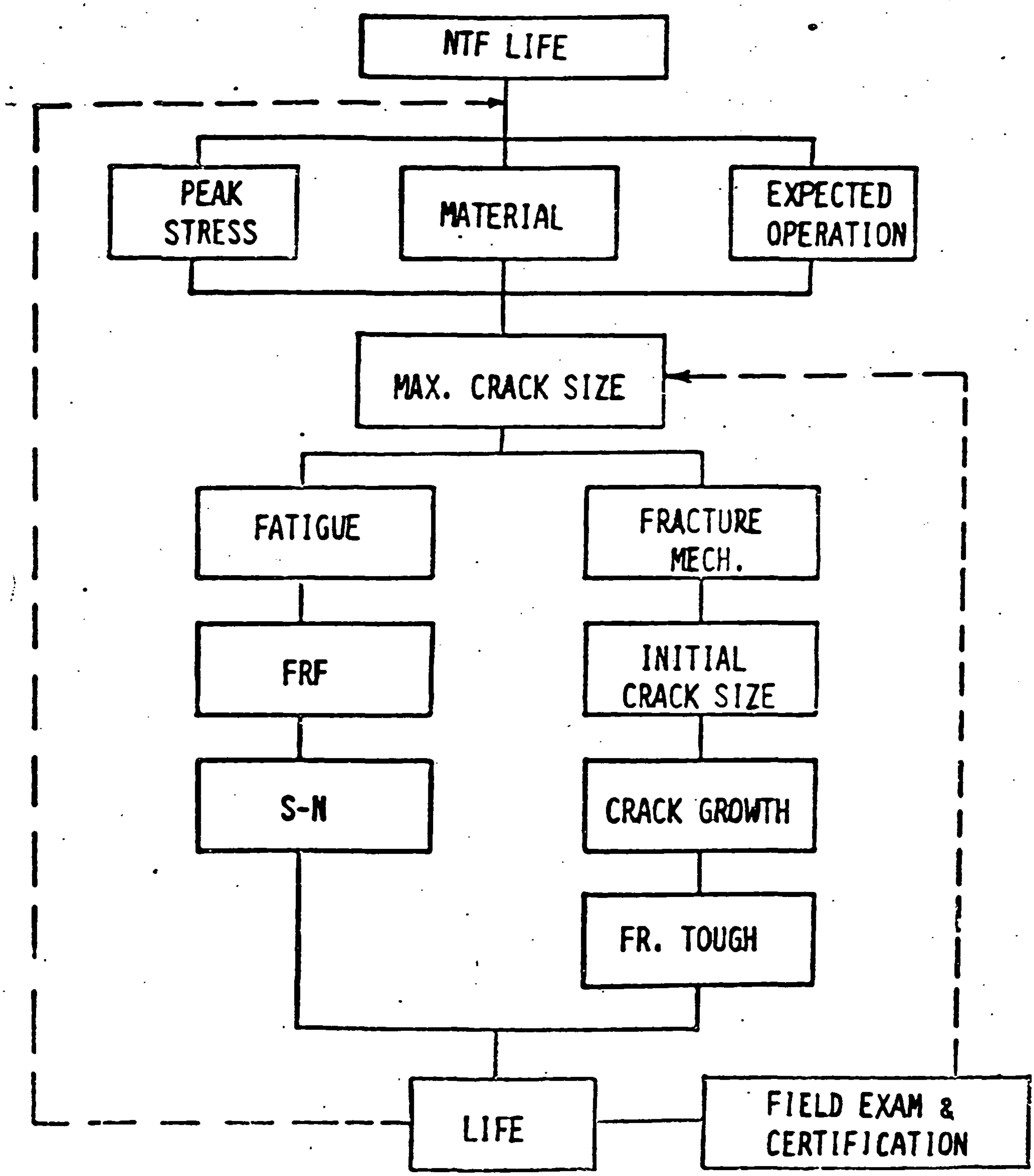
APPROACH



Taylor, J.T.; Lewis, P.E.; and Ramsey, J.W.,Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 197[illegible]

BASIS FOR LIFE CYCLE FAT. ESTIMATE

→ SHEAR WAVE ULTRASONIC TESTING

- BASIS FOR INSPECTION FREQUENCY FOR NTF 50 YEAR LIFE REQUIREMENT

  1. ASSUME .03" MAX. INITIAL FLAW SIZE (APPLY FATIGUE REDUCTION FACTOR)
  2. APPLY OTHER APPROPRIATE ASME CODE FATIGUE REDUCTION FACTORS
  3. USE NTF PROJECTED LIFE CYCLE HISTORY (PRESSURE AND TEMPERATURES)
  4. USE STRESSES FROM RESULTS OF NTF SHELL DESIGN
  5. DETERMINE FATIGUE LIFE FROM ASME CODE S-N CURVES

- NO SECONDARY INSPECTIONS DICTATED BY UT RESULTS OR AFTER REPAIR

- ROUTINE INSPECTIONS (I.E. VISUAL AND MONITORING OF SELECTED AREAS) ASSUMED TO BE INDEPENDENT OF MATERIAL SELECTION

- ASSUME VARIATIONS FROM FULL UT TECHNIQUE WILL AVERAGE OUT

- NO REPAIRS INCLUDED

- NO CRACKS → INFINITE LIFE EVERYWHERE

REFERENCES

1. ASME Boiler and Pressure Vessel Code. 1974 Edition.

2. Taylor, J.T.; Lewis, P.E.; and Ramsey, J.W.,Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 1974.

3. McCormick, Caleb W.: The NASTRAN User's Manual. NASA SP-222(01), June 1972.

4. Cohen, G. A.: User Document for Computer Programs for Ring-Stiffened Shell of Revolution. NASA CR-2086, March 1973.

5. ASME Boiler and Pressure Vessel Code. Section VIII, Division 2, 1974 Edition.

6. O'Donnel, W. J.; and Purdy, C.M.: The Fatigue Strength of Members Containing Cracks. Journal of Engineering for Industry, May 1964.

7. Ramsey, J.W.,Jr.: Stress Concentration Factors for Circular, Reinforced Penetrations in Pressurized Cylindrical Shells. Ph.D. Dissertation, University of Virginia, May 1975.

8. NTF Operational Profile by Dr. W. S. Lassiter, dated 12/22/75

9. NTF Operational Procedures for Minimizing Moisture Condensation by Dr. W. S. Lassiter, dated 1/16/76

10. Vibration Committee Memo by Dr. J. W. Ramsey, Jr., updated 1/18/76

NO

ASME CODE SECTION VIII

DIVISION 1 PROVIDES REQUIREMENTS FOR:

- DESIGN
- FABRICATION
- INSPECTION
- CERTIFICATION
- HYDRO 1.5 X DESIGN PRESSURE (36 KSI)
- PNEUMATIC 1.25 X DESIGN PRESSURE (30 KSI)

DIVISION 2 PROVIDES FOR IMPROVED QUALITY BY:

- MORE RESTRICTION ON CHOICE OF MATERIALS
- MORE PRECISE DESIGN PROCEDURES
- PROHIBITS SOME COMMON DESIGN DETAILS
- FABRICATION PROCEDURES ARE SPECIFICALLY DELINEATED
- MORE COMPLETE TESTING AND INSPECTION
- HYDRO 1.25 X DESIGN PRESSURE (40 KSI)
- PNEUMATIC 1.15 X DESIGN PRESSURE (36KSI)
- PROVIDES FOR FATIGUE LIFE DUE TO CYCLIC PRESSURE/TEMPERATURES

NTF NOW APPROACHES THIS WITH DIV. I ALLOWABLES

DESIGN (STRESS) CRITERIA

I. SECTION VIII - DIVISION I

PRESSURE: -15 TO 119 PSIG
TEMPERATURE: -320 TO 150°F

II. MATERIALS

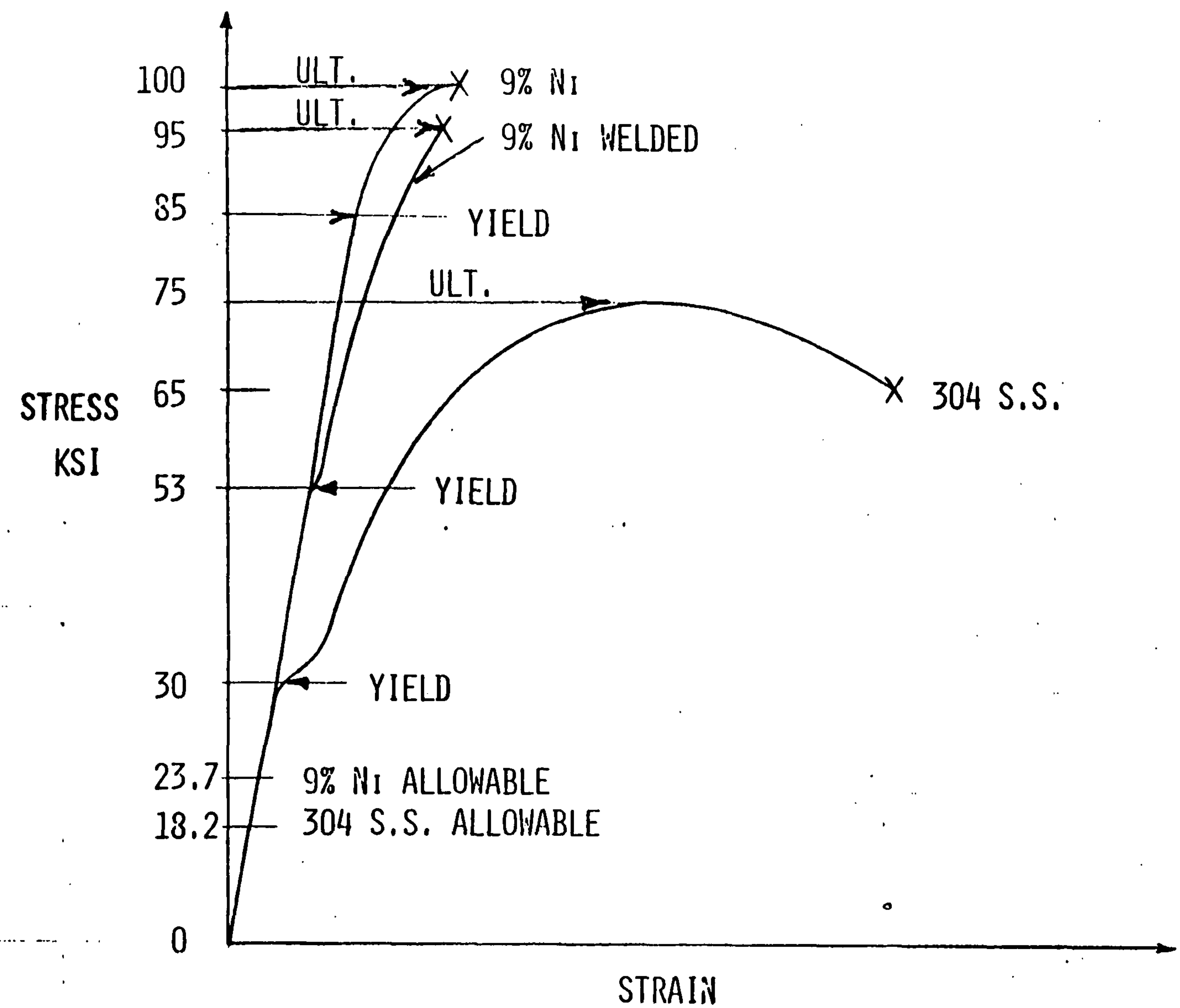
	9% Ni STEEL
PLATE	SA-553-I
FORGINGS	SA-552
WELD CONSUMABLES	INCO-WELD A,B
	INCONEL 82

III. MATERIAL PROPERTIES (2" PLATE)

YIELD STRENGTH - PLATE OR FORGING	85 KSI
WELD METAL (MIN.)	52.5 KSI
TENSILE STRENGTH - PLATE OR FORGING	100 KSI
WELD METAL (MIN.)	95 KSI

IV. ALLOWABLE STRESSES (150°F)

SECTION VIII DIV. I	23.7 KSI
SECTION VIII DIV. II	31.7 KSI



STRESS-STRAIN RELATIONSHIPS

FOR

NTF SHELL MATERIALS

-7-

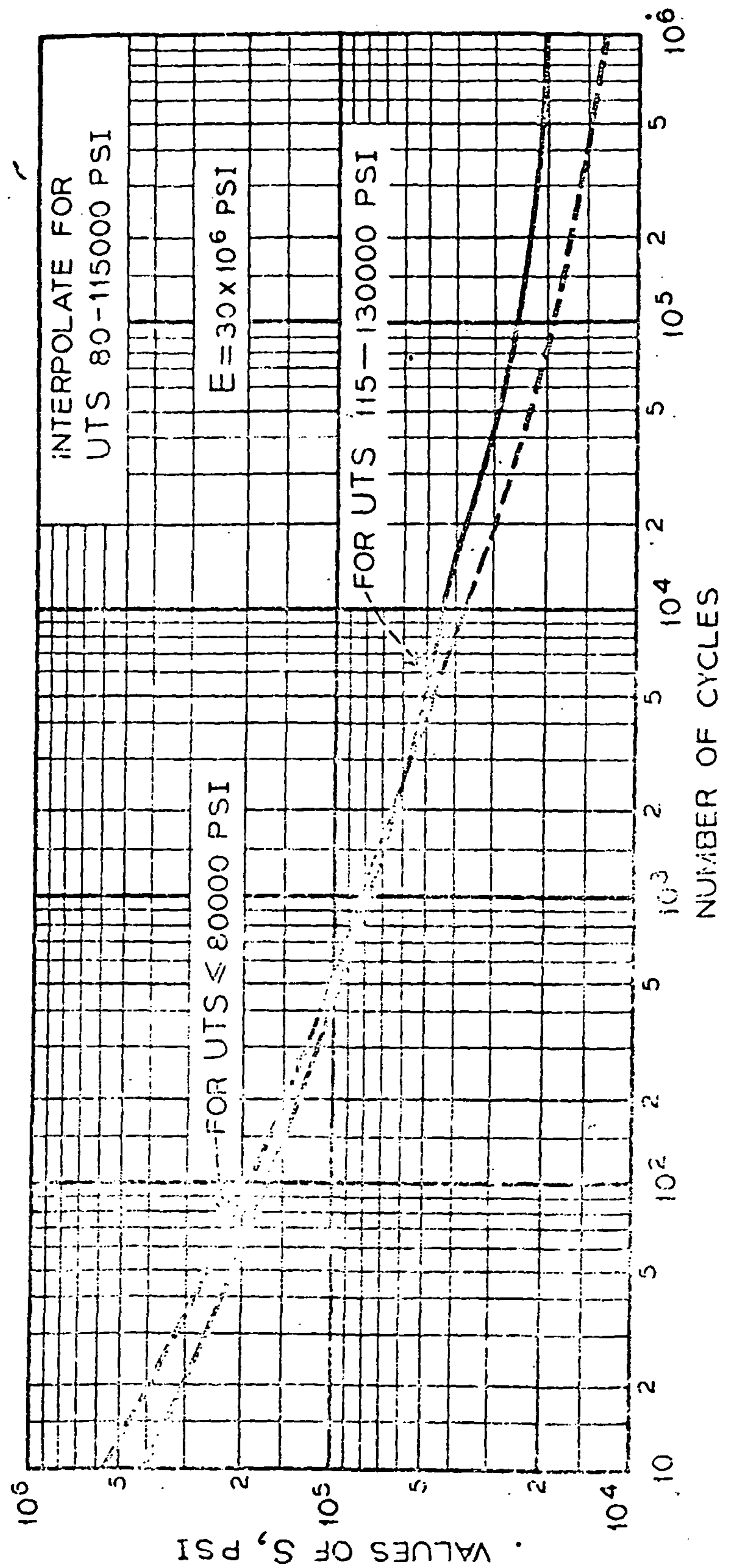


FIG. 5-110.1 DESIGN FATIGUE CURVES FOR CARBON, LOW-ALLOY, SERIES 4XX, HIGH-ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 700 F

NTF CRYOGENIC DUTY CYCLES

CASE	PROGRAM	POLARS PER PROGRAM	MIX FACTOR	PROGRAMS PER YEAR	POLARS PER YEAR
I-A	CRUISE A/C	160	30	15	2400
II	MANEUVERING A/C	200	30	12	2400
III	Mi, R, Q EFFECTS	100	40	30	3200
			TOTAL		8000

FIGURE 1

NTF OPERATIONAL PROFILE

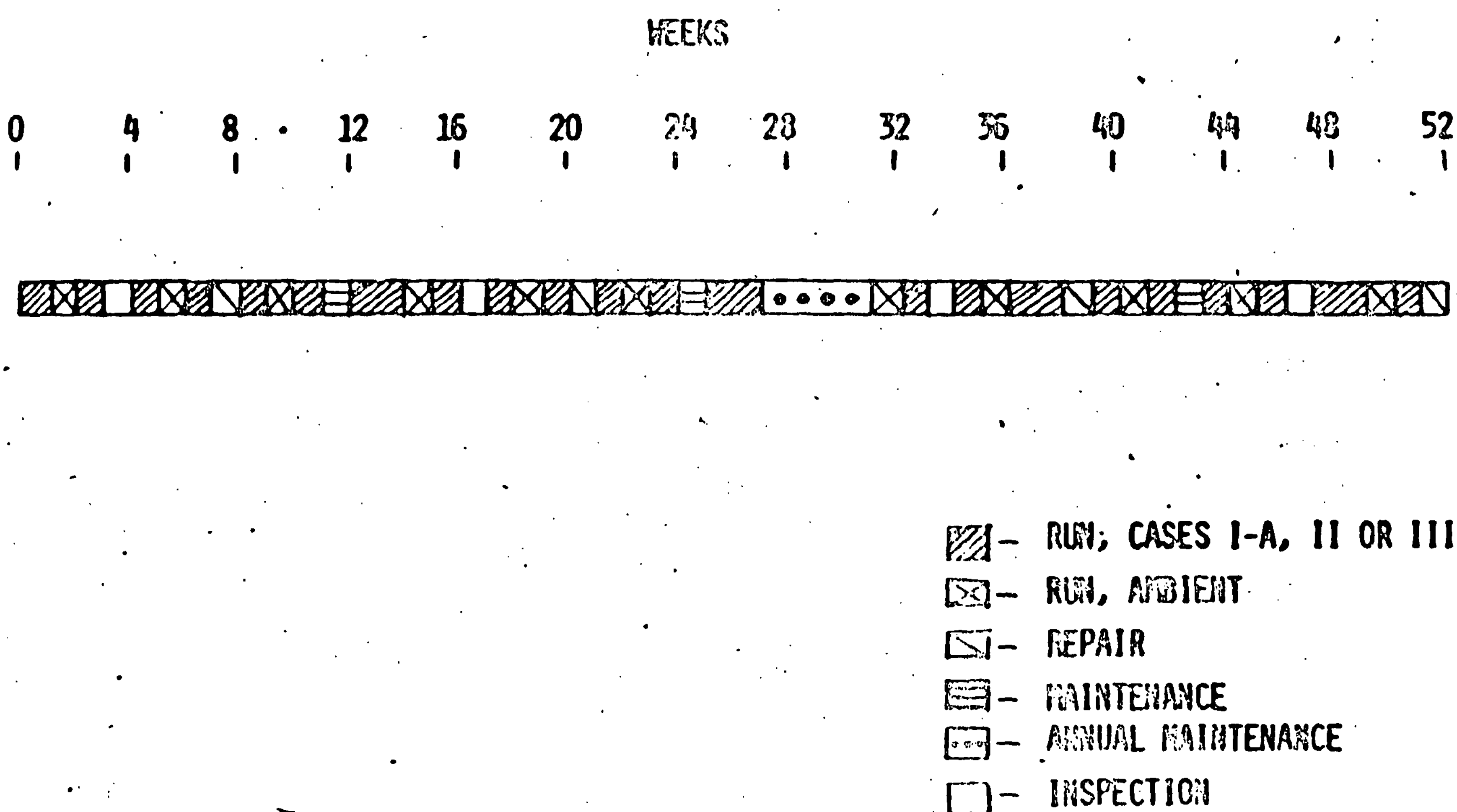


FIGURE 2

ASSUMPTIONS

- ENTIRE TUNNEL BROUGHT TO ATMOSPHERE ON FRIDAY FOR WEEKLY INSPECTION - REMAINS AT ATMOSHPERE (T~70°F) OVER WEEKEND
- THREE SHIFTS DURING WEEK AS REQUIRED - NONE ON WEEKEND
- 12 HOURS BETWEEN PROGRAMS FOR MODEL CHANGE - TEST SECTION OPEN FOR CHANGES.
- PERIODIC REPAIR, MAINTENANCE AND INSPECTION DURATION OF ONE WEEK EACH.
- ONE YEARLY 4-WEEK PERIOD FOR MAINTENANCE, THOROUGH INSPECTION.

FIGURE 3

NTF WEEKLY OPERATIONAL SCHEDULE

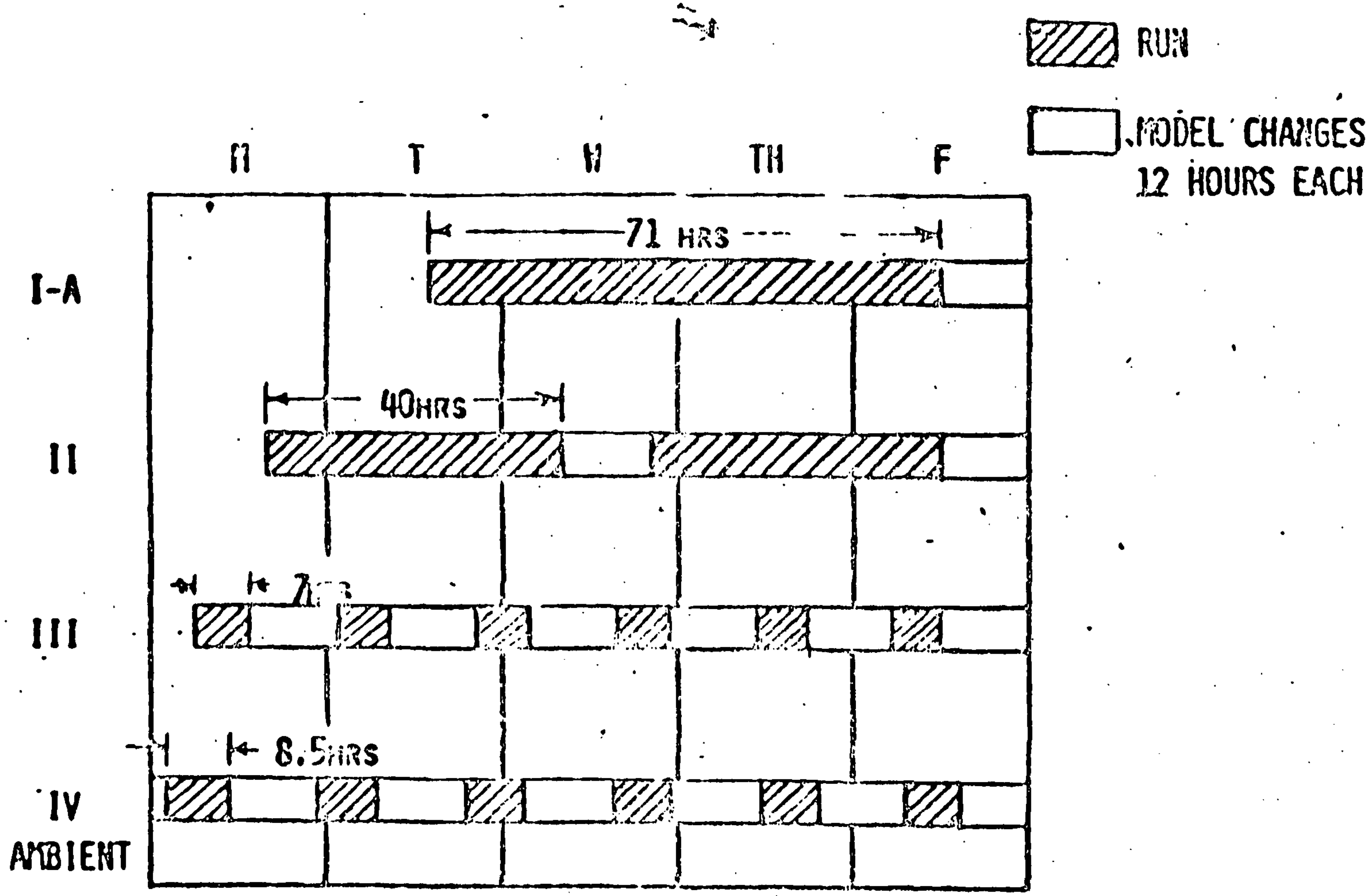
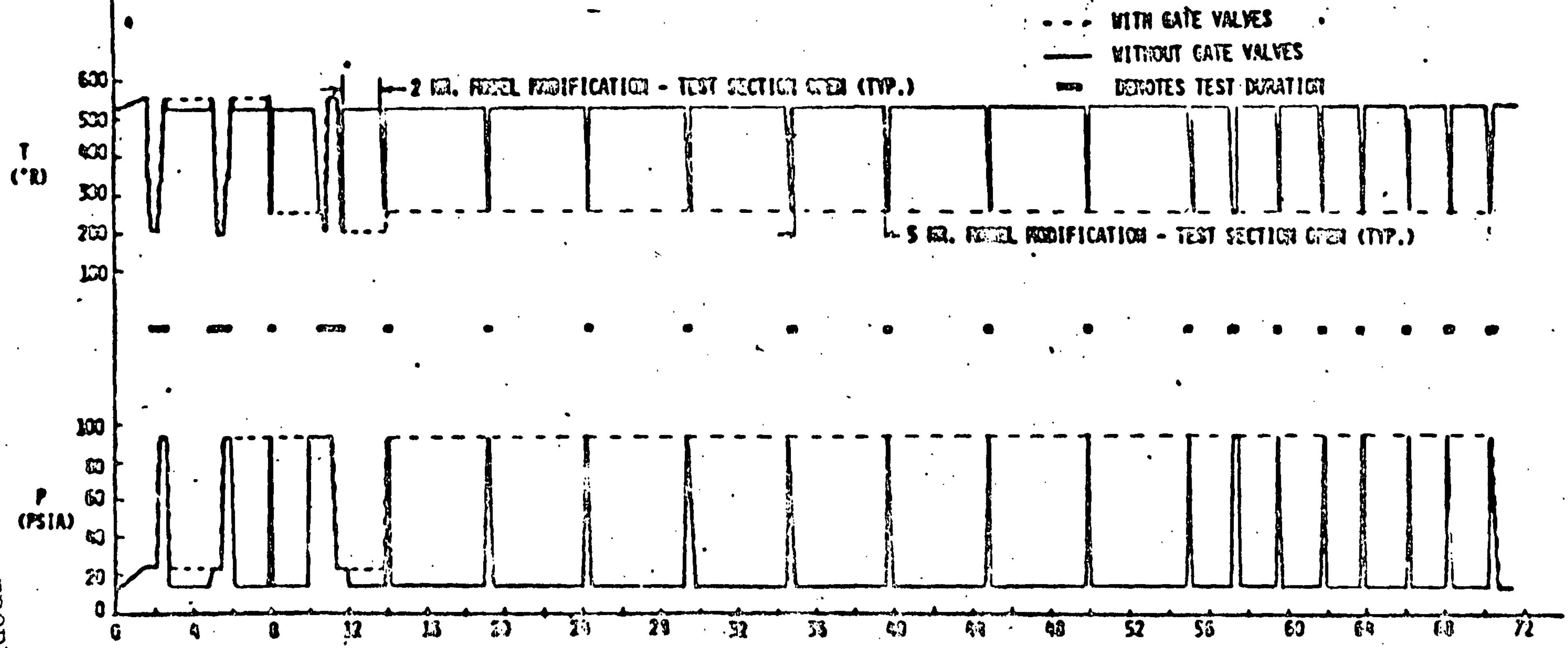


FIGURE 4

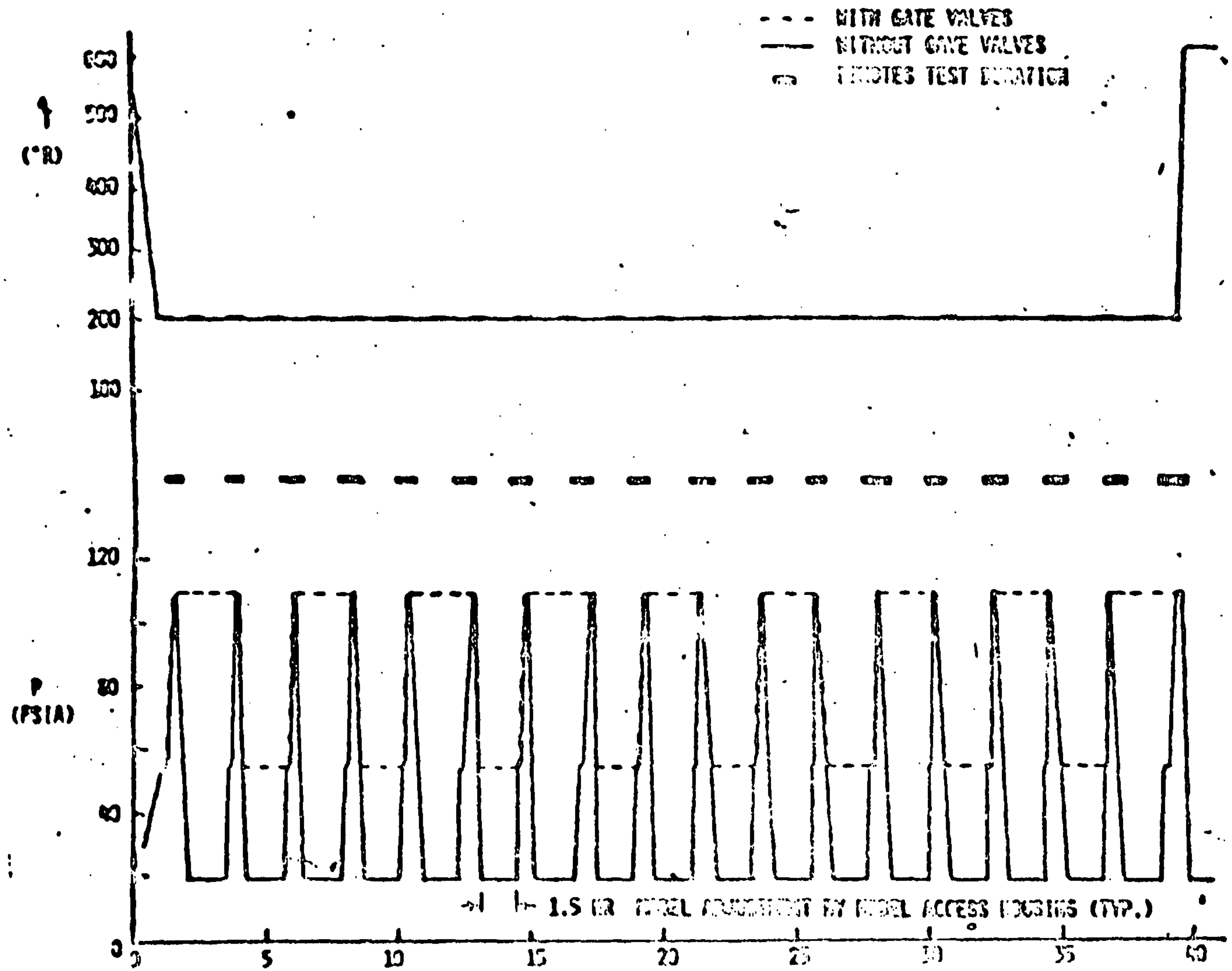
CASE I-A - FCT
PRESSURE AND TEMPERATURE PROFILE



NOTE: LO_2 SHUT OFF DURING MODEL MODIFICATIONS-TEMPERATURE OF TUNNEL INCREASES DUE TO HEAT LEAKS

FIGURE 5

CASE II - PRESSURIZED AIRCRAFT
PRESSURE AND TEMPERATURE PROFILE



NOTE: LN_2 SHUT OFF DURING PANEL ADJUSTMENTS-TEMPERATURE OF TUNNEL INCREASES DUE TO HEAT LEAKS

FIGURE 6

CASE III - BASIC RESEARCH
PRESSURE PROFILE

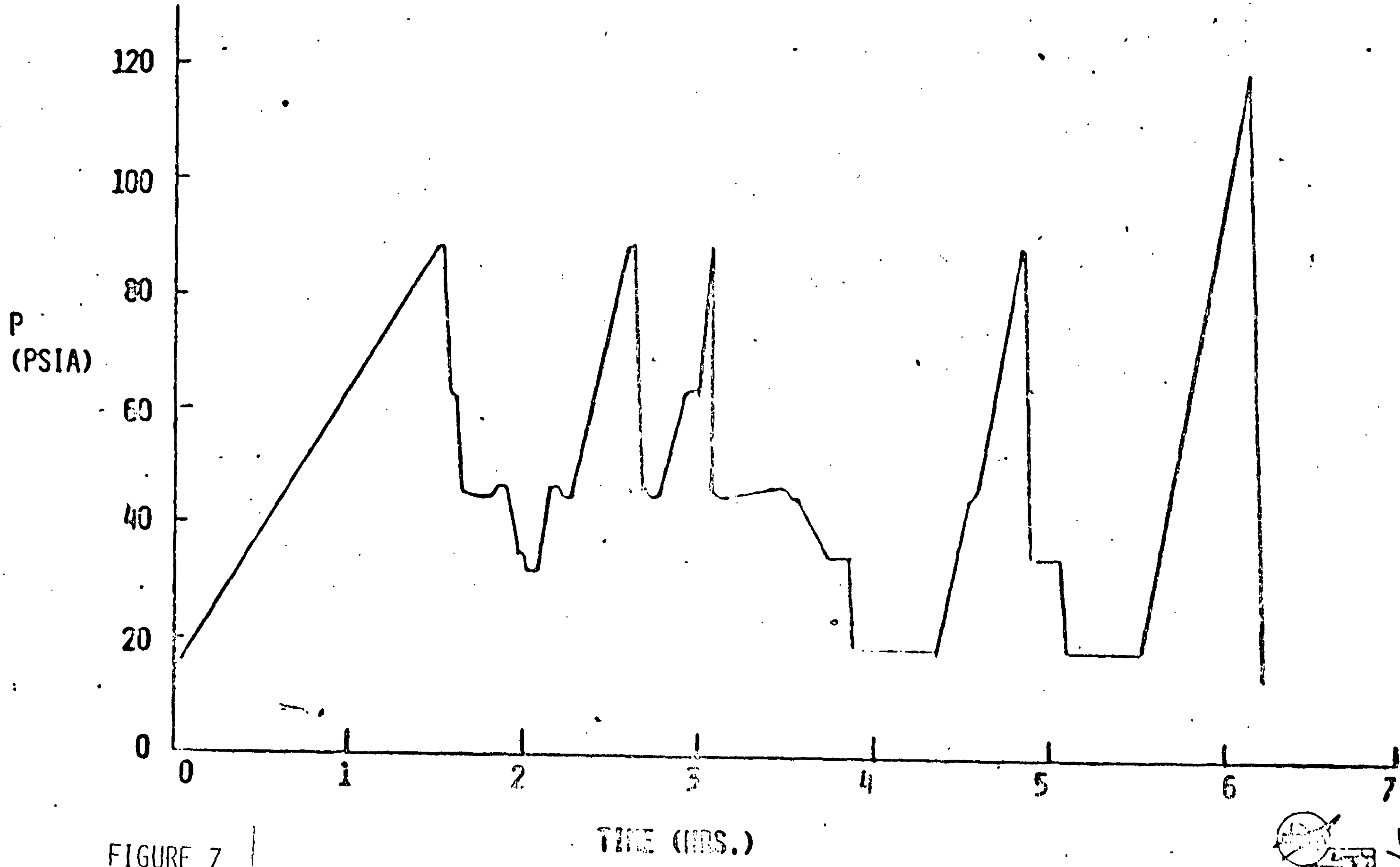


FIGURE 7

CASE III - BASIC RESEARCH TEMPERATURE PROFILE

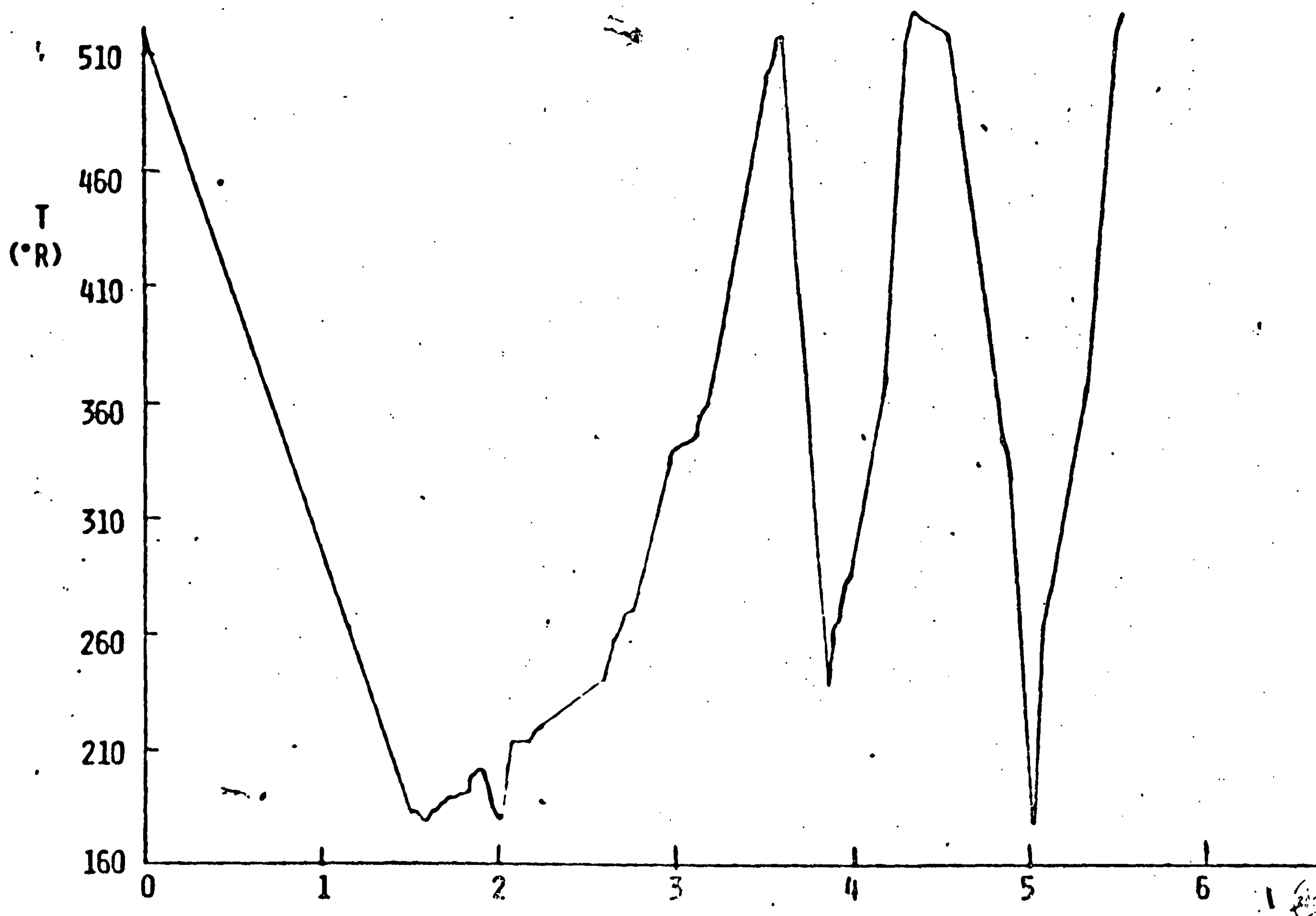


FIGURE 8

CASE IV - AMBIENT MODE

PRESSURE AND TEMPERATURE PROFILES

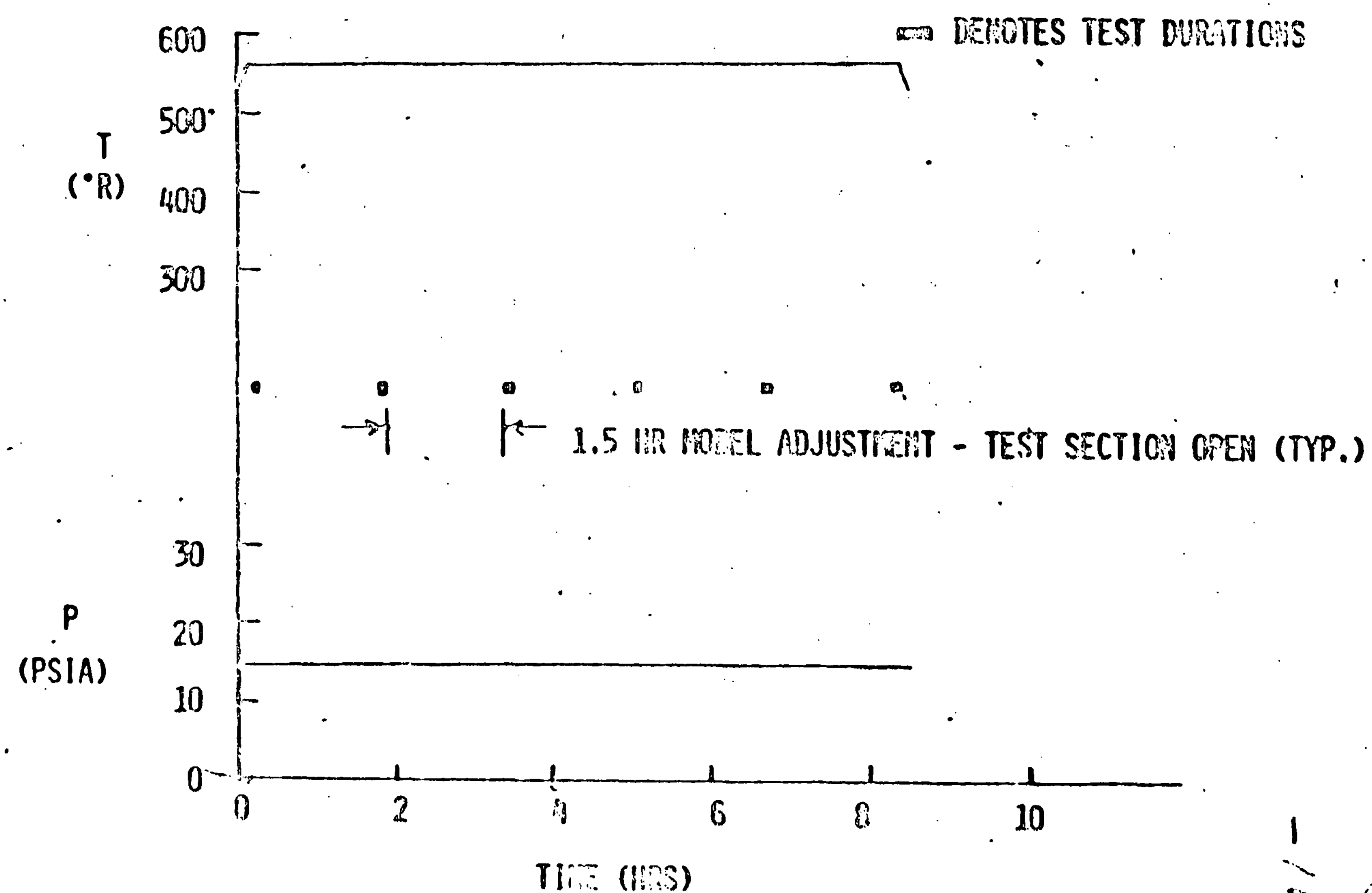


FIGURE 9

OPERATIONAL PROCEDURES

FOR

MINIMIZING MOISTURE IN THE NTF

INDEX

CASE A - CONSTRUCTION PHASE

CASE B - INITIAL STARTUP AND COOLDOWN

CASE C - CRYOGENIC CONDITION → AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS → CRYOGENIC CONDITION

1. Weekend, annual, and as required inspections.
2. Repair and maintenance as required.
3. Ambient test following a cryogenic test.
4. Cryogenic tests.

CASE D - CRYOGENIC CONDITION → AMBIENT CONDITION FOR TEST SECTION AND PLENUM ACCESS ONLY → CRYOGENIC CONDITION

1. Model modifications/changes during research test programs.
2. Inspection, repair, and maintenance of test section, plenum, and model support apparatus as required.

CASE E - CRYOGENIC CONDITION → MODEL ACCESS THROUGH MODEL ACCESS HOUSING → CRYOGENIC CONDITION

1. Model adjustments during research test program.
2. Model inspection, repair, and maintenance as required.

CASE F - AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS → AMBIENT TEST → AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS

1. Ambient tests.
2. Model change/modification/adjustment during research test programs.
3. Inspection, repair, and maintenance as required.

NOTE: (TBD) indicates that a number is to be determined.

NOTE: Many of these procedures imply manual operations but in reality will be automatic control operations.

DESCRIPTION OF PROCEDURES

CASE A - CONSTRUCTION PHASE

During the construction and installation phases it is highly improbable that the tunnel shell interior and the insulation system can be completely protected from humid environments. It is recommended that once the shell is complete and installation of the insulation commences, all tunnel shell openings to the outside environment be closed and work occur through only those accesses exposed to the environment inside the building (such as the test section) which is conditioned by air conditioning and heating. It is recommended that relative humidity of this conditioned environment not exceed about 50 percent. This will prevent the insulation, upon being installed, from experiencing the very high relative humidities often occurring in the Tidewater area.

CASE B - INITIAL STARTUP AND COOLDOWN

1. Close and secure all tunnel accesses (including exhaust valve).

2. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.

3. Close vacuum system valve and backfill tunnel to about one atmosphere with dry heated air.

4. Repeat steps 2 and 3 until tunnel dewpoint is down to about 435°R. During this time maintain tunnel stream temperature above dewpoint temperature.

5. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.

6. Close vacuum system valve.

7. Start fan and operate at minimum speed.

8. Open LN_2 valve and inject LN_2 into tunnel at low mass flow rate.

9. When pressure increases to about one atmosphere, open exhaust valve to maintain constant pressure in order to purge system.

10. Never allow stream temperature to exceed 635°R.

11. Purge system by maintaining constant pressure for at least ___(TBD) hours with a stream dewpoint temperature of below 420°R.

12. Maintain stream temperature above dewpoint of stream until dewpoint temperature decreases below 380°R and stream oxygen level less than ___(TBD) percent by volume.

13. Attain test conditions by controlling LN_2 flow rate, fan speed and pressure.

CASE C - CRYOGENIC CONDITION ⟶ AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS ⟶ CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN_2 inlet valve.

2. Operate fan such that stream is heated and maintained at about ___(TBD) °R for at least _____(TBD) hours to warm tunnel interior. Maintain tunnel pressure at about one atmosphere.

3. If at end of a week, shut off fan and allow tunnel to warm up over weekend without opening. Assure that exhaust valve is closed.

4. If not at end of week, continue heating tunnel as in step 2 until liner and insulation considered sufficiently warm for opening tunnel.

5. Shut off fan and close exhaust valve.

6. Open vacuum system valve and evacuate tunnel to 8.3 ~~(TBD)~~ psia with vacuum system.

7. Close vacuum system valve and repressurize tunnel to about one atmosphere with dry, heated air.

8. Repeat steps 6 and 7 until oxygen level in tunnel is at least 20 percent by volume.

9. Open doors to tunnel and perform inspection, repair and maintenance as required. During this time maintain oxygen level at 20 percent or above by volume and air temperature above 500 °R by maintaining a positive pressure in the tunnel with dry, heated air.

10. During any time the fan is not turning and the tunnel contains dry, heated air, maintain a positive pressure in the tunnel with the dry air.

II. AMBIENT TO CRYO

1. Close and secure all tunnel accesses.

2. Close dry air inlet valve.

3. Open valve to vacuum system and evacuate tunnel to about 3 psia. Close vacuum system valve.

4. Start fan and operate at minimum speed.

5. Open LN_2 inlet valve and inlet LN_2 at low mass flow rate.

6. Open exhaust valve to maintain pressure at about 15 psia.

7. Maintain stream temperature above dewpoint of stream until dewpoint of stream decreases below 380°R and oxygen level decreases below ___(TBD) percent by volume.

8. Never allow stream temperature to exceed 635°R.

9. Attain test conditions by controlling LN_2 mass flow rate, fan speed, and pressure.

CASE D - CRYOGENIC CONDITION ⟶ AMBIENT CONDITION FOR TEST SECTION AND PLENUM ACCESS ONLY ⟶ CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN_2 inlet valve.

2. Close exhaust valve.

3. Shut off fan.

4. Close and secure gate valves.

5. Relieve plenum and test section of pressure to one atmosphere through plenum pressure control valve.

6. Purge plenum and test section with ___(TBD) lbs per second mass flow of dry, heated air until oxygen content level reaches at least 20 percent by volume and until metal surfaces to be contacted warm sufficiently, depending on work to be performed.

7. Adjust dry air inlet mass flow rate as required in order to maintain a ___(TBD) psia positive pressure, an air temperature of above 500°R, and an oxygen level of at least 20 percent by volume while working in the test section and plenum volume.

8. Perform work as required.

II. AMBIENT TO CRYO

1. Close and secure test section and plenum doors.

2. Close dry air exit and inlet valves.

3. Open gate valve bypass valve and pressurize plenum and test section with cold GN_2 from tunnel.

4. Open gate valves.

5. Start fan and slowly increase speed.

6. Attain test conditions by controlling LN_2 flow rate, fan speed, and pressure.

CASE E - CRYOGENIC CONDITION → MODEL ACCESS VIA MODEL ACCESS HOUSING → CRYOGENIC CONDITION

I. CRYO TO MODEL ACCESS HOUSING INSERTION

1. Close LN_2 inlet valve.
2. Close exhaust valve.
3. Shut off fan.
4. Close and secure gate valves.
5. Relieve plenum and test section pressure to one atmosphere through plenum pressure control valve.
6. Condition model access housing tubes with warm, dry air.
7. Open plenum and test section doors.
8. Insert and seal model access housing tubes.
9. Circulate warm, dry air through housing such that oxygen level is maintained to at least 20 percent by volume and temperature maintained above 500°R.
10. Perform model adjustment/inspection as required.

II. MODEL ADJUSTMENT/INSPECTION TO CRYO

1. Close doors to housing such that dry air environment in housing is maintained once personnel are evacuated.
2. Retract housing tubes.
3. Close and secure test section and plenum doors.
4. Open gate valve bypass valve and pressurize plenum and test section with cold GN_2 from tunnel.
5. Open gate valves.
6. Start fan and slowly increase speed.
7. Attain test conditions by controlling LN_2 flow rate, fan speed, and pressure.

CASE F - AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS ⟶ AMBIENT TEST ⟶ AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS

I. AMBIENT CONDITION TO AMBIENT TEST

1. Close and secure all tunnel accesses.

2. Close dry air inlet valve.

3. Start fan.

4. Attain test conditions by controlling fan speed, cooling coil water flow, and pressure.

5. Perform test.

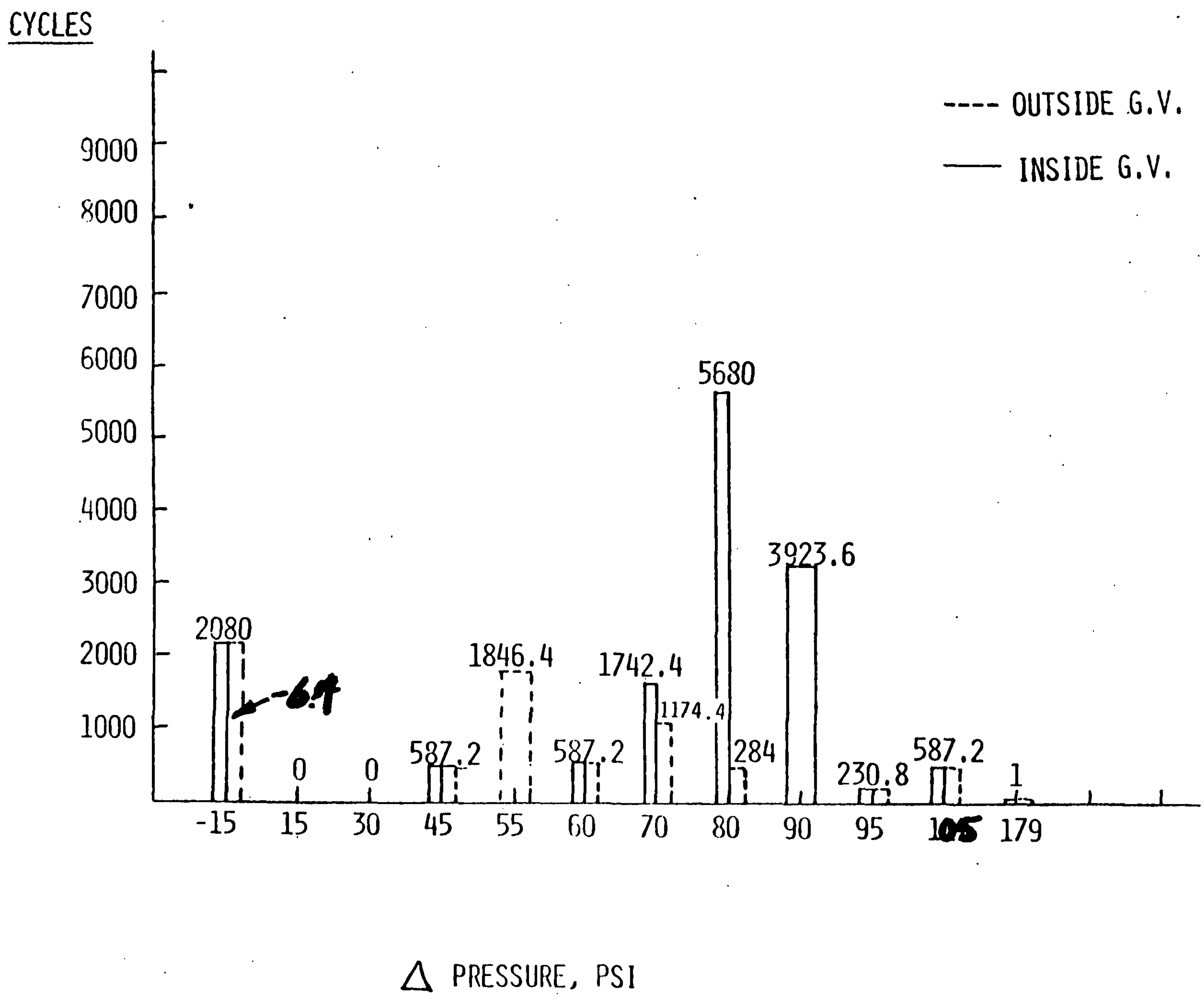
II. AMBIENT TEST TO AMBIENT CONDITION

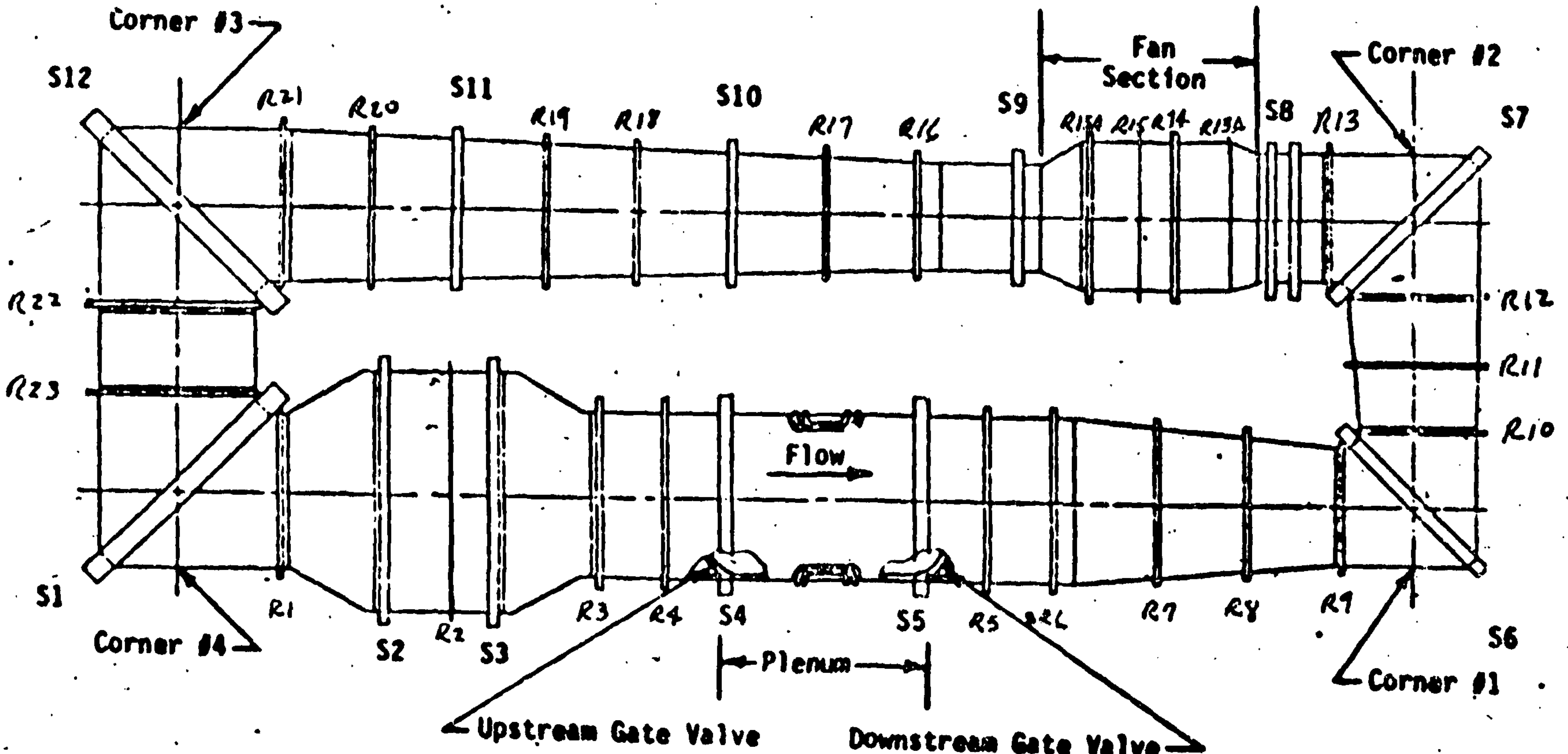
1. Shut off fan.

2. Open dry air inlet valve to maintain positive pressure of ___(TBD) psia in tunnel.

3. Before entering tunnel, assure that oxygen content is at least 20 percent by volume and temperature above 500°R.

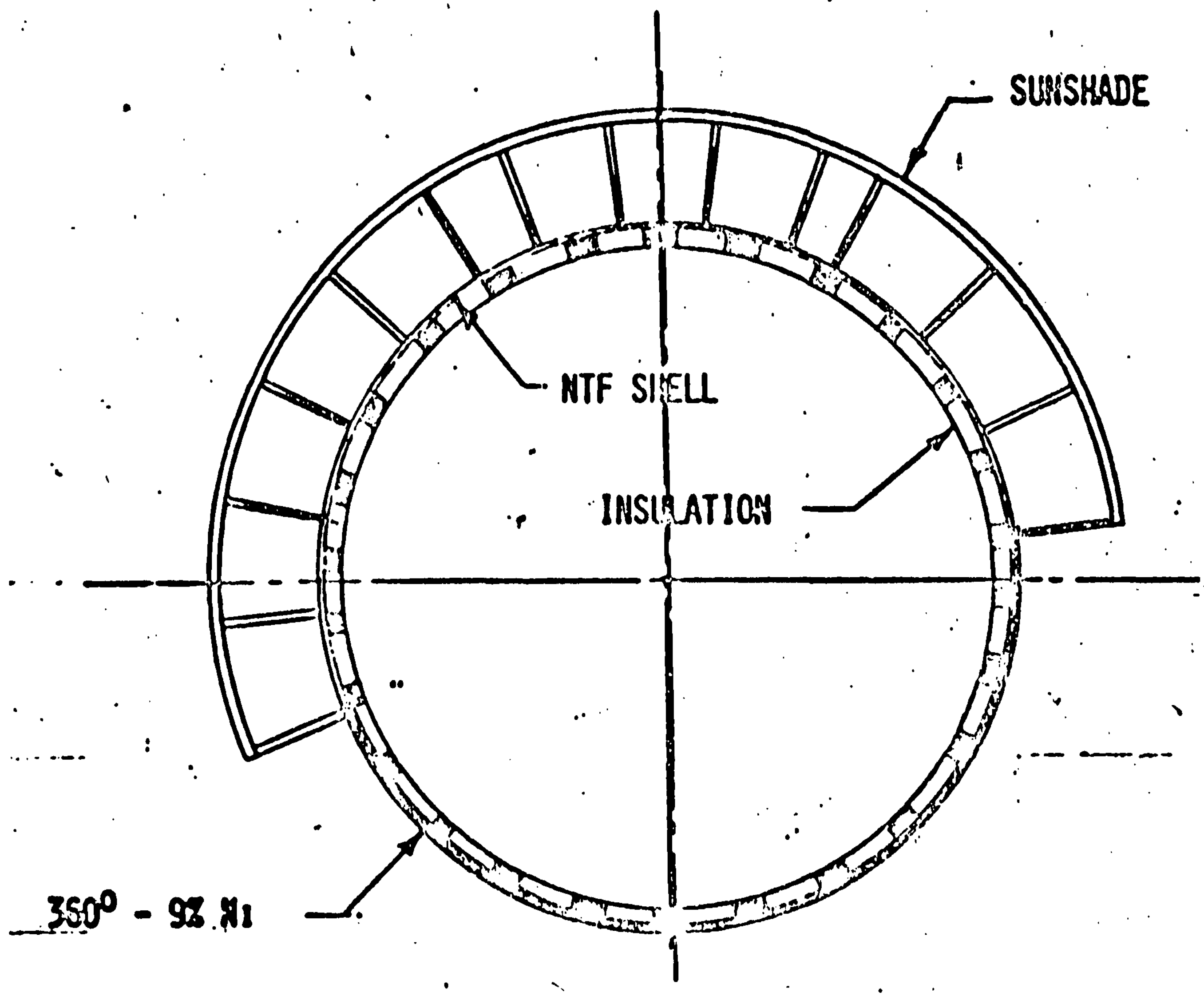
20 YEAR PRESSURE CYCLIC PROJECTION OF NTF





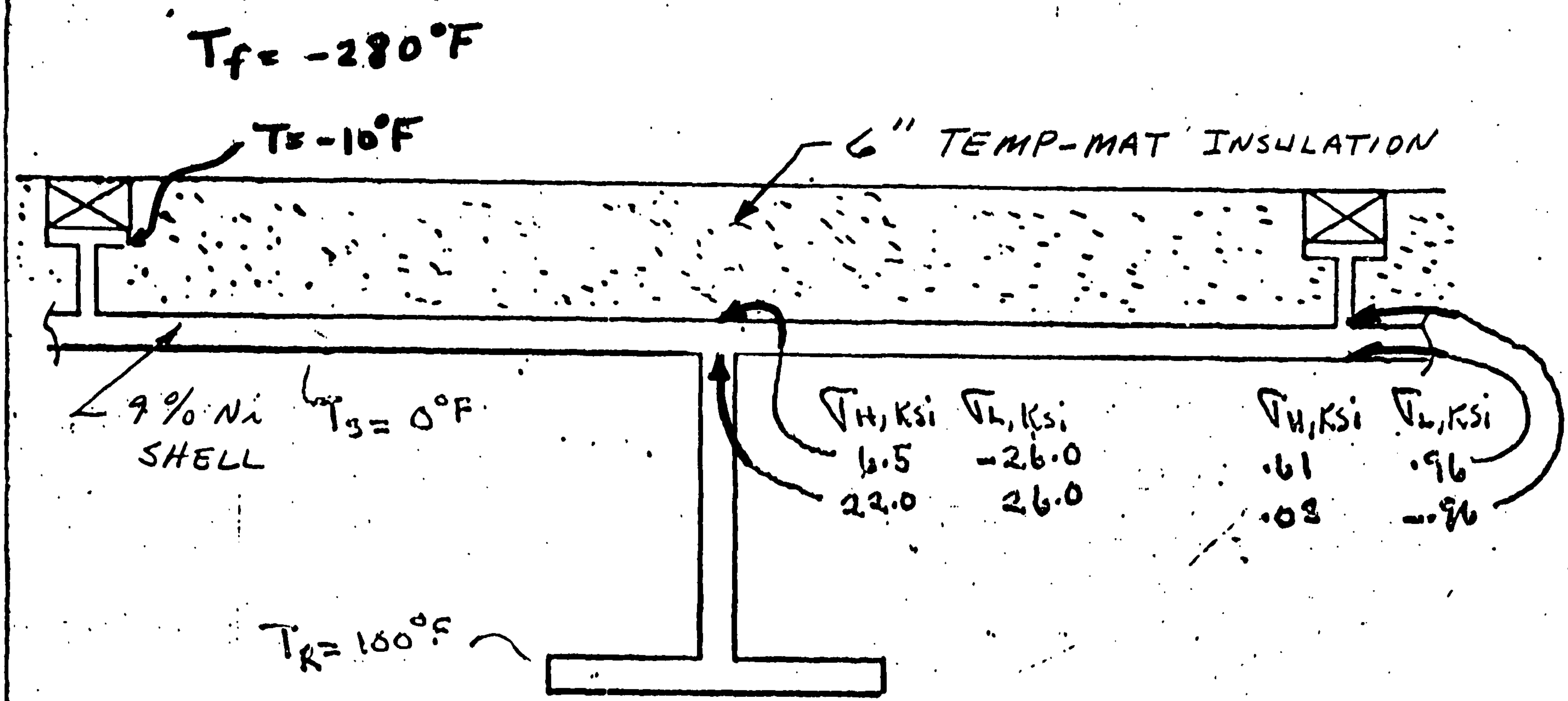
NTF PRESSURE SHELL

PLAN VIEW



EXTERIOR SURFACE PAINTING FOR NTF-SHELL

THERMAL PROFILE



T_a = 100°F

NOTE: The new Baseline Insulation is a closed cell material - "Rohacell," which results in reducing the above stresses by a factor of 10.0.

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9% NICKEL LIFE CYCLE for a "Rohacell" Insulation

DESIGNATION	FATIGUE LIFE (YRS)	INSPECTION SCHEDULE (YEARS) 5	10	15	20	25	30	35	40	45	50
S 1	20				I				I		
R 1	27					I					
S 2	13		I			I			I		
S 3	16			I			I			I	
R 3	38							I			
S 4	26					I					
S 5	26					I					
R 6	38							I			
R 9	38							I			
S 6	20				I				I		
R 10	38							I			
R 12	38							I			
S 7	20				I				I		
S 8	38							I			
R 13A	24				I				I		
R 15A	24				I				I		
S 9	38							I			
R 21	38							I			
S 12	20				I				I		
9 x 12 DOOR	35							I			
DOOR REINF. (FRAME	35							I			
FRAME RING	35							I			
FORGING JOINT	35							I			
GUSSETS	35							I			
BULKHEAD FLANGE[1]	26					I					
FLANGE[2]	26					I					
MID FLANGE	26					I					
OUTER FLANGE	26					I					
OUTER RINGS	50+										
INTERIOR BRACKETS INSULATION TABS	50+										
PENETRATIONS	50+										
PLENUM INT. TABS & INTERIOR BRACKETS	30						I				
LONGITUDINAL WELDS	50+										
CIRCUM. WELDS	50+										

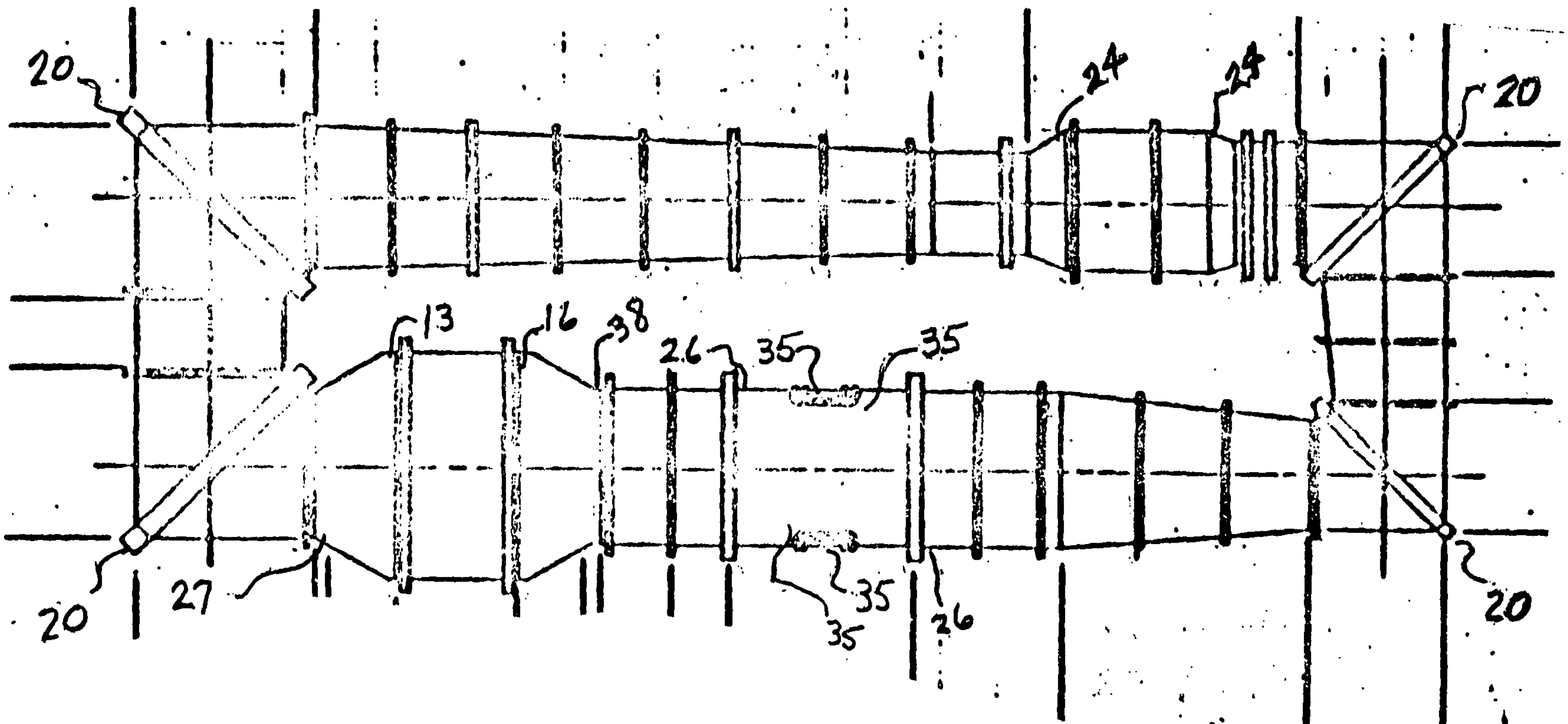
INTERNAL INSULATION

HTF PRESSURE SHELL

9% Ni

<50 YEARS (AS NOTED)

>50 YEARS OTHER



NTF QC PROGRAM FOR CONSTRUCTION — ASME CODE EQUIVALENT SECT. 8 DIV. 2 & SECT. 3

- NEAR 100% X-RAY PRESSURE WELDS
- DYE PENETRANT WELD PASSES
- 100% ULTRASONIC EXAMINATION OF PLATES
- WELDING PER ASME SECTION 9
- NONDESTRUCTIVE EXAMINATION BY ASME SECT. 5 AND 11
- CLOSE NASA/LaRC INSPECTION CONTROL
- ALL SIGNIFICANT DEFECTS REPAIRED