PRESSURE VESSEL AND CLOSURE

DESIGN STATUS REVIEW

AEROGEO NUCLEAR SYSTEMS COMPANY
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REVIEW SCOPE

ACCOMPLISHMENTS
UNRESOLVED DESIGN ITEMS
DESIGN REQUIREMENTS
PVCS DESIGN
MATERIALS
PVCS TIME-POSITION OF REVIEW
PVCS RELIABILITY
TASKS TO BE COMPLETED BEFORE DDR
SUMMARY STATUS
PVCS DESIGN STATUS REVIEW

ACCOMPLISHMENTS
ACCOMPLISHMENTS

PRELIMINARY ISSUE OF DATA ITEM E-105 COMPLETED

PRELIMINARY ISSUE OF PVCS FMA COMPLETED

DESIGN AND LAYOUT OF A PVCS FOR 7075-T73 CYLINDER AND 6061-T6 CLOSURE (LAYOUT NO. 1138808)

NUCLEAR ANALYSIS OF LAYOUT NO. 1138808, FOR THE OCTOBER TRANSMITTAL OF THE NSS MODEL

THERMAL ANALYSIS OF THE 400C ENGINE PVCS - COMPLETED AND PUBLISHED IN DATA ITEM S-031

UPDATE OF THERMAL ANALYSIS FOR 1138808 CONFIGURATION AND NEW NUCLEAR HEATING RATES

INTERMEDIATE STRESS ANALYSIS OF 400C ENGINE PVCS, COMPLETED AND PUBLISHED IN DATA ITEM S-036

UPDATE OF INTERMEDIATE STRESS ANALYSIS FOR 1138808 CONFIGURATION

DESIGN OF NCX PRESSURE VESSEL CLOSURE COMPLETED

DESIGN OF PRECISION CASTING MOLD FOR 3-D PHOTOELASTIC TEST OF PVCS CLOSURE COMPLETED

PRELIMINARY ISSUE OF TEST PLAN FOR 3-D PHOTOELASTIC TEST COMPLETED
PVCS DESIGN STATUS REVIEW

UNRESOLVED DESIGN ITEMS
<table>
<thead>
<tr>
<th>UNRESOLVED PROBLEMS</th>
<th>POTENTIAL SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRESS ANALYSIS OF A CLOSURE WITH 30 OFF CENTER PORTS CANNOT BE PREFORMED BY CONVENTIONAL METHODS</td>
<td>A 3-D PHOTOELASTIC TEST PROGRAM OF THE CLOSURE IS PLANNED FOR CY 71</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>ENGINE SYSTEM CHANGES CAUSING SUBSEQUENT STATE POINT DATA AND INTERFACE CHANGES</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>STATUS</strong></td>
<td></td>
</tr>
<tr>
<td>THE DESIGN OF A PRECISION CASTING MOLD FOR A 1/4 SCALE MODEL OF THE 1138808 CLOSURE HAS BEEN COMPLETED</td>
<td></td>
</tr>
<tr>
<td>TEST IS SCHEDULED FOR COMPLETION 7-1-71</td>
<td></td>
</tr>
<tr>
<td>INCORPORATION OF TEST RESULTS INTO CLOSURE STRESS ANALYSIS IS SCHEDULED FOR THE LAST QUARTER OF CY 71</td>
<td></td>
</tr>
<tr>
<td>FREEZE ENGINE DESIGN AND INTERFACE CONTROL DRAWINGS</td>
<td></td>
</tr>
</tbody>
</table>
UNRESOLVED DESIGN ITEMS

<table>
<thead>
<tr>
<th>UNRESOLVED PROBLEMS</th>
<th>POTENTIAL SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRELIMINARY ANALYSIS INDICATE THAT THE PVCS TEMPERATURE WILL REACH APPROXIMATELY 600°F, DURING COAST, DUE TO SOLAR HEATING. THE MAXIMUM TEMPERATURE THE PVCS MATERIAL CAN WITHSTAND WITHOUT HEAT TREATMENT DEGRADATION IS 275°F</td>
<td>PROVIDE A THERMAL COATING ON THE PVCS EXTERIOR SURFACE</td>
</tr>
</tbody>
</table>

**STATUS**

THERMAL COATINGS ARE BEING INVESTIGATED BY PROJECT 187 DURING CY 71

MORE DETAILED ANALYSES OF SPACE ENVIRONMENT ARE PLANNED FOR CY 72

PRELIMINARY ANALYSIS INDICATE THE PVCS TEMPERATURE CAN BE HELD TO 136°F WITH AN ALUMINUM OXIDE COATING HAVING AN ABSORPTIVITY OF 0.52 AND AN EMITTANCE OF 0.64. THESE VALUES ARE MINIMUM FOR EMITTANCE AND MAXIMUM FOR ABSORPTIVITY AND INCLUDE ALLOWANCES FOR DEGRADATION DUE TO ULTRAVIOLET AND NEUTRON EXPOSURE.
**UNRESOLVED DESIGN ITEMS**

<table>
<thead>
<tr>
<th>UNRESOLVED PROBLEMS</th>
<th>POTENTIAL SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>THE PVCS PRIME MATERIAL (7039-T63) IS SUSCEPTIBLE TO STRESS CORROSION CRACKING.</strong></td>
<td><strong>CHANGE THE PVCS MATERIAL TO:</strong></td>
</tr>
<tr>
<td>A THRESHOLD STRESS OF 15 KSI AND 13 KSI HAS BEEN EXTRAPOLATED FOR AN EXPOSURE TIME OF 6 MONTHS AND 2 YEARS RESPECTIVELY. THIS DATA IS PRESENTED IN THE NEXT VUGRAPH.</td>
<td>7075-T73 CYLINDER</td>
</tr>
<tr>
<td></td>
<td>6061-T6 CLOSURE</td>
</tr>
</tbody>
</table>

**STATUS**

- **ALCOA GREEN LETTER DATED 1 AUGUST 1962** SHOWS A THRESHOLD STRESS OF 47 KSI FOR 7075-T73.
- **AGC TEST DATA SHOWS NO STRESS CORROSION CRACKING IN 6061-T6 UP TO 35 KSI STRESS LEVEL FOR 655 DAYS EXPOSURE TO SEA COAST ENVIRONMENT.**
- **AGC TEST SHOW THAT THE FLAME SPRAY PROCESS USED TO ATTACH INSTRUMENTATION LEADS TO THE PVCS IS COMPATIBLE WITH 7075-T73 AND NO DEGRADATION OF MATERIAL PROPERTIES WILL RESULT (TEST COMPLETED AND REPORT IN PROCESS).**
PVCS DESIGN STATUS REVIEW

DESIGN REQUIREMENTS
DESIGN REQUIREMENTS

CONTAIN AND DIRECT THE FLOW OF HYDROGEN PROPELLANT
TRANSMIT ENGINE LOADS AND PROVIDE A STRUCTURAL INTERFACE BETWEEN THE NOZZLE AND LOWER THRUST STRUCTURE
ENCLOSE AND PROVIDE SUPPORT FOR THE NSS
PROVIDE MECHANICAL AND STRUCTURAL SUPPORT FOR INTERFACING COMPONENTS AND SUBSYSTEMS
PVCS JOINT SEALS ARE REQUIRED TO LIMIT EXTERNAL LEAKAGE TO TBD STD CC/SEC PER INCH OF SEAL DIAMETER
PVCS MUST BE RELIABILITY ALLOCATION OF .957
THE PVCS MUST MEET THE NORMAL MODE OPERATING SERVICE LIFE OF 10 HOURS ACCUMULATED IN MULTIPLE BURN CYCLES UP TO 60 OF VARYING LENGTH UP TO 1 HOUR
STORAGE - CONTROLLED ENVIRONMENT 5 YEARS - LAUNCH PAD 6 MONTHS - SPACE 3 YEARS
MAJOR PROPELLANT SYSTEM REQUIREMENTS (STEADY STATE)

SPECIFICATION EXTREMES

<table>
<thead>
<tr>
<th></th>
<th>TOL</th>
<th>NSOL</th>
<th>NEOL</th>
<th>MSOL</th>
<th>MEOL</th>
<th>NTSOL</th>
<th>NTEOL</th>
<th>MTSOL</th>
<th>MTEOL</th>
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<tbody>
<tr>
<td>REFLECTOR INLET</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>PRESS, PSIA</td>
<td>+39</td>
<td>1175</td>
<td>1166</td>
<td>1128</td>
<td>1121</td>
<td>709</td>
<td>704</td>
<td>841</td>
<td>838</td>
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<tr>
<td>TEMP, °R</td>
<td>+14</td>
<td>191</td>
<td>195</td>
<td>204</td>
<td>210</td>
<td>210</td>
<td>222</td>
<td>212</td>
<td>222</td>
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<tr>
<td>REFLECTOR OUTLET</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PRESS, PSIA</td>
<td>+37</td>
<td>1117</td>
<td>1111</td>
<td>1090</td>
<td>1085</td>
<td>674</td>
<td>672</td>
<td>810</td>
<td>810</td>
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<tr>
<td>TEMP, °R</td>
<td>+24</td>
<td>252</td>
<td>250</td>
<td>266</td>
<td>275</td>
<td>279</td>
<td>295</td>
<td>279</td>
<td>294</td>
</tr>
<tr>
<td>FLOW, LB/SEC</td>
<td>+0.40</td>
<td>6.95</td>
<td>6.61</td>
<td>5.35</td>
<td>5.07</td>
<td>4.02</td>
<td>3.70</td>
<td>4.08</td>
<td>3.78</td>
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<tr>
<td>EXTENSION SHIELD OUTLET</td>
<td></td>
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<td></td>
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<tr>
<td>PRESS, PSIA</td>
<td>+35</td>
<td>1107</td>
<td>1101</td>
<td>1083</td>
<td>1079</td>
<td>666</td>
<td>665</td>
<td>804</td>
<td>804</td>
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<tr>
<td>TEMP, °R</td>
<td>+29</td>
<td>280</td>
<td>284</td>
<td>297</td>
<td>301</td>
<td>306</td>
<td>309</td>
<td>309</td>
<td>312</td>
</tr>
<tr>
<td>FLOW, LB/SEC</td>
<td>+0.70</td>
<td>25.2</td>
<td>25.0</td>
<td>20.0</td>
<td>20.1</td>
<td>16.4</td>
<td>16.5</td>
<td>16.4</td>
<td>16.4</td>
</tr>
</tbody>
</table>

SOURCE: NETAP ENGINE
MEMO 7860:0330
8-20-70
PVCS LOAD DIAGRAM
NORMAL FULL POWER, STEADY STATE
(START OF LIFE)

75,000 LBS THRUST

1154 PSI

1144 PSI

1215 PSI

2,242,394 LBS FLANGE LOAD

75,000 LBS THRUST

AEROJET NUCLEAR SYSTEMS COMPANY
CONFIGURATION DESCRIPTION

CLOSURE
6061-T6 AA

CYLINDER
7075-T73 AA

REACTOR
MID-CORE
54.320 DIA

NOZZLE
46.295 DIA REF

85.650 (7 FT 1.650 IN.)

100.015

PVCS LAYOUT NO. 1138808

AEROJET NUCLEAR SYSTEMS COMPANY
CLOSURE CONFIGURATION DESCRIPTION

CDA PORT (18 PLACES)

124 BOLTS 5/8 DIA

INSTRUMENTATION PORT (10 PLACES)

THRUST STRUCTURE

TDL, TIL PORT

2:1 ELLIPSE

32.00 DIA

49.00 DIA

II AEROJET NUCLEAR SYSTEMS COMPANY
PVCS DESIGN STATUS REVIEW
STRUCTURAL SUPPORT COOLANT PORT CONCEPT
DESCRIPTION

5.000 DIA
MIN DIA REQD
BY WANL

28.500
DIA

14.640

4.500 DIA

AEROJET NUCLEAR SYSTEMS COMPANY
PVCS DESIGN STATUS REVIEW
STRUCTURAL SUPPORT COOLANT BYPASS PORT CONCEPT
DESCRIPTION

30.840 DIA

2.625 DIA
MIN DIA REQD
BY WANL

14.640

THRUST STRUCTURE

2.156 DIA

PV CLOSURE

AEROJET NUCLEAR SYSTEMS COMPANY
TURBINE INLET

PV CLOSURE

7IN. I.D. LINE

TURBINE DISCHARGE

TIL & TDL PORT CONCEPT DESCRIPTION
FORWARD CLOSURE JOINT CONFIGURATION #1138808

.625-18 UNF-3A
124 BOLTS

NORMAL REQD
PRELOAD
LBS/BOLT

| MAX OPERATING |
| STRESS PSI |
| MARGIN OF SAF |
| ON OPERATING |
| STRESS |

57,600
319,000
-.55

CLOSURE

CYLINDER

54.320 DIA
FORWARD JOINT ALTERNATE CONCEPT #3

.625-18 UNF-3A BOLTS (124)

.625-18 UNF-3A BOLTS (60)

CLOSURE

CYLINDER

1138808 CONCEPT

54.320 DIA

<table>
<thead>
<tr>
<th>NORMAL REQD PRELOAD LBS/BOLT</th>
<th>MAX OPERATING STRESS PSI</th>
<th>MARGIN OF SAF ON OPERATING STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>29,800</td>
<td>140,000</td>
<td>+ .03</td>
</tr>
</tbody>
</table>

AEROJET NUCLEAR SYSTEMS COMPANY
FORWARD JOINT ALTERNATE CONCEPT #8

.750-16 UNJF-3A
120 BOLTS
EQUALLY SPACED

CLOSURE

2.85

CYLINDER

54.320 DIA

NORMAL REQD
PRELOAD
LBS/BOLT

36,500

MAX OPERATING
STRESS
PSI

129,200

MARGIN OF SAF
ON OPERATING
STRESS

+.11

AEROSPACE NUCLEAR SYSTEMS COMPANY
FORWARD JOINT ALTERNATE CONCEPT #9

ADVANTAGES
LOWER BOLT LOADS
LIGHTER THAN CONCEPT #3
LOWER CLOSURE MEMBRANE
STRESSES THAN CONCEPT #8

<table>
<thead>
<tr>
<th>NORMAL REQD PRELOAD LBS/BOLT</th>
<th>MAX OPERATING STRESS PSI</th>
<th>MARGIN OF SAF ON OPERATING STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>35,800</td>
<td>134,000</td>
<td>+ .04</td>
</tr>
</tbody>
</table>

WITH DISCONTINUITY STRESS ANALYSIS
FLOW REQUIREMENTS ESTABLISHED PROBABILISTICALLY

CYLINDER MIDWALL TEMPERATURE OF APPROX MIDCORE AT OPERATIONAL GAP

FLOW REQUIREMENT

TEMPERATURE LIMIT

FLOW RATE, LB/SEC

CYLINDER THICKNESS

ZERO M.S. FOR 7075-T73

7.8

9.1

1.0

.94

.88

10

-1

AEROJET NUCLEAR SYSTEMS COMPANY
LITERATURE REVIEW INDICATES AN ENHANCEMENT FACTOR FROM 4.6 TO 8.0 CAN BE ACHIEVED BY INSTALLING TURBULENCE PROMOTERS. AN INCREASE IN EFFICIENCY OF 6.32 CAN BE OBTAINED USING THE GEOMETRY SHOWN ABOVE. WHILE A FACTOR OF LESS THAN 2.0 IS REQUIRED TO REDUCE THE WALL TEMPERATURE TO AN ACCEPTABLE LIMIT WITH THE ALLOCATED 6.21 LB/SEC FLOW (FOR THE SPECIFICATION EXTREME CASE).
PVCS DESIGN STATUS REVIEW

MATERIALS
<table>
<thead>
<tr>
<th>PROPERTIES OF FORGINGS</th>
<th>DATA CATEGORY 7075-T73</th>
<th>DATA CATEGORY 6061-T6</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONGITUDINAL TENSILE STRENGTH (ULT AND YIELD)</td>
<td>B*</td>
<td>B***</td>
</tr>
<tr>
<td>LONG TRANSVERSE TENSILE STRENGTH (ULT AND YIELD)</td>
<td>B*</td>
<td>B***</td>
</tr>
<tr>
<td>SHORT TRANSVERSE TENSILE STRENGTH (ULT AND YIELD)</td>
<td>B*</td>
<td>B***</td>
</tr>
<tr>
<td>LONGITUDINAL ELONGATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LONG TRANSVERSE ELONGATION</td>
<td>B&amp;C*</td>
<td>C***</td>
</tr>
<tr>
<td>SHORT TRANSVERSE ELONGATION</td>
<td>B&amp;C*</td>
<td>C***</td>
</tr>
<tr>
<td>MODULUS OF ELASTICITY</td>
<td>B*</td>
<td>C***</td>
</tr>
<tr>
<td>FRACTURE TOUGHNESS</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>FATIGUE - HIGH AND LOW CYCLE</td>
<td>D</td>
<td>B&amp;D</td>
</tr>
<tr>
<td>STRESS CORROSION</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>THERMAL CONDUCTIVITY</td>
<td>B**</td>
<td>B***</td>
</tr>
<tr>
<td>SPECIFIC HEAT</td>
<td>B**</td>
<td>B***</td>
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<tr>
<td>THERMAL EXPANSION</td>
<td>B**</td>
<td>B***</td>
</tr>
</tbody>
</table>

* REFERENCE DATA RELEASE MEMO M-21, SUPP. 1, REV 2
** MIL-HDB-5
*** NERVA MATERIALS DATA BOOK

Highest sustained tensile stress tested at KSC that did not cause failure, 100 psi.

Specimens did not fail at highest stress tested.


Aerojet Nuclear Systems Company.
PRESSURE VESSEL SAFE DESIGN LIMITS FOR STRESS CORROSION RESISTANCE OF AA-7039-T63

TEST CONDITIONS:
- SEA COAST EXPOSURE AT KENNEDY SPACE CENTER
- ALL MATERIAL SHORT TRANSVERSE ORIENTATION

SUSTAINED SHORT TRANSVERSE STRESS, KSI

SAFE WORKING AREA

POTENTIAL FAILURE AREA

DAYS TO FAILURE

1000

DESIGN LIMIT

6 MO. 2 YR

100

50

40

30

20

10

0

PV FORGING FLANGE FAILURE

PV FORGING WALL FAILURE

PV FORGING FLANGE STILL IN TEST

PV FORGING WALL STILL IN TEST

AEROJET NUCLEAR SYSTEMS COMPANY
6061 ALUMINUM ALLOY - T-6 HAND FORGINGS

TENSILE STRENGTH, 1000 KSI

ULTIMATE
CATEGORY "B" DATA
YIELD

ELONGATION, %

CATEGtORY "C" DATA

REF. NERVA MATERIALS HANDBOOK

TEMPERATURE, °F

AEROJET NUCLEAR SYSTEMS COMPANY
7075 Aluminum Alloy - T73 Forging (LT)

![Graph showing Tensile Strength and Elongation data as a function of temperature. The graph includes lines for Ftu "B" Data, Fty "B" Data, and Elongation "C" Data.](image-url)
INFLUENCE OF IRRADIATION AND ANNEALING ON PV ALLOYS 7039-T63 AND 7075-T73

ELONGATION OF AA 7039-T63 (RING FORGING) AND AA 7075-T73 AT 140°R AS EFFECTED BY NEUTRON FLUENCE AND 540°R ANNEALING

140° TENSILE ELONGATION

○ IRRAD 7039-T63
● 340°R ANNEAL IRRAD 7039-T63
□ 540°R ANNEAL IRRAD 7039-T63
△ IRRAD 7075-T73

NOTE: MAXIMUM TOTAL EXPOSURE FOR 60 MIN FIRING = 10^{18} nvt

EQUIVALENT TO 10 HRS CONTINUOUS FP OPERATION

AEROGO NUCLEAR SYSTEMS COMPANY
CRITICAL FRACTURE TOUGHNESS OF AA 7039-T63, AA 7075-T73 AND AA 6061-T6
(MEAN TEST VALUES)
(STATISTICAL ALLOWABLE VALUES NOT YET AVAILABLE FOR COMPARISON WITH 6061 AND 7075)

FRACTURE TOUGHNESS
KSI $\sqrt{N}$ CRITICAL PLANE
STRAIN INTENSITY
($K_{IC}$)

STEP FORGING AA-6061-T6 (3)
PV FLANGE AA 7039-T63 (* .11 IN. AT -320 + .270 AT RT)
PV WALL AA 7039-T63 (2) (* .052 IN. AT .320 + .150 IN. AT RT)
7075-T73 FORGING (4)

(1) RADIAL FLAW DRIVEN BY CIRCUMFERENTIAL STRESS
(2) AXIAL FLAW DRIVEN BY CIRCUMFERENTIAL STRESS
(3) LONG TRANSVERSE FLAW DRIVEN BY LONGITUDINAL STRESS
(4) TRANSVERSE 3.5 IN. EXTRUSION DATA FROM LITERATURE (RT ONLY)
—ESTIMATION BASED UPON 7039-T63 DATA TREND
* CRITICAL FLAW SIZE

AEROGST NUCLEAR SYSTEMS COMPANY
### FLAME SPRAY DEGRADATION TESTS
#### TENSILE PROPERTIES
(7075-T73)

<table>
<thead>
<tr>
<th>PHYSICAL PROPERTIES</th>
<th>SPECIMEN DESCRIPTION</th>
<th>MIL HANDBOOK 5 ALLOWABLES (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONTROL</td>
<td>COATED (1)</td>
</tr>
<tr>
<td></td>
<td>LONG</td>
<td>TRANS</td>
</tr>
<tr>
<td>$F_{tu}$, KSI</td>
<td>70.6</td>
<td>72.5</td>
</tr>
<tr>
<td>$F_{ty}$, KSI</td>
<td>59.9</td>
<td>62.0</td>
</tr>
<tr>
<td>ELONGATION, %</td>
<td>12.6</td>
<td>9.8</td>
</tr>
<tr>
<td>MOD. OF ELASTICITY</td>
<td>10.03</td>
<td>10.03</td>
</tr>
</tbody>
</table>

(1) TESTED WITH NICKEL ALUMINIDE LAYER ONLY
(2) TESTED WITH ALL COATING STRIPPED BY MACHINING
(3) MIL HANDBOOK 5 "S" BASIS ALLOWABLES FOR 1" PLATE (SPEC MINIMUMS)

**NOTES:**
A. MAXIMUM RECORDED SPECIMEN TEMPERATURE 225°F DURING COATING PROCESS
B. EQUILIBRIUM TEMPERATURE 180°F DURING COATING PROCESS
PVCS DESIGN STATUS REVIEW

TIME POSITION OF REVIEW
TIME POSITION OF REVIEW

DESIGN

1. CONCEPT SELECTED
2. FULL POWER NUCLEAR ANALYSIS FOR NUCLEAR STAGE
3. FULL POWER STEADY STATE THERMAL ANALYSIS
4. FULL POWER STEADY STATE INTERMEDIATE STRESS ANALYSIS
5. PRELIMINARY ISSUE OF PVCS FMA
6. PRELIMINARY ISSUE OF DATA ITEM E-105
7. MATERIAL SELECTED

LOAD ANALYSIS
1. LOAD ANALYSIS
2. DETAIL STRESS ANALYSIS
3. PHOTOELASTIC TEST OF CLOSURE
4. TRANSIENT THERMAL ANALYSIS
5. TRANSIENT STRESS ANAL.
6. FIRST CUT RELIABILITY ANALYSIS
7. GROUND TEST NUCL. HEATING RATES

FAB OF DEV UNIT  DEV TEST

FABRICATION OF DR-1 UNIT

DR-1 TEST

TECHNICAL STATUS REVIEW

DDR

AEROJET NUCLEAR SYSTEMS COMPANY
PVCS DESIGN STATUS REVIEW

RELIABILITY

AEROJET NUCLEAR SYSTEMS COMPANY
PVCS RELIABILITY APPORTIONMENT TO FAILURE MODE LEVEL

<table>
<thead>
<tr>
<th>FAILURE</th>
<th>POTENTIAL FAILURE RATING</th>
<th>FAILURE PROBABILITY</th>
<th>APPORTIONED RELIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PVCS FAILS TO CONTAIN PROPELLANT</td>
<td>3</td>
<td>$0.9 \times 10^{-6}$</td>
<td>0.91</td>
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<tr>
<td>2. PVCS FAILS TO PROVIDE STRUCTURAL INTERFACE BETWEEN THE NOZZLE AND LOWER THRUST STRUCTURE</td>
<td>4</td>
<td>$1.2 \times 10^{-6}$</td>
<td>0.9588</td>
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<tr>
<td>3. PVCS FAILS TO ENCLOSE AND SUPPORT THE NUCLEAR SUBSYSTEM</td>
<td>1</td>
<td>$0.3 \times 10^{-6}$</td>
<td>0.967</td>
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<tr>
<td>4. PVCS FAILS TO PROVIDE MECHANICAL AND STRUCTURAL SUPPORT FOR INTERFACING SUBSYSTEMS AND COMPONENTS</td>
<td>2</td>
<td>$0.6 \times 10^{-6}$</td>
<td>0.964</td>
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</tbody>
</table>

TOTAL RELIABILITY APPORTIONED TO PVCS ($R_1 \times R_2 \times R_3 \times R_4$) 0.9570

AEROJET NUCLEAR SYSTEMS COMPANY
PVCS RELIABILITY APPORTIONMENT TO THE MECHANISM LEVEL OF FAILURE - MODE NO. 2

<table>
<thead>
<tr>
<th>MODE AND MECHANISM</th>
<th>POTENTIAL FAILURE RATING</th>
<th>FAILURE PROBABILITY</th>
<th>APPORTIONED RELIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2. PVCS FAILS TO PROVIDE STRUCTURAL INTERFACE BETWEEN NOZZLE AND LOWER THRUST STRUCTURE</strong></td>
<td></td>
<td>1.0</td>
<td>1.2 x 10^-6</td>
</tr>
<tr>
<td>A. CIRCUMFERENTIAL MEMBRANE FAILURE NEXT TO FLANGE</td>
<td>1.0</td>
<td>0.12 x 10^-6</td>
<td>0.9688</td>
</tr>
<tr>
<td>B. STRUCTURAL FAILURE OF P.V. WALL</td>
<td>3.0</td>
<td>0.36 x 10^-6</td>
<td>0.9664</td>
</tr>
<tr>
<td>C. STRUCTURAL FAILURE OF P.V. CLOSURE JOINT (BOLTS AND INSERTS)</td>
<td>2.0</td>
<td>0.24 x 10^-6</td>
<td>0.9676</td>
</tr>
<tr>
<td>D. FAILURE OF P.V. MEMBRANE NEXT TO CLOSURE JOINT</td>
<td>1.0</td>
<td>0.12 x 10^-6</td>
<td>0.9688</td>
</tr>
<tr>
<td>E. SHEAR LIP FAILURE OF P.V. CLOSURE</td>
<td>0.5</td>
<td>0.06 x 10^-6</td>
<td>0.9740</td>
</tr>
<tr>
<td>F. FAILURE OF P.V. FLANGE BETWEEN BOLT HOLES</td>
<td>0.5</td>
<td>0.06 x 10^-6</td>
<td>0.9740</td>
</tr>
<tr>
<td>G. FAILURE OF P.V. CLOSURE NEXT TO CLOSURE JOINT FLANGE</td>
<td>1.0</td>
<td>0.12 x 10^-6</td>
<td>0.9688</td>
</tr>
<tr>
<td>H. FAILURE OF P.V. CLOSURE AT LOWER THRUST STRUCTURE J oint</td>
<td>1.0</td>
<td>0.12 x 10^-6</td>
<td>0.9688</td>
</tr>
</tbody>
</table>
STEPS IN ASSESSING RELIABILITY

1. DEFINE LOAD LIMITS.
2. SELECT MATERIAL
3. DETERMINE STRESS INTENSITY LIMIT (SIL) BASED ON MINIMUM STRENGTH.
4. DETERMINE LIMITING STRESS INTENSITY (LSI) BASED ON MAXIMUM STRESS.
5. CHECK FOR POSITIVE MARGIN OF SAFETY
   \[ M.S. = \frac{\text{SIL}}{\text{LSI}} - 1 \]
6. DETERMINE MEAN STRENGTH \( \bar{S} \), AND STRENGTH VARIABILITY \( D_S \)
7. DETERMINE MEAN STRESS \( \bar{s} \), AND STRESS VARIABILITY \( D_s \)
8. CALCULATE RELIABILITY USING:
   \[ J = \frac{\bar{S} - \bar{s}}{\sqrt{D_S^2 + D_s^2}} \]
9. FIND R FROM CURVE OF R VS J
MARGIN OF SAFETY CALCULATION FOR FAILURE MECHANISM 2B
(Failure of P.V. Wall due to Pressure Induced Hoop Stress)

\[ \text{M.S.} = \frac{\text{SIL}}{\text{LSI}} - 1 = \frac{.85 (F_{\text{ty min}})}{\text{MAX STRESS}} - 1 \]

**Strength**

From DRM M-21 Rev 2, \( F_{\text{ty}} \) at 120°F = 58.0 KSI, \( D_S = 2.4 \text{ KSI} \)

And \( K = 2.76 \)

\[ \text{SIL} = .85 (F_{\text{ty}} - K D_S) = .85 (58.0 - 2.76 \times 2.4) = 43.67 \text{ KSI} \]

**Stress**

\[ \text{Hoop Stress} = \frac{PR}{t} \]

\[ P = 1175 + 39 \text{ PSI}, \quad R = 27.16 + .005 \text{ IN}, \quad t = .780 + .010 \text{ IN} \]

\[ \text{LSI} = \frac{(P_{\text{MAX}} X R_{\text{MAX}})}{t_{\text{MIN}}} = \frac{(1189\times 27.165)}{.770} = 41.77 \text{ KSI} \]

\[ \text{M.S.} = \frac{\text{SIL}}{\text{LSI}} - 1 = \frac{43.67}{41.77} - 1 = .046 \]
RELIABILITY CALCULATION FOR FAILURE MECHANISM 2B
(Failure of PV wall due to pressure induced hoop stress)

Mean Stress ($s$) = \( \frac{(P_{AV})(R_{AV})}{t_{AV}} \) = \( \frac{(1146)(27.16)}{.780} \) = 39.90 KSI

\* $D_s$ from propagation of variances = .474 KSI

Mean Strength ($S$) = 58.0 KSI from DRM M-21 Rev 2

$D_S$ = 2.4 KSI from DRM M-21 Rev 2

\[ J = \frac{S - s}{\sqrt{D_s^2 + D_s^2}} = \frac{58 - 39.9}{\sqrt{(2.4)^2 + (.474)^2}} = 7.40 \]

$R$ = .9885 from graph of $J$ vs $R$, page 13 of NRP-411 Rev "A" (Sample size 10)
(This value compares with an apportioned reliability of .964 shown on previous VUGraph)

\* $D_s$ = \( \left( \frac{\partial s}{\partial P} \right)^2 D_P^2 + \left( \frac{\partial s}{\partial R} \right)^2 D_R^2 + \left( \frac{\partial s}{\partial t} \right)^2 D_t^2 \)

$D_P$ = 12.7 PSI from engine NETAP data

$D_R$ = .00167 from drawing tolerance

$D_t$ = .0033 from drawing tolerance

AEROJET NUCLEAR SYSTEMS COMPANY
## RELIABILITY OF FAILURE MECHANISMS WHICH HAVE BEEN ASSESSED *

<table>
<thead>
<tr>
<th>IV. PVCS FAILS TO CONTAIN PROPELLANT</th>
<th>ALLOCATED</th>
<th>ASSESSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. LEAKAGE AT NOZZLE TO PV JOINT</td>
<td>.96</td>
<td>TBD</td>
</tr>
<tr>
<td>1. INSERTS PULL OUT OF ALUMINUM</td>
<td>.96865</td>
<td>TBD</td>
</tr>
<tr>
<td>C. LEAKAGE AT PV TO CLOSURE JOINT</td>
<td>.9664</td>
<td>&gt;.9788</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V. PVCS FAILS TO PROVIDE STRUCTURAL INTERFACE BETWEEN NOZZLE AND LOWER THRUST STRUCTURE</th>
<th>ALLOCATED</th>
<th>ASSESSED</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. STRUCTURAL FAILURE OF PV WALL IN HIGH STRESS REGION</td>
<td>.9664</td>
<td>.968</td>
</tr>
<tr>
<td>C. FAILURE OF PV TO CLOSURE JOINT</td>
<td>.9676</td>
<td>.938</td>
</tr>
<tr>
<td>E. SHEAR LIP FAILURE OF PV CLOSURE</td>
<td>.974</td>
<td>&gt;.910</td>
</tr>
<tr>
<td>F. FAILURE OF PV CLOSURE FLANGE BETWEEN BOLT HOLES</td>
<td>.974</td>
<td>&gt;.910</td>
</tr>
</tbody>
</table>

| VI. PVCS FAILS TO ENCLOSE AND SUPPORT NSS                                              | .967      | TBD      |

| VII. PVCS FAILS TO PROVIDE MECHANICAL AND STRUCTURAL SUPPORT FOR INTERFACING SUBSYSTEMS AND COMPONENTS | .964      | TBD      |

* RELIABILITY HAS BEEN ASSESSED FOR 6 OUT OF 26 FAILURE MECHANISMS
PVCS DESIGN STATUS REVIEW

TASKS TO BE COMPLETED BEFORE DDR
TASKS TO BE COMPLETED BEFORE DDR

CONDUCT PHOTOELASTIC TEST OF CLOSURE

COMPLETE ROM PRESSURE VESSEL ASSEMBLY RELIABILITY ASSESSMENTS

CONDUCT DETAILED STRESS ANALYSIS INCLUDING HIGH AND LOW CYCLE
FATIGUE AND FRACTURE MECHANICS

CONDUCT THERMAL AND STRESS ANALYSIS FOR CRITICAL TRANSIENT
CONDITIONS

CALCULATE NUCLEAR HEATING RATES FOR GROUND TEST CONDITIONS

CALCULATE DYNAMIC AND STATIC LOADS FOR TRANSIENT CONDITION
AND STEADY STATE CONDITIONS

TURBULENCE PROMOTOR STUDY
PVCS DESIGN STATUS REVIEW

SUMMARY STATUS
SUMMARY STATUS

BASIC CONCEPT SATISFACTORY - LENDS ITSELF TO REFINEMENTS

DESIGN REQUIREMENTS CAN BE MET

RELIABILITY GOALS CAN BE MET

READY TO PROCEED INTO DETAILED DESIGN PHASE

RECOMMENDATION:
ACCEPT 7075-T73 CYLINDER AND 6061-T6 CLOSURE AS PVCS MATERIALS
PVCS DESIGN STATUS REVIEW

REDUNDANT SEAL EVALUATION

NOT PRESENTED
PVCS DESIGN STATUS REVIEW
RENDUNDANT SEAL CONFIGURATION FOR SSCL & TIL-TDL INTERFACES

SSCL

.165 CLEARANCE

TIL & TDL JOINT

THRUST STRUCTURE

AEROJET NUCLEAR SYSTEMS COMPANY
REDUNDANT SEAL CONFIGURATION FOR SSBL & TIL-TDL INTERFACES

THRUST STRUCTURE

TDL, TIL JOINT

SSBL JOINT

PV CLOSURE
REDUNDANT SEAL CONFIGURATION FOR CLOSURE/CYLINDER INTERFACE

OMEGA SEAL

"K" SEAL

CLOSURE

CYLINDER

OMEGA SEAL

"K" SEAL

AEROTOMO NUCLEAR SYSTEMS COMPANY
**INCREASED WEIGHT REQUIRED FOR REDUNDANT SEALS IN PVCS**

<table>
<thead>
<tr>
<th>INTERFACE</th>
<th>APPROX. WT INCREASE, LBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURE VESSEL TO CLOSURE FLANGES</td>
<td>15.61</td>
</tr>
<tr>
<td>STRUCTURAL SUPPORT COOLANT BYPASS FLANGES</td>
<td>1.85</td>
</tr>
<tr>
<td>STRUCTURAL SUPPORT COOLANT LINE FLANGES</td>
<td>2.99</td>
</tr>
<tr>
<td>TURBINE INLET &amp; TURBINE EXHAUST LINE FLANGES</td>
<td>8.33</td>
</tr>
<tr>
<td>CONTROL DRUM ACTUATOR FLANGES</td>
<td>5.53</td>
</tr>
<tr>
<td><strong>TOTAL WEIGHT INCREASE OF PVCS</strong></td>
<td><strong>34.31</strong></td>
</tr>
</tbody>
</table>

AEROJET NUCLEAR SYSTEMS COMPANY
EFFECT OF LEAKAGE AT REFLECTOR OUTLET ON ENGINE $I_{sp}$

[Graph showing the relationship between leakage rate (STD CC/SEC) and loss of $I_{sp}$ (SEC).]

AEROJET NUCLEAR SYSTEMS COMPANY
$I_{sp}$ VS WEIGHT (COMPONENT)

APPROXIMATELY 1 LB WT IS EQUIVALENT TO 1000 STD CC LEAKAGE IN THE AMOUNT OF $I_{sp}$ LOSS

BASED ON:

$\frac{809 \text{ LB PAYLOAD/SEC} \cdot I_{sp}}{2.8} = 289 \text{ LB WT/SEC} \cdot I_{sp}$