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NERVA IRRADIATION PROGRAM

GTR 23 - VOLUME I

COMBINED EFFECTS OF REACTOR RADIATION AND CRYOGENIC TEMPERATURE ON NERVA STRUCTURAL MATERIALS

NUCLEAR AEROSPACE RESEARCH FACILITY
NERVA IRRADIATION PROGRAM
GTR 23 - VOLUME I
COMBINED EFFECTS OF REACTOR RADIATION
AND CRYOGENIC TEMPERATURE ON NERVA
STRUCTURAL MATERIALS

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of the
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Cleveland, Ohio 44135

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Modification 10

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FOREWORD

GTR-23 is the last in a series of radiation effects tests performed for NASA's NERVA program at the Nuclear Aerospace Research Facility (NARF) at the Fort Worth operation of Convair Aerospace Division of General Dynamics Corporation. Previous tests in this series span ten years and are described in General Dynamics' reports.

The NERVA program is administered by the joint NASA/AEC Space Nuclear Systems Office. At the initiation of GTR-23, Aerojet Nuclear Systems Company was the prime contractor for developing the NERVA engine, and Westinghouse Astronuclear Laboratory was responsible for developing the nuclear reactor. These companies and the Los Alamos Scientific Laboratory (LASL) provided the test specimens and test specifications for GTR 23. The realignment of the NERVA program has shifted Aerojet's and Westinghouse's tasks to LASL which will now receive and analyze all of the GTR-23 test results.

Volume II of this report describes the irradiation and testing of the electronic components included in GTR 23.
SUMMARY

Specimens fabricated from structural materials that were candidates for certain NERVA applications were irradiated in liquid nitrogen, liquid hydrogen, water, and air. The specimens irradiated in LN$_2$ were stored in LN$_2$ and finally tested in LN$_2$, or at some higher temperature in a few instances. The specimens irradiated in LH$_2$ underwent an unplanned warmup while in storage so this portion of the test was lost; some specimens were tested in LN$_2$ but none were tested in LH$_2$.

The test specimens and test specifications were provided by Aerojet Nuclear Systems Company and Westinghouse Astronuclear Laboratory. However, with the termination of these companies' participation in the program, the Los Alamos Scientific Laboratories has been designated as the recipient of the raw data and untested specimens.

The Ground Test Reactor was the radiation source. The test specimens consisted mainly of tensile and fracture toughness specimens of several different materials, but other types of specimens such as tear, flexure, springs, and lubricant were also irradiated. Tables S-1, S-2, and S-3 list the materials and give information pertinent to the test.
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<thead>
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<th>Material</th>
<th>Type</th>
<th>Specimen</th>
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<th>No. Specimens - Cont/Irrad</th>
<th>% Change (Irrad - Control) at Same Test Temp</th>
<th>Text Ref Page</th>
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<td>3/3</td>
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<td>3/3</td>
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<td>3/3</td>
<td>0.25 -1.6 1.4</td>
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<td>550d/540</td>
<td>3/3</td>
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<td>140/140</td>
<td>5/5</td>
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<td>2/2</td>
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<td>(Plate)</td>
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<td>2/2</td>
<td>1.9 20.0* 7.7</td>
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<td>4/4</td>
<td>9.7* 4.2 2.2</td>
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<td>4/4</td>
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<td>140/140</td>
<td>2/3</td>
<td>1.7* -8.8 19.8*</td>
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<td>- - -</td>
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<td>3/3</td>
<td>13.6* -24.4 -16.2</td>
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<td>Notched</td>
<td>1.45 (18)</td>
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<td>9/9</td>
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<td>9/9</td>
<td>18.0* -67.4* -16.9*</td>
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<td>8/7</td>
<td>-3.3 (Fracture stress)</td>
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<td>8/9</td>
<td>92.4* -30.1* -7.1</td>
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Table S-1
MATERIALS TENSILE TESTED, TEST CONDITIONS, AND PERCENT CHANGE IN PROPERTIES WITH SIGNIFICANCE TEST (Cont'd)

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<th>Material</th>
<th>Type Specimen</th>
<th>Exposure E &gt; 1 MeV (n/cm²)</th>
<th>Temp Irrad/test (°C)</th>
<th>No. Specimens Cont/Irrad</th>
<th>% Change (Irrad - Control) at Same Test Temp</th>
<th>Yield</th>
<th>Elong</th>
<th>Area Reduct</th>
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<td>8/8</td>
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<td>(Bar)</td>
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<td>4.29 (18)</td>
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<td>8/8</td>
<td>47.1* (Fracture stress)</td>
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<tr>
<td>Al 6061-T61</td>
<td>Buttonhead</td>
<td>1.41 (18)</td>
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<td>8/8</td>
<td>31.4* -38.3* -11.3</td>
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<td>8/9</td>
<td>45.9* -65.4* -23.8*</td>
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<td>7/75 (17)</td>
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<td>13.3 -6.8 -1.3</td>
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<td>7/8</td>
<td>14.5* (Fracture stress)</td>
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<td>140/140</td>
<td>7/8</td>
<td>20.6* (Fracture stress)</td>
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<tr>
<td>Al 5086-H-34</td>
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<td>3/3</td>
<td>39.1* -28.9* -5.2</td>
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<td>3.90 (17)</td>
<td>140/340</td>
<td>3/3</td>
<td>18.5* -7.6 6.3</td>
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<td>29.5* -24.1* -1.5</td>
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<td>3.90 (17)</td>
<td>140/540</td>
<td>3/3</td>
<td>1.3 7.8 59.0*</td>
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<td></td>
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<td>140/540</td>
<td>3/3</td>
<td>44.8* -5.9 8.6</td>
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<td>3/3</td>
<td>-2.49 6.9 15.6*</td>
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<td>3/3</td>
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<td>2/3</td>
<td>6.0 144.4 166.2*</td>
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<td>2/3</td>
<td>10.6 222.2 168.4*</td>
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a. Maximum where different for various specimens in group
b. Asterisk indicates significant change at the 95% confidence level
c. Annealed for 100 min at 540°C
D. Irradiated in water
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<th>No. Specimens</th>
<th>KQ (ksi √in.)</th>
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<td>140/406</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>25.32 2.13</td>
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<td>28.83 0.24</td>
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<td>140/140</td>
<td>4</td>
<td>27.20 0.88</td>
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<td>Exposure</td>
<td>Temp Irrad/Test (°C/R)</td>
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<td>$K_{Q}$ (ksi/√in.)</td>
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<td>66.10</td>
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<td>WOL</td>
<td>Control</td>
<td>-/140</td>
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<td>9.83</td>
<td>1.01</td>
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<td>3.25 (18)</td>
<td>140/140</td>
<td>2</td>
<td>6.13</td>
<td>1.05</td>
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<td>Control</td>
<td>-/540</td>
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<td>11.34</td>
<td>2.19</td>
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<td></td>
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<td>140/540</td>
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<td>11.94</td>
<td>-</td>
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<td>Fatigue cracked</td>
<td>Control</td>
<td>-/140</td>
<td>2</td>
<td>442.5</td>
<td>-</td>
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<td>3.17 (18)</td>
<td>140/140</td>
<td>3</td>
<td>301.8</td>
<td>116.6</td>
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<td>ZrC (Plate)</td>
<td>Similar to compact tension</td>
<td>Control</td>
<td>-/140</td>
<td>1</td>
<td>442.5</td>
<td>-</td>
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<td>2.89 (18)</td>
<td>140/140</td>
<td>3</td>
<td>310.8</td>
<td>116.6</td>
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<td></td>
<td>Control</td>
<td>-/540</td>
<td>2</td>
<td>370.8</td>
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<td>4</td>
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<td>1.24</td>
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<td>52.64</td>
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<td>-/140</td>
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<td>7.76</td>
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<td>2.29 (18)</td>
<td>140/140</td>
<td>2</td>
<td>19.20</td>
<td>1.11</td>
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<td></td>
<td>Control</td>
<td>-/540</td>
<td>1</td>
<td>6.98</td>
<td>-</td>
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<td></td>
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<td>2.25 (18)</td>
<td>140/540</td>
<td>3</td>
<td>14.19</td>
<td>1.63</td>
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**Table S-2**

MATERIALS FRACTURE TOUGHNESS TESTED, TEST CONDITIONS, AND AVERAGED DATA (Cont’d)

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<thead>
<tr>
<th>Material</th>
<th>Type Specimen</th>
<th>Exposure$^a$ E &gt; 1 MeV (n/cm$^2$)</th>
<th>Temp Irrad/Test ($^0$R)</th>
<th>No. Specimens</th>
<th>$K_O$ (ksi√in.) Ave Std Dev % Std Dev</th>
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<tr>
<td>CU B$^N$</td>
<td>Center cracked sheet Control 2.39 (18) 140/140 2 6.78 0.95 14.1</td>
<td>140/540 3 16.37 2.50 15.3</td>
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<td></td>
<td>Control 2.35 (18) 140/540 3 5.93 0.47 8.0</td>
<td>15.61 1.20 7.7</td>
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<td></td>
</tr>
</tbody>
</table>

- a. Maximum where different for various specimens in group
- b. Two lots of specimens
- c. Annealed for 100 min at 540$^0$R
- d. Toughness calculated on basis of ultimate load
- e. $K_{UO}$ is calculated at ultimate load using initial crack length
- f. $K_O$ is calculated at 5% offset load using initial crack length
## Table S-3

**MATERIALS FOR MISCELLANEOUS TESTS, TEST CONDITIONS, AND PERCENT CHANGE IN PROPERTIES WITH SIGNIFICANCE TEST**

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Exposurea E &gt;1 MeV (n/cm²)</th>
<th>Temp Irrad/test (°R)</th>
<th>No. Specimens Cont/Irrad</th>
<th>% Change (irrad - control) at Same Test Temp</th>
<th>Text Ref Page</th>
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<tr>
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<td></td>
<td>Tear Strength, Energy to Initiate, Energy to Propagate</td>
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<td>Al 5086-H-34</td>
<td>Kahn-type tear</td>
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<tr>
<td>(Sheet)</td>
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<td>3/3</td>
<td>13.1* b -15.2 -33.3*</td>
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<td>2.86 (17)</td>
<td>140/340</td>
<td>3/2</td>
<td>2.5* 4.5 7.5</td>
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<td>2.78 (17)</td>
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<td>4/4</td>
<td>-0.08 18.2 13.3</td>
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<td>Welded</td>
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<td>140/140</td>
<td>3/3</td>
<td>40.9* 16.4 -9.9</td>
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<td></td>
<td></td>
<td>2.84 (17)</td>
<td>140/340</td>
<td>3/3</td>
<td>13.9 -0.45 -0.22</td>
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<td>4/4</td>
<td>5.3 -21.9 12.0</td>
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<td>Heat Affected Zone</td>
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<td>3/3</td>
<td>9.5* 0.11 20.5*</td>
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<td>2.4 -21.4* -4.3</td>
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<td>Flexure (bar)</td>
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<td>4/3</td>
<td>Max Stress 6.3 0.78</td>
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<td>4/4</td>
<td>Deflection 7.4 24.7</td>
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<td>4/4</td>
<td>Max Stress -13.5*</td>
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<td>Feuralon, Flexure (bar)</td>
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<td>140/140</td>
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<td>Max Stress 9.0 0.22</td>
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<td>3.5 (9) rad (C)</td>
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<td>7/6</td>
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<td>3.5 (9) rad (C)</td>
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<td>4/4</td>
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</table>

**Notes:**
- a. Maximum where different for various specimens in group
- b. Significant change at the 95% confidence level
Table S-1 contains a summary of the tensile test data. The percent change between the average values for irradiated and control specimens tested at the same temperature are tabulated for 0.2% offset yield stress and bench-measured elongation and area reduction. A "t" test was used to evaluate the significance or nonsignificance of the observed differences in the averages. In making the statistical test, a probability of \( \alpha = 0.05 \) (95% confidence level) was used. Significance at this level is indicated in the table by the asterisk. When the difference is not indicated as being significant, it does not necessarily mean there is no difference; it may only be that the experiment was not sensitive enough to detect the difference if it existed.

Table S-2 gives the averaged fracture toughness data. Because the averages include data from some specimens with invalid fatigue precracks, differences were not taken. The interpretation of these data should include an evaluation of precrack information given in Section 5.3 for each individual specimen.

Table S-3 summarizes the information for a tear test of an aluminum, the flexure test of ZrC, and the tensile and flexure tests of Feuralon. The percent change between averaged
values for irradiated and control specimens are given, and the significance at the 95% confidence level is indicated.

Beryllium-copper Belleville springs were irradiated in LN$_2$ and A-286 springs were irradiated in LN$_2$ and in air at 540° and 1200° R. Neither type spring had a significant change in properties as a result of the irradiation.

As a part of Test Plan M-40-1, specimens encapsulated in a 1000-psi hydrogen gas atmosphere were irradiated in LN$_2$. The Hastelloy X and Titanium 5Al 2.5Sn from the LN$_2$ irradiation were maintained in LN$_2$ after irradiation and tested in LN$_2$ after being removed from the capsules. Averages for properties of encapsulated and unencapsulated specimens at approximately equal fluence groups were compared; 0.2% offset yield, maximum stress, and bench elongation were the properties considered for unnotched specimens, while the maximum stress was used for notched specimens. The encapsulated aluminum specimens were not tested because it was not possible to remove them without extensive damage to the specimens. Statistically significant differences (at the 95% confidence level) were noted for several properties of Hastelloy X, both unnotched and notched. No significant differences were found for the titanium specimens. The results of the analysis are summarized in Table S-4.
Table S-4

EFFECTS OF IRRADIATION IN HIGH-PRESSURE HYDROGEN GAS - TEST PLAN M-40-1
(Some data from Table S-1 included)

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<th>Material and Specimen Type</th>
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<td>Fluence Group</td>
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<td>High</td>
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<tr>
<td>Titanium 5Al 2.5Sn</td>
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<td>Notched</td>
<td>Low</td>
</tr>
<tr>
<td>Notched</td>
<td>High</td>
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</table>
Actuator lubricant specimens were irradiated in LH$_2$. The solid-film lubricant used was a proprietary formulation known as "Vac Kote" and was applied by Bell Brothers Research Corporation, Boulder, Colorado.

Sliding wear tests were performed on six irradiated and seven control specimens at 540$^\circ$R; seven irradiated and six controls were tested at 1000$^\circ$R. Results of the sliding wear tests (Tables 5-35 and 5-36) showed no significant change in wear life of the lubricant at 1000$^\circ$R; however, there was a significant improvement in wear life of the irradiated specimens at 540$^\circ$R.
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Corrections

Page 2 - 8  Labels are inverted on photograph.
Page 5 - 17 Under Neutron fluence 12.6(18) should be 1.26(18)
I. INTRODUCTION

This report documents the results of the irradiation testing of selected structural materials in the experiment designated GTR 23. The tests were performed at the Nuclear Aerospace Research Facility, operated by General Dynamics, in support of the NASA-AEC NERVA program. The components were selected and provided by Aerojet Nuclear Systems Company (ANSC), Westinghouse Astronuclear Laboratory (WANL), and the Los Alamos Scientific Laboratory (LASL).

A total of 805 material specimens were irradiated in liquid hydrogen, liquid nitrogen, water, or air. Prior to the irradiation, a mapping run was performed to ascertain proper specimen locations for the assigned neutron fluences in the LH$_2$ and LN$_2$ dewars. The mapping run was made on 17 May 1972 at a power level of 100 kW for one hour.

The 6000-MWh irradiation began 24 May 1972. The test plan called for keeping the specimens in the LN$_2$ and LH$_2$ dewars submerged in cryogen from the beginning of the irradiation through postirradiation testing. After 2676-MWh of operation, detonations in the ice that had accumulated on the exhaust line to the LH$_2$ dewar forced a reactor shutdown and termination of
LH$_2$ flow. Investigations proved that the detonations were not the result of hydrogen leakage and on 8 June the LH$_2$ dewar was again filled and the irradiation was resumed.

Shortly after reaching the 10-MW power level (~45 min), a number of detonations in and around the LN$_2$ dewar forced another shutdown. Because these detonations damaged the dump valves in the dewar, the dewar was removed from the irradiation cell and the specimens were transferred to holding dewars in the Irradiated Materials Laboratory. The irradiation of all other specimens was resumed on 21 June and concluded on 7 July 1972.

The detonations in the LH$_2$ exhaust line and LN$_2$ dewar resulted in deviations from the test plan in that the specimens in LH$_2$ had a warmup about midway through the irradiation and the specimens in LN$_2$ received about half of the planned exposure. During the period after the irradiation when the radioactivity of the LH$_2$ dewar and specimens was decaying sufficiently to enable handling, the liquid hydrogen supply was depleted because of a faulty gage on the supply trailer. As a result of the ensuing warmup, it was decided that the LH$_2$ specimens would not be tested. Most of these specimens were shipped to the Los Alamos Scientific Laboratories. Tests on the specimens irradiated in LN$_2$, water, and in air were carried out as planned.
Section II describes the test materials and specimens; Section III outlines the irradiation and dosimetry procedures; Section IV describes the test equipment and methods; and Section V is devoted to the discussion of the individual tests and the presentation of the test results.
II. TEST MATERIALS AND SPECIMENS

Table 2-1 lists the materials irradiated in GTR 23, the type of test, and other pertinent information. Not all of the irradiated specimens were tested at NARF, principally those from the abortive liquid hydrogen test but including some to be tested elsewhere and some destroyed in the LN$_2$ dewar; these are indicated in the table.

Figures 2-1 through 2-5 illustrate typical specimens of each configuration. The metal tensile specimens (Fig. 2-1) were either flat (gage lengths of 1.0, 1.5, or 2.31 in.) or two styles of round buttonhead (both 1.5-in. gage length); the notched tensile specimens were all of round buttonhead configuration with a notch diameter of nominally 0.18 in.

The fracture toughness specimens (Fig. 2-2) consisted of three sizes of compact tension specimens and one WOL type (Be). The small ZrC specimens and the beryllium specimens had straight machined notches; all other specimens had chevron-style notches. The nominal dimensions (in inches) for the various configurations were as follows (see Fig. 5-1 for a sketch of the compact tension specimen):

2-1
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<td>1138365</td>
<td>2.50</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>100E439 H38</td>
<td>2.50</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1139208</td>
<td>1.875</td>
<td>1.50</td>
<td>0.75</td>
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<td>577F544 H14F</td>
<td>0.62</td>
<td>0.50</td>
<td>0.25</td>
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<td>100E439 H18</td>
<td>3.20</td>
<td>2.55</td>
<td>1.00</td>
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With the exception of the ZrC, all of these specimens were fatigue cracked.

Typical center cracked sheet fracture toughness specimens of titanium and copper-boron are shown in Figure 2-3. The titanium specimens were nominally 3.00 in. wide and 0.20 in. thick. The CuB$^{10}$ sheets were about 3.2 in. wide and 0.1 in. thick and the CuB$^N$ sheets were about 3.1 in. by 0.05 in. The actual dimensions of each specimen are given in the data tables of Section 5-3.

Specimens illustrated in Figure 2-4 are the Al 5086-H-34 tear, Feuralon tensile (1.0-in. gage length) and flexure (5.00 in. long, 0.50 in. wide, 0.25 in. thick), fibrous graphite flexure (4.0 in. long, 0.25 in. wide, 0.2 in. thick), Al 7075-T73 adhesion, and the Timken race used in the sliding wear test of the actuator lubricant. Figure 2-5 shows an A-286 spring and a copper-boron Belleville spring.

Available pedigree data for the materials are contained in Appendix A.
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<th>Type of Test</th>
<th>Configuration Drawing</th>
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<td>Tensile&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>LH₂</td>
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<td>Helium</td>
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<td>M-7-2</td>
<td>Ti 6Al-4V</td>
<td>Tensile</td>
<td>1138194</td>
<td>LN₂ &amp; H₂O</td>
</tr>
<tr>
<td></td>
<td>M-9-1</td>
<td>Ti 6Al-4V</td>
<td>Sheet Fracture Toughness</td>
<td>1138226</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>M-9-3</td>
<td>Ti 6Al-4V</td>
<td>Tensile</td>
<td>1138194</td>
<td>LN₂</td>
</tr>
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<td></td>
<td>M-14-1</td>
<td>Feuralon, Type AW</td>
<td>Tensile</td>
<td>1139068</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>M-14-2</td>
<td>Feuralon, Type AW</td>
<td>Flexure</td>
<td>1138147</td>
<td>LH₂</td>
</tr>
<tr>
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<td>M-16-1</td>
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<td>M-16-2</td>
<td>18 Ni Maraging Steel</td>
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<tr>
<td></td>
<td>M-21-1</td>
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<td>1138365</td>
<td>LN₂</td>
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<tr>
<td></td>
<td>M-21-2</td>
<td>A1 7075-T73</td>
<td>Fracture Toughness</td>
<td>1138365</td>
<td>LN₂</td>
</tr>
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<td>M-21-4</td>
<td>A1 7075-T73</td>
<td>Adhesion&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>LN₂ &amp; H₂O</td>
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<tr>
<td></td>
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<td>AISI 9310 Steel</td>
<td>Tensile</td>
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<td>LN₂</td>
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<td>LN₂</td>
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<tr>
<td></td>
<td>M-38-1</td>
<td>ARMCO Alloy 22-13-5</td>
<td>Tensile</td>
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<td>LN₂</td>
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<td>M-38-3</td>
<td>ARMCO Alloy 22-13-5</td>
<td>Fracture Toughness</td>
<td>1138365</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>M-38-4</td>
<td>ARMCO Alloy 22-13-5</td>
<td>Tensile</td>
<td>1138365</td>
<td>LN₂</td>
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<tr>
<td></td>
<td>M-39-1</td>
<td>Be Cu Springs</td>
<td>Spring Constants</td>
<td>N/A</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>M-40-1</td>
<td>Hastelloy X</td>
<td>Tensile&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1138265</td>
<td>LN₂ &amp; H₂O</td>
</tr>
<tr>
<td></td>
<td>M-40-1</td>
<td>Ti 5A1 2.55n ELI</td>
<td>Tensile</td>
<td>1139567</td>
<td>LN₂ &amp; H₂O</td>
</tr>
<tr>
<td></td>
<td>M-40-1 &amp; RTS-60</td>
<td>A1 6061-T61</td>
<td>Tensile</td>
<td>(389D082 H01)</td>
<td>LN₂ &amp; H₂O</td>
</tr>
<tr>
<td></td>
<td>44A004</td>
<td>Bearing Retainers</td>
<td>Tensile&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1139961</td>
<td>LH₂</td>
</tr>
<tr>
<td></td>
<td>RTS-56</td>
<td>Actuator Lubricant</td>
<td>Timken Race</td>
<td>N/A</td>
<td>LH₂</td>
</tr>
<tr>
<td></td>
<td>RTS-58</td>
<td>A-286 Springs</td>
<td>Spring Constants</td>
<td>388D992</td>
<td>LN₂, LH₂, Air</td>
</tr>
<tr>
<td></td>
<td>RTS-61</td>
<td>A1 6061-T61</td>
<td>Fracture Toughness</td>
<td>1000B439 H38</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-62</td>
<td>A1 5086-H-34</td>
<td>Tensile</td>
<td>1000B445 H05</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-63</td>
<td>A1 5086-H-34</td>
<td>Tear</td>
<td>1000B445 H05</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
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<td>CuNi10</td>
<td>Sheet Fracture Toughness</td>
<td>577F686 H03</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-65</td>
<td>CuNi</td>
<td>Sheet Fracture Toughness</td>
<td>577F686 H04</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-66</td>
<td>ZrC</td>
<td>Flexure</td>
<td>388D613</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-67</td>
<td>ZrC</td>
<td>Fracture Toughness</td>
<td>577F544 H14F</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-68</td>
<td>A-286</td>
<td>Tensile&lt;sup&gt;d&lt;/sup&gt;</td>
<td>609B231</td>
<td>LN₂</td>
</tr>
<tr>
<td></td>
<td>RTS-69</td>
<td>Beryllium</td>
<td>Fracture Toughness&lt;sup&gt;d&lt;/sup&gt;</td>
<td>100B439 H18</td>
<td>LN₂</td>
</tr>
</tbody>
</table>

<sup>a</sup>Specimens shipped to LASL for testing.
<sup>b</sup>Some specimens shipped to LASL for testing.
<sup>c</sup>Specimens lost due to detonations in dewar.
<sup>d</sup>Some specimens lost due to detonation in dewar.
<sup>e</sup>Unnotched and notched specimens were irradiated bare in the cryogens and in steel capsules pressurized with hydrogen gas at 1000±25 psig. The encapsulated specimens were irradiated in LN₂ only.
Figure 2-1 Configurations of Tensile Specimens
Figure 2-2 Configurations of Compact-Tension Type Fracture Toughness Specimens
Figure 2-3 Configurations of Sheet Fracture Toughness Specimens
Figure 2-4 Configurations of Miscellaneous Specimens

ANSC 1138310 (Adhesion)

ANSC 1139068 (Feuralon)

ANSC 1138147 (Feuralon)

ANSC 1138147 (Fibrous Graphite)

WANL 100E445 (Tear)

Timken Race

2-7
Figure 2-5 Configurations of Springs

A-286 Spring

BeCu Belleville Spring
III. IRRADIATION PROCEDURES

Test GTR 23 consisted of the irradiation and testing of selected components and structural materials which were irradiated in LN$_2$, LH$_2$, water, and air. The fast-neutron fluences required by the ANSC and WANL tests called for an irradiation of 6000 MWh. A separate low-power-level mapping run was made to confirm the correct positioning of the test specimens in the irradiation fixtures.  

3.1 Radiation Source

The 10-MW Ground Test Reactor (GTR), which served as the radiation source for this experiment, is a light water-moderated, heterogeneous, solid-fuel reactor. The core contains 33 MTR-type aluminum-clad fuel elements and five control rod assemblies. The core is suspended by an aluminum frame from upper structural members of an aluminum tank. The water-filled tank is located at one end of a below-grade pool leaving a dry irradiation cell at the other end. The reactor is carried by a horizontal positioning mechanism that permits it to be moved into and out of the closet-like structure built into the north wall of the GTR tank. When in the closet, three faces of the core are available for irradiation of test items placed adjacent to the
three sides of the closet - designated east, west, and north. The hydrogen dewar was placed in the east position, the nitrogen dewar in the north position, and the table for components in air in the west position.

The reactor closet is constructed of 1-in. aluminum plate covered (on areas adjacent to the reactor core) by a 20-mil thickness of cadmium to attenuate thermal neutrons. The cadmium extends 36 in. east and west from the closet along the tank wall and 36 in. up and down from the horizontal centerline of the reactor core. The centerline is 59 in. above the irradiation cell floor.

3.2 Irradiation Fixtures

3.2.1 Liquid Hydrogen Dewar

The liquid hydrogen dewar was a double-walled stainless-steel vessel with the annulus evacuated to provide an insulating barrier. Inner dimensions were 24-in. diameter by 40-in. height.

The dewar was equipped with two supply lines, one exhaust line, and two liquid level probes. Effluent hydrogen gas was exhausted directly through a port in the dewar lid to an exhaust gas system which carried it to the flare stack where it was burned.

All penetrations through the LH₂ dewar lid were enclosed by an inerting shroud atop the lid. The purpose of the shroud was
to provide an inert atmosphere (gaseous helium) in the immediate vicinity of penetrations at the lid and far enough above the lid to allow the lines and cables to warm to near cell temperature. The shroud was continually purged with helium gas; the outflowing gas was monitored for hydrogen content and exhausted through the GH₂ exhaust system. The seal between the shroud and the dewar lid was a bolted flange with a compressible gasket. Penetrations into the shroud were through welded or bolted flanges for lines and tubing and hermetic connectors for electrical harnesses.

3.2.2 Liquid Nitrogen Dewar

The liquid nitrogen dewar was of similar design to those used previously in tests GTR 20C and GTR 22; it consisted of a removable inner LN₂ container and an outer chamber which maintained a flow of GN₂ around the LN₂ container. The inner container was designed in such a manner that when it was attached to the dewar lid effluent gaseous nitrogen flowed over the front edge (reactor side) of the LN₂ container, down the front face, under the LN₂ container, and back up and out the dewar vents. Barrier plates on either side of the LN₂ container formed the exhaust path for the GN₂. The continuous flow of cold GN₂ provided sufficient cooling of the reactor side of the irradiation dewar to preclude excessive heating. The dewar was equipped
with two LN$_2$ supply lines, two liquid level probes, two dump valves, and four exhaust tubes.

The pressures and liquid levels in both the LN$_2$ and LH$_2$ dewars were monitored and controlled from the Radiation Effects Test System (RETS) Console. The liquid level probes were equipped both with resistors and thermocouples located at predetermined points throughout the depth of the dewar. The resistors were connected to a discrete-level indicator/annunciator panel. The thermocouples were connected, through a switch selector, to Bristol recorder-controllers. The Bristols provide automatic level control at any of the probe thermocouple locations.

Pressures in both dewars and in the shroud of the LH$_2$ dewar were sensed by 0–15 psig transducers. The transducers were located outside the high radiation field of the GTR cell and were connected to the dewars with copper tubing. The transducer outputs were displayed at the RETS console.

3.2.3 West Table and Water Rack

An open table was installed at the west irradiation position to hold the air-irradiated specimens. The specimens were grouped by target fluence and located accordingly on the table which extended from the closet to the cell wall.
The specimens irradiated in water were installed in a water rack which attached directly to the south face of the GTR frame.

3.3 Dosimetry Procedures

Target neutron exposures for the components were specified as the fluences of neutrons of energy greater than 1 MeV. To arrive at a specimen arrangement for the various irradiation fixtures and then determine by measurement the actual exposure of each specimen required the following steps:

1. Based on data from previous irradiations, a specimen layout based on the required neutron fluences was made for each fixture.

2. Specimen locations were verified or adjusted by use of data from a short-duration mapping irradiation.

3. Neutron fluences received by the specimens during the actual irradiation were measured by means of nickel foils. Conversion factors necessary to convert measured fluences to the proper energy range (E > 1 MeV) were based on neutron spectral data obtained in this and previous tests.

Prior to the 6000-MWh irradiation, both dewars and the water rack (but not the air table) were mapped in a one-hour irradiation at a power level of 100 kW. The dewars were filled with cryogen and most of the material specimens were in place, but to avoid possible damage to the electronic components during the subsequent warmup and handling to remove the dosimeters, most
of them were not in place during the mapping. Dosimeters were placed at or near the planned locations, however. Upon completion of the irradiation, which was made on 17 May 1972, the fixtures were removed from the irradiation cell and the dosimetry was retrieved for measurement. Fluxes measured with sulfur pellets (E > 2.9 MeV) were converted to fluxes of E > 1 MeV and projected to fluences for 6000 MWh. Data from indium foils (E > 0.85 MeV) in conjunction with spectral data from previous tests were used to make the energy conversion. The conversion factors (E > 2.9 MeV to E > 1 MeV) were 2.85 for air and ranged from 2.4 to 3.7 for the LH$_2$ dewar and from 3.4 to 4.8 for the LN$_2$ dewar.

Cobalt glass dosimeters were irradiated during the mapping run at some locations of interest. Neutron-to-gamma ratios were then used to estimate total gamma doses.

The fast-neutron fluences received by the test specimens during the GTR-23 irradiation were measured with nickel foils attached to or placed near them. Data from these foils in conjunction with the energy-range conversion factor were used to compute fluences of E > 1 MeV.

Table 3-1 gives error assignments for pertinent dosimetry measurements.
### Table 3-1

ERROR ANALYSIS OF DOSIMETRY MEASUREMENTS

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Accuracy and/or Precision</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuclear Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutron detectors (count data)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>. Sulfur E &gt;2.9 MeV</td>
<td>+1%</td>
<td>Estimated from count data obtained in the mapping run.</td>
</tr>
<tr>
<td>. Phosphorus E &lt;0.48 eV</td>
<td>+2%</td>
<td>&quot;</td>
</tr>
<tr>
<td>. Indium E &gt;0.85 MeV</td>
<td>+2%</td>
<td>&quot;</td>
</tr>
<tr>
<td>. Nickel E &gt;2.9 MeV</td>
<td>+1%</td>
<td>Estimated from count data obtained from actual test configuration (6000 MWh).</td>
</tr>
<tr>
<td>Weight</td>
<td>+1%</td>
<td>Estimated from sample.</td>
</tr>
<tr>
<td>Intercalibration of Counters</td>
<td>+1%</td>
<td>Estimated from counting same foil on each counter.</td>
</tr>
<tr>
<td>Gamma (Cobalt Glass)</td>
<td>+3%</td>
<td>Estimated from pairs of Cobalt glass gamma detectors from mapping run.</td>
</tr>
<tr>
<td>GTR Spectrum E &gt;1 MeV</td>
<td>+10%</td>
<td>Estimated from threshold detectors - Al, 8.1 MeV; S, 2.9 MeV; U, 1.5 MeV; In, 0.85 MeV; Np, 0.75 MeV; and Pu, 1 keV.</td>
</tr>
<tr>
<td>Basic calibration of counters</td>
<td>+5%</td>
<td>Calibrations of counters with: 4 pi counters; beta-gamma coincidence counting and counting standard source techniques.</td>
</tr>
<tr>
<td>Source of Error</td>
<td>Accuracy and/or Precision</td>
<td>Basis</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Extrapolation from mapping run data to measured Ni fluences for specimen irradiation</td>
<td>±10%</td>
<td>Judgment.</td>
</tr>
<tr>
<td>Combined (E &gt; 1 MeV)</td>
<td>±15%</td>
<td>Root mean square.</td>
</tr>
<tr>
<td>Thermal neutron fluence (E &lt; 0.48 eV)</td>
<td>±7%</td>
<td>Estimated by the difference between bare and cadmium covered phosphorus (1/ν) detectors which are activated independent of spectrum shape up to cadmium flux. Each detector uncertainty is ±5%.</td>
</tr>
<tr>
<td>Averaging of fluence for each group of specimen (E &lt; 0.48 eV)</td>
<td>±5%</td>
<td>Used only average fluence for each group of specimen instead of individuals.</td>
</tr>
<tr>
<td>Combined (E &lt; 0.48 eV)</td>
<td>±18%</td>
<td>Root mean square: extrapolation from mapping run data, calibration of counters, etc.</td>
</tr>
<tr>
<td>Gamma Dose</td>
<td>±19%</td>
<td>Estimated from gamma/neutron ratio obtained from mapping run with cobalt glass gamma detectors and sulfur neutron detectors (2.9 MeV) and measured Ni fluence (2.9 MeV) from 6000 MWh test.</td>
</tr>
</tbody>
</table>
3.4 GTR-23 Irradiation

The 6000-MWh irradiation was started on 24 May 1972 and was concluded on 7 July 1972. A summary of the reactor log is given in Table 3-2. It should be noted that the elapsed time at power includes only the time the reactor was operating in the closet position.

3.5 Postirradiation

The specimens irradiated in LN$_2$ were stored in LN$_2$. Those to be tested in LN$_2$ were transferred to the test apparatus without being removed from the cryogen. Specimens tested at temperatures above $140^\circ$R were transferred from LN$_2$ to the appropriate temperature control apparatus at the time of the test. At completion of the testing, the specimens were measured and photographed, as specified, or placed in storage until post-test measurements were complete.

The specimens irradiated in LH$_2$ were removed from the dewar at an appropriate time and placed in storage at ambient temperature until testing or shipment to LASL.
### Table 3-2

**SUMMARY OF GTR-23 REACTOR LOG**

<table>
<thead>
<tr>
<th>Power Level (MW)</th>
<th>Elapsed Time at Power (h)</th>
<th>Accumulated Exposure (MWh)</th>
<th>Remarks</th>
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<tr>
<td>4</td>
<td>0.33</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.47</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4.12</td>
<td>45.8</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>24.11</td>
<td>286.9</td>
<td>GTR scram.</td>
</tr>
<tr>
<td>1</td>
<td>0.10</td>
<td>287.0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>25.97</td>
<td>546.7</td>
<td>GTR retracted; hydrogen leak on ramp.</td>
</tr>
<tr>
<td>9.2</td>
<td>0.23</td>
<td>548.8</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>30.92</td>
<td>858.0</td>
<td></td>
</tr>
<tr>
<td>9.5</td>
<td>0.28</td>
<td>860.7</td>
<td>GTR retracted; electronic components data cycle.</td>
</tr>
<tr>
<td>10</td>
<td>24.40</td>
<td>1140.7</td>
<td></td>
</tr>
<tr>
<td>9.6</td>
<td>0.03</td>
<td>1105.0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20.52</td>
<td>1310.2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.17</td>
<td>1311.6</td>
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<td>9.15</td>
<td>1403.1</td>
<td></td>
</tr>
<tr>
<td>9.1</td>
<td>0.17</td>
<td>1404.6</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10.72</td>
<td>1511.8</td>
<td></td>
</tr>
<tr>
<td>9.3</td>
<td>0.12</td>
<td>1512.9</td>
<td>GTR scram.</td>
</tr>
<tr>
<td>10</td>
<td>116.35</td>
<td>2676.4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.06</td>
<td>2676.5</td>
<td>GTR shutdown; detonations in ice on GH₂ exhaust line.</td>
</tr>
<tr>
<td>10</td>
<td>0.78</td>
<td>2684.3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3.20</td>
<td>2716.3</td>
<td>GTR shutdown; malfunction of irradiation-cell exhaust dampers.</td>
</tr>
<tr>
<td>10</td>
<td>217.10</td>
<td>4887.3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6.92</td>
<td>4956.5</td>
<td>GTR shutdown; broken air line.</td>
</tr>
<tr>
<td>10</td>
<td>104.45</td>
<td>6001.0</td>
<td>GTR scram</td>
</tr>
</tbody>
</table>
IV. TEST EQUIPMENT AND METHODS

4.1 Test Equipment

Equipment required for performing specified tests on GTR 23 test specimens included:

1. Tensile test machines and associated components for tension tests and fracture toughness tests at test temperatures called for in the test specifications.

2. Displacement gages for fracture toughness tests.

3. A sliding wear tester for testing an actuator lubricant.

Additional equipment used included an optical comparator for determination of physical dimensions of test specimens before and after testing and a macrocamera with Polaroid attachment for photographing individual specimens.

4.1.1 Tensile Test Machine and Accessories

Three tensile test machines were employed in testing the ANSC and WANL specimens. They were the Model TT-C and Model TT-D Instron machines and the Model 120A Baldwin test machine. The Model TT-C (10,000-lb load capacity) and the Model TT-D (20,000-lb load capacity) Instrons were used for testing of all tensile, fracture toughness, tear, and flexure specimens with the exception of the Ti 6Al 4V fracture toughness specimens which were tested on the Baldwin machine (120,000-lb load capacity).
The cryostat of the type used for immersing ANSC and WANL specimens in LN$_2$ while being tested is shown installed in the Instron strain frame in Figure 4-1. Figure 4-2 shows the Baldwin tester with cryostat in place. The cryostats were fabricated of urethane foam material. The inner and outer surfaces were coated with successive layers of RTV 102 silicone adhesive and fiberglass cloth, with the final layer of RTV 102.

For WANL tensile and fracture toughness tests at 276°, 340° and 406°R, a double-walled container having small holes in the inner wall was used for temperature control of the test specimen. The container enclosed the grip and specimen section of the Instron load train. Cold nitrogen gas supplied at a controlled rate between the chamber walls flowed over the test specimen and grips. The flow rate of the cold GN$_2$ was adjusted to keep the specimen at the desired temperature during testing. This double-walled container was also used for annealing of specimens at temperatures between 140° and 540°R. The specimens were suspended in the wire basket within the cylinder wall along with a dummy specimen instrumented with a thermocouple to monitor temperatures during annealing. The flow rate of the cold nitrogen gas was adjusted to keep the specimen at the desired temperature.
Figure 4-1 Instron Cryostat Mounted in Test Position
Figure 4-2  Baldwin Tester Used for Testing Titanium Fracture Toughness Specimens
In tensile tests performed above $540^\circ R$ (one material) specimen test temperature was maintained by use of a Norton Model 2285 furnace set up as shown in Figure 4-3. The temperature calibration procedures for elevated temperature tests and for the low temperature tests between $140^\circ$ and $540^\circ R$ are described in Sections 4.2.2.1 and 4.2.2.2, respectively.

4.1.2 Displacement Gages for Use in Fracture Toughness Tests

The displacement gages used in fracture toughness tests were made according to ASTM Part 31, "Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," dated 31 May 1970. Figure 4-4 is a drawing of a typical displacement gage mounted in a specimen, and Figure 4-5 is a photograph of a displacement gage mounted in a specimen. Figure 4-6 is a dimensional drawing of the beams and spacer block.

The cantilever beams were made of either alpha or beta titanium, depending upon the availability of the material.

Two types of foil strain gages were purchased from two separate manufacturers. Epoxy bonding material compatible with the respective gages was chosen to bond the strain gages to the beams. Strain gage type SA-06-125AC-350, manufactured by Micro-Measurements, Romulus, Michigan, was bonded onto the beams with
Figure 4-3  Norton Model 2285 Split Furnace Installed on Instron Model TT-D Tester
Figure 4-4 Typical Displacement Gage Mounted in a Specimen
Figure 4-5  Fracture Toughness Specimen with Displacement Gage in Place
Figure 4-6  Dimensional Drawing of Displacement Gage Beams and Spacer Block
Di-Bond 600 epoxy. Strain gage type FSM-25-35S6, manufactured by BLH Electronics, Waltham, Mass., was bonded onto the beams with EPY 550 epoxy.

Two gages of the same type were bonded onto each of the two beams as close as possible to the beam spacer block. The four gages were connected as shown in the sketch below. The bridge circuit provides maximum displacement gage sensitivity and self temperature compensation.

Displacement Gage Bridge Circuit

4.2 Test Methods

4.2.1 Axiality Checks for the ANSC Tensile Specimens

In order to ascertain that the pull rods, the specimen grips, and the specimens within the grips were all aligned so as to provide axial loading of the test specimens, axiality checks were performed prior to initiating tensile tests. The checks were performed at room temperature on both Instron machines using a strain gage instrumented specimen provided by ANSC.
The axiality checks were performed in accordance with ANSC Preliminary Standard Procedure RE-1, "Procedure for Axiality Determination for Tensile Test Apparatus," dated July 1970. The procedure provides a method for assessment of the stability of the load train, the magnitudes and directions of the bending strains over the specimen length, and proportions of the bending strain due to test apparatus and test specimens.

The following are the general requirements of the procedure:

1. **Axiality Test Specimen (ATS)**
   a. The ATS shall be of the same configuration in the grip or holder area and the same length as the specimens used for data collection.
   b. The ATS shall be of a material and dimension sufficient to withstand the anticipated load required to yield the data collection specimens without yielding the ATS. The maximum anticipated load should correspond to approximately 60 to 70 percent of the ATS material yield strength.

2. **Load Train**
   a. Mark all load train components with a continuous vertical line. All components, except the ATS, must be kept in the same angular position throughout the test series.
   b. Record the relationship between the location of the load train vertical line and some permanent fixture of the test machine. An accuracy of $+5^\circ$ is sufficient for this purpose.
   c. Record the relationship between the ATS and the test machine so that location of strain gages with respect to the test machine can be determined.
d. The condition of the load train for the axiality test shall be the same as for data collection.

3. **Strain Gages**

Foil gages of 120-ohm resistance shall be used. Size of the gage will be determined by the space available.

4. **Collection of Axiality Data**

Record strain gage readings in microinches per inch.

a. Take strain gage readings with the load train hanging freely.

b. Load the ATS to the required value and hold constant while recording the output from the strain gages.

c. Release the load and read the gages again.

d. Rotate the ATS 180° and repeat the test. Do not rotate the load train or any portion thereof.

e. Return the specimen to its original position. Repeat the cycle of two loadings (specimen at 0° and 180°) so as to obtain five loadings in the first position (0°) alternating with five loadings in the second position (180°).

Axiality tests performed prior to testing all buttonhead specimens were accomplished with an Inconel 718 buttonhead specimen fabricated to AGC Drawing No. 1134298-1 with strain gage assemblies mounted according to AGC Drawing No. 1138347. The ATS was equipped with two sets of four strain gages each. One set of four gages was placed near each end of the gage section,
and the gages were spaced circumferentially (90° Apart) as indicated in the sketch below.

![Sketch of Strain Gage Location for Round Axiality Test Specimen (ATS)](image)

The results of axially tests performed prior to testing the buttonhead specimens showed that the maximum bending strain due to the apparatus was 6.8%. ANSC has concluded that a tolerance of 9.2% maximum bending strain due to apparatus at the center of the specimen will provide acceptable axially.

4.2.2 Temperature Calibration Procedures

4.2.2.1 Calibration Procedures for 740°R

In the test requiring specimens to be tested at a temperature of 740°R, the temperature of the specimen during testing
was controlled by monitoring and regulating the temperatures of the specimen grips. The calibration procedure was as follows:

1. Thermocouples were embedded in both the upper and lower grips.

2. A thermocouple was resistance welded or embedded in the center of the gage-length section of a specimen of the same configuration and material as that to be tested.

3. The thermocouple-instrumented specimen was then placed in the Instron grips and the furnace was closed.

4. Power was applied to the furnace by each of three temperature controllers. When the specimen-mounted thermocouple reached the desired test temperature, the control setting for each controller was adjusted to maintain the desired test temperature and to minimize temperature gradients between the specimen and grips.

5. With the specimen temperature stabilized, the setting for each temperature controller was noted.

6. During the tests, the temperature of each specimen was controlled by the three temperature controllers and monitored by the temperatures of the upper and lower grips.

The calibration procedure was repeated several times at each test temperature to ensure reproducible results.

4.2.2.2 Calibration of Cold GN₂ Fixture for Temperatures Between 140° and 540°R

Calibration of the double-walled GN₂ temperature control fixture for test temperatures of 276°, 340°, and 406°R was
accomplished in much the same manner as for elevated tempera-
ture tests. The calibration procedure was as follows:

1. Thermocouples were embedded in both the upper and lower grips.

2. A thermocouple was resistance welded or embedded in the center of the gage-length section of a specimen of the same configuration and material as that to be tested.

3. The Instron cryostat was filled with LN₂.

4. The thermocouple-instrumented specimen was then placed in the Instron grips and the double-walled GN₂ fixture lowered into position to encase the grips and specimen.

5. The LN₂ was drained from the cryostat and flow of cold GN₂ through the double-walled fixture was initiated.

6. Flow of GN₂ was controlled manually until the temperature approached to within about 50° of the desired temperature, at which time the system was switched to automatic control and brought to the test temperature. Once the temperature was reached, the set-point of the automatic control was adjusted to maintain the desired temperature. The automatic control actuated a solenoid valve which supplied GN₂ upon demand as sensed by one of the grip thermocouples.

4.2.3 Annealing of Specimens at 540°R

The thermocouple-instrumented specimen was placed in LN₂ and allowed to cold soak for 30 minutes. Then it was removed from the LN₂ and placed in a water bath. The time/temperature profile of the instrumented specimen was monitored and the time required for it to reach 540°R was noted; this was found to be approximately 1 minute. Therefore, specimens scheduled for annealing at 540°R
were removed from LN2 and submerged in water (1 gallon) until approximately 5 minutes before the annealing period was complete. They were then removed from the water, dipped in acetone, and dried. At the end of the specified annealing period plus 1 minute, the specimens were returned to LN2 until tested.

4.2.4 Tensile Tests

For those specimens tested at 1400R, a cryostat, as described in Section 4.1.1, was installed in the tensile test machine as shown in Figure 4-1. The specimen to be tested was transferred from the handling dewar to the cryostat using a small dipper so that it remained submerged in LN2 at all times. The specimen was then loaded into the grips and tested to fracture in accordance with the applicable test specifications.

For tensile tests at 3400 the double-walled fixture described in Section 4.1.1 was used in conjunction with the LN2 cryostat used in testing at 1400R. The fixture was installed in the tensile test machine so that it enclosed the specimen grips. With the cryostat filled with LN2, the specimen was loaded into the grips and cold GN2 flow was initiated to the annealing fixture. The LN2 was then drained from the cryostat. The GN2 flow rate and temperature was varied as required to warm the specimen to the desired temperature, as indicated by the grip thermocouples,
and to maintain it at temperature until the specimen had been tested to fracture.

For tests performed at 740°R, the Norton Model 2285 furnace was installed on the Instron Model TT-D tester as shown in Figure 4-3. The furnace was preheated to the desired temperature and control settings established at each test temperature using the procedures outlined in Section 4.2.2. Each specimen to be tested was removed from the LN$_2$ storage dewar and placed in a water bath (1 gallon) for approximately 1 minute. Then it was dipped in acetone and dried. The specimen was then placed in the Instron grips, heated to the desired test temperature, and (after a 5-minute soak period at temperature) pulled to fracture.

4.2.5 Fracture Toughness Tests

All of the fracture toughness specimens were tested in accordance with the applicable specifications. The displacement gage, described in Section 4.1.2 (Fig. 4-7), was used on all of the materials tested as fracture toughness specimens with the exception of the small ZrC specimens and the titanium sheet specimens.

Tests were performed at 140°R by use of the cryostat installed in the Instron. Specimens were transferred from the storage dewar to the test cryostat under LN$_2$. The displacement
gage was installed in the test specimen opening between the two gage points, allowed to stabilize at LN₂ temperature, and adjusted by the procedures described below.

For fracture toughness tests at temperatures between 140° and 540°R, the same fixtures and procedures as described for the tensile tests were used. Specimens to be tested at 540°R were removed from the LN₂ storage dewar and placed in a water bath for approximately 1 minute. It was then dipped in acetone and dried. Installation and use of the displacement gage was the same regardless of the test temperature.

The criteria used for evaluating the displacement gages conformed to that stated in ASTM Part 31, "Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," dated 31 May 1970. Each displacement gage was tested over a range adequate for measuring the relative displacement of two gage points of a specimen under test. At zero displacement the distance between the gage points for the specimens tested was 0.20 in. and at maximum displacement, just before crack extension, the distance between the gage points was less than 0.25 in. Hence, the displacement gages were tested over a displacement range from 0.20 in. to 0.25 in.
The equipment used for evaluating the displacement gages consisted of a Boeckeler Micrometer, a strain gage switching and balancing unit, a strain indicator, a dewar to contain LN₂, and miscellaneous hardware.

The Boeckeler Micrometer that was used for displacement interval settings is a precision instrument manufactured by Arizona Tool and Die Co., Tucson, Arizona. The instrument can be read to 0.00002 in. Special jaws were made for the micrometer with knife edges comparable to the gage points of a specimen. The knife edges allowed proper engagement of the displacement gage.

A Model 225 Switching and Balancing Unit and a Model 120C Strain Indicator, both manufactured by BLH Electronics, Inc., were used for balancing and indicating displacement gage output. The strain indicator has a readability of 1 microinch/inch.

A minimum of three sets of data were recorded at test temperatures of 140°, 273°, 406°, and 540°R. Temperature stabilization for 30 min was allowed (as required by the test specification) at each test temperature before readings were taken. To obtain accurate data it was necessary to maintain the gage and a portion of the micrometer at the test temperature. Readings were obtained for ten displacement intervals of 0.005 in. between 0.20 in. and 0.25 in. After each set of data, the gage was removed and re-installed in the micrometer before the next set of data was taken.
The data were analyzed to detect deviations from linearity over the displacement range. The required linearity corresponded to a maximum deviation of 0.001 in. of the individual displacement readings from a least-squares best-fit straight line through the data. Displacement gages which did not conform to the linearity criterion were rejected.

In setting up for the fracture toughness testing, the displacement gage was connected to the Instron chart drive system by means of an external balance potentiometer and the Instron strain-gage preamplifier as shown in the sketch below.

![Sketch of Displacement Gage Connected with Instron Chart Drive System](image)

Calibration of the displacement gage and Instron system was obtained with the displacement gage set in the micrometer initially at 0.20 in. opening and the gage and a portion of the micrometer at the test temperature. After 30 min for temperature stabilization, the strain-gage preamplifier was nulled by alternately adjusting the external balance potentiometer and
strain-gage preamplifier balance control. Upon completion of null, the displacement gage was opened to force chart travel. The gain of the preamplifier was adjusted to give the desired chart travel. Normally, this was 1 in. for 0.004 in. of displacement gage opening. Linearity of the system was satisfactory over the operating range.

In testing the fracture toughness specimens, the displacement gage was placed in the specimen opening between the two gage points, allowed to stabilize at the test temperature, and then adjusted to null by the method described previously. The specimens were pulled at a constant loading rate, with the exception of CuB, with the load being recorded on the x axis of the Instron chart. Chart travel in the y direction was proportional to the displacement change between the two gage points. A linear record of displacement vs load was obtained up to the point of crack extension.

4.2.6 Tear Test

The tear test was performed by use of the Model TT-D Instron machine operated in the same manner as for tensile tests. Tests at 140° and 340° were by the same techniques as described in Section 4.2.4. A load/deformation curve plotted on the Instron recorder with the machine operating at a constant crosshead speed provided the required data.
4.2.7 Flexure Tests

Flexure tests were performed on two materials by the procedure described in ASTM Procedure D790 (Ref. 1). The Feuralon plastic was tested with a setup similar to that illustrated in Sketch (a) of D790. Three-eighths-inch-diameter rods were used for support and loading; the span was 4.0 in. The Model TT-D Instron operating at a constant crosshead speed was used to apply the load.

A test fixture for the small ZrC flexure specimens was not available so the procedure was somewhat different in that the supports were flat surfaces with a one-inch span. The load was applied with a 3/8-in.-diam rod by use of the Model TT-D Instron operating at a constant crosshead speed.

4.2.8 Test of Springs

The springs were loaded in compression by use of the Model TT-C Instron. Load was applied at a constant crosshead speed up to the maximum specified deflection. The Belleville springs were tested in a fixture which mechanically limited the compression to 0.081 in. Load/deflection charts recorded on the Instron recorder provided the required data.

4.2.9 Sliding Wear Test

The actuator lubricant was tested by use of the Hohman A-6 sliding wear tester (Fig. 4-7). A bearing load of 110 lb per
Figure 4-7 Diagrammatic Sketch of Hohman A-6 Wear Tester
rub shoe was applied to the test cup having a speed of 128 sliding feet per minute. The test was terminated when the friction coefficient reached 0.4.

4.2.10 Bench Measurements

Bench measurement data used for calculating percent elongation and percent reduction of area were measured with a Scherrer-Tumico Model P-1500 optical comparator. Special fixtures were designed to align the broken specimens and fit them together, thus facilitating determination of specimen length at fracture and cross-sectional area. These measurements were compared with preirradiation data which were also obtained with the optical comparator.

Bench measurement data required for determination of fracture toughness characteristics were also obtained with the Scherrer-Tumico optical comparator. The dimensions of the pre-crack profile were measured after fracture; all other measurements were obtained prior to irradiation.

4.2.11 Photography

Photographs were taken showing the fracture surface of selected broken specimens. These photographs are not contained in this report but were submitted directly to LASL.
V. PRESENTATION OF DATA

5.1 Tensile Data

The tensile data in Tables 5-1 through 5-16 are presented in the following order:

M-9-1 Titanium 6Al 4V (sheet)
M-9-2 Titanium 6Al 4V (welded sheet)
M-16-1 18 Ni Maraging Steel
M-21-1 Aluminum 7075-T73
M-31-1 AISI 9310 Steel
M-38-1 ARMCO 22-13-5 Steel
M-38-4 ARMCO 22-13-5 Steel
M-40-1 Titanium 5Al 2.5Sn (unnotched and notched)
M-40-1 Hastelloy X (unnotched and notched)
RTS-60 Aluminum 6061-T61 (unnotched and notched)
RTS-62 Aluminum 5086-H-34 (unwelded and welded sheet)

The following general information and property data are presented in the data tables for the unnotched specimens:

1. Designation of the material
2. Drawing number
3. Specimen number
4. Test condition (control or irradiated)
5. Instron crosshead speed
6. Irradiation and test temperatures
7. Anneal time and temperature (if any)
8. Yield stress at 0.2% offset
9. Maximum stress
10. Fracture stress
11. Percent elongation from both Instron chart and bench measurements
12. Percent area reduction from bench measurements

13. Fracture location specified as 1, 2, 3, or 4 corresponding to the sections indicated in the sketch. Sections 1, 2, and 3 were of an equal length that depended upon the elongation. T or O indicates that the break was, roughly, transverse or oblique, respectively.

\[
\begin{array}{c}
\text{Gage Section} \\
1/8''
\end{array}
\]

4 3 2 1 2 3 4

Similar information is given for the notched specimens except that the tensile data consists of:

1. Average notch diameter
2. Area at notch
3. Fracture load
4. Fracture stress

Averages, standard deviations, and percent standard deviations have been computed for each group of specimens irradiated and tested under the same conditions. Table S-1 in the Summary gives the percent difference between data for the irradiated and control specimens and indicates if the difference is statistically significant at the 95% confidence level.
### Table 5-1

**TENSILE DATA FOR TITANIUM α-2/4V SHEET IRRADIATED AT 140°R AND TESTED AT 140° AND 540°R**

*Crosshead Speed = 0.075 in./min*  
*(Specification M-9-1)*

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*Annealed for 100 min at 540°R*

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ANSC Dwg. No. 1138194-1909. Data to be used for material evaluation only. Do not use for design.
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Tensile data for Titanium 6Al-4V sheet irradiated in water at 550° and tested at 140° and 540°. Crosshead speed = 0.075 in./min. (Specification M-91) ANSC Dwg. No. 1138194-1909. Data to be used for material evaluation only. Do not use for design.
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Crosshead Speed = 0.050 in./min

(Tensile Data for Titanium 6Al 4V Welded Sheet Irradiated and Tested at 140° R
(Specification M-9-2)

* ANSC Dwg. No. 1138194-2709. Data to be used for material evaluation only. Do not use for design.*
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ANSC Dwg. No. 1138265-120. Data to be used for material evaluation only. Do not use for design.
### Table 5-5

**TENSILE DATA FOR ALUMINUM 7075-T73 FORGING IRRADIATED AND TESTED AT 140°R**

Crosshead Speed = 0.050 in./min

(Specification M-21-1)

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ANSC Dwg. No. 1138265-114. Data to be used for material evaluation only. Do not use for design.
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Table 5-6
TENSILE DATA FOR AISI 9310 BAR IRRADIATED AND TESTED AT 140° R
(Specification M-31-1)

Crosshead Speed = 0.050 in./min

ANSC Dwg. No. 1138265-117. Data to be used for material evaluation only. Do not use for design.
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Crosshead Speed = 0.050 in./min

Table 5-7
TENSILE DATA FOR ARMCO ALLOY 22-13-5 WELDED FORGING IRRADIATED AND TESTED AT 140° R
(Specification M-38-1)

Note: ANSC Dwg. No. 1118388-3215. Data to be used for material evaluation only. Do not use for design.
Table 5-8
TENSILE DATA FOR ARMCO ALLOY 22-13-5 PLATE IRRADIATED AND TESTED AT 140°F
(Specification M-38-4)

<table>
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<th>Elastic</th>
<th>Fracture</th>
<th>% Elongation</th>
<th>% Area Reduction (Bench)</th>
<th>Fracture Location</th>
<th>Neutron Fluence (n/cm²)</th>
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<td>(ksi)</td>
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<td>To Fracture</td>
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ANSC Dwg. No. 1138265-115. Data to be used for material evaluation only. Do not use for design.
Table 5-9-A

TENSILE DATA FOR UNNOTCHED TITANIUM 5A1 2.5Sn IRRADIATED AND TESTED AT 140°C

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<th>% Area Reduct (Bench)</th>
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ANSC Dwg No. 1138265. Data to be used for material evaluation only. Do not use for design.
Table 5-9-B

TENSILE DATA FOR UNNOTCHED TITANIUM 5A1 2.5Sn ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 1400°F AND TESTED AT 1400°F

(Specification N-60-1)

Crosshead speed = 0.05 in./min

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<th>% Elongation</th>
<th>% Area Reduct (Bench)</th>
<th>Fracture Location</th>
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<td>Bench</td>
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Radiation Exposure

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ANSC Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.

aArea taken to be 0.0314 in.².
Table 5-10-A
TENSILE DATA FOR NOTCHED TITANIUM 5A1 2.5Sn IRRADIATED AND TESTED AT 140°F
(Specification M-40-1)

Crosshead Speed = 0.050 in/min

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<th>Area at Notch (in.²)</th>
<th>Fracture Load* (lb)</th>
<th>Fracture Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
<th>E &gt;1 MeV</th>
<th>E &lt;0.48 eV</th>
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* Fracture load is same maximum load

** Not included in average

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.
Table 5-10-B

TENSILE DATA FOR NOTCHED TITANIUM 5Al 2.5Sn ENCAPSULATED IN HYDROGEN
GAS AND IRRADIATED AT 140ºR AND TESTED AT 140ºR
(Specification M-40-1)

Crosshead speed = 0.05 in./min

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<th>Specimen No.</th>
<th>Max Load (lb)</th>
<th>Max Stress(^a) (ksi)</th>
<th>Fracture Load (lb)</th>
<th>Fracture Stress(^a) (ksi)</th>
<th>Neutron Fluence (n/cm(^2))</th>
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<tbody>
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ANSO Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

\(^a\)Area at notch taken to be 0.026 in.\(^2\).
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<tr>
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<th>Test Temp (°F)</th>
<th>Tensile Stress % Elongation</th>
<th>Radiation Exposure</th>
<th>Neutron Fluence (n/cm²)</th>
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<td>% Area Reduct (Bench)</td>
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Note: ANSC Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.

*This group of specimens was inadvertently warmed briefly during handling; the time/temperature profile is not known.

**The value of the tensile stress is the average of at least three specimens.**
# Table 5-11-B

TENSILE DATA FOR UNNOTCHED HASTELLOY X ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°F AND TESTED AT 140°F

(Specification M-40-1)

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<td>Fract (ksi)</td>
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<td>To Fract</td>
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<td>21.5</td>
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<td>1.97</td>
</tr>
<tr>
<td>% Std Dev</td>
<td>3.47</td>
<td>3.40</td>
<td>4.52</td>
<td>8.83</td>
<td>7.41</td>
</tr>
</tbody>
</table>

ANSO Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.

aArea taken to be 0.0314 in.².
Table 5-12-A
TENSILE DATA FOR NOTCHED HASTELLOY X IRRADIATED AND TESTED AT 140°R
(Specification M-40-1)

Crosshead Speed = 0.050 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Ave Diam. (in.)</th>
<th>Ave Notch Area at Notch (in.²)</th>
<th>Max Load (lb)</th>
<th>Max Stress (ksi)</th>
<th>Fracture Load (lb)</th>
<th>Fracture Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E &gt; 1 MeV E &lt; 0.48 eV</td>
</tr>
</tbody>
</table>

Control

| 54 | 0.1820 | 0.0260  | 4620 | 177.7 | 4500 | 173.1 |   |
| 57 | 0.1819 | 0.0260  | 4670 | 178.8 | 4550 | 175.2 |   |
| 61 | 0.1821 | 0.0260  | 4520 | 173.6 | 4300 | 165.2 |   |
| 64 | 0.1820 | 0.0260  | 4610 | 177.3 | 4500 | 173.1 |   |
| 66 | 0.1814 | 0.0258  | 4470 | 173.0 | 4300 | 166.4 |   |
| 68 | 0.1821 | 0.0260  | 4480 | 172.0 | 4250 | 163.2 |   |
| 76 | 0.1820 | 0.0260  | 4510 | 173.5 | 4400 | 169.2 |   |
| 77 | 0.1821 | 0.0260  | 4430 | 170.1 | 4250 | 163.2 |   |
| Ave|       |         | 4539 | 174.5 | 4381 | 168.6 |   |

Ave

<table>
<thead>
<tr>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Avg</th>
<th>Std Dev</th>
<th>% Std Dev</th>
</tr>
</thead>
<tbody>
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<td>3.1</td>
<td>2.8</td>
<td>122.3</td>
<td>4.8</td>
<td>2.8</td>
</tr>
<tr>
<td>1.9</td>
<td>1.8</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 72a | 0.1828 | 0.0262  | 5400 | 205.8 | 5300 | 201.9 |   |
| 80a | 0.1816 | 0.0259  | 5500 | 212.3 | 4500 | 173.7 | 8.50(17) 4.9(16) |
| 53a | 0.1818 | 0.0259  | 5590 | 215.5 | 5400 | 208.1 | 1.00(18) 4.9(16) |
| 67a | 0.1822 | 0.0261  | 5660 | 217.2 | 5500 | 211.1 | 1.14(18) 4.9(16) |
| Ave |       |         | 5537 | 212.7 | 5175 | 198.7 | 1.20(18) 4.9(16) |

Ave

<table>
<thead>
<tr>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Avg</th>
<th>Std Dev</th>
<th>% Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>112.7</td>
<td>2.0</td>
<td>5.0</td>
<td>8.8</td>
<td>457.4</td>
<td>17.1</td>
<td>8.6</td>
</tr>
<tr>
<td>2.0</td>
<td>2.4</td>
<td>8.8</td>
<td></td>
<td></td>
<td>8.6</td>
<td></td>
</tr>
</tbody>
</table>

| 62 | 0.1821 | 0.0260  | 6600 | 253.6 | 6450 | 247.8 |   |
| 75 | 0.1823 | 0.0261  | 6590 | 252.5 | 6480 | 248.3 | 1.30(18) 4.9(16) |
| 90 | 0.1819 | 0.0260  | 6230 | 239.7 | 6100 | 234.7 | 1.35(18) 4.9(16) |
| 89 | 0.1825 | 0.0262  | 6630 | 253.5 | 6500 | 248.5 | 1.44(18) 4.9(16) |
| Ave |       |         | 6512 | 249.8 | 6382 | 244.8 |   |

Ave

<table>
<thead>
<tr>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Std Dev</th>
<th>% Std Dev</th>
<th>Avg</th>
<th>Std Dev</th>
<th>% Std Dev</th>
</tr>
</thead>
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<tr>
<td>189.1</td>
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<td>6.8</td>
<td>3.0</td>
<td>189.5</td>
<td>6.8</td>
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<td>2.9</td>
<td>2.7</td>
<td>6.8</td>
<td></td>
<td></td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

| 84 | 0.1821 | 0.0260  | 6630 | 254.6 | 6450 | 247.7 |   |
| 51 | 0.1819 | 0.0260  | 6630 | 255.1 | 6500 | 250.1 | 3.80(18) 4.5(16) |
| 83 | 0.1820 | 0.0260  | 6390 | 253.3 | 6400 | 246.0 | 3.95(18) 4.5(16) |
| 70 | 0.1827 | 0.0262  | 6650 | 253.8 | 6450 | 246.2 | 4.04(18) 4.5(16) |

aThis group of specimens was inadvertently warmed briefly during handling; the time-temperature profile is not known.
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Ave Notch Diam. (in.)</th>
<th>Ave Notch Area at Notch (in.)²</th>
<th>Max Load (lb)</th>
<th>Max Stress (ksi)</th>
<th>Fracture Load (lb)</th>
<th>Fracture Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
<th>E &gt;1 MeV</th>
<th>E &lt;0.48 eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>0.1818</td>
<td>0.0260</td>
<td>6600</td>
<td>254.3</td>
<td>6450</td>
<td>248.5</td>
<td></td>
<td>4.08(18)</td>
<td>4.5(16)</td>
</tr>
<tr>
<td>69</td>
<td>0.1819</td>
<td>0.0260</td>
<td>6490</td>
<td>249.7</td>
<td>6300</td>
<td>242.4</td>
<td></td>
<td>4.08(18)</td>
<td>4.5(16)</td>
</tr>
<tr>
<td>59</td>
<td>0.1819</td>
<td>0.0260</td>
<td>6500</td>
<td>250.1</td>
<td>6300</td>
<td>242.4</td>
<td></td>
<td>4.19(18)</td>
<td>4.5(16)</td>
</tr>
<tr>
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<td>6880</td>
<td>263.9</td>
<td>6800</td>
<td>260.8</td>
<td></td>
<td>4.29(18)</td>
<td>4.5(16)</td>
</tr>
<tr>
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<td></td>
<td>6621</td>
<td>254.4</td>
<td>6456</td>
<td>248.0</td>
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<td>4.08(18)</td>
<td>4.5(16)</td>
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<tr>
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<td>4.4</td>
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<tr>
<td>% Std Dev</td>
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<td>1.7</td>
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<td>2.4</td>
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<td></td>
</tr>
</tbody>
</table>

Table 5-12-A
TENSILE DATA FOR NOTCHED HASTELLOY X IRRADIATED AND TESTED AT 140° (Cont'd)
(Specification M-40-1)

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.
Table 5-12-B

TENSILE DATA FOR NOTCHED HASTELLOY X ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°F AND TESTED AT 140°F
(Specification M-40-1)

Crosshead speed = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Max Load (lb)</th>
<th>Max Stress(^a) (ksi)</th>
<th>Fracture Load (lb)</th>
<th>Fracture Stress(^a) (ksi)</th>
<th>Neutron Fluence (n/cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E &gt; 1 MeV</td>
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<td>5480</td>
<td>221.5</td>
<td>5280</td>
<td>213.8</td>
<td>2.09(18)</td>
</tr>
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<td>48</td>
<td>5760</td>
<td>210.8</td>
<td>5560</td>
<td>203.1</td>
<td>2.10(18)</td>
</tr>
<tr>
<td>Ave</td>
<td></td>
<td>216.2</td>
<td></td>
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<td>2.10(18)</td>
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<td>Std Dev</td>
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<td>4.9(16)</td>
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<td>% Std Dev</td>
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<td>3.50</td>
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<td>6100</td>
<td>234.6</td>
<td>3.35(18)</td>
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<td></td>
<td>4.5(16)</td>
</tr>
</tbody>
</table>

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

\(^a\)Area at notch taken to be 0.026 in.\(^2\).
Table 5-13
TENSILE DATA FOR UNNOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AT 1400°C AND TESTED AT 140°C, 340°C, and 540°C
(Specification RTS-60 and M-40-1)

Crosshead Speed = 0.050 in./min

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Test Temp (°C)</th>
<th>Tensile Stress</th>
<th>% Elongation</th>
<th>% Area Reduction (Bench)</th>
<th>Fracture Location</th>
<th>Radiation Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.2% Offset</td>
<td>Max (ksi)</td>
<td>Fract (ksi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ksi)</td>
<td>(ksi)</td>
<td></td>
<td></td>
<td>n/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>6.9</td>
<td>7.0</td>
<td>15.4</td>
<td>2/T Control</td>
</tr>
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</tr>
<tr>
<td>702</td>
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<td>63.2</td>
<td>62.3</td>
<td></td>
<td></td>
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<tr>
<td>703</td>
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<td>47.2</td>
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<td>704</td>
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<td>70.1</td>
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<tr>
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<tr>
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<td>Avg</td>
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<tr>
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<td>3.9</td>
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<td></td>
</tr>
<tr>
<td>% Std Dev</td>
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<td>10.0</td>
<td>10.0</td>
<td></td>
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</tr>
<tr>
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<tr>
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<td>6.3</td>
<td>6.3</td>
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<tr>
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<td></td>
</tr>
</tbody>
</table>

WANL Dwg. No. 389D082H01. Data to be used for material evaluation only. Do not use for design.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Test Temp (°R)</th>
<th>Tensile Stress</th>
<th>% Elongation</th>
<th>% Area Reduction (Bench)</th>
<th>Fracture Location</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.2% Offset (ksi)</td>
<td>Max (ksi)</td>
<td>Fract (ksi)</td>
<td>Bench</td>
<td>Chart</td>
</tr>
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<td>% Std Dev</td>
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Table 5-14
TENSILE DATA FOR NOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AND TESTED AT 140°C
(Specification RTS-60 and M-40-1)

Crosshead Speed = 0.050 in./min

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<th>Ave Notch Diam (in.)</th>
<th>Area at Notch (in.²)</th>
<th>Fracture Load* (lb)</th>
<th>Fracture Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
<th>E &gt;1 MeV</th>
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Table 5-14
TENSILE DATA FOR NOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AND TESTED AT 1400°F (Cont'd)
(Specification RTS-60 and M-40-1)

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* Fracture load is same as maximum load.

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Do not use for design.
Table 5-15

TENSILE DATA FOR UNWELDED ALUMINUM 5086-H-34 (DM-311) SHEET IRRADIATED AT 140°K AND TESTED AT SEVERAL TEMPERATURES (Specification RTS-62)

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WANL Dwg No. 100E445 H01. Data to be used for material evaluation only. Do not use for design.
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* not used in average
## Table 5-16

### TENSILE DATA FOR WELDED ALUMINUM 5086-H-34 (DM-311) SHEET IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES

*(Specification RTS-62)*

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<th>Fracture Location</th>
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WANL Dwg No. 100E445 G02. Data to be used for material evaluation only. Do not use for design.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Test Temp (°F)</th>
<th>Tensile Stress</th>
<th>% Elongation</th>
<th>% Area Reduction (Bench)</th>
<th>Fracture Location</th>
<th>Radiation Exposure</th>
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</thead>
<tbody>
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<td>0.2% Offset (ksi)</td>
<td>Max (ksi)</td>
<td>Fract (ksi)</td>
<td>Bench</td>
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</table>
5.2 Tear Strength Data

One material, Aluminum 5086-H-34 (RTS-63), was evaluated in a Kahn-type tear test in which the sharp-notched specimens (Fig. 2-4 and sketch below) were loaded in the Instron tester until a crack developed at the root of the notch and traveled across the width of the specimen. The load/deformation curves provided the maximum load, from which the tear strength was computed, and the area under the curve, which is the energy required to initiate and propagate a crack.

The tear strength, \( S_t \), was computed from (Ref. 2)

\[
S_t = \frac{P}{A} + \frac{Mc}{I} = \frac{P}{bt} + 3\frac{P}{bt} = 4\frac{P}{bt}
\]

where:
- \( P \) = maximum load, lb
- \( A \) = net area, in.\(^2\), = \( bt \)
- \( M \) = moment, in.-lb
- \( c \) = distance from centroid to extreme fibers, in.
- \( I \) = moment of inertia, in.\(^4\)
- \( b \) = width at root of notch, in.
- \( t \) = thickness, in.

![Tear Specimen Sketch](image-url)
The measured values of \( t \) and \( P \) are tabulated in the data table; b was taken to be 0.995 in. for all specimens and other dimensions are shown in the sketch.

If the load/deformation curve is divided into two sections by a vertical line passing through the point of maximum load, the area under the first part of the curve is a measure of the energy necessary to initiate the crack and the area under the second part of the curve represents the energy necessary to propagate the crack across the specimen. Because of the length of the recorder traces, several feet in some instances, the two areas were obtained by a procedure in which three pairs of data points \((x_{i-2}, y_{i-2}; x_{i-1}, y_{i-1}, x_{i}, y_{i})\) from the Instron record were fitted to the function

\[
y_{i} = A x_{i}^2 + B x_{i} + C
\]

and integrated between the limits \( x_{i-2} \) and \( x_{i} \). The first two points were then dropped and the next two points, \( x_{i+1} \) and \( x_{i+2} \), were added to \( x_{i} \) and integrated between \( x_{i} \) and \( x_{i+2} \), and so on. The summation of the integrals over the two sections of the Instron records gave the required data. Enough points were used to assure an accuracy in the area of at least \( \pm 1.5\% \). The computations were made by use of the Hewlett-Packard 9100B desk calculator.
Table 5-17 presents the tear strength and area data for the aluminum alloy specimens, which were either unwelded (UW) or welded (W) or had a heat affected zone (HAZ). Table 5-18 gives the averages and standard deviations for each type specimen at each test condition. Table S-3 in the Summary gives the percent difference between data for the irradiated and control specimens and indicates if the difference is statistically significant at the 95% confidence level.
Table 5-17
TEAR STRENGTH DATA FOR ALUMINUM 5086-H-34 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE)
IRRADIATED AT 140° R AND TESTED AT SEVERAL TEMPERATURES
(Specification RTS 63)

Crosshead Speed = 0.050 in./min

<table>
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<th>Thickness (in.)</th>
<th>Max Load (lb)</th>
<th>Tear Strength (ksi)</th>
<th>Energy (in.-lb) To Initiate Crack</th>
<th>Energy (in.-lb) To Propagate Crack</th>
<th>Total Energy (in.-lb)</th>
<th>Unit Energy (in.-lb/in.²)</th>
<th>Total Neutron Fluence (n/cm²)</th>
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Note: The values in parentheses indicate the uncertainty in the measurements.
Table 5-17
TEAR STRENGTH DATA FOR ALUMINUM 5086-H36 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE)
IRRADIATED AT 140° R AND TESTED AT SEVERAL TEMPERATURES (Cont'd)
(Specification RTS 63)

| Specimen No. Type | Test Temp. °R | Thickness (in.) | Max Load (lb) | Tear Strength (ksi) | Energy (in.-lb) To Initiate Crack | Propagate Crack | Total Energy (in.-lb) | Unit Energy (in.-lb/in.²) Propagation Total | Neutron Fluence (n/cm²)
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<td>1084 1719</td>
<td>2.85(17) 1.8(16)</td>
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<td>1080</td>
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### Table 5-17
TEAR STRENGTH DATA FOR ALUMINUM 5086-H-34 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE) 
IRRADIATED AT 140°C AND TESTED AT SEVERAL TEMPERATURES (Cont'd) 
(Specification RTS 63)

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<th>Thickness (in.)</th>
<th>Max Load (lb)</th>
<th>Tear Strength (ksi)</th>
<th>Energy (in.-lb) To Initiate Crack</th>
<th>Energy (in.-lb) To Propagate Crack</th>
<th>Total Energy (in.-lb)</th>
<th>Unit Energy (in.-lb/in.²)</th>
<th>Neutron Fluence (n/cm²)</th>
<th>Neutron Fluence E &gt;1.0 MeV</th>
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WANL Dwg. No. 100E445-H05, G06. Data to be used for material evaluation only. Do not use for design.
Table 5-18
AVERAGE, STANDARD DEVIATION, AND PERCENT STANDARD DEVIATION FOR TEAR STRENGTH DATA

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<th>Specimen Type</th>
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<th>Tear Strength</th>
<th>Energy to Initiate Crack</th>
<th>Energy to Propagate Crack</th>
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<td>Std Dev</td>
<td>% Std Dev</td>
<td>Ave (in.-lb)</td>
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<td>Std Dev</td>
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5.3 Fracture Toughness Data

Three types of precracked fracture toughness specimens were tested: compact tension, WOL (wedge open loading), and sheet. In addition, one material, ZrC, was in the form of small compact-tension-type specimens without precracks. The computational methods described below were used in obtaining the tabulated results.

5.3.1 Compact Tension Specimens

The fracture toughness data for the compact tension specimens presented in Tables 5-19 through 5-25 are in the following order:

- M-7-1 Aluminum 6061-T6
- RTS-61 Aluminum 6061-T61
- M-21-2 Aluminum 7075-T73
- M-16-2 18 Ni Maraging Steel
- M-31-2 AISI 9310 Steel
- M-38-3 ARMCO 22-13-5 Steel
- RTS-67 ZrC (not precracked)

Data reduction for these materials was performed in accordance with the procedures recommended in the proposed ASTM Standard E399-70T (Ref. 3). This method covers the determination of the plane-strain fracture toughness characteristics of a notched and fatigue-cracked specimen. In this method, measurement of the plane-strain fracture toughness, $K_{IC}$, is based on the lowest load at which significant extension of the crack occurs. $K_{IC}$ is determined from the load/displacement record, i.e., a graph.
showing wedge opening vs Instron load, and the critical specimen dimensions shown in Figure 5-1. Referring to Figure 5-2, which illustrates the three types of load/displacement record that could result, $K_{IC}$ is calculated as follows: the secant line, $OPS$, is drawn through the origin with a slope 5% less than the slope of the tangent OA to the initial part of the record. The load at the intersection of the secant with the record is $P_S$. If the load at every point on the record which precedes $P_S$ is lower than $P_S$, $P_Q$ is equal to $P_S$ (Fig. 5-2, Type I); if, however, there is a maximum load preceding $P_S$ which exceeds it, then the maximum load is $P_Q$ (Fig. 5-2, Types II and III). The conditional plane-strain fracture toughness, $K_Q$, is calculated from

$$K_Q = \frac{P_Q}{BW^{1/2}} \left[ 29.6\left(\frac{a}{W}\right)^{1/2} - 185.5\left(\frac{a}{W}\right)^{3/2} + 655.7\left(\frac{a}{W}\right)^{5/2} - 1017.0\left(\frac{a}{W}\right)^{7/2} + 638.9\left(\frac{a}{W}\right)^{9/2} \right]$$

(5-1)

where $P_Q$ = maximum load, lb  
$B$ = thickness of specimen, in.  
$W$ = width of specimen, in.  
$a$ = average crack length, in., is the distance from precrack profile to the center of the holes where load is applied, i.e.,

$$a = \frac{a_{1/4} + a_{1/2} + a_{3/4}}{3} - \left(\frac{Z_2 - Y_2}{2}\right)$$

5-38
Figure 5-1 Measurements Required for Compact Tension Specimens
Figure 5-2 Principal Types of Load/Displacement Records
For the brittle ZrC specimens, which were not precracked, only the ultimate load could be obtained since they broke sharply. Equation 5-1 was used with $P_U$ replacing $P_Q$ and $A$, the average length of the machined notch, replacing $a$.

According to the proposed ASTM procedure (Ref. 3) the plane-strain fracture toughness $K_{IC}$ is equal to the conditional value $K_Q$ only if certain constraints are satisfied. In computing the $K_Q$ values given in the data tables, the specimen precracks were also evaluated on the basis of the following criteria for invalid precracks:

1. Surface trace of fatigue crack is less than 0.05 in.
2. Internal trace of fatigue crack front is closer to the machined notched root than 0.05 in.
3. Difference between two crack length measurements exceeds 5% of the average.
4. Surface trace of fatigue crack is less than 90% of average crack length, $a$.

Table 5-27 contains a tabulation of those fracture toughness specimens which are invalid on the basis of one or more of the above criteria. The computed values for the criteria are given in order that it may be seen how much they are outside the specified limit. Specimens not listed in Table 5-27 are valid on the basis of the above four criteria.
Table S-2 of the summary contains the average conditional plain-strain fracture toughness \((K_Q, K_{U0}, \text{ or } K_O)\) for each group of specimens (including WOL and sheet). All the data were averaged without regard for invalid specimens. No statistical treatment has been performed because the validity of the specimens and perhaps other factors should be considered by anyone wishing to draw conclusions from this data.

To facilitate calculation of the fracture toughness characteristics, a computer program was prepared for the Hewlett-Packard Model 9100B desk calculator. All fracture toughness data reduction was accomplished in this manner.

5.3.2 **WOL Specimens**

The beryllium fracture toughness specimens (RTS-69) were of the WOL type (Fig. 2-2). The following equation, provided by WNL, was used to compute \(K_Q\):

\[
K_Q = \frac{P_Q}{3a^2} \left[ -5.605 + 61.27 \left( \frac{a}{W} \right) - 141.08 \left( \frac{a}{W} \right)^2 + 142.80 \left( \frac{a}{W} \right)^3 \right] \tag{5-2}
\]

where the symbols are defined as previously. The data are given in Table 5-26. Specimens with invalid precracks based on the criteria given in Section 5.3.1 are listed in Table 5-27.

5.3.3 **Sheet Specimens**

Test specimens of the center-crack tension panel configuration were used for copper-boron (RTS-64 and RTS-65) and
Titanium 6Al 4V (M-9-3). The data reduction was performed in accordance with the WANL procedure summarized below.

Three fracture toughness stress intensity factors were computed from

\[ K_x = \frac{P_x \sqrt{A_x}}{BW} \left[ 1.77 + 0.227 \left( \frac{2A_x}{W} \right) - 0.510 \left( \frac{2A_x}{W} \right)^2 + 2.7 \left( \frac{2A_x}{W} \right)^3 \right] \]  \hspace{1cm} (5-3)

where 
- \( K_x \) = stress intensity factor, ksi \( \sqrt{\text{in}} \). 
- \( A_x \) = half-crack length, in. 
- \( B \) = specimen thickness, in. 
- \( W \) = specimen width, in. 
- \( P_x \) = load, lb

The crack length, which is illustrated in Figure 5-3, was measured both before \( (2C_0) \) and, if possible, after tensile testing \( (2C_1) \).

The stress intensity factor associated with the threshold, or onset, of slow, stable tear where the crack slowly extends after reaching a threshold stress level, \( K_0 \), is computed from Equation 5-3 using the initial crack length, \( 2C_0 \), and the 5\% offset load, \( P_0 \).

For those specimens which could be unloaded after having reached an ultimate load but before fracture (6 of 17 CuB specimens but no titanium specimens), the stress intensity factor associated with fracture, \( K_1 \), was calculated from Equation 5-3 using the ultimate load, \( P_U \), and the crack width after testing, \( 2C_1 \).
Measurements Made before Testing

Measurements Made after Testing

Figure 5-3 Measurements Required for Center-Crack Fracture Toughness Specimens
Since the initial portion of the load/deflection record was not linear for all specimens and hence the effects of radiation could not be effectively analyzed from $K_0$ data, and most specimens could not be unloaded before fracture, thus negating an analysis based upon $K_1$ data, an effective stress factor, $K_U$, was computed for purposes of evaluating the effects of radiation. It was computed at ultimate load, $P_U$, using the initial crack length, $2C_0$.

Where applicable, gross and net section stress values were calculated from

\[ \sigma_{\text{gross}} = \frac{P_U}{W_B} \]  \hspace{1cm} (5-4)

\[ \sigma_{\text{net}} = \frac{P_U}{B(W-2C_1)} \]  \hspace{1cm} (5-5)

where $\sigma_{\text{gross}}$ is the maximum gross stress, $\sigma_{\text{net}}$ is the net section stress, and other symbols are as previously defined.

Tables 5-28 and 5-29 give the data for the CuB and titanium, respectively.
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<th>Edge Meas</th>
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FRACTURE TOUGHNESS DATA FOR ALUMINUM 6061-T6 IRRADIATED AND TESTED AT 140°R  
(Specification M-7-1)  
Loading Rate = 6250 lb/min  
Lot A  
Lot B  
ANSC Dwg. No. 1138365-07. Data to be used for material evaluation only. Do not use for design.
Table 5-20

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<th>K_T (in.)</th>
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WANL Dwg. No. 100E439H38. Data to be used for material evaluation only. Do not use for design.
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<th>E &lt; 0.48 eV</th>
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<th>Crack Length (in.)</th>
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### Table 5-21

**FRACTURE TOUGHNESS DATA FOR ALUMINUM 7075-T73 FORGING IRRADIATED AND TESTED AT 140°R**  
(Specification M-21-2)

Loading Rate = 6250 lb/min

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*Annealed for 100 min at 540°R.*
Table 5-22
FRACTURE TOUGHNESS DATA FOR 18 NI MARAGING STEEL IRRADIATED AND TESTED AT 140°<sub>R</sub>
(Specification N-16-2)

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<td>0.7084</td>
<td>0.7052</td>
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<td>3975</td>
<td>39579</td>
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<td>0.6549</td>
<td>0.7118</td>
<td>0.7229</td>
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</table>

Lot A - Specimen Numbers 1 to 14, Lot B - Specimen Numbers 15 to 28

ANSC Doc. No. 1139208-118. Data to be used for material evaluation only. Do not use for design.
Table 5-23

FRACTURE TOUGHNESS DATA FOR SAE 9310 STEEL BAR IRRADIATED AND TESTED AT 140°F
(Specification M-31-2)

Loading Rate = 6250 lb/min

| Specimen Number | $P_o$ (lb) | $K_o$ (psi·in.) | $P_f$ Ultimate Load (lb) | Radiation Exposure Neutron Fluence (n/cm²) | Machined Notch Edge Crack Length (in.) | Control | 0.9269 | 1.0484 | 1.0657 | 1.0338 | 0.9203 | 0.8381 | 0.9064 | 0.9563 | 0.9637 | 0.9680 | 0.9322 | 0.8405 | 0.9264 | 0.9670 | 0.9639 | 0.9467 | 0.9101 | 0.8472 | 0.9364 | 0.9868 | 0.9854 | 0.9716 | 0.9351 | 0.8336 | 0.9248 | 0.9549 | 0.9458 | 0.9338 | 0.8919 | 0.8412 | 0.9200 | 0.9630 | 0.9769 | 0.9866 | 0.9519 | 0.8407 | 0.9439 | 0.9585 | 0.9589 | 0.9536 | 0.9375 | 0.8339 | 0.9393 | 0.9435 | 0.9540 | 0.9536 | 0.9235 | 0.8339 | 0.9148 | 0.9517 | 0.9600 | 0.9695 | 0.9432 | 0.8381 | 0.9482 | 0.9901 | 0.9794 | 0.9625 | 0.9310 | 0.8436 | 0.9216 | 0.9583 | 0.9625 | 0.9560 | 0.9232 | 0.8376 | 0.9130 | 0.9505 | 0.9651 | 0.9732 | 0.9521 | 0.8308 | 0.9105 | 0.9496 | 0.9540 | 0.9508 | 0.9348 | 0.8377 | 0.9313 | 0.9684 | 0.9684 | 0.9655 | 0.9479 | 0.8435 | 0.9095 | 0.9424 | 0.9574 | 0.9595 | 0.9334 | 0.8406 | 0.9016 | 0.9368 | 0.9463 | 0.9463 | 0.9439 | 0.9133 | 0.8191 | 0.9060 | 0.9448 | 0.9552 | 0.9592 | 0.9420 | 0.7957 | 0.8557 | 0.8883 | 0.9556 | 0.9731 | 0.9768 | 0.9491 | 0.8565 | 0.9378 | 0.9750 | 0.9707 | 0.9579 | 0.9211 | 0.8456 | 0.8962 | 0.9439 | 0.9588 | 0.9641 | 0.9352 | 0.8398 | 0.8904 | 0.9408 | 0.9469 | 0.9455 | 0.9266 | 0.8308 | 0.8957 | 0.9440 | 0.9449 | 0.9320 | 0.9001 | 0.8332 | 0.9018 | 0.9291 | 0.9308 | 0.9315 | 0.9121 | 0.8376 | 0.9141 | 0.9463 | 0.9488 | 0.9451 | 0.9243 | 0.8381 | 0.9430 | 0.9476 | 0.9560 | 0.9387 | 0.9267 | 0.8308 | 0.9671 | 0.9911 | 0.9770 | 0.9536 | 0.9263 | 0.8341

ANSC Dwg. No. 1138365-117. Data to be used for material evaluation only. Do not use for design.
Table 5-24
FRACUTRE TOUGHNESS DATA FOR ARMCO 22-13-5 PLATE IRRADIATED AND TESTED AT 140^\circ R
(Specification M-38-3)

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>F_{u} (lb)</th>
<th>X_{u} (psi/in.)</th>
<th>F_{y} UUT Load (lb)</th>
<th>Neutron Fluence (n/cm^2)</th>
<th>Machine Notch Length (in.)</th>
<th>Crack Length (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E &gt; 1 MeV</td>
<td>E &lt; 0.48 eV</td>
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<tr>
<td>457</td>
<td>10905</td>
<td>85211</td>
<td>10905</td>
<td>Control</td>
<td>0.8410</td>
<td>0.9861</td>
</tr>
<tr>
<td>458</td>
<td>11280</td>
<td>91620</td>
<td>11220</td>
<td>Control</td>
<td>0.8555</td>
<td>1.0077</td>
</tr>
<tr>
<td>461</td>
<td>11250</td>
<td>88735</td>
<td>11250</td>
<td>1.20(17)</td>
<td>5.8(15)</td>
<td>0.8389</td>
</tr>
<tr>
<td>451</td>
<td>88735</td>
<td>11225</td>
<td>9900</td>
<td>1.20(17)</td>
<td>5.8(15)</td>
<td>0.9359</td>
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<tr>
<td>466</td>
<td>10350</td>
<td>80597</td>
<td>10350</td>
<td>1.20(17)</td>
<td>5.8(15)</td>
<td>0.9491</td>
</tr>
<tr>
<td>458</td>
<td>11370</td>
<td>91370</td>
<td>11370</td>
<td>1.20(17)</td>
<td>5.8(15)</td>
<td>0.9465</td>
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</tbody>
</table>

* Displacement gage came out.

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<tr>
<th>Specimen Number</th>
<th>F_{u} (lb)</th>
<th>X_{u} (psi/in.)</th>
<th>F_{y} UUT Load (lb)</th>
<th>Neutron Fluence (n/cm^2)</th>
<th>Machine Notch Length (in.)</th>
<th>Crack Length (in.)</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>E &gt; 1 MeV</td>
<td>E &lt; 0.48 eV</td>
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</tr>
<tr>
<td>457</td>
<td>10905</td>
<td>85211</td>
<td>10905</td>
<td>Control</td>
<td>0.8410</td>
<td>0.9861</td>
</tr>
<tr>
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<td>10890</td>
<td>Control</td>
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<td>1.0093</td>
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<td>91620</td>
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<td>Control</td>
<td>0.8555</td>
<td>1.0077</td>
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<tr>
<td>467</td>
<td>11220</td>
<td>87775</td>
<td>11220</td>
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<td>1.0059</td>
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<td>82476</td>
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<td>Control</td>
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<td>1.0006</td>
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<tr>
<td>461</td>
<td>11250</td>
<td>88735</td>
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<tr>
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<td>79298</td>
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<td>5.8(15)</td>
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<td>82715</td>
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<tr>
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<td>11370</td>
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<td>5.8(15)</td>
<td>0.8463</td>
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</table>

ANSC Dwg. No. 1138365-15. Data to be used for material evaluation only. Do not use for design.
Table 5-25
FRACRURE TOUGHNESS DATA FOR ZrC PLATE IRRADIATED AT 140⁰R AND TESTED AT 140⁰R AND 540⁰R
(Specification RTS-67)

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Test Temp (⁰R)</th>
<th>B Specimen Thickness (in.)</th>
<th>W Specimen Width (in.)</th>
<th>Ave Machine Notch (in.)</th>
<th>Pu Ult Load (lb)</th>
<th>K_u (psi/in.)</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
<td>140</td>
<td>0.2492</td>
<td>0.4949</td>
<td>0.2281</td>
<td>9.03</td>
<td>442.5</td>
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<tr>
<td>501</td>
<td>540</td>
<td>0.2482</td>
<td>0.4975</td>
<td>0.2285</td>
<td>7.80</td>
<td>381.1</td>
<td>Control</td>
</tr>
<tr>
<td>507</td>
<td>540</td>
<td>0.2485</td>
<td>0.4962</td>
<td>0.2285</td>
<td>7.35</td>
<td>360.4</td>
<td>Control</td>
</tr>
<tr>
<td>519</td>
<td>140</td>
<td>0.2490</td>
<td>0.4978</td>
<td>0.2286</td>
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<td>2.63(18) 4.0(16)</td>
</tr>
<tr>
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<td>140</td>
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<td>0.4962</td>
<td>0.2292</td>
<td>6.18</td>
<td>303.9</td>
<td>2.82(18) 4.0(16)</td>
</tr>
<tr>
<td>515</td>
<td>140</td>
<td>0.2486</td>
<td>0.4984</td>
<td>0.2293</td>
<td>4.05</td>
<td>197.8</td>
<td>2.89(18) 4.0(16)</td>
</tr>
<tr>
<td>509</td>
<td>540</td>
<td>0.2490</td>
<td>0.4956</td>
<td>0.2287</td>
<td>7.26</td>
<td>356.4</td>
<td>2.35(18) 4.0(16)</td>
</tr>
<tr>
<td>508</td>
<td>540</td>
<td>0.2489</td>
<td>0.4975</td>
<td>0.2278</td>
<td>7.95</td>
<td>385.8</td>
<td>2.41(18) 4.0(16)</td>
</tr>
<tr>
<td>506</td>
<td>540</td>
<td>0.2487</td>
<td>0.4970</td>
<td>0.2274</td>
<td>8.25</td>
<td>400.6</td>
<td>2.48(18) 4.0(16)</td>
</tr>
<tr>
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<td>540</td>
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<td>0.2276</td>
<td>8.88</td>
<td>431.9</td>
<td>2.61(18) 4.0(16)</td>
</tr>
</tbody>
</table>

*a toughness calculated on basis of ultimate load.

WANL Dwg. No. 577F544H14F. Data to be used for material evaluation only. Do not use for design.
**Table 5-26**

FRACTURE TOUGHNESS DATA FOR BERYLLIUM IRRADIATED AT 140^0R AND TESTED AT 140^0 and 540^0R

*Specification RTS-69*

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Test Temp (°R)</th>
<th>Pu Ulc Load (lb)</th>
<th>K_d (psi√in.)</th>
<th>Pu Ulc Load (lb)</th>
<th>Radiation Exposure Neutron Fluence (n/cm²)</th>
<th>Machined Notch Edges</th>
<th>Crack Length (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>140</td>
<td>2060</td>
<td>10540</td>
<td>2060</td>
<td>Control E &gt;1 MeV 0.8649</td>
<td>0.9230 0.9382 0.9447 0.9427 0.9294</td>
<td>0.8649</td>
</tr>
<tr>
<td>27</td>
<td>140</td>
<td>1804</td>
<td>9118</td>
<td>1804</td>
<td>Control E &gt;1 MeV 0.8599</td>
<td>0.9141 0.9288 0.9240 0.9202 0.9318</td>
<td>0.8599</td>
</tr>
<tr>
<td>25</td>
<td>140</td>
<td>1344</td>
<td>6875</td>
<td>1344</td>
<td>3.22(18) 4.0(16) 0.8700</td>
<td>0.9235 0.9440 0.9413 0.9404 0.9318</td>
<td>0.8700</td>
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<tr>
<td>26</td>
<td>140</td>
<td>1072</td>
<td>5385</td>
<td>1072</td>
<td>3.25(18) 4.0(16) 0.8613</td>
<td>0.9023 0.9077 0.9116 0.9133 0.9245</td>
<td>0.8613</td>
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<tr>
<td>24</td>
<td>540</td>
<td>1920</td>
<td>9790</td>
<td>1920</td>
<td>Control E &gt;1 MeV 0.8724</td>
<td>0.9250 0.9361 0.9414 0.9342 0.9215</td>
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</tr>
<tr>
<td>30</td>
<td>540</td>
<td>2560</td>
<td>12880</td>
<td>2560</td>
<td>Control E &gt;1 MeV 0.8709</td>
<td>0.9193 0.9171 0.9164 0.9186 0.9177</td>
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<tr>
<td>29</td>
<td>540</td>
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<td>11936</td>
<td>2390</td>
<td>3.00(18) 4.0(16) 0.8731</td>
<td>0.9054 0.9092 0.9058 0.9059 0.9112</td>
<td>0.8731</td>
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</table>

WANL Doc. No. 1002439 H18. Data to be used for material evaluation only. Do not use for design.
### Table 5-27

**INVALID FRACTURE TOUGHNESS SPECIMENS BASED ON FOUR FATIGUE CRACK CRITERIA**

<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen No.</th>
<th>1 Surface Trace (in.)</th>
<th>2 Internal Trace (in.)</th>
<th>3 Trace Difference (%)</th>
<th>4 Surface Trace (%)</th>
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<tbody>
<tr>
<td>Al 6061-T6</td>
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<td>6.0</td>
<td>89.6</td>
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<td>354</td>
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<td>6.2</td>
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</tr>
</tbody>
</table>

**Criteria:**
1. Surface trace of fatigue crack is less than 0.05 in.
2. Internal trace of fatigue crack front is closer to the machined notched root than 0.05 in.
3. Difference between two crack length measurements exceeds 5 percent of the average.
4. Surface trace of crack is less than 90% of average crack length, a.
<table>
<thead>
<tr>
<th>Material</th>
<th>Specimen No.</th>
<th>1 Surface Trace (in.)</th>
<th>2 Internal Trace (in.)</th>
<th>3 Trace Difference (%)</th>
<th>4 Surface Trace (%)</th>
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<tr>
<td></td>
<td>417</td>
<td>-</td>
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<td>89.6</td>
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<td></td>
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<td></td>
<td>412</td>
<td>-</td>
<td>-</td>
<td>5.4</td>
<td>-</td>
</tr>
<tr>
<td>18 Ni Maraging Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No invalid specimens</td>
</tr>
<tr>
<td>SAE 9310 Steel</td>
<td>88</td>
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<td>-</td>
<td>-</td>
<td>87.7</td>
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Table 5-27 (cont'd)

<table>
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<th>Material</th>
<th>Specimen No.</th>
<th>Surface Trace (in.)</th>
<th>Internal Trace (in.)</th>
<th>Trace Difference (%)</th>
<th>Surface Trace (%)</th>
</tr>
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<tbody>
<tr>
<td>ARMCO 22-13-5</td>
<td>453</td>
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<td>-</td>
<td>-</td>
<td>89.7</td>
</tr>
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<td>Specimens not precracked</td>
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<td></td>
<td></td>
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<td>-</td>
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<td>30</td>
<td>0.047</td>
<td>0.046</td>
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<td>-</td>
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</tr>
<tr>
<td></td>
<td>26</td>
<td>0.041</td>
<td>0.046</td>
<td>-</td>
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</tbody>
</table>
### Table 5-28

**Fracture Toughness Data for Cu B^10 (18%) (DM-180) and Cu B^N (18%) (DM-198) Sheet Irradiated at 140^oR and Tested at 140^oR and 540^oR**

(Specifications RTS-64 and RTS-65)

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Material</th>
<th>Test Temp (°F)</th>
<th>W</th>
<th>Initial Crack (in.)</th>
<th>Final Crack (in.)</th>
<th>P_{5%}</th>
<th>P_{ult}</th>
<th>Offset Load (lb)</th>
<th>F Max Stress (ksi)</th>
<th>Net Section Stress (ksi)</th>
<th>K_0</th>
<th>K_1</th>
<th>K_{50}</th>
<th>Neutron Fluence (n/cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Cu B^10</td>
<td>140</td>
<td>0.0992</td>
<td>3.3493</td>
<td>1.1434</td>
<td>1.7777</td>
<td>1800</td>
<td>3565</td>
<td>5.42</td>
<td>10.73</td>
<td>22.87</td>
<td>7.76</td>
<td>21.75</td>
<td>15.38</td>
</tr>
<tr>
<td>12</td>
<td>Cu B^10</td>
<td>540</td>
<td>0.0990</td>
<td>3.3171</td>
<td>1.0818</td>
<td>1.7461</td>
<td>1655</td>
<td>2715</td>
<td>5.04</td>
<td>8.27</td>
<td>17.49</td>
<td>6.98</td>
<td>16.57</td>
<td>11.45</td>
</tr>
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<td>Cu B^10</td>
<td>140</td>
<td>0.0998</td>
<td>3.1883</td>
<td>0.9574</td>
<td>b</td>
<td>4540</td>
<td>6630</td>
<td>14.27</td>
<td>20.21</td>
<td>-</td>
<td>18.41</td>
<td>-</td>
<td>26.08</td>
</tr>
<tr>
<td>6</td>
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<td>140</td>
<td>0.0988</td>
<td>3.2773</td>
<td>1.1048</td>
<td>b</td>
<td>4600</td>
<td>6310</td>
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<td>-</td>
<td>19.98</td>
<td>-</td>
<td>27.40</td>
</tr>
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<td>Cu B^10</td>
<td>540</td>
<td>0.0993</td>
<td>3.2917</td>
<td>1.1332</td>
<td>b</td>
<td>3550</td>
<td>4200</td>
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<td>12.85</td>
<td>-</td>
<td>14.64</td>
<td>-</td>
<td>18.36</td>
</tr>
<tr>
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<td>Cu B^10</td>
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<td>0.0991</td>
<td>3.2098</td>
<td>1.1835</td>
<td>b</td>
<td>3550</td>
<td>4085</td>
<td>10.53</td>
<td>12.84</td>
<td>-</td>
<td>15.55</td>
<td>-</td>
<td>18.96</td>
</tr>
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<td>Cu B^10</td>
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<td>4235</td>
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<td>-</td>
<td>12.38</td>
<td>-</td>
<td>17.77</td>
</tr>
<tr>
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<td>3.0700</td>
<td>1.3747</td>
<td>1.7497</td>
<td>650</td>
<td>1414</td>
<td>3.66</td>
<td>7.95</td>
<td>18.50</td>
<td>6.10</td>
<td>16.62</td>
<td>13.27</td>
</tr>
<tr>
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<td>3.0883</td>
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<td>1.8619</td>
<td>730</td>
<td>1400</td>
<td>4.06</td>
<td>7.79</td>
<td>19.61</td>
<td>7.45</td>
<td>17.38</td>
<td>14.29</td>
</tr>
<tr>
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<td>Cu B^N</td>
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<td>0.0588</td>
<td>3.0261</td>
<td>1.4565</td>
<td>1.7601</td>
<td>644</td>
<td>1202</td>
<td>3.62</td>
<td>6.76</td>
<td>15.90</td>
<td>6.37</td>
<td>14.15</td>
<td>11.89</td>
</tr>
<tr>
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<td>Cu B^N</td>
<td>540</td>
<td>0.0579</td>
<td>3.1014</td>
<td>1.4423</td>
<td>b</td>
<td>564</td>
<td>1272</td>
<td>3.14</td>
<td>7.08</td>
<td>-</td>
<td>5.43</td>
<td>-</td>
<td>12.25</td>
</tr>
<tr>
<td>14</td>
<td>Cu B^N</td>
<td>540</td>
<td>0.0579</td>
<td>3.0737</td>
<td>1.4488</td>
<td>1.6333</td>
<td>612</td>
<td>1138</td>
<td>3.44</td>
<td>6.28</td>
<td>13.41</td>
<td>5.99</td>
<td>12.22</td>
<td>10.94</td>
</tr>
<tr>
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<td>Cu B^N</td>
<td>140</td>
<td>0.0587</td>
<td>3.0500</td>
<td>1.4653</td>
<td>b</td>
<td>1840</td>
<td>2765</td>
<td>10.28</td>
<td>15.44</td>
<td>-</td>
<td>18.13</td>
<td>-</td>
<td>27.24</td>
</tr>
<tr>
<td>5</td>
<td>Cu B^N</td>
<td>140</td>
<td>0.0587</td>
<td>3.1180</td>
<td>1.3947</td>
<td>b</td>
<td>1600</td>
<td>2510</td>
<td>8.74</td>
<td>13.71</td>
<td>-</td>
<td>16.68</td>
<td>-</td>
<td>23.03</td>
</tr>
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<td>0.0590</td>
<td>3.0757</td>
<td>1.4088</td>
<td>b</td>
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<td>2042</td>
<td>8.60</td>
<td>11.25</td>
<td>-</td>
<td>16.62</td>
<td>-</td>
<td>19.14</td>
</tr>
<tr>
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<td>Cu B^N</td>
<td>540</td>
<td>0.0585</td>
<td>3.0061</td>
<td>1.4543</td>
<td>b</td>
<td>1526</td>
<td>1604</td>
<td>8.68</td>
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<td>-</td>
<td>15.29</td>
<td>-</td>
<td>16.07</td>
</tr>
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<td>0.0588</td>
<td>3.0941</td>
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<td>2190</td>
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<td>12.04</td>
<td>-</td>
<td>16.94</td>
<td>-</td>
<td>20.27</td>
</tr>
</tbody>
</table>

**Notes:**
- **K_{50}** is calculated at ultimate load using initial crack length.
- **a** Specimen broke at ultimate load; no measurement of final crack length was possible.
- Data to be used for material evaluation only. Do not use for design.

---

WANL Deg No. 577F686H03 and 577F686H04. Data to be used for material evaluation only. Do not use for design.
Table 5-29
FRACTURE TOUGHNESS DATA FOR TITANIUM 6Al 4V WELDED SHEET IRRADIATED AND TESTED AT 140\(^\circ\)R
(Specification M-9-3)

Loading Rate = 23,000 lb/min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>B Thickness (in.)</th>
<th>W Width (in.)</th>
<th>(2C_0) Initial Crack (in.)</th>
<th>(2C_1) Final Crack (in.)</th>
<th>(P_U) Ultimate Load (lb)</th>
<th>Ultimate Stress (ksi)</th>
<th>(K_{U0}) (ksi (\sqrt{\text{in.}}))</th>
<th>Neutron Fluence n/cm(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.2021</td>
<td>3.0065</td>
<td>1.1320</td>
<td>B</td>
<td>26300</td>
<td>43.28</td>
<td>61.61</td>
<td>Control</td>
</tr>
<tr>
<td>9</td>
<td>0.2043</td>
<td>3.0076</td>
<td>1.1185</td>
<td>28000</td>
<td>45.57</td>
<td>65.52</td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>13</td>
<td>0.2056</td>
<td>3.0068</td>
<td>1.1399</td>
<td>28000</td>
<td>45.29</td>
<td>65.99</td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>16</td>
<td>0.2046</td>
<td>3.0068</td>
<td>1.1357</td>
<td>26200</td>
<td>42.59</td>
<td>61.89</td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>18</td>
<td>0.2035</td>
<td>3.0059</td>
<td>1.0858</td>
<td>27400</td>
<td>44.79</td>
<td>63.13</td>
<td></td>
<td>3.16(16) 1.8(15)</td>
</tr>
<tr>
<td>10</td>
<td>0.2062</td>
<td>3.0074</td>
<td>1.0283</td>
<td>27600</td>
<td>44.51</td>
<td>60.51</td>
<td></td>
<td>3.21(16) 1.8(15)</td>
</tr>
<tr>
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<td>1.0437</td>
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<td>44.43</td>
<td>60.99</td>
<td></td>
<td>3.25(16) 1.8(15)</td>
</tr>
<tr>
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<td>1.0955</td>
<td>27600</td>
<td>44.42</td>
<td>62.96</td>
<td></td>
<td>3.28(16) 1.8(15)</td>
</tr>
<tr>
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<td>0.2003</td>
<td>3.0058</td>
<td>1.0811</td>
<td>26100</td>
<td>43.35</td>
<td>60.92</td>
<td></td>
<td>3.33(16) 1.8(15)</td>
</tr>
<tr>
<td>21</td>
<td>0.2035</td>
<td>3.0078</td>
<td>1.0634</td>
<td>23200</td>
<td>37.90</td>
<td>52.67</td>
<td></td>
<td>5.60(17) 1.8(16)</td>
</tr>
<tr>
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<td>1.0998</td>
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<td>38.37</td>
<td>54.54</td>
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<td>5.66(17) 1.8(16)</td>
</tr>
<tr>
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<td>1.0555</td>
<td>22250</td>
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<td>5.70(17) 1.8(16)</td>
</tr>
<tr>
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<td>1.0883</td>
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<td>54.40</td>
<td></td>
<td>5.75(17) 1.8(16)</td>
</tr>
<tr>
<td>8</td>
<td>0.2043</td>
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<td>1.0618</td>
<td>23000</td>
<td>37.46</td>
<td>52.01</td>
<td></td>
<td>5.81(17) 1.8(16)</td>
</tr>
</tbody>
</table>

ANSO Dwg No. 1138226-2909. Data to be used for material evaluation only. Do not use for design.

\(^a\)K_{U0} is calculated at ultimate load using initial crack length.

\(^b\)All specimens broke at the ultimate load; no measurement of final crack length was possible.
5.4 Flexure Data

The ZrC flexure specimens (RTS-66) were tested by an ASTM procedure (Ref. 1) which actually applies to plastics. However, data provided by WANL for a control specimen indicated that Equation 3 of ASTM D790 was used. This equation gives the maximum fiber stress in a simple beam supported at two points and loaded at the midpoint:

\[ S = \frac{3PL}{2bd^2} \quad (5-6) \]

where
- \( S \) = stress in the outer fiber at midspan, psi
- \( P \) = maximum load, lb
- \( L \) = span, in. (= 1 in.)
- \( b \) = width of beam, in.
- \( d \) = depth (thickness) of beam, in.

Table 5-30 gives the results of the measurements and computations using Equation 5-6. The table also includes a "Chart Deflection" which is the specimen deflection at rupture as determined from chart travel with the Instron operating at a constant crosshead speed. Table S-3 of the Summary gives the percent differences between data for irradiated and control specimens.
# Table 5-30

FLEXURE DATA FOR ZrC PLATE IRRADIATED AT 140°OR AND TESTED AT 140°OR AND 540°OR

(Specification RTS-66)

Crosshead Speed = 0.005 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Test Temp (°R)</th>
<th>Width (in.)</th>
<th>Thickness (in.)</th>
<th>Chart Deflection (in.)</th>
<th>Max Load (lb)</th>
<th>Max Fiber Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
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<td>611</td>
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<td>0.2487</td>
<td>0.1993</td>
<td>0.0099</td>
<td>12.0</td>
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</tr>
<tr>
<td>614</td>
<td>140</td>
<td>0.2491</td>
<td>0.1992</td>
<td>0.0120</td>
<td>11.4</td>
<td>1.73</td>
<td>Control</td>
</tr>
<tr>
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</tr>
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</tr>
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<td>1.88</td>
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</tr>
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<td>Ave</td>
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</tr>
<tr>
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</tr>
<tr>
<td>% Std Dev</td>
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<td>6.7</td>
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</tr>
<tr>
<td>615</td>
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<td>0.1989</td>
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<td>1.89</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
<tr>
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<td>13.8</td>
<td>2.08</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
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<td>0.1983</td>
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</tr>
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<td>0.11</td>
<td>Control</td>
</tr>
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<td></td>
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<td>5.6</td>
<td>5.3</td>
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</tr>
<tr>
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</tr>
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<td>0.0073</td>
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<td>1.72</td>
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<td>0.1994</td>
<td>0.0100</td>
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<td>1.58</td>
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<td>0.0080</td>
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<td>2.10</td>
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<td>Control</td>
</tr>
<tr>
<td>Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>0.0012</td>
<td>1.8</td>
<td>0.27</td>
<td>Control</td>
</tr>
<tr>
<td>% Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>13.6</td>
<td>14.5</td>
<td>14.2</td>
<td>Control</td>
</tr>
<tr>
<td>603</td>
<td>540</td>
<td>0.2496</td>
<td>0.1989</td>
<td>0.0180</td>
<td>12.9</td>
<td>1.96</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
<tr>
<td>605</td>
<td>540</td>
<td>0.2486</td>
<td>0.1981</td>
<td>0.0085*</td>
<td>4.3*</td>
<td>0.66*</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
</tbody>
</table>
Table 5-30
FLEXURE DATA FOR ZrC PLATE IRRADIATED AT 140°R AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification RTS-66)

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Test Temp (°R)</th>
<th>Width (in.)</th>
<th>Thickness (in.)</th>
<th>Chart Deflection (in.)</th>
<th>Max Load (lb)</th>
<th>Max Fiber Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>606</td>
<td>540</td>
<td>0.2495</td>
<td>0.1982</td>
<td>0.0070</td>
<td>11.0</td>
<td>1.68</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
<tr>
<td>608</td>
<td>540</td>
<td>0.2488</td>
<td>0.1992</td>
<td>0.0107</td>
<td>10.6</td>
<td>1.60</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
<tr>
<td>609</td>
<td>540</td>
<td>0.2491</td>
<td>0.1993</td>
<td>0.0066</td>
<td>11.2</td>
<td>1.70</td>
<td>2.84 (18) 4.0 (16)</td>
</tr>
<tr>
<td>Ave</td>
<td>540</td>
<td></td>
<td></td>
<td>0.0106</td>
<td>11.4</td>
<td>1.74</td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>0.0053</td>
<td>1.0</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
<td>8.9</td>
<td>9.0</td>
<td></td>
</tr>
</tbody>
</table>

* Not included in average

WANL Dwg. No. 388D613. Data to be used for material evaluation only. Do not use for design.
5.5 Data for Springs

Beryllium-copper Belleville springs (M-39-1) and A-286 coil springs (Fig. 2-5) (RTS-58) were tested in compression. The load required to compress the Belleville springs to a height of 0.081 in. is tabulated in Table 5-31. The heights at loads of 50, 100, and 150 lb taken from the Instron record are also tabulated in Table 5-31. While there is an observed difference between the pre- and post-irradiation measurements, a comparison of data for the uncompressed control springs indicates a bias between the measurements taken before the irradiation and those taken following the irradiation. Although the source of this discrepancy could not be determined, the assumption of a bias results in the conclusion that there is no statistically significant difference between the pre- and post-irradiation data for the irradiated springs.

The A-286 springs were compressed at a constant rate to a length slightly less than 2.754 in. The spring constants at lengths of 3.292 and 2.754 in. were then determined from the load/deflection records. The data are in Table 5-32. Again an apparent bias combined with the variability in the data leads to the conclusion that there is no statistically significant difference between the pre- and post-irradiation measurements.
### Table 5-31

LOAD DEFORMATION OF BERYLLIUM-COPPER BELLEVILLE SPRINGS IRRADIATED AT 140°R

*(Specification M-39-1)*

<table>
<thead>
<tr>
<th>Crosshead Speed = 0.050 in./min</th>
<th>Neutron Fluence (n/cm²)</th>
<th>Height at 540°R (in.)</th>
<th>Test Temp.</th>
<th>Load (lb) at 0.081 in. Height</th>
<th>Height (in.) at Given Load (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E &gt; 1 MeV E &lt; 0.48 eV</td>
<td></td>
<td></td>
<td></td>
<td>Pre Post 50 100 150 Post 50 100 150</td>
</tr>
<tr>
<td>Spring No.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pre Post 50 100 150 Post 50 100 150</td>
</tr>
<tr>
<td>11 Control&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.152 540</td>
<td>178 165</td>
<td>0.130 0.114 0.097</td>
<td>0.132 0.114 0.091</td>
<td></td>
</tr>
<tr>
<td>3 Control</td>
<td>0.163 540</td>
<td>180 165</td>
<td>0.129 0.114 0.097</td>
<td>0.131 0.114 0.091</td>
<td></td>
</tr>
<tr>
<td>6 Control</td>
<td>0.149 540</td>
<td>192 177</td>
<td>0.130 0.115 0.100</td>
<td>0.132 0.116 0.096</td>
<td></td>
</tr>
<tr>
<td>11 Control</td>
<td>140</td>
<td>170 175</td>
<td>0.126 0.112 0.091</td>
<td>0.130 0.116 0.094</td>
<td></td>
</tr>
<tr>
<td>3 Control</td>
<td>140</td>
<td>175 172</td>
<td>0.125 0.110 0.093</td>
<td>0.127 0.114 0.092</td>
<td></td>
</tr>
<tr>
<td>6 Control</td>
<td>140</td>
<td>192 172</td>
<td>0.133 0.118 0.101</td>
<td>0.129 0.116 0.094</td>
<td></td>
</tr>
<tr>
<td>12 7.39(17) 1.80(16)</td>
<td>0.160 540</td>
<td>176 160</td>
<td>0.129 0.113 0.096</td>
<td>0.131 0.111 0.088</td>
<td></td>
</tr>
<tr>
<td>9 7.39(17) 1.80(16)</td>
<td>0.152 540</td>
<td>178 168</td>
<td>0.131 0.115 0.099</td>
<td>0.131 0.114 0.093</td>
<td></td>
</tr>
<tr>
<td>7 7.39(17) 1.80(16)</td>
<td>0.150 540</td>
<td>179 168</td>
<td>0.131 0.115 0.098</td>
<td>0.132 0.115 0.093</td>
<td></td>
</tr>
<tr>
<td>12 7.39(17) 1.80(16)</td>
<td>140</td>
<td>173 169</td>
<td>0.128 0.113 0.093</td>
<td>0.126 0.111 0.087</td>
<td></td>
</tr>
<tr>
<td>9 7.39(17) 1.80(16)</td>
<td>140</td>
<td>175 154</td>
<td>0.128 0.112 0.092</td>
<td>0.128 0.112 0.083</td>
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</tr>
<tr>
<td>7 7.39(17) 1.80(16)</td>
<td>140</td>
<td>173 170</td>
<td>0.129 0.113 0.091</td>
<td>0.132 0.117 0.095</td>
<td></td>
</tr>
<tr>
<td>5 Control&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.153 540</td>
<td>178 177</td>
<td>0.130 0.115 0.098</td>
<td>0.133 0.117 0.095</td>
<td></td>
</tr>
<tr>
<td>8 Control</td>
<td>0.143 540</td>
<td>172 168</td>
<td>0.128 0.113 0.096</td>
<td>0.130 0.114 0.092</td>
<td></td>
</tr>
<tr>
<td>10 Control</td>
<td>0.150 540</td>
<td>172 159</td>
<td>0.128 0.113 0.096</td>
<td>0.130 0.112 0.088</td>
<td></td>
</tr>
<tr>
<td>5 Control</td>
<td>140</td>
<td>183 182</td>
<td>0.130 0.116 0.097</td>
<td>0.130 0.116 0.095</td>
<td></td>
</tr>
<tr>
<td>8 Control</td>
<td>140</td>
<td>178 168</td>
<td>0.129 0.115 0.096</td>
<td>0.129 0.115 0.091</td>
<td></td>
</tr>
<tr>
<td>10 Control</td>
<td>140</td>
<td>170 168</td>
<td>0.127 0.113 0.093</td>
<td>0.129 0.114 0.091</td>
<td></td>
</tr>
<tr>
<td>2 7.39(17) 1.80(16)</td>
<td>0.151 540</td>
<td>183 185</td>
<td>0.131 0.116 0.101</td>
<td>0.136 0.121 0.103</td>
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</tr>
<tr>
<td>1 7.39(17) 1.80(16)</td>
<td>0.154 540</td>
<td>169 169</td>
<td>0.127 0.111 0.093</td>
<td>0.135 0.116 0.092</td>
<td></td>
</tr>
<tr>
<td>4 7.39(17) 1.80(16)</td>
<td>0.151 540</td>
<td>182 185</td>
<td>0.130 0.115 0.100</td>
<td>0.134 0.119 0.101</td>
<td></td>
</tr>
<tr>
<td>2 7.39(17) 1.80(16)</td>
<td>140</td>
<td>185 173</td>
<td>0.130 0.115 0.098</td>
<td>0.129 0.114 0.090</td>
<td></td>
</tr>
<tr>
<td>1 7.39(17) 1.80(16)</td>
<td>140</td>
<td>170 158</td>
<td>0.126 0.112 0.091</td>
<td>0.126 0.110 0.086</td>
<td></td>
</tr>
<tr>
<td>4 7.39(17) 1.80(16)</td>
<td>140</td>
<td>170 169</td>
<td>0.127 0.112 0.089</td>
<td>0.133 0.114 0.091</td>
<td></td>
</tr>
</tbody>
</table>

Springs compressed to 0.08 in. during irradiation.

Springs compressed to 0.07 in. during irradiation.

**ANSC Dwg. No. N/A.** Data to be used for material evaluation only. Do not use for design.

<sup>a</sup>Control springs were compressed for a comparable period of time at 140°R.
<table>
<thead>
<tr>
<th>Spring No.</th>
<th>Neutron Fluence (n/cm²)</th>
<th>Height at 540°F (in.)</th>
<th>Test Temp.</th>
<th>Load (lb) at 0.081 in. Height</th>
<th>Height (in.) at Given Load (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E &gt; 1 MeV E &lt; 0.48 eV</td>
<td></td>
<td></td>
<td>Pre Post 50 100 150</td>
<td>Pre Post 50 100 150</td>
</tr>
<tr>
<td>13</td>
<td>Control</td>
<td>0.154</td>
<td>540</td>
<td>167 157</td>
<td>0.127 0.111 0.093 0.127 0.111 0.085</td>
</tr>
<tr>
<td>14</td>
<td>Control</td>
<td>0.157</td>
<td>540</td>
<td>172 170</td>
<td>0.129 0.113 0.096 0.131 0.116 0.094</td>
</tr>
<tr>
<td>15</td>
<td>Control</td>
<td>0.156</td>
<td>540</td>
<td>181 164</td>
<td>0.134 0.113 0.099 0.131 0.112 0.090</td>
</tr>
<tr>
<td>16</td>
<td>Control</td>
<td>0.150</td>
<td>540</td>
<td>176 163</td>
<td>0.128 0.114 0.098 0.130 0.112 0.089</td>
</tr>
</tbody>
</table>

Springs uncompressed.
Table 5-32
FREE LENGTH AND SPRING CONSTANT FOR A-286 SPRINGS
(Specification RTS-58)

<table>
<thead>
<tr>
<th>Spring No.</th>
<th>Irrad. Temp (°R)</th>
<th>Test Temp (°R)</th>
<th>Preirradiation</th>
<th>Postirradiation</th>
<th>Neutron Fluence (n/cm²)</th>
<th>E &gt; 1 MeV</th>
<th>E &lt; 0.48 eV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spring Length (in.)</td>
<td>Spring Const. (lb/in.)</td>
<td>no.</td>
<td>Temp</td>
<td>Length (in.)</td>
</tr>
<tr>
<td>15</td>
<td>140</td>
<td>140</td>
<td>3.865 58.5 63.0</td>
<td>3.855 57.9 63.1</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>140</td>
<td>140</td>
<td>3.895 52.7 62.2</td>
<td>3.882 53.1 60.0</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>140</td>
<td>540</td>
<td>3.863 59.0 67.7</td>
<td>3.853 58.6 64.9</td>
<td>4.30(17) 1.8(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>140</td>
<td>540</td>
<td>3.893 53.7 64.0</td>
<td>3.878 52.6 60.1</td>
<td>4.30(17) 1.8(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>140</td>
<td>540</td>
<td>3.860 59.2 60.9</td>
<td>3.852 57.1 59.9</td>
<td>4.30(17) 1.8(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>540</td>
<td>540</td>
<td>3.900 54.8 61.1</td>
<td>3.876 54.5 60.0</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>540</td>
<td>540</td>
<td>3.890 54.2 56.8</td>
<td>3.863 53.2 56.6</td>
<td>8.34(17) 2.0(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>540</td>
<td>540</td>
<td>3.902 53.6 59.1</td>
<td>3.865 54.6 59.4</td>
<td>8.34(17) 2.0(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1200</td>
<td>540</td>
<td>3.880 54.3 57.6</td>
<td>3.876 52.7 57.0</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>540</td>
<td>3.892 53.5 56.4</td>
<td>c</td>
<td>9.64(17) 2.0(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1200</td>
<td>540</td>
<td>3.895 53.4 57.7</td>
<td>c</td>
<td>9.64(17) 2.0(16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1200</td>
<td>540</td>
<td>3.901 54.5 63.6</td>
<td>c</td>
<td>9.64(17) 2.0(16)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specimen configuration: WANL Dwg. 388D992
Data to be used for material evaluation only. Do not use for design.

aConstant at spring lengths of 3.292 and 2.754 in. Springs were compressed to a length of 2.754 in. for irradiation.
bThe control springs were maintained at the same temperature as the irradiated springs for a comparable period of time.
cSprings could not be removed from the bolts used to compress them because of galling of the threads.
5.6 **Tensile and Flexure Data for Feuralon**

The Feuralon plastic material was tested in the form of tensile specimens (M-14-1) and flexure specimens (M-14-2). The test procedures were essentially as described for the metal tensile and flexure specimens. The specimens were irradiated in liquid hydrogen.

Table 5-33 gives the tensile data. Since the material does not yield, only the maximum (or ultimate) load and stress were obtained.

The maximum fiber stress given in Table 5-34 was computed by use of Equation 5-6 with an L (span) of 4 in. The deflection of the beam at rupture was determined from the chart travel with the Instron operating at a constant crosshead speed; this is given as "Chart Deflection" in Table 5-34.

Table S-3 of the Summary gives the percent difference between data for the irradiated specimens and indicates if the difference is statistically significant at the 95% confidence level.
### Table 5-33
TENSILE DATA FOR FEURALON IRRADIATED AT 400°F TO A GAMMA DOSE OF 4.3 x 10⁹ RAD(C)
AND TESTED AT 140°F AND 540°F
(Specification M-14-1)

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Test Temp (°F)</th>
<th>Ave Diam (in.)</th>
<th>Ave Area (in²)</th>
<th>Max Load (lb)</th>
<th>Max Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>140</td>
<td>0.2462</td>
<td>0.0476</td>
<td>808</td>
<td>17.0</td>
<td>Control</td>
</tr>
<tr>
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<td>140</td>
<td>0.2502</td>
<td>0.0491</td>
<td>688</td>
<td>14.0</td>
<td>Control</td>
</tr>
<tr>
<td>16</td>
<td>140</td>
<td>0.2519</td>
<td>0.0498</td>
<td>747</td>
<td>15.0</td>
<td>Control</td>
</tr>
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<td>0.0484</td>
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<td></td>
<td></td>
<td>756</td>
<td>15.5</td>
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</tr>
<tr>
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<td></td>
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<td>5.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td></td>
<td></td>
<td></td>
<td>51.9</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>140</td>
<td>0.2473</td>
<td>0.0480</td>
<td>659</td>
<td>13.7</td>
<td>2.68 (16) 3.0 (16)</td>
</tr>
<tr>
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<td>140</td>
<td>0.2464</td>
<td>0.0477</td>
<td>686</td>
<td>14.4</td>
<td>2.68 (16) 3.0 (16)</td>
</tr>
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<td>140</td>
<td>0.2497</td>
<td>0.0490</td>
<td>637</td>
<td>13.0</td>
<td>2.68 (16) 3.0 (16)</td>
</tr>
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<td>140</td>
<td>0.2484</td>
<td>0.0485</td>
<td>600</td>
<td>12.4</td>
<td>2.68 (16) 3.0 (16)</td>
</tr>
<tr>
<td>Ave</td>
<td></td>
<td></td>
<td></td>
<td>645</td>
<td>13.4</td>
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</tr>
<tr>
<td>Std Dev</td>
<td></td>
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<td>0.9</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
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<td></td>
<td></td>
<td>5.6</td>
<td>6.5</td>
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</tr>
<tr>
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<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
<td>8.4</td>
<td></td>
</tr>
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<td>0.0490</td>
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Crosshead Speed = 0.050 in./min
Table 5-33
TENSILE DATA FOR FEURALON IRRADIATED AT 40° or TO A GAMMA DOSE OF 4.3 x 10^9 RAD(C)
AND TESTED AT 140° and 540° (Cont’d)
(Specification M-14-1)

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<th>Ave Area (in²)</th>
<th>Max Load (lb)</th>
<th>Max Stress (ksi)</th>
<th>Neutron Fluence (n/cm²)</th>
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Table 5-33
TENSILE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 4.3 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification M-14-1)

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<th>Max Load (lb)</th>
<th>Max Stress (ksi)</th>
<th>Neutron Fluence (n/cm^2)</th>
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ANSC Dwg. No. 1139068-15. Data to be used for material evaluation only. Do not use for design.
Table 5-34

FLEXURE DATA FOR FEURALON IRRADIATED AT 40° R TO A GAMMA DOSE OF 3.5 x 10^9 RAD(C)
AND TESTED AT 140° R AND 540° R
(Specification M-14-2)

Crosshead Speed = 0.050 in./min

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Table 5-34
FLEXURE DATA FOR FEURALON IRRADIATED AT 40° R TO A GAMMA DOSE OF 3.5 x 10⁹ RAD(C)
AND TESTED AT 140° R AND 540° R (Cont'd)
(Specification M-14-2)

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<th>Chart Deflection (in.)</th>
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<td>0.2625</td>
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<td>22.2</td>
<td>Control</td>
</tr>
<tr>
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<td>0.3035</td>
<td>0.2750</td>
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<td>0.3059</td>
<td>0.2900</td>
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</tr>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td>4.1</td>
<td>7.3</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Specimen No.</td>
<td>Temp (°R)</td>
<td>Width (in.)</td>
<td>Thickness (in.)</td>
<td>Chart Deflection (in.)</td>
<td>Max Load (lb)</td>
<td>Max Fiber Stress (ksi)</td>
<td>Neutron Fluence (n/cm²)</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------</td>
<td>-------------</td>
<td>-----------------</td>
<td>------------------------</td>
<td>--------------</td>
<td>------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E &gt; 1 MeV E &lt; 0.48 eV</td>
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<tr>
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<td>140</td>
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<td>0.3045</td>
<td>0.2475</td>
<td>168.8</td>
<td>21.8</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
<tr>
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<td>0.5015</td>
<td>0.3057</td>
<td>0.2700</td>
<td>186.4</td>
<td>23.9</td>
<td>2.08 (16) 3.0 (16)</td>
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<tr>
<td>39</td>
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<td>0.3024</td>
<td>0.2550</td>
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<td>22.6</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
<tr>
<td>38</td>
<td>140</td>
<td>0.5014</td>
<td>0.3047</td>
<td>0.2250</td>
<td>150.8</td>
<td>19.4</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
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<td>0.2569</td>
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<td>8.6</td>
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<tr>
<td>46</td>
<td>540</td>
<td>0.5021</td>
<td>0.3043</td>
<td>0.4625</td>
<td>128.3</td>
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<tr>
<td>32</td>
<td>540</td>
<td>0.4988</td>
<td>0.3053</td>
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<td>45</td>
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<tr>
<td>33</td>
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<td>0.5016</td>
<td>0.3051</td>
<td>0.3475</td>
<td>115.5</td>
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<td></td>
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<td>0.4206</td>
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<td>% Std Dev</td>
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<td></td>
<td>15.2</td>
<td>6.9</td>
<td>7.1</td>
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</tr>
<tr>
<td>44</td>
<td>540</td>
<td>0.5029</td>
<td>0.3054</td>
<td>0.3300</td>
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<td>15.1</td>
<td>2.08 (16) 3.0 (16)</td>
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<tr>
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<td>540</td>
<td>0.5005</td>
<td>0.3035</td>
<td>0.3850</td>
<td>126.8</td>
<td>16.5</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
<tr>
<td>43</td>
<td>540</td>
<td>0.5008</td>
<td>0.3048</td>
<td>0.3800</td>
<td>128.6</td>
<td>16.6</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
<tr>
<td>41</td>
<td>540</td>
<td>0.4988</td>
<td>0.3031</td>
<td>0.3200</td>
<td>114.0</td>
<td>14.9</td>
<td>2.08 (16) 3.0 (16)</td>
</tr>
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<td>0.3538</td>
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<tr>
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<td></td>
<td>0.0335</td>
<td>7.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>% Std Dev</td>
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<td></td>
<td></td>
<td>9.5</td>
<td>5.7</td>
<td>5.7</td>
<td></td>
</tr>
</tbody>
</table>

ANSC Dwg. No. 1138147-15. Data to be used for material evaluation only. Do not use for design.
5.7 Data for Actuator Lubricant

The solid-film lubricant evaluated in this study was formulated and applied to the test specimens by Ball Brothers Research Corporation, Boulder, Colorado. The lubricant is known as "Vac Kote" and its formulation is proprietary.

Test specimens were irradiated in liquid hydrogen and were subsequently tested at temperatures of 540° and 1000°R. Results of the sliding wear tests are presented in Tables 5-35 and 5-36.

Friction measurements were made during all runs and the test machine was adjusted to cut off automatically when the friction coefficient reached 0.4. The 0.4 friction coefficient is an arbitrary value selected as the failure point in previous wear-life studies at NARF. Because other investigators often select a lower friction value as the failure point, wear-life (cycles) at friction coefficients of 0.1, 0.2, and 0.3 are also reported.

In performing the sliding wear tests, the load was applied after the machine was at operating speed (355 rpm). In the tests at elevated temperature (1000°R), the machine was started and the load applied prior to reaching test temperature in order to prevent plastic deformation of the film surface by the rub shoes while coming to temperature. Test temperature was reached during the first 4000 cycles in all cases.
In all runs on irradiated and control specimens, the friction coefficient was 0.05 to 0.07 when the load was first applied. After a period of 2 to 3 minutes of running, the friction coefficient would drop to 0.02 to 0.04 and remain at this level until just prior to commencement of film failure.
## Table 5-35

WEAR-LIFE CHARACTERISTICS OF "VAC-KOTE" SOLID-FILM LUBRICANT AT 540°C

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Film Thickness (10^-4 in.)</th>
<th>Wear Life (cycles)</th>
<th>Cycles at Friction Coefficient of</th>
<th>Test Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Control Specimens</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>6</td>
<td>59,683</td>
<td>58,000</td>
<td>59,420</td>
</tr>
<tr>
<td>24</td>
<td>8</td>
<td>88,292</td>
<td>81,700</td>
<td>86,100</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>41,118</td>
<td>40,960</td>
<td>41,000</td>
</tr>
<tr>
<td>27</td>
<td>8</td>
<td>60,363</td>
<td>57,750</td>
<td>59,300</td>
</tr>
<tr>
<td>31</td>
<td>8</td>
<td>55,579</td>
<td>55,350</td>
<td>55,460</td>
</tr>
<tr>
<td>16</td>
<td>7</td>
<td>59,413</td>
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<td>59,350</td>
</tr>
<tr>
<td>37</td>
<td>8</td>
<td>*107,495</td>
<td>*106,240</td>
<td>*106,720</td>
</tr>
</tbody>
</table>

*Ave* included in average

| **Irradiated Specimens** |                            |                    |     |     |     |                  |
|--------------------------|---------------------------|--------------------|     |     |     |                  |
| 9                        | 5                         | 130,000            | 128,300 | 128,750 | 130,100 | 1-16-73          |
| 13                       | 6                         | 119,623            | 117,140 | 118,270 | 119,673 | 1-23-73          |
| 6                        | 7                         | 188,118            | 182,170 | 184,200 | 188,100 | 1-24-73          |
| 1                        | 7                         | 137,123            | 134,350 | 136,100 | 137,000 | 2-15-73          |
| 17                       | 8                         | 115,907            | 113,400 | 114,600 | 115,480 | 12-6-72          |
| 19                       | 7                         | *157,318           | *156,350 | *156,740 | *157,318 | 12-4-72          |

*Ave* included in average

<table>
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<tr>
<th></th>
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<th>Ave</th>
<th>Ave</th>
<th>Ave</th>
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</thead>
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<td>141,348</td>
<td>138,618</td>
<td>139,777</td>
<td>141,278</td>
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</table>

Test Conditions: Hohman A-6 machine: load 110 lb/shoe; speed 355 rpm (128 sliding ft/min); substrate 440-C steel; rub shoe, 440-C steel
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Film Thickness (10^{-4} in.)</th>
<th>Wear Life (cycles)</th>
<th>Cycles at Friction Coefficient of 0.1</th>
<th>Cycles at Friction Coefficient of 0.2</th>
<th>Cycles at Friction Coefficient of 0.3</th>
<th>Test Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Specimens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>28,333</td>
<td>26,700</td>
<td>27,500</td>
<td>27,900</td>
<td>10-23-72</td>
</tr>
<tr>
<td>34</td>
<td>7</td>
<td>33,894</td>
<td>31,300</td>
<td>32,560</td>
<td>33,400</td>
<td>11-6-72</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
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<td>24,730</td>
<td>26,530</td>
<td>26,780</td>
<td>11-29-72</td>
</tr>
<tr>
<td>29</td>
<td>9</td>
<td>32,052</td>
<td>26,920</td>
<td>27,900</td>
<td>30,400</td>
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<tr>
<td>20</td>
<td>7</td>
<td>32,090</td>
<td>25,700</td>
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<td>31,900</td>
<td>3-1-73</td>
</tr>
<tr>
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<td>6</td>
<td>26,905</td>
<td>23,320</td>
<td>24,120</td>
<td>26,875</td>
<td>3-2-73</td>
</tr>
<tr>
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<td>26,445</td>
<td>27,618</td>
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<tr>
<td>Irradiated Specimens</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>9</td>
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<td>27,280</td>
<td>27,670</td>
<td>28,430</td>
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<tr>
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<td>8</td>
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<td>27,450</td>
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<td>27,332</td>
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<td>25,800</td>
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<td>29,183</td>
<td>26,350</td>
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<td>29,550</td>
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<td>27,594</td>
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Test Conditions: Hohman A-6 machine: load 110 lb/shoe; speed 355 rpm (128 sliding ft/min); substrate 440-C steel; rub shoe, 440-C steel
APPENDIX A

PEDIGREE DATA
PEDIGREE DATA FORM

TEST N-7-1

I. MATERIAL

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<tr>
<th>ITEM</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILL No.</th>
<th>SIZE</th>
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</thead>
<tbody>
<tr>
<td>Al 6061-T6</td>
<td>N 01494</td>
<td>Earle M. Jorgensen Co.</td>
<td>Plate</td>
<td>462862</td>
<td>533301</td>
<td>1 in. thick</td>
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</table>

SPECIFICATION

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<th>FORGE SOURCE</th>
<th>FORGING T.O.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
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II. SPECIFICATION REQUIREMENTS

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<th>Mn</th>
<th>Fe</th>
<th>Zn</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cu-Ta</th>
<th>Zr</th>
<th>B</th>
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<td>.15</td>
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</tr>
<tr>
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<td>.15</td>
<td>.15</td>
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MECH. PROPERTIES

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<tr>
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<th>STRESS, Ksi</th>
<th>YIELD .2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
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<td>MAX</td>
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<td>35</td>
<td>9</td>
<td>76</td>
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<td>MIN</td>
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OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

P. O. N 01494: None

IV. SOURCE DATA:

Deviations from Purchase Order:

P. O. N 01494: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

P. O. N 01494: None

VI. NERVA PROCESSING:

Deviation from Fab Order:

IDO 962852: None

P. O. N 01669: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS:

Lot A = Heat 462862, Serial No. 880345 thru 880354
Lot B = Heat 533301, Serial No. 880355 thru 880365

Date
ITEM:

I. MATERIAL P.O. No. SOURCE FORM HEAT NO. BILLET NO. SIZE

| Ti 6Al4V  | NO1453 | Universal Titanium Co., Inc. | Sheet | G-50532 | 1/4" thick |

SPECFICATION FORGE SOURCE FORGING SIZE HEAT TREATMENT HEAT TREAT SOURCE

II. SPECIFICATION REQUIREMENTS:

| CHEMISTRY | V C Mn Fe Ni Cu O Cr Al Ti Mg Co Mo Cu+Ta Zr B OTHER |
|-----------|------|-------|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|
| MAX       | 3.5  | .08   | .20 | .05 | .015 | 20  | 6.75|     |     |     |     | .40 |
| MIN       | 4.5  |       |     |     |      |     |     | 5.5 |     |     |     |     |

MECH. PROPERTIES TEMP.°F STRESS, KSI YIELD .2% KSI ELONG. % HEAT TREATMENT GRAIN SIZE

| MAX       | 134  | 126  | 6.0 |
| MIN       | Ambient |     |     |

OTHER

III. PURCHASE ORDER DATA:

Deviation from Purchase Order:

P.O. NO1453: None

IV. SOURCE DATA:

Deviation from Purchase Order:

P.O. NO1453: None

V. RECEIVING AND INSPECTION DATA:

Deviation from Purchase Order:

P.O. NO1453 - None

VI. NERVA PROCESSING:

Deviation from Fab Order:

P.O. NO1453: None

P.O. NO1661 - Dimensional discrepancies were reported but will not affect test results

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS:

Specimens fabricated from rolling direction of plate. Specimen serial numbers are 880001 through 880030.

140°F unirradiated properties:

Max strength 209 ksi

0.2% yield strength 202 ksi

A-3
<table>
<thead>
<tr>
<th>ITEM:</th>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
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<td>N 01897</td>
<td>Universal Titanium Co., Inc.</td>
<td>Plate welded</td>
<td>C50532</td>
<td>1/4&quot; thick</td>
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</table>

**SPECIFICATION**

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<th>SOURCE</th>
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<th>FORGING SIZE</th>
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<th>HEAT TREAT SOURCE</th>
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<td>Weld per MIL-T-5021 and ACC-STD-1194-12B</td>
<td>Airline Welding and Engineering</td>
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</table>

**SPECIFICATION REQUIREMENTS**

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<th>Fe</th>
<th>Nb</th>
<th>Si</th>
<th>O</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Nb+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
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<table>
<thead>
<tr>
<th>MECH. PROPERTIES</th>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD .2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
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<tbody>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stress relieve at 1100°F for 2 hours</td>
<td></td>
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**OTHER**

### III. PURCHASE ORDER DATA

P. O. N 01897

Deviations from specification:

P. O. N 01897 - None

### V. RECEIVING AND INSPECTION DATA

P. O. N 01897

Deviations from Purchase Order:

P. O. N 01897 - None

### IV. SOURCE DATA

P. O. N 01897

Deviations from Purchase Order:

P. O. N 01897 - None

### VI. NERVA PROCESSING

P. O. N 01947

Deviations from Fab Order:

P. O. N 01947 - Parts of weldment were porous but these parts were not used to fabricate specimens.  
P. O. N 01695 - Specimens did not meet flatness requirement. They were bowed up to .005 inch from end to end.

### VII. PRE-SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Results: Serial numbers are 880046 thru 880060.

Date
## PEDIGREE DATA FORM

### Test N-9-3

#### ITEM:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti Al-4V</td>
<td>NO1897</td>
<td>IDG 961115</td>
<td>Universal Titanium Co., Inc.</td>
<td>Plate welded</td>
<td>G-50532</td>
<td>1/4&quot; thick</td>
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### SPECIFICATION

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<tr>
<th>FORGE SOURCE</th>
<th>FORGING T.D.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crucible Steel</td>
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### II. SPECIFICATION REQUIREMENTS

#### CHEMISTRY

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<tr>
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<th>C</th>
<th>Mn</th>
<th>Fe</th>
<th>N</th>
<th>H</th>
<th>O</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
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<tbody>
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#### MECH. PROPERTIES

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<tr>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD 2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
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</thead>
<tbody>
<tr>
<td>MAX</td>
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<td></td>
<td></td>
<td>Stress Relieve 1100°F for 2 hours</td>
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<td>MIN</td>
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<tr>
<td>OTHER</td>
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</tbody>
</table>

### III. PURCHASE ORDER DATA:

Deviations from specification:

- PO NO1897: None

### V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

- PO NO1897: None

### IV. SOURCE DATA:

Deviations from Purchase Order:

- PO NO1897: None

### VI. NERVA PROCESSING:

Deviation from Fab Order:

- PO NO1947: Porous areas in percent material. Porous areas not used.
- PO NO1695: Parts are bowed end to end from .007/.010. IDG 961115: None

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS: Serial numbers are 5/N 880007 thru 880021.

Date

---

A-5
## APPENDIX A

### PIEGHEE DATA FORM

<table>
<thead>
<tr>
<th>ITEM:</th>
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<tbody>
<tr>
<td><strong>I. MATERIAL</strong></td>
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<tr>
<td>Feralon</td>
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<td><strong>SPECIFICATION</strong></td>
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<tr>
<td>Type AV</td>
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<thead>
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<th><strong>II. SPECIFICATION REQUIREMENTS</strong></th>
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<tr>
<td><strong>CHEMISTRY</strong></td>
</tr>
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<td>MAX</td>
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<tr>
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<table>
<thead>
<tr>
<th><strong>III. PURCHASE ORDER DATA:</strong></th>
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</thead>
<tbody>
<tr>
<td>Lot 1 PO N00714</td>
</tr>
<tr>
<td>Lot 2 PO N01358</td>
</tr>
<tr>
<td>Deviations from specification:</td>
</tr>
<tr>
<td>PO N00714 - None</td>
</tr>
<tr>
<td>PO N01358 - None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>V. RECEIVING AND INSPECTION DATA:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviations from Purchase Order:</td>
</tr>
<tr>
<td>PO N00714 - Thickness varied from .250 to .420 inch</td>
</tr>
<tr>
<td>PO N01358 - Thickness varied from .370 to .440 inch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>IV. SOURCE DATA:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviations from Purchase Order:</td>
</tr>
<tr>
<td>PO N00714 - None</td>
</tr>
<tr>
<td>PO N01358 - None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>VI. NERVA PROCESSING:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot 1 PO N01252</td>
</tr>
<tr>
<td>Lot 2 PO N01528</td>
</tr>
<tr>
<td>Deviation from Fab Order:</td>
</tr>
<tr>
<td>PO N01252 - Specimens / up to .008 (should be .002 max.) and / up to .012 (should be .002 max.)</td>
</tr>
<tr>
<td>PO N01528 - S/N 16 1D A .010 is .022. It should be .010 max.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND, TEST CHECKOUT FOR TEST AGENCY USE</strong></th>
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</thead>
<tbody>
<tr>
<td>RESULTS:</td>
</tr>
<tr>
<td>Lot 1 S/N 01 thru 16</td>
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<tr>
<td>Lot 2 S/N 31 thru 46</td>
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<table>
<thead>
<tr>
<th>Serialization:</th>
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<tbody>
<tr>
<td>As purchased, Lot 1 consisted of S/N 01 thru 16 and Lot 2 consisted of S/N 880001 thru 880016. Lot 2 was reserialized S/N 31 thru 46 as indicated above to facilitate GTR-23 testing.</td>
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</table>

---

**A-6**
# APPENDIX A

## PEDIGREE DATA FORM

### ITEM:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
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<th>SIZE</th>
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<tr>
<td>I.</td>
<td>Feuralon</td>
<td>NO0714</td>
<td>Bene' Corp</td>
<td>Sheet</td>
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<td>1/4&quot;x10&quot;x10&quot;</td>
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<table>
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<th>HEAT TREAT SOURCE</th>
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<th>MECH. PROPERTIES</th>
<th>TEMP°F</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
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<table>
<thead>
<tr>
<th>III. PURCHASE ORDER DATA:</th>
<th>Lot 1 PO NO0714</th>
<th>Lot 2 PO NO1358</th>
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<tbody>
<tr>
<td>Deviations from specification:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO NO0714 - None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO NO1358 - None</td>
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<td></td>
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</tbody>
</table>

| IV. SOURCE DATA: | |
| Deviations from Purchase Order: | |
| PO NO0714 - None | |
| PO NO1358 - None | |

| V. RECEIVING AND INSPECTION DATA: | |
| Deviations from Purchase Order: | |
| PO NO0714 - Thickness varied from .250 to .420 in. | |
| PO NO1358 - Thickness varied from .370 to .440 in. | |

<table>
<thead>
<tr>
<th>VI. NERVA PROCESSING:</th>
<th>Lot 1 PO NO1252</th>
<th>Lot 2 PO NO1528</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation from Fab Order:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO NO1252 - Specimen are up to .020 inches short and parallelity is up to .006 (should be .002 max.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO NO1528 - Specimen 1 and 2 required to be .002 max. Actuals are up to .007.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE | |
| RESULTS: | Lot 1 S/N 1 thru 24 | Lot 2 S/N 31 thru 46 |
| Serialization: | As purchased, Lot 1 consisted of S/N 21 thru 36 and 40 thru 47. Lot 2 consisted of S/N 880029 thru 880064. They were reserialized to S/N 1 thru 24 and 31 thru 46 as indicated above to facilitate GTR-23 testing. |
### II. MATERIAL

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLT NO.</th>
<th>SIZE</th>
</tr>
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<tbody>
<tr>
<td>01655</td>
<td>Vasco</td>
<td>Plate</td>
<td>04642</td>
<td>1634A</td>
<td>.75&quot; X 12&quot;</td>
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<td>01529</td>
<td>Pacific Steel</td>
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<td>24&quot;</td>
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### III. SPECIFICATION REQUIREMENTS

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<th>Ni</th>
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<th>Ti</th>
<th>Mg</th>
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<th>Mo</th>
<th>Cb+Ta</th>
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<table>
<thead>
<tr>
<th>MECH. PROPERTIES</th>
<th>TEMP. °F</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
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### IV. SOURCE DATA

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>P.O. No.</th>
<th>Deviations from Purchase Order:</th>
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<td>01175</td>
<td>01655</td>
<td>P.O. N 01175 - None</td>
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<tr>
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<td>P.O. N 01655 - None</td>
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### V. RECEIVING AND INSPECTION DATA

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<th>Deviations from Purchase Order:</th>
</tr>
</thead>
<tbody>
<tr>
<td>01175</td>
<td>P.O. N 01175 - None</td>
</tr>
<tr>
<td>01655</td>
<td>P.O. N 01655 - None</td>
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### VI. NERVA PROCESSING

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>Deviations from Fab Order:</th>
</tr>
</thead>
<tbody>
<tr>
<td>01529</td>
<td>P.O. N 01529 - None</td>
</tr>
<tr>
<td>01655</td>
<td>IDO 961146 - None</td>
</tr>
</tbody>
</table>

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

- RESULTS:
  - Lot 1: Purchased on P.O. N 01655, S/N 880168 thru 880173.
  - Lot 2: Purchased on P.O. N 01175, S/N 880174 thru 880179.

- Unirradiated room temperature tensile properties:
  - Ultimate Strength = 266 KSI
  - Yield Strength = 259 KSI
  - Elongation = 10%
### MATERIAL

<table>
<thead>
<tr>
<th>Material</th>
<th>P.O. No.</th>
<th>Source</th>
<th>Form</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 Ni Maraging Steel</td>
<td>N 01655</td>
<td>N 01375</td>
<td>Vance</td>
<td>06642</td>
<td>1634A</td>
<td>.75&quot;X 12&quot;</td>
</tr>
<tr>
<td></td>
<td>N 01425</td>
<td>IDN 961114</td>
<td>Pacific Steel Plate</td>
<td></td>
<td></td>
<td>X 24&quot;</td>
</tr>
</tbody>
</table>

### SPECIFICATION

- **FORGE SOURCE**: Bendix Corp. Fluid Division, Spec. E18-V
- **FORGING I.D.**: Teledyne Vasco
- **FORGING SIZE**: Age 3 hours at 900°F
- **HEAT TREAT**: Aerojet Liquid Rocket Co.

### SPECIFICATION REQUIREMENTS

#### CHEMISTRY

|    | C   | Mn  | Fe  | S   | Si  | Cu  | Ni  | Cr  | Al  | Ti  | Mg  | Co  | Mo  | Nb  | Ti  | Zr  | B  | OTHER |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|-------|
| MAX| .010|     | .03 |     | .004|     | .18 |    | .05 |     | .80 | .40 |     |     |     |    | .30  |
| MIN|     | .003| .007| .003|     | .010|     |     |     | .010|     | .02 | .001| .006|     |    |     |

#### MECH. PROPERTIES

<table>
<thead>
<tr>
<th></th>
<th>TEMP.°F</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
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#### OTHER

<p>| | | | | | | |</p>
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<tr>
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<th></th>
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### III. PURCHASE ORDER DATA

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>Deviations from specification:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 01175</td>
<td>P.O. N 01175 - None</td>
</tr>
<tr>
<td>N 01655</td>
<td>P.O. N 01655 - None</td>
</tr>
</tbody>
</table>

### IV. SOURCE DATA

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>Deviations from purchase order:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 01175</td>
<td>P.O. N 01175 - None</td>
</tr>
<tr>
<td>N 01655</td>
<td>P.O. N 01655 - None</td>
</tr>
</tbody>
</table>

### V. RECEIVING AND INSPECTION DATA

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>Deviations from purchase order:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 01175</td>
<td>P.O. N 01175 - None</td>
</tr>
<tr>
<td>N 01655</td>
<td>P.O. N 01655 - None</td>
</tr>
</tbody>
</table>

### VI. NERVA PROCESSING

<table>
<thead>
<tr>
<th>P.O. No.</th>
<th>Deviation from fab order:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 01425</td>
<td>P.O. N 01425 - None</td>
</tr>
<tr>
<td>N 01529</td>
<td>IDN 961114 - None</td>
</tr>
</tbody>
</table>

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

#### RESULTS:

- **Lot A**: Material purchased on P.O. N 01655; S/N 880027 thru 880038 and 880114 thru 880131
- **Lot B**: Material purchased on P.O. N 01175; S/N 880251 thru 880280

Max load at 300 cycles per minute is expected to be less than 7000 pounds.

---

A-9
### I. MATERIAL

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 7075-773</td>
<td>N 00655</td>
<td>Wyman-Gordon Company</td>
<td>Forging</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

### II. SPECIFICATION REQUIREMENTS

#### MATERIAL

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>Cu</th>
<th>Mn</th>
<th>Fe</th>
<th>Si</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>6.1</td>
<td>0.30</td>
<td>0.7</td>
<td>0.50</td>
<td>2.0</td>
<td>0.40</td>
<td>0.20</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>5.1</td>
<td>0.20</td>
<td>1.2</td>
<td>1.2</td>
<td>0.18</td>
<td>Bal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

#### MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD 2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>Room Temp</td>
<td>62</td>
<td>53</td>
<td>T-73</td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### III. PURCHASE ORDER DATA

<table>
<thead>
<tr>
<th>P.O. N 00655</th>
<th>V. RECEIVING AND INSPECTION DATA:</th>
<th>P.O. N 00655</th>
</tr>
</thead>
</table>

#### Deviations from specification: None

#### Deviations from Purchase Order: None

### IV. SOURCE DATA

<table>
<thead>
<tr>
<th>P.O. N 00655</th>
<th>VI. NERVA PROCESSING:</th>
<th>P.O. N 01584</th>
</tr>
</thead>
</table>

#### Deviations from Purchase Order: None

#### Deviation from Fab Order:
- Stress corrosion tests deleted per SIR 1017
- Specimens identified by vibro peel per SIR 11590

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

**RESULTS:** Specimens from forging F1, S/N 880156 thru 880167.

- 140°F unirradiated properties:
  - Max strength 90 ksi
  - .2% yield strength 70 ksi
  - Elongation 12%

---

*A-10*
ITEM:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 7075-T73</td>
<td>NO0655</td>
<td>Wyman-Gordon Co.</td>
<td>Forging</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

SPECIFICATION

<table>
<thead>
<tr>
<th>FORGE SOURCE</th>
<th>FORGE/ BAR</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-A-22721/B</td>
<td>Wyman-Gordon Company</td>
<td>32&quot; at Base</td>
<td>49 1/2&quot; at Base</td>
<td>7-73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45° at Top</td>
<td>50 1/2&quot; at Top</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18 1/2&quot; High</td>
<td></td>
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II. SPECIFICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>MAX</th>
<th>MIN</th>
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</thead>
<tbody>
<tr>
<td>Zn</td>
<td>6.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Mn</td>
<td>0.36</td>
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<tr>
<td>Fe</td>
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<tr>
<td>S</td>
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<td>0.50</td>
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<tr>
<td>Si</td>
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<tr>
<td>Cu</td>
<td>0.40</td>
<td>0.40</td>
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<tr>
<td>Ni</td>
<td>0.20</td>
<td>0.20</td>
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<tr>
<td>Cr</td>
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<td>2.9</td>
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<tr>
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<td>Ti</td>
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<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
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<tr>
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<td>0.15</td>
</tr>
<tr>
<td>Ni</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Co</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ni</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
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<td>0.15</td>
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<tr>
<td>Mg</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Co</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ni</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Co</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ni</td>
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<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
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<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
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<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
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<td>0.15</td>
</tr>
<tr>
<td>Co</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ni</td>
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<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
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<td>0.15</td>
</tr>
<tr>
<td>Co</td>
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<td>0.15</td>
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<tr>
<td>Ni</td>
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<td>0.15</td>
</tr>
<tr>
<td>Cu</td>
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<td>0.15</td>
</tr>
<tr>
<td>Ti</td>
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<td>0.15</td>
</tr>
<tr>
<td>Mg</td>
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<td>0.15</td>
</tr>
<tr>
<td>Co</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>

MECH. PROPERTIES

<table>
<thead>
<tr>
<th>TEMP. °F</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>FLONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>Ambient</td>
<td>62</td>
<td>52</td>
<td>3</td>
<td>T-73</td>
</tr>
</tbody>
</table>

III. PURCHASE ORDER DATA:

Deviations from specification:

PO NO 00655: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO NO 00655: None

VI. NERVA PROCESSING:

Deviations from Purchase Order:

PO NO0655: Stress corrosion tests deleted per SIR 1017.

PO NO0584: Specimens identified by vibro peen per SIR 11699.

100 661115: Fatigue crack on 5 specimens were extended per IR 512463.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS:

Lot A specimens from Forging 8/1 are S/N 880301 through 880317 and 880138 through 880348.

Lot B specimens from Forging 8/2 are S/N 880333 through 880344 and 880411 through 880617.
### Item:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 7075-T73 with Al flame spray coating</td>
<td>N 01517</td>
<td>Pacific Metals Division, A.M. Castle Co.</td>
<td>Sheet</td>
<td>53860</td>
<td>.187&quot; x 48&quot;</td>
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<tr>
<td></td>
<td>N 01881</td>
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</tr>
<tr>
<td></td>
<td>N 01948</td>
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#### II. Specification Requirements

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>Zn</th>
<th>C</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>6.1</td>
<td>0.30</td>
<td>0.7</td>
<td>0.50</td>
<td>2.0</td>
<td>0.40</td>
<td>0.20</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>5.1</td>
<td>1.2</td>
<td>0.16</td>
<td>8.1</td>
<td>2.1</td>
<td>0.15</td>
<td></td>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>MECH. PROPERTIES</th>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD .2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

#### III. Purchase Order Data:

- P. O. N 01517

- Deviations from specification:
  - P. O. N 01517 - None

#### IV. Source Data:

- P. O. N 01517

- Deviations from Purchase Order:
  - P. O. N 01517 - None

#### V. Receiving and Inspection Data:

- P. O. N 01517

- Deviations from Purchase Order:
  - P.O. N 01517 - Sheet not stamped with identification prior to heat treatment. Dispositioned conditionally accept for tests other than base metal properties testing.

#### VI. Nerva Processing:

- P. O. N 01881

- Deviation from Fab Order:
  - P. O. N 01881 - None

- P. O. N 01948 - SIR 1042 authorizes use of equipment developed after flame spray specification was prepared.

#### VII. Pre Shipment Testing - Material Characterization and Test Checkout for Test Agency Use

- **Date:**

#### Results:

- Specimen S/N 88006 thru 880115 fabricated on P. O. N 01881.
  - Serial numbers 880066 thru 880097 are used for GTR-23
### PEDIGREE DATA FORM

#### Test M-31-1

**ITEM:**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE 9310</td>
<td>NO0837</td>
<td>Exle M. Jorgensen</td>
<td>Bar</td>
<td>1923443</td>
<td></td>
<td>4&quot; dia X 6&quot; long</td>
</tr>
</tbody>
</table>

**SPECIFICATION**

<table>
<thead>
<tr>
<th>FORGE SOURCE</th>
<th>FORGING I.D.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Republic Steel</td>
<td></td>
<td></td>
<td>Same as test M-31-2 specimens except no carbon used.</td>
<td>Cal Doran</td>
</tr>
</tbody>
</table>

**II. SPECIFICATION REQUIREMENTS**

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>F</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>.015</td>
<td>.13</td>
<td>.70</td>
<td>.015</td>
<td>.35</td>
<td>.35</td>
<td>3.50</td>
<td>1.40</td>
<td></td>
<td></td>
<td></td>
<td>.13</td>
<td></td>
<td>.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>.07</td>
<td>.40</td>
<td>.20</td>
<td>3.00</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MECH. PROPERTIES**

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**III. PURCHASE ORDER DATA:**

Deviations from specification:
- PO NO0837: None

Deviations from fabricated order:
- PO NO0837: None

**IV. SOURCE DATA:**

Deviations from fabricated order:
- PO NO0837: None

**V. RECEIVING AND INSPECTION DATA:**

Deviations from purchased order:
- PO NO0837: None

**VI. NERVA PROCESSING:**

Deviations from fabricated order:
- PO NO1460: None

**VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE**

**RESULTS:** Specimen serial numbers are 880001 through 880008.

- 140°F unirradiated properties
  - Max strength 210 ksi
  - .2% yield strength 170 ksi
  - Elongation 20%

_A-13_
### PEDIGREE DATA FORM

#### Test M-31-2

#### ITEM:

<table>
<thead>
<tr>
<th>1. MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE 9316</td>
<td>N 00837</td>
<td>N 01832</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 01452</td>
<td>N 01675</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 01460</td>
<td>TDO 96113</td>
<td>Bar</td>
<td>3923443</td>
<td>3521068</td>
<td>6&quot; Dia</td>
</tr>
</tbody>
</table>

**SPECIFICATION**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>FORGING</th>
<th>FORGING SIZE</th>
<th>HEAT TREAT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Republic Steel</td>
<td></td>
<td></td>
<td>Carburized to .013 .018&quot; deep, surface hardness of RC 58 minimum.</td>
<td>Cal Doran</td>
</tr>
</tbody>
</table>

#### II. SPECIFICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>P</th>
<th>C</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>0.015</td>
<td>0.13</td>
<td>0.70</td>
<td>0.015</td>
<td>0.35</td>
<td>0.35</td>
<td>3.50</td>
<td>1.40</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.08</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>0.07</td>
<td>0.40</td>
<td>0.20</td>
<td>3.00</td>
<td>1.00</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MECH. PROPERTIES</th>
<th>TEMP. °F</th>
<th>STRESS, KSI</th>
<th>YIELD .2% KSI</th>
<th>ELONG. %</th>
<th>HEAT TREAT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### III. PURCHASE ORDER DATA:

- P. O. N 00837
- P. O. N 01452

Deviations from specification:
- P. O. N 00837 - None
- P. O. N 01452 - None

#### IV. SOURCE DATA:

- P. O. N 00837
- P. O. N 01452

Deviations from Purchase Order:
- P. O. N 00837 - None
- P. O. N 01452 - None

#### V. RECEIVING AND INSPECTION DATA:

- P. O. N 00837
- P. O. N 01452

Deviations from Purchase Order:
- P. O. N 00837 - None
- P. O. N 01452 - None

#### VI. NERVA PROCESSING:

Deviation from Fab Order:
- P. O. N 01460 - None
- P. O. N 01513 - None
- P. O. N 01832 - None
- P. O. N 01875 - None

IDO 96113 - None

- Specimen serial numbers lost during carburization. Lots were separated by spectral analysis and re-serialized on IDO 960520.

#### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

**RESULTS:**

- Lot A purchased on P.O. N 00837 from Erle M. Jorgensen & Co., Heat 3923443, Serial Numbers 880097 thru 880161 and 880422 thru 880431.
- Lot B purchased on P.O. N 01452 from Allen Frye Steel Co., Heat 3821068, Serial Numbers 880132 thru 880146 and 880432 thru 880441.

Max expected load at 300 cycles per minute is 6000 pounds

---

A-14
### PEDIGREE DATA FORM

**ITEM:**

<table>
<thead>
<tr>
<th>I. MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEROCO</td>
<td>N 02116</td>
<td>Aerojet Liquid Rocket Co.</td>
<td>Forged</td>
<td>038096</td>
<td>N 00090</td>
<td></td>
</tr>
<tr>
<td>22-13-5</td>
<td>N 00772</td>
<td>S.O. A83296</td>
<td>All soldered</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SPECIFICATION:**

<table>
<thead>
<tr>
<th>FORGE SOURCE</th>
<th>FORGING T.D.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1550°F + 1825°F + 1775°F</td>
<td>Pyromet Industries</td>
</tr>
</tbody>
</table>

**SOURCE DATA:**

<table>
<thead>
<tr>
<th>P.O. N 00090</th>
<th>Deviations from Purchase Order:</th>
<th>P.O. N 00090</th>
<th>Deviations from Purchase Order:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

**IV. SOURCE DATA:**

<table>
<thead>
<tr>
<th>P.O. N 00090</th>
<th>Deviations from Purchase Order:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

**VI. NERVA PROCESSING:**

<table>
<thead>
<tr>
<th>P.O. N 02116</th>
<th>Deviation from Fab Order:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S.O. A 83296 - None</td>
</tr>
<tr>
<td>P.O. N 00772</td>
<td>P.O. N 02116 - None</td>
</tr>
</tbody>
</table>

**VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE:**

<table>
<thead>
<tr>
<th>Results: Serial Numbers are 1-3, 1-4, 2-3, 2-4, 6-3, 6-4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>1-1</td>
</tr>
<tr>
<td>2-1</td>
</tr>
<tr>
<td>6-1</td>
</tr>
</tbody>
</table>

**Control Data (test at 140°F):**

---

**A-15**
**I. MATERIAL**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHNSO</td>
<td>N-00231</td>
<td>N-02321</td>
<td>C. O. Carlson, Inc.</td>
<td>300321-1C</td>
<td>1 1/4“ x 8” x 48”</td>
<td></td>
</tr>
<tr>
<td>N-00522</td>
<td>N-00525</td>
<td>N-02060</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SPECIFICATION**

<table>
<thead>
<tr>
<th>FORGE SOURCE</th>
<th>FORGING I.D.</th>
<th>FORGING SIZE</th>
<th>HEAT NO. TREAT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyromet Industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**II. SPECIFICATION REQUIREMENTS**

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>C</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>No</th>
<th>Cl+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>.042</td>
<td>.468</td>
<td>Bal</td>
<td>.010</td>
<td>.41</td>
<td>12.42</td>
<td>21.19</td>
<td>2.22</td>
<td>.16</td>
<td>.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MECH. PROPERTIES</td>
<td>TEMP.&quot;F</td>
<td>STRESS, Ksf</td>
<td>YIELD .2% Ksf</td>
<td>ELONG. %</td>
<td>HEAT TREATMENT</td>
<td>GRAIN SIZE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX</td>
<td>Simulated furnace braze cycles for Phoebe II A nozzle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**III. PURCHASE ORDER DATA:**

**P.O. N-00231**

**V. RECEIVING AND INSPECTION DATA:**

**P.O. N-00231**

Deviations from Purchase Order:

None

**IV. SOURCE DATA:**

**P.O. N-00231**

Deviations from Purchase Order:

None

**VI. NERVA PROCESSING:**

**P.O. N-0052**

Deviation from Fab Order:

P.O. N-00952 - None
P.O. N-02060 - None
P.O. N-02321 - None

**VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE**

**RESULTS:** Specimen serial numbers are 880451 thru 880470.

140°K unirradiated $K_{IC} = 84$ ksi $\sqrt{in}$
**PEDIGREE DATA FORM**

**ITEM:**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARMCO</td>
<td>N 00231</td>
<td>G.O. Carlson, Inc.</td>
<td>Plate</td>
<td>300331-1C</td>
<td></td>
<td>1 1/4&quot; x 8&quot;</td>
</tr>
<tr>
<td>22-13-5</td>
<td>N 00952</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 00260</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SPECIFICATION**

<table>
<thead>
<tr>
<th>SOURCE No.</th>
<th>FORGING NO.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6663</td>
<td></td>
<td>1950°F +</td>
<td>Pyromet</td>
</tr>
<tr>
<td>1025°F</td>
<td></td>
<td>1775°F</td>
<td>Industries</td>
</tr>
<tr>
<td>1775°F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SPECIFICATION REQUIREMENTS**

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>.042</td>
<td>4.68</td>
<td>.010</td>
<td>.41</td>
<td>12.42</td>
<td>21.19</td>
<td>2.22</td>
<td>.16</td>
<td>.73</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MECH. PROPERTIES**

<table>
<thead>
<tr>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD .2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated Braze</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PURCHASE ORDER DATA:**

<table>
<thead>
<tr>
<th>PO N 00231</th>
</tr>
</thead>
</table>

Deviations from specification: None

**SOURCE DATA:**

<table>
<thead>
<tr>
<th>PO N 00231</th>
</tr>
</thead>
</table>

Deviations from Purchase Order: None

**RECEIVING AND INSPECTION DATA:**

<table>
<thead>
<tr>
<th>PO N 00231</th>
</tr>
</thead>
</table>

Deviations from Purchase Order: None

**NERVA PROCESSING:**

<table>
<thead>
<tr>
<th>PO N 00952</th>
<th>PO N 02060</th>
</tr>
</thead>
</table>

Deviation from Fab Order: None

PO N 00952 - None

PO N 02060 - None

**PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE**

**RESULTS:** Specimen S/N 880210 thru 880218

<table>
<thead>
<tr>
<th>Property</th>
<th>$3 \times 10^{18}$ psi</th>
<th>$8 \times 10^{18}$ psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength</td>
<td>150ksi</td>
<td>180ksi</td>
</tr>
<tr>
<td>Maximum Strength</td>
<td>215ksi</td>
<td>235ksi</td>
</tr>
<tr>
<td>Elongation</td>
<td>15%</td>
<td>12%</td>
</tr>
</tbody>
</table>

A-17
### T-7 PEDIGREE DATA FORM

**Test M-39-1**

### 1. MATERIAL

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL</th>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORGE</th>
<th>HEAT NO.</th>
<th>BILLET NO.</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BeCu</td>
<td>N-02245</td>
<td>Pacific Spring Engineering Co.</td>
<td>Belleville Springs</td>
<td>4-1076</td>
<td>Lot No 1-7-523</td>
<td>6.7&quot; OD 3.2&quot; ID .162 high</td>
</tr>
</tbody>
</table>

### 2. SPECIFICATION

<table>
<thead>
<tr>
<th>FORGE SOURCE</th>
<th>FORGING T.D.</th>
<th>FORGING SIZE</th>
<th>HEAT TREATMENT</th>
<th>HEAT TREAT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Spring Engineering Co. P/N 10080</td>
<td></td>
<td></td>
<td>600°F for 2 hours</td>
<td>Pacific Spring Engineering Co.</td>
</tr>
</tbody>
</table>

### II. SPECIFICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>CHEMISTRY</th>
<th>C</th>
<th>Mn</th>
<th>Fe</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cr+Ta</th>
<th>Zr</th>
<th>B</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>2.0</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>MIN</td>
<td>1.8</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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</table>

### MECH. PROPERTIES

<table>
<thead>
<tr>
<th>TEMP. °F</th>
<th>STRESS, Ksi</th>
<th>YIELD .2% Ksi</th>
<th>ELONG. %</th>
<th>HEAT TREATMENT</th>
<th>GRAIN SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
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<tr>
<td>MIN</td>
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</tbody>
</table>

**OTHER**  BeCu alloy 172 per ASTM-B 194, 1/4 hard in precipitation heat treat condition.

### III. PURCHASE ORDER DATA:

| P.O. N-02245 | Deviations from specification: | None |

### V. RECEIVING AND INSPECTION DATA:

| P.O. N-02245 | Deviations from Purchase Order: | None |

### IV. SOURCE DATA:

| P.O. N-02245 | Deviations from Purchase Order: | None |

### VI. NERVA PROCESSING:

| Deviation from Fab Order: | None |

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

**RESULTS:**

<table>
<thead>
<tr>
<th>Pb</th>
<th>.004</th>
<th>Zn</th>
<th>.030</th>
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</thead>
<tbody>
<tr>
<td>Sn</td>
<td>.05</td>
<td>Be</td>
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<tr>
<td>Si</td>
<td>.09</td>
<td>Co</td>
<td>.21</td>
</tr>
<tr>
<td>Cr</td>
<td>.003</td>
<td>Al</td>
<td>.06</td>
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<tr>
<td>Ni</td>
<td>.02</td>
<td>Mn</td>
<td>.009</td>
</tr>
<tr>
<td>Cu</td>
<td>Bal</td>
<td>Ag</td>
<td>.015</td>
</tr>
<tr>
<td>Fe</td>
<td>.10</td>
<td></td>
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</tbody>
</table>

Approximately 190 pounds required to compress spring .100 inch.
<table>
<thead>
<tr>
<th>ITEM:</th>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I. MATERIAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.O. No.</td>
<td>Source</td>
<td>Form</td>
<td>Heat No.</td>
<td>Billet No.</td>
<td>Size</td>
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<tr>
<td>102554</td>
<td>Wyman-Gordon Co.</td>
<td>Forging</td>
<td>None</td>
<td>None</td>
<td>1/2&quot; dia X 10&quot; long</td>
</tr>
<tr>
<td>NO1974</td>
<td>1139576</td>
<td>4</td>
<td>8/8 880024 thru 880043 per PO NO1515</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO1315</td>
<td>1138791-10</td>
<td>8/8 880001 thru 880003</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| NO2722 | 1138791-10 | 8/8 880024 thru 880033 
| NO1550 | 1138791-10 | 8/8 880024 thru 880033 |
| SPECIFICATION | | | | | |
| FORGING SOURCE | FORMING TEMP | FORMING SIZE | HEAT TREATMENT | HEAT TREAT SOURCE |
| Wyman-Gordon Co. | 17" dia X 10" long | Vacuum anneal at 1400°F | Wyman-Gordon Co. |
| AGC 90163A | | | | |

III. PURCHASE ORDER DATA:
Deviations from specification:

PO 102554: None
PO 102554: None
PO NO1515 - None
PO NO1550 - None

IV. SOURCE DATA:
Deviations from Purchase Order:

PO 102554: None
PO NO1515 - None
PO NO1974 Fill tube with .020" wall thickness was used; reworked per SDAR 40123 to provide .016" wall in seal-off area.
PO NO2722: None

V. RECEIVING AND INSPECTION DATA:
Deviations from Purchase Order:

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO NO1515 - None
PO NO1550 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS:

P/N 1138265 - 104 "A" 8/8 880024 thru 880043 per PO NO1515
P/N 1138791-10 | 8/8 880001 thru 880003
P/N 1138791-10 | 8/8 880024 thru 880033

Specimens oriented perpendicular to radial direction of forgings.

P/N 1138791-1 and 1138791-10: The capsule walls were removed to contact specimen button heads to improve heat transfer.
PEDIGREE DATA FORM

Page 2 of 3

ITEM:

I. MATERIAL: N01109 N01150 N01874 N01151 N01251 N01515 N02272

SOURCE: Stellite (Cabot Corp)

FORM: Bar

HEAT NO.: 2610-0-4007

BILLET NO.: .75"X 15'

SPECIFICATION FORGE SOURCE FORGING I.D. FORGING SIZE HEAT TREATMENT HEAT TREAT SOURCE

ACG 90056E except weld test Simulated braze per PO N01251 Pyromet Ind.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY

| W | C | Mn | Fe | S | Si | Cu | Ni | Cr | Al | Ti | V | Co | Mo | P | Zr | B | OTHER |
|---|---|----|----|---|----|----|----|----|----|----|---|----|----|---|---|---|---|---|
| MAX | 1.00 | 0.15 | 1.00 | 20.00 | 0.01 | 1.00 | 0.35 | 22.00 | 0.02 | 0.02 | 0.50 | 2.50 | 10.00 | 0.20 | 0.02 | 0.001 | |
| MIN | 0.20 | 0.05 | 17.00 | - | - | - | Bal | 20.50 | - | - | 0.50 | 8.00 | - | - | - | - | - |

MECH. PROPERTIES

TEMP. °F STRESS, KSI YIELD .2% KSI ELONG. % HEAT TREATMENT GRAIN SIZE

| MAX | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

| MIN | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

OTHER

III. PURCHASE ORDER DATA:

PO N01109 PO N01251

Deviations from specification:

PO N01109 - None

PO N01251 - None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N01109 - None

PO N01251 - None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N01109 - None

PO N01251 - None

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01515 - None

PO N01550 - None

Req N01874 Fill tube with .020" wall thickness was used. Reworked per SDAR 40123 to provide .016" wall in seal-off area.

PO N02722: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

RESULTS:

P/N 1138265-110-8 S/N 880084 thru 880143 per PO N01515

P/N 1138567-10 NC S/N 880046 thru 880090 per PO N01550

P/N 1138791-3 S/N 880084 thru 880093

P/N 1138791-12 S/N 880046 thru 580050

P/N 1138791-3 and 1138791-12: The capsule walls were sanded to contact specimen button heads to improve heat transfer.

Date

A-20
### I. MATERIAL

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<thead>
<tr>
<th>P.O. No.</th>
<th>SOURCE</th>
<th>FORM</th>
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<th>BILLET NO.</th>
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### II. SPECIFICATION

#### II. SPECIFICATION REQUIREMENTS

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<tr>
<th>CHEMISTRY</th>
<th>C</th>
<th>Mn</th>
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<th>S</th>
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<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mg</th>
<th>Co</th>
<th>Mo</th>
<th>Cb+Ta</th>
<th>Zr</th>
<th>B</th>
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### III. PURCHASE ORDER DATA:

Deviations from specification:

### V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

### IV. SOURCE DATA:

Deviations from Purchase Order:

### VI. NERVA PROCESSING:

Deviation from Fab Order:

### VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

**RESULTS:**

See WNL RTS 60 for pedigree information.

P/N 1138791-2 S/N 725 thru 731 and 770 thru 776 and
P/N 1138791-11 S/N 833 thru 838:

The capsule walls were swaged to contact specimen button heads
to improve heat transfer.

---

**A-21**
REFERENCES

