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FINAL REPORT

GTR-20C

CRYOGENIC RADIATION EFFECTS

ON AISI 347 STEEL FORGING

NERVA Program, Contract SNP-1

March 1971

MASTER

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL

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K. Sato
K. Sato, Manager
Engineering Staff
Aerojet Nuclear Systems Company

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I. INTRODUCTION

AISI 347 is an 18-8 chrome nickel type stainless steel. This face centered cubic austenitic stainless steel is not subject to poor low temperature ductility and is widely used in cryogenic applications. In NERVA applications the alloy is a candidate material for valve components, nozzle jacket and tubes, and lines. These applications involve the use of forged and sheet material. Maximum expected fluences range to 3×10^{19} n/cm² (> 1 MeV) at temperature from 40 to 2060°R (Ref. 1).

Previous testing (GTR-19, Ref. 2) has shown that elongation of AISI 347 plate is decreased from 27.2% for the control to 26.2% for specimens irradiated in liquid hydrogen to a fluence of 3×10^{17} n/cm² (> 1 MeV) and tested in liquid hydrogen.

The objective of the current investigation (ANSC Test No. 37NRO 027) was to obtain mechanical property data (tensile) on forging material specimens irradiated to neutron fluences up to 5×10^{18} n/cm² (> 1 MeV) at 140°R.

This test was part of GTR-20C, a joint ANSC and WANL irradiation test.* Data were reported to ANSC by the testing agency (General Dynamics/Aerospace Div/Fort Worth Operation - Nuclear Aerospace Research Facility) in monthly progress and data reports.

II. SUMMARY

Tensile button-head specimens fabricated from a AISI 347 forging were irradiated to three fluences (approximately 6×10^{17} n/cm², 1×10^{18} n/cm² and 5×10^{18} n/cm² > 1 MeV) and subsequently tensile tested at 140°R. During irradiation and testing, the specimens were submerged in liquid nitrogen to maintain the cryogenic temperature.

*The GTR-20C was conducted at the General Dynamics 10 - megawatt Ground Test Reactor at Fort Worth, Texas. The test consisted of: (1) ANSC-Inconel 718 Tensile and Fracture Toughness, Al 7039-T63 Tensile and Fracture Toughness, Ti-5Al 2.5 Sn Tensile and Fracture Toughness, 347 Stainless Steel Tensile, Hastelloy X tensile, A-286 tensile and notched tensile, Bearing Retainer, AG Carb 101 and (2) WANL-Beryllium tensile and fracture toughness, Inconel 718 tensile, leak and spring constant, A-286, Bath and CuB¹⁰.

Nine specimens irradiated to a fluence of approximately $5 \times 10^{18} \text{ n/cm}^2 > 1 \text{ MeV}$ were annealed at 540°R for three time periods, 3 each at 10, 100, and 1000 minutes prior to tensile testing in liquid nitrogen. During the 100 minute annealing period resonant frequency measurements were conducted on three of these specimens to determine Young's modulus changes.

The AISI 347 forging tensile property most sensitive to radiation was 0.2% offset yield strength, which exhibited significant increases for each level of fluence (6.2×10^{17} , 1.2×10^{18} and $5.0 \times 10^{18} \text{ n/cm}^2 > 1 \text{ MeV}$). The 0.2% offset yield strength showed significant decreases for each annealing period (10, 100 and 1000 minutes at 540°R). Approximately equal reductions in 0.2% offset yield strength were obtained for each of the three time periods of annealing.

Ultimate strength increased with all levels of fluence and showed a significant (95% confidence) increase at a mean fluence of $5.0 \times 10^{18} \text{ n/cm}^2 > 1 \text{ MeV}$. Annealing produced no significant changes in ultimate strength.

No significant changes due to irradiation and annealing were observed in percent elongation and reduction of area for AISI 347 forging specimens.

In all three of the AISI 347 forging tensile specimens irradiated to a mean fluence of $5.0 \times 10^{18} \text{ n/cm}^2 (> 1 \text{ MeV})$ a significant reduction in resonant frequency, Hz, was observed indicating a small decrease (about 2%) in Young's modulus due to irradiation.

III. CONCLUSIONS AND RECOMMENDATIONS

AISI 347 forging alloy is not subject to significant radiation embrittlement at fluences from 6×10^{17} to $5 \times 10^{18} \text{ n/cm}^2 (> 1 \text{ MeV})$ at 140°R. The maximum mean percentage change in elongation was a decrease from 51.6% (mean control) to 50.0% (mean fluence $1.2 \times 10^{18} \text{ n/cm}^2 > 1 \text{ MeV}$).

The 0.2% offset yield strength showed significant (95% confidence) increases for each level of fluence (6.2×10^{17} , 1.2×10^{18} and 5.0×10^{18} n/cm² > 1 MeV) reaching a maximum of 121.9 ksi mean at a fluence level of 4.9×10^{18} n/cm² > 1 MeV, an increase of 169% over the control mean of 45.9 ksi. Annealing of specimens irradiated to 5.2×10^{18} n/cm² > 1 MeV for 10 minutes at 540°R reduced the 0.2% offset yield strength to a mean value of 106.9 ksi.

It is recommended that no further tensile testing of AISI 347 forging material at 140°R and in the range of 6×10^{17} n/cm² to 5×10^{18} n/cm² > 1 MeV be conducted. Additionally, it is recommended that design allowables for AISI 347 forging in the above environment be based on unirradiated data.

Limited studies of resonant frequency measurements (used to determine changes in Young's modulus) of high fluence level (5.0×10^{18} n/cm² > 1 MeV) tensile specimens during the 100 minute annealing period at 540°R showed an average decrease in resonant frequency of 14.5 Hz, or 0.8%. In order to avoid unknown annealing effects, any future testing of resonant frequency should be conducted at test temperatures and using a uniform cross-section to determine true modulus values.

IV. TEST SPECIMENS AND PROCEDURES

Specimen pedigree data for AISI 347 Forging is presented in Table 1. Chemical analysis of the material is presented in Table 2. Twenty four tensile specimens (4 control and 20 irradiated) were tested. Tensile test specimens of AISI 347 Forging were round button-head configuration shown in Figure 1.

The specimens were mounted in racks and irradiated while immersed in liquid nitrogen (approximately 140°R), to three levels of neutron fluence. Figure 2 shows a view of the specimen rack before installation in the high fluence

North Dewar and Figure 3 shows the test rack used in the low fluence East Dewar. During irradiation, the liquid nitrogen level was maintained above the specimen racks. The low fluence dewar (East position) had been used in GTR-21. It is equipped with three fill lines, three exhaust tubes and one dump valve and two liquid level probes. The high fluence dewar (North position) was a new design for this test. The dewar consisted of a removable liquid nitrogen chamber and an outer gaseous nitrogen chamber (Figure 4). It is equipped with two liquid nitrogen supply lines, two liquid level probes, two dump valves, and two exhaust tubes for redundancy.

The reactor operating time during the 6000 MW-h irradiation (21 May to 19 June 70) was 684 hours, 41 minutes. Upon completion of the irradiation, the specimens were transferred to the Irradiated Materials Laboratory where tensile tests were performed in liquid nitrogen (approximately 140°R).

The tensile testing was performed with a Model TT-D split console Instron Tensile test machine having a variable range load capacity of 20,000 lb. A set of Rene' 41 specimen grips and A-286 pull rods were employed during testing. The shoulder loaded button-head tensile specimens were tested with a constant 0.05 in/min Instron cross head speed. Based on a 1.5 inch gage length this corresponds to average strain rate of 0.033 in/in/min in the plastic region. A light weight silastic covered polystyrene foam cryostat attached to the bottom pull rod was used to keep the specimens submerged in liquid nitrogen during the tensile testing.

Axiality testing* was performed immediately prior to tensile testing to verify that the pull rods, the specimen grips, and the test specimens were all aligned to provide axial loading of the test specimens.

* Standard Procedure RE-1, Procedure for Axiality Determination for Tensile Test Apparatus (Preliminary) ANSC July 1970

Axiality testing was accomplished at ambient temperature. Each test consisted of five separate runs. The procedure provides for the determination of the eccentricity of loading, including direction, over the entire length of the specimen (AGC Print 1138347, Figure No. 5) and separation of the causes due to specimen and apparatus. The run-to-run results indicated good consistency in the bending strain magnitude and direction, and therefore a stable load train. A stable load train is required for a valid axiality test.

The maximum value of bending strain due to apparatus, expressed as a percentage of strain at the center of the specimen, is tabulated below. Example of the graphical solutions is shown in Figure 6.

RESULTS OF AXIALITY TESTS

<u>Test Type Scheduled</u>	<u>Tensile</u>
<u>Environment</u>	<u>Air</u>
<u>Bending due to Apparatus, %⁽¹⁾</u>	<u>7.1</u>

For annealing studies, a dummy tensile specimen (AGC Print #1138357, Figure 7) instrumented with a thermocouple and the nine tensile specimens were placed in an annealing container. The specimens were brought to 540°R with water in approximately 3 minutes, rinsed in acetone, and gaseous nitrogen dried. Each group of three specimens was maintained at approximately 540°R for a time period of 10, 100 or 1000 minutes. The temperature of the test specimens during annealing was inferred from the temperature of the instrumented specimen. Following the anneal cycle, the specimens were resubmerged in liquid nitrogen until after tensile testing.

-
- (1) The bending strain due to the apparatus is the maximum strain at the specimen surface in excess of the strain at the center of the specimen, expressed as a percent of strain at the center.

During the 100 minute annealing period resonant frequency measurements were performed on three of the high fluence button-head specimens which had been measured before irradiation and one unirradiated control specimen. A block diagram of the resonant frequency testing set-up is shown in Figure 8.

V. TEST RESULTS

A. PROPERTY VALUES

1. Tensile

Property values for individual tensile specimens are given in the Appendix Table A-1. These data are based on data provided in raw data charts, monthly progress letters and data reports from General Dynamics, Fort Worth Operation. Results obtained for each group of AISI 347 specimens are summarized in Table 3. Mean values and standard deviations are given for ultimate and yield strengths, elongation and reduction of area.

2. Resonant Frequency

Pre-irradiated and post-irradiation resonant frequency measurements results are provided in Table 4 for four specimens (1 control and three irradiated to a fluence level of 5.0×10^{18} n/cm² (>1 MeV). Mean values and standard deviations are given.

B. STRESS-STRAIN CURVES

Typical stress-strain curves for control and irradiated tensile specimens of AISI 347 are shown in Figure 9. The curves were drawn from estimated modulus of elasticity from handbook data and the curve shapes from test charts of load vs cross head travel.

C. DOSIMETRY

The fluences reported for individual specimens in Appendix Table A-1 are based on the mapping run and dosimetry obtained during irradiation of the specimens. Dosimetry foils were attached to each specimen rack and the analysis of these foils resulted in the fluences reported.

D. ANALYSIS

The analysis of the data generally followed a two-step process:

1. Analysis of Variance

For each tensile property (ultimate strength, 0.2% offset yield strength, elongation and reduction of area), a one way analysis of variance was conducted in the categories of controls, low fluence, medium fluence and high fluence. Thus, for each property, the significant effects due to any fluence category were identified, with the F-test. Annealing was evaluated for the high fluence tests using categories on unannealed, 10 minute, 100 minute and 1000 minute anneal.

2. Contrasts

To define the magnitude of the effects that were evaluated contrasts were made between the means of any groups which were of interest.

The statistical method for checking any or all contrasts is accomplished by the use of the "q" statistic to provide limits for contrasts as follows:

$$\bar{X}_A - \bar{X}_B \pm q s_p / \sqrt{n}$$

where:

$\bar{X}_A$ = mean value of any set of data from k tests

$$= \frac{\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_k}{k}$$

$\bar{X}_B$ = Mean value of any other set of data

q = Table value (Table A-10, Natrella, Ref. 3
or A-18, Dixon and Massey, Ref. 4) for 95%
confidence.

s_p = Pooled standard deviation (from analysis of variance)

n = Number of replicates in each test.

VI. EVALUATION OF RESULTS

A. TENSILE TESTS AISI 347 FORGING

1. Effect of Fluence on Tensile Properties

The effect of fluence on the tensile properties was evaluated by analysis of variance and comparison of group means. The groups were the four fluence levels; controls; low fluence (6×10^{17} n/cm², >1 MeV); medium fluence (1×10^{18}); and high fluence (5×10^{18}). The method of evaluation is detailed in Appendix B, Table B-1, "Analysis of Variance for Tensile Properties AISI 347 Forging", "Comparison of Group Means (Difference and Percentages) for Effect of Fluence on Tensile Properties of AISI 347 Forging", "Pooled Standard Deviations for Various Tensile Properties of AISI 347 Forging." The analysis of variance and contrasts are discussed in Section VI D. Individual specimen tensile properties are tabulated in Appendix A, Table A-1 and group means are summarized in Table 3.

The analysis of variance identified any significant fluence effects and provided an estimate of standard deviation. In addition to the detailed analyses Appendix B, Tables B-1, B-3, and B-5, the contrasts are

shown graphically in Table 5 as "Differences" and Table 6 as "percentages". Table 7 is a summary of all effects indicating significant changes and direction of change.

A tabulation of the standard deviations of tensile data is shown in Appendix B, Table B-5. These values may be required in future analyses to provide an independent estimate of variance.

The percentage elongation displayed no significant changes at 95% confidence due to irradiation. The maximum mean percentage change in elongation was a decrease from 51.6% (mean control) to 50.0% (mean fluence 1.2×10^{18} n/cm² > 1 MeV). No significant change in elongation was observed at the maximum mean fluence 4.9×10^{18} n/cm² > 1 MeV. The effect of fluence on elongation of AISI 347 Forging is shown graphically in Figure 12.

The reduction of area exhibited very high variance and any changes due to fluence were not detectable with a confidence level of 95%. A minor decrease in mean reduction of area to 40.6% at a fluence of 1.2×10^{18} n/cm² > 1 MeV from 46.1% (mean control) was observed. The effect of fluence on reduction of area of AISI 347 Forging is shown graphically in Figure 13.

The 0.2% offset yield strength showed significant (95% confidence) increases for each level of fluence (6.2×10^{17} , 1.2×10^{18} and 4.9×10^{18} n/cm² > 1 MeV) reaching of maximum of 121.9 ksi mean at a mean fluence of 4.9×10^{18} n/cm² > 1 MeV an increase of 169% over the control mean of 45.4 ksi. The effect of fluence on 0.2% offset yield strength is shown graphically in Figure 10.

Ultimate strength increased with all levels of fluence and showed a significant (95% confidence) increase at a mean fluence of 4.9×10^{18} n/cm² > 1 MeV. The effect of fluence on ultimate strength of AISI 347 Forging is shown graphically in Figure 11.

2. Effect of Annealing on Tensile Properties

Twelve specimens were exposed in the high fluence zone (4.2 to 5.9 n/cm² > 1 MeV). Nine of the specimens were annealed at 540°R, three each for 10, 100 and 1000 minutes prior to tensile testing at 140°R.

The analysis of variance identified any significant annealing effects and provided an estimate of standard deviation. In addition to the detailed analysis (Appendix B, Table B-2 and B-4), the contrasts are shown graphically in Table 8 as "Differences" and Table 9 as "Percentages". Table 10 is a summary of effects indicating significant changes and direction of change.

Annealing of the specimens over the three time periods produced no significant changes at 95% confidence in tensile properties of ultimate strength, percent elongation and percent reduction of area. The 0.2% offset yield strength showed significant (95% confidence) decreases for each annealing period (10, 100 and 1000 minutes) reaching a minimum of 106.9 ksi after 10 minutes of annealing at 540°R. The annealing periods of 10, 100 and 1000 minutes at 540°R resulted in approximately equal reductions of 0.2% offset yield strengths.

B. RESONANT FREQUENCY TESTS AISI 347 FORGING

Pre-irradiation and post-irradiation resonant frequency measurements results are provided in Table 4 for four specimens (1 control and three irradiated to a fluence of 5.0×10^{18} n/cm² (> 1 MeV)). Mean values, standard deviations, and significance at 99% confidence using the t-statistic are given.

The dynamic modulus of a material of uniform circular cross section is proportional to the square of the resonant frequency in accordance with the equation:

$$E = \rho_4 L^2 f_s^2$$

where:

ρ = density, g/cm³

L = length of sample with uniform cross-section, cm.

f_s = resonant frequency of the sample, cps.

E = Young's Modulus, dynes/cm²

Since the buttonhead specimens were not of uniform cross-section throughout their lengths, the true modulus could not be easily calculated. However, the true modulus will be of the form

$$E = \rho f_s^2 F(L, W, T)$$

where F (L, W, T) is a function of the dimensions of the buttonhead specimens. A change in the resonant frequency will reflect a change in the modulus which can be calculated since

$$\frac{\Delta E}{E} = \frac{f_s^2 - f_s^1}{f_s^2}$$

where $\Delta E = E - E^1$

E^1 = Young's Modulus of irradiated specimen, dynes/cm²

f_s^1 = Resonant frequency of irradiated specimens

The initial readings were made on three consecutive days during the mornings and afternoons. The original and final resonant frequency readings are listed in Table 4. The three irradiated test specimens showed a decrease in the mean reading of resonant frequency of 11.5 to 17.5 Hz, or 0.6% to 1.0%. This resulted in a decrease in the moduli which was significant at the 99% confidence level. The control (specimen B-14), tested at the time the original readings were made and at the time post-irradiation tests were made, indicated no significant change in test conditions.

REFERENCES

1. S110 Radiation Effects Analysis Report - Nozzle, s110-XAN08-W181F1, September 1970
2. Final Report GTR-19 Test to Determine Cryogenic Radiation Effects on Structural Materials, RN-S-0520, September 1969
3. Natrella, M. G., Experimental Statistical NBS Handbook 91, October 1966
4. Dixon, Wilfrid J. and Massey, Frank J., Jr., Introduction to Statistical Analysis, Second Edition, 1957

FIGURES

1. Configuration of Round, Button-Head Tensile Specimens
2. High Fluence Dewar (North) Reactor Face Test Rack
3. Low Fluence Dewar (East) Test Rack
4. High Fluence LN_2 Dewar
5. Axiality Specimen Strain Gage Assembly
6. Graphical Solution for Axiality of Apparatus - Tensile Test
7. Annealing Thermocouple Button-Head Specimen
8. Block Diagram Resonant Frequency System
9. Typical Stress - Strain Curves for AISI 347 Forging
10. Effect of Fluence on 0.2% Offset Yield Strength of AISI 347 Forging Specimens at 140°R
11. Effect of Fluence on Ultimate Strength of AISI 347 Forging Specimens at 140°R
12. Effect of Fluence on Elongation of AISI 347 Forging Specimens at 140°R
13. Effect of Fluence on Reduction of Area of AISI 347 Forging Specimens at 140°R

NOTES:

- ① SMOOTH TRANSITION IS REQUIRED BETWEEN ALL INTERSECTING RADII AND SURFACES TANGENT TO RADII.
- ② NO DIA IN THIS SECTION MAY BE LESS THAN THAT MEASURED AT THE Q_L OF DATUM A.
- ③ THESE DIMENSIONS TO BE INSPECTED AND RECORDED. INSPECTION RECORDS SHALL BE MARKED WITH PART SERIALIZATION NO.

Figure 1 - Configuration of Round, Button-Head Tensile Specimens

Figure 2 - High Fluence Dewar (North) Reactor Face Test Rack (GD/FWD,
GTR-20C Test Plan & Procedures Document, 9 June 70, Figure 3-2)

Figure 3 - Low Fluence Dewar (East) Test Rack (GD/FWD, GTR-20C
 Test Plan & Procedures Document, 9 June 70, Figure 3-5)

FIGURE 4 - HIGH FLUENCE LN₂ DEWAR (GD/FWD GTR-20C TEST PLAN
AND PROCEDURES DOCUMENT, 11 MAY 1970, FIGURE 3-1)

NOTES:

1.

BOND TERMINAL TO SPECIMEN

2.

MATERIALS: BLH ELECTRONICS, INC. A
DIVISION OF SATEC SYSTEMS CORP.
WALTHAM MASS. 02154

AXIALITY SPECIMEN STRAIN GAGE ASSEMBLY

FIGURE 5

Figure 6 - Graphical Solution for Axiality of Apparatus - Tensile Test

ANNEALING THERMOCOUPLE BUTTONHEAD SPECIMEN

FIGURE 7

BLOCK DIAGRAM
RESONANT FREQUENCY SYSTEM

FIGURE 8

Figure 9 - Typical Stress-Strain Curves
For AISI 347 Forging

Figure 10 - Effect of Fluence on 0.2% Offset Yield Strength of AISI 347 Forging Specimens at 140°R

Figure 11- Effect of Fluence on Ultimate Strength of AISI 347 Forging Specimens at 140°R

Figure 12 - Effect of Fluence on Elongation of AISI 347 Forging Specimens at 140°R

Figure 13 - Effect of Fluence on Reduction of Area of AISI 347 Forging Specimens at 140°R

TABLES

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TABLE 1

SPECIMEN PEDIGREE OF AISI 347 FORGING

<u>Material</u>	<u>P. O. No.</u>	<u>Source</u>	<u>Form</u>	<u>Heat No.</u>	<u>Specification</u>	<u>Heat Treat Source</u>
AISI 347	202178	Ladish	Forging	3340915	QQ-S-763C	Ladish (material subjected to three furnace brazing cycles after testing)

TABLE 2

CHEMICAL ANALYSIS OF AISI 347 FORGING

Material	C	Mn	P	S	Si	Ni	Cr	Cb + Ta
AISI 347 Forging	0.057	1.34	0.014	0.007	0.59	11.52	17.16	1.10

TABLE 3

TENSILE PROPERTY SUMMARY, AISI 347 FORGING

Environment		Property		
Neutron Fluence n/cm^2 (> 1 MeV)	Temp., °R Irrad. & Test	Mean Value	Std. Dev.	Sample Size
0.2% Offset Yield Strength, ksi				
None	140	45.4	1.99	4
6.2×10^{17}	140	68.0	0.82	4
1.2×10^{18}	140	86.0	4.42	4
4.9×10^{18}	140	121.9	2.21	3
5.2×10^{18}	140 ⁽¹⁾	106.9	6.21	3
4.7×10^{18}	140 ⁽²⁾	109.8	1.37	3
5.1×10^{18}	140 ⁽³⁾	107.3	2.72	3
Ultimate Strength, ksi				
None	140	176.8	1.50	4
6.2×10^{17}	140	177.2	1.08	4
1.2×10^{18}	140	178.6	0.85	4
4.9×10^{18}	140	179.4	1.33	3
5.2×10^{18}	140 ⁽¹⁾	180.2	0.00	3
4.7×10^{18}	140 ⁽²⁾	183.1	4.22	3
5.1×10^{18}	140 ⁽³⁾	179.8	0.60	3
Elongation, % ⁽⁴⁾				
None	140	51.6	6.02	4
6.2×10^{17}	140	50.2	5.09	4
1.2×10^{18}	140	50.2	4.69	4
4.9×10^{18}	140	52.4	3.33	3
5.2×10^{18}	140 ⁽¹⁾	51.0	3.02	3
4.7×10^{18}	140 ⁽²⁾	51.7	2.61	3
5.1×10^{18}	140 ⁽³⁾	48.8	4.69	3
Reduction in Area, %				
None	140	46.1	13.86	4
6.2×10^{17}	140	43.6	11.08	4
1.2×10^{18}	140	40.6	9.92	4
4.9×10^{18}	140	49.0	11.54	3
5.2×10^{18}	140 ⁽¹⁾	50.2	7.29	3
4.7×10^{18}	140 ⁽²⁾	43.9	10.85	3
5.1×10^{18}	140 ⁽³⁾	51.5	10.68	3

TABLE 3 (Cont'd.)

- (1) Annealed at 540°R for 10 minutes
- (2) Annealed at 540°R for 100 minutes
- (3) Annealed at 540°R for 1000 minutes
- (4) Elongation was computed from load deflection charts for 1.5 inch gage length

TABLE 4

NON-IRRADIATED AND IRRADIATED RESONANT FREQUENCY (Hz)
MEASUREMENTS OF AISI 347 FORGING BUTTON-HEAD
TENSILE SPECIMENS

Specimen I.D.	B-14		B-2		A-21		A-25	
Test Condition	Pre-Irrad- iation Control	Post-Irrad- iation ⁽¹⁾ Control	Pre-Irrad- iation	Post-Irrad- iation ⁽²⁾	Pre-Irrad- iation	Post-Irrad- iation ⁽²⁾	Pre-Irrad- iation	Post-Irrad- iation ⁽²⁾
	1782.6	1780.0	1772.4	1744.6	1789.1	1785.6	1774.9	1753.4
	1780.6	1780.8	1766.0	1750.8	1791.9	1785.5	1776.3	1752.7
	1786.1	1782.2	1771.7	1756.1	1791.6	1786.4	1781.9	1773.9
	1782.8	1780.8	1771.4	1756.3	1790.2	1776.9	1780.0	1765.3
				1756.9		1777.1		1766.3
						1775.0		1766.8
						1774.0		1764.6
						1772.9		1763.0
								1766.2
								1766.5
Mean ($\bar{X}$)	1783.0	1780.9	1770.4	1752.9	1790.7	1779.2	1778.3	1763.9
Difference (d)	-2.1			-17.5		-11.5		-14.4
Std.Dev. (s_p)	1.74			4.43		4.81		5.75
Observed t (t)	1.69			5.87**		3.91**		4.24**
Deg. of Freedom (df)	6			7		10		12
Percent-age	-0.1			-1.0		-0.6		-0.8

(1) Control, unirradiated

(2) Fluence, n/cm^2 ($> 1 \text{ MeV}$), $4.2 \text{ to } 5.3 \times 10^{18}$

** t greater than Table t, indicating a significant difference in means at greater than 99% confidence

TABLE 5
EFFECT OF TEST CONDITIONS ON TENSILE PROPERTIES OF AISI 347
FORGING CONTRAST OF MEANS (DIFFERENCES)

CONTRAST ⁽¹⁾	Mean Differences and 95% Confidence Intervals																				
	Ultimate Stress, KSI										0.2% Offset Yield Stress, KSI										
	-	-	-	-	0	+	+	+	+	+	-	-	-	-	0	+	+	+	+	+	
	8	6	4	2	0	2	4	6	8		100	80	60	40	20	0	20	40	60	80	100
Control ⁽²⁾ vs Low Level Irrad. ⁽³⁾																	+				
Low Level Irrad ⁽³⁾ vs Med. Level Irrad. ⁽⁴⁾																	+				
Med Level Irrad ⁽⁴⁾ vs High Level Irrad. ⁽⁵⁾																		+			
Control ⁽²⁾ vs Med Level Irrad. ⁽⁴⁾																		+			
Control ⁽²⁾ vs High Level Irrad. ⁽⁵⁾																			+		

	Elongation Chart, %										Reduction of Area, %										
	-	-	-	-	0	+	+	+	+	+	-	-	-	-	0	+	+	+	+	+	
	16	12	8	4	0	4	8	12	14		50	40	30	20	10	0	10	20	30	40	50
Control ⁽²⁾ vs Low Level Irrad. ⁽³⁾																					
Low Level Irrad ⁽³⁾ vs Med Level Irrad. ⁽⁴⁾																					
Med Level Irrad. ⁽⁴⁾ vs High Level Irrad. ⁽⁵⁾																					
Control ⁽²⁾ vs Med. Level Irrad. ⁽⁴⁾																					
Control ⁽²⁾ vs High Level Irrad. ⁽⁵⁾																					

(1) Comparisons are second condition compared to first condition.

(2) Control means (Ref.) - Unirradiated - Ultimate 176.8 ksi, 0.2% offset yield 45.4 ksi, Elongation 51.6% Reduction of Area, 46.1%.

(3) Low level irradiation fluence, 6×10^{17} n/cm² (> 1 MeV).

(4) Medium level irradiation fluence, 1×10^{18} n/cm² (> 1 MeV).

(5) High level irradiation fluence, 5×10^{18} n/cm² (> 1 MeV).

TABLE 6
EFFECT OF TEST CONDITIONS ON TENSILE PROPERTIES OF AISI 347
FORGING CONTRAST OF MEANS (PERCENTAGES)

CONTRAST ⁽¹⁾	Percent Differences and 95% Confidence Limits																							
	Ultimate Stress, KSI												0.2% Offset Yield Stress, KSI											
	-						+						-						+					
	4	3	2	1	0	1	2	3	4	175	150	125	100	75	50	25	0	25	50	75	100	125	150	175
Control ⁽²⁾ vs Low Level Irrad. ⁽³⁾																			+					
Low Level Irrad. ⁽³⁾ vs Med Level Irrad. ⁽⁴⁾																			+					
Med. Level Irrad. ⁽⁴⁾ vs High Level Irrad. ⁽⁵⁾																			+					
Control ⁽²⁾ vs Med. Level Irrad. ⁽⁴⁾																				+				
Control ⁽²⁾ vs High Level Irrad. ⁽⁵⁾																							+	
	Elongation Chart, %												Reduction of Area, %											
	-						+						-						+					
	40	30	20	10	0	10	20	30	40	100	80	60	40	20	0	20	40	60	80	100				
Control ⁽²⁾ vs Low Level Irrad. ⁽³⁾																								
Low Level Irrad. ⁽³⁾ vs Med Level Irrad. ⁽⁴⁾																								
Med Level Irrad. ⁽⁴⁾ vs High Level Irrad. ⁽⁵⁾																								
Control ⁽²⁾ vs Med. Level Irrad. ⁽⁴⁾																								
Control ⁽²⁾ vs High Level Irrad. ⁽⁵⁾																								

(1) Comparisons are second condition compared to first condition.

(2) Control means (Ref.) - Unirradiated - Ultimate 176.8 ksi, 0.2% offset yield 45.4 ksi, Elongation 51.6% Reduction of Area, 46.1%.

(3) Low level irradiation fluence, 6×10^{17} n/cm² (>1 MeV).

(4) Medium level irradiation fluence, 1×10^{18} n/cm² (>1 MeV).

(5) High level irradiation fluence, 5×10^{18} n/cm² (>1 MeV).

TABLE 7
SUMMARY-EFFECT OF TEST CONDITIONS
GROUP MEANS TENSILE TESTS OF
AISI 347 FORGING

Comparison ⁽¹⁾	Ultimate Strength	0.2% Offset Yield Strength	Elongation	Reduction of Area
Control ⁽²⁾ vs low level irradi ⁽³⁾	-0-	+	-0-	-0-
Low level irradi ⁽³⁾ vs med level irradi ⁽⁴⁾	-0-	+	-0-	-0-
Med level irradi ⁽⁴⁾ vs high level irradi ⁽⁵⁾	-0-	+	-0-	-0-
Control ⁽²⁾ vs med level irradi ⁽⁴⁾	-0-	+	-0-	-0-
Control ⁽²⁾ vs high level irradi ⁽⁵⁾	+	+	-0-	-0-

(1) Comparisons are second condition compared to first condition

(2) Control means (Ref.) - unirradiated - ultimate 176.8 ksi, 0.2% offset yield 45.4 ksi, Elongation 51.6%, Reduction of Area 46.1%

(3) Low level irradiation fluence, 6×10^{17} n/cm² (> 1 MeV)

(4) Medium level irradiation fluence, 1×10^{18} n/cm² (> 1 MeV)

(5) High level irradiation fluence, 5×10^{18} n/cm² (> 1 MeV)

+ Significant increase in property value, 95% confidence level

- Significant decrease in property value, 95% confidence level

-0- No change detected at 95% confidence level

TABLE 8

EFFECT OF ANNEALING ON 0.2% OFFSET YIELD STRENGTH AND
 ULTIMATE STRENGTH OF AISI 347 FORGING CONTRAST OF MEANS (DIFFERENCES)

CONTRAST ⁽¹⁾	Mean Differences and 95% Confidence Intervals																			
	Ultimate Stress, KSI										0.2% Offset Yield Stress, KSI									
	-					+					-					+				
	8	6	4	2	0	2	4	6	8	25	20	15	10	5	0	5	10	15	20	25
Unannealed ⁽²⁾ vs 10 Min. Anneal. ⁽³⁾																				
10 Min Anneal ⁽³⁾ vs 100 Min Anneal ⁽⁴⁾																				
100 Min Anneal ⁽⁴⁾ vs 1000 Min Anneal ⁽⁵⁾																				
Unannealed ⁽²⁾ vs 100 Min. Anneal ⁽⁴⁾																				
Unannealed ⁽²⁾ vs 1000 Min. Anneal ⁽⁵⁾																				

(1) Comparisons are second condition compared to first condition.

(2) Unannealed Means (Ref.) Fluence 5×10^{18} n/cm² (> 1 MeV) - Ultimate strength 179.4 ksi, 0.2% offset yield strength 121.9 ksi

(3) Fluence 5×10^{18} n/cm² (> 1 MeV) - Annealed at 540°R for 10 minutes.

(4) Fluence 5×10^{18} n/cm² (> 1 MeV) - Annealed at 540°R for 100 minutes.

(5) Fluence 5×10^{18} n/cm² (> 1 MeV) - Annealed at 540°R for 1000 minutes.

TABLE 9

EFFECT OF ANNEALING ON 0.2% OFFSET YIELD STRENGTH AND ULTIMATE
STRENGTH OF AISI 347 FORGING CONTRAST OF MEANS (PERCENTAGES)

CONTRAST ⁽¹⁾	Percent Differences and 95% Confidence Limits																			
	Ultimate Stress, KSI										0.2% Offset Yield Stress, KSI									
	-					+					-					+				
	8	6	4	2	0	2	4	6	8		25	20	15	10	5	0	5	10	15	20
Unannealed ⁽²⁾ vs 10 Min. Anneal ⁽³⁾																				
10 Min. Anneal ⁽³⁾ vs 100 Min. Anneal ⁽⁴⁾																				
100 Min. Anneal ⁽⁴⁾ vs 1000 Min. Anneal ⁽⁵⁾																				
Unannealed ⁽²⁾ vs 100 Min. Anneal ⁽⁴⁾																				
Unannealed ⁽²⁾ vs 1000 Min. Anneal ⁽⁵⁾																				

(1) Comparisons are second condition compared to first condition.

(2) Unannealed Means (Ref.) Fluence 5×10^{18} n/cm² (>1 MeV) - Ultimate strength 179.4 ksi, 0.2% offset yield strength 121.9 ksi.

(3) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 10 minutes.

(4) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 100 minutes.

(5) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 1000 minutes.

TABLE 10

SUMMARY - EFFECT OF ANNEALING GROUP MEANS, 0.2%
OFFSET YIELD STRENGTH AND ULTIMATE STRENGTH OF
AISI 347 FORGING

Comparison ⁽¹⁾	Ultimate Strength	0.2% Offset Yield Strength
Unannealed ⁽²⁾ vs 10 min anneal ⁽³⁾	-0-	-
10 min anneal ⁽³⁾ vs 100 min anneal ⁽⁴⁾	-0-	-0-
100 min anneal ⁽⁴⁾ vs 1000 min anneal ⁽⁵⁾	-0-	-0-
Unannealed ⁽²⁾ vs 100 min anneal ⁽⁴⁾	-0-	-
Unannealed ⁽²⁾ vs 1000 min anneal ⁽⁵⁾	-0-	-

(1) Comparisons are second condition compared to first condition.

(2) Unannealed means (Ref.) Fluence 5×10^{18} n/cm² (>1 MeV) - Ultimate strength 179.4 ksi, 0.2% offset yield strength 121.9 ksi

(3) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 10 minutes

(4) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 100 minutes

(5) Fluence 5×10^{18} n/cm² (>1 MeV) - Annealed at 540°R for 1000 minutes

+ Significant increase in property value, 95% confidence level

- Significant decrease in property value, 95% confidence

-0- No change detected at 95% confidence level

APPENDIX A

This appendix presents detailed data for AISI 347 stainless steel forging tensile tests conducted in GTR-20C.

TABLES

APPENDIX A

No.

A-1 Tensile Results Individual Specimens of AISI 347 Forging
Irradiated and Tested at 140°R

TABLE A-1

TENSILE⁽¹⁾ RESULTS INDIVIDUAL SPECIMENS OF AISI 347 IRRADIATED AND TESTED AT 140°R

Specimen Number	Anneal Time @ 540°R (min)	Test Order	0.2% Offset Yield Stress (ksi)	Ultimate Strength (ksi)	Fracture Strength (ksi)	% Elongation		% Area Reduction (Bench)	Neutron Fluence (n/cm ²)	
						Bench	Chart		(> 1 MeV)	(< 0.48 eV)
B16	0	5	47.7	177.6	151.2	57.0	56.4	56.4	Control	Control
A28	0	12	46.2	177.0	165.5	49.9	49.8	44.8	Control	Control
B14	0	17	43.1	177.9	152.8	56.2	56.4	56.1	Control	Control
A07	0	1	44.6	174.6	173.6	45.0	43.9	26.9	Control	Control
$\bar{X}$			45.4	176.8	160.8	52.03	51.6	46.05		
A24	0	22	67.6	176.0	172.5	45.5	45.9	34.7	6.1(17)	2.0(16)
A01	0	16	67.2	178.3	177.3	44.8	45.7	33.5	6.2(17)	2.0(16)
A11	0	8		178.0	156.6	54.7	54.9	51.3	6.2(17)	2.0(16)
B10	0	19	69.1	176.7	149.6	54.2	54.3	54.9	6.2(17)	2.0(16)
$\bar{X}$			68.0	177.2	164.0	49.8	50.2	43.6		
A04	0	14	83.8	178.6	175.4	43.9	44.5	27.3	1.2(18)	4.1(16)
A03	0	15	83.9	178.3	170.3	52.1	52.2	42.4	1.2(18)	4.1(16)
B15	0	10	83.6	179.8	156.0	54.8	55.2	51.3	1.2(18)	4.1(16)
A27	0	23	92.6	177.8	170.4	48.3	48.0	41.4	1.2(18)	4.1(16)
$\bar{X}$			86.0	178.6	168.0	49.8	50.0	40.6		
B13	0	6	122.5	180.2	158.5	55.8	56.2	54.0	5.0(18)	1.4(17)
A15	0	21	123.7	180.2	178.3	50.4	50.7	35.8	4.4(18)	1.4(17)
B08	0	13	119.4	177.9	151.2	49.7	50.2	57.2	5.2(18)	1.4(17)
$\bar{X}$			121.9	179.4	162.7	51.97	52.4	49.0		
A12	10	9	113.8	180.2	172.6	44.2	48.2	41.8	4.3(18)	1.4(17)
A09	10	2	105.0	180.2	153.7	52.3	54.2	54.9	5.9(18)	1.4(17)
A10	10	11	101.8	180.2	158.8	49.8	50.6	53.9	5.4(18)	1.4(17)
$\bar{X}$			106.9	180.2	161.7	48.77	51.0	50.2		
A21	100	20	110.4	184.8	172.1	49.7	51.5	44.2	4.7(18)	1.4(17)
A25	100	24	110.7	186.2	182.9	48.6	49.2	32.9	4.2(18)	1.4(17)
B02	100	4	108.2	178.3	154.4	53.9	54.4	54.6	5.3(18)	1.4(17)
$\bar{X}$			109.8	183.1	169.8	50.7	51.7	43.9		
A20	1000	7	108.4	180.4	171.3	42.7	44.5	39.2	4.7(18)	1.4(17)
B01	1000	3	109.3	179.2	151.2	52.6	53.8	57.6	5.6(18)	1.4(17)
B11	1000	18	104.2	179.8	152.2	47.5	48.1	57.8	4.9(18)	1.4(17)
$\bar{X}$			107.3	179.8	159.6	47.6	48.8	51.5		

(1) Strain rate 0.33 in/in/minute

APPENDIX B

This appendix presents analyses of test data for AISI 347 stainless steel forging tensile tests conducted in GTR-20C.

TABLES

APPENDIX B

No.

- B-1 Analysis of Variance for Tensile Properties AISI 347 Forging
- B-2 Analysis of Variance for Tensile Properties (Annealed) AISI 347 Forging
- B-3 Comparison of Group Means (Differences and Percentages) for Effect of Fluence on Tensile Properties of AISI 347 Forging
- B-4 Comparison of Group Means (Differences and Percentages) for Effect of Annealing on Yield and Ultimate Strength of AISI 347 Forging
- B-5 Pooled Standard Deviations for Various Tensile Properties of AISI 347 Forging

TABLE B-1

ANALYSIS OF VARIANCE FOR TENSILE PROPERTIES AISI 347 FORGING

Method: One way analysis with the following categories - controls, low fluence, medium fluence, and high fluence.

1. Reduction of Area (Unannealed), (%)

	Control	Low Fluence	Medium Fluence	High Fluence	
	56.4	34.7	27.3	54.0	
	44.8	33.5	42.4	35.8	
	56.1	51.3	51.3	57.2	
	26.9	54.9	41.4		
$\bar{X}$	46.1	43.6	40.6	49.0	
Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	134.42	44.808	0.32721	No
Due to Exp. Error	11	1506.40	136.94		
Total	14	1640.82			

Standard Deviation = 11.70%

2. Percentage Elongation (unannealed), %

	Control	Low Fluence	Medium Fluence	High Fluence		
	56.4	45.9	44.5	56.2		
	49.8	45.7	52.2	50.7		
	56.4	54.9	55.2	50.2		
	43.9	54.3	48.0			
$\bar{X}$	51.6	50.2	50.0	52.4		
	Source	df	S.S.	M.S.	Obs.F	Significant
	Due to Categories	3	31.332	10.444	0.4548	No
	Due to Exp. Error	11	252.63	22.966		
	Total	14	283.96			

Standard Deviation = 4.79%

TABLE B-1 (Cont'd.)

ANALYSIS OF VARIANCE FOR TENSILE PROPERTIES AISI 347 FORGING

3. 0.2% Offset Yield Strength (unannealed) (ksi)

	Control	Low Fluence	Medium Fluence	High Fluence	
	47.7	67.6	83.8	122.5	
	46.2	67.2	83.9	123.7	
	43.1	67.9	83.6	119.4	
	44.6	69.1	92.6		
$\bar{X}$	45.4	70.0	86.0	121.9	
Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	10679.0	3559.6	475.86	Yes-at 99% Confidence
Due to Exp. Error	11	82.284	7.4804		
Total	14	10761.			

Standard Deviation = 2.73 ksi

4. Ultimate Strength (unannealed) (ksi)

	Control	Low Fluence	Medium Fluence	High Fluence		
	177.6	176.0	178.6	180.2		
	177.0	178.3	178.3	180.2		
	177.9	178.0	179.8	179.9		
	174.6	176.7	177.8			
$\bar{X}$	176.8	177.3	178.6	179.4		
	<u>Source</u>	<u>df</u>	<u>S.S.</u>	<u>M.S.</u>	<u>Obs.F</u>	<u>Significant</u>
Due to Categories	3	15.898	5.2992	3.6543	Yes-at 95% Confidence	
Due to Exp. Error	<u>11</u>	<u>15.952</u>	<u>1.4502</u>			
Total	14	31.849				

Standard Deviation 1.20 ksi

Controls: Unirradiated

Low Fluence: 5×10^{17} n/cm² (> 1 MeV)Med Fluence: 1×10^{18} n/cm² (> 1 MeV)High Fluence: 5×10^{18} n/cm² (> 1 MeV)

TABLE B-2

ANALYSIS OF VARIANCE FOR TENSILE PROPERTIES

(ANNEALED) AISI 347 FORGING

Method: One way analysis with the following categories high fluence (no anneal), high fluence (10 min. anneal) high fluence (100 min. anneal) and high fluence (1000 min. anneal)

1. Reduction of Area (annealed) high fluence⁽¹⁾ (%)

Anneal time at 540°R, min		-0-	10	100	1000
		54.0	41.8	44.2	39.2
		35.8	54.9	32.9	57.6
		57.2	53.9	54.6	57.8
	$\bar{X}$	49.0	50.2	43.9	51.5
Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	100.2	33.401	0.3194	No
Due to Exp. Error	8	836.59	104.57		
Total	11	936.79			

Standard Deviation = 10.22%

2. Percent Elongation (annealed) high fluence⁽¹⁾ (%)

Anneal time at 540°R, min		-0-	10	100	1000
		56.2	48.2	51.5	44.5
		50.7	54.2	49.2	53.8
		50.2	50.6	54.4	48.1
	$\bar{X}$	52.4	51.0	51.7	48.8
Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	20.09	6.6967	0.6139	No
Due to Exp. Error	8	87.267	10.908		
Total	11	107.36			

Standard Deviation = 3.30%

TABLE B-2 (Cont'd.)

ANALYSIS OF VARIANCE FOR TENSILE PROPERTIES

(ANNEALED) AISI 347 FORGING

3. 0.2% Offset Yield Strength (annealed) high fluence⁽¹⁾ (ksi)

Anneal time at 540°R, min	-0-	10	100	1000
	122.5	113.8	110.4	108.4
	123.7	105.0	110.7	109.3
	119.4	101.8	108.2	104.2
$\bar{X}$	121.9	106.9	109.8	107.3

Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	448.71	149.57	11.329	Yes-99% Confidence
Due to Exp. Error	8	105.62	13.203		
Total	11	554.33			

Standard deviation = 3.63 ksi

4. Ultimate Strength (annealed) high fluence⁽¹⁾ (ksi)

Anneal time at 540°R, min	-0-	10	100	1000
	180.2	180.2	184.8	180.4
	180.2	180.2	186.2	179.2
	177.9	180.2	178.3	179.8
$\bar{X}$	179.4	180.2	183.1	179.8

Source	df	S.S.	M.S.	Obs.F	Significant
Due to Categories	3	25.22	8.4067	1.6903	No
Due to Exp. Error	8	39.787	4.9733		
Total	11	65.007			

Standard Deviation = 2.23 ksi

(1) High fluence: 5×10^{18} n/cm² (> 1 MeV)

TABLE B-3

COMPARISON OF GROUP MEANS (DIFFERENCES AND PERCENTAGES)
FOR EFFECT OF FLUENCE ON TENSILE PROPERTIES OF
AISI 347 FORGING

Method: Contrasts Ref. Dixon and Massey, p. 170 (2nd Edition)
and Natrella, Hdbk 91

All properties $\nu = 11$ df
 t (Natrella) = k (Dixon, Massey) = 4 categories
 $q_{.95} = 4.26$ (Table)

Contrasts using $\pm q s / \sqrt{n}$
where x = pooled standard deviation
 n = number of replicates (effective)

MEAN DIFFERENCE AND 95% CONFIDENCE LIMITS ⁽²⁾

	<u>RA</u> <u>%</u>	<u>Elongation</u> <u>%</u>	<u>Yield Strength</u> <u>ksi</u>	<u>Ultimate Strength</u> <u>ksi</u>
s	11.70	5.00	2.74	1.20
n	3.7	3.7	3.7	3.7
$\pm q s / \sqrt{n}$	<u>+25.91</u>	<u>+11.06</u>	<u>+6.1</u>	<u>+2.7</u>
<u>CONTRAST</u> ⁽¹⁾				
Control vs Low Q	-2.45	-1.43	+22.6*	+0.5
Low Q vs Med Q	-3.00	-0.23	+18.0*	+1.4
Med Q vs High Q	+8.40	+2.39	+35.9*	+0.8
Control vs Med Q	-5.45	-1.65	+40.6*	+1.9
Control vs High Q	+2.95	+0.74	+76.5*	+2.7*
Control Means (Ref)	46.05	51.63	45.4	176.8

TABLE B-3 (Cont'd.)

CONTRASTS EXPRESSED AS PERCENT CHANGE

	<u>RA</u> <u>%</u>	<u>Elongation</u> <u>%</u>	<u>Yield Strength</u> <u>ksi</u>	<u>Ultimate Strength</u> <u>ksi</u>
Control vs Low Q	-5.3 $\pm$ 56.3	-2.8 $\pm$ 21.4	+49.8 $\pm$ 13.4*	+0.3 $\pm$ 1.5
Low Q vs Med Q	-6.9 $\pm$ 59.4	-0.5 $\pm$ 22.0	+26.5 $\pm$ 13.4*	+0.8 $\pm$ 1.5
Med Q vs High Q	+20.7 $\pm$ 63.8	+4.8 $\pm$ 22.1	+41.7 $\pm$ 7.1*	+0.4 $\pm$ 1.5
Control vs Med Q	-11.8 $\pm$ 56.3	-3.2 $\pm$ 21.4	+89.4 $\pm$ 13.4*	+1.1 $\pm$ 1.5
Control vs High Q	+6.4 $\pm$ 56.3	+1.4 $\pm$ 21.4	+168.5 $\pm$ 13.4*	+1.5 $\pm$ 1.5*

Control: Unirradiated

Low Q: 6×10^{17} n/cm² (> 1 MeV)

Med Q: 1×10^{18} n/cm² (> 1 MeV)

High Q: 5×10^{18} n/cm² (> 1 MeV)

- (1) Comparisons are second condition compared to first condition.
- (2) Significant contrasts at the 95% confidence level indicated by asterisk.

TABLE B-4

COMPARISON OF GROUP MEANS (DIFFERENCES AND PERCENTAGES)
FOR EFFECT OF ANNEALING ON YIELD AND ULTIMATE STRENGTH OF
AISI 347 FORGING

Method: Contrasts Ref. Dixon and Massey, p. 170 (2nd Edition)
and Natrella, Hdbk 91

All properties $\nu = 8$ df
 t (Natrella) = k (Dixon, Massey) = 4 categories
 $q_{.95} = 4.53$ (Table)
 Contrasts using $\pm q s / \sqrt{n}$
 s = pooled standard deviation
 n = number of replicates

MEAN DIFFERENCE AND 95% CONFIDENCE LIMITS⁽²⁾

	Yield Strength ksi	Ultimate Strength ksi
s	3.63	2.23
n	3	3
$\pm q s / \sqrt{n}$	± 9.5	± 5.8
<u>CONTRAST⁽¹⁾</u>		
Unannealed vs 10 min. anneal	-15.0*	+0.8
10 min. vs 100 min. anneal	+2.9	+2.9
100 min. vs 1000 min. anneal	-2.5	-3.3
Unann. vs 100 min. anneal	-12.1*	+3.7
Unann. vs 1000 min. anneal	-14.6*	+0.4
Unannealed Means (Ref)	121.9	179.4

TABLE B-4 (Cont'd.)

CONTRASTS EXPRESSED AS PERCENT CHANGE

	<u>Yield Strength</u>	<u>Ultimate Strength</u>
Unannealed vs 10 min. anneal	-12.3 $\pm$ 7.8*	+0.4 $\pm$ 3.2
10 min. vs 100 min. anneal	+2.7 $\pm$ 8.9	+1.6 $\pm$ 3.2
100 min. vs 1000 min. anneal	-2.3 $\pm$ 8.7	-1.8 $\pm$ 3.2
Unann. vs 100 min. anneal	-9.9 $\pm$ 7.8*	+2.1 $\pm$ 3.2
Unann. vs 1000 min. anneal	-12.0 $\pm$ 7.8*	+0.2 $\pm$ 3.2

(1) Comparisons are second condition compared to first condition.

(2) Significant contrasts at the 95% confidence level indicated by asterisk.

Fluence: 5×10^{18} n/cm² >1.0 MeV

TABLE B-5

POOLED STANDARD DEVIATIONS FOR VARIOUS TENSILE
PROPERTIES OF AISI 347 FORGING

<u>Property</u>	<u>Standard Deviation</u>	<u>Degrees of Freedom</u>
Ultimate Strength, ksi	1.20	11
0.2% Offset Yield Strength, ksi	2.74	11
Elongation, %	5.00	11
Reduction of Area, %	11.70	11

AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL

APR 27 1971

N2130:7368

PPV:ml

Space Nuclear Systems Office
Cleveland Extension
National Aeronautics & Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. R. W. Schroeder, Chief

Subject: Final Report s110-XSS13-W181f1, GTR-20C,
Cryogenic Radiation Effects on AISI 347
Steel Forging, Contract SNP-1, March 1971

Gentlemen:

Eight (8) copies of the subject Final Report are submitted in
partial fulfillment of Project 181, Contract SNP-1.

Additional copies are available upon request.

Very truly yours,

AEROJET NUCLEAR SYSTEMS COMPANY

J. T. Paul
Manager of Contracts
NERVA Rocket Operations

Enclosure:

- (1) Final Report s110-XSS13-W181f1
(8 copies)

cc: M. M. Carness, SNSO-C/Sacramento (w/o encl.)
A. C. Sanderson, WANL/Pittsburgh (w/encl. - 3 copies)
C. R. Dippel, WANL/Sacramento (w/o encl.)