NASA CR - 72428
LAC ER - 9887

LOW TEMPERATURE ANNEALING OF IRRADIATED COMMERCIALLY PURE TITANIUM

GPO PRICE $ ____
CSFTI PRICE(S) $ ____
Hard copy (HC) [redacted]
Microfiche (MF) [redacted]
ff 653 July 65

by

LOCKHEED NUCLEAR PRODUCTS

C. A. Schwanbeck, Project Manager

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-10298

LOCKHEED NUCLEAR PRODUCTS

NOTICE

Requests for copies of this report should be referred to

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Attention: AFSS-A
Washington, D.C. 20546

NASA CR - 72428
LAC ER - 9887

TOPICAL REPORT

LOW TEMPERATURE ANNEALING OF IRRADIATED COMMERCIALLY PURE TITANIUM

by

LOCKHEED NUCLEAR PRODUCTS

C. A. Schwanbeck, Project Manager

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

May 1968

Contract NAS 3-10298

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Nuclear Systems Division
Fred A. Haley, Project Manager
Advanced Systems Division
John C. Liwosz, Jr.

LOCKHEED NUCLEAR PRODUCTS
LOCKHEED-GEORGIA COMPANY

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

FOREWORD

This report is submitted to the National Aeronautics and Space Administration, Lewis Research Center, by the Lockheed-Georgia Company in accordance with the requirements of Article XXI, NASA Contract NAS 3-10298.

PRECEDING PAGE BLANK NOT FILMED.

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED.

LIST OF TABLES AND FIGURES

PRECEDING PAGE BLANK NOT FILMED.

LIST OF SYMBOLS

n/cm^2	fast fluence, in neutrons per square centimeter, with energies above 0.5 MeV or 80 fJ
MeV	million electron volts
fJ	femtojoules
°K	degrees Kelvin
Ksi	thousands of pounds per square inch
kN/cm^2	kilo newtons per square centimeter
MN/cm^2	mega newtons per square centimeter
F_{tu}	Ultimate tensile strength
F_{ty}	Tensile yield strength

LOW TEMPERATURE ANNEALING OF IRRADIATED COMMERCIALLY PURE TITANIUM

by

LOCKHEED NUCLEAR PRODUCTS

C. A. Schwanbeck, Project Manager

1 SUMMARY

This report describes the results obtained in an experimental study of the effects of post-irradiation annealing at cryogenic temperatures on the tensile properties of commercially pure titanium (Titanium 55A-Annealed). Test specimens were exposed to fluences of 6 x 10^{17} n/cm^2, with neutrons energies greater than 0.5 MeV (80 femtojoules), at 17°K. The irradiated specimens were tested after annealing periods of one hour (3.6 x 10^3 sec) at 78°K and 178°K. Parallel sample lots were tested at the annealing temperature and after recooling to 17°K. Additional specimens were tested at 17°K following irradiation at 17°K with no post-irradiation annealing period.

The sample lots tested at 17°K following post-irradiation annealing showed that a pronounced reduction of the ultimate tensile strength occured at temperatures below 78°K, while a less pronounced effect on the tensile yield strength occurred over the entire annealing temperature range.

The sample lots tested at the post-irradiation annealing temperature showed a gradual reduction in the irradiation effect on the ultimate tensile strength over the range of test temperatures. This reduction was substantial while there was relatively little reduction in the yield strength.

The residual effects of irradiation on the yield strength after annealing at 78°K and 178°K are, within the limits of experimental accuracy, independent of testing temperature. This contrasts with the results from aluminum similarly investigated in an earlier program.

PRECEDING PAGE BLANK NOT FILMED.

2 INTRODUCTION

The concept of using hydrogen, stored in the liquid state, as the propellant for nuclear rockets to be used on trans-lunar missions is attractive because of the high specific impulses obtainable. Engineers responsible for the design of this sophisticated hardware require a knowledge of the combined effects of neutron irradiation and cryogenic temperatures on structural materials. Since lattice defects introduced by neutron irradiation are mobile even at liquid hydrogen temperature (20.5°K), irradiation and testing must be conducted at a temperature at least this low to observe effects which might occur in structural components of nuclear rockets.

Earlier test programs, conducted at the Plum Brook Reactor Facility of the NASA Lewis Research Center under Contracts NASw-114 and NAS3-7985, studied the following effects:

- The effect of fast neutron fluences* of 10^{17} n/cm^2 at 17°K on the tensile properties of thirty-three (33) metals and alloys including titanium alloys (ref. 1)
- The effect of fluences up to 10^{18} n/cm^2 at 17°K on the tensile properties of commercially pure titanium and several titanium alloys (ref. 2)
- The effect of fast neutron fluences of 10^{17} n/cm^2 at 17°K on the low-cycle fatigue properties of commercially pure titanium and two alloyed titaniums (ref. 2)
- The effects of irradiation temperature and post-irradiation annealing on high purity aluminum (ref. 2).

The results obtained in the irradiation effects studies on Titanium 55A (annealed) conducted in the earlier programs (refs. 1 and 2) showed that a small but measurable increase in strength parameters exhibited a direct dependence on irradiation level for specimens irradiated and tested at 17°K. This was accompanied by a slight reduction in the ductility parameters. An increase in the F_{ty}/F_{tu} ratio was an observable radiation effect.

As a result of these programs, a further series of tests was authorized by Contract NAS3-10298. One series of tests from this program, a study of the effects of post-irradiation annealing on unalloyed titanium (Titanium 55A), has been completed. These tests included tensile tests on Titanium 55A, sample lots of three specimens, after irradiation to a fluence of 6×10^{17} n/cm^2 at 17°K followed by annealing periods of one hour (3.6×10^3 sec) at 78°K and 178°K respectively. Parallel sample sets were tested at the annealing temperature and after recooling to 17°K. Control tests of unirradiated specimens were made after a similar thermal cycling exposure. The test results obtained are reported and discussed in the following sections of this report.

* Neutron energies greater than 0.5 MeV or 80 femtojoules.

PRECEDING PAGE BLANK NOT FILMED.

3 TEST MATERIAL

All test specimens were fabricated from a common lot of material; the same lot was used in the earlier test programs reported in references 1 and 2. According to the vendor, the Kroll process was used to produce elemental titanium from rutile ($Ti\ O_2$) through chlorination of a mixture of the ore and tar followed by reaction with metallic magnesium. The resultant sponge was vacuum melted in water cooled copper crucibles using consumable electrode techniques. Ingot reduction was accomplished through rolling with break down passes above the beta transus; finishing operations were in the alpha range. The finished material was annealed at 1300°F (980°K) for two hours (7.2×10^3 sec) followed by cooling in still air. The test material had the following chemical composition:

Fe	C		N		H		O	
wt%	wt%	At%	wt%	At%	wt%	At%	wt%	At%
0.19	0.032	0.13	0.023	0.08	0.006	0.29	0.218	0.65

with the remainder titanium.

4 TEST SPECIMENS

Due to space limitations in the irradiation access port (HB-2) and refrigeration capacity limitations, the specimen used was a miniaturization of the standard round specimen of ASTM E 8-66 (ref. 3), with a nominal gage diameter of 0.125 inch (0.318 cm) and a nominal gage length of 0.5 inch (1.27 cm). The tensile specimen used is shown in Figure 1. The ratios of the significant parameters are the same as for the standard ASTM specimen. Unirradiated control specimens were run for each thermal environment of the irradiation testing program to ensure a common basis for the evaluation of irradiation effects.

PRECEDING PAGE BLANK NOT FILMED.

5 TEST EQUIPMENT AND PROCEDURES

The studies of annealing effects performed in this experiment fall into two general cases:

1. Specimen irradiated to 6×10^{17} n/cm^2 at 17°K, annealed for 1 hour (3.6×10^3 sec) at higher cryogenic temperatures (78°K and 178°K), re-cooled to 17°K for 1 hour (3.6×10^3 sec) and tested at 17°K.

2. Specimen irradiated to 6×10^{17} n/cm^2 at 17°K, annealed for 1 hour (3.6×10^3 sec) at higher cryogenic temperatures and tested at the annealing temperatures.

Unirradiated control specimens were tested after low temperature thermal cycling identical to that received by the irradiated specimens except that the initial exposure at 17°K was for one hour (3.6×10^3 sec) rather than the 75 to 110 hour (2.7×10^5 to 4.0×10^5 sec) at 17°K required to achieve a fluence of 6×10^{17} n/cm^2 in HB-2.

All testing was conducted, as nearly as feasible, in accordance with American Society of Testing Materials Specifications ASTM E 184-62 and E 8-66 (ref. 3).

5.1 IRRADIATION TEST LOOP

All testing was performed at the NASA Plum Brook Reactor Facility using the horizontal beam port on the north face of the reactor core, designated as HB-2, as the irradiation facility. The testing machines are contained in cryogenic test loops capable of insertion into the 6" (15.24 cm) diameter beam port. Transfer tables provide the capability of insertion and withdrawal of the loops from HB-2 and provide rotation to permit positioning the loops in a radially aligned hot cave for specimen change. Specimen temperature control is maintained with an 1150 watt refrigerator using helium as the cryogenic fluid. Detailed descriptions of the test hardware may be found in references 1 and 2. A drawing of the test loop is shown in Figure 2. The load control system, shown schematically in Figure 3, permits axial loading of the specimen in tension or compression with applied forces up to 5000 lbs (22,240 newtons).

The temperature of the test specimen was controlled by platinum resistance sensors located in the inlet and outlet refrigerant lines. The validity of this method of control had been verified in an earlier program by comparison of the readings of these sensors with especially calibrated thermocouples affixed to a test specimen held in the specimen location of the test loop at all temperatures of interest, both in-pile and out-of-pile (refs. 1 and 2).

Control of the irradiation fluence was based on calculations made from the reactor power level and the control rod bank height. This method was established by threshold foil measurements made during the earlier programs and is described in detail in references 1 and 2.

5.2 TENSILE TESTING PROCEDURES

Tensile test methods conformed as nearly as possible to ASTM E 8-66 (ref. 3). The load rate was monitored, during elastic behavior of the specimen, by controlling the incremental strain at less than 0.0015 in/in/min (2.5×10^{-5}/sec). The load was monitored with a proving ring type dynamometer calibrated to within two percent of a National Bureau of Standards certified reed type proving ring. The extensometer used was classified as ASTM E 83-64T, class B-2 under actual operational conditions. Extensometers of this classification, while adequate for the determination of the yield strength of metallic materials, are not normally used for measuring the modulus of elasticity or deviation from Hooke's Law. Therefore, the modulus values included in this report should not be considered as absolute values.

The principal departure from the ASTM testing procedures is in specimen geometry, discussed in Section 5.1.

Ductility parameters, elongation in 4D, and reduction of area were obtained by post-testing measurements of failed specimens in accordance with paragraphs 26 and 27 of ASTM E 8-66 (ref. 3).

The F_{ty} was obtained by the 0.2% offset method.

The fracture stress was obtained by dividing the load at fracture by the cross-sectional area of the failed specimen at the point of fracture. The data required for correcting this stress for the tri-axial state of stress during plastic instability are not available; therefore, this parameter as reported is of questionable reliability (ref. 4, p 246).

The accuracy and calibration of the test system are discussed in references 1 and 2.

6 TEST RESULTS

The test results for the test program are given in Tables I and II and shown graphically in Figures 4 and 5.

In both cases, the data from the control specimens are given and plotted with the results from the irradiated specimens.

6.1 TEST RESULTS FOR SPECIMENS TESTED AT 17°K AFTER POST-IRRADIATION ANNEALING

The test data obtained from tensile specimens tested at 17°K following annealing at 78°K and 178°K of effects induced by irradiation to 6×10^{17} n/cm^2 at 17°K are shown in Table I and Figure 4.

Examination of Figure 4 shows that the principal annealing effect in the F_{tu} occurs between 17°K and 78°K while the effect on the F_{ty} appears fairly linear with temperature over the range from 17°K to 178°K. This is also indicated by the convergence at both end points of the curves showing the F_{ty}/F_{tu} ratio at the several temperatures. The effect of annealing on the ductility parameters appears to be negligible in this temperature range.

There was no apparent irradiation effect on the fracture stress.

6.2 TEST RESULTS FOR SPECIMENS TESTED AT THE ANNEALING TEMPERATURE AFTER POST-IRRADIATION ANNEALING

The test data obtained from tensile specimens tested at the annealing temperature following post-irradiation annealing at 78°K and 178°K after irradiation to 6×10^{17} n/cm^2 at 17°K are shown in Table II and Figure 5.

Examination of Figure 5 shows that the annealing of the effect of irradiation on the F_{tu} is more nearly linear with respect to temperature over the range from 17°K to 178°K than was noted for the specimen tested at 17°K following similar post-irradiation anneals. The gradual convergence of the curves plotting the F_{tu} values for unirradiated and irradiated specimens with increasing annealing and test temperatures shows an essentially linear mitigation of the radiation effects on the F_{tu} as a function of temperature. The curve of the effect of annealing and test temperature on the F_{ty} shows no such convergence; the unirradiated and irradiated specimens produce parallel curves. This causes a divergence of the F_{ty}/F_{tu} ratio curves with increasing temperature. The cryogenic effects on the ductility parameters appear to be of greater significance than the minor irradiation induced embrittlement observed in the curves. As with the specimen post-anneal tested at 17°K, the annealing of ductility parameters seems slight. The apparent maxima near 80°K, observable on both ductility parameters, is a cryogenic effect unrelated to irradiation. Similar peaks have been reported by other investigators working on the cryogenic behavior of titanium and titanium alloys (ref. 5 and 6).

There was no apparent irradiation effect on the fracture stress.

7 ANALYSIS OF TEST RESULTS

The statistical significance of differences between various sample means of several tensile properties reported in Tables I and II were calculated using the method described in Appendix A. Results of these calculations are summarized in tabular form in this appendix. Other properties reported in Tables I and II were not statistically analyzed; the F_{ty}/F_{tu} ratio was calculated from values that were analyzed, the modulus and the fracture stress values were derived from measurements of insufficient exactness to warrant statistical analysis, and the reduction of area is of little engineering interest and is a rather imprecise value used primarily as a measure of material quality. Although in this program only three specimens were tested for each set of conditions, these analyses show that in only a few cases is there a significant probability that the testing of additional specimens might have changed the statistical significance of the results.

Statistical analysis of the data obtained from unirradiated specimens yields the anticipated results; there is no significant difference in the mechanical properties of any sample lots tested at 17°K regardless of prior cryogenic thermal cycling and statistically significant and large effects of test temperature are observable. The observed increase in the strength functions due to neutron irradiation are verified statistically. Substantial residual irradiation strengthening is observable after post-irradiation annealing when tested at either the annealing temperature or after recooling to 17°K.

Comparison of the F_{tu} values of the irradiated specimens tested at 17°K following post-irradiation anneals at 78°K and 178°K show that the major portion of the annealing has occurred at temperatures below 78°K; the difference in the values for this parameter after annealing at 78°K and 178°K is not significant statistically at the 90% confidence level.

The changes in the F_{ty} values in the same sets of specimens show an essentially linear response to annealing temperature. Although the net change in the parameter after annealing at 78°K is of marginal statistical validity at the 90% confidence level, the plot of arithmetic means (fig. 4) indicates that the annealing effect on the F_{ty} is probably uniform over the temperature range investigated. This is one instance where a larger sample lot might be expected to verify a trend obscured by data scatter in a small specimen sample.

Statistical comparisons of the elongation data presented in Table I show that annealing of either irradiated or unirradiated material at 78 or 178°K followed by tests at 17°K does not significantly change the amount of elongation from that of material tested at 17°K without intermediate anneals at 78 or 178°K. A small (about 3%) but statistically significant reduction in the amount of elongation occurred in the material irradiated and tested at 17°K. The slight reductions in elongation recorded for irradiated samples annealed at 78 or 178°K prior to testing at 17°K are not statistically significant. Very small reductions in elongation in the irradiated samples tested at the annealing temperatures of 78 and 178°K were recorded. The reduction at 78° is statistically significant but that at 178° is not.

Variations in test temperatures produce apparent differences in the amount of reduction of area in Titanium 55A during tensile tests. No apparent effects of radiation on this property were obtained in this program.

Figure 6 is a graphical presentation of the effects of annealing and test temperatures on radiation induced changes in the strength parameters of titanium. The mean difference between groups of irradiated and unirradiated specimens tested under each set of thermal conditions is plotted with one standard deviation on either side of the mean indicated. This difference is the residual radiation effect on these properties representing an increase in strength. The magnitude of the standard deviation for the F_{tu} data point for the specimens tested at 17°K following post-irradiation annealing at 178°K might lead to misleading interpretation of these data in Figure 6. Since, due to theoretical considerations, this plot is not likely to be concave upwards, the curve must be biased intuitively to provide a meaningful plot. The data points are not, of course, absolute values; they are measured values and allowance must be made for experimental uncertainty in evaluation. Such data can not be handled in a purely statistical manner. Consideration of probable solid state and metallurgical mechanisms must be given in data interpretation.

In general, the irradiation induced increase in the ultimate tensile strength, while not as large as that in the yield strength, is annealed more rapidly than the increase in the yield strength. This is true regardless of testing temperature for annealing at 78°K and true for the measurement at the annealing temperature of 178°K. This results in a higher yield to ultimate ratio (0.917) for annealing and testing at 178°K than for any other test condition.

The absolute decrease in the residual effect on annealing at 178°K and testing at 17°K is about the same in the ultimate tensile strength as in the yield strength.

The residual effect , in any case, regardless of parameter, annealing, or test temperature is no less than 30 percent of the irradiation induced increase at 17°K without annealing.

A more surprising result is that the residual effects on the yield strength are, within the limits of experimental accuracy, independent of the test temperature. In terms of dislocation theory, this means that defects introduced by the neutron irradiation at 17°K and remaining at temperatures up to 178°K act as obstacles to plastic flow that cannot be overcome by thermal fluctuations up to 178°K (ref. 6). Such obstacles are assumed to be large (greater than 20×10^{-10} meters [ref. 7]) and to have stress fields like those associated with large precipitates or dislocations on intersecting slip planes. They affect the temperature dependence only indirectly and they might be expected to form and remain in titanium under the described test conditions.

At the same time, with regard to the other residual effects, the combined effects of recombination of close vacancy-interstitial pairs and interstitial migration to trapping sites (ref. 8) at temperatures up to 178°K might be expected to reduce the irradiation effect on the yield strength. And it can be argued that this diffusion of defects could reduce the irradiation effect on the ultimate strength even more by eliminating some of the sources of work hardening. The fact that this is not indicated by the ductility data, which if anything indicate an increase in hardening sources, at least for tests at 17°K, might be attributed to the limited precision of these measurements.

There are certain differences between the irradiation annealing effects in titanium and the irradiation annealing effects reported for aluminum in reference 2. These differences are attributable to differences in the unirradiated materials and differences in the effects of irradiation before annealing as well as to differences in annealing phenomena. The most apparent differences between titanium and aluminum are in the residual irradiation effects. Annealing is much slower in titanium than in aluminum for a given annealing temperature. Also temperature dependence of the residual effects is less pronounced than in aluminum. Both of these effects might be related to the much higher melting point of titanium. A lower defect diffusion rate would be expected in titanium and the number and distribution of defects before annealing would be expected to differ from aluminum at least because of the higher melting point and possibly because of other fundamental differences such as crystal structures and grain sizes.

Serrated yielding, reported by other investigations at 4°K (ref. 6) was not observed in the load-elongation curves obtained from cryogenic testing of titanium in this program. The lowest test temperature in this program, 17°K, is 0.009 of the absolute melting temperature, that used by Kula in the work reported in reference 6 was 0.002 of the melting temperature. The pronounced increase in resistance to plastic deformation observed in all body centered cubic and some hexagonal close packed lattices at extremely low temperatures (ref. 10) may occur between these two temperatures in titanium.

PRECEDING PAGE BLANK NOT FILMED.

8 CONCLUDING REMARKS

Tensile testing of commercially pure titanium has been performed under various test conditions after irradiation to 6×10^{17} n/cm^2 (with energies greater than 80 fJ) at 17°K. Tensile test characteristics were obtained at the irradiation temperature after one hour (3.6×10^3 sec) at 78°K and after one hour at 178°K. Tensile measurements were also made at the two annealing temperatures following the same irradiation and annealing. These results along with those from similarly irradiated specimens without annealing have been compared to results from unirradiated specimens at the same test temperatures.

Irradiation to 6×10^{17} n/cm^2 at 17°K, without annealing, increases the ultimate tensile strength of this material by about 10%, the tensile yield strength by about 20%, over the values obtained at 17°K without irradiation. A slight irradiation induced reduction in the values of the ductility parameters is observable.

Testing at 17°K following post-irradiation annealing at 78°K showed a distinct diminution in the irradiation induced increase in the ultimate tensile strength. The annealing effect on the tensile yield strength of these specimens was less pronounced. Testing at 17°K following post-irradiation annealing at 178°K showed about equal reductions of both of these strength parameters. These data verify the importance of maintaining the temperature of interest throughout irradiation and testing periods, and all intervening time between these periods, in cryogenic-irradiation effect studies.

Testing at the annealing temperatures, following post-irradiation anneals at 78°K and 178°K, showed a substantial temperature dependent reduction on the ultimate tensile strength with relatively little annealing effect observed on the yield strength.

Residual irradiation induced increases in both strength parameters remained regardless of the annealing and test temperatures. The smallest remaining residual effect was in the ultimate tensile strength after annealing at 178°K and testing at the annealing temperature. This residual increase was only about 30 percent of the increase measured at 17°K without annealing. Other residual increases after annealing at 178°K and measuring at either 178°K or 17°K were equal to about 50 percent of the effects measured without annealing.

There were little, if any, annealing effects on the ductility parameters, regardless of the annealing and test temperatures.

There are certain differences between irradiation annealing effects in titanium and those in aluminum, the most obvious being much larger residual effects in the strength parameters in titanium than in aluminum. Also, these residual effects are less test-temperature dependent in titanium than in aluminum.

PRECEDING PAGE BLANK NOT FILMED.

9 REFERENCES

1. Lockheed Nuclear Products: Effect of Nuclear Radiation on Materials at Cryogenic Temperatures; Final Report Contracts NASw-114 and NAS 3-7987, NASA CR-54881; LAC ER-8434, 1966.

2. Lockheed Nuclear Products: Effect of Nuclear Radiation on Materials at Cryogenic Temperatures: Final Report, Contract NAS 3-7985, NASA CR-72332; LAC ER-9757, 1967.

3. Anon: ASTM Standards, The American Society for Testing and Materials, 1966.

4. Dieter, George F. Jr.: Mechanical Metallurgy. McGraw-Hill Book Co., Inc., 1961.

5. Cryogenics Materials Data Handbook, Technical Document Report No. ML-TDR-64-280, February 1965.

6. Kula, E. B. and De Sisto, T. S.: Plastic Behavior of Metals at Cryogenic Temperatures. Behavior of Metals at Cryogenic Temperatures, ASTM STP 387, 1966.

7. Billington, D. S.: Radiation Effects in Metals and Alloys. Effects of Radiation on Materials, J. J. Harwood et al, ed., Reinhold Publishing Corp., N. Y., 1958, pp 99-125.

8. Holmes, D. K.: Radiation Damage in Non-Fissionable Metals. The Interaction of Radiation and Solids, R. Strumane et al, ed., North-Holland Publishing Company (Amsterdam), 1964. (Available from John Wiley and Sons, New York).

9. Wechsler, M. S.: Radiation Embrittlement of Metals and Alloys. The Interaction of Radiation with Solids, R. Strumane et al, ed., North-Holland Publishing Company (Amsterdam), 1964. (Available from John Wiley and Sons, New York).

10. Wessel, E.T.: Some Basic and Engineering Considerations Regarding the Fracture of Metals at Cryogenic Temperatures. Behavior of Material at Cryogenic Temperature, STP 387, 1966.

10 TABLES

PRECEDING PAGE BLANK NOT FILMED.

TABLE I

TENSILE TEST RESULTS, TITANIUM 55A (ANNEALED) TESTED AT 17°K AFTER STABILIZATION AT 17°K WITH INTERIM WARMING TO INDICATED TEMPERATURE, IRRADIATION, AS INDICATED, AT 17°K

Specimen	Temp. °K	Irradiation n/cm^2	F_{tu} Ksi	F_{tu} kN/cm^2	F_{ty} Ksi	F_{ty} kN/cm^2	F_{ty}/F_{tu} **	Elongation in 0.5 in (4D) %	Reduction of Area %	Fracture Stress Ksi	Fracture Stress kN/cm^2	Modulus (#) E 10^3 Ksi	Modulus (#) E MN/cm^2
1 Aa 2	17	None	188	129	134	92.6	0.72	30	47	352	243	19	13
1 Aa 3	17	None	182	125	131	90.3	0.72	31	48	346	239	18	12
1 Aa 211	17	None	185	127	126	87.2	0.68	32	44	328	226	19	13
Mean *	17	None	184.7	127.3	130.6	90.05	0.707	31.0	46.3	342.0	235.8	19	13
1 Aa 16	78	None	188	130	135	92.9	0.71	35	44	335	231	18	12
1 Aa 19	78	None	184	127	136	93.6	0.74	28	48	344	237	19	13
1 Aa 34	78	None	184	127	131	90.4	0.71	30	46	321	221	19	13
Mean *	78	None	185.2	127.7	133.9	92.30	0.720	31.0	46.0	333.3	229.8	19	13
1 Aa 24	178	None	186	129	134	92.5	0.72	36	50	373	257	18	12
1 Aa 25	178	None	176	122	131	90.5	0.74	32	52	358	247	18	12
1 Aa 53	178	None	184	127	134	92.5	0.73	31	54	396	273	19	13
Mean *	178	None	182.1	125.6	133.2	91.82	0.730	33.0	52.0	375.7	259.0	18	12
1 Aa 153 (a)	17	6×10^{17}	211	145	154	106	0.73	27	38	341	235	15	10
1 Aa 200 (a)	17	6×10^{17}	203	140	154	106	0.75	29	45	370	255	20	14
1 Aa 203 (a)	17	6×10^{17}	204	141	158	109	0.78	29	46	380	262	19	13
Mean *	17	6×10^{17}	206.0	142.0	155.3	107.1	0.753	28.3	43.0	363.7	250.8	18	12
1 Aa 4	78	6×10^{17}	190	131	152	104	0.80	24	47	320	221	-	-
1 Aa 14	78	6×10^{17}	195	134	152	105	0.78	26	44	322	222	20	14
1 Aa 47	78	6×10^{17}	196	135	151	104	0.77	30	47	371	256	19	13
Mean *	78	6×10^{17}	193.6	133.5	151.7	104.6	0.783	26.7	46.0	337.7	232.8	20	14
1 Aa 28	178	6×10^{17}	192	132	145	100	0.76	29	48	338	233	19	13
1 Aa 41	178	6×10^{17}	195	134	149	102	0.76	27	46	360	248	22	15
1 Aa 50	178	6×10^{17}	194	134	146	101	0.75	30	47	352	243	20	14
Mean *	178	6×10^{17}	193.4	133.4	146.7	101.2	0.757	28.7	47.0	350.0	241.3	20	14

(a) Previously reported in ref. 2.
For Comparison Purposes Only
\- Not determinable

* Means obtained before rounding
** Ratios obtained before rounding
Means are of ratios

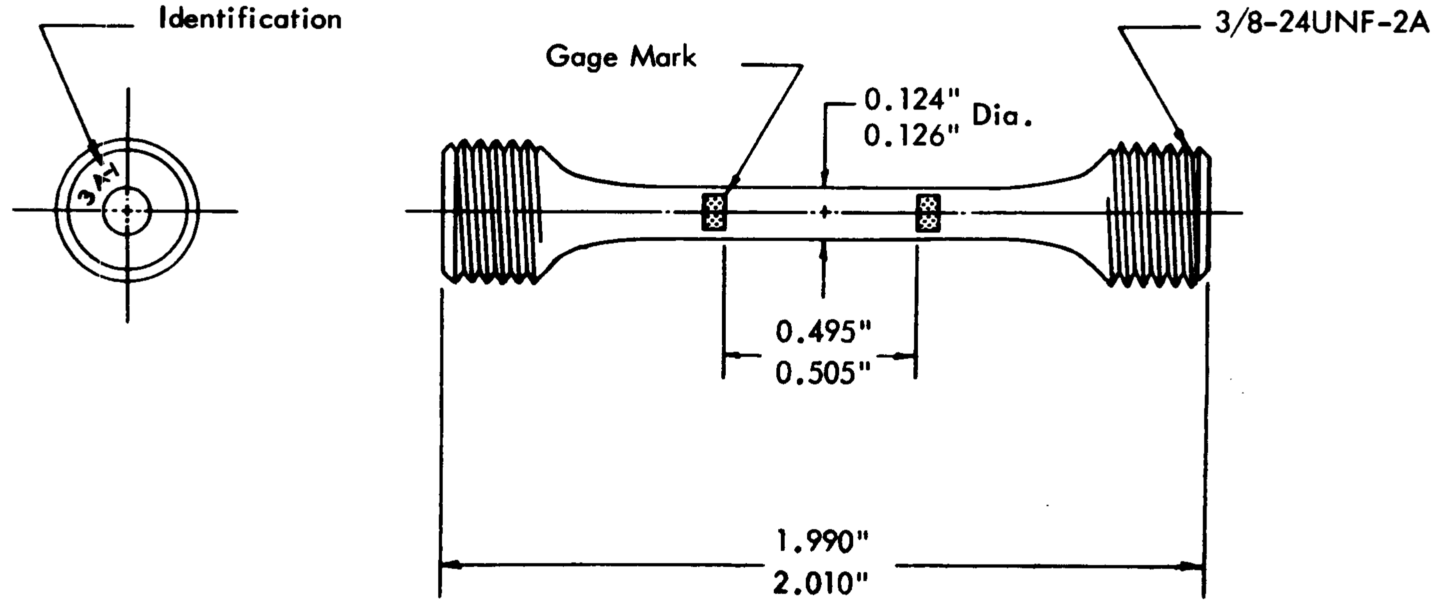
TABLE II TENSILE TEST RESULTS, TITANIUM 55A (ANNEALED) TESTED AT INDICATED TEMPERATURE AFTER STABILIZATION AT 17°K; IRRADIATION, AS INDICATED, AT 17°K

Specimen	Temp. °K	Irradiation n/cm^2	F_{tu} Ksi	F_{tu} kN/cm^2	F_{ty} Ksi	F_{ty} kN/cm^2	F_{ty}/F_{tu} **	Elongation in 0.5 in (4D) %	Reduction of Area %	Fracture Stress Ksi	Fracture Stress kN/cm^2	Modulus (#) E 10^3 Ksi	Modulus (#) E MN/cm^2
Range of 3(b)	17	None	182-188	125-129	126-134	87.2-92.6	0.68-0.72	30-32	44-48	328-352	226-243	18-19	12-13
Mean of 3(b)	17	None	184.7	127.3	130.6	90.05	0.707	31.0	46.3	342.0	235.8	19	13
1 Aa 11	78	None	138	95.3	106	72.9	0.76	47	67	327	225	18	12
1 Aa 195	78	None	137	94.2	106	73.2	0.78	51	68	294	203	17	12
1 Aa 201	78	None	134	92.7	103	70.8	0.76	52	66	300	207	20	14
Mean *	78	None	136.4	94.07	104.9	72.31	0.767	50.0	67.0	307.0	211.7	18	12
1 Aa 17	178	None	95.2	65.6	79.9	55.1	0.84	35	61	181	125	15	10
1 Aa 51	178	None	94.3	65.0	78.9	54.4	0.84	26	62	238	164	21	15
1 Aa 59	178	None	94.2	65.0	76.9	53.0	0.82	30	64	186	128	17	12
Mean *	178	None	94.57	65.21	78.57	54.17	0.833	30.3	62.3	201.7	139.1	18	12
Range of 5(c)	300	None	65.1-69.4	44.9-47.9	47.5-63.3	32.8-43.6	0.73-0.91	25-33	59-65	-	-	12-14	8-10
Mean of 5(c)	300	None	67.00	46.20	53.50	36.89	0.798	30.0	62.3	-	-	14	10
Range of 3(b)	17	6×10^{17}	203-211	140-145	154-158	106-109	0.73-0.78	27-29	38-46	341-380	235-262	15-20	10-14
Mean of 3(b)	17	6×10^{17}	206.0	142.0	155.3	107.1	0.753	28.3	43.0	363.7	250.8	18	12
1 Aa 1	78	6×10^{17}	145	99.8	120	82.9	0.83	39	66	305	210	19	13
1 Aa 42	78	6×10^{17}	147	101.4	126	86.6	0.85	41	63	293	202	20	14
1 Aa 212	78	6×10^{17}	145	99.8	116	79.8	0.80	43	63	302	208	18	12
Mean *	78	6×10^{17}	145.5	100.3	120.6	83.13	0.827	41.0	64.0	300.0	206.8	19	13
1 Aa 23	178	6×10^{17}	101	69.5	90.7	62.5	0.90	25	64	200	138	17	12
1 Aa 35	178	6×10^{17}	101	69.5	92.7	63.9	0.92	29	63	191	132	20	14
1 Aa 45	178	6×10^{17}	100	68.9	92.6	63.8	0.93	30	64	191	132	18	12
Mean *	178	6×10^{17}	100.5	69.32	92.00	63.43	0.917	28.0	63.7	194.0	133.8	18	12

(b) From Table 1
(c) Previously reported in ref. 1
For comparison purposes only
\- Not determinable

* Means obtained before rounding
** Ratios obtained before rounding
Means are of ratios

11 FIGURES



Note: Diameter at gage marks shall be center diameter + $\begin{matrix}0.002"\\0.004"\end{matrix}$.

FIGURE 1 TENSILE SPECIMEN

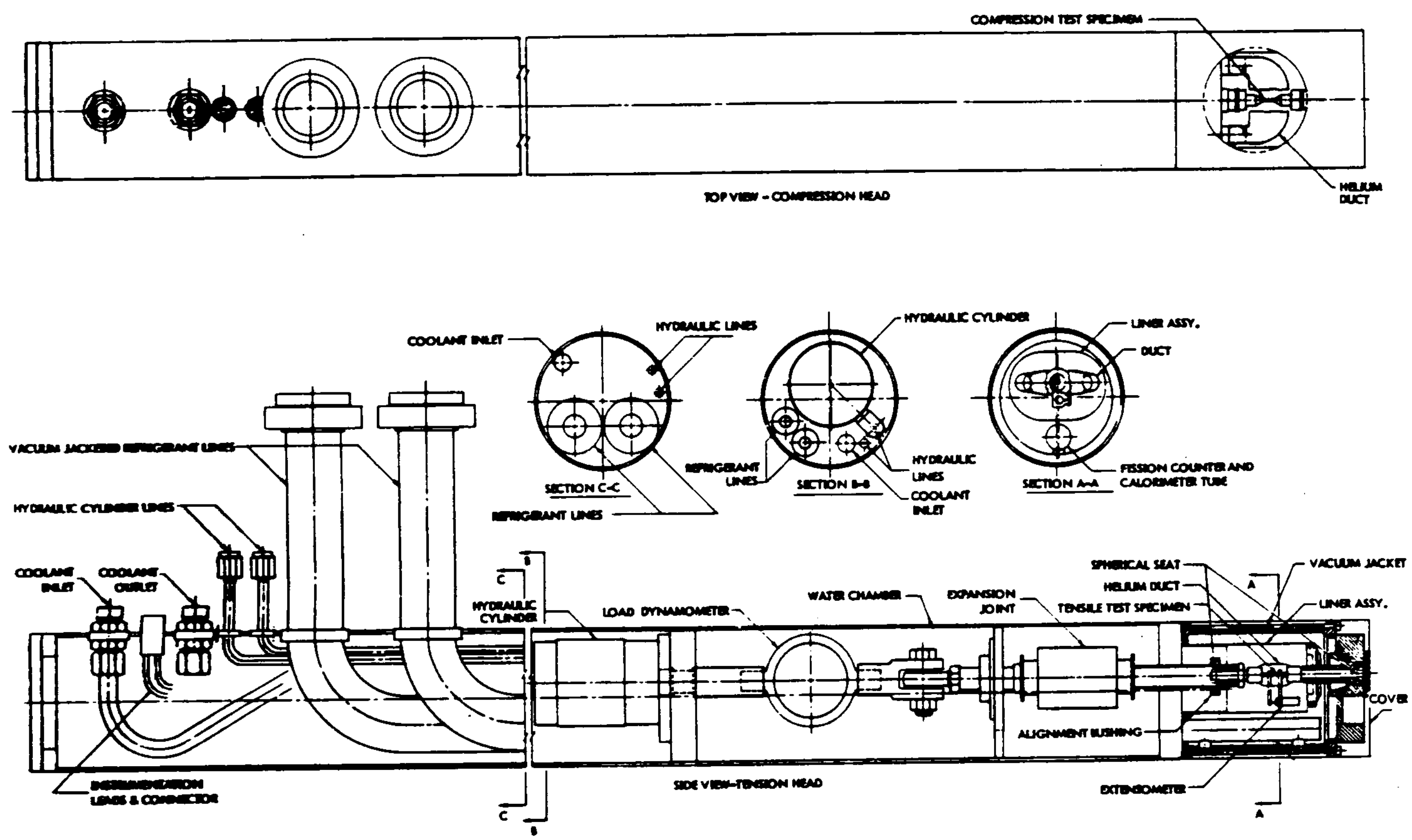


FIGURE 2 TENSILE TEST LOOP

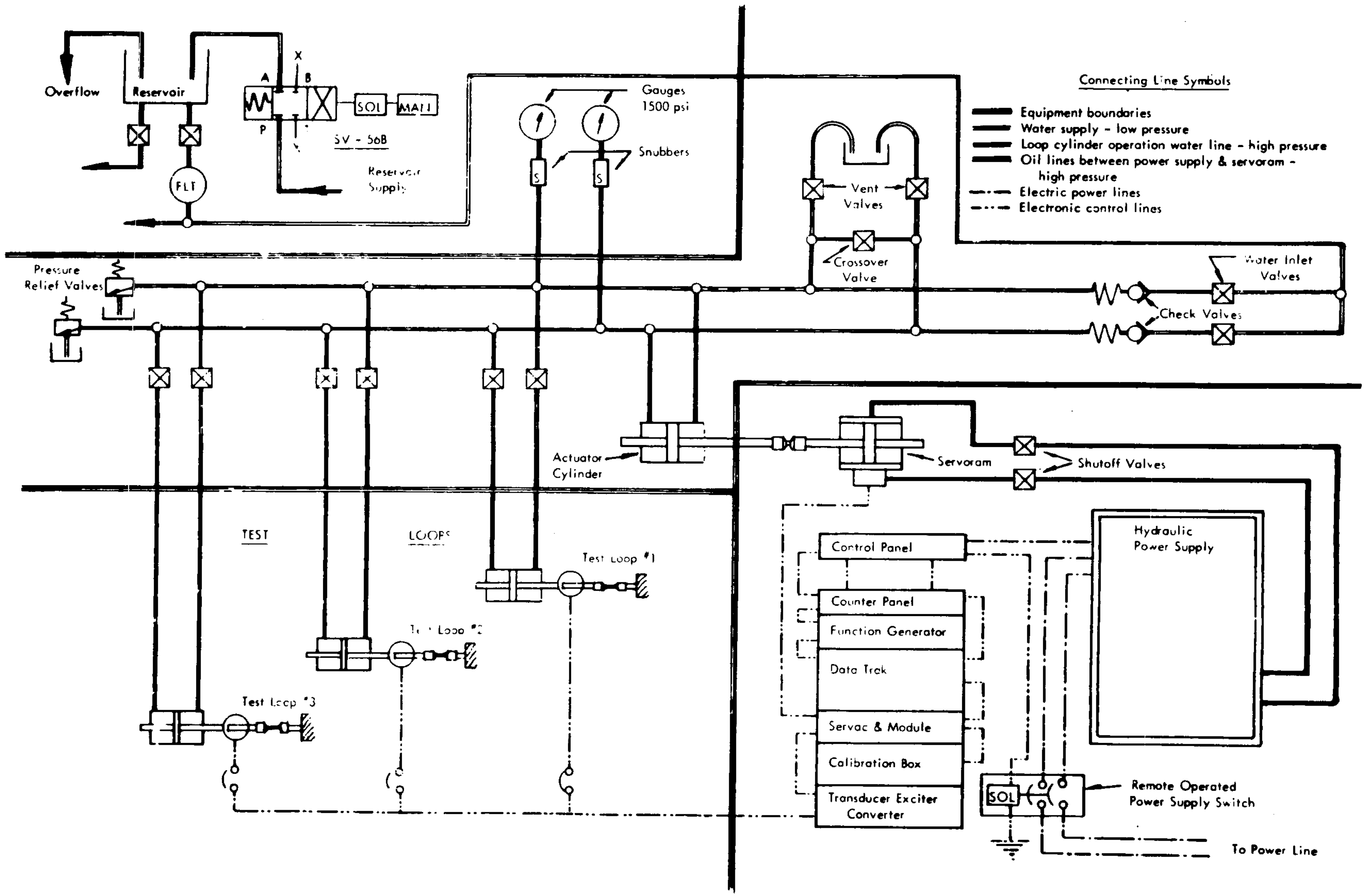


FIGURE 3 LOAD CONTROL SYSTEM (SCHEMATIC)

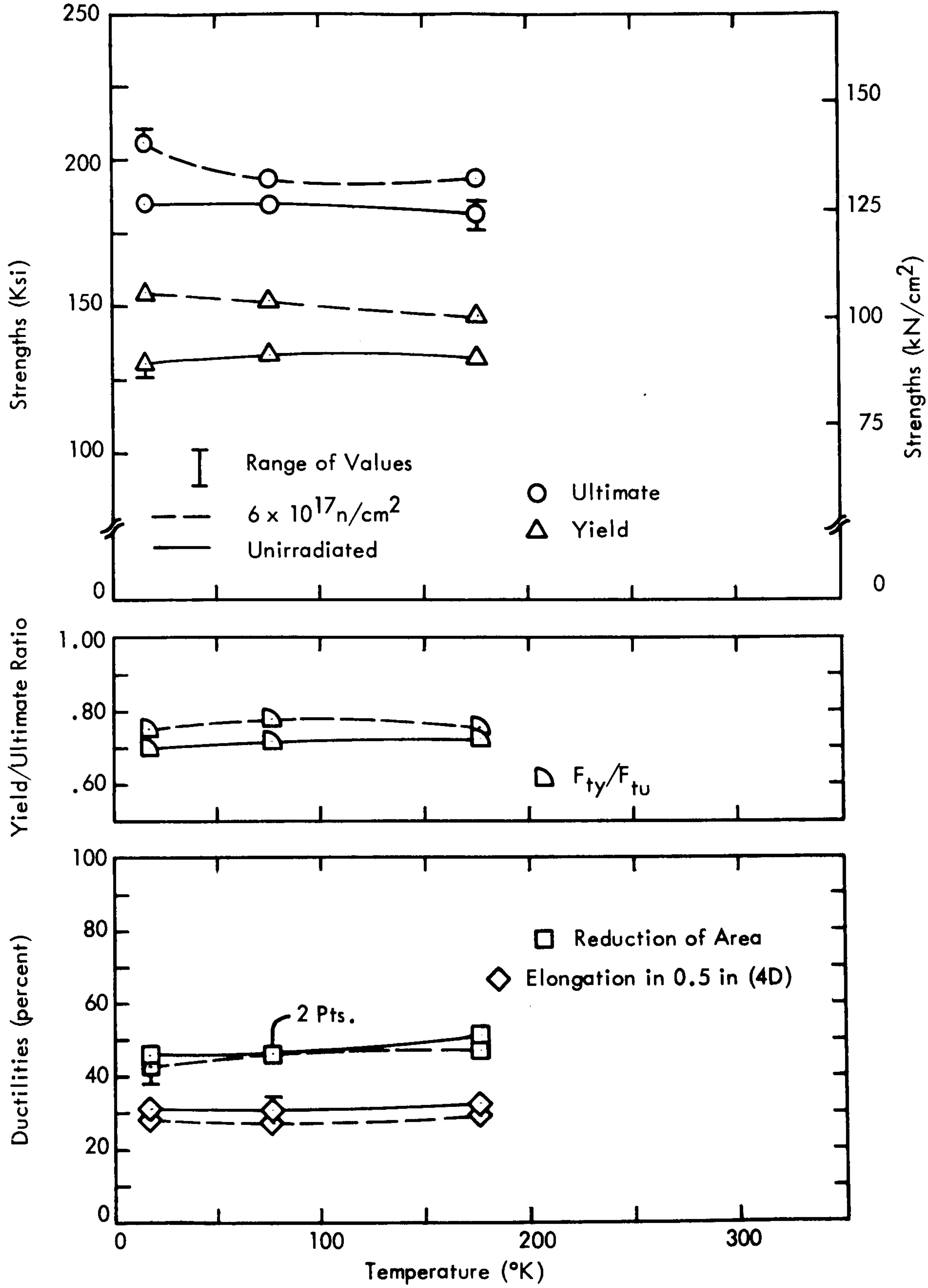


FIGURE 4 EFFECTS OF ANNEALING FOLLOWING IRRADIATION TO 6×10^{17} n/cm^2 AT 17°K, TESTED AT 17°K, TITANIUM 55A (ANNEALED)

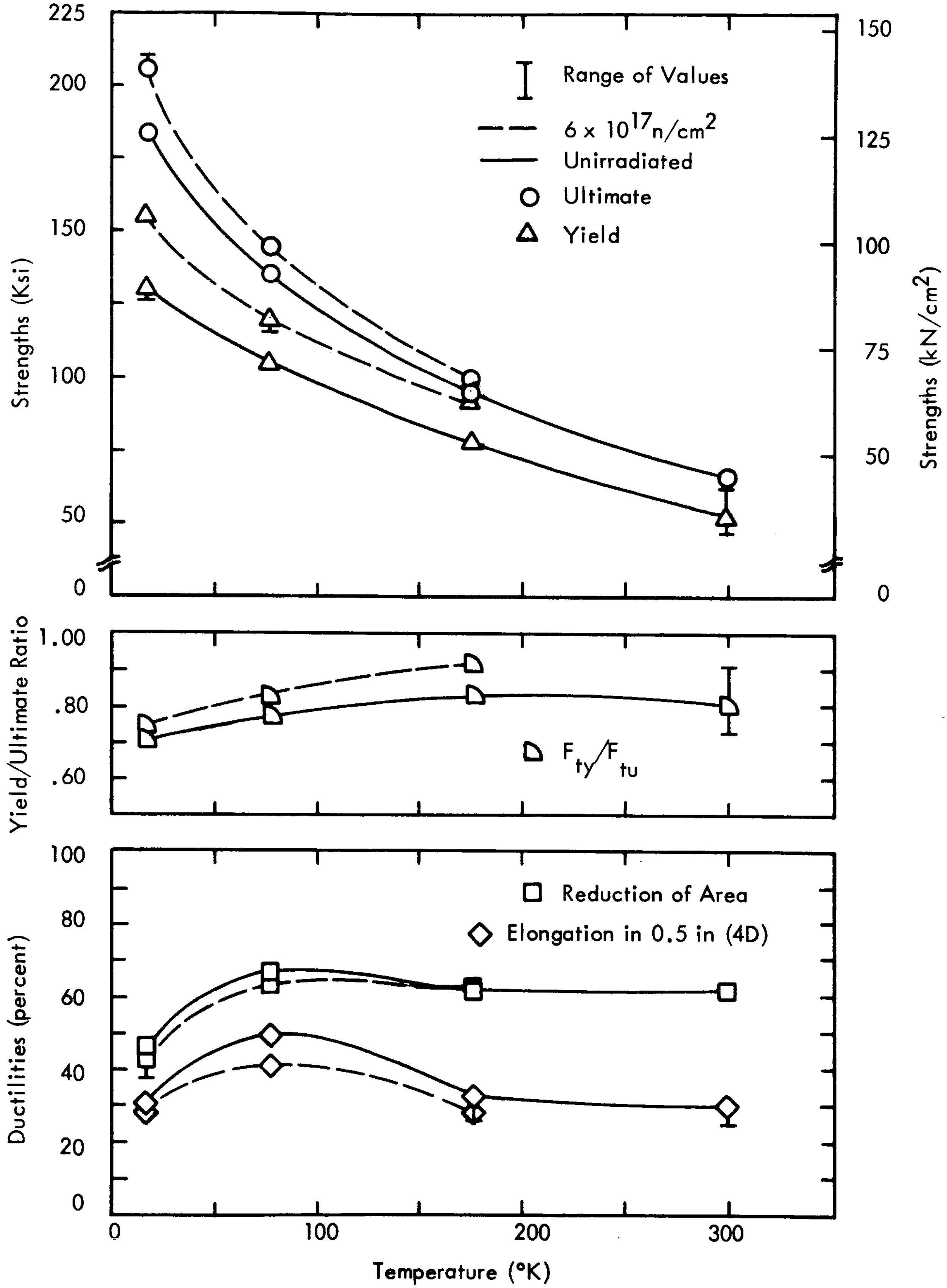


FIGURE 5 EFFECTS OF TESTING TEMPERATURE TITANIUM 55A (ANNEALED), TESTED UNIRRADIATED AND FOLLOWING IRRADIATION TO $6 \times 10^{17} n/cm^2$ AT 17°K

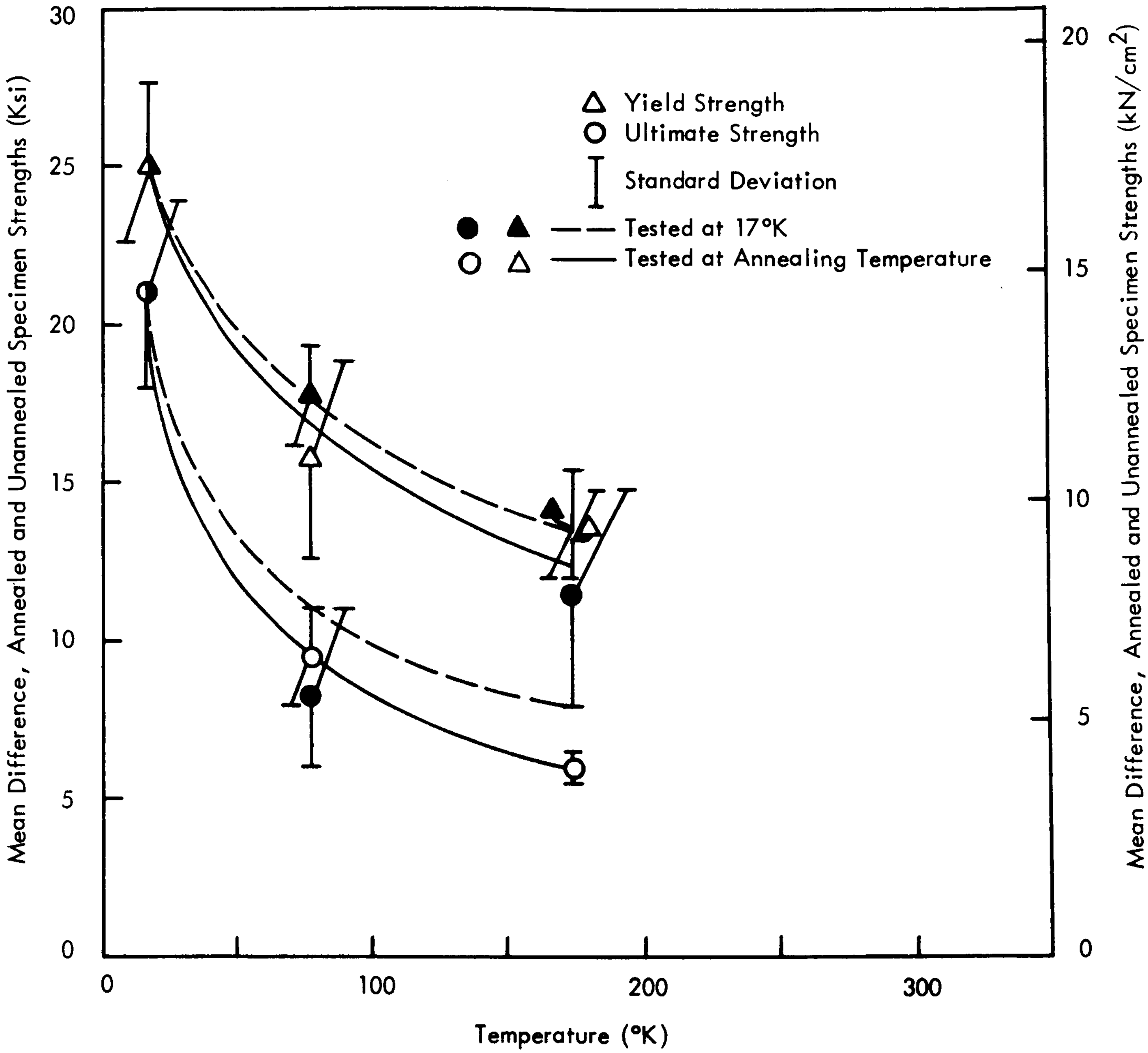


FIGURE 6 EFFECT OF ANNEALING ON IRRADIATION INDUCED CHANGES IN TENSILE PROPERTIES OF TITANIUM 55A IRRADIATED TO 6×10^{17} n/cm^2 AT 17°K

APPENDIX A

SIGNIFICANCE OF THE DIFFERENCE BETWEEN TWO SAMPLE MEANS

To determine if the difference between the means of two groups of samples is statistically significant the null hypothesis, that the two sample means $\bar{X}_1$ and $\bar{X}_2$ are from the same population with respect to the population mean $\bar{X}_p$, is used. This hypothesis is tested by determining the probability of t, where t is the ratio of $\bar{X}_1 - \bar{X}_2$ to an estimate of the standard error of the difference between the two sample means.

The standard error of the difference between two sample means, $\sigma_{\bar{X}_1 - \bar{X}_2}$ is given by:

$$\sigma_{\bar{X}_1 - \bar{X}_2} = \sigma \sqrt{\frac{1}{N_1} + \frac{1}{N_2}} \qquad (1)$$

where σ is the standard deviation of the population and N_1 and N_2 are the number of items in sample one and sample two, respectively.

Since the value of σ is unknown, its value must be estimated from the information given by the two samples. This estimate is $\hat{\sigma}_{1+2}$ obtained from:

$$\hat{\sigma}_{1+2} = \sqrt{\frac{\sum x_1^2 + \sum x_2^2}{N_1 - 1 + N_2 - 1}} \qquad (2)$$

$\sum x_1^2$ and $\sum x_2^2$ can be obtained by:

$$\sum x^2 = \sum X^2 - \frac{\left(\sum X\right)^2}{N} \qquad (3)$$

where X is the parameter value of each of the N items in the sample.

Having determined the value of $\hat{\sigma}_{1+2}$ with equations (3) and (2), an estimate of the standard error of the difference between the two means is obtained from:

$$\hat{\sigma}_{\bar{X}_1 - \bar{X}_2} = \hat{\sigma}_{1+2} \sqrt{\frac{1}{N_1} + \frac{1}{N_2}} \tag{4}$$

Equation (4) is derived from equation (1).

Finally the desired significance ratio t is obtained from:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\hat{\sigma}_{\bar{X}_1 - \bar{X}_2}}$$

This value of t and a t-distribution table (available in most statistics textbooks) are used to obtain the probability (P) of obtaining a value equal to $\pm$ t or more. The degrees of freedom n in this case is:

$$n = N_1 - 1 + N_2 - 1$$

Since one degree of freedom was lost when $\sum x_1^2$ was computed about $\bar{X}_1$ and another degree of freedom was lost when $\sum x_2^2$ was computed about $\bar{X}_2$.

Tables A-II, A-III and A-IV present a summary of statistical evaluation of the data for the strength function and the elongation values presented in table I and II. The group designation are defined as shown in Table A-I.

TABLE A-1

GROUP DESIGNATIONS FOR STATISTICAL ANALYSIS

Group	Irradiation Exposure $n/cm^2 \times 10^{-17}$	Temperature, Degrees K		
		Irradiation	Interim	Test
A	0	*	None	17
B	0	*	78	17
C	0	*	178	17
D	6	17	None	17
E	6	17	78	17
F	6	17	178	17
G	0	*	78	78
H	0	*	178	178
I	6	17	78	78
J	6	17	178	178

*All unirradiated specimens stabilized at 17°K prior to warm-up to interim temperature

TABLE A-II

SUMMARY OF STATISTICAL ANALYSES OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN GROUP MEAN VALUES OF TENSILE ULTIMATE STRENGTH DATA ON TITANIUM 55A PRESENTED IN TABLES I AND II

Statistical Parameters	Groups Compared								
	A & B	A & C	B & C	D & E	D & F	E & F	A & D	B & E	C & F
$\hat{\sigma}_{1+2}$	2.69	4.30	4.09	3.84	3.30	2.55	3.74	2.87	3.90
$\hat{\sigma}_{\bar{X}_1-\bar{X}_2}$	2.20	3.51	3.34	3.14	2.68	2.08	3.06	2.35	3.19
$\bar{X}_1-\bar{X}_2$	0.5	2.6	3.1	12.4	12.6	0.2	21.3	8.4	11.3
t	.227	.741	.928	3.95	4.70	0.096	6.96	3.57	3.54
P	.80	0.50	.40	.02	.01	1.0	(a)	.03	.03
Significant at P = .05	No	No	No	Yes	Yes	No	Yes	Yes	Yes

Statistical Parameters	Groups Compared								
	A & G	A & H	G & H	D & I	D & J	I & J	A & D	G & I	H & J
$\hat{\sigma}_{1+2}$	2.60	2.18	1.58	3.20	3.12	1.00	3.74	1.73	.707
$\hat{\sigma}_{\bar{X}_1-\bar{X}_2}$	2.12	1.78	1.29	2.61	2.55	.817	3.06	1.41	.577
$\bar{X}_1-\bar{X}_2$	48.3	90.1	41.8	60.5	105.5	45.0	21.3	9.1	5.9
t	22.8	50.6	32.4	23.2	41.4	55.1	6.96	6.45	10.2
P	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Significant at P = .05	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(a) $0 < P < .01$

TABLE A-III

SUMMARY OF STATISTICAL ANALYSES OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN GROUP MEAN VALUES OF TENSILE YIELD STRENGTH DATA ON TITANIUM 55A PRESENTED IN TABLES I AND II

Statistical Parameters	Groups Compared								
	A & B	A & C	B & C	D & E	D & F	E & F	A & D	B & E	C & F
$\hat{\sigma}_{1+2}$	3.43	3.12	2.24	1.73	2.24	1.58	3.32	1.94	1.94
$\hat{\sigma}_{\bar{X}_1 - \bar{X}_2}$	2.80	2.55	1.83	1.41	1.83	1.29	2.71	1.58	1.58
$\bar{X}_1 - \bar{X}_2$	3.3	2.9	0.7	3.6	8.6	5.0	24.7	17.8	13.5
t	1.18	1.14	.382	2.55	4.70	3.88	9.11	11.3	8.54
P	.30	.30	.70	.07	.01	.02	(a)	(a)	(a)
Significant at P = .05	No	No	No	No	Yes	Yes	Yes	Yes	Yes

Statistical Parameters	Groups Compared								
	A & G	A & H	G & H	D & I	D & J	I & J	A & D	G & I	H & J
$\hat{\sigma}_{1+2}$	3.12	2.08	1.66	3.94	1.87	3.68	3.32	3.78	1.41
$\hat{\sigma}_{\bar{X}_1 - \bar{X}_2}$	2.55	2.52	1.35	3.21	1.53	3.00	2.71	3.08	1.16
$\bar{X}_1 - \bar{X}_2$	25.7	52.0	26.3	34.7	63.3	28.6	24.7	15.7	13.4
t	10.1	20.6	19.5	10.8	41.4	9.53	9.11	5.10	11.6
P	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
Significant at P = .05	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(a) $0 < P < .01$

TABLE A-IV

SUMMARY OF STATISTICAL ANALYSES OF SIGNIFICANCE OF THE DIFFERENCE BETWEEN GROUP MEAN VALUES OF ELONGATION DATA ON TITANIUM 55A PRESENTED IN TABLES I AND II

Statistical Parameters	Groups Compared								
	A & B	A & C	B & C	D & E	D & F	E & F	A & D	B & E	C & F
$\hat{\sigma}_{1+2}$	2.65	2.00	3.16	2.29	1.41	2.45	1.12	3.35	2.18
$\hat{\sigma}_{\bar{X}_1-\bar{X}_2}$	2.16	1.63	2.58	1.87	1.16	2.00	.913	2.74	1.78
$\bar{X}_1-\bar{X}_2$	0	2.0	2.0	1.6	0.4	2.0	2.7	4.3	4.3
t	0	1.22	.775	.855	.346	1.00	2.96	1.57	2.42
P	1.00	.30	.50	.45	.75	.40	.04	.20	.07
Significant at P = .05	No	No	No	No	No	No	Yes	No	No

Statistical Parameters	Groups Compared								
	A & G	A & H	G & H	D & I	D & J	I & J	A & D	G & I	H & J
$\hat{\sigma}_{1+2}$	2.00	3.28	3.71	1.66	2.06	2.34	1.12	2.34	3.71
$\hat{\sigma}_{\bar{X}_1-\bar{X}_2}$	1.63	2.68	3.03	1.34	1.68	1.92	.913	1.92	3.03
$\bar{X}_1-\bar{X}_2$	19.0	0.7	19.7	12.7	0.3	13.0	2.7	9.0	2.3
t	11.6	.262	6.51	9.38	.178	6.79	2.96	4.70	.760
P	(a)	.80	(a)	(a)	.85	(a)	.04	.01	.50
Significant at P = .05	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No

(a) $0 < P < .01$

APPENDIX B DISTRIBUTION

NASA-Lewis Research Center (3)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Charles L. Younger (NSD)

NASA-Lewis Research Center (1)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: T. J. Flanagan (P&SD)

NASA-Lewis Research Center (1)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Norman T. Musial

NASA-Scientific & Technical
Information Facility (6)
Box 5700
Bethesda, Maryland 20014
Attention: NASA Representative
(CRT)

NASA-Lewis Research Center (2)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Library

NASA-Lewis Research Center (1)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Report Control Office

U. S. Atomic Energy Commission (3)
Technical Reports Library
Washington, D.C.

U. S. Atomic Energy Commission (1)
Division of Technical Information
Extension
P. O. Box 62
Oak Ridge, Tennessee 37831

National Aeronautics & Space
Administration (1)
Washington, D.C. 20546
Attention: George C. Deutsch
(Code RRM)

National Aeronautics & Space
Administration (1)
Washington, D.C. 20546
Attention: David Novik, Chief
(Code RNV)

AEC-NASA Space Nuclear Propulsion
Office (2)
U. S. Atomic Energy Commission
Washington, D.C. 20545
Attention: F. C. Schwenk

AEC-NASA Space Nuclear Propulsion
Office (1)
U. S. Atomic Energy Commission
Washington, D.C. 20545
Attention: J. E. Morrissey

National Aeronautics & Space
Administration (1)
Space Nuclear Propulsion Office-
Cleveland
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: L. C. Corrington

NASA-Lewis Research Center (3)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: M.H. Krasner,
Mail Stop 49-2

NASA-Lewis Research Center (1)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: H.J. Heppler, Jr.

NASA-Lewis Research Center (2)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Dr. John C. Liwosz

NASA-Plum Brook Station (3)
Sandusky, Ohio 44870
Attention: Don B. Crandall

NASA-Lewis Research Center (1)
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Office of Reliability &
Quality Assurance

NASA-Ames Research Center (1)
Moffett Field, California 94035
Attention: Library

NASA-Flight Research Center (1)
P.O. Box 273
Edwards, California 93523
Attention: Library

NASA-Goddard Space Flight Center (1)
Greenbelt, Maryland 20771
Attention: Library

Jet Propulsion Laboratory (1)
4800 Oak Grove Drive
Pasadena, California 91103
Attention: Library

NASA-Langley Research Center (1)
Langley Station
Hampton, Virginia 23365
Attention: Library

NASA-Manned Spacecraft Center (1)
Houston, Texas 77001
Attention: Library

NASA-Western Operations (1)
150 Pico Boulevard
Santa Monica, California 90406
Attention: Library

NASA-Marshall Space Flight Center (1)
Huntsville, Alabama 35812
Attention: Library

NASA-Marshall Space Flight Center (1)
Huntsville, Alabama 35812
Attention: W.Y. Jordan, P&VE-FN

NASA-Marshall Space Flight Center (1)
Huntsville, Alabama 35812
Attention: Dr. W.R. Lucas,
M-P & VE-M

NASA-Marshall Space Flight Center (1)
Huntsville, Alabama 35812
Attention: R.D. Shelton, M-RP-N

Aerojet-General Corporation (1)
P.O. Box 1947
Sacramento, California
Attention: W.A. Greenhow, Manager
Radiation Effects Program
Department 7431

Aerojet-General Corporation (2)
P.O. Box 1947
Sacramento, California
Attention: C.K. Soppet, Manager
Nuclear Operations

Aerojet-General Corporation (3)
P.O. Box 296
Azusa, California
Attention: C.N. Trent, Associate Director
NERVA Operations

Aerojet-General Corporation (1)
P.O. Box 1947
Sacramento, California
Attention: Dr. W. Weleff

Aerojet-General Nucleonics (1)
A Division of Aerojet-General
Corporation
P.O. Box 77
San Ramon, California 94583
Attention: G. A. Linenberger,
General Manager

Aluminum Company of America (1)
P.O. Box 1012
New Kensington, Pennsylvania
Attention: Edwin H. Spuhler

Argonne National Laboratories (1)
P.O. Box 299
Lemont, Illinois
Attention: T. H. Blewitt

Argonne National Laboratory (1)
Library Services Dept. 203-CE 125
9700 South Cass Avenue
Argonne, Illinois 60440
Attention: Report Section

Arthur D. Little Company, Inc. (1)
20 Acorn Park
Cambridge, Massachusetts 02140
Attention: Miss Elisabeth Harrington
Engineering Sciences Library

Atomics International (4)
P.O. Box 309
Canoga Park, California
Attention: F. E. Farhat, Librarian

Battelle Memorial Institute (1)
505 King Avenue
Columbus, Ohio 43201
Attention: D.J. Hammon, Radiation
Effects Information Center

Battelle Memorial Institute (1)
505 King Avenue
Columbus, Ohio 43201
Attention: Roger J. Runck

Battelle Memorial Institute (1)
Northwest Laboratories
326 Building, 300 Area
Richland, Washington 99352
Attention: Dr. T. T. Claudson

Battelle-Northwest (1)
P.O. Box 999
Richland, Washington 99352
Attention: Spencer H. Bush

Beech Aircraft Corporation (1)
P.O. Box 631
Boulder, Colorado 80301
Attention: Technical Library

The Bendix Corporation (1)
Research Laboratory Division
Southfield, Michigan
Attention: Frank W. Poblenz,
Library Services

The Boeing Company (1)
Aerospace Group
P.O. Box 3707
Seattle, Washington 98124
Attention: Ruth E. Peerenboom,
Processes Supervisor

Brookhaven National Laboratory (1)
Upton Long Island, New York 11973
Attention: D.H. Gurinsky

Brookhaven National Laboratory (1)
Upton Long Island, New York 11973
Attention: Paul W. Levy, Department of Physics

Bureau of Naval Weapons (1)
Washington, D.C.
Attention: J.H. Terry, Captain, RRNU

California Institute of Technology (1)
1201 East California Street
Pasadena, California 91109
Attention: General Library

Carbone Company (1)
Toonton, New Jersey
Attention: E.P. Eaton

Carpenter Steel Company (1)
P.O. Box 662
Reading, Pennsylvania
Attention: Neil J. Culp

Department of the Army (1)
United States Army Munitions Command
Frankford Arsenal
Philadelphia, Pennsylvania
Attention: Librarian

Douglas Aircraft Company, Inc. (2)
Missile & Space Systems Division
3000 Ocean Park Blvd.
Santa Monica, California 90406
Attention: A2-260 Library

General Dynamics/Convair (1)
P.O. Box 1128
San Diego, California 92112
Attention: A. Hurlich, Manager Materials & Processes Section, Mail Zone 572-00

General Dynamics/Fort Worth (1)
P.O. Box 748
Fort Worth, Texas 76101
Attention: Mr. Bob Vollmer, Administrative Assistant President's Office

General Electric Company (1)
Nuclear Materials & Propulsion Operation
P.O. Box 132
Cincinnati, Ohio 45215
Attention: J.W. Stephenson

Hughes Aircraft Company (1)
Nucleonics Division
Fullerton, California
Attention: Dr. A.M. Liebschutz

IIT Research Institute (1)
10 W. 35th Street
Chicago 16, Illinois
Attention: D.J. McPherson, Vice President

International Nickel Company, Inc. (1)
Huntington Alloy Products Division
Huntington, West Virginia
Attention: E.B. Fernsler

Kaman Aircraft Corporation (1)
Kaman Nuclear Division
Colorado Springs, Colorado
Attention: Mary G. Brown, Librarian

Lockheed-California Company (1)
P.O. Box 551
Burbank, California 91503
Attention: Dr. Lewis Larmore

Lockheed-California Company (2)
Burbank, California 91503
Attention: Central Library, Bldg. 63 Scientific & Technical Information Center

Lockheed-California Company (1)
Burbank, California 91503
Attention: H.B. Wiley,
Engineering Research

Lockheed-Georgia Company (1)
Nuclear Laboratory
P.O. Box 128
Dawsonville, Georgia
Attention: Dr. M.M. Miller, Manager
Nuclear Aerospace Division

Lockheed-Georgia Company (15)
P.O. Box 2155
Sandusky, Ohio 44870
Attention: C. A. Schwanbeck

Lockheed-Georgia Company (1)
Nuclear Laboratory
P.O. Box 128
Dawsonville, Georgia
Attention: Information Center

Lockheed Missiles & Space Company (1)
3251 Hanover Street
Palo Alto, California
Attention: John C. McDonald,
Materials Research Staff

Lockheed Missiles & Space Company (2)
3251 Hanover Street
Palo Alto, California
Attention: Sci-Tech Information Center

Lockheed Aircraft Corporation
Lockheed Missiles & Space Company (1)
P.O. Box 551, Burbank, California
Attention: M.A. Steinberg

Lockheed Missiles & Space Company (1)
Sunnyvale, California
Attention: H.F. Plank, Nuclear Space
Programs

Los Alamos Scientific Laboratory (1)
P.O. Box 1663
Los Alamos, New Mexico 87544
Attention: Glen A. Graves

Los Alamos Scientific Laboratory (3)
P.O. Box 1663
Los Alamos, New Mexico 87544
Attention: Report Library

The Martin Company (1)
P.O. Box 179
Denver, Colorado 80201
Attention: F.R. Schwartzberg, G0534

Mechanical Properties Data Center (1)
Suttons Bay, Michigan 49682
Attention: Matthew J. Kanold,
Administrative Assistant

National Bureau of Standards (1)
Boulder, Colorado 80302
Attention: Cryogenic Data Center

National Bureau of Standards (1)
Cryogenic Engineering Laboratory
Boulder, Colorado 80302
Attention: R.P. Reed

North American Aviation (1)
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, California
Attention: Technical Information Center

North American Aviation, Inc. (1)
Space & Information Systems Division
12214 Lakewood Blvd.
Downey, California 90241
Attention: Technical Information Center
D/41-096-410, AJ01
For: T. M. Littman, D/141-093-33

Northrop Corporation (1)
Norair Division
3901 W. Broadway
Hawthorne, California
Attention: Technical Information 3343-32

Oak Ridge National Laboratory (1)
Oak Ridge, Tennessee 37831
Attention: D.S. Billington

Ohio State University Libraries (1)
Serial Division
1858 Neil Avenue
Columbus, Ohio 43210

Pennsylvania State University (1)
105 Hammond Building
University Park, Pennsylvania 16802
Attention: Mr. Joseph Marin, Engineering
Mechanics Department

Picatinny Arsenal (1)
Technical Information Section,
SMUPA-VA6
Dover, New Jersey 07801
Attention: Commanding Officer

Purdue University (1)
Lafayette, Indiana
Attention: Librarian

Pure Carbon Company (1)
Wellsville Street
Saint Marys, Pennsylvania
Attention: Robert Paxon

Reynolds Metals Company (1)
6601 West Broad Street
Richmond, Virginia
Attention: L. E. Householder

Rice University (1)
P.O. Box 1892
Houston, Texas 77001
Attention: The Fondren Library

Rocketdyne (1)
A Division of North American
Aviation, Inc.
6633 Canoga Avenue
Canoga Park, California
Attention: Mr. G.A. Fairboirn,
D/596-174Z-2

Sandia Corporation (1)
P.O. Box 5800
Sandia Base
Albuquerque, New Mexico 87115
Attention: Technical Library

Southeastern Research Insitute (1)
Birmingham, Alabama
Attention: J.R. Kaitus

Special Metals, Inc. (1)
New Hartford, New York
Attention: Robert Neilsen

Titanium Metals Corporation of America (1)
233 Broadway
New York, New York
Attention: E.F. Erbin, Staff

TRW Systems (1)
Technical Information Center
One Space Park
Redondo Beach, California 90278

U.S. Air Force (1)
Air Force Weapons Laboratory
Kirtland AFB, New Mexico 87117
Attention: Technical Library (WLIL)

U.S. Air Force (1)
AF Materials Laboratory, Research &
Technology Division, AFSC
Wright-Patterson AFB, Ohio 45433
Attention: Harold M. Hormann

U.S. Air Force (1)
Foreign Technology Division, TDEPR
Wright-Patterson AFB, Ohio 45433
Attention: Lt. Schauffle

U.S. Air Force (1)
AFML (MAAM) (1A)
Wright-Patterson AFB, Ohio 45433

U.S. Army Materials Research Agency (1)
Watertown Arsenal
Watertown, Massachusetts
Attention: T.S. DeSisto

U.S. Naval Research Laboratory (1)
Washington, D.C. 20390
Attention: Dr. Albert V.H. Masket, Mechanics Division, Code 6204

U.S. Naval Research Laboratory (1)
Washington, D.C. 20390
Attention: L.E. Steele, Head, Reactor Materials Branch, Metallurgy Division

United States Steel Corporation (1)
Monroeville, Pennsylvania
Attention: Waldo Roll

University of California (1)
Lawrence Radiation Laboratory
Berkeley, California
Attention: Technical Information Division

University of California (1)
Lawrence Radiation Laboratory
P.O. Box 808
Livermore, California
Attention: Technical Information Division

University of California (1)
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico 87544
Attention: W.L. Kirk

University of California (1)
405 Hilgard Avenue
Los Angeles, California 90024
Attention: Engineering & Mathematical Sciences Library

University of California (1)
University Research Library
Los Angeles, California 90024
Attention: Serials Department

University of Chicago (1)
5640 Ellis
Chicago, Illinois 60637
Attention: Institute of Metals Library

University of Colorado (1)
Engineering Research Center
Boulder, Colorado
Attention: K.D. Timmerhaus, Associate Dean of Engineering

University of Georgia Libraries (2)
Athens, Georgia 30601
Attention: Acquisitions Division

University of Michigan (1)
Ann Arbor, Michigan 48104
Attention: Robert G. Carter, University Library

Westinghouse Electric Corporation (1)
Astronuclear Laboratory
P.O. Box 10864
Pittsburgh, Pennsylvania 15236
Attention: Dr. D.E. Thomas, Manager Materials Department

Westinghouse Electric Corporation (1)
Metallurgical Division
Pittsburgh, Pennsylvania 15235
Attention: E.T. Wessel, Research & Development Center

Westinghouse Electric Corporation (1)
Astronuclear Laboratory
P.O. Box 10864
Pittsburgh, Pennsylvania 15236
Attention: John Coombe

A B S T R A C T

Commercially pure titanium (Titanium 55A - Annealed) was tested in tension after post-irradiation annealing at 78°K and 178°K following irradiation to 6×10^{17} n/cm^2 ($E > 0.5$ MeV, 80 fJ) at 17°K. Tests were performed both at the annealing temperature and after re-cooling to 17°K. Post-irradiation annealing at 78°K or 178°K prior to testing at either the annealing temperature or at 17°K substantially reduced the radiation induced strength increases but did not appreciably affect ductility properties.