

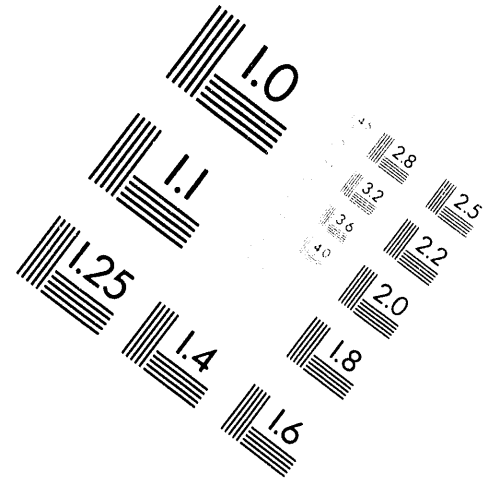
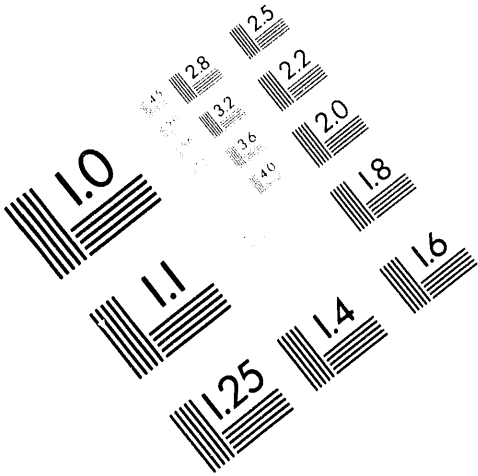


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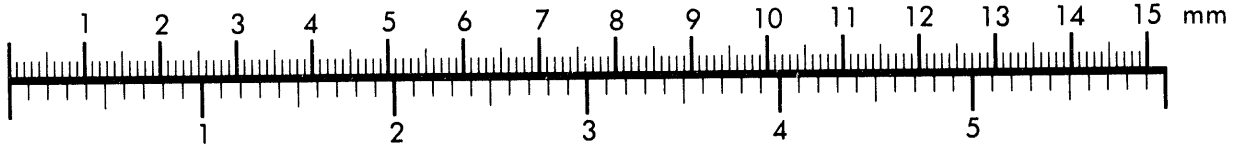
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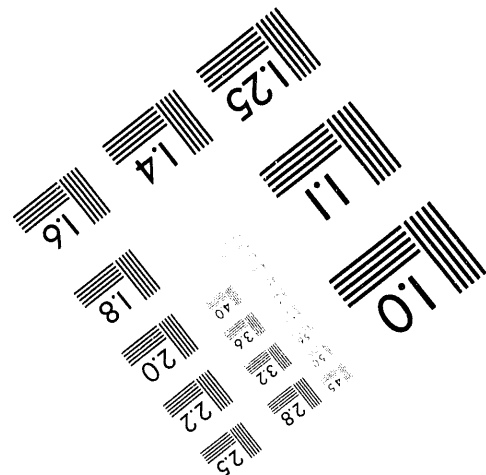
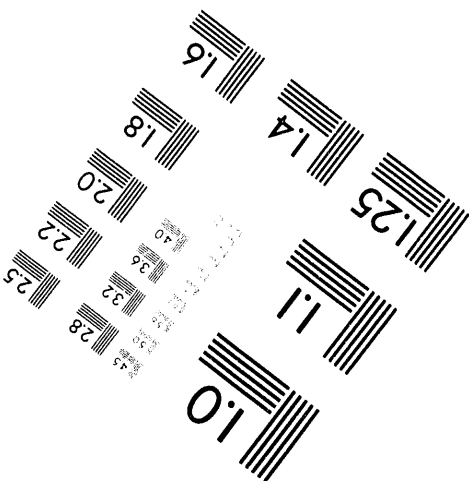
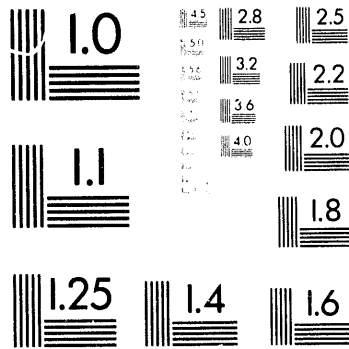
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**EFFECTS OF INTERNAL HELIUM ON TENSILE  
PROPERTIES OF AUSTENITIC STAINLESS STEELS AND  
RELATED ALLOYS AT 820°C**

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A document prepared for FIFTH INTERNATIONAL CONFERENCE ON HYDROGEN EFFECTS ON MATERIAL BEHAVIOR at Moran, Wyoming, USA from 9/11/94 thru 9/15/94.

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EFFECTS OF INTERNAL HELIUM ON TENSILE PROPERTIES OF  
AUSTENITIC STAINLESS STEELS AND RELATED ALLOYS AT 820°C

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Abstract

Tensile tests of uncharged, protium-charged, and tritium-charged and aged specimens of annealed Incoloy™ 903 alloy and high-energy-rate-forged (HERF) 316L stainless steel showed that 47-432 appm of internal He-3 caused drastic decreases in ductility at temperatures above about 600°C. Recent tests have been performed to determine the He-3 concentration thresholds for loss of ductility at 820°C for these alloys plus HERF Incoloy 903 alloy, 316LN, 304L and Nitronic 40 stainless steels, and Nickel 200 alloy. The decrease in ductility at 820°C as a function of internal He-3 concentration was found to be greatest for annealed 316LN and Nitronic 40 stainless steels and least for HERF 316L stainless steel. These results suggest that the effect of He-3 on ductility at 820°C may be influenced more by the metallurgical condition of the material than the composition.

*Elliot A. Oak* 5/23/94  
Technical Review      Date

*T. Motyka* 5-23-94  
Derivative Classifier      Date

## Introduction

Austenitic stainless steels are used for construction of tritium-handling equipment at the United States Department of Energy's Savannah River Site. Proper equipment design requires an understanding of how tensile properties of these stainless steels are affected by internal helium-3 (He-3) produced by radioactive decay of absorbed tritium. Rapid heating tensile testing from room temperature to above 1000°C has been used to determine these effects. The original objective of this study was to determine tensile properties for uncharged, protium-charged, and tritium-charged and aged specimens of annealed Incoloy™ 903 alloy and high-energy-rate-forged (HERF) 316L stainless steel (1). Initial tests of annealed Incoloy 903 alloy containing 47 atomic parts per million (appm) of He-3 and HERF 316L stainless steel with 156 appm He-3 showed drastic decreases in ductility at temperatures above about 600°C. Thus, a second objective was established to determine the He-3 concentration thresholds for loss of ductility at about 800°C for these alloys plus others of interest to SRS.

## Materials and Experimental Methods

HERF Incoloy 903 alloy and HERF 316L stainless steel were provided by Los Alamos National Laboratory. A composition report sent with the Incoloy 903 alloy is given in Table 1. No report was available for the HERF 316L stainless steel so a typical composition is given in Table 1. Round bar specimens with gage diameters of 2.9 mm and gage lengths of 22 mm were prepared by Metal Samples Company. Some HERF Incoloy 903 alloy specimens were annealed at 955°C for one hour and water quenched to remove the  $\gamma$ -Ni<sub>3</sub>Al precipitation-hardening phase. Specimens of annealed Incoloy 903 alloy and HERF 316L stainless steel were charged with high pressure tritium at 150°C for six months and aged at 0°C for periods of six, twenty-two and forty-eight months prior to testing to produce about 50-500 appm of internal He-3 from radioactive decay of the absorbed tritium. Companion specimens were charged with protium under similar conditions for use in determining effects of hydrogen in the absence of He-3.

Specimens of several austenitic stainless steels and alloys of interest to SRS were charged uniformly with tritium by heating at 300°C for two weeks at pressures of 2 kPa and 200 kPa and aged at room temperature for about one month to produce low concentrations of internal He-3 for use in determining thresholds for loss of ductility near 800°C. Materials included HERF and annealed Incoloy 903 alloy and HERF 316L stainless steel plus annealed 316LN stainless steel, 304L stainless steel with a Brinell hardness number (BHN) of 235, Nitronic™ 40 stainless steel from hot-rolled and annealed plate, and annealed Nickel 200 alloy provided by Metal Samples Company. Reported compositions of these alloys are given in Table 1.

Rapid heating tensile tests were performed on an Instron tensile testing machine equipped with an environmental chamber connected to an off-gas exhaust system to remove evolved tritium. A quartz lamp heated the specimen with temperature controlled and monitored with small platinum-rhodium thermocouples spot-welded to the gage section. A specimen could be heated in air to the desired test temperature within about a minute and held at constant temperature (within 20°C) for testing. Tests were conducted at an extension rate of 0.21 mm/sec. Ultimate tensile strength (UTS), 0.2% offset yield strength (OYS), total elongation (TE), uniform elongation (UE) and nonuniform elongation (NE) were determined from load-time recordings. UE was considered to occur under uniaxial tension up to the point of maximum load where necking usually begins. Reduction-in-area (RA) values were determined from diameter measurements made from calibrated scanning electron microscope (SEM) images of specimen fracture surfaces. Thin slices about 0.2 mm thick from gage lengths of tested specimens were sent to the Rocketdyne Division of Rockwell International Corporation for analyses by isotope-dilution gas mass spectrometry following vaporization in a resistance-heated graphite crucible to determine He-3 contents (2).

## Results

Strength and ductility parameters for uncharged, protium-charged and tritium-charged and forty-eight-months aged (118 appm He-3) specimens of annealed Incoloy 903 alloy are plotted as functions of test temperature in Figures 1. Similar results for HERF 316L stainless steel (432 appm He-3) are shown in Figure 2. Strength and ductility parameters for uncharged specimens of these alloys plus HERF Incoloy 903 alloy, 316LN, 304L and Nitronic 40 stainless steels, and Nickel 200 alloy determined at room temperature (about 25°C) and 820±20°C are presented in Table 2. Figure 3 shows the relative values (100% for uncharged specimens) of these properties at 820°C as functions of He-3 content for all the materials except HERF Incoloy 903 alloy. Specimens of HERF Incoloy 903 alloy were charged with tritium at 2 kPa only. Testing at 820°C yielded relative property values of 124% OYS, 132% UTS, 87.8% TE, 125% UE, 81.1% NE and 98.7% RA for 0.067 appm He-3. Figure 4 compares the effects of He-3 concentrations on the individual tensile properties for all the materials tested.

## Discussion

Results for annealed Incoloy 903 alloy (Figure 1) and HERF 316L stainless steel (Figure 2) show how absorbed tritium slightly strengthens these materials at temperatures up to about 800°C but greatly decreases ductility at temperatures above about 600°C. The absence of these effects for protium-charged specimens shows that they are caused by internal He-3 from radioactive decay of the absorbed tritium. Internal helium increases OYS more than UTS. Specimens containing He-3 failed at temperatures above 600°C by intergranular, brittle fracture compared to ductile, transgranular fracture for specimens with no internal helium. Absolute values for UE are very low at 820°C. NE, the primary contributor to TE, and RA are particularly sensitive to internal helium which restricts the necking process. Thus, embrittlement above 600°C is thought to involve interactions between the internal helium and the complex triaxial stress state that arises when necking starts.

Annealed Nickel 200 alloy containing 0.045 appm He-3 exhibited no degradation of ductility at 820°C. Specimens failed by plastic attenuation like companion uncharged specimens. Annealed Incoloy 903 alloy with 0.042 appm He-3, HERF Incoloy 903 alloy with 0.067 appm He-3 and HERF 316L stainless steel with 0.43 appm He-3 had slightly lower values for RA and NE at 820°C than companion uncharged and protium-charged specimens. These ductile failures exhibited transgranular fracture surfaces like the companion specimens but with smaller dimples. Moderate decreases in NE and RA occurred for 304L stainless steel with 0.47 appm He-3 and HERF 316L stainless steel with 11.7 appm He-3. Fracture surfaces showed a mixture of brittle, intergranular rupture and ductile, transgranular rupture. Drastic decreases in NE and RA at 820°C occurred for annealed Incoloy 903 alloy with 1.8, 47, 71 and 118 appm He-3, HERF 316L stainless steel with 156, 318 and 432 appm He-3, annealed 316LN stainless steel with 0.36 and 7.6 appm He-3, 304L stainless steel with 4.1 appm He-3, Nitronic 40 stainless steel with 0.65 and 8.1 appm He-3, and annealed Nickel 200 alloy with 1.5 appm He-3. All these specimens failed in a brittle manner and fracture surfaces showed only intergranular rupture.

## Summary

The effects of He-3 concentration on ductility at 820°C vary widely for the stainless steels and alloys investigated in this study. HERF 316L stainless steel has the lowest rate of decrease in ductility as a function of He-3 concentration. In contrast, annealed 316LN stainless steel has the highest rate. Decreases to relative values of <20% for NE and < 40% for RA occurred for 0.36 appm He-3 in annealed 316LN stainless steel compared to 156 appm He-3 in HERF 316L stainless steel. These results suggest that these effects may be influenced more by the metallurgical condition of the material than the composition. In general, annealed materials appear to be more sensitive to the presence of He-3. It is unfortunate that specimens of HERF Incoloy 903 alloy with concentrations of He-3 higher than 0.067 appm were not available for testing so that results could be compared with those for annealed Incoloy 903 alloy.

### Acknowledgements

A. Nobile and J. R. Wermer charged specimens with tritium at 2 and 200 kPa. C. L. Angerman arranged for specimens to be charged with tritium at high pressure. S. O. Brunson charged specimens with protium. L. J. Harpring and E. R. Selden developed the equipment for rapid heating tensile testing. Tensile tests were performed by R. L. Cone, S. O. Brunson, A. T. Crumm and D. P. Healy. Examinations of fractured specimens were performed by K. A. Dunn, C. L. Shelor, S. B. Rhodes and P. L. Morgan. S. M. Wood prepared samples for helium-3 analysis. This work was supported by the U. S. Department of Energy under contract number DE-AC09-89SR18035.

### References

1. W. C. Mosley, Rapid Heating Tensile Tests of High-Energy-Rate-Forged 316L Stainless Steel Charged with Hydrogen and Tritium, presented at the IMS-AIME 1989 Fall Meeting, Indianapolis, Indiana, October 1-5, 1989, DP-MS-89-9.
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Table 1. Compositions (w/o) of Austenitic Stainless Steels and Alloys Used in This Study

Incoloy 903	Reported: 41.31 Fe, 38.11 Ni, 14.97 Co, 2.92 Nb+Ta, 1.38 Ti, 1.03 Al, 0.16 Si, 0.11 Mn, 0.01 C, 0.001 S
316L Stainless Steel	Typical: 17.0 Cr, 12.0 Ni, 2.5 Mo, 0.03 max C, balance Fe
316LN Stainless Steel	Reported: 16.52 Cr, 10.15 Cr, 2.08 Mo, 1.77 Mn, 0.56 Si, 0.27 Cu, 0.12 Co, 0.119 N, 0.030 P, 0.020 C, 0.015 S, balance Fe
304L Stainless Steel	Reported: 18.53 Cr, 8.78 Ni, 1.28 Mn, 0.49 Si, 0.32 Cu, 0.29 Mo, 0.10 Co, 0.073 N, 0.027 P, 0.022 S, 0.018 C, <0.01 Ti, balance Fe
Nitronic 40 Stainless Steel	Reported: 19.21 Cr, 9.02 Mn, 7.16 Ni, 0.43 Si, 0.27 N, 0.14 Cu, 0.09 Mo, 0.06 Co, 0.033 C, 0.019 P, 0.001 S, balance Fe
Nickel 200 Alloy	Reported: 99.74 Ni, 0.14 Mn, 0.09 C, 0.01 Si, 0.01 Cu, 0.01 Fe, and 0.003 S

Table 2. Mechanical Properties of Austenitic Stainless Steels and Alloys at 25°C and 820°C

<u>MATERIAL</u>	<u>QYS</u> MPa	<u>UTS</u> MPa	<u>TE</u> %	<u>LE</u> %	<u>NE</u> %	<u>RA</u> %
HERF INCOLOY 903 ALLOY						
25°C	540	849	35.1	27.9	7.2	70.6
820°C	241	241	28.2	1.5	26.7	97.7
ANNEALED INCOLOY 903 ALLOY						
25°C	353	710	38.9	32.7	6.2	76.8
820°C	193	255	30.8	4.8	26.0	97.0
HERF 316L STAINLESS STEEL						
25°C	425	696	34.0	26.2	7.8	75.1
820°C	196	256	22.6	5.7	16.9	97.2
ANNEALED 316LN STAINLESS STEEL						
25°C	341	654	50.4	39.3	11.1	76.4
820°C	115	186	25.4	9.3	16.1	82.4
304L STAINLESS STEEL (BHN=235)						
25°C	680	753	52.1	33.7	18.4	76.8
820°C	259	267	27.3	4.3	23.0	74.1
NITRONIC 40 STAINLESS STEEL FROM HOT-ROLLED AND ANNEALED PLATE						
25°C	417	732	50.6	38.9	11.6	81.9
820°C	137	220	25.2	9.3	16.0	92.5
ANNEALED NICKEL 200 ALLOY						
25°C	199	489	61.7	52.1	9.6	78.3
820°C	57	83	61.0	19.2	41.8	100.0

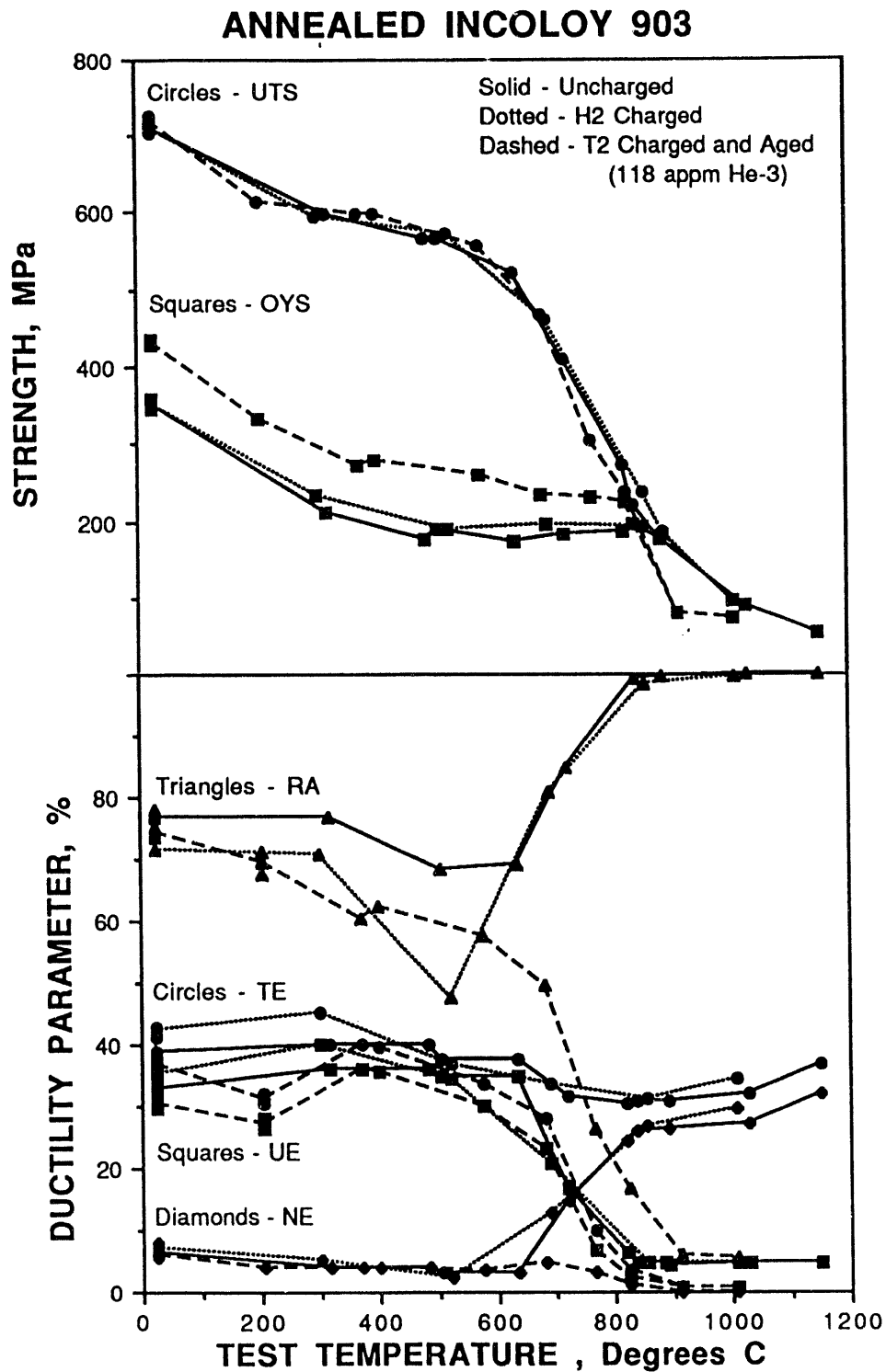


Figure 1- Tensile properties of uncharged, protium-charged and tritium-charged and forty-eight-months aged (118 appm He-3) specimens of annealed Incoloy 903 alloy as functions of test temperature.

## HERF 316L STAINLESS STEEL

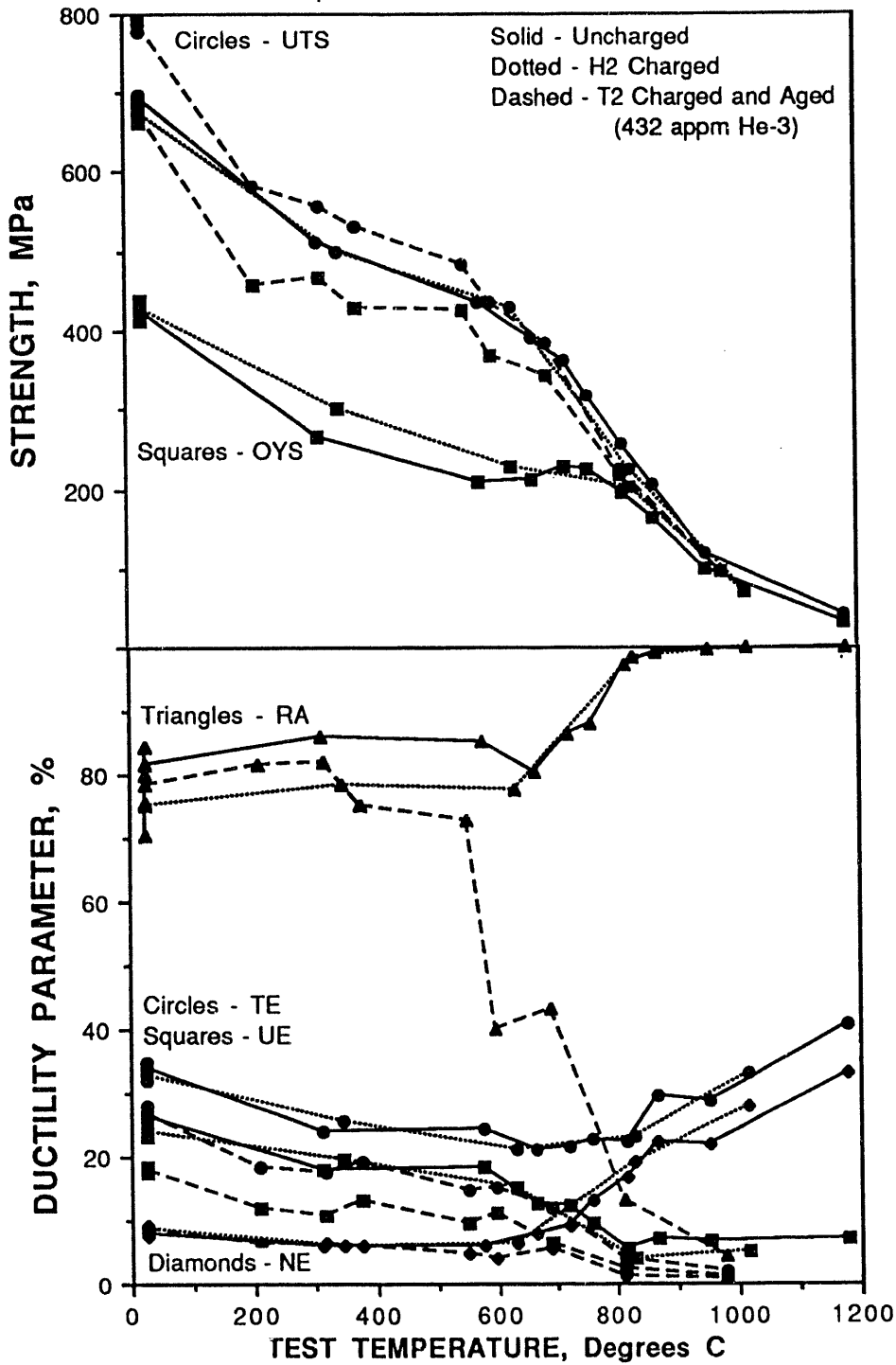


Figure 2- Tensile properties of uncharged, protium-charged and tritium-charged and forty-eight- months aged (432 appm He-3) specimens of HERF 316L stainless steel as functions of test temperature.

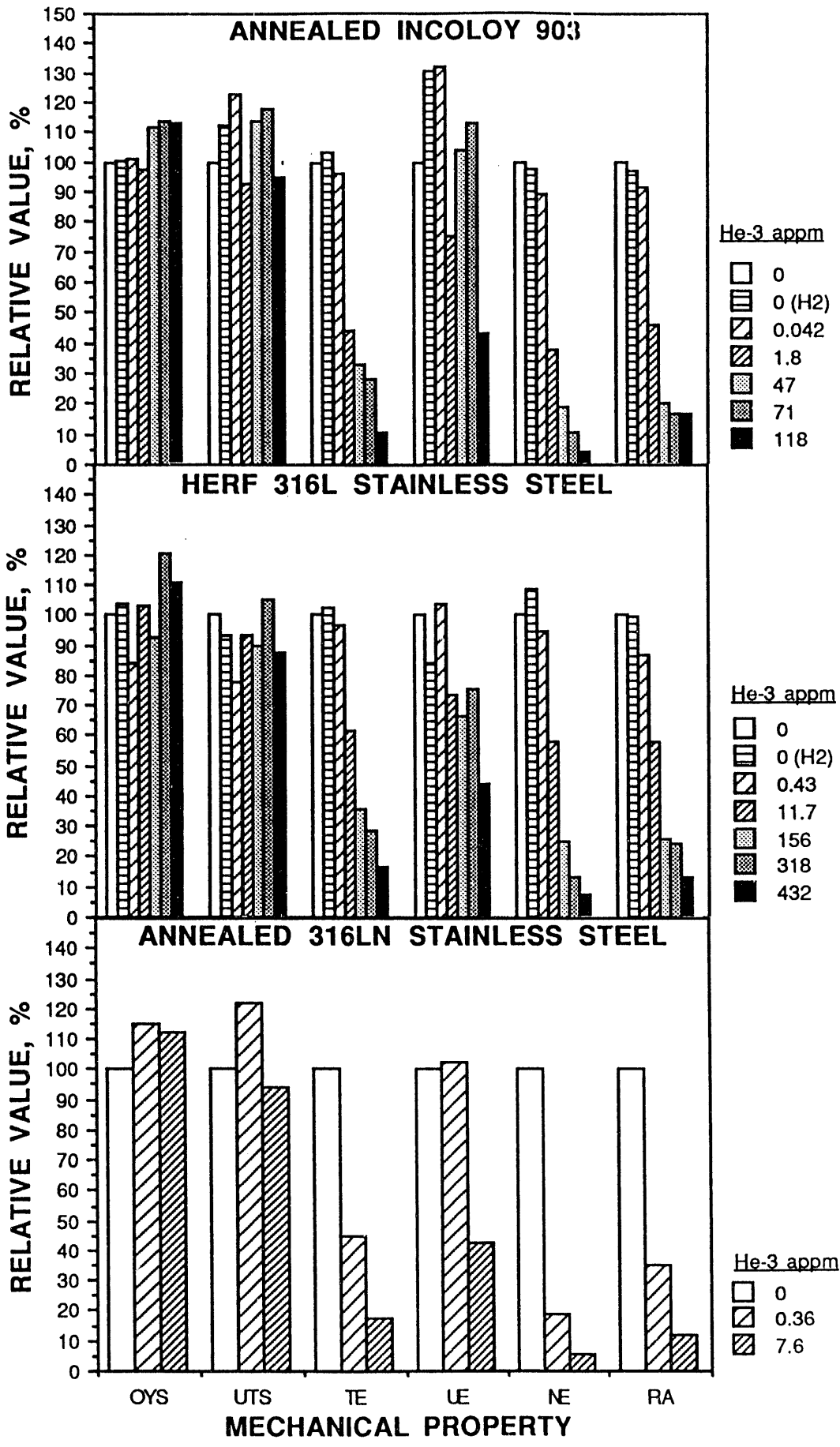


Figure 3- Relative values of 820°C tensile properties for uncharged, protium-charged and tritium-charged and aged austenitic stainless steels and alloys.

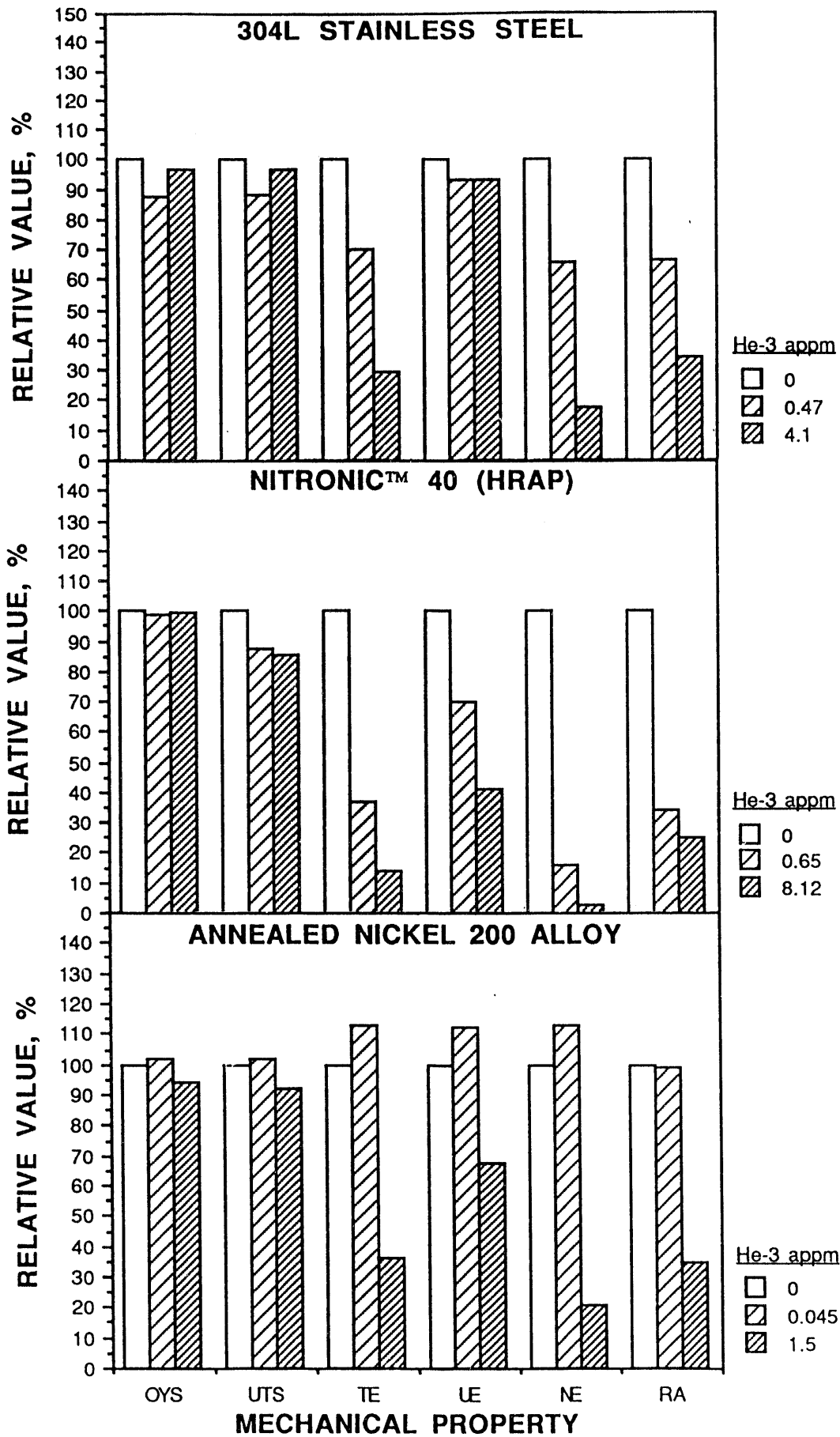


Figure 3 (cont.)- Relative values of 820°C tensile properties for uncharged, protium-charged and tritium-charged and aged austenitic stainless steels and alloys.

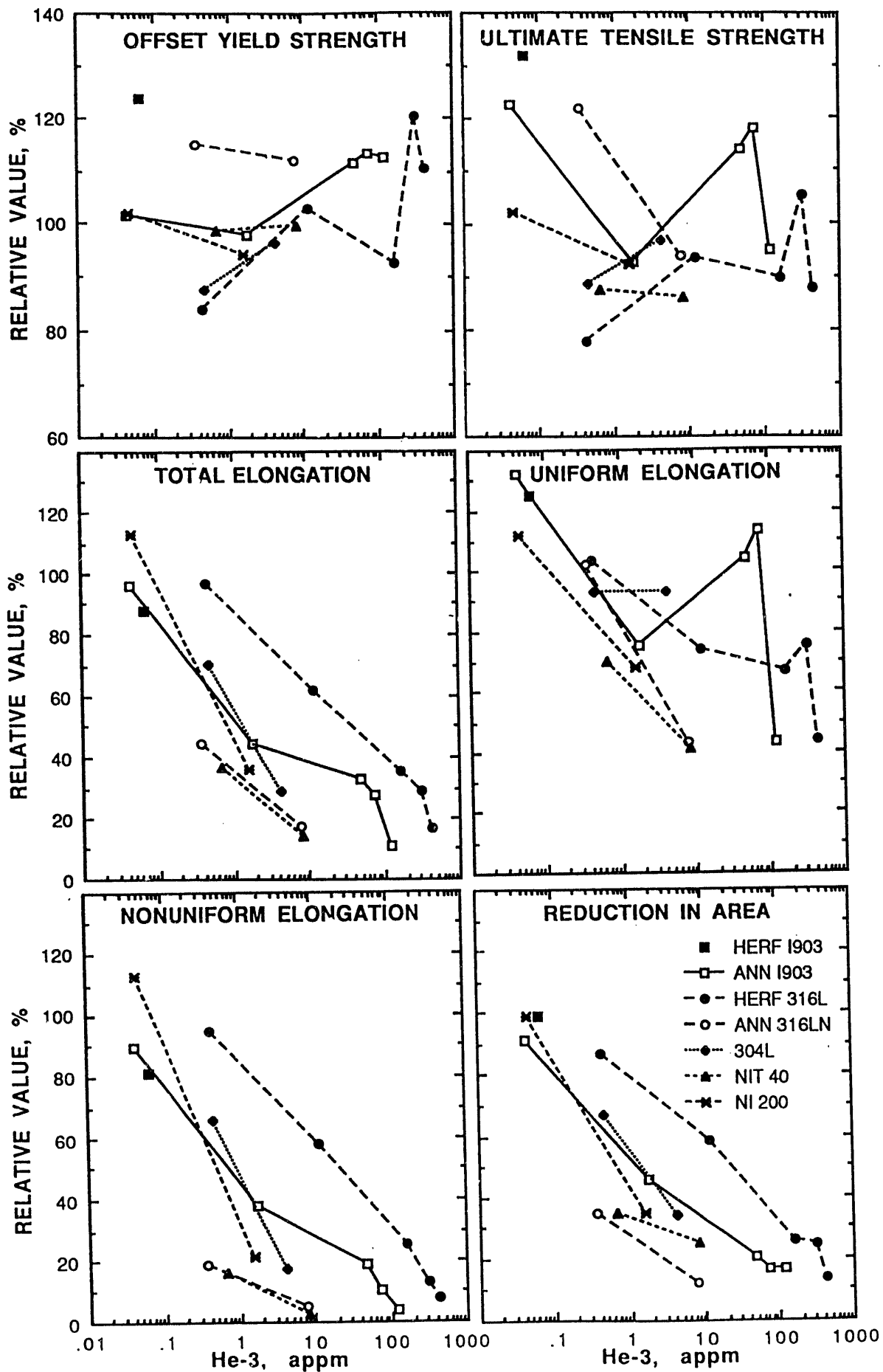


Figure 4- Relative values of 820°C tensile properties as functions of He-3 content for uncharged, protium-charged and tritium-charged and aged austenitic stainless steels and alloys.

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