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FATIGUE BEHAVIOR OF TYPE 316 STAINLESS STEEL
FOLLOWING NEUTRON IRRADIATION INDUCING HELIUM*

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EHB

Since a tokamak fusion reactor operates in a cyclic mode, thermal stresses will result in fatigue in structural components, especially the first wall and blanket. Type 316 stainless steel in the 20% cold-worked condition has been irradiated in the HFIR in order to introduce helium as well as displacement damage. A miniature hourglass specimen was developed for the reactor irradiations and subsequent fully reversed low cycle fatigue testing.

For material irradiated and tested at 430°C in vacuum to a damage level of 7—15 dpa and containing 200—1000 appm He, a reduction in life by a factor of 3—10 was observed. An attempt was made to predict irradiated fatigue life by fitting data from irradiated material to a power law equation similar to the universal slopes equation and using ductility ratios from tensile tests to modify the equation for irradiated material. This method has been used successfully for unirradiated materials, but overpredicts fatigue life for the irradiated material containing helium. This suggests that another factor is involved in fatigue life in such materials: a likely prospect is helium. Evidence of an unusual fracture mechanism similar to channel fracture was also observed. The flat facet-like surfaces are similar to those observed on the fracture surfaces of similarly irradiated tensile specimens when the crack propagages along slip bands resulting from preirradiation cold working.

THE 14 MeV NEUTRONS FROM FUSION RESULT

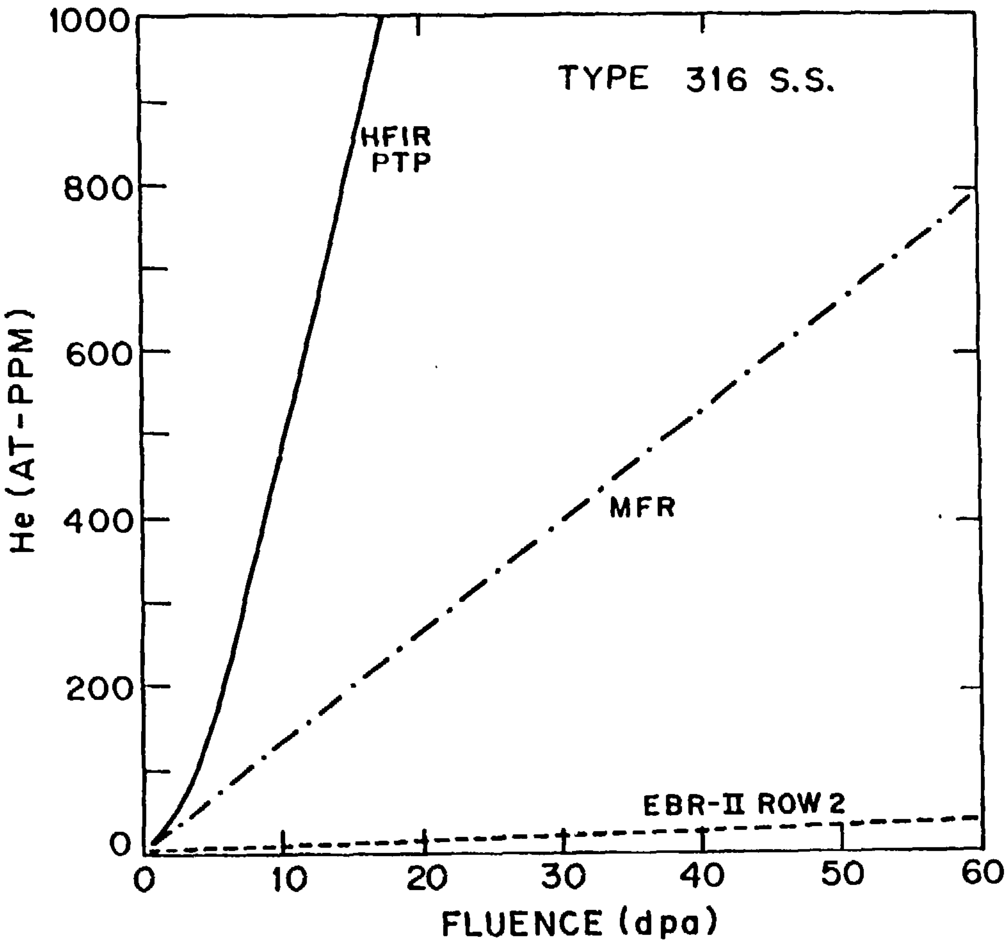
IN HELIUM PRODUCTION AS WELL AS

DISPLACEMENT DAMAGE

BECAUSE OF THE CYCLIC MODE OF OPERATION
OF MOST TOKAMAKS, FATIGUE OF STRUCTURAL
MATERIALS IS A MAJOR CONCERN

SINCE A HIGH INTENSITY SOURCE OF 14 MeV NEUTRONS IS NOT YET AVAILABLE, FISSION REACTORS ARE USED TO PRODUCE HELIUM BY TRANSMUTATION OF NICKEL

THE HFIR INTRODUCES HELIUM IN STAINLESS STEEL AT A FASTER RATE THAN A FUSION REACTOR, PERMITTING STUDIES OF HELIUM EFFECTS AT AN ACCELERATED PACE.



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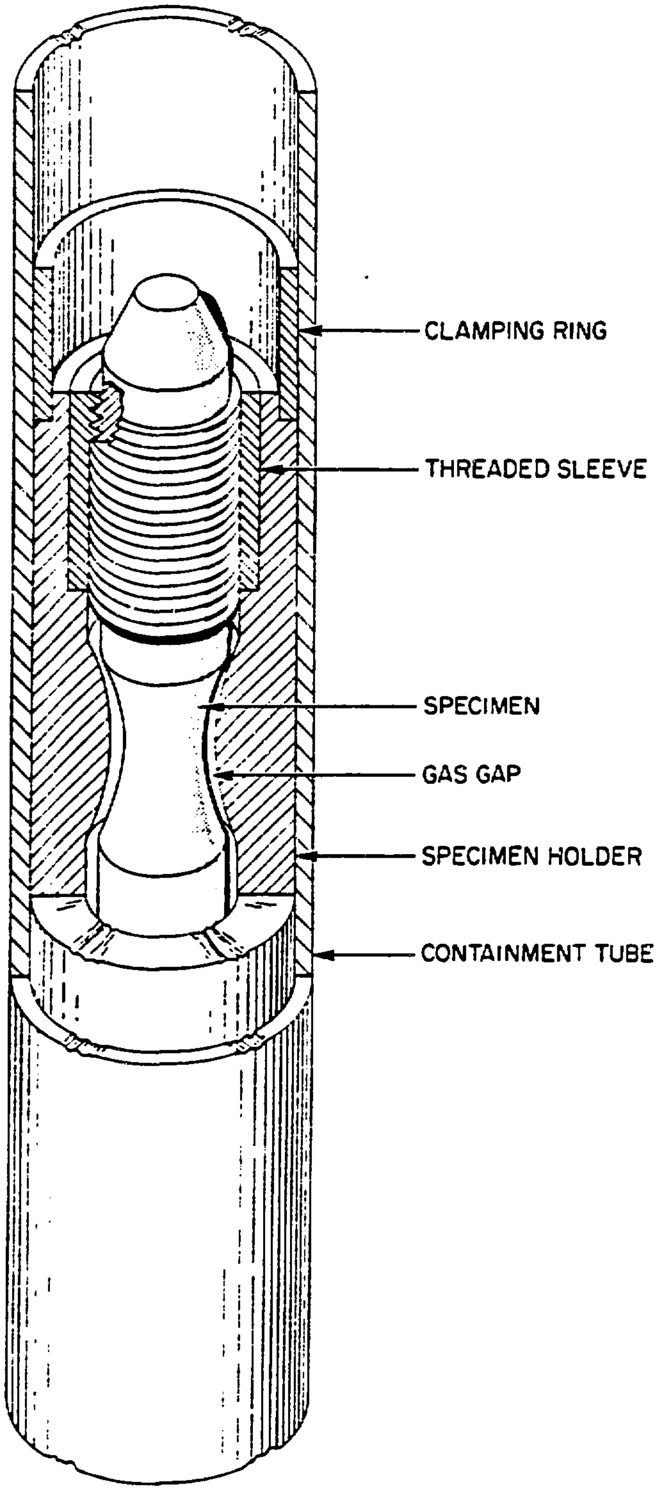
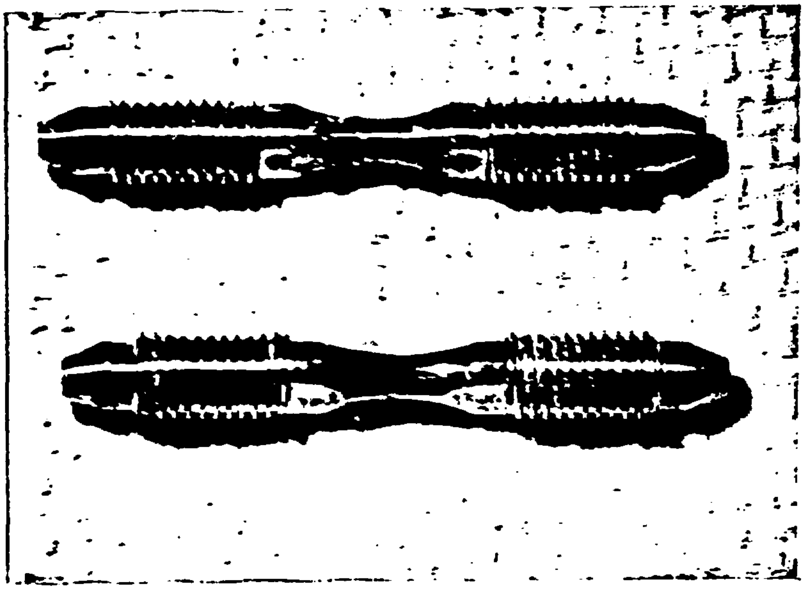


TEMPERATURE MONITORS WERE PLACED

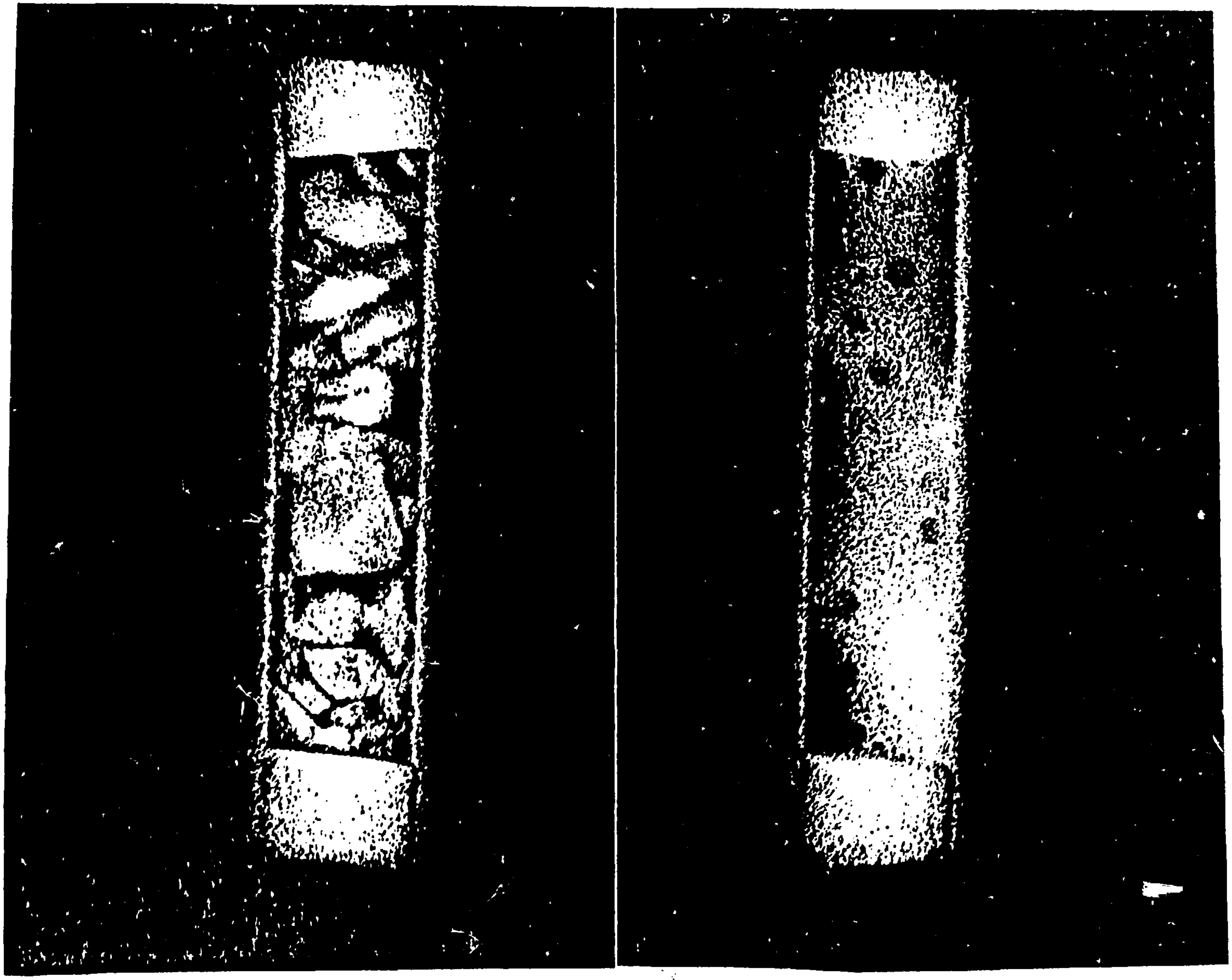
IN SOME SPECIMENS:

1. LOW MELTING ALLOYS

2. SiC



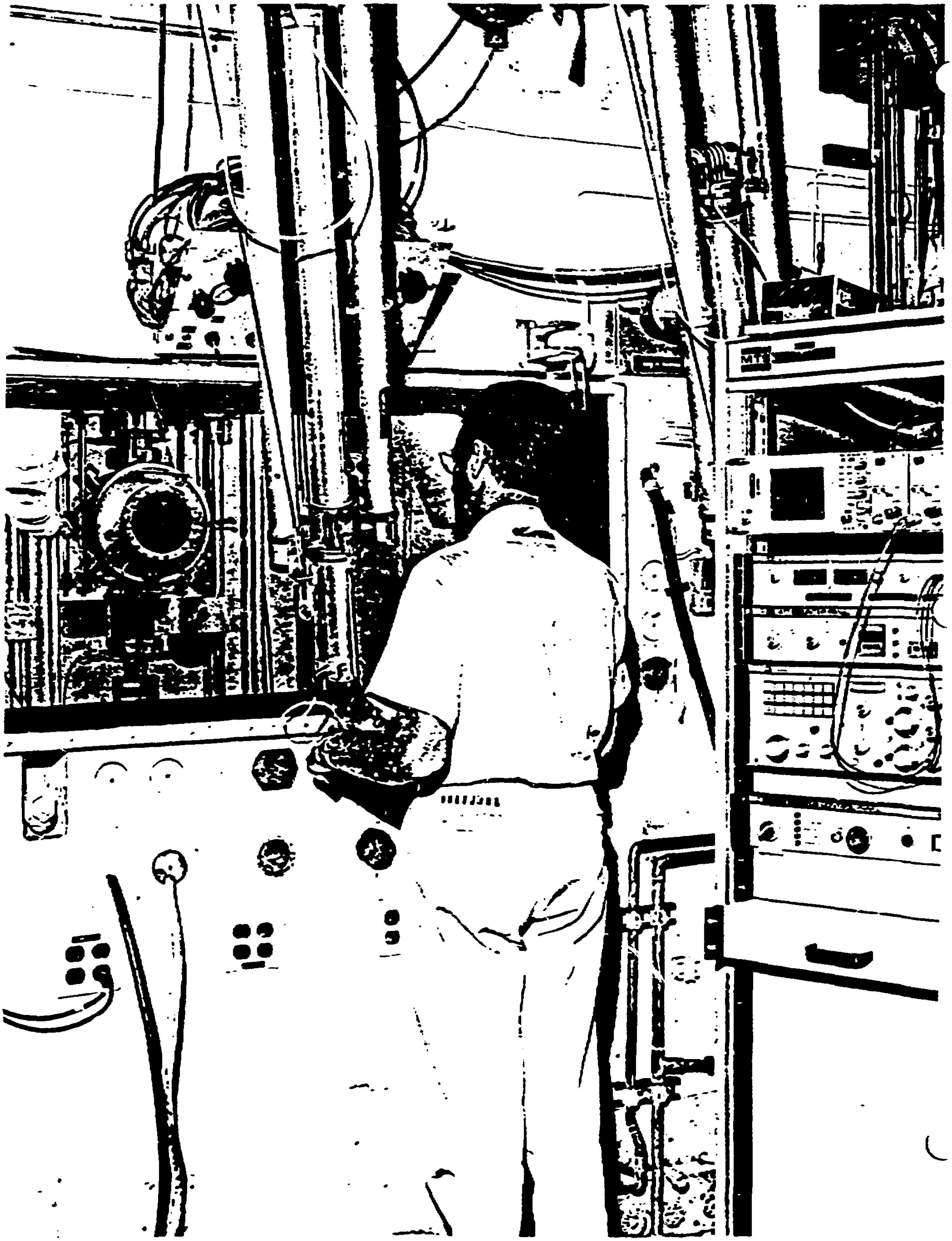
CAPSULES ARE RADIOGRAPHED TO DETERMINE MELTING (SELENIUM)

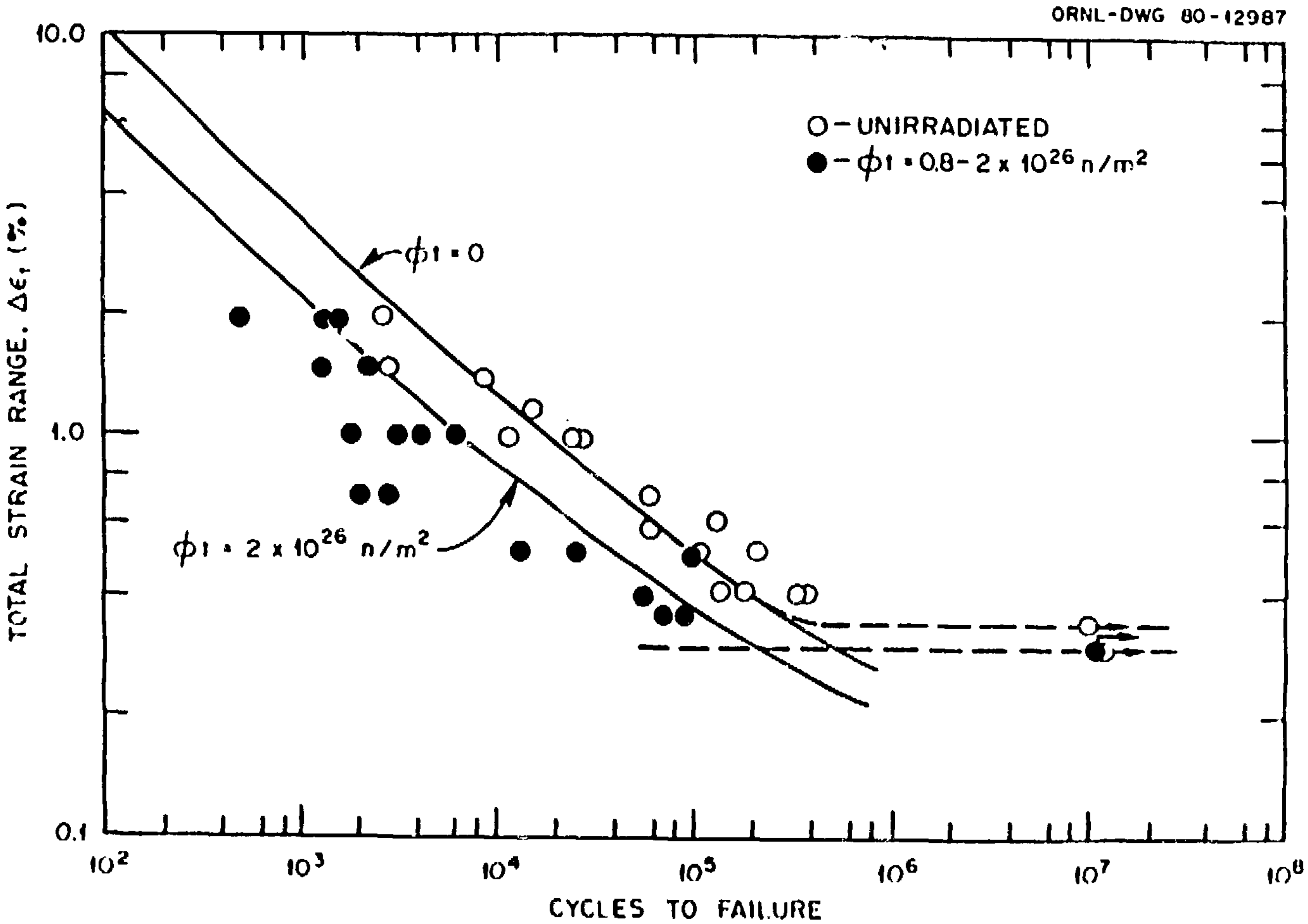


AN ALLOY WITH T_m = 385°C MELTED.

SiC INDICATED 430 ± 10°C

AN MTS HYDRAULIC TESTING MACHINE
EQUIPPED WITH A VACUUM CHAMBER AND
CAPABLE OF 600°C TESTING WAS INSTALLED
IN A HOT CELL.
HAS RUN SUCCESSFULLY FOR 3800 HR





Fatigue Life Of 20% C.W. Type 316 Stainless Steel Irradiated In HFIR At 430 °C And Tested At Irradiation Temperature (200–1,000 appm He, 5–15 dpa).

AN EQUATION OF THE FORM OF THE
UNIVERSAL SLOPES EQUATION WAS FIT
TO THE UNIRRADIATED SPECIMEN DATA

$$\Delta\varepsilon_t = 2\,\frac{\sigma_u}{E}\,N_f^{-0.12} + D^{0.5}\,N_f^{-0.5}$$

USING HFIR TENSILE DATA FROM A

SIMILAR HEAT OF STEEL,

IRRADIATED LIFE WAS PREDICTED.

$\phi t_f = 2 \times 10^{26}\ n/m^2$

$\sigma_\mu = 613$ MPa

RA = 30%

STRENGTH AND DUCTILITY ALONE

DO NOT DETERMINE FATIGUE LIFE

IN IRRADIATED MATERIALS.

MIGRATION OF HELIUM TO DISCONTINUITIES

AIDED BY CYCLIC DISLOCATION MOTION

CAN CONTRIBUTE TO DEGRADATION.

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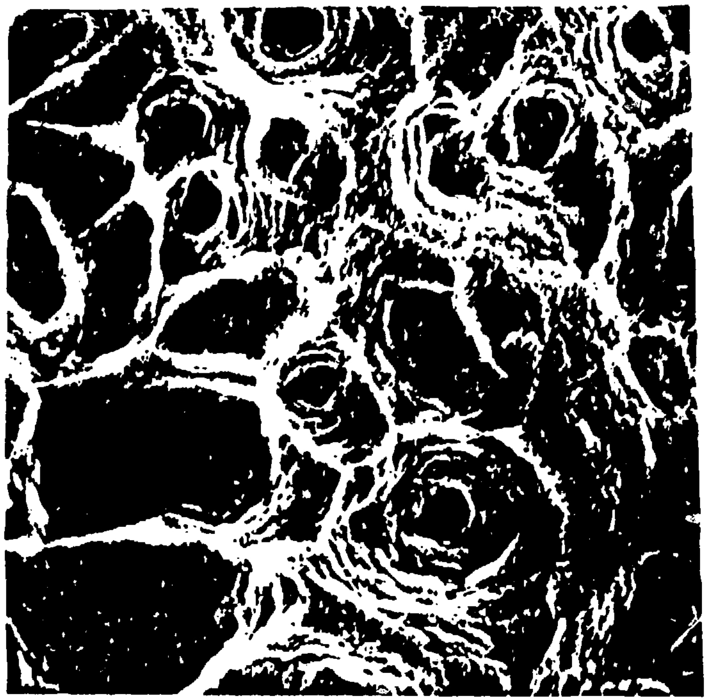
THE FRACTURE SURFACE OF IRRADIATED SPECIMENS RESEMBLES CLEAVAGE OR CHANNEL FRACTURE.

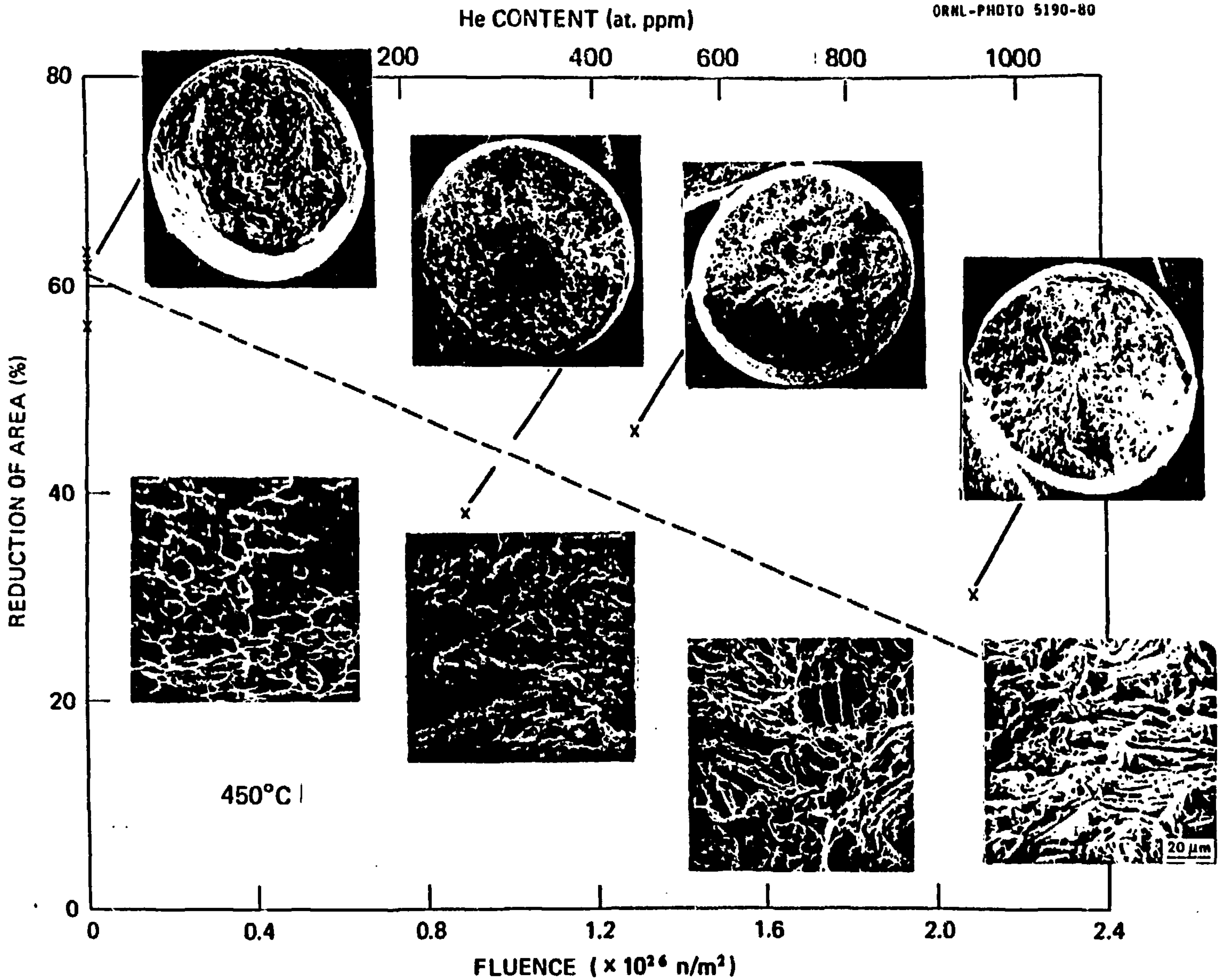


$\phi t = 0$

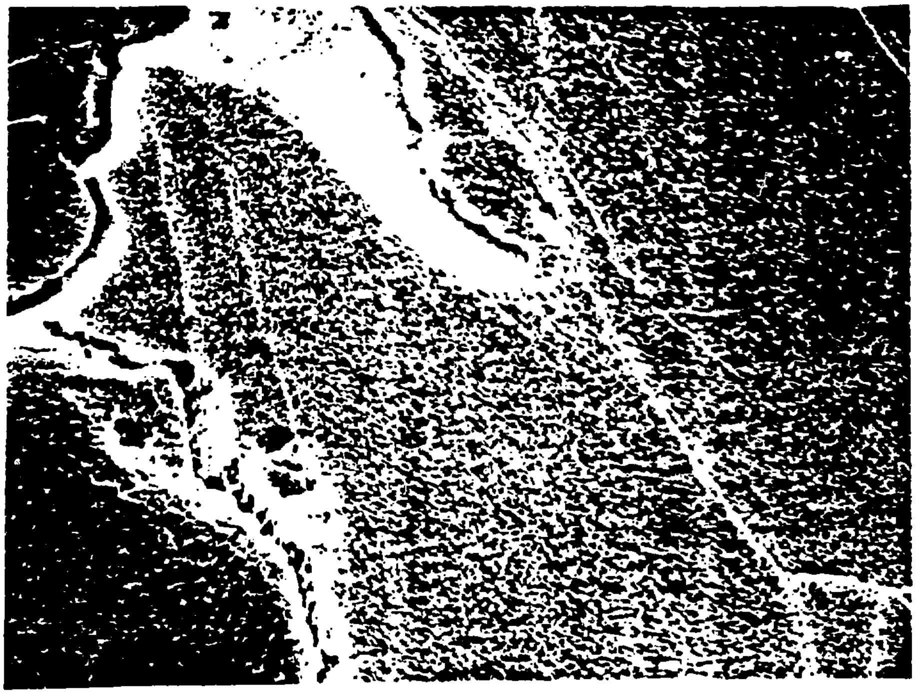
$\phi t = 1.4 \times 10^{26}\ n/m^2$

$\Delta\epsilon_t = 0.5\%$

A new brittle fracture mechanism appears



CRACKS FOLLOW SLIP BANDS RESULTING FROM COLD WORK



POSSIBLE CAUSES:

1. NUCLEATION OF HELIUM BUBBLES ALONG SLIP BANDS.
2. NUCLEATION OF PRECIPITATES ALONG SLIP BANDS.
3. EITHER, FOLLOWED BY LOCALIZED FRACTURE ALONG CLOSELY SPACED SLIP PLANES.

SUMMARY

1. FATIGUE LIFE REDUCED BY FACTOR OF 3-10 AT 430°C, 5-15 dpa.
2. AN ENDURANCE WAS OBSERVED AT $\Delta \varepsilon_t$ = 0.3%.
3. A POWER LAW EQUATION DOES NOT PREDICT FATIGUE IN HFIR IRRADIATED MATERIALS.
4. A LOCALIZED CRYSTALLOGRAPHIC FRACTURE MODE APPEARS.