Helium Bubble Microstructures in Austenitic Stainless Steels and Metal Hydride Materials




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Outline

- Helium Bubbles in Austenitic Stainless Steels:
  - Basic Helium Bubble Microstructures (Tritium-Tricked Material)
    - Typical nucleation sites and bubble distributions
  - Fusion Weld Heat-Affected Zones (Tritium-Tricked Material)
    - Influence of elevated temperature and solidification stresses
  - Irradiated and Welded Type 304 Stainless Steel
    - Irradiation damage, elevated temperature and solidification stresses
  - Retired Tritium Reservoir
    - Bubbles in the inner wall region following burst testing
- Helium Bubbles in Lanthanum-Nickel-Aluminum Metal Hydrides
  - $LaNi_{4.7}Al_{0.3}$

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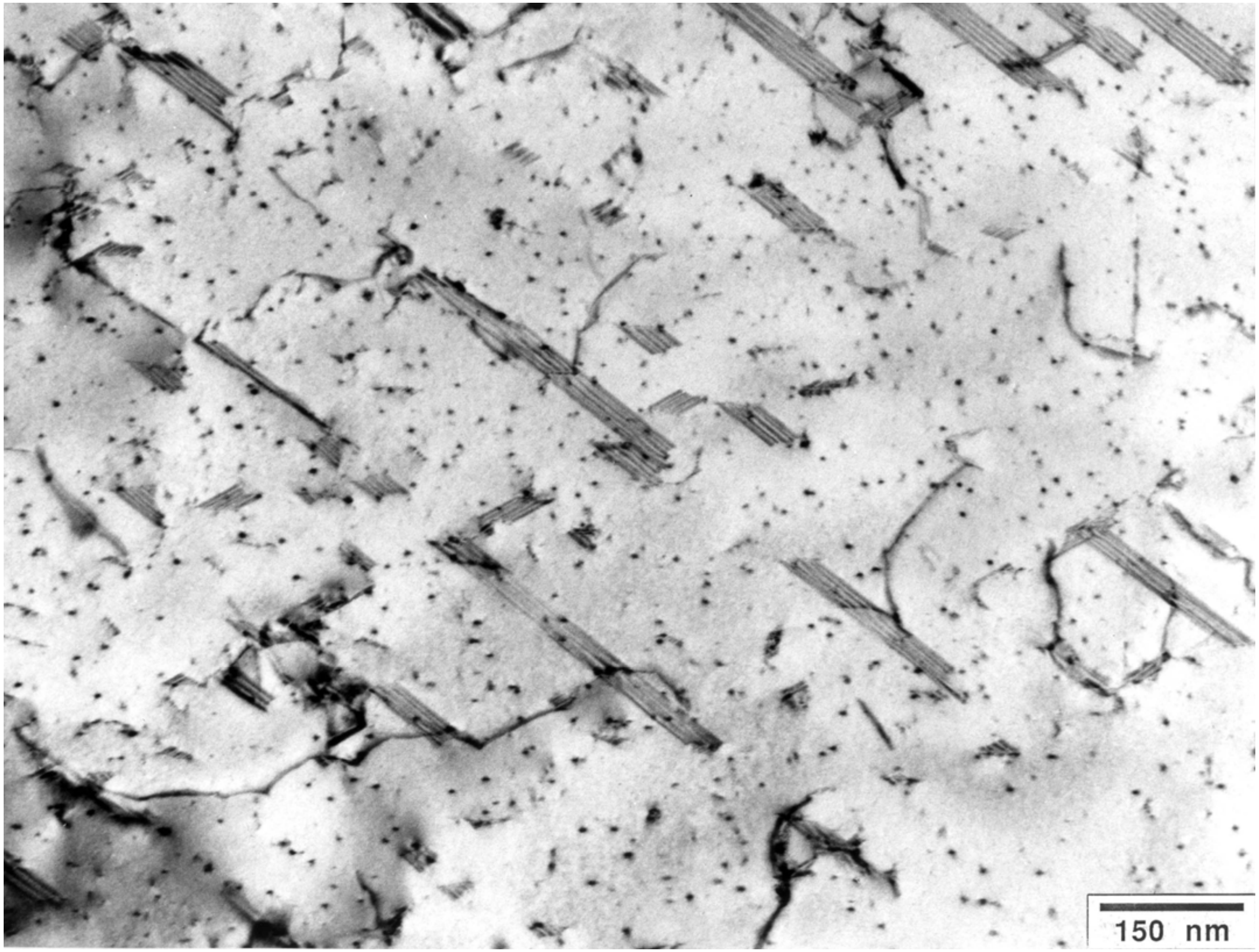
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –150 appm He



Strain contrast from bubbles in the austenite matrix

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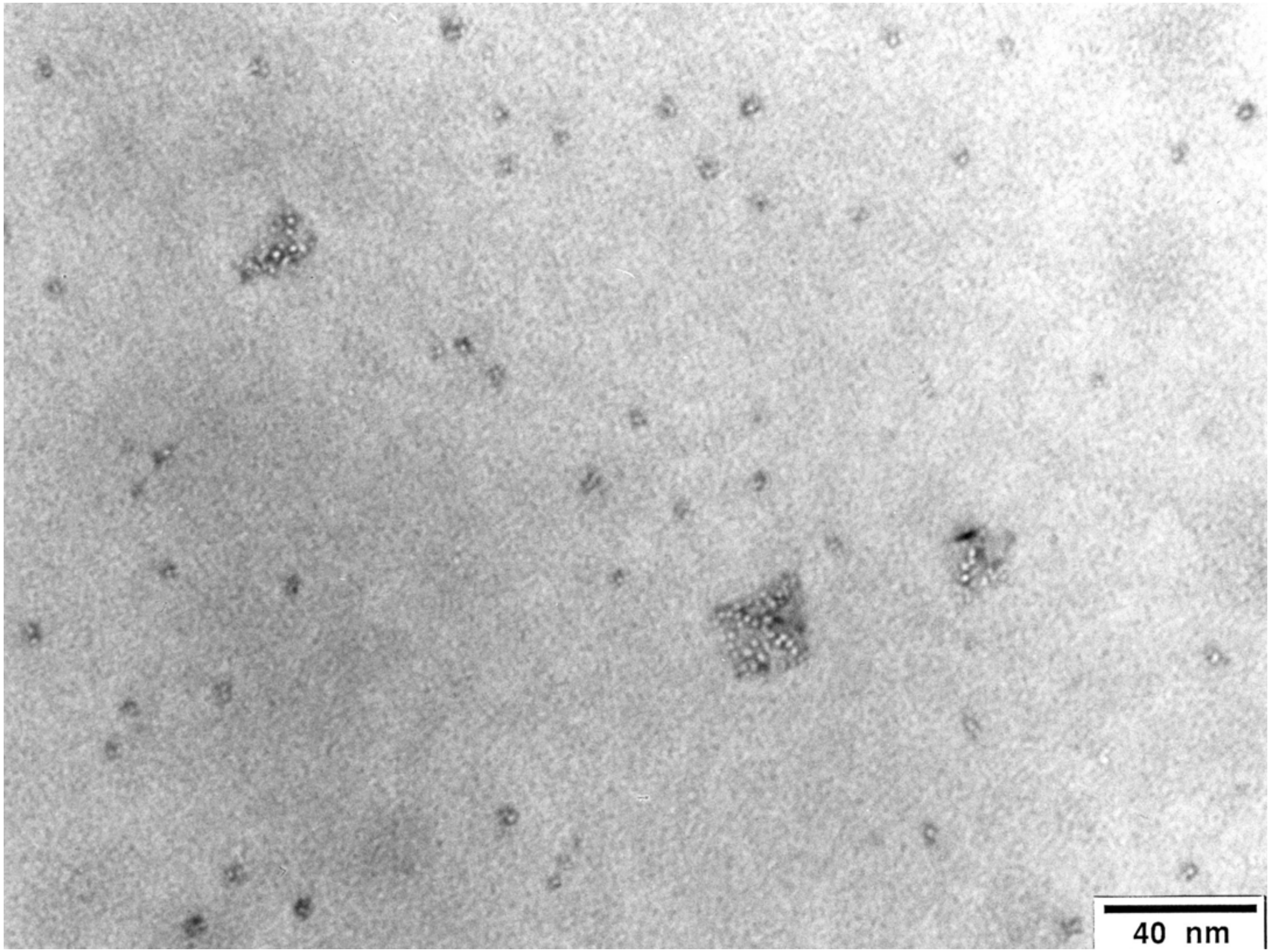
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –150 appm He



“Homogeneously” nucleated bubbles and bubbles on dislocations

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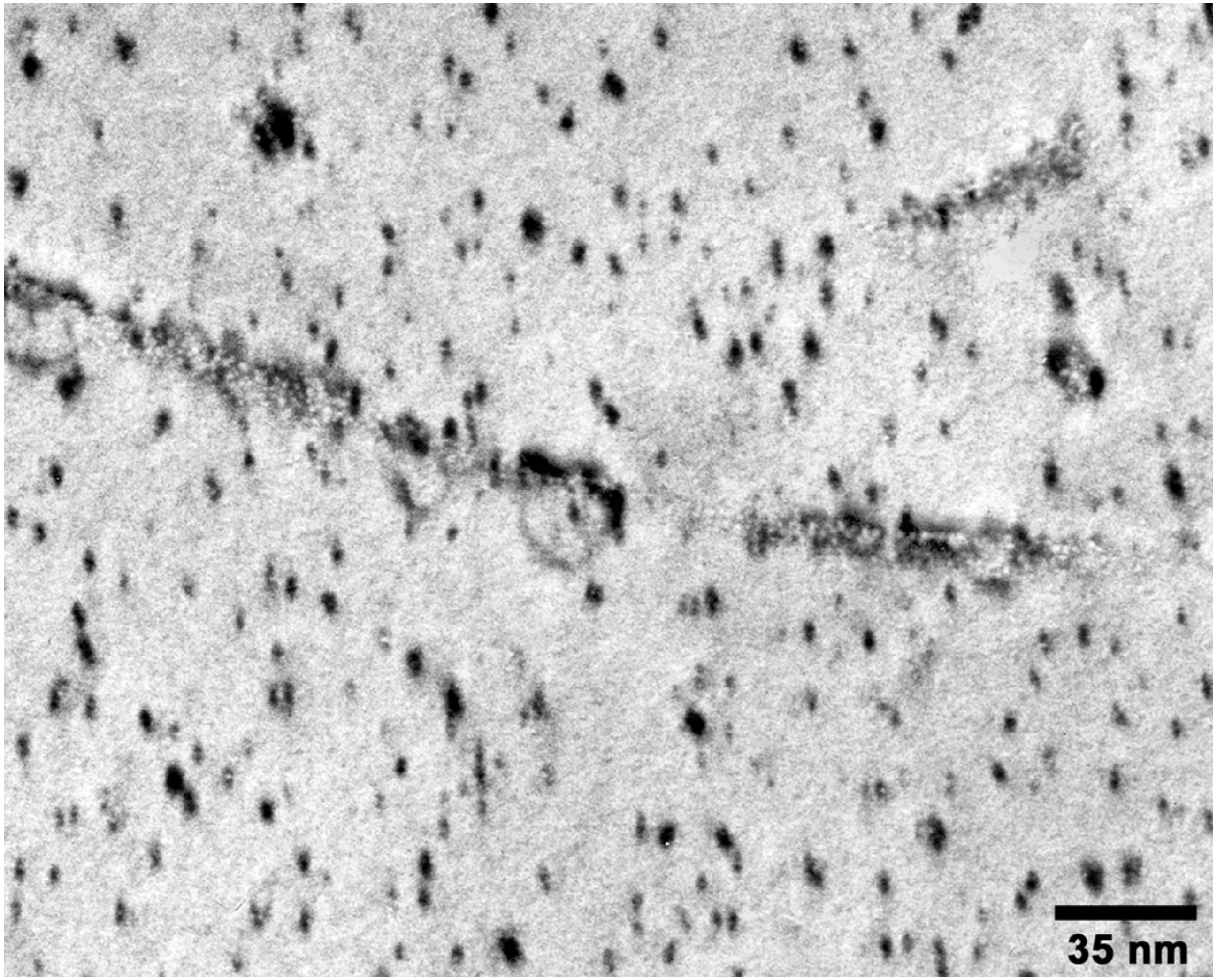
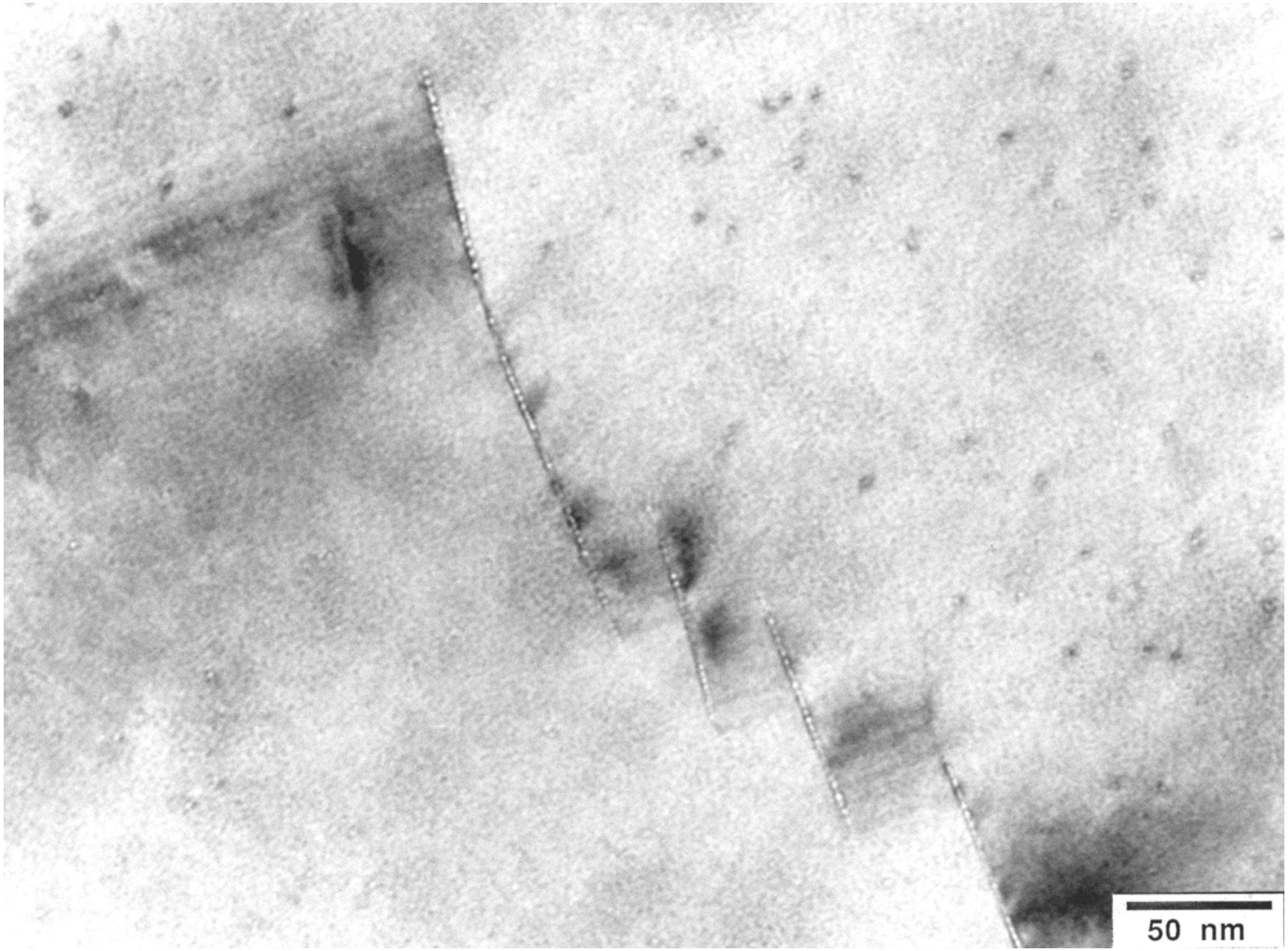
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –390 appm He



Large number of bubbles on dislocations

Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –150 appm He



Bubbles on incoherent twin boundaries

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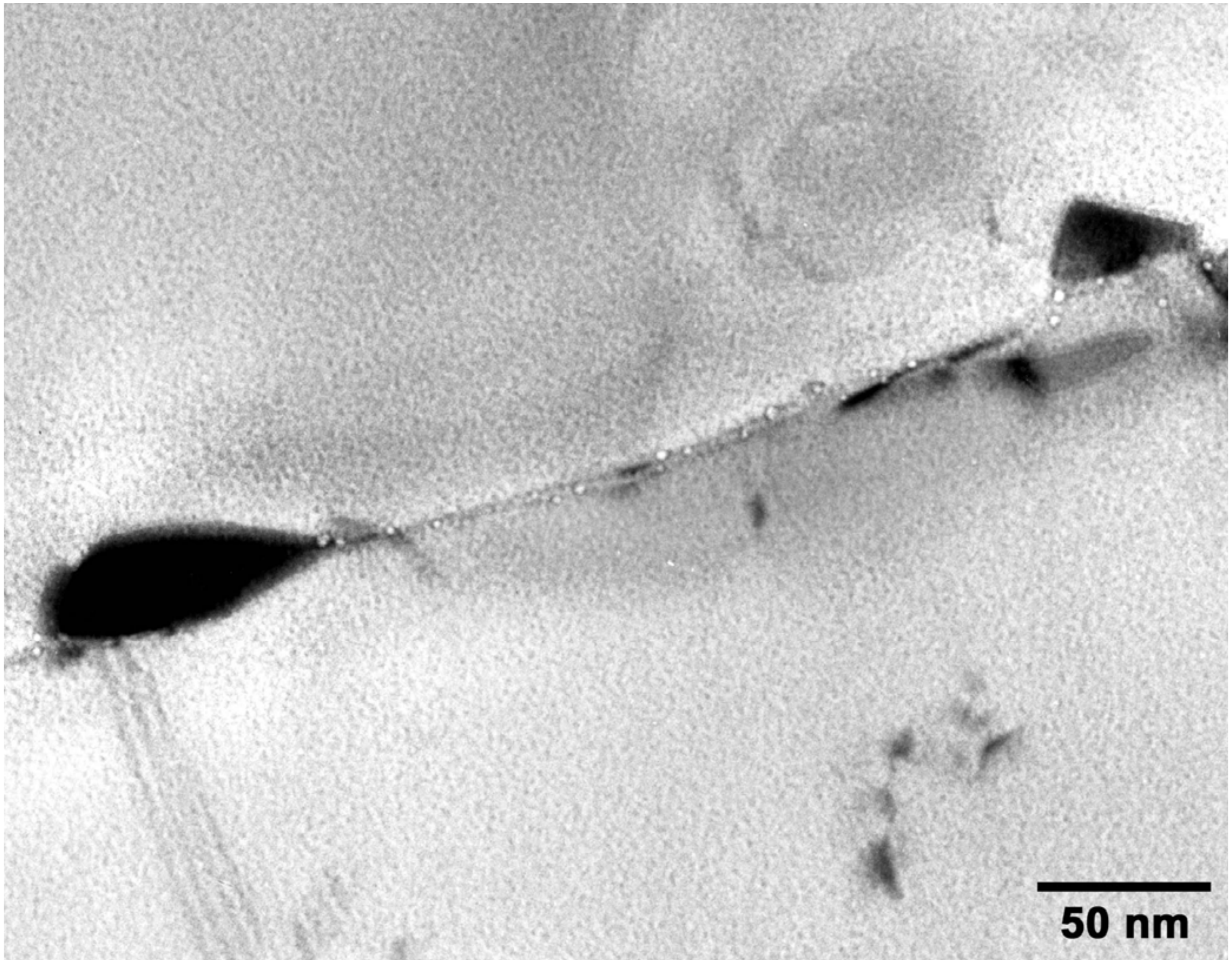
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –150 appm He



Bubbles on a high angle grain boundary and at carbide/matrix interfaces

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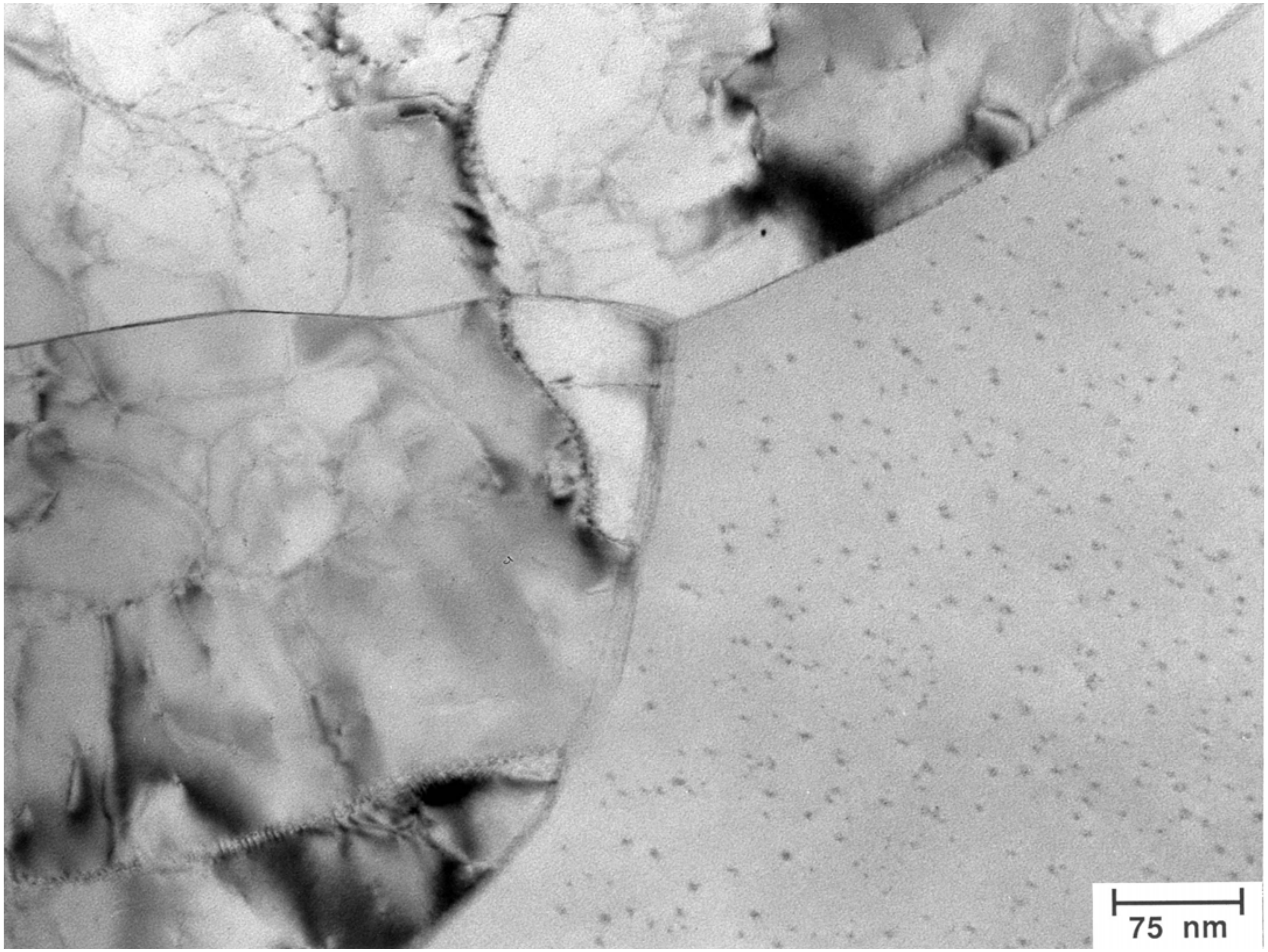
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –150 appm He



Bubbles in a recrystallized grain and bubble-free zone at the grain boundary

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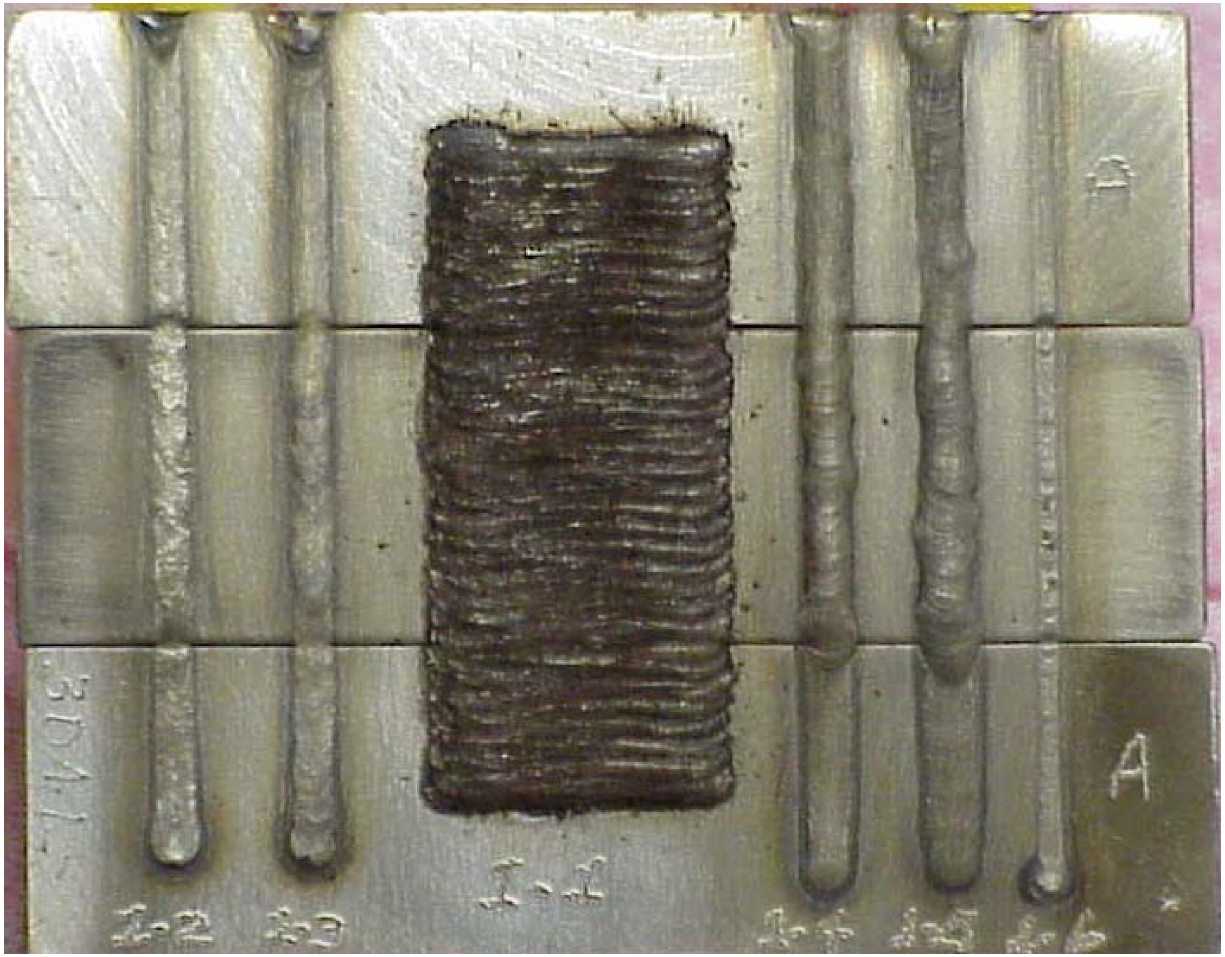
Helium Bubbles in Fusion Weld Heat –Affected Zones



Low heat input (~25 kJ/in^2) GMAW overlay (center) and autogenous GTAW stringer beads

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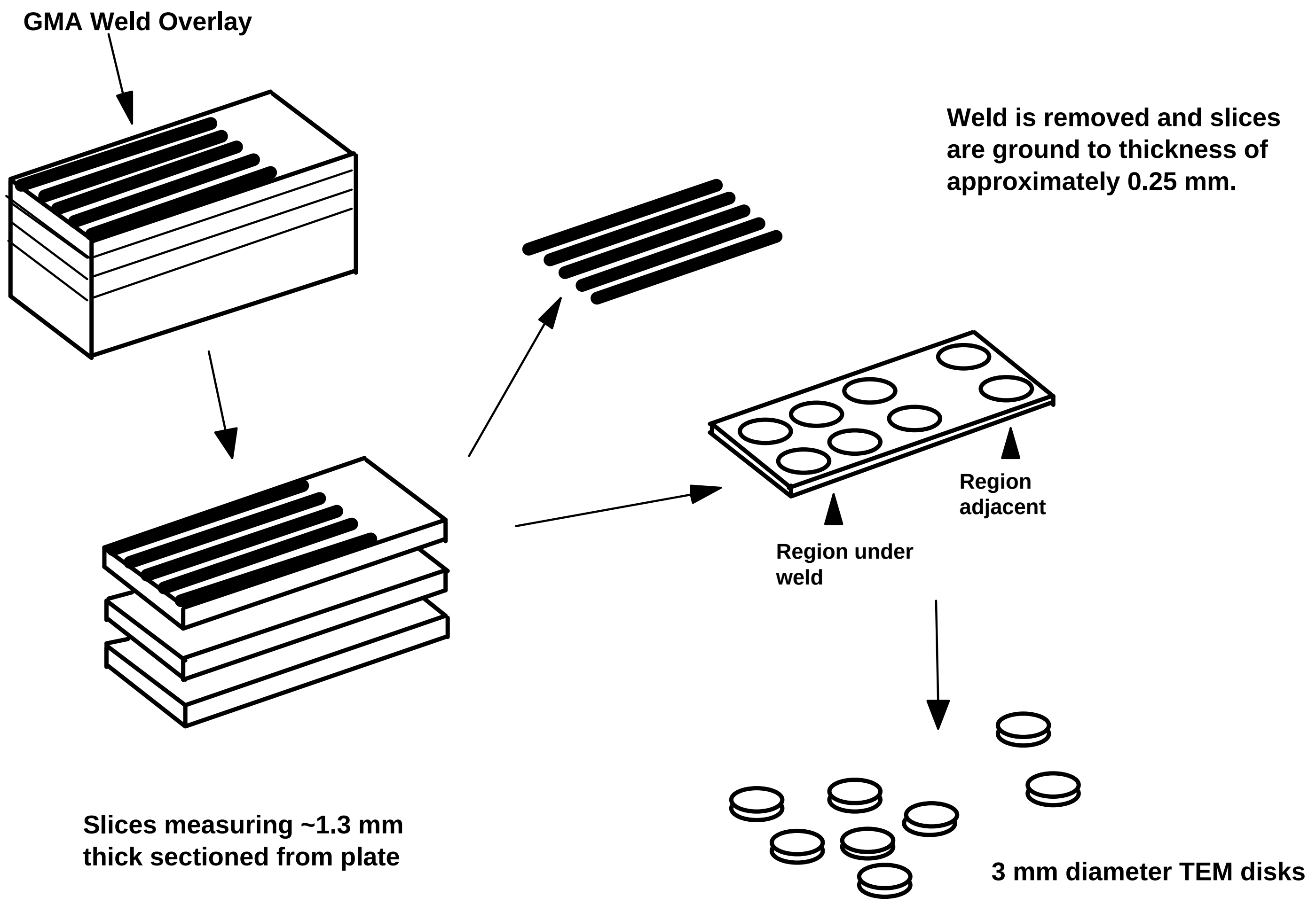
Helium Bubbles in Fusion Weld Heat –Affected Zones



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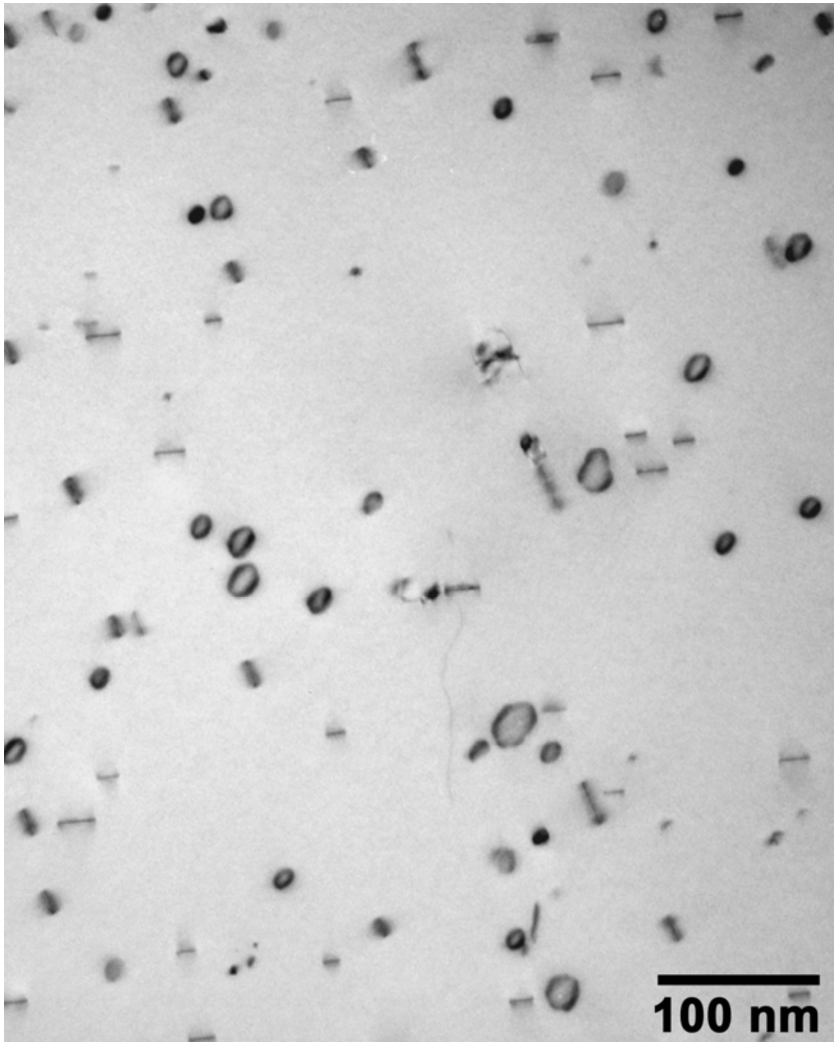
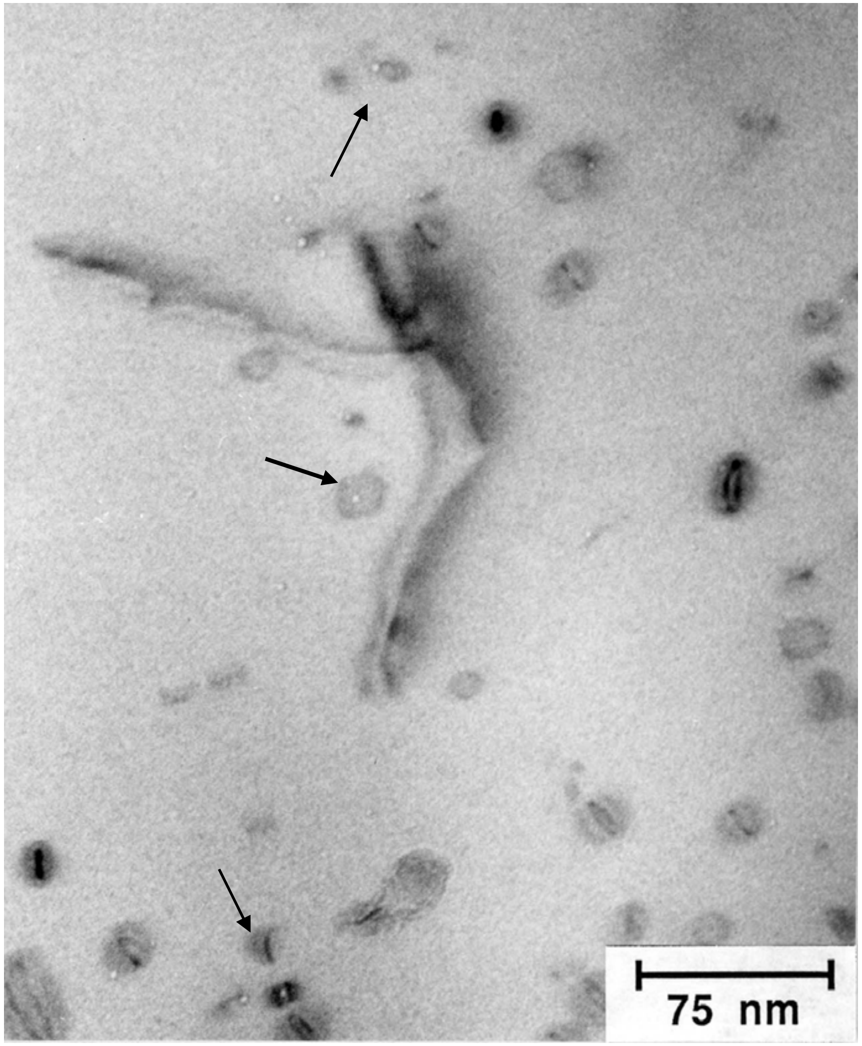
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He





Dislocation loops (and bubbles) in the austenite matrix – base material

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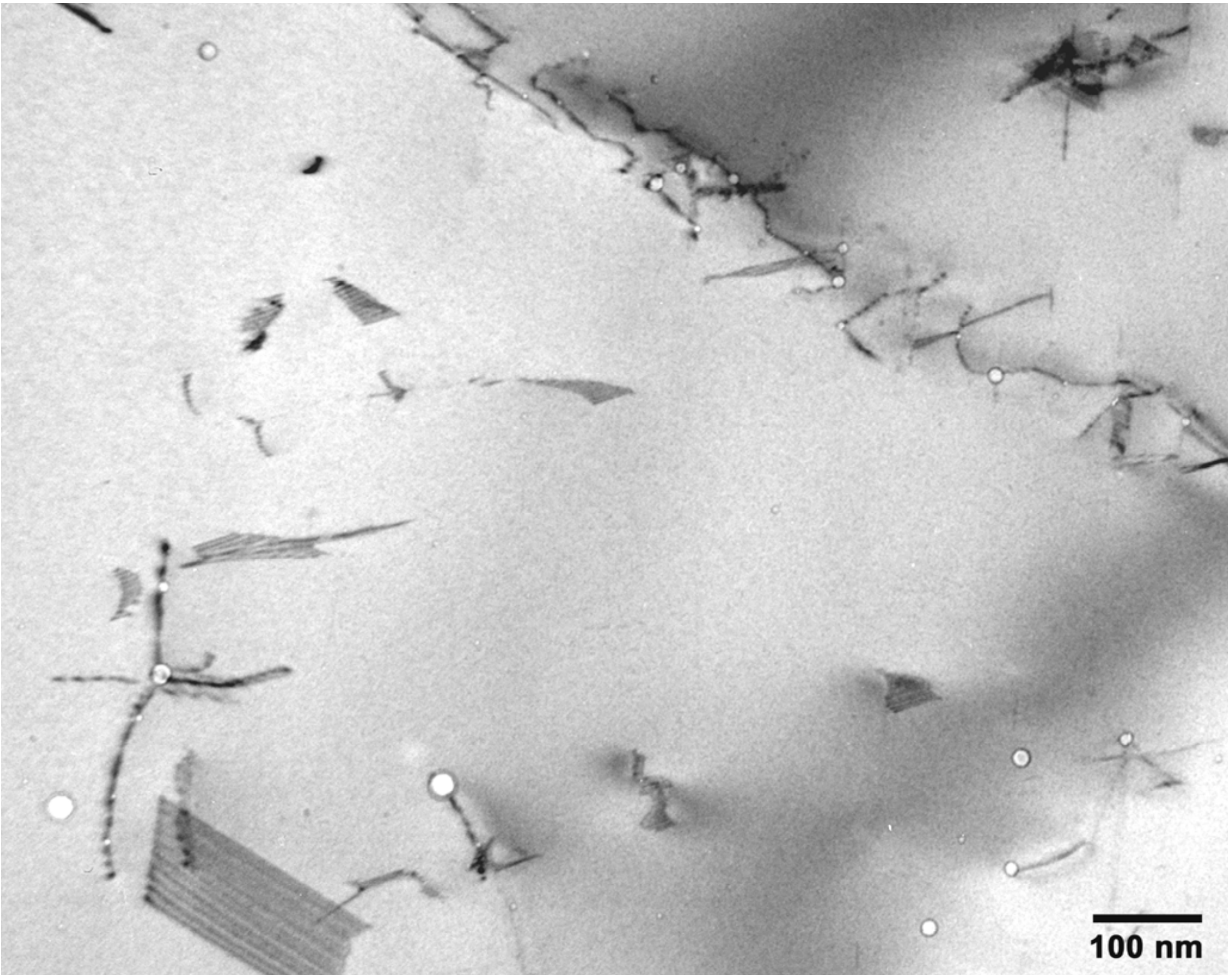
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He



Helium bubble microstructure in HAZ at 0.5 mm beneath the GMAW overlay

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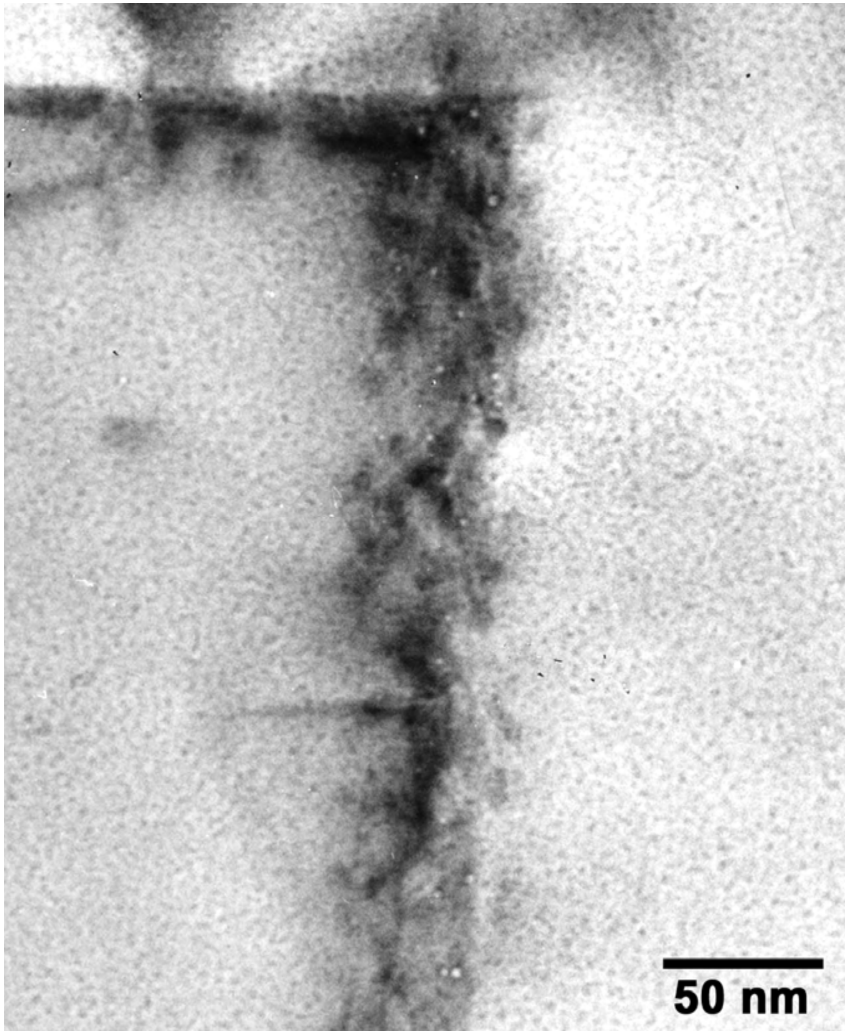
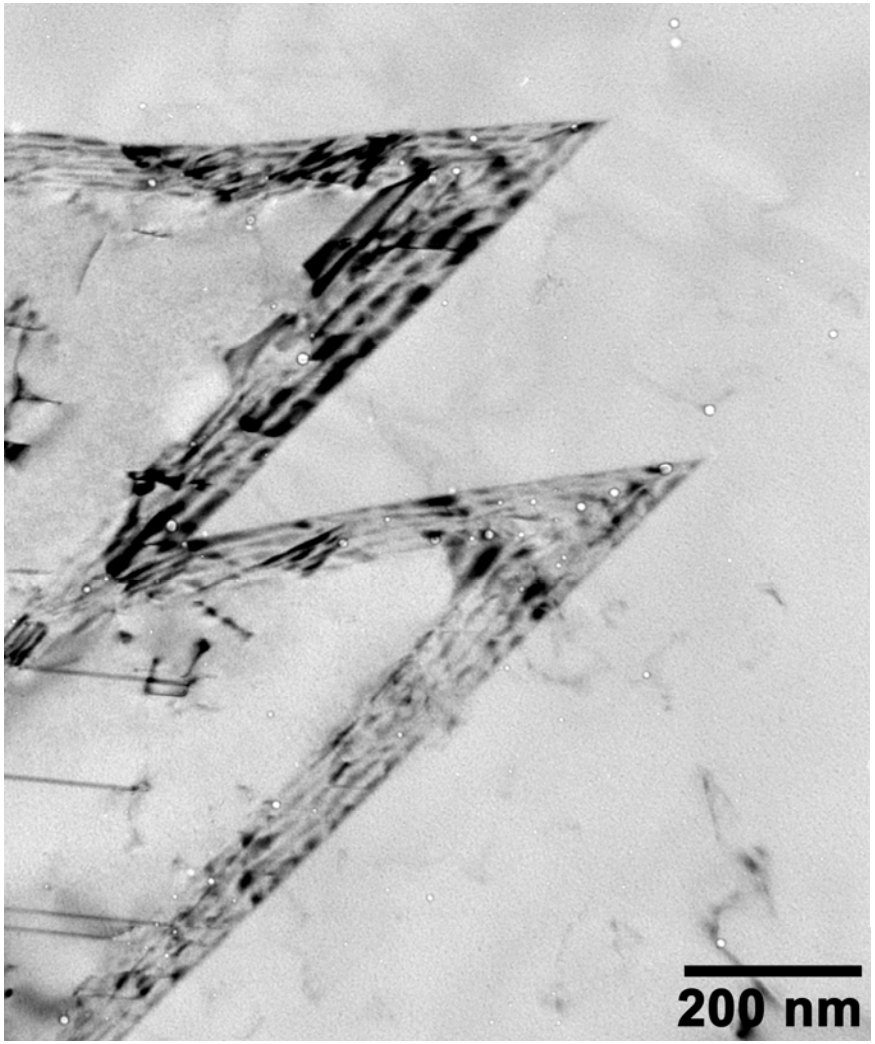
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He





Bubbles on incoherent twin boundaries – base metal and HAZ

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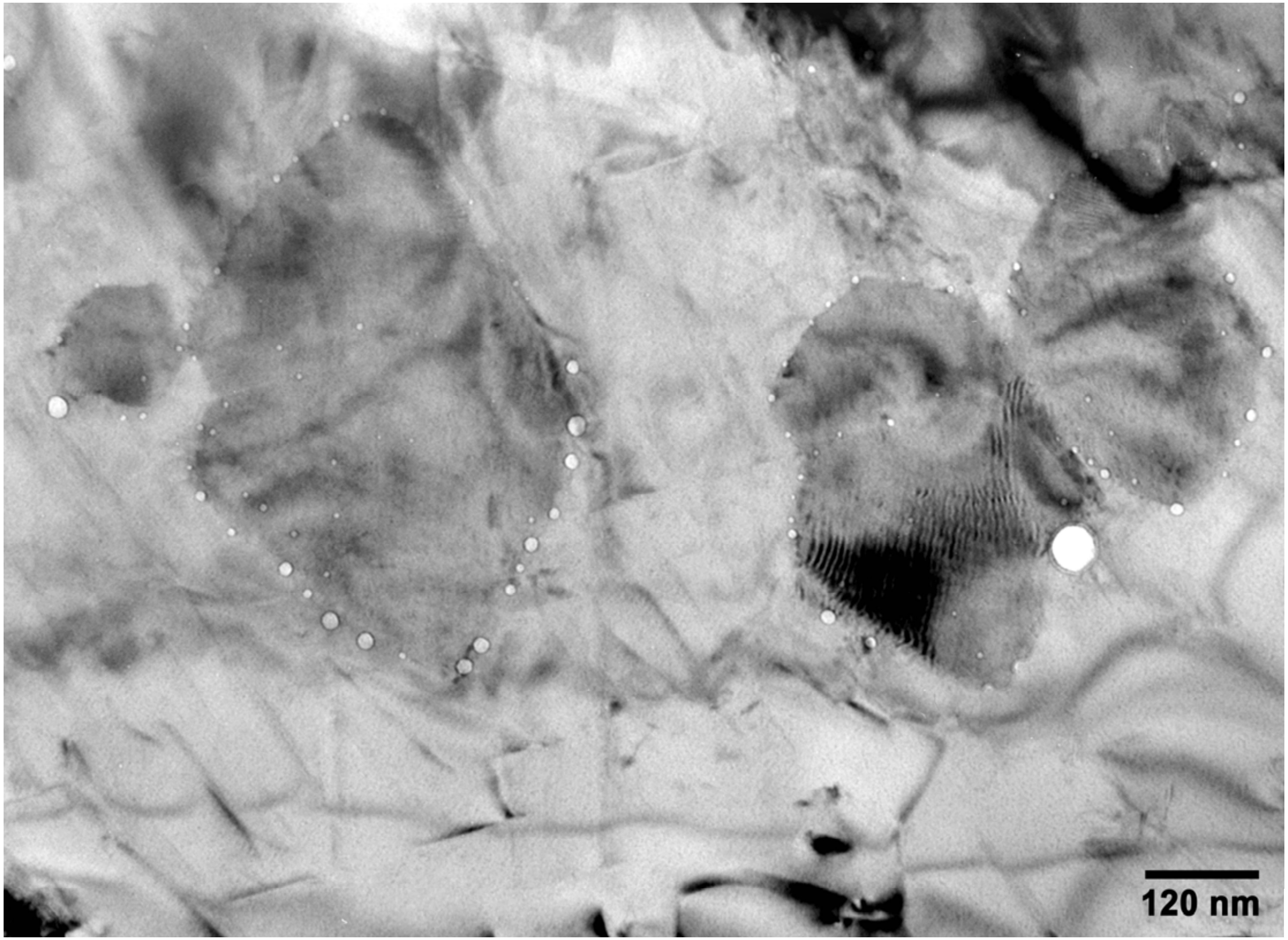
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He



Bubbles on carbides in the HAZ – 0.5 mm beneath the GMAW overlay

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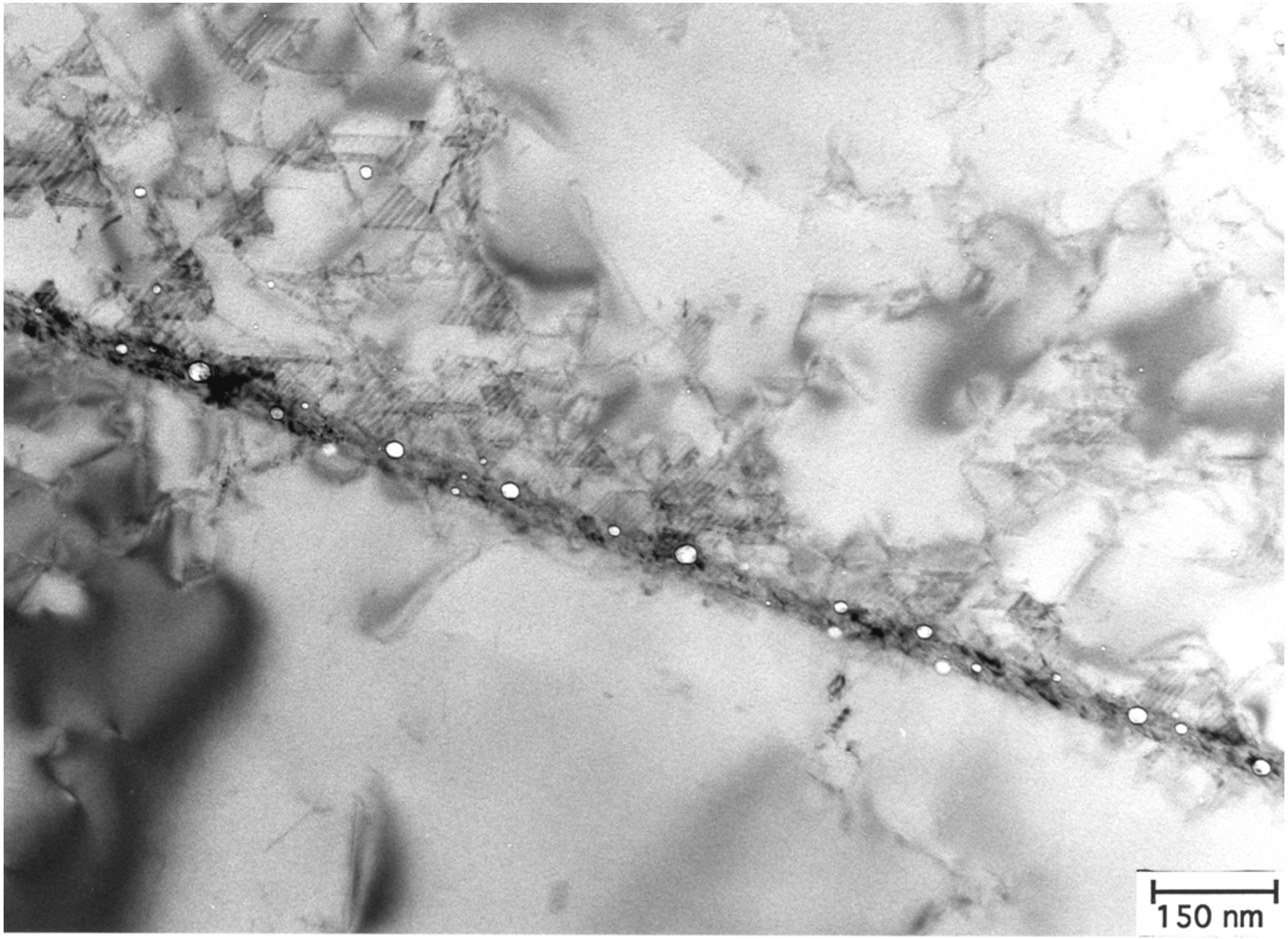
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He



Bubbles on a high angle grain boundary in the HAZ – 0.5 mm beneath the GMAW overlay

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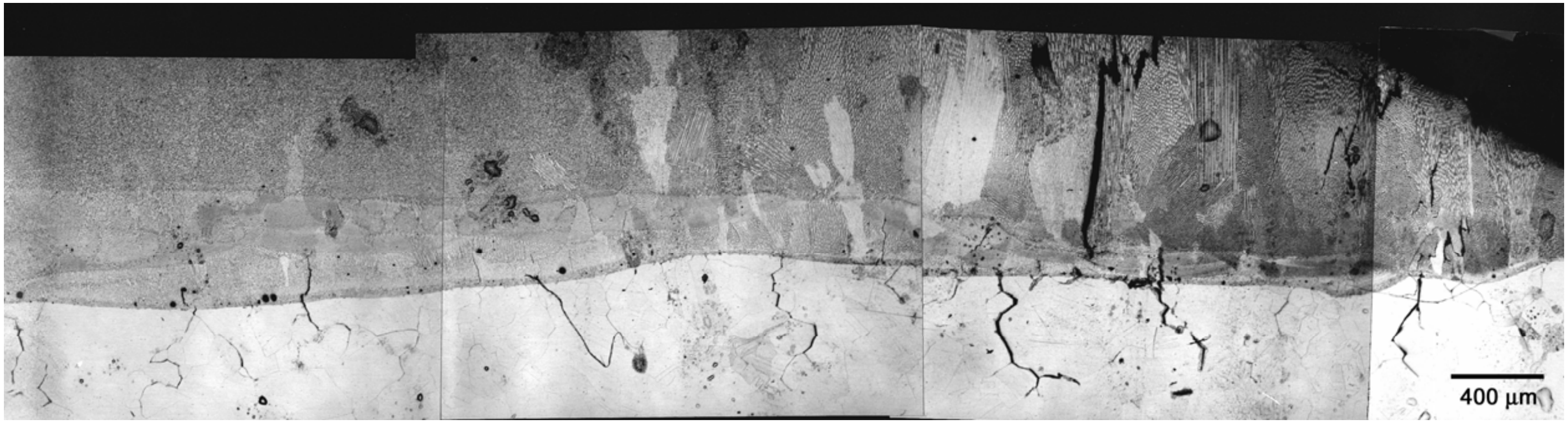
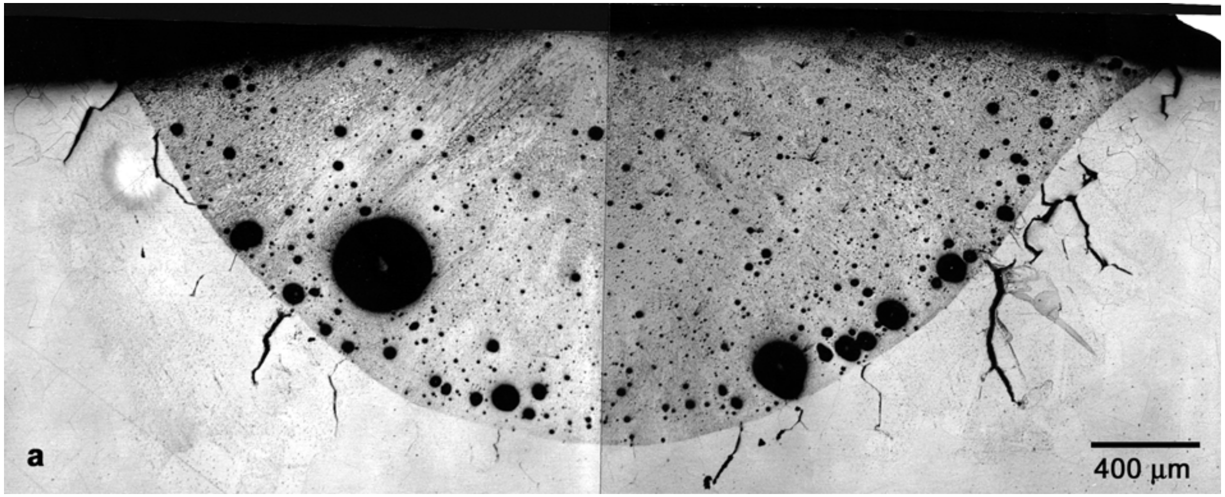
Helium Bubbles in Fusion Weld Heat–Affected Zones – 147 appm He





Bubble growth and coalescence can lead to He embrittlement cracking in HAZs

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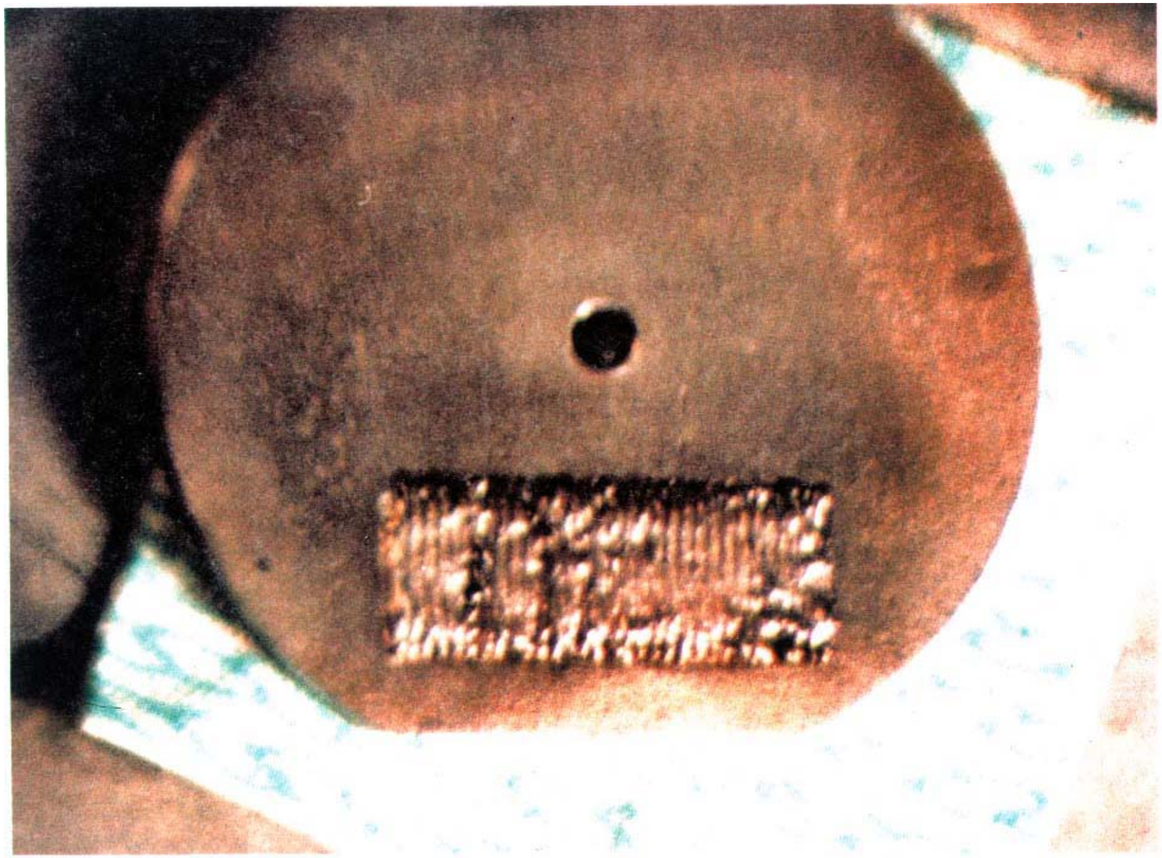
Helium Bubbles in Irradiated and Welded 304 Stainless Steel

Overlay Weld on a Disc Removed from an SRS Reactor Tank Wall



3.0 inches

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Helium Bubbles in Irradiated and Welded 304 Stainless Steel

- Type 304 stainless steel from tank wall of a retired reactor at SRS.
  - 1.3 cm thick plate
  - Thermal and fast neutron fluences(energies > 0.1 MeV):
    - 2.6×10^{21} n/cm^2 – inside surface
    - 7.6×10^{20} n/cm^2 - outside surface
  - He^4 concentration 10.4 appm (inside) 5.0 appm (outside)
  - GMAW overlay
    - 308L filler wire
    - Weld penetration 0.08 mm into base metal

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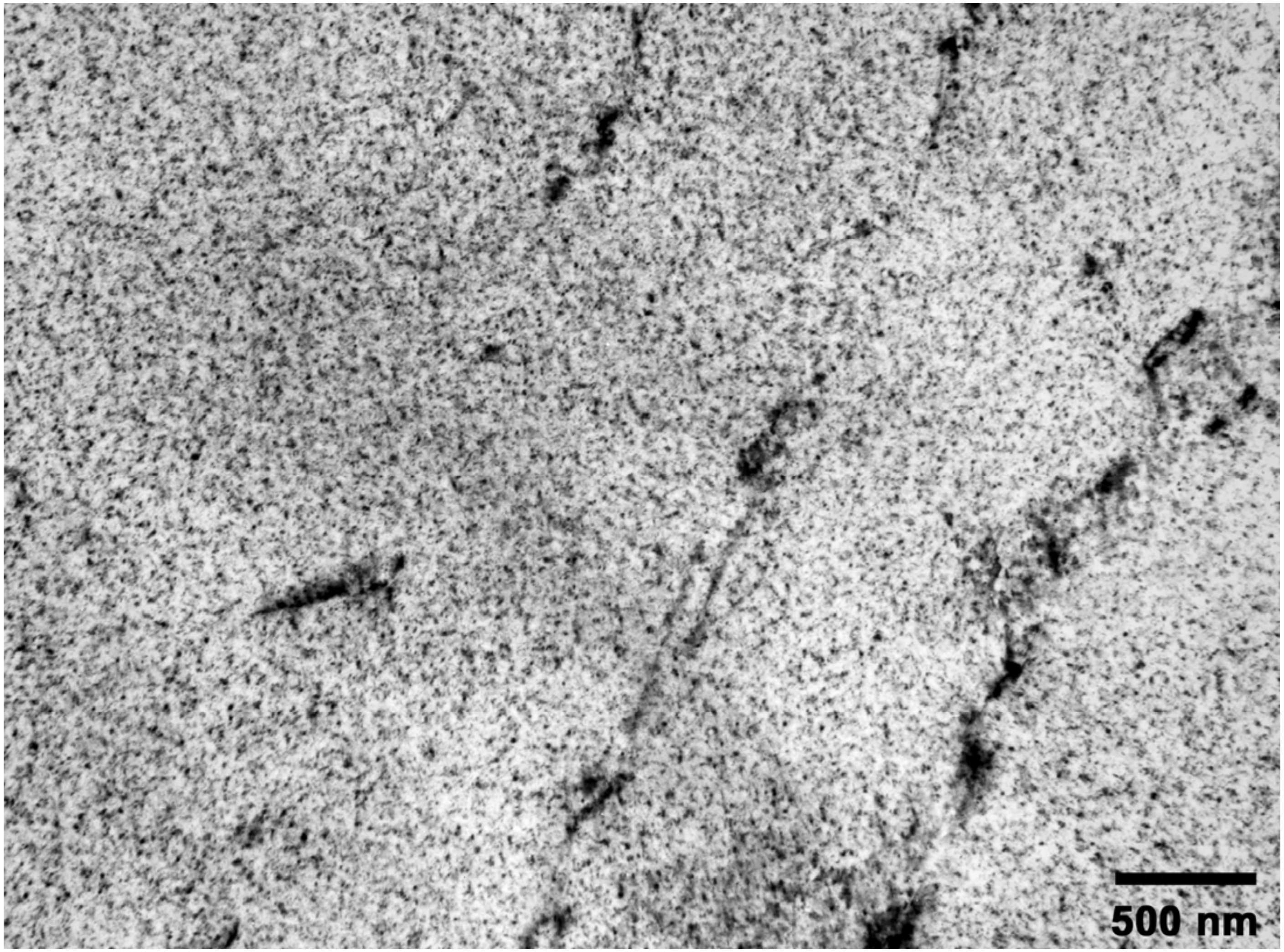
Helium Bubbles in Irradiated and Welded 304 Stainless Steel – 10 appm He



Radiation damage and dislocations in the base material

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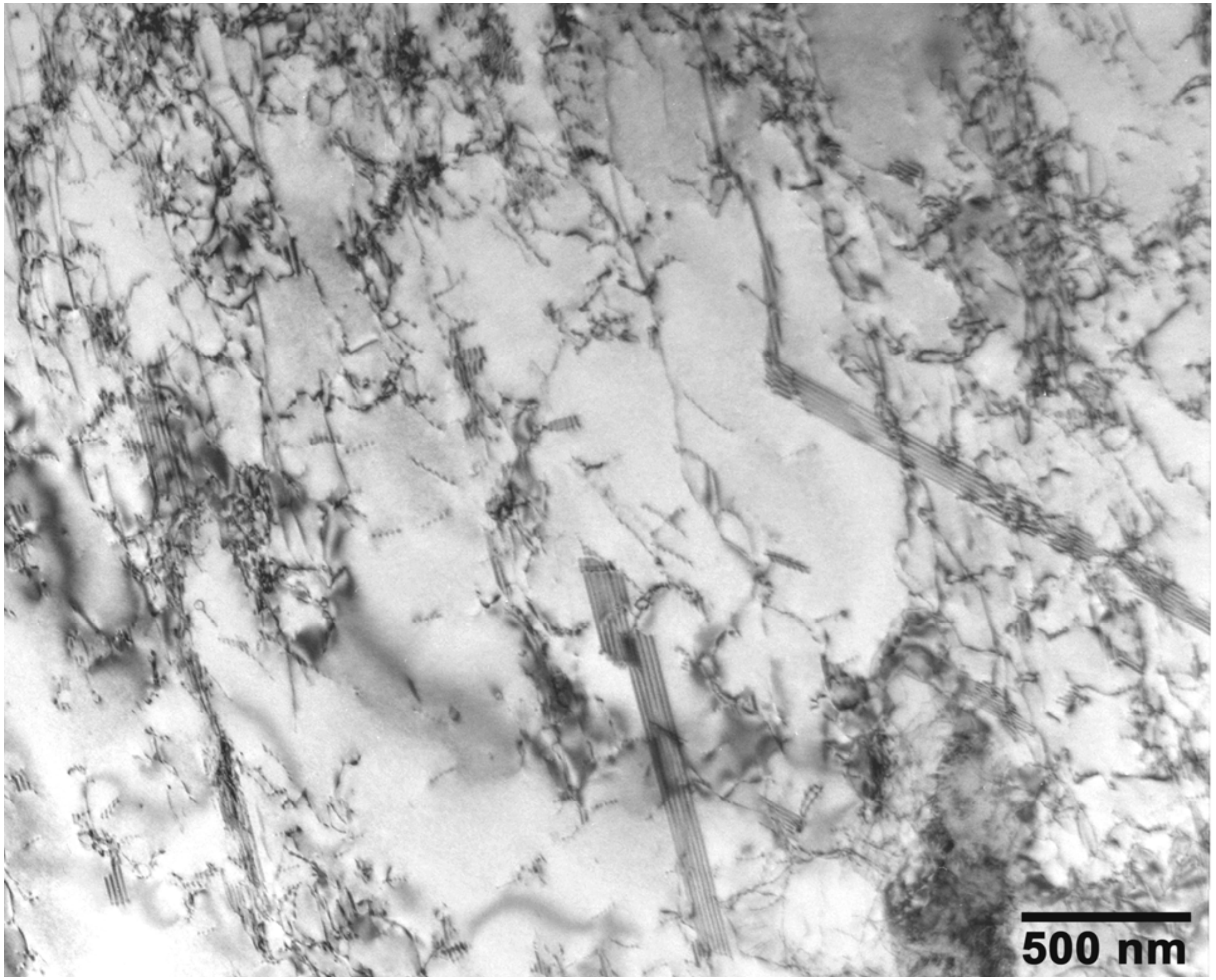
Helium Bubbles in Irradiated and Welded 304 Stainless Steel – 10 appm He



Dislocation substructure in GMAW HAZ

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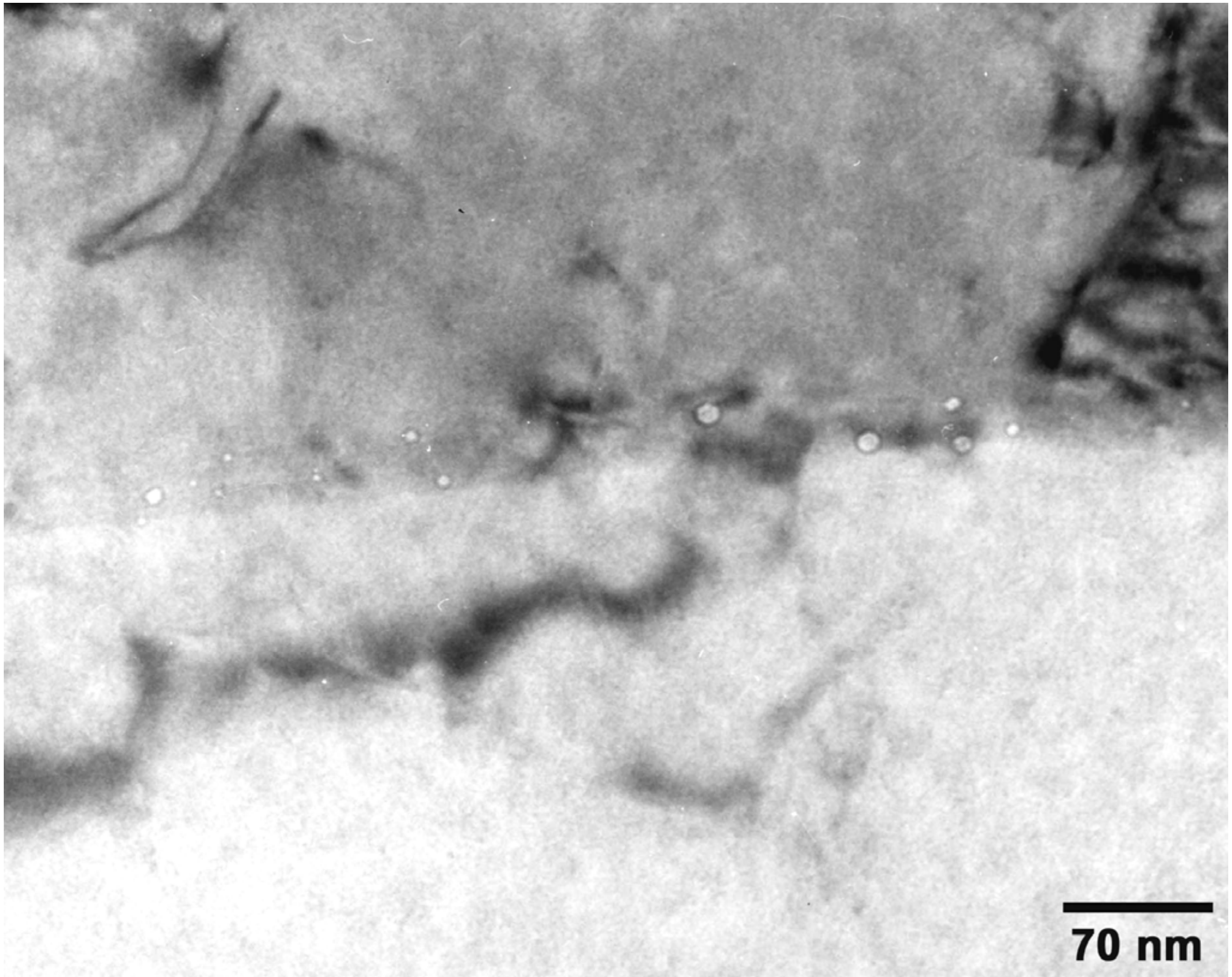
Helium Bubbles in Irradiated and Welded 304 Stainless Steel – 10 appm He



Large helium bubbles in the GMAW HAZ

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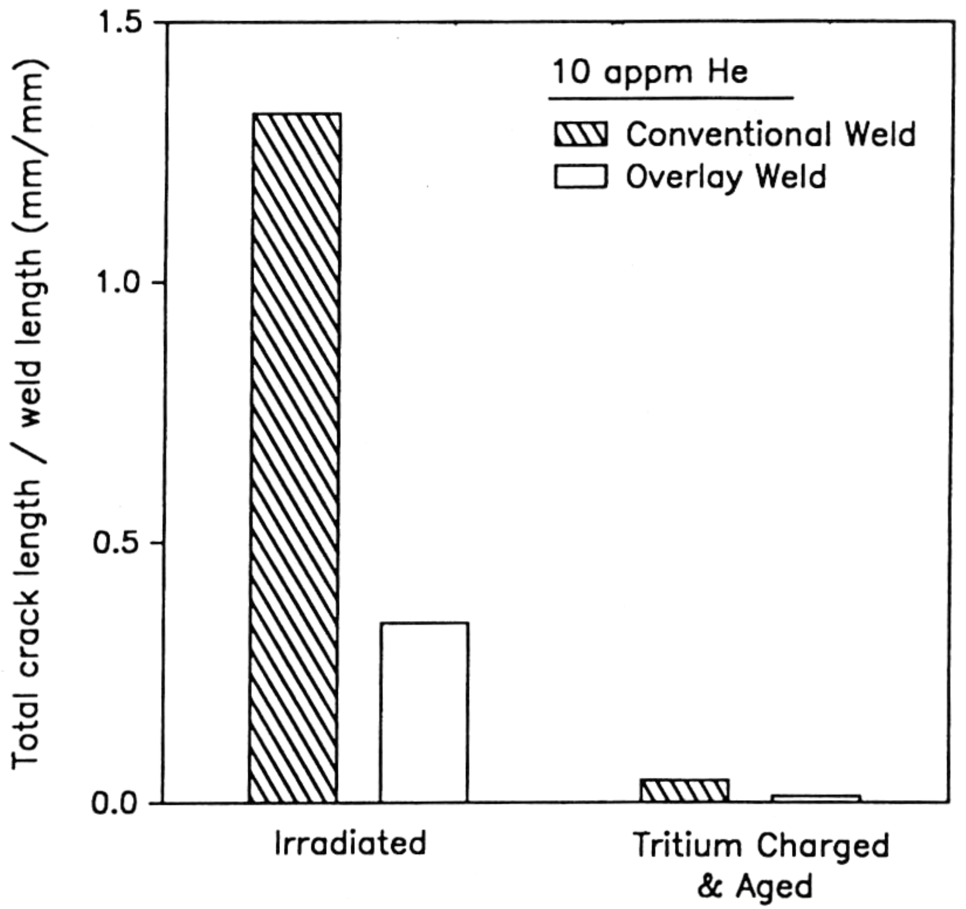
Helium Bubbles in Irradiated and Welded 304 Stainless Steel – 10 appm He



~30x more cracking seen in irradiated material compared to tritium-tricked (at the same He level)

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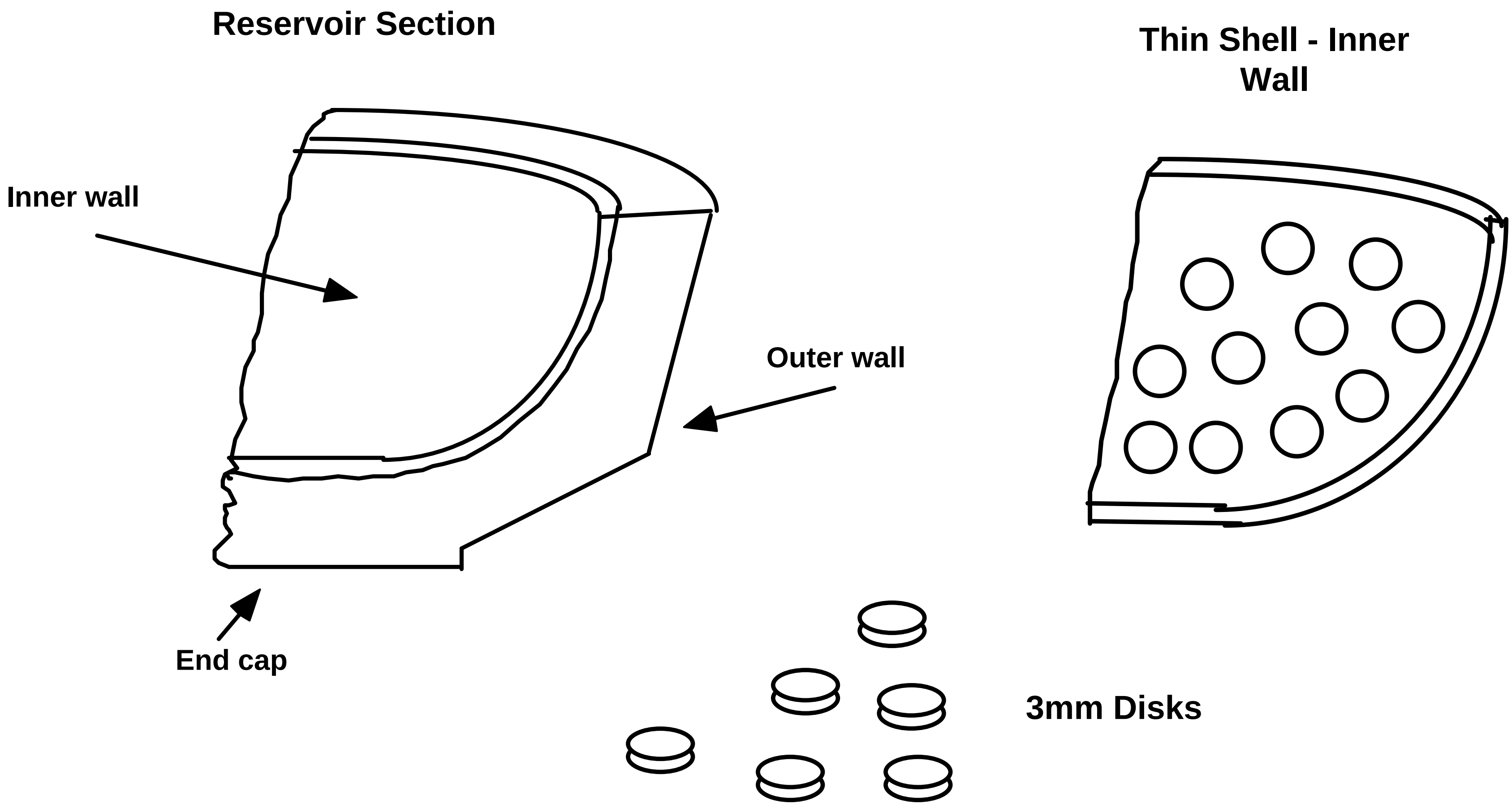
Helium Bubbles in a Retired Tritium Reservoir -~375 appm He (ave.)



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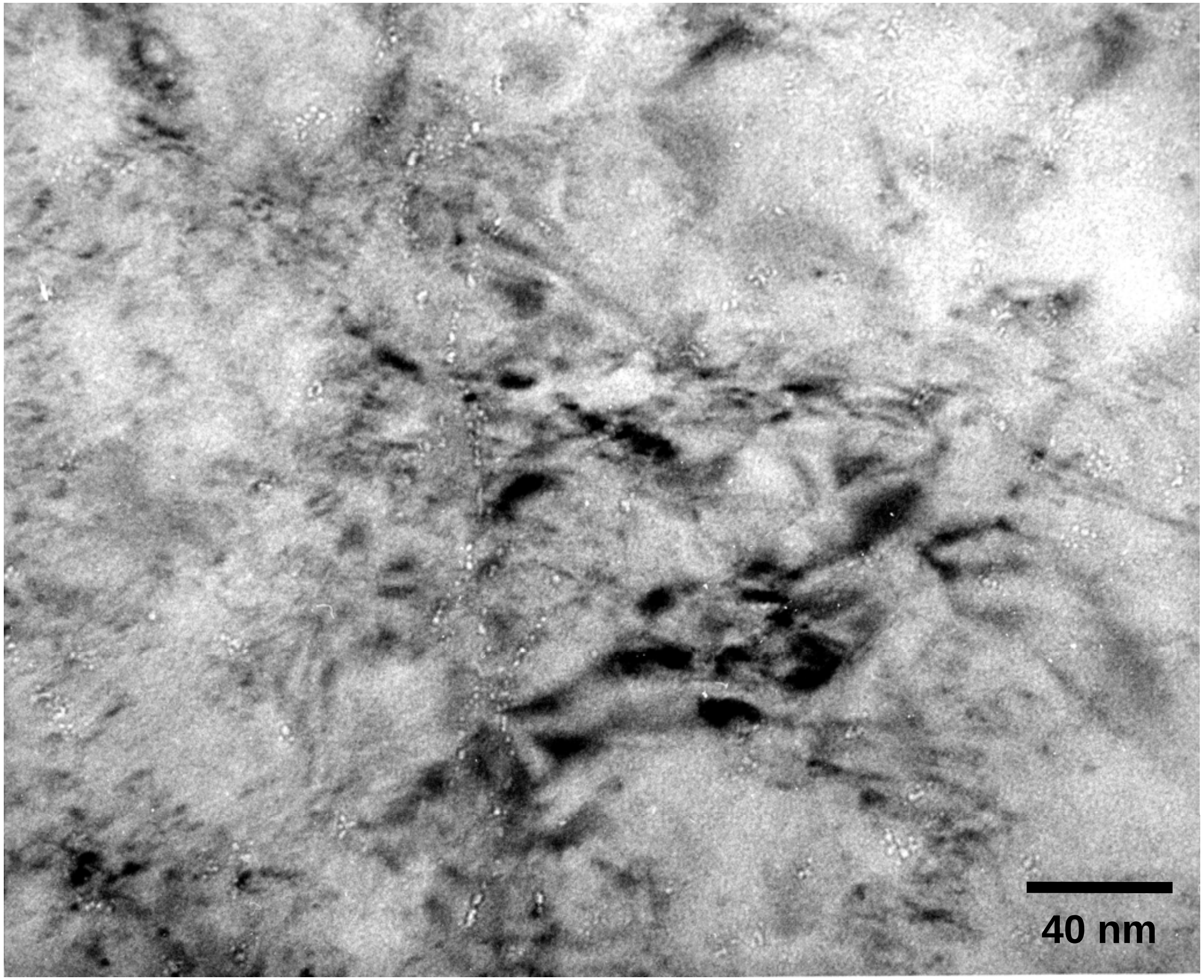
Helium Bubbles in a Retired Tritium Reservoir -~375 appm He (ave.)



Helium bubbles on dislocations and “clusters” of bubbles visible in the matrix

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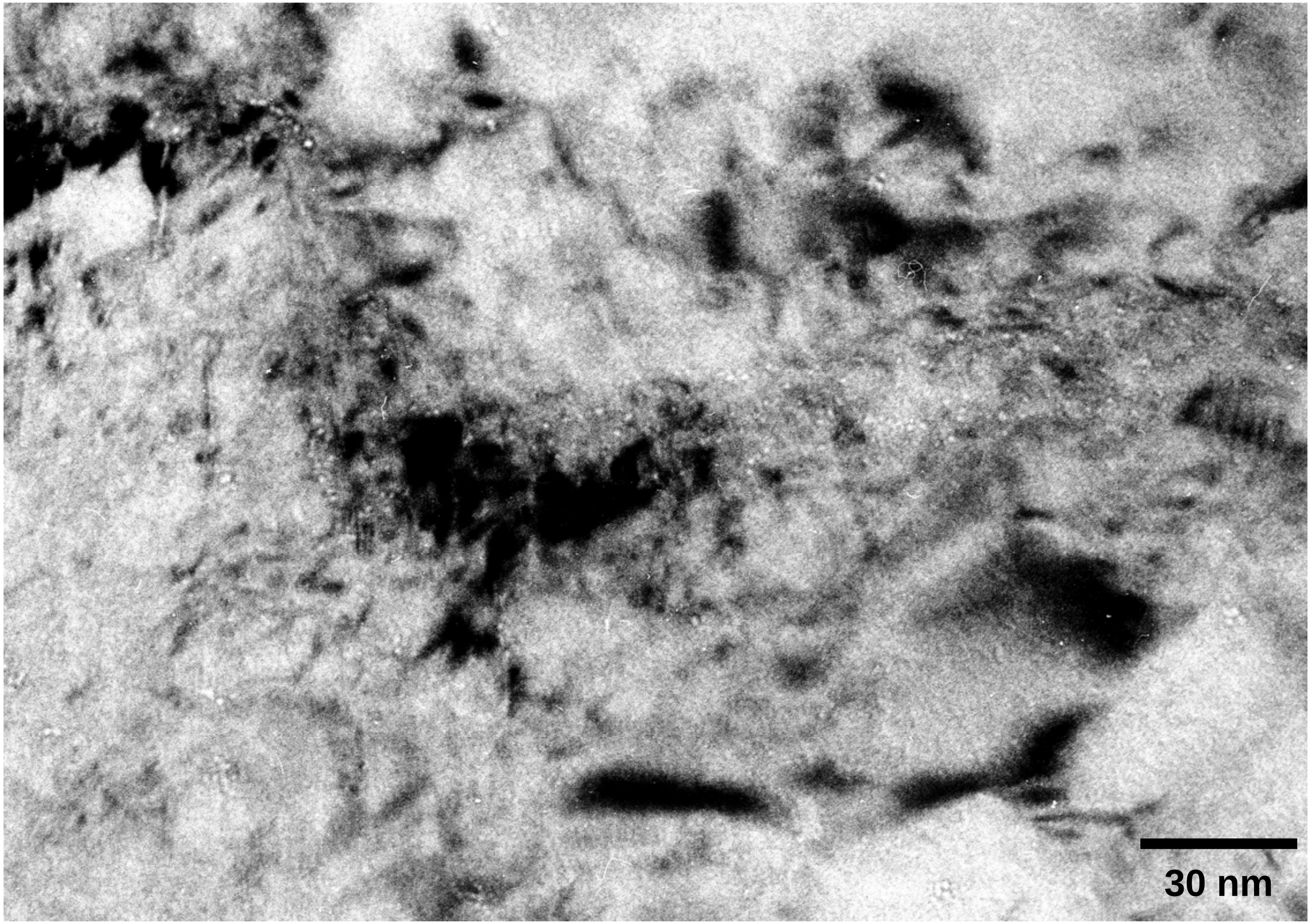
Helium Bubbles in a Retired Tritium Reservoir -~375 appm He (ave.)



He bubbles on an incoherent twin boundary

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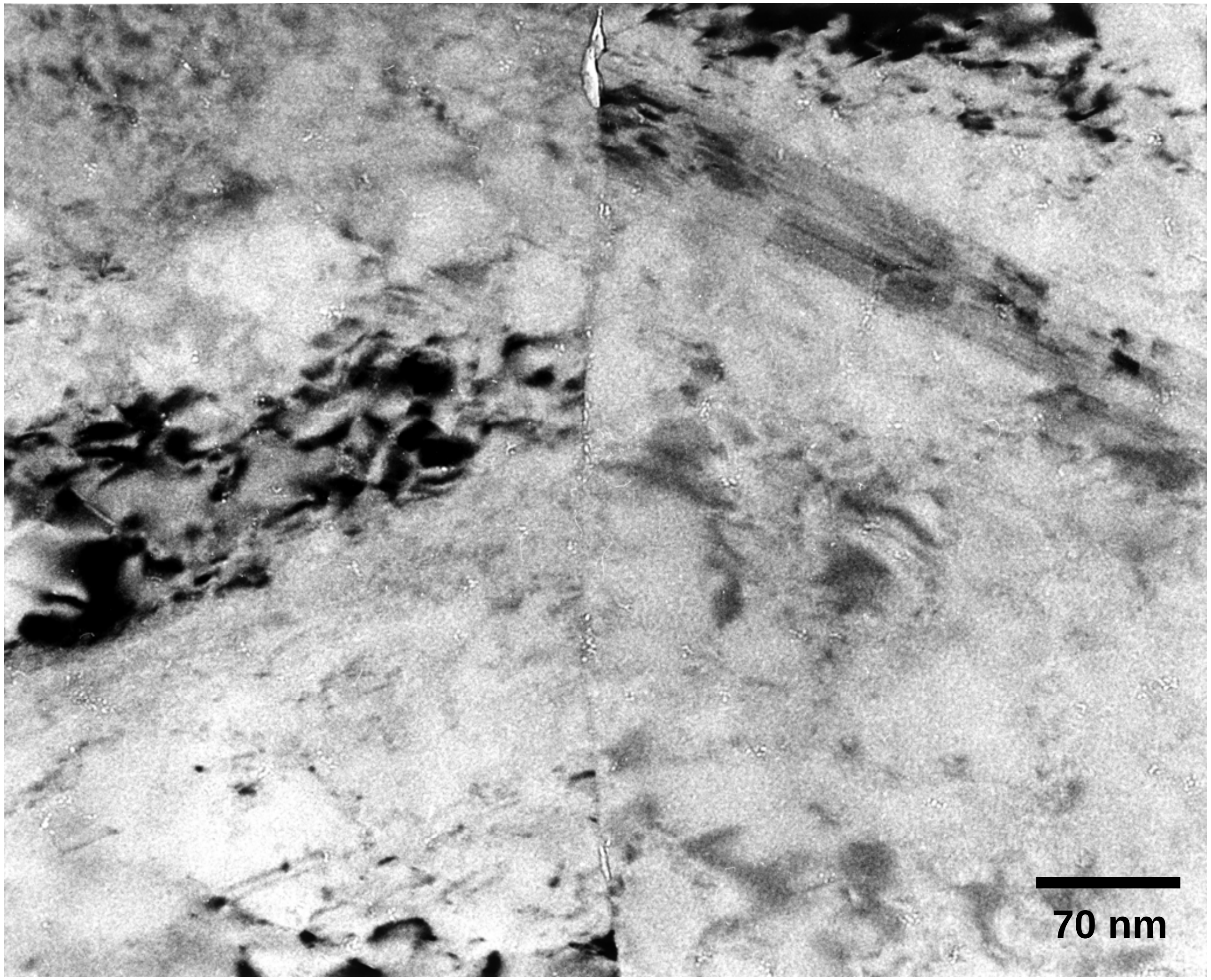
Helium Bubbles in a Retired Tritium Reservoir -~375 appm He (ave.)

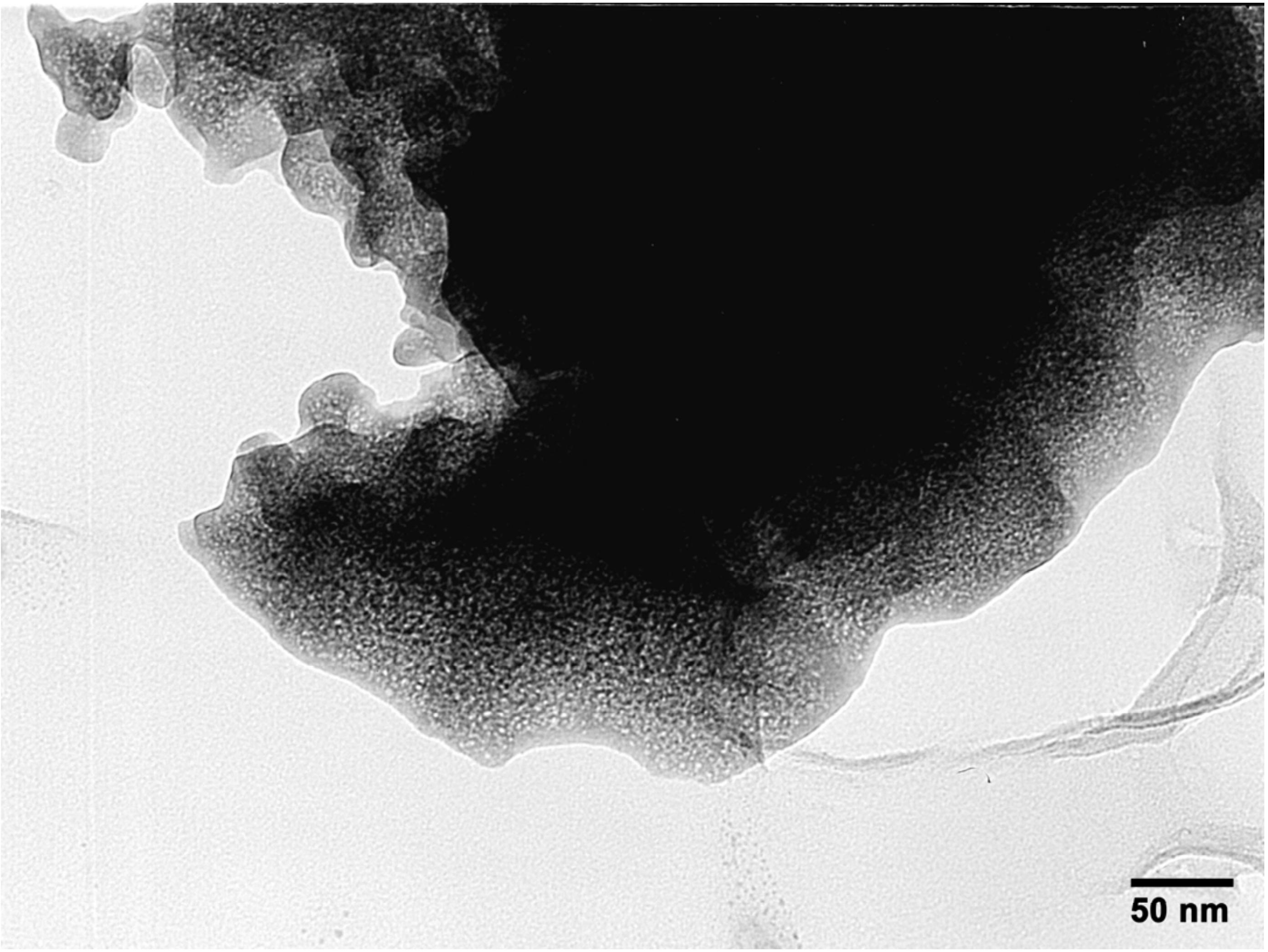


Cavity formation at a grain boundary

Lanthanum-Nickel-Aluminum Metal Hydrides

- Metal hydrides used to store tritium
  - Several alloys investigated/conditions
    - $LaNi_5$
    - $LaNi_{4.75}Al_{0.25}$ – 200 day and 5 year samples
    - $LaNi_{4.7}Al_{0.3}$ – 21 month bed
      - 50,000 appm He
      - Vacuumed outgassed to remove tritium (centerline temp ~ 300°C, higher near vessel walls)
- TEM samples
  - Powder crushed and dispersed in acetone
  - Deposited on C-covered, Cu grid
  - Phases present:
    - $LaNi_{4.7}Al_{0.3}$ – matrix, Ni_3Al, La_2O_3, $La(OH)_3$

Lanthanum-Nickel-Aluminum Metal Hydrides – 50,000 appm He



Small, helium bubbles in a single phase, $LaNi_{4.7}Al_{0.3}$ region

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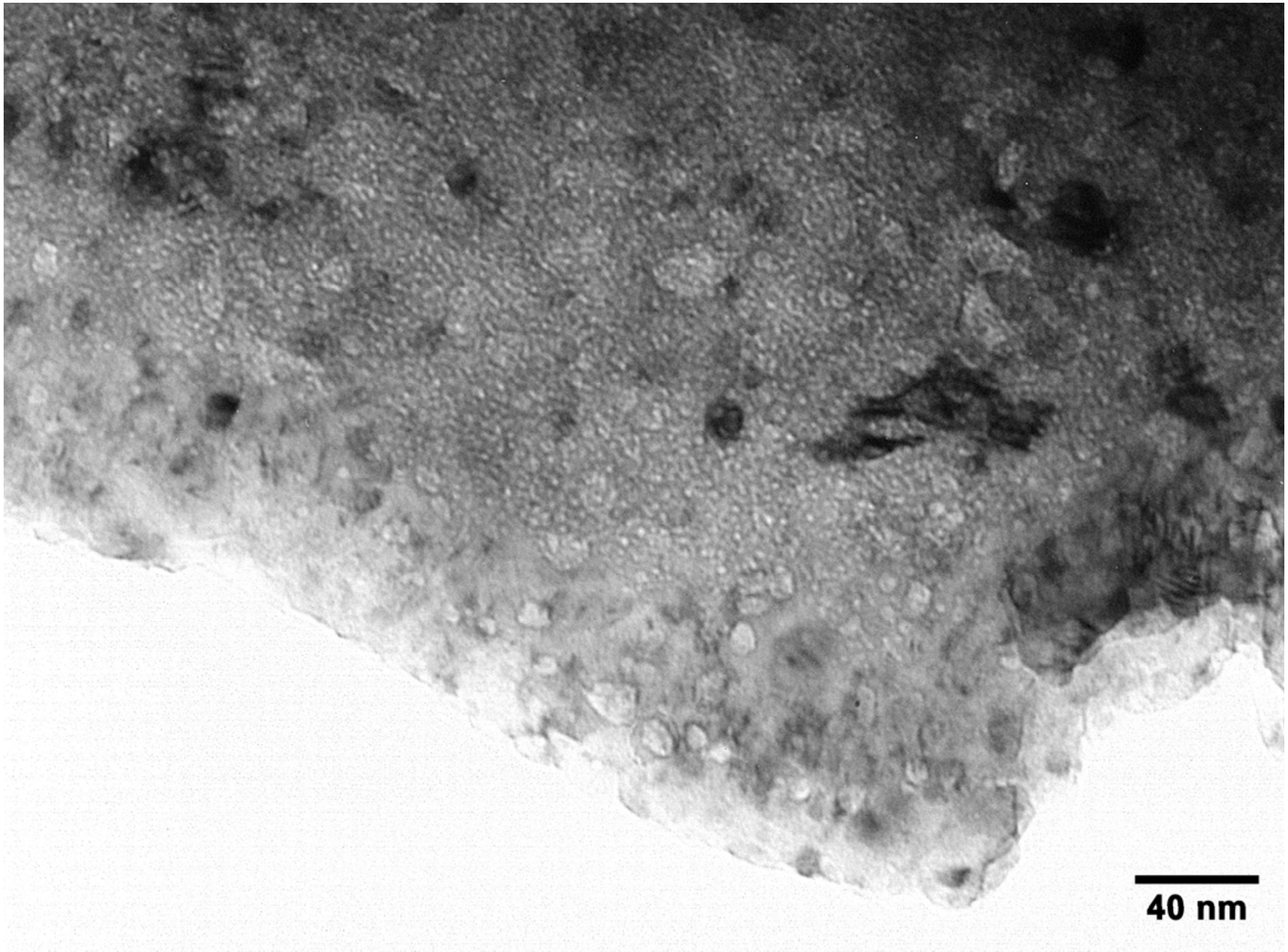
Lanthanum-Nickel-Aluminum Metal Hydrides – 50,000 appm He



Polycrystalline “shard” containing many small bubbles and facetted bubbles/voids

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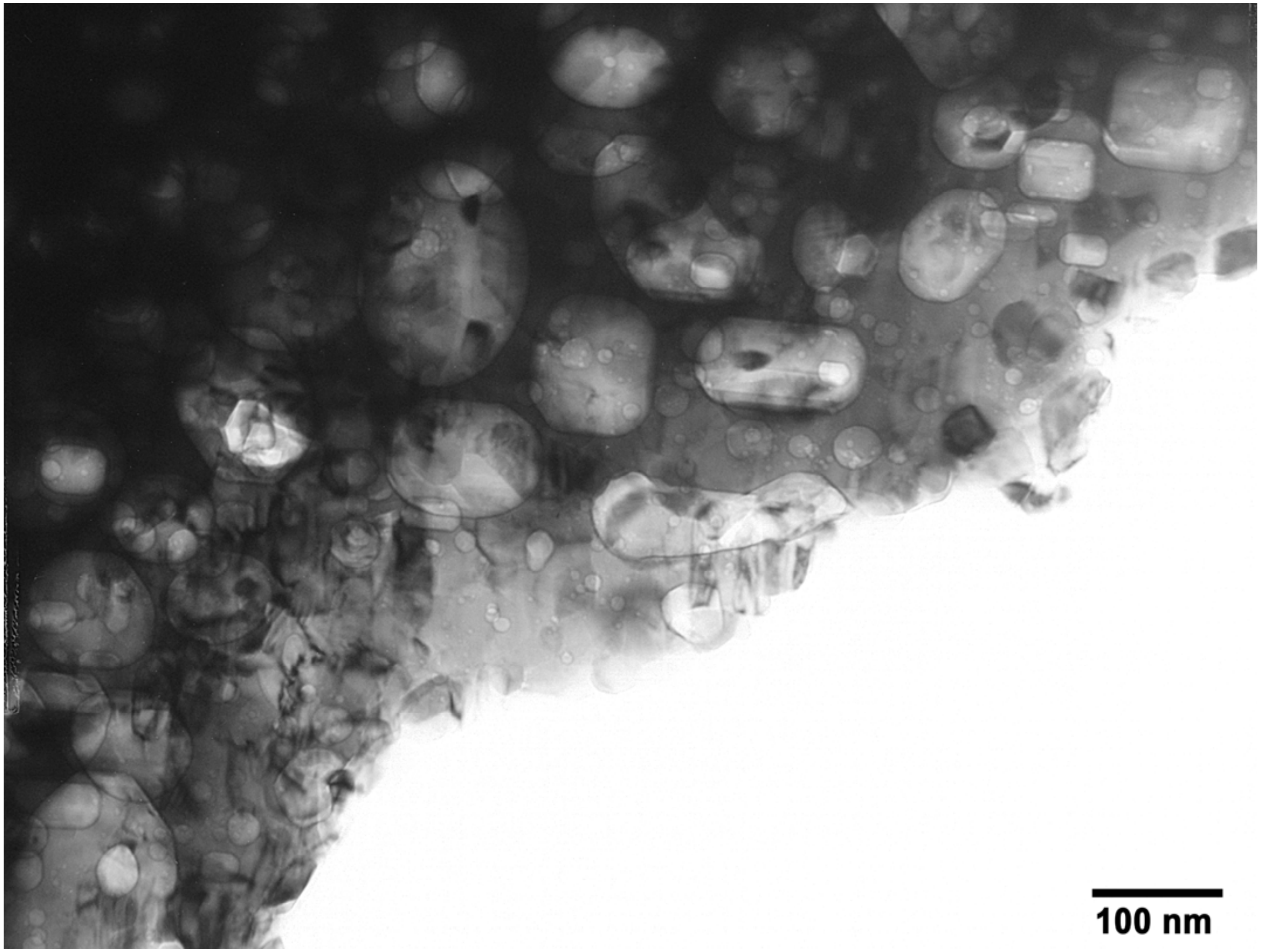
Lanthanum-Nickel-Aluminum Metal Hydrides – 50,000 appm He



Large, facetted bubbles/voids in material near the vessel wall

Helium Bubble Microstructures in Austenitic Stainless Steels and Metal Hydride Materials

- Summary:
  - The development of helium bubble microstructures (e.g., in stainless steels) are extremely dependent on the pre-existing microstructure
    - Dislocation density
    - Precipitate distribution
    - Grain boundary types and area
    - Vacancy concentration
    - Irradiation-induced defects
  - Elevated temperature excursions and the coinciding microstructural changes that occur can lead to significant helium re-distribution and bubble growth/coarsening.
  - Tritium-tricked material is different than irradiated material but cold work may be a substitute for displacement damage.

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Helium Bubble Microstructures in Austenitic Stainless Steels and Metal Hydride Materials

- Future Endeavors
  - SRNL continues to study tritium effects on materials (stainless steels, polymers, hydrides)
  - Facilities exist to tritium-charge-and-age materials and to analyze the microstructure/mechanical property relationships that develop as a result of helium ingrowth.
  - SRNL is interested in teaming with others to explore new materials/systems

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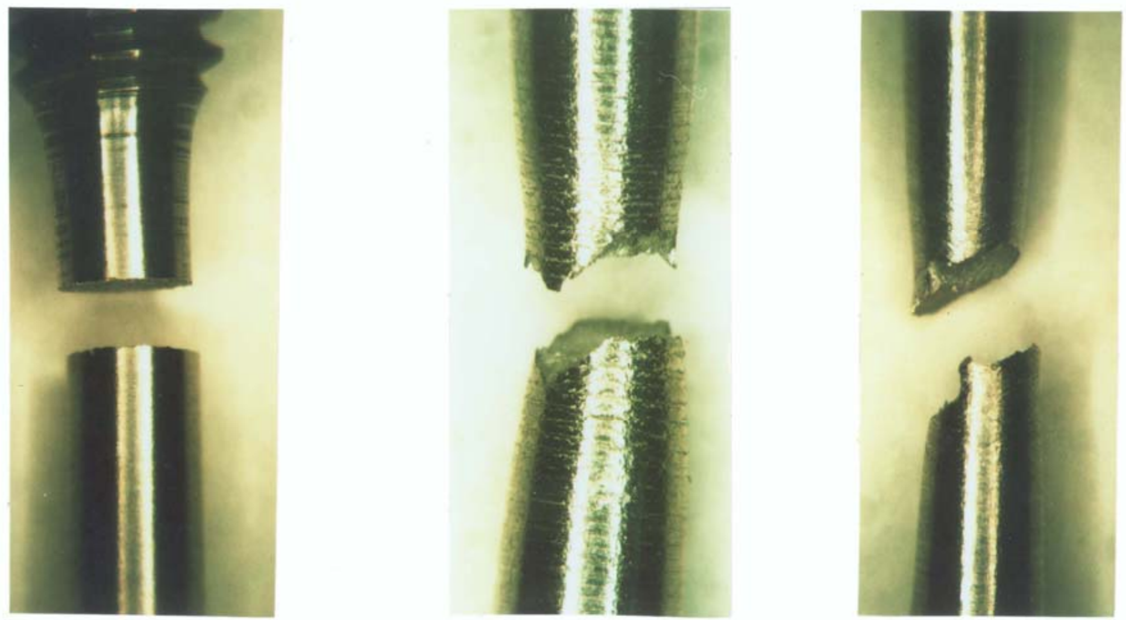
Extra Slides

Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –390 appm He

Why Are Annealed Microstructures More Susceptible to Helium Embrittlement Than HERF Microstructures?



Annealed 75 ksi	HERF 96 ksi	HERF 135 ksi

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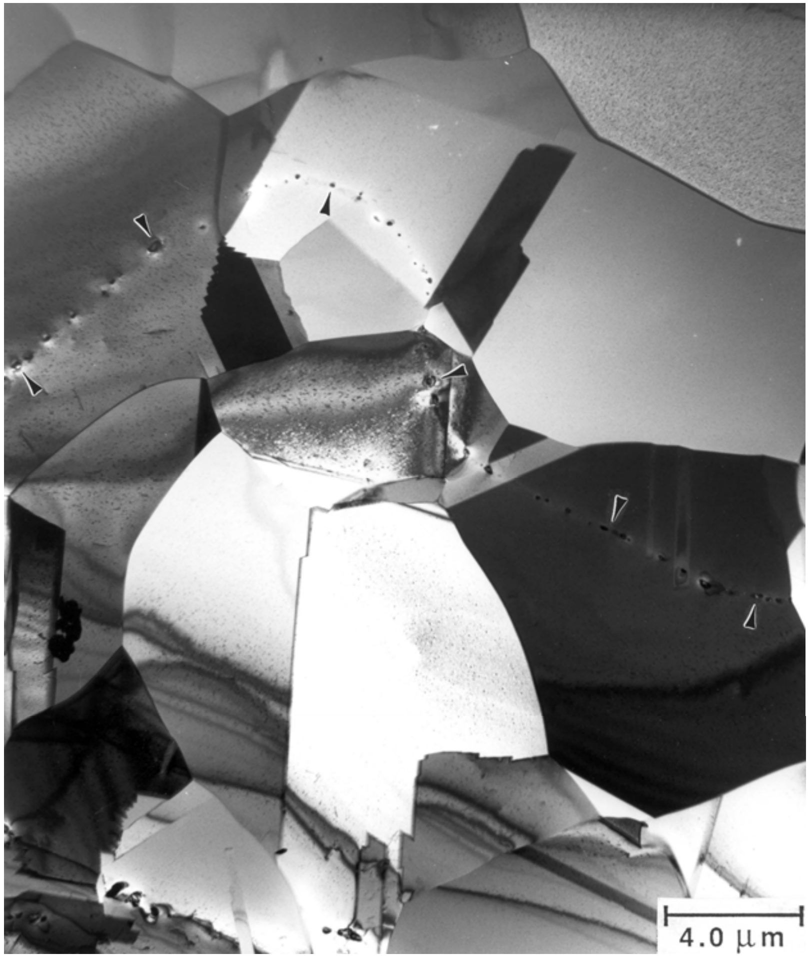
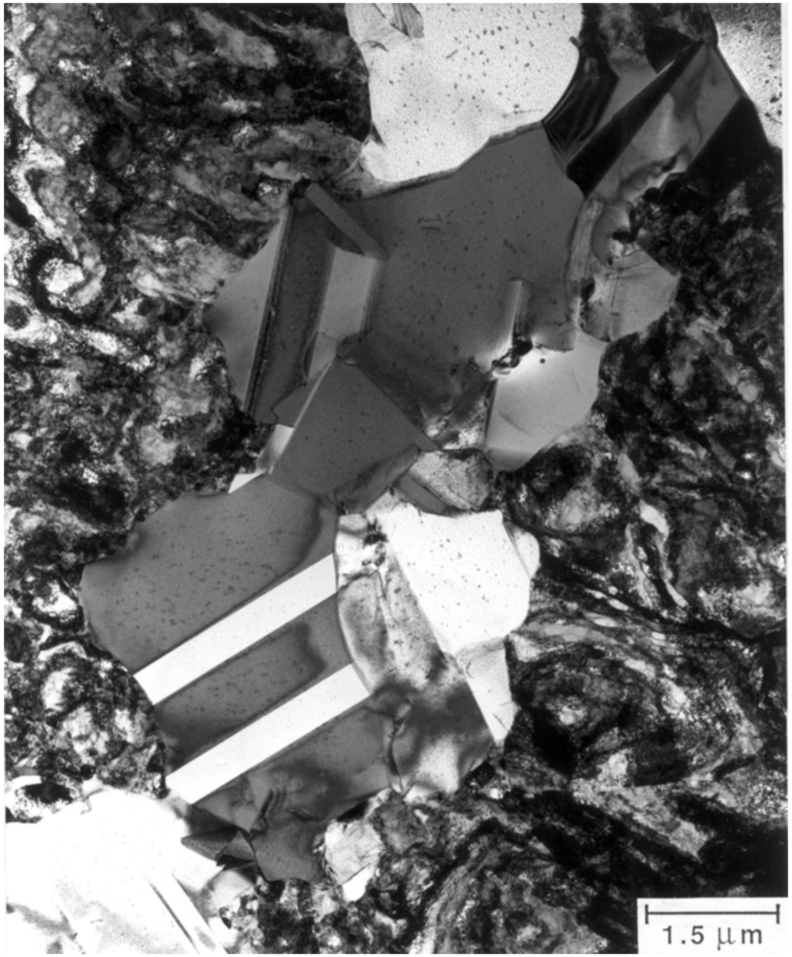
Helium Bubbles in HERF 21Cr-6Ni-9Mn Stainless Steel –390 appm He





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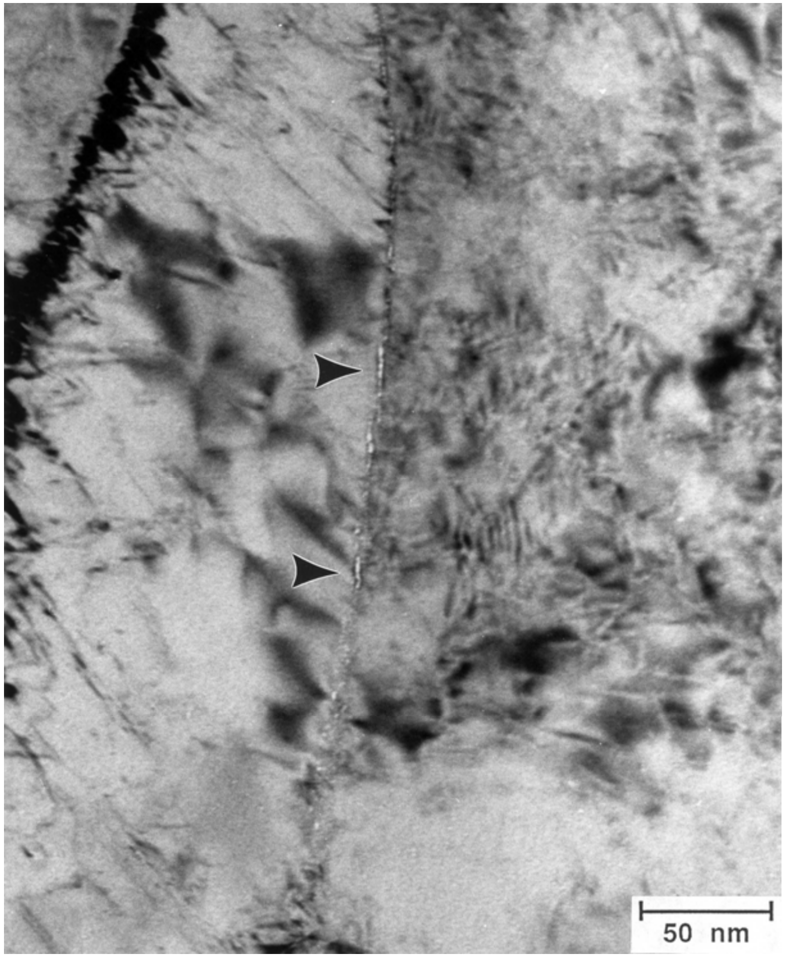

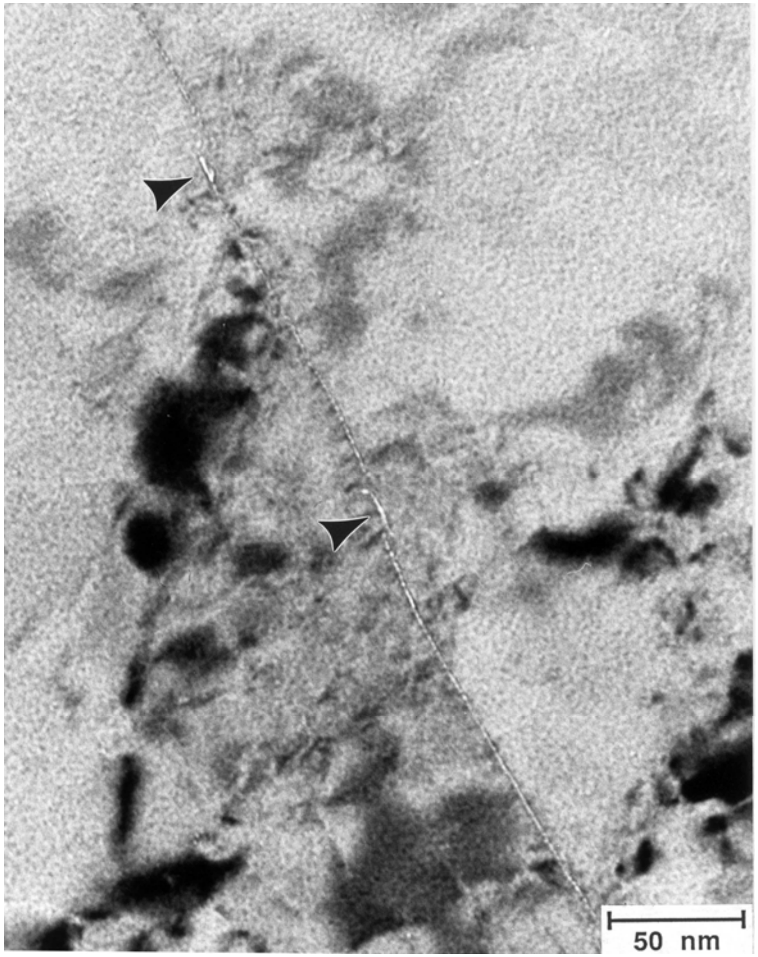

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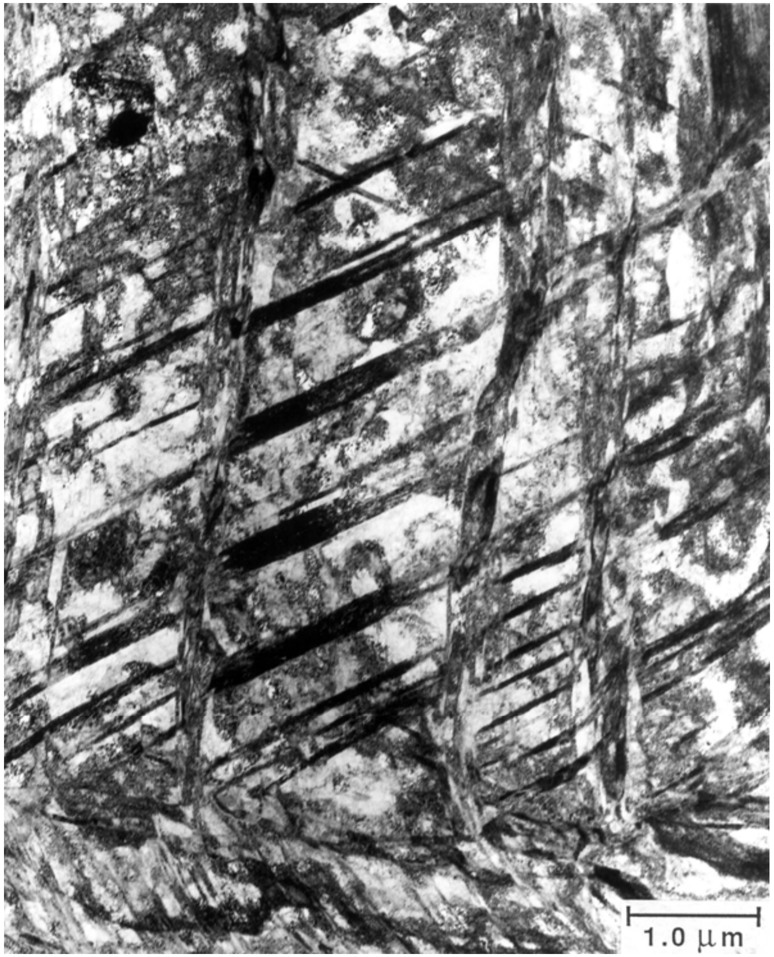

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