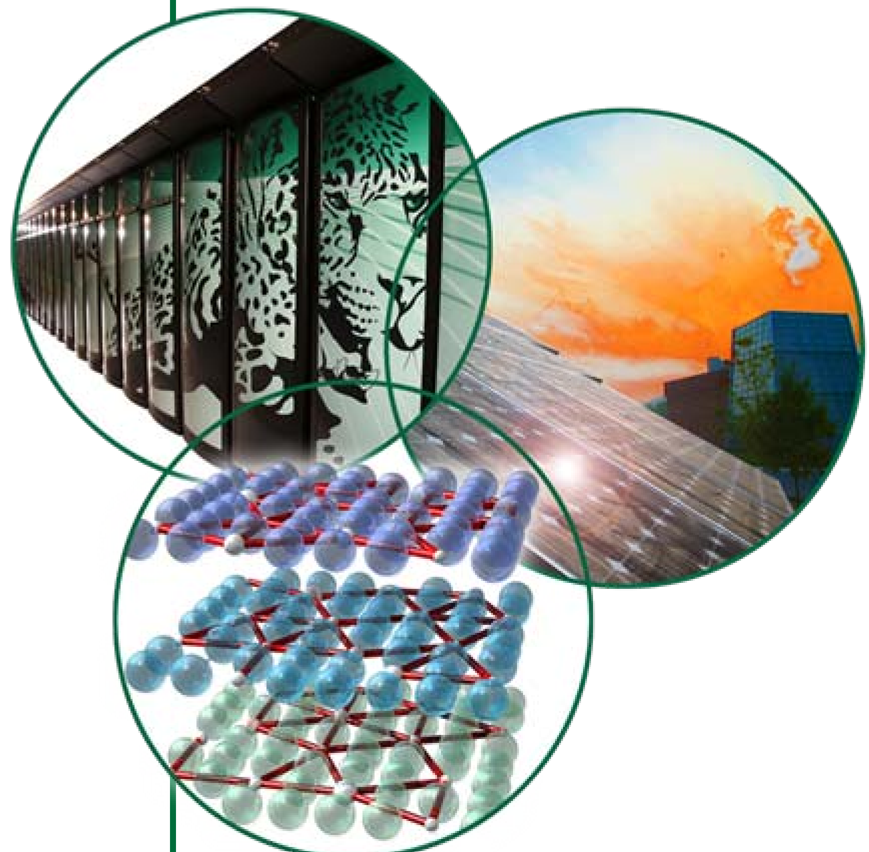
Improving the Performance of Creep-Strength-Enhanced Ferritic Steels

Mike Santella



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Purpose is to build fundamental understanding needed to increase operating temperatures

Specific goals include:

- Improving the structural performance of creep-strength-enhanced ferritic steels (9-12Cr-Mo steels)
- Provide science-based guidelines for maximizing safe operating temperatures
- Understand the fundamental causes of current temperature limitations
- Develop approaches for increasing practical operating temperatures

Activities combine basic & applied R&D with strong power industry interactions

- CRADA with Alstom Power, Inc. - "*Analysis of Off-Normal Metallurgical Conditions on the Performance of Advanced Cr-Mo Steels*"
- Collaboration with National Institute for Materials Science (NIMS), Japan - "*Mechanisms of Type IV Weld Failures in Cr-Mo Steels*"
- Involvement with materials issues relating to the ASME Boiler and Pressure Vessel Code (Section II: Materials)
- Technical support for DOE/OCDO Ultrasupercritical Steam Boiler Consortium not included in defined ORNL Tasks
- MOA with Central Research Institute of Electric Power Industry (CRIEPI), Japan - "*Joint Research on Properties of Alloy 263 and 263 Weldments*"

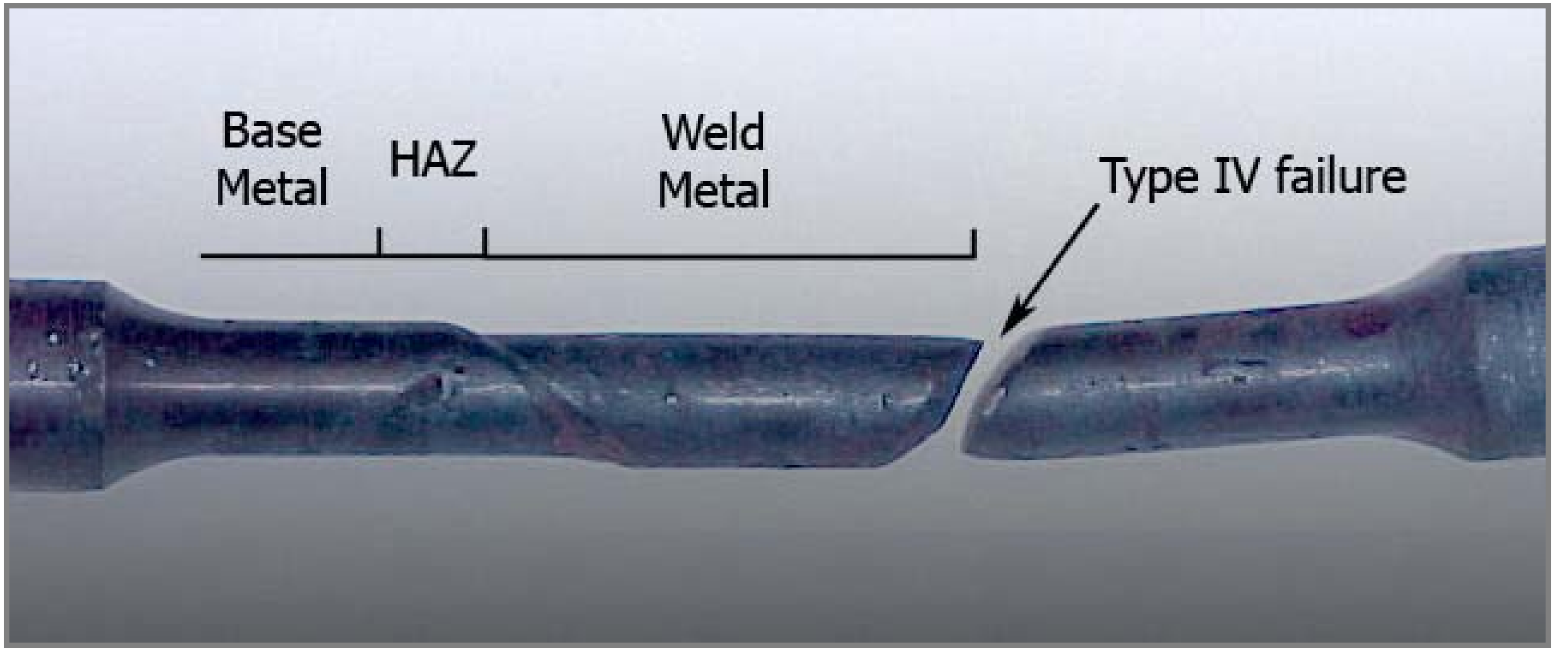
Milestones/Progress:

- FY2009
  - Complete design of a furnace and a plan to install it on a loading frame at the High-Flux Isotope Reactor neutron diffraction beam line

    Status: Suspended due to funding constraints
  - Prepare a technical paper manuscript or CRADA report related to control of alloy composition and heat treatment

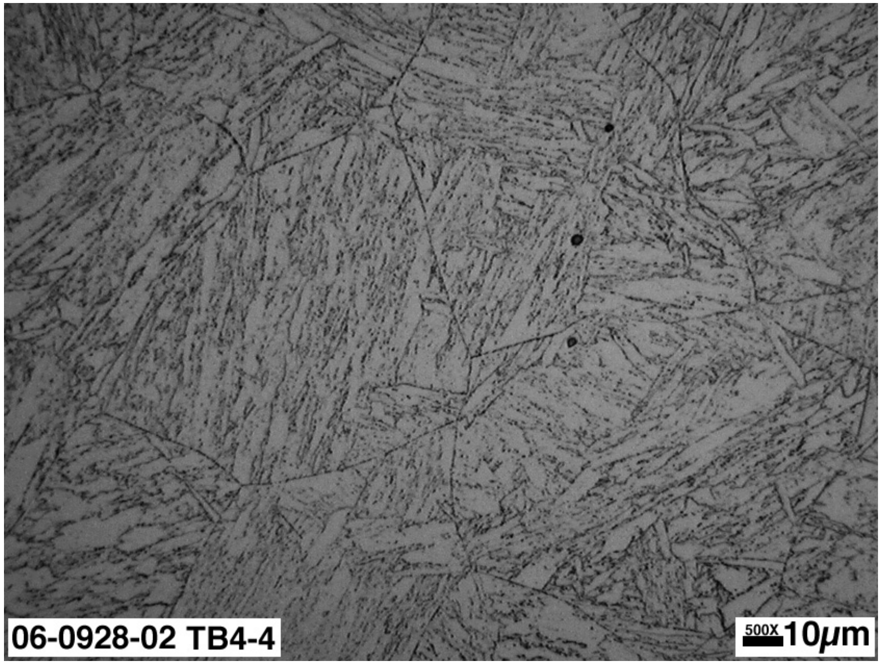
    Status: On-schedule

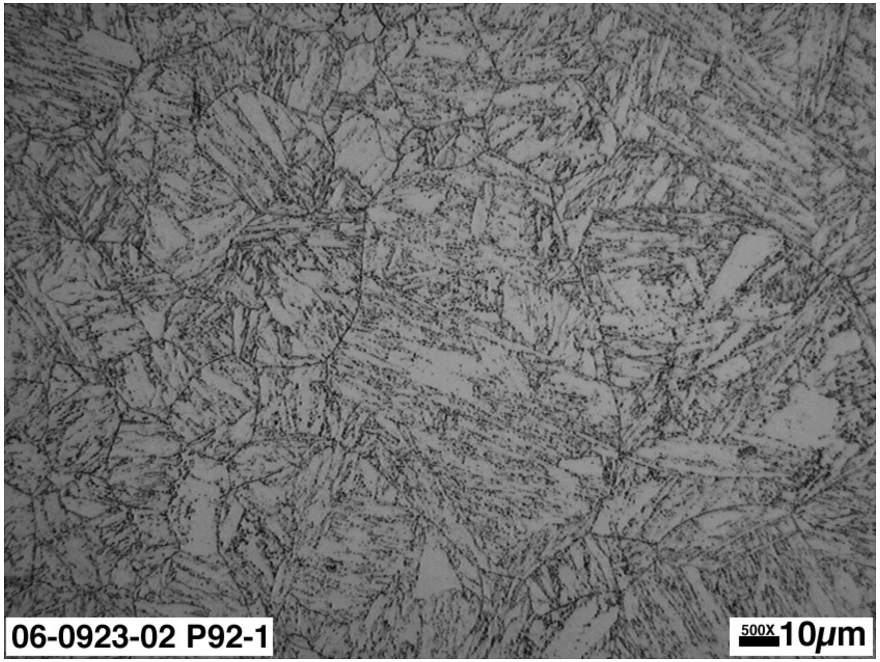
Long-time properties may not meet projections from short-time data



- Type IV failure of Cr-Mo steel welds is due to weakened microstructures in HAZs
- Unexpected behavior that causes unscheduled, premature utility outages

Experimental 9Cr steels developed at NIMS appear resistant to Type IV failure



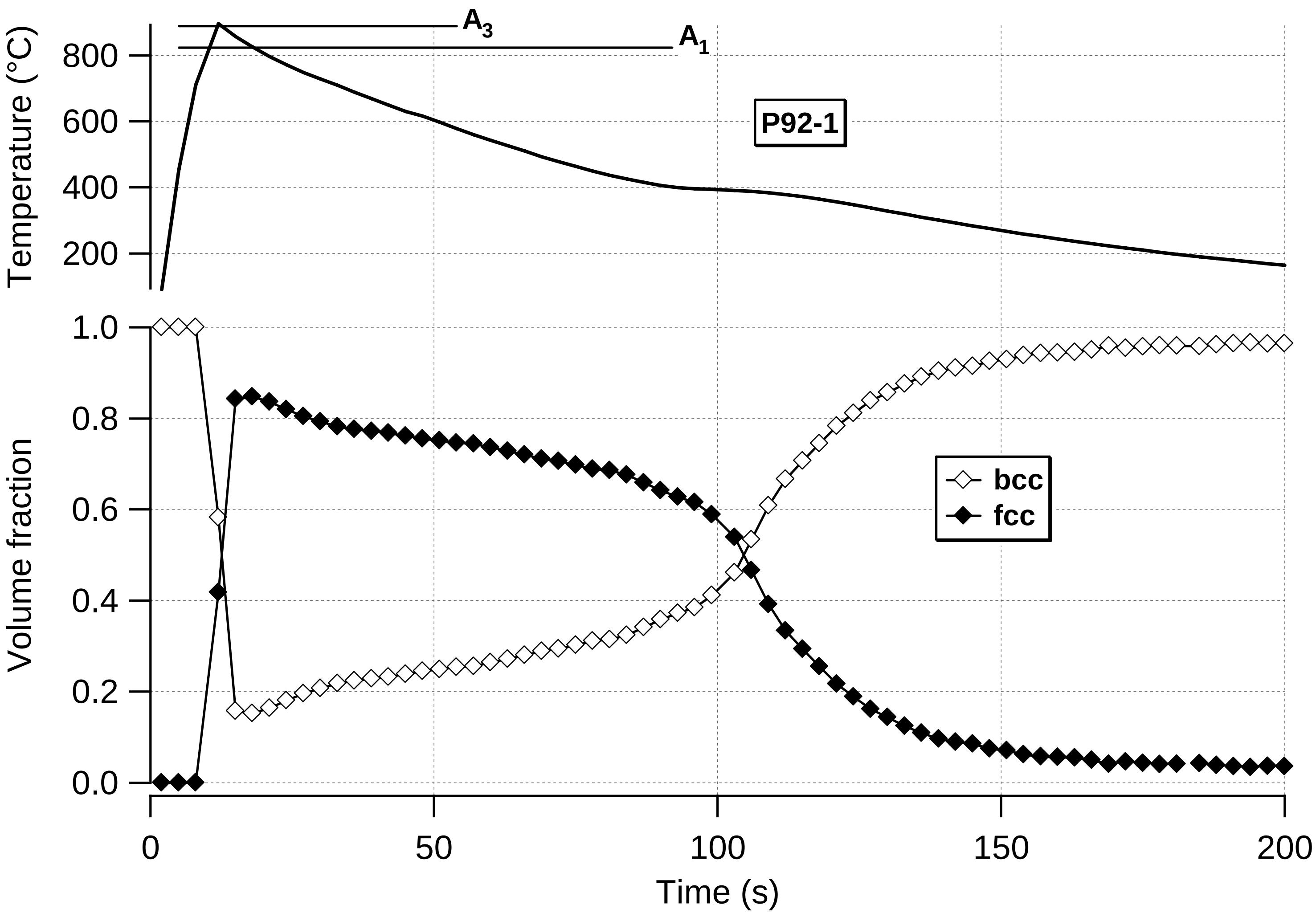


N130B: 0.077C-0.49Mn-0.30Si-8.97Cr-0.046Nb-0.18V-2.87W-2.91Co-0.0015N-0.013B

P92 (ref.): 0.09C-0.47Mn-0.16Si-8.72Cr-0.06Nb-0.21V-1.87W-0.45Mo-0.050N-0.002B

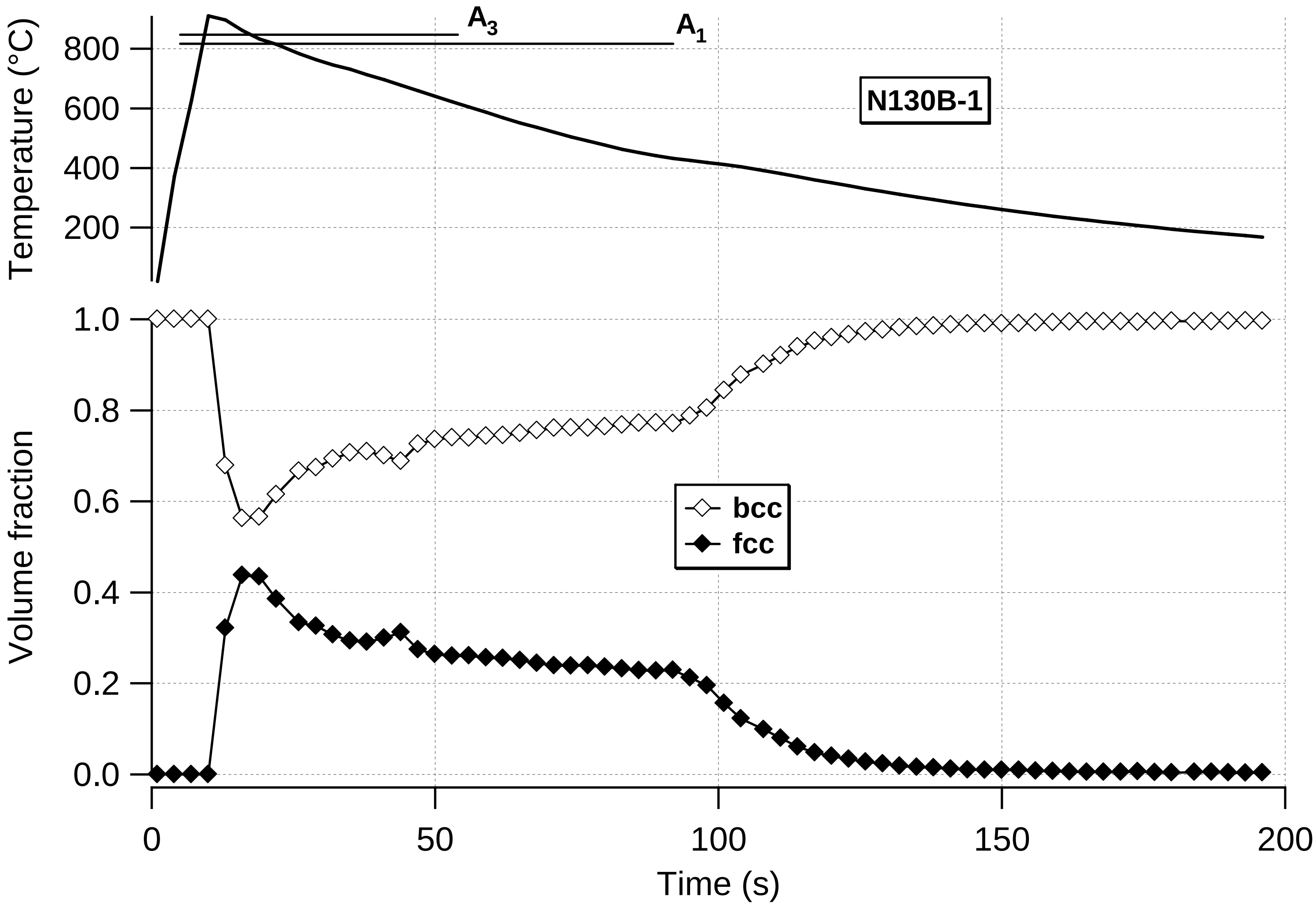
Key features of N130 B – low N, high B

Heating to low peak temperatures transformed P92 rapidly to high fraction of austenite



- Result: 15% untransformed α, 22% new α, 60.4% new α', 2.3% γ

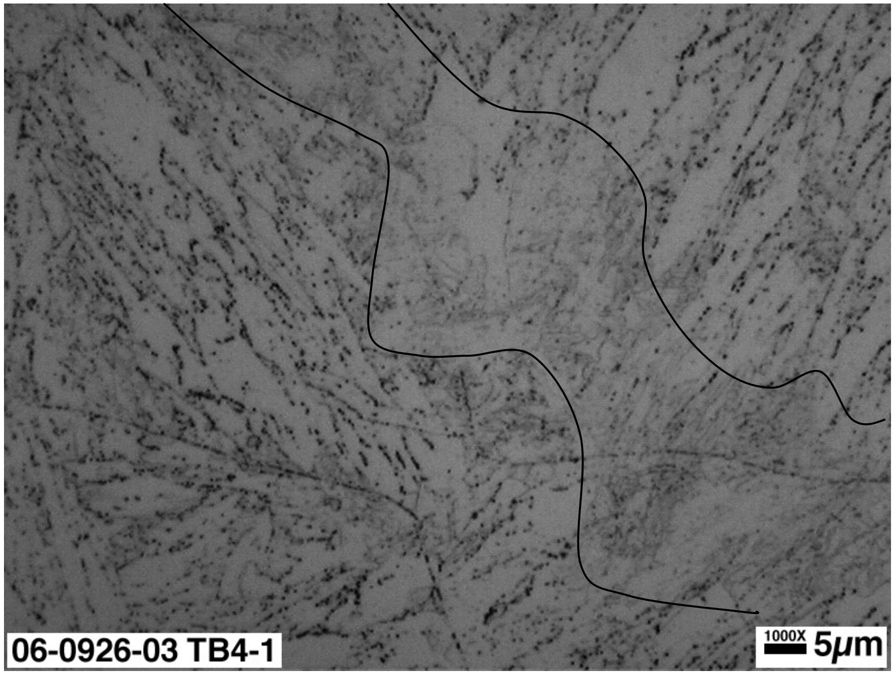
Heating to low peak temperatures retained a high fraction of untransfomed α in N130B



- Result: 56% untransformed α, 21% new α, 23% new α′, 0% γ

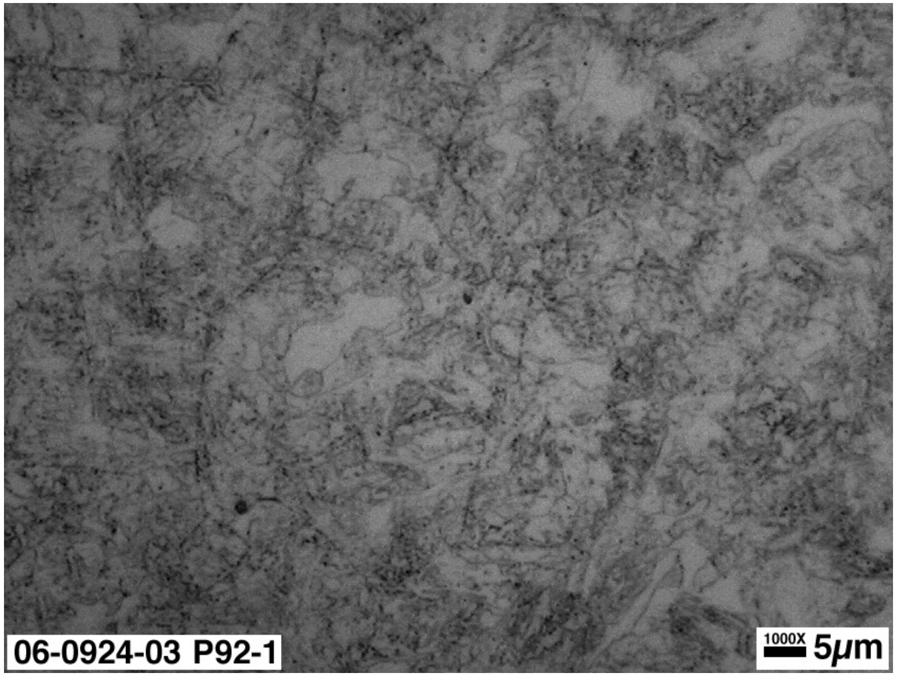
Microstructures were consistent with diffraction data at low HAZ peak T's

N130B



- T_{Peak} = 911°C (A_3 = 860°C)
- 56% untransformed α, 21% new α, 23% new α', 0% γ
- H_V = 2.57 GPa

P92



- T_{Peak} = 896°C (A_3 = 893°C)
- 15% untransformed α, 22% new α, 60.4% new α', 2.3% γ
- H_V = 4.02 GPa

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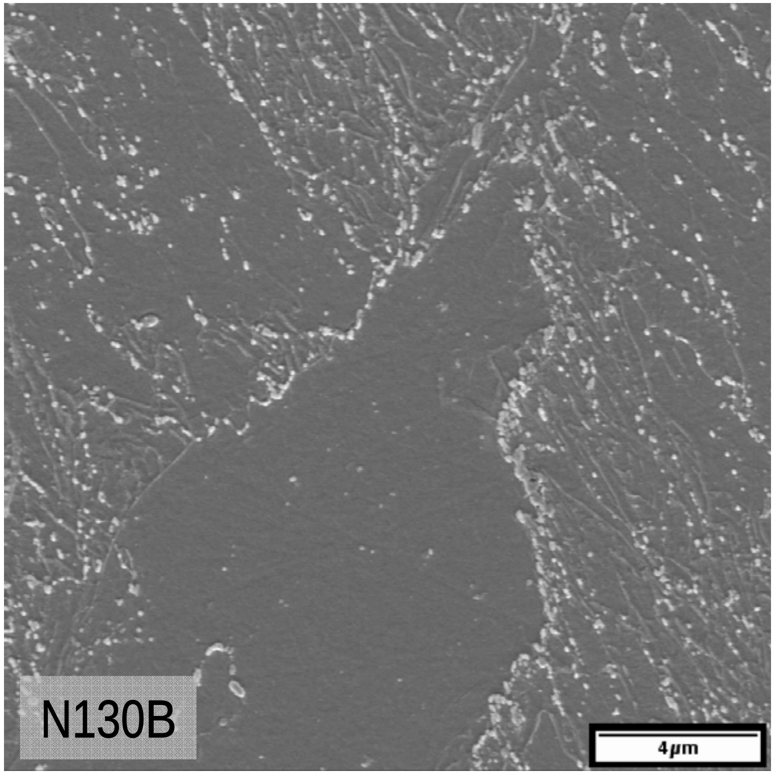
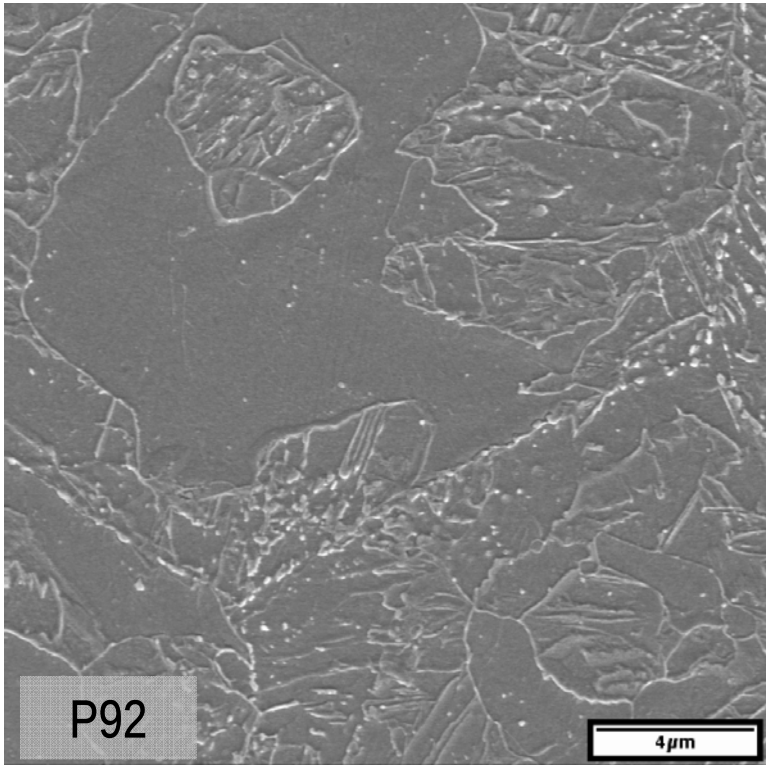
Carbide dissolution in N130B was also sluggish





	Predicted $M_{23}C_6$ Composition, at%								
Alloy	Fe	Cr	Co	Mn	Mo	V	W	B	C
N130B	23.3	53.1	0.3	0.6	---	0.6	1.4	3.9	16.8
P92	21.6	50.8	---	0.8	3.5	0.6	2.1	0.08	20.6

Summary:

- For low HAZ peak temperatures, < ~ 980°C, neither steel transformed completely to austenite
  - Both contained untransformed ferrite with greater amounts in N130B
  - During cooling, new ferrite appeared in both
  - For similar conditions, N130B contained lesser amounts of new martensite
- For similar conditions, N130B retained less γ (if any)
- Dissolution of $M_{23}C_6$ in N130B was also sluggish, possibly due to B content

Do these differences influence properties?
How? Why?

Milestones/Progress:

- FY2010
  - Initiate creep testing of specimens subjected to simulated heat-affected zone heat treatments during synchrotron diffraction

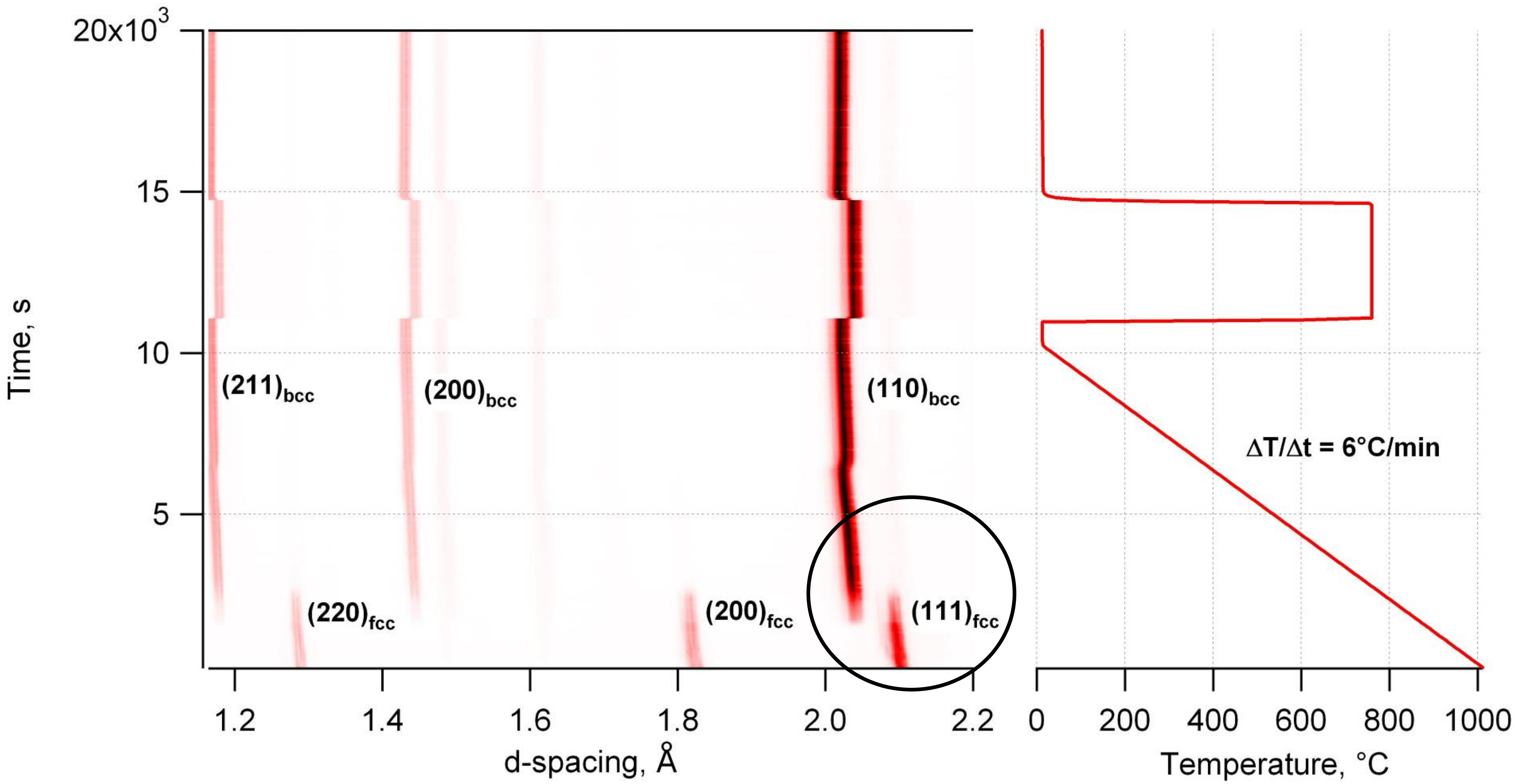
    Status: On-schedule

    - Heat treatments/diffraction experiments are complete
    - Data is being analyzed
    - Preferred creep specimen geometry is under discussion

CSEF steels must be heat treated as specified to achieve desired properties

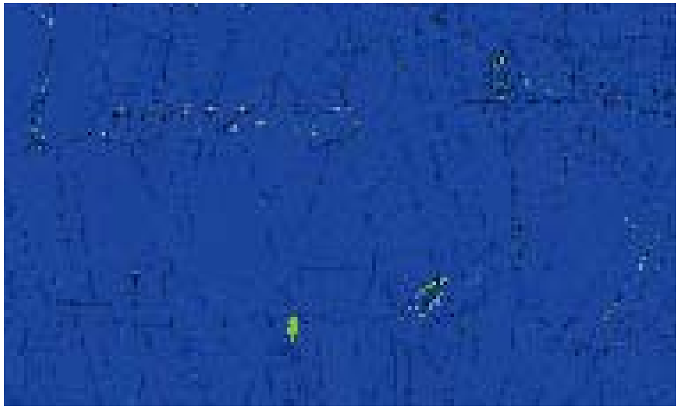
- CRADA with Alstom Power, Inc. - "*Analysis of Off-Normal Metallurgical Conditions on the Performance of Advanced Cr-Mo Steels*"
  - Can these heat treatments be accepted without compromising creep properties of 9Cr steel :
    - Tempering for exceptionally long times (100 h-vs-2 h)?
    - Tempering in $\alpha + \gamma$ phase field under any circumstances?
    - Slowly cooling from austenitizing temperatures in N + T?
    - Holding metal for long times at ~ 500°C during cooling from normalizing treatments?
  - How does one know these have *not* been done?

Real-time diffraction from 9Cr steel Ht 30176 during slow cooling from 1050°C

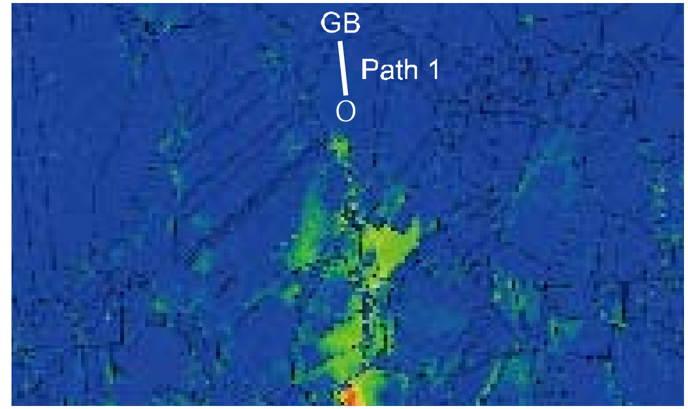


- Austenite begins transforming to ferrite between ~ 770-870°C
- Result is martensite + ferrite rather than ferrite
- Creep properties are not likely to be as desired

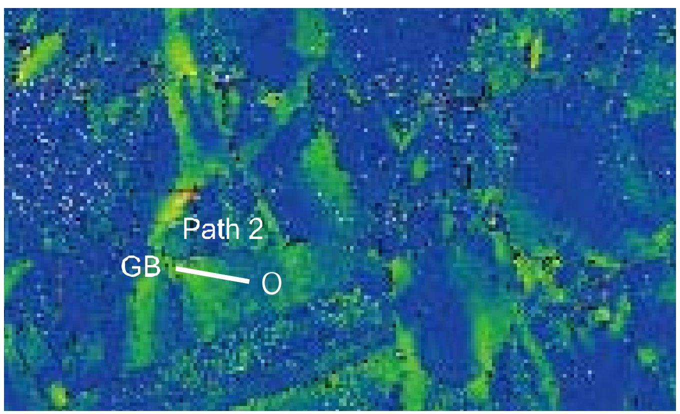
Creep-fatigue loading dramatically reduces life of nickel-based alloys



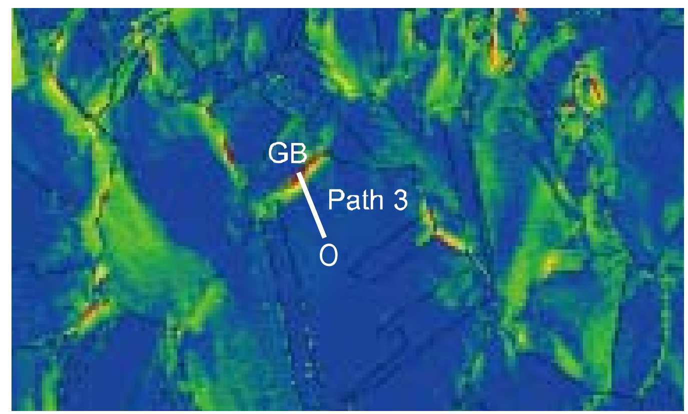
(a) Aged, 750˚C, 216hr



(b) Fatigue, 750˚C, 0.7%, 2070Cycles



(c) Creep, 750˚C, 180MPa, 3013.1hr

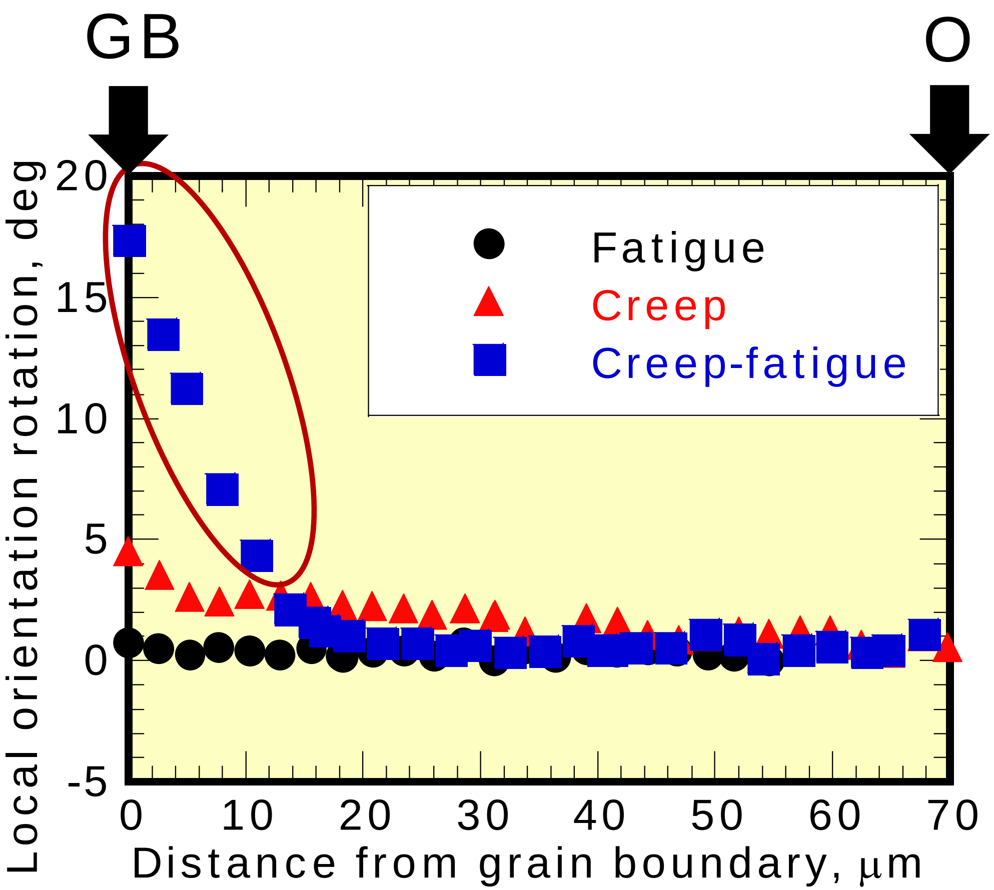


(d) Creep-fatigue, 750˚C, 0.7%, TH6min, 737Cycles

200µm

- MOA with Central Research Institute of Electric Power Industry (CRIEPI), Japan - "*Joint Research on Properties of Alloy 263 and 263 Weldments*"

Rotation of atomic planes near grain boundaries increases strain concentration



- 15 degrees rotation within 10 microns from GB in creep-fatigue condition
  - High dislocation density
  - High mismatch of strain
- Concentration of "creep deformation" near the GB is likely cause of remarkably low life, intergranular failure in C-F conditions

Source: Dr. Masato Yamamoto, CRIEPI, Japan, from work done at ORNL

Improving Performance of CSEF Steels and Ni-based Alloys

Highlights:

- Using advanced tools – like APS – to better understand new high-performance alloys
  - Collaboration with NIMS, Alstom CRADA
- Leveraging resources to investigate ways to increase performance of Ni-based alloys
  - Collaboration with CRIEPI
- Using unique capabilities and fundamental understanding to assist ASME and manufacturers in better informed use of CSEF steels and Ni-based alloys
  - Using computational thermodynamic analysis to enable more robust alloy specifications
  - Supporting component design and reliability with testing and analysis of mechanical behavior