

Fossil Boiler Water Chemistry Experiences and Challenges

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IAPWS Symposium 2010

Niagara Falls, Ontario

July 21, 2010

The Babcock & Wilcox Company

B&W Technical
Services Group, Inc.



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Small Industrial Boilers



Subcritical Boilers



SCR Systems



Dry Scrubbers



Supercritical Boilers



Wet Scrubbers

Fossil Boiler Water Chemistry

Water Treatment Initiatives & Experiences

▶ ***Water Treatment Initiatives***

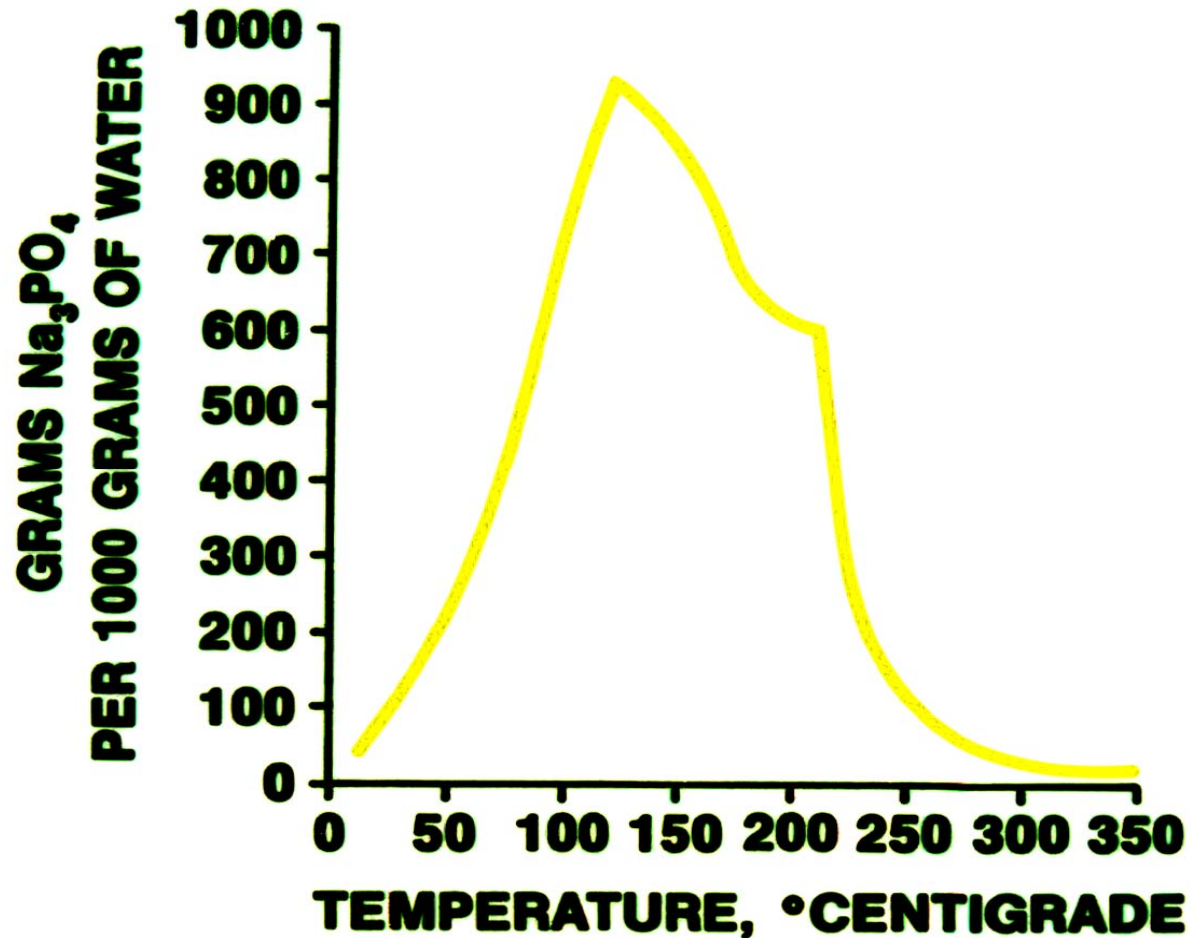
- Congruent phosphate treatment
- Reducing AVT
- ASME Guidelines
- Equilibrium phosphate
- Polymer treatments
- Oxygenated treatment (OT)

▶ ***Experiences***

- Acid phosphate corrosion
- Under-deposit corrosion
- Oxidation/exfoliation
- Long term overheat/creep
- Sub-ASME applications

Fossil Boiler Water Chemistry

Phosphate Hideout



Fossil Boiler Water Chemistry

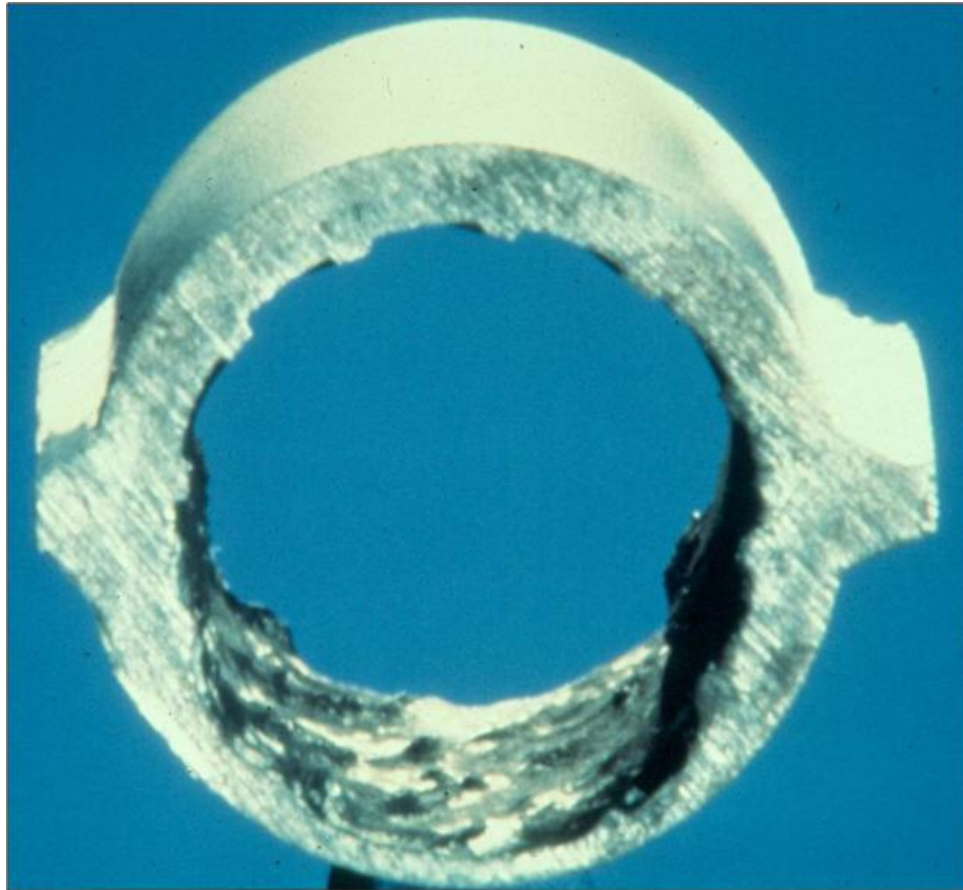
Consequences of Phosphate Hideout

- ▶ *Sodium to phosphate ratio increases in the boiler water (possibility of caustic corrosion)*

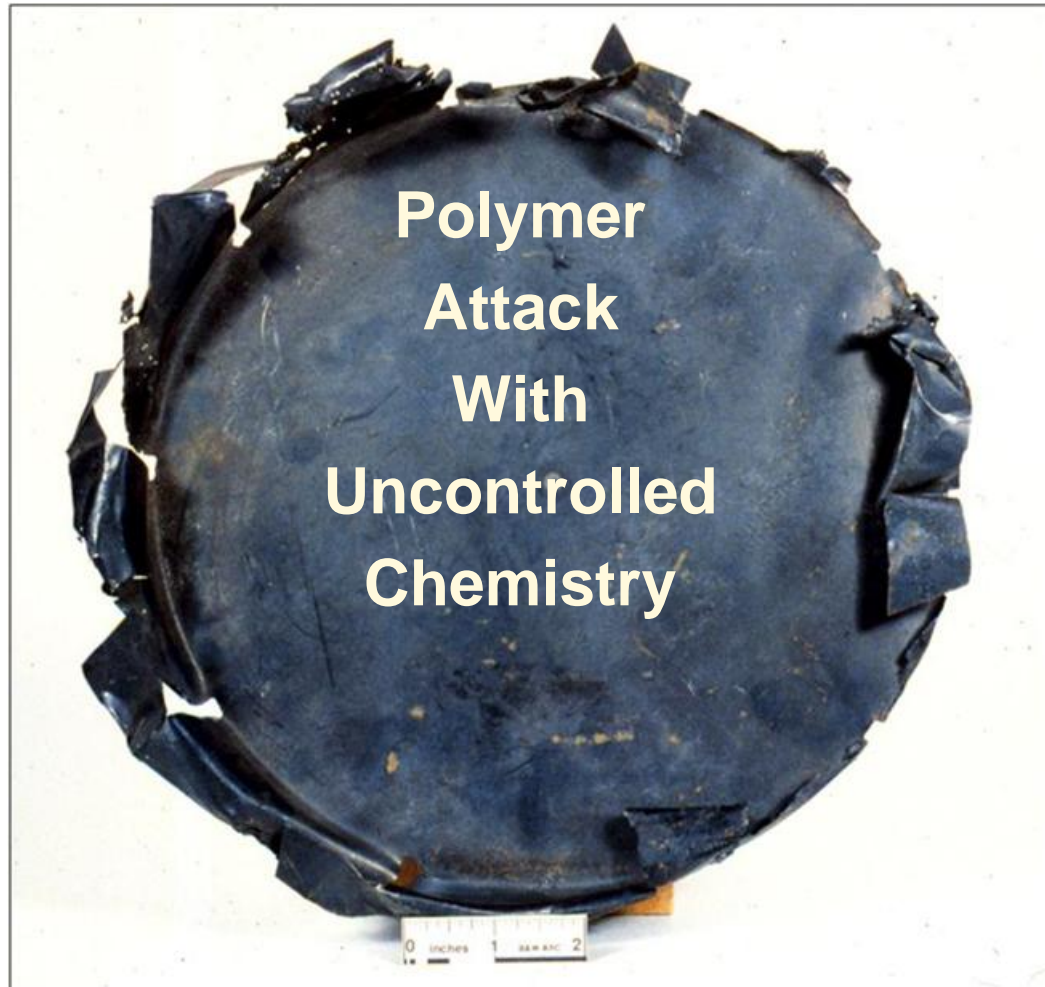
- ▶ *Sodium to phosphate ratio decreases in the deposits*
 - Leads to “acid” phosphate corrosion attack
 - Disruption of the magnetite layer

Fossil Boiler Water Chemistry

Acid Phosphate Attack



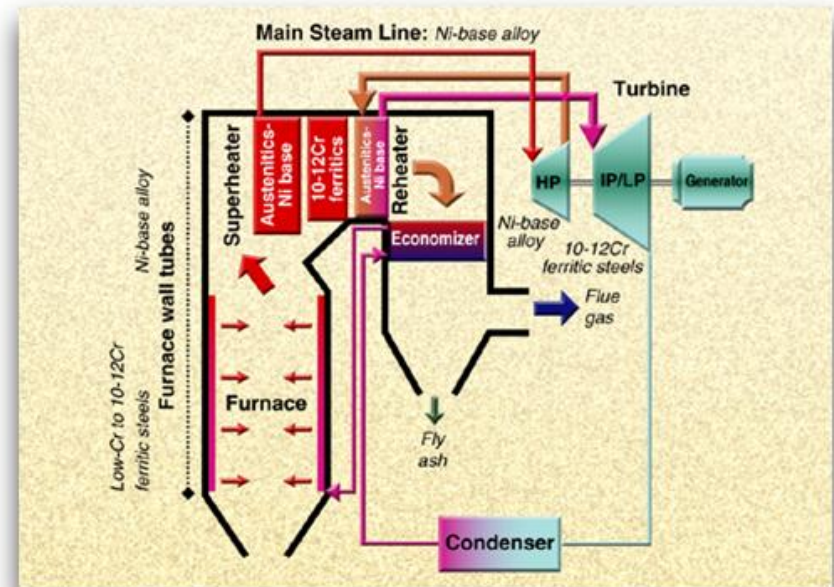
Fossil Boiler Water Chemistry



USC Boiler Development Program

USC Boilers to Operate at Elevated Temperatures/Pressures

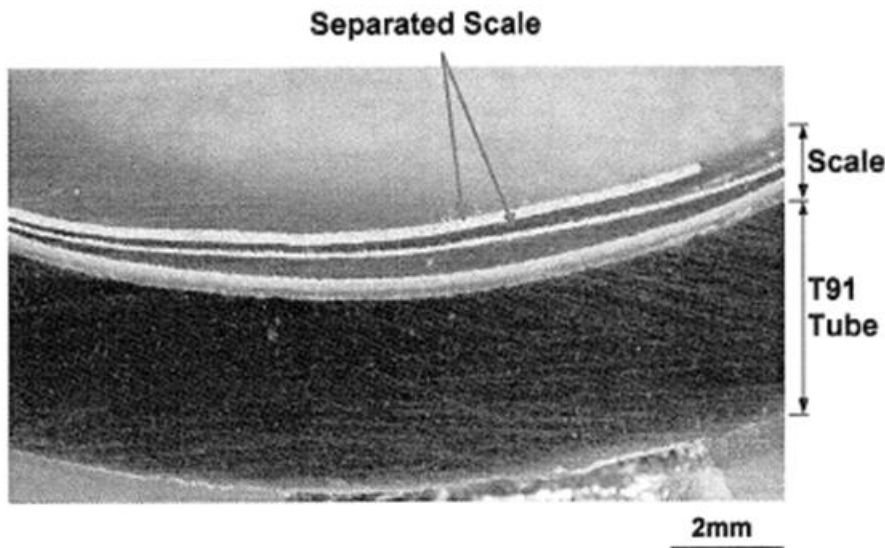
- ▶ Target 5100 psia/1400°F steam
- ▶ Target efficiencies of ~45%
- ▶ Reduce emissions by ~30% and fit into existing footprint



DOE, OCDO, EPRI, OEM Consortium, ORNL

Steam Side Oxidation Concerns

- ▶ **Loss of sound structural material**
- ▶ **Insulate material leading to overheating**
- ▶ **Exfoliation/tube plugging/turbine erosion**



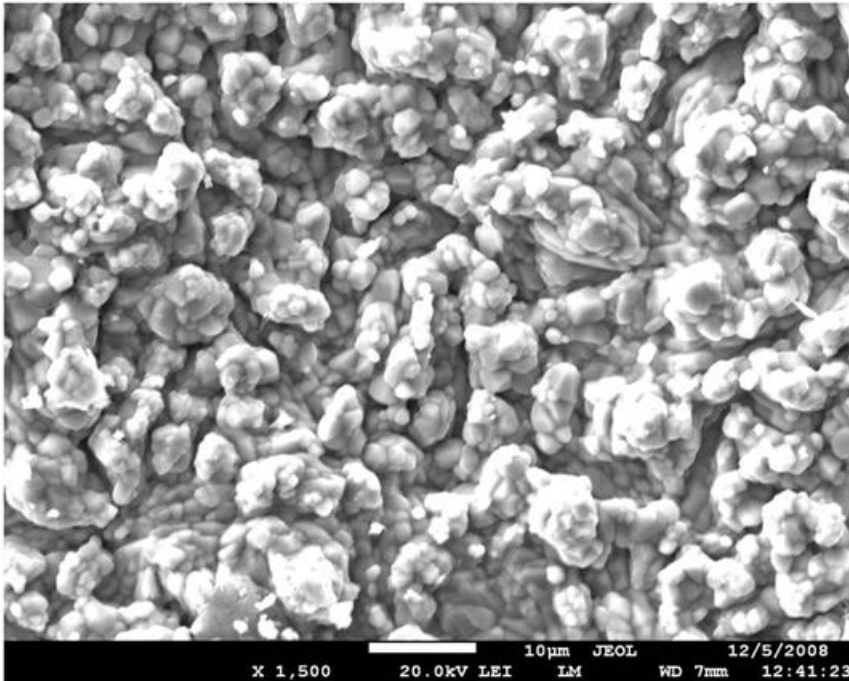
Insulating Oxide on T91
(courtesy Dr. F. Masuyama)



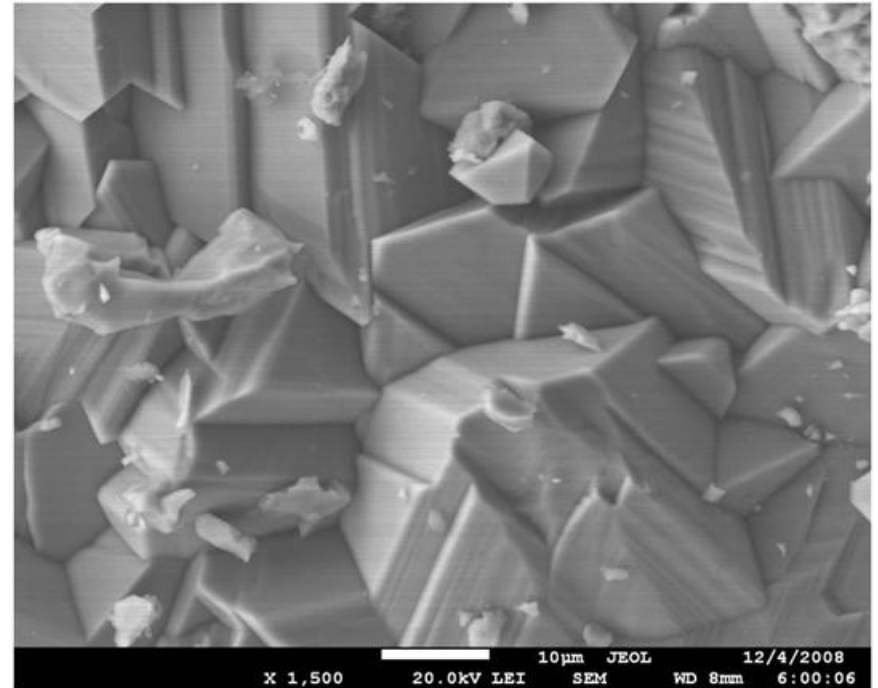
Exfoliated Oxide from 347H Tubing

Steam Side Oxidation Concerns

Oxide Formation/Dissolution/Exfoliation



***Oxide on Austenitic Material
Supercritical Conditions***

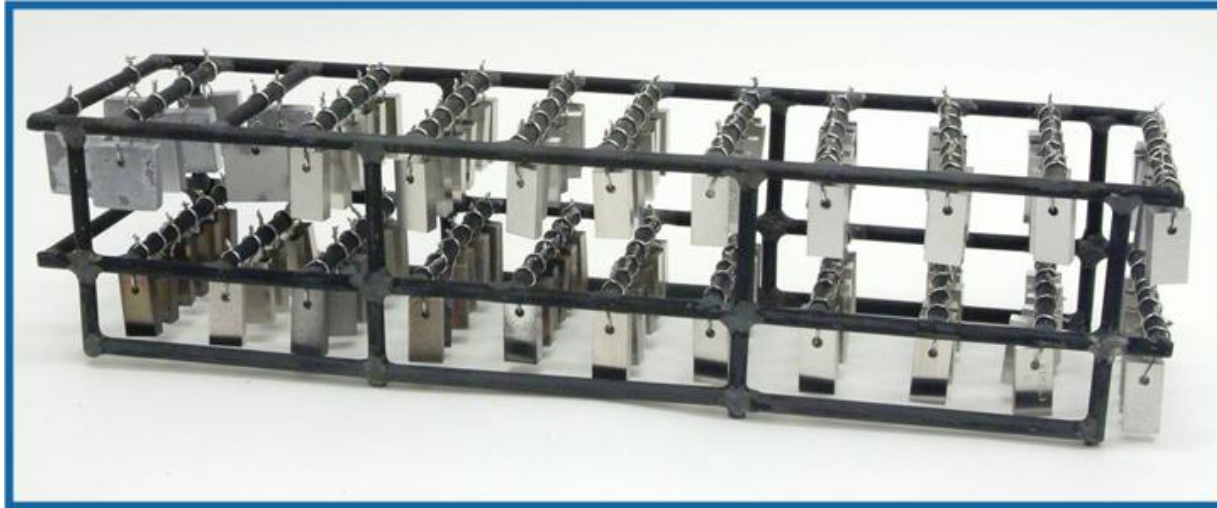


***Oxide on Austenitic Material
Supercritical Conditions***

USC Steam Oxidation Test Program

Test Conditions

- ▶ **OT Steam (NH_3 , O_2)**
- ▶ **Test Runs @ 650°C, 750°C, 800°C (1202°F, 1382°F, 1472°F)**
- ▶ **Specimen Removal @ 1000, 2000, and 4000 Hours**
- ▶ **Evaluate Specimen Weight Change and Scale Morphology**



J.M. Sarver (B&W) Presentation @

14th International Conference on Environmental Degradation of Materials in Nuclear Power Systems

Oxidation Rate Calculation

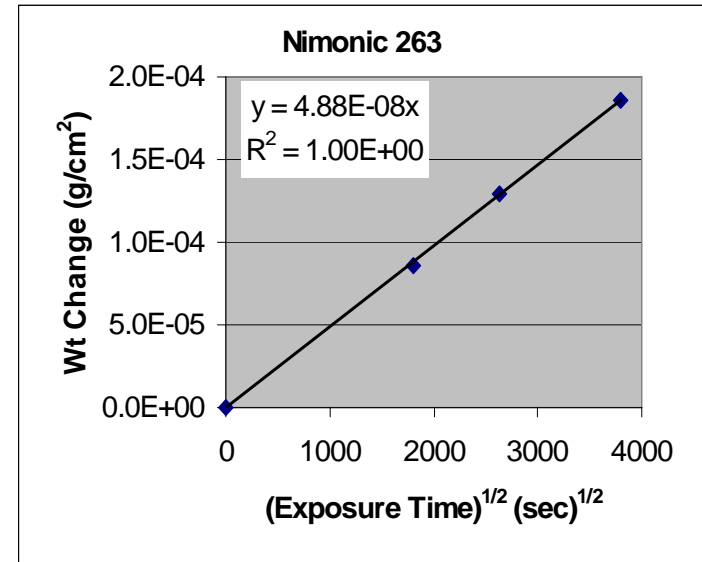
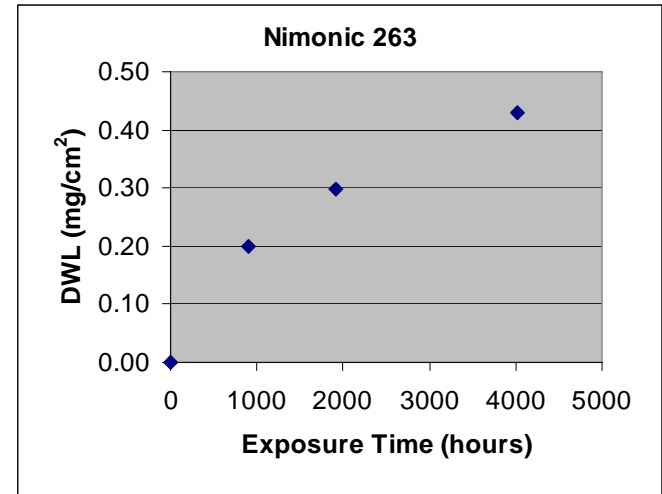
$$\frac{dx}{dt} = \frac{k_p}{x} \quad \Rightarrow \quad xdx = k_p dt$$

$$\int xdx = \frac{x^2}{2} \quad ; \quad \int k_p dt = k_p t$$

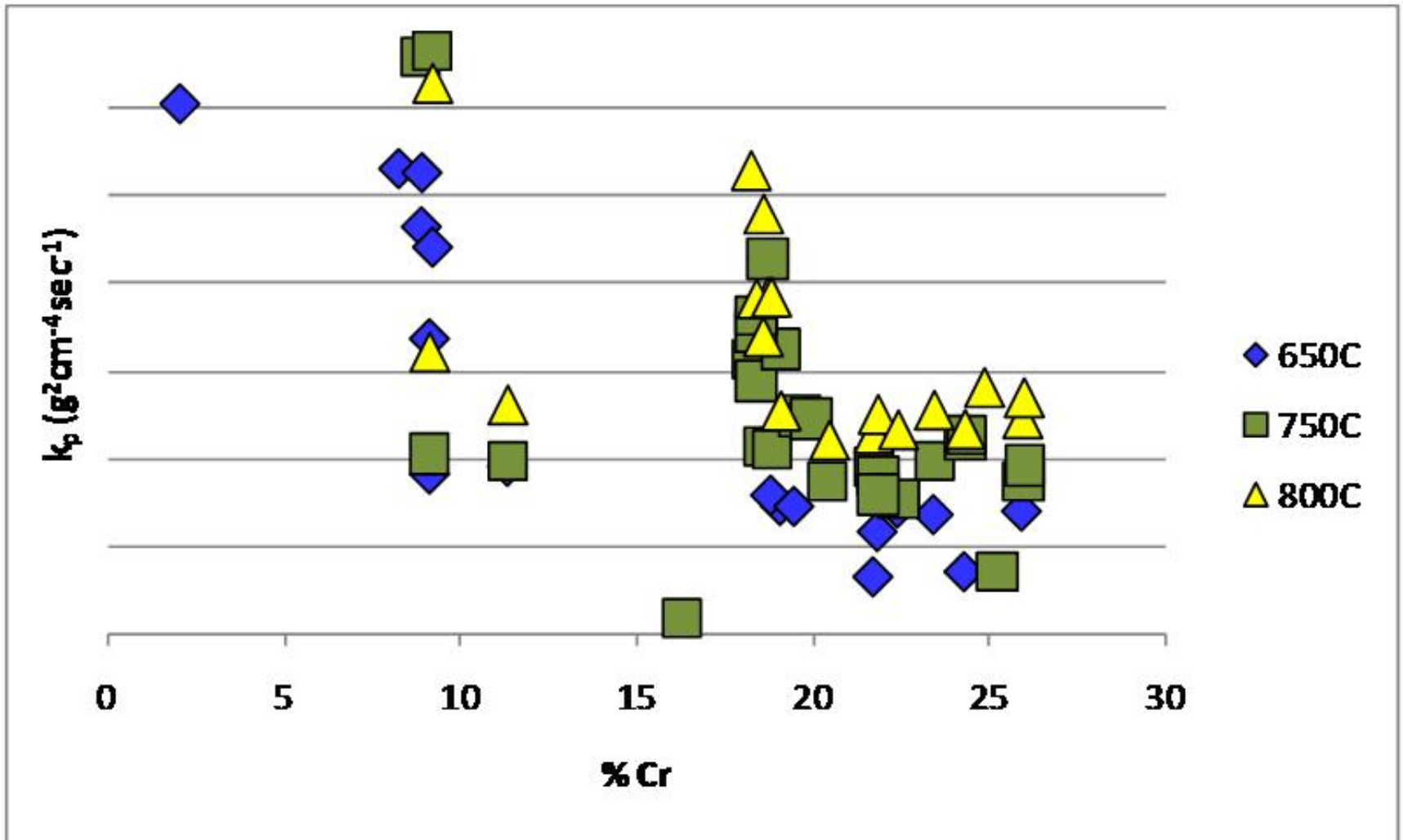
$$\frac{x^2}{2} = k_p t \quad \Rightarrow \quad k_p = \frac{1}{2} \left(\frac{x}{t^{1/2}} \right)^2$$

$$k_p = \frac{1}{2} (\text{Slope})^2 = \frac{1}{2} (4.88 \times 10^{-8})^2$$

$$k_p = 1.20 \times 10^{-15} \text{ g}^2 \text{ cm}^{-4} \text{ s}^{-1}$$

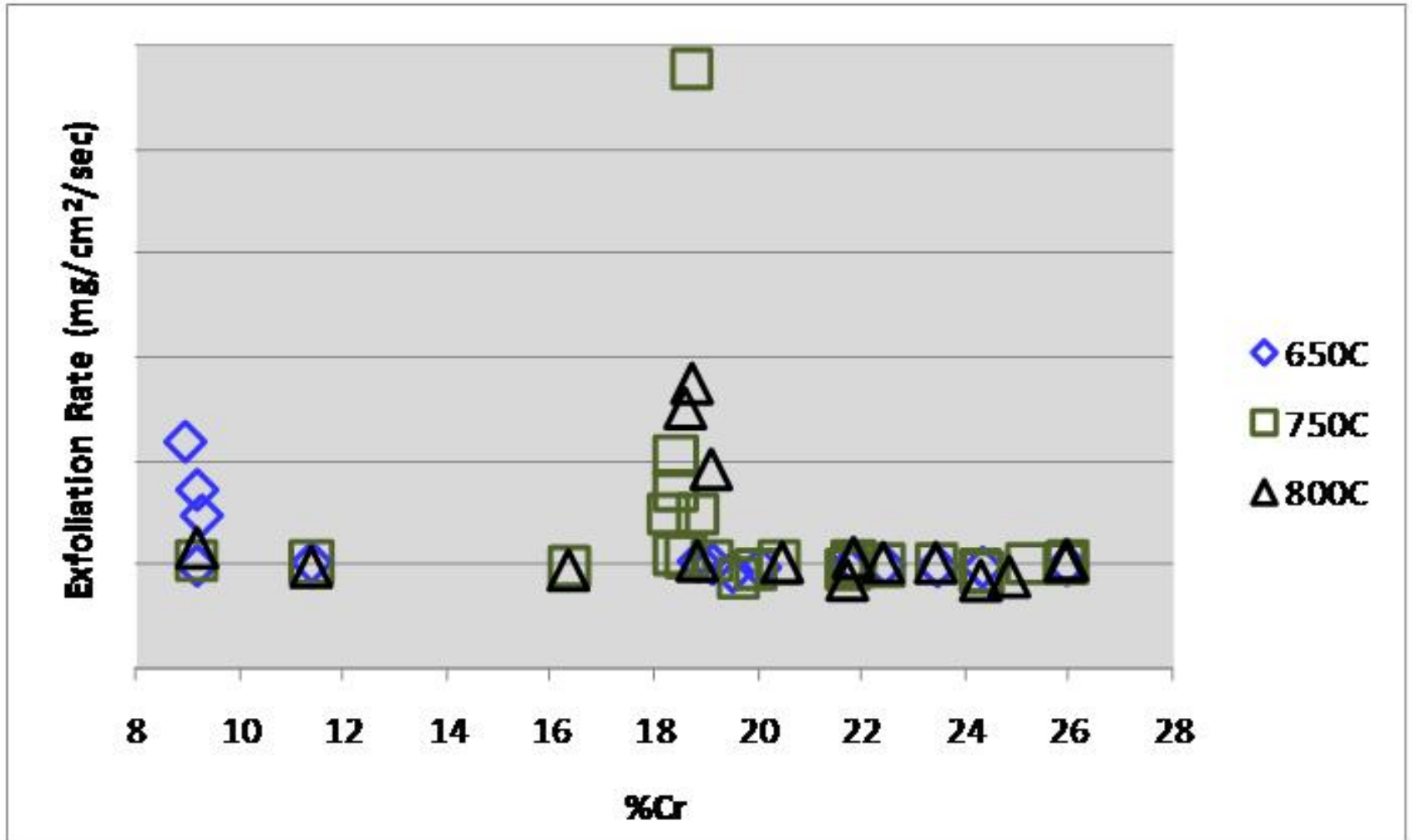


Steam Oxidation Rate Constants



J.M. Sarver - 14th International Conference on Environmental Degradation of Materials in Nuclear Power Systems

Relative Exfoliation Rates



J.M. Sarver - 14th International Conference on Environmental Degradation of Materials in Nuclear Power Systems

Oxide Evaluation

Low Cr Ferritics (T23)

- ▶ **High Oxidation at 650°C**
 - Iron oxide outer layer
 - Inner oxide contains some Cr
- ▶ **Through-Thickness Oxidation after 1,000 Hours at 800°C**

**T23 after 1,000
Hours in 800°C
Steam**

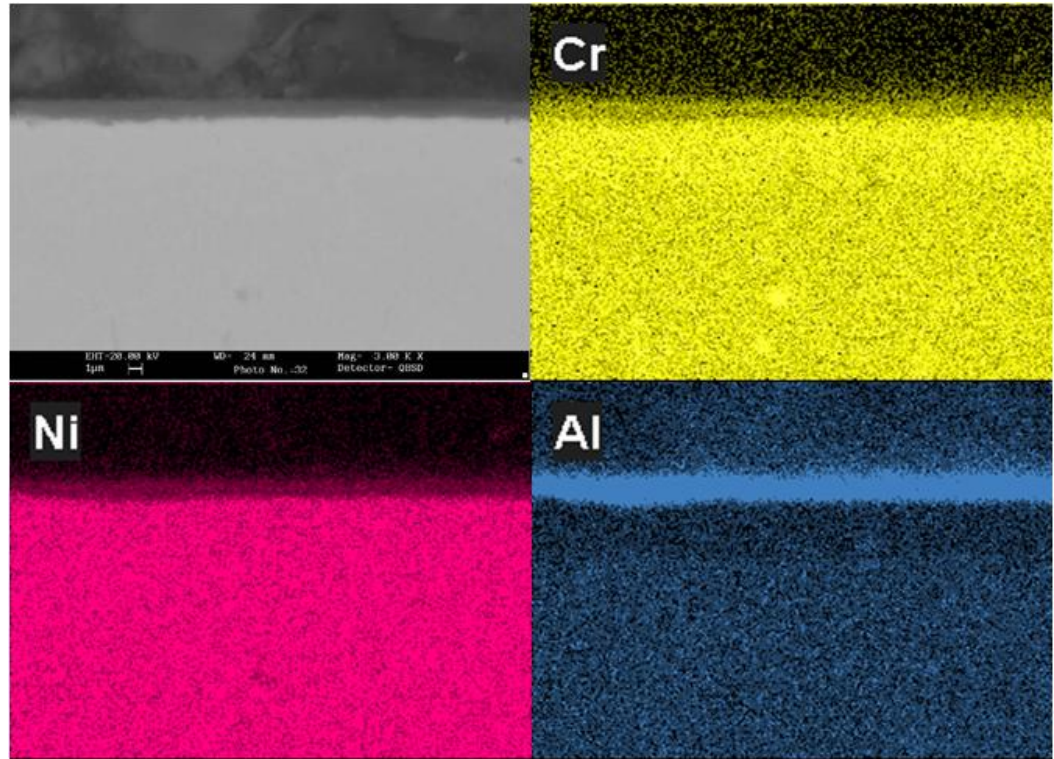


Oxide Evaluation

Low Cr Ni-Based Alloy (Alloy 214)

▶ *Essentially no Oxidation at 800°C*

- Al oxide forms
- Evidence of Al-depletion
- Some Cr and Ni in Oxide

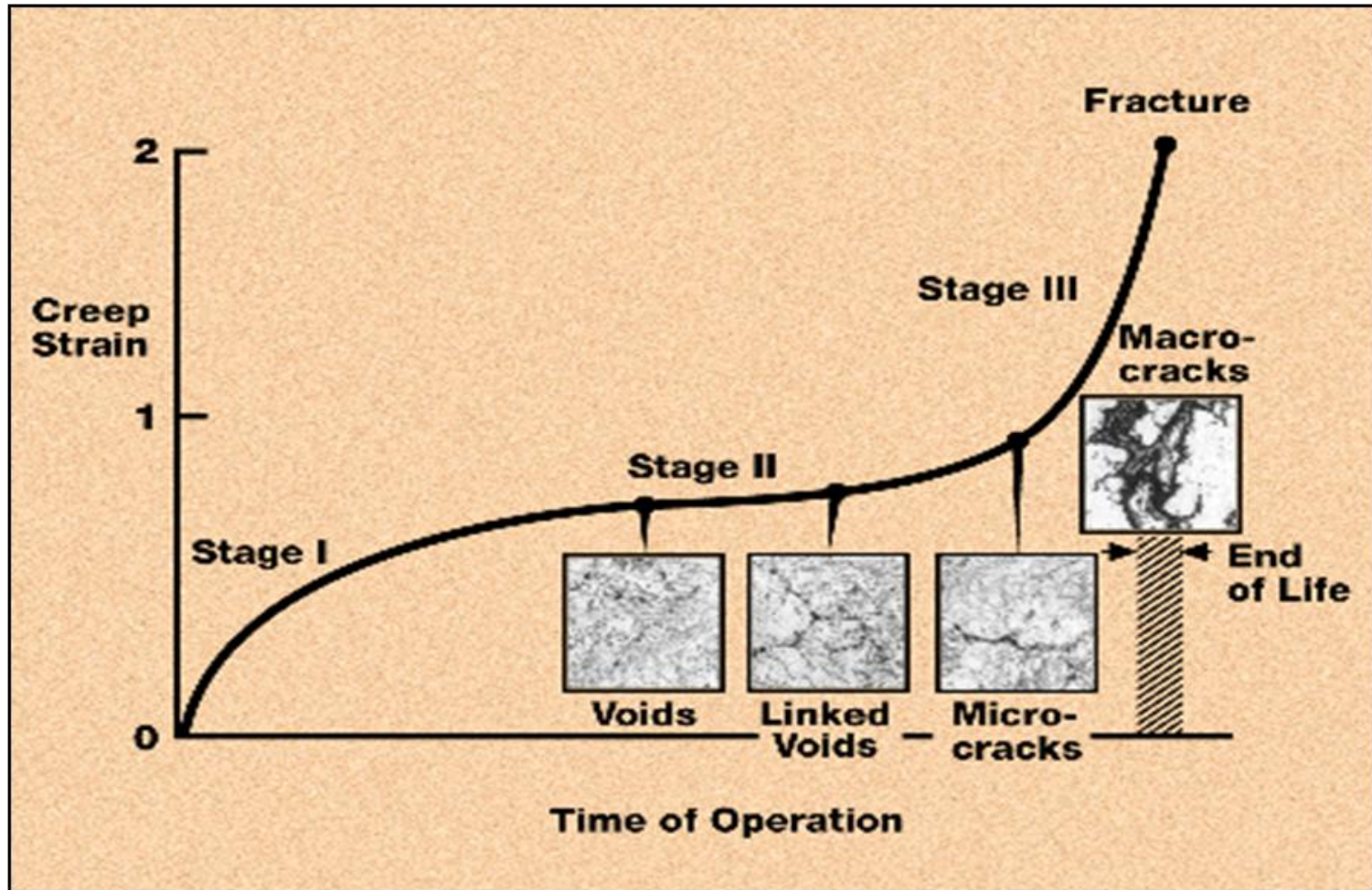


Other USC Issues

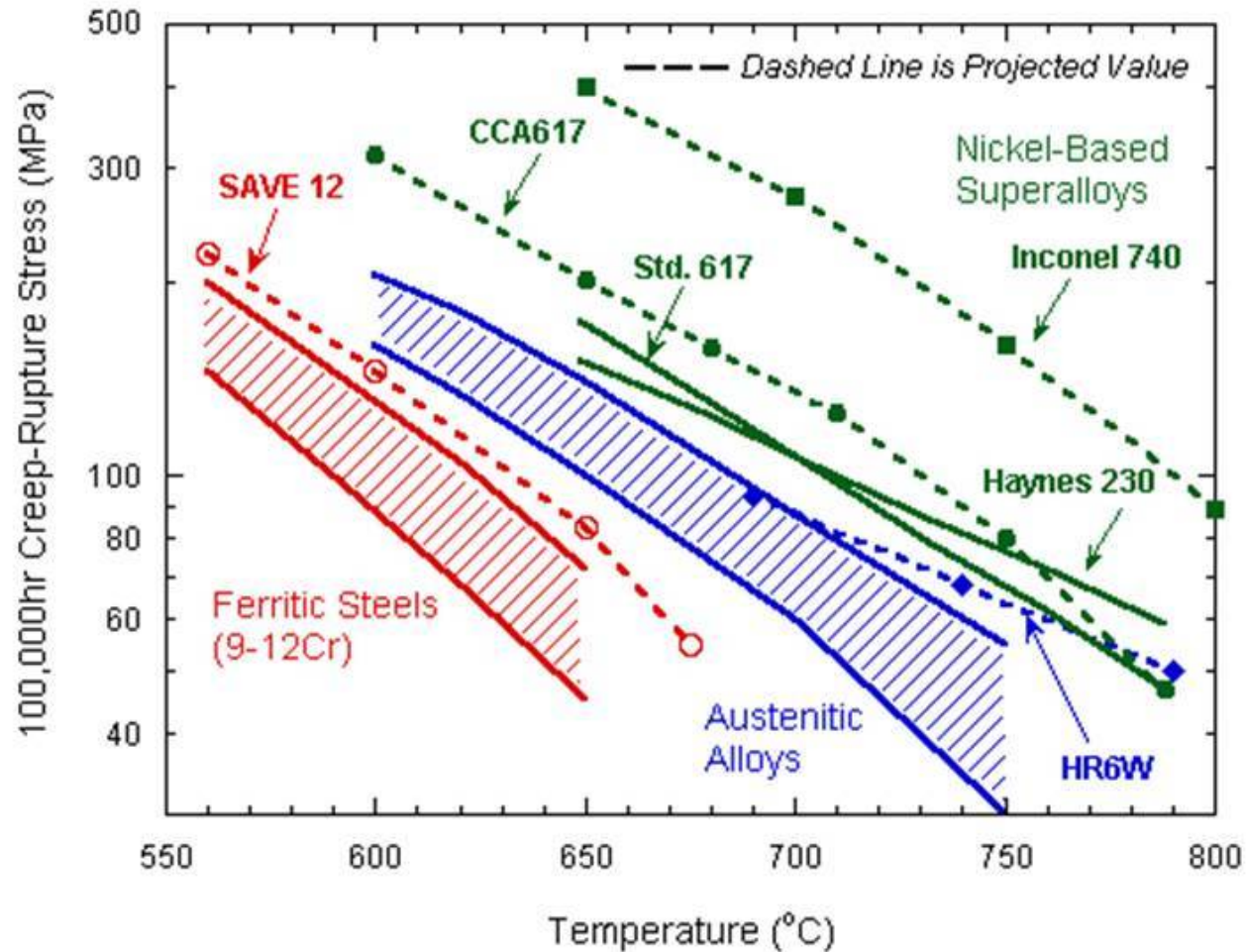


LONG/TERM OVERHEAT . . . CREEP

Long Term Overheat/Creep

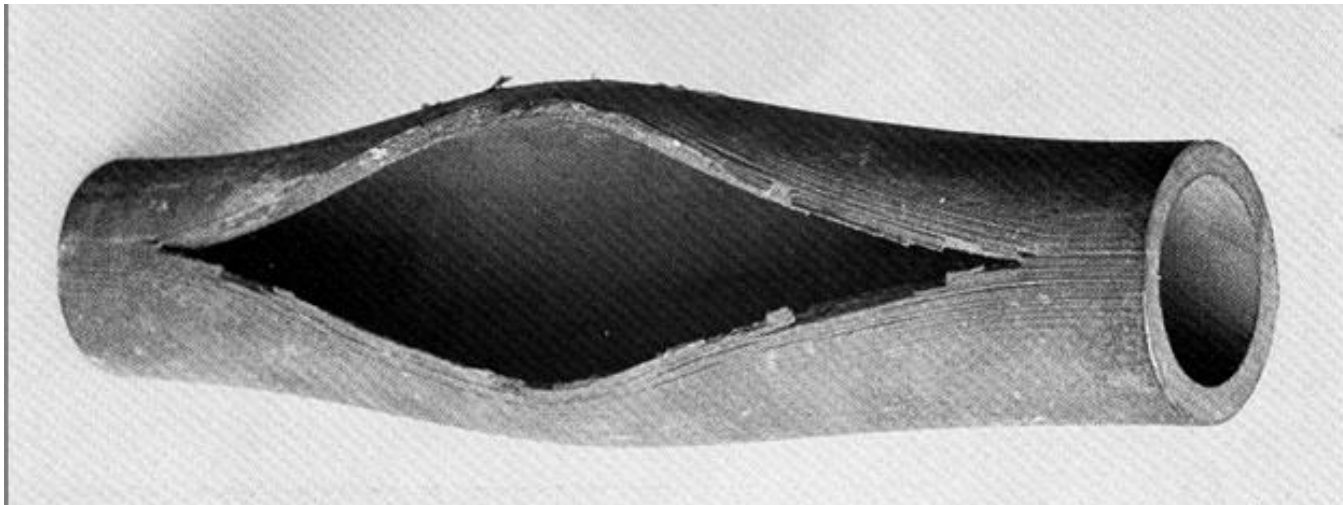


100,000 Hr Creep-Rupture Plot



R. Viswanathan - 8th Ultra-Steel Workshop, Tsukuba, Japan, July 2004

Long Term Overheat/Creep



Short Term Overheat



***Superheater Failures during
Initial Plant Startup***

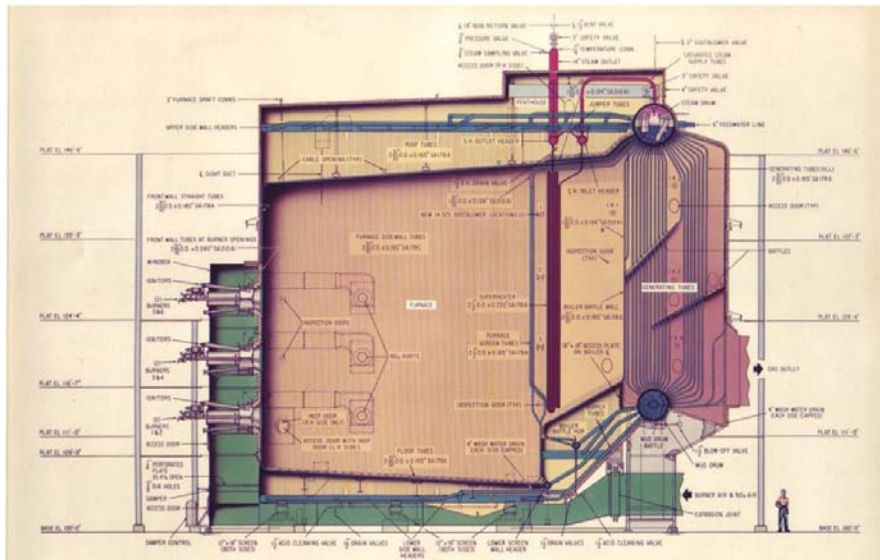
Operation with Sub-ASME Water

Drum Boiler for Tar Sands Application

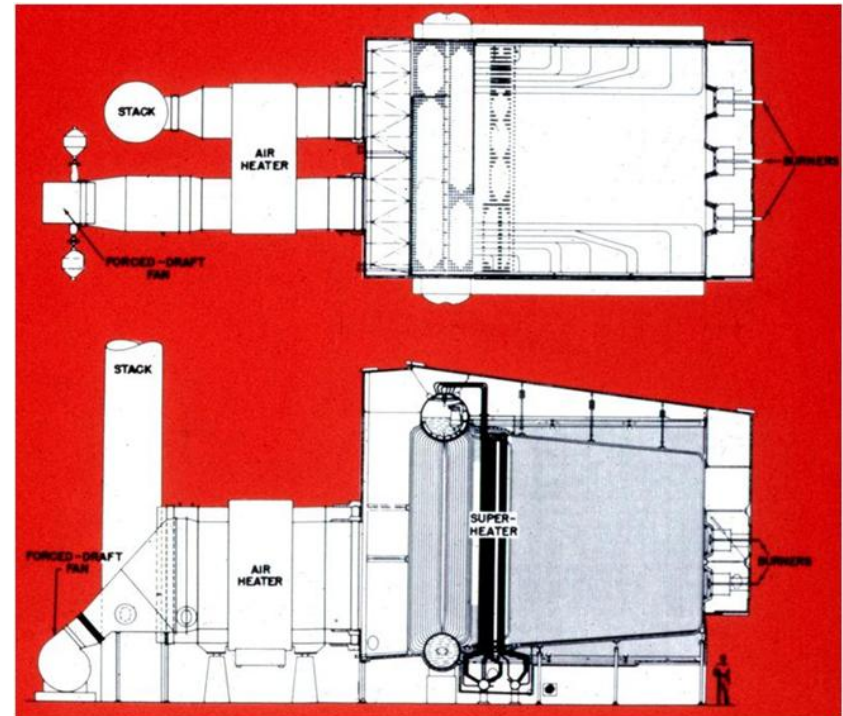
▶ Recycled Water from an Evaporator

- Sub-ASME quality water for some constituents
- Non-turbine application

▶ What are the Risks?



B&W PFT Boiler



Schematic – Oil Fired Industrial Boiler

Operation with Sub-ASME Water

Background on ASME Consensus Guidelines

- ▶ ASME Industrial Boiler Subcommittee formed in 1973 with Initial Guidelines Issued in 1975 (IWC Presentation)
- ▶ Committee of Vendors, Manufacturers, Consultants and Users
- ▶ ASME Document No. H00156 Issued in 1979
- ▶ D.E. Simon II, "Feedwater Quality in Modern Industrial Boilers: A Consensus of Proper Current Operating Practices," *Proceedings of the 36th International Water Conference*, 1975 pp 65-69
- ▶ "Feedwater Quality in Modern Industrial Boilers: Consensus on Current Practice," **Power**, February 1978, pp 58-59
- ▶ D.E. Simon II and A.W. Fynsk, "Suggested Control Values for Feedwater and Boiler Water Quality in Industrial Boilers," Paper present at Industrial Power Conference, Houston, TX, October 26-29, 1980. ASME Paper Number 80-IPC/Pwr-8

Operation with Sub-ASME Water

Comments Related to the ASME Consensus Guidelines

- ▶ *Guidelines and **Not** Standards*
- ▶ *Values for current design boilers with high heat fluxes, physical size restrictions, and relatively small diameter steam drums and furnaces*
- ▶ *A primary purpose is to prevent entry of depositable species in the boiler*
- ▶ *Guidelines predicated on periodic inspections and cleaning when required*
- ▶ *Silica values based on volatile carryover, but assumed to also prevent internal deposition of complex silicates*
- ▶ *The alkalinity value of 20% of TDS based on an early “rule of thumb” established for locomotive boilers and never seriously challenged*

Operation with Sub-ASME Water

Conservative Boiler Design for Tar Sands Applications

- ▶ ***Limit furnace volume heat release to 25,00-35,000 BTU/hr/ft³***
- ▶ ***Minimize local heat flux = 25,000-50,000 Btu/hr/ft²***
- ▶ ***Maximize circulating velocity & turbulence (MLR tubes)***
- ▶ ***Short waterwall and short generating bank circuits reduce circuit pressure drop and top quality***
- ▶ ***Ensure flow stability***
 - In all circuits
 - Over the load range
- ▶ ***Provision for easy inspection, acid cleaning, high pressure water wash, and bank replacement***

ASME Feedwater vs. Evaporators

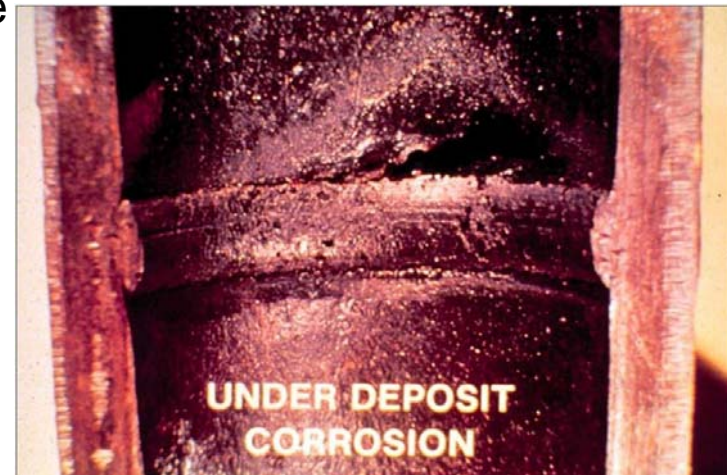
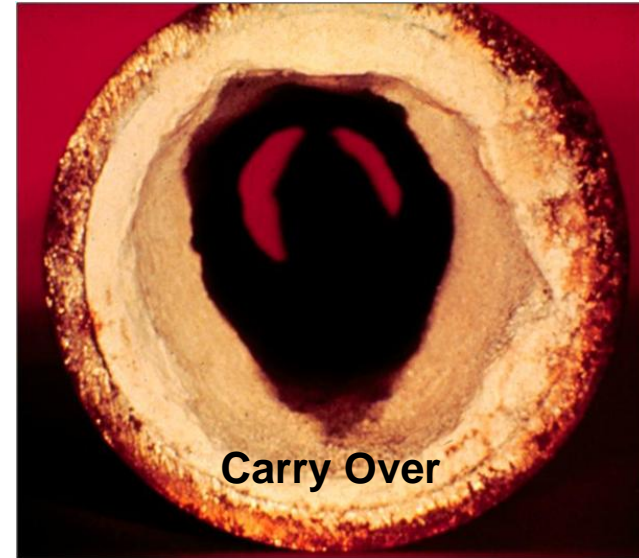
	Best Case ASME (900 – 1000 psig)	Expected Evaps Per GE 8/20/08	B&W's Worst Case Design
Organic, ppm TOC Oil & Grease	<0.2 <0.2	0.1 – 1	<1 <0.2
Silica, ppm	<0.4	0.04 – 0.2	<0.8
Ca + Mg, ppm	<0.02	0.015	<0.015
Iron, ppm	<0.02	<0.01	<0.02
Chloride, ppm	<7	2.5	4.9
Sulfate, ppm	<30	<1	<2
TDS, ppm	<40	<5	<45
pH	8.8 – 9.6	8.8 – 9.6	8.8 – 9.6
Blowdown Rate	5%		5%

Bryan Stone (B&W) - 2008 SPE Feedwater Discussion

Operation with Sub-ASME Water

Water Chemistry Philosophies

- ▶ **Better to prevent contaminants from entering the boiler than to treat them in the boiler**
- ▶ **Still there is room for sub-ASME water in non-turbine applications**
 - Utilize conservative boiler design
 - Treatment options are available
- ▶ **Ultimately need to minimize the deposition and to quantify the risks**



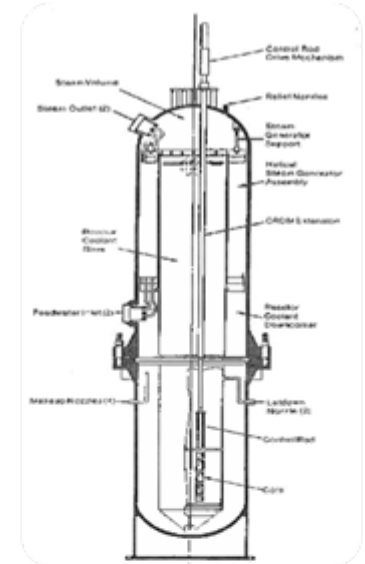
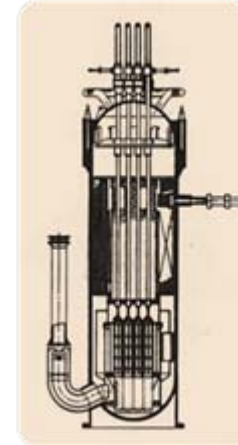
Integral PWRs



NSSS for NS Savannah



Consolidated nuclear steam generator
NS Otto Hahn

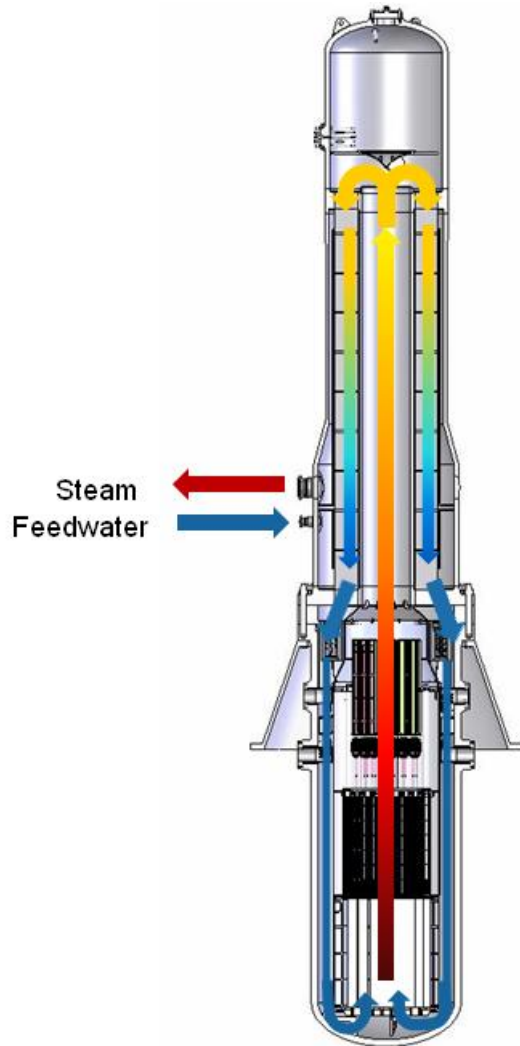


SMPP design



- ▶ **Integral 125 Mwe modular reactor with SG, pressurizer**
- ▶ **Utilize “industry standard” PWR fuel**
- ▶ **Rail shippable**
- ▶ **Fully independent reactor modules that can be combined as needed**

B&W mPower™ Integral Reactor Design



Thermal Power:	~400 MWt (NRC public website)
Reactor Coolant:	Typical PWR pressure 620°F Outlet Temperature (NRC public website)
Active Core Volume:	Scaling Closer to a BWR in Volume
Reactor Vessel:	Dimensions not released
Fuel Assemblies:	17x17 fuel pin array 69 fuel assemblies Core dimensions not released
Steam Generator	Simple B&W OTSG with superheat

Thank You

B&W

babcock & wilcox canada ltd.

B&W

power generation group

