

**DOE Office of Fossil Energy-EPRI
Workshop on Heat Exchangers for sCO₂ Power Cycles**

**A Brief Overview of Current State of
Knowledge of HT Corrosion in sCO₂**

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Hilton Mission Bay San Diego, October 15, 2015

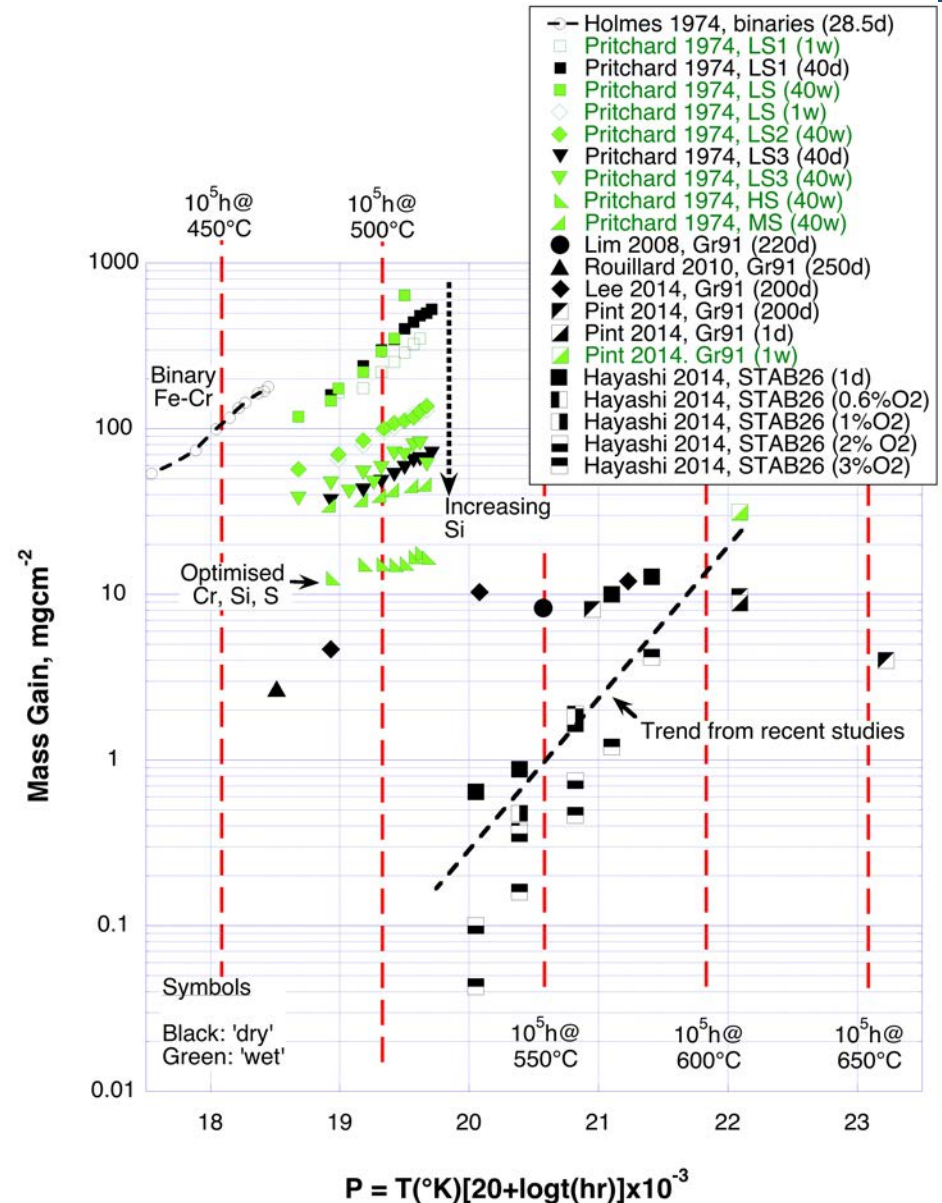
Prior Experience of Corrosion in sCO₂

Significant research in support of UK gas-cooled reactors:

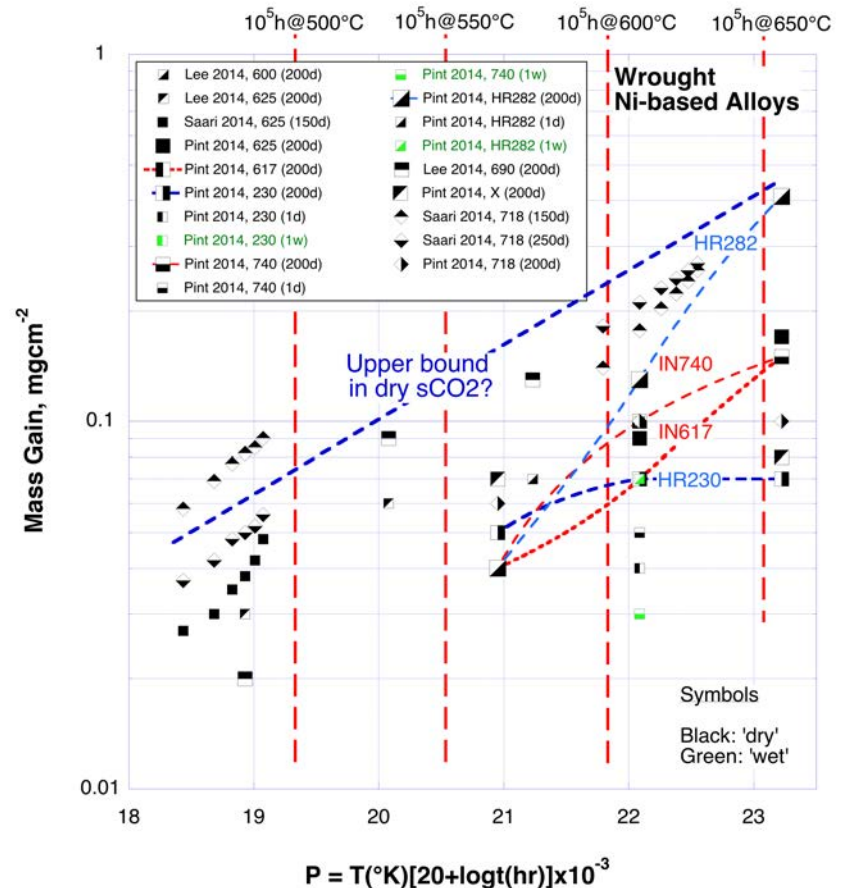
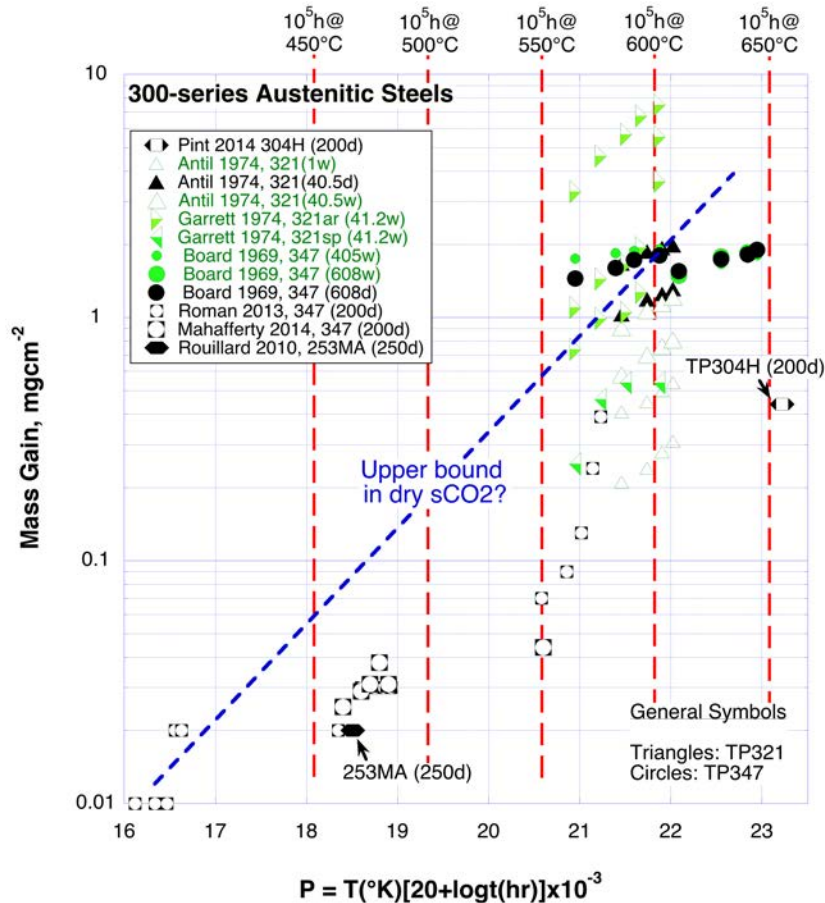
- Tests at 40 bar, ≤550°C (ferritics); 650-850°C (austenitics)
- Ferritics: 'breakaway oxidation' (exposures to 95kh)
 - *attributed to effects of C*
- Austenitics: potential problems only with ≤18Cr-8Ni
 - *C pickup when duplex scales formed*
 - *for higher-Cr alloys, C pick-up only in initial stages, or after exfoliation; sigma phase?*
 - *expected to meet requirements (250kh)*
 - *test exposures to 25kh*
- Key contributions from additions of CH₄ and H₂O

Recent Results

- Higher T and P , but shorter t than earlier UK studies
- No systematic reports of effects of impurities in $s\text{CO}_2$
- Kinetics appear \pm consistent

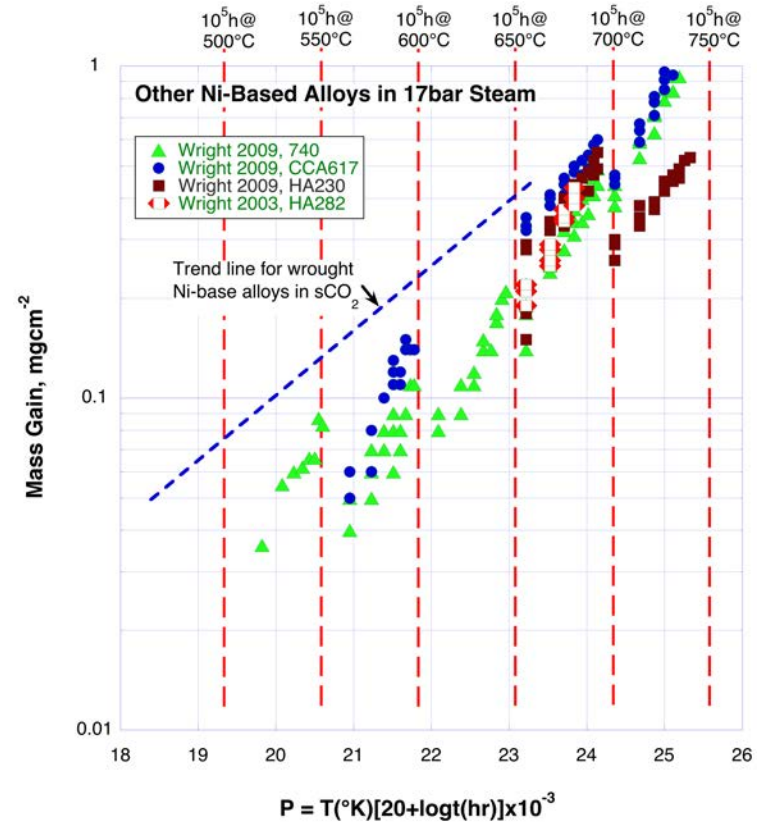
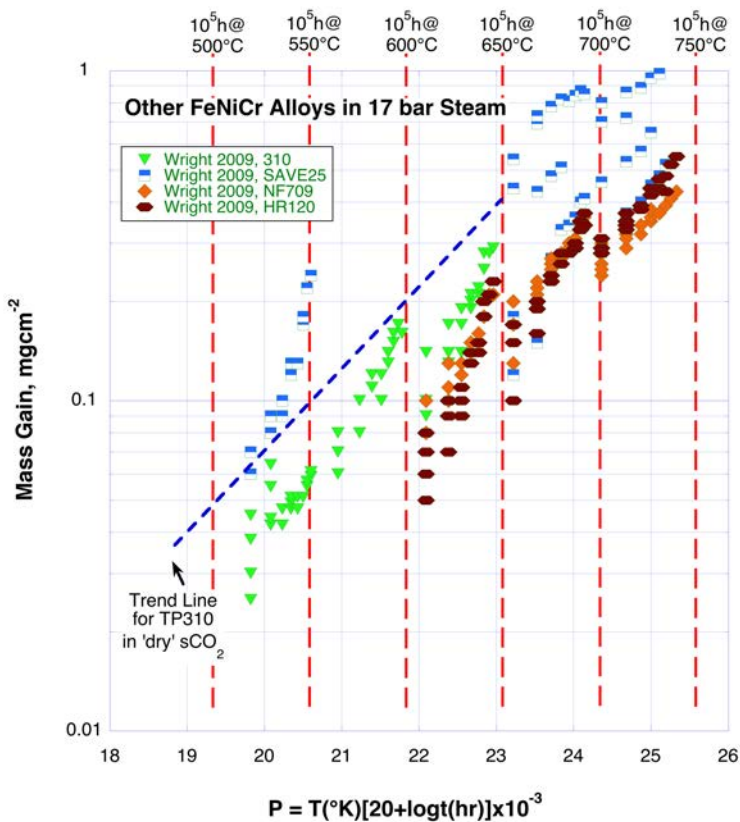


Oxidation Kinetics of Austenitics in sCO₂



Similar Kinetics in sCO₂ & HP Steam

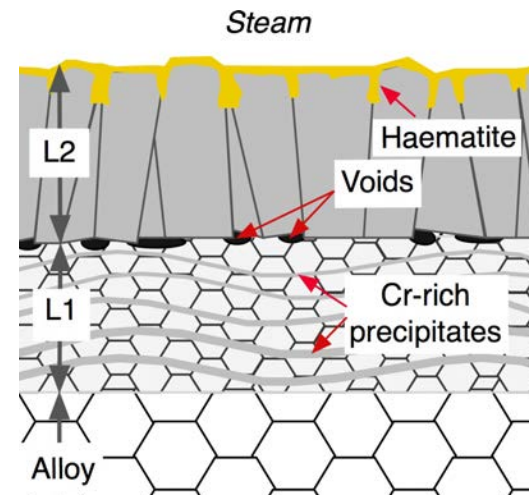
Steam data (lab) suggest no change in mechanism ≤ 4 kh at 650-800°C



Scale Morphologies Compared to HP Steam?

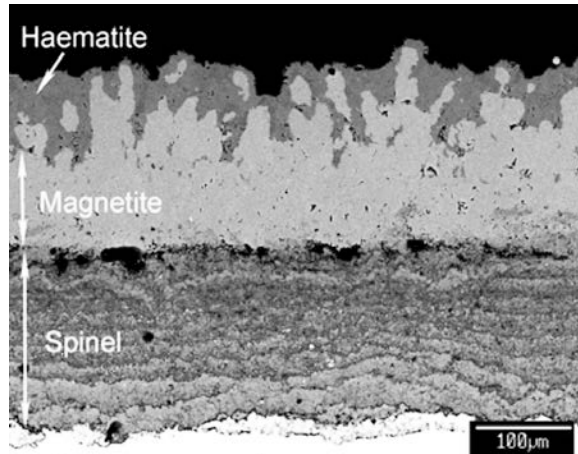
- Steam oxidation: different scale morphologies than in air
 - $H_2O = O^+ + OH^-$: mobility of all 3(?) in scales
 - typically 2-layered scales: Fe-Cr spinel (inner, L1), magnetite (outer, L2)

Schematic representation:
cross section of fully-developed scale
on T91 in HP steam (EPRI Atlas) →

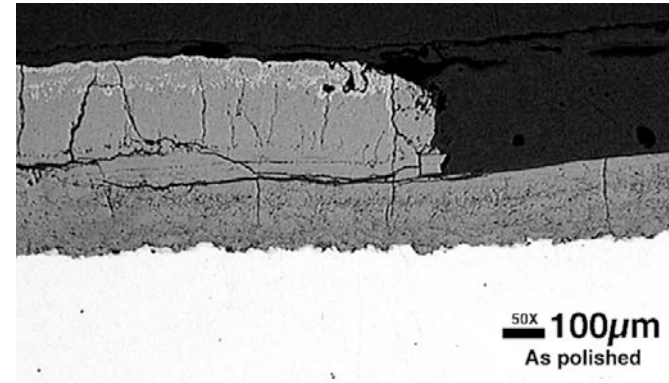


- sCO₂ involves: $CO_2 = O^+ + CO^-$
 - similar oxidation process (i.e. similar scale morphologies)
 - and, carburization expected

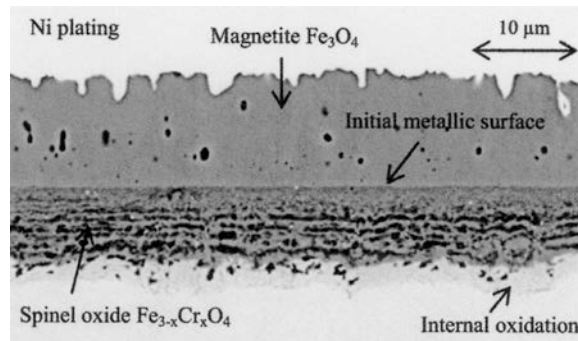
Actual Scale Morphologies Ferritics



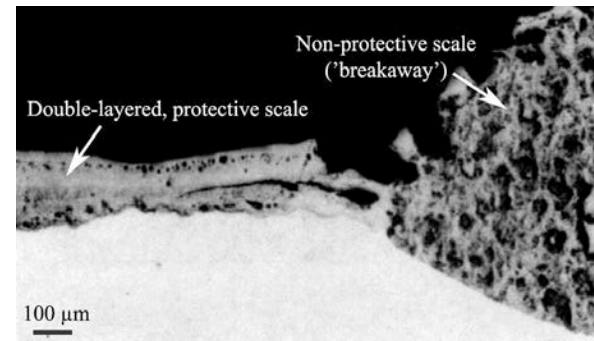
Tg1, 64kh at 566°C & 138 bar steam (EPRI Atlas)



Tg1, 155kh at 538°C & 17 bar steam (EPRI Atlas)

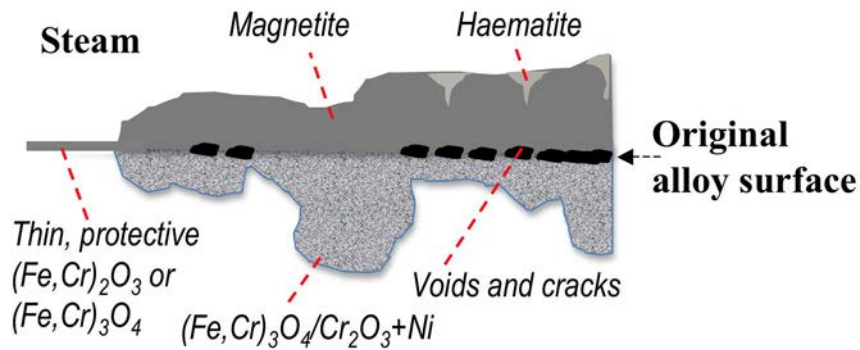


Tg1, ≈300h at 550°C & 250 bar CO₂ (Rouillard, 2010)



Fe-9Cr, ≤9kh at 550°C & 40 bar CO₂ (Harrison, 1974)

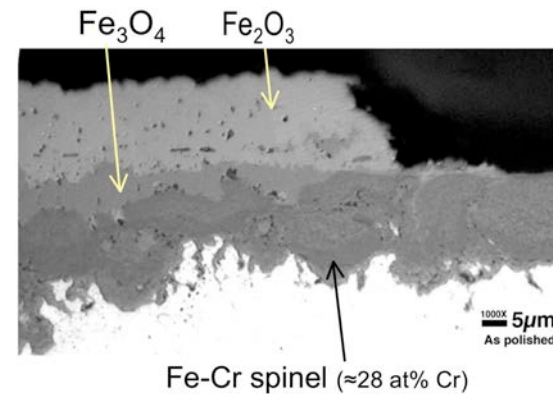
Actual Scale Morphologies Austenitics



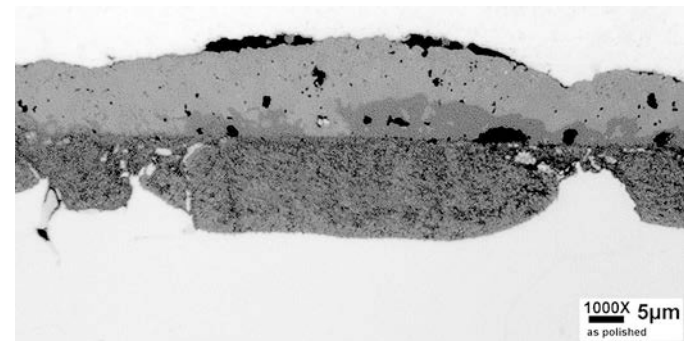
Main features of scale in HP steam
(Wright & Dooley, 2011)



TP347HFG, 500h at 700°C & 200 bar CO₂ (Pint & Keiser, 2014)



TP347HFG, 11kh at 670°C & 251 bar steam
(EPRI Atlas)



Summary: Immediate Needs

- Longer-term exposures (10kh+?)
 - *onset of failure*
 - *kinetics for thin sections*
- Morphological characterization
 - *departure from expectations (HP steam)*
 - fate of C?
 - influence of brazing elements?