Materials Performance in CO_2 and in CO_2-Steam Environments

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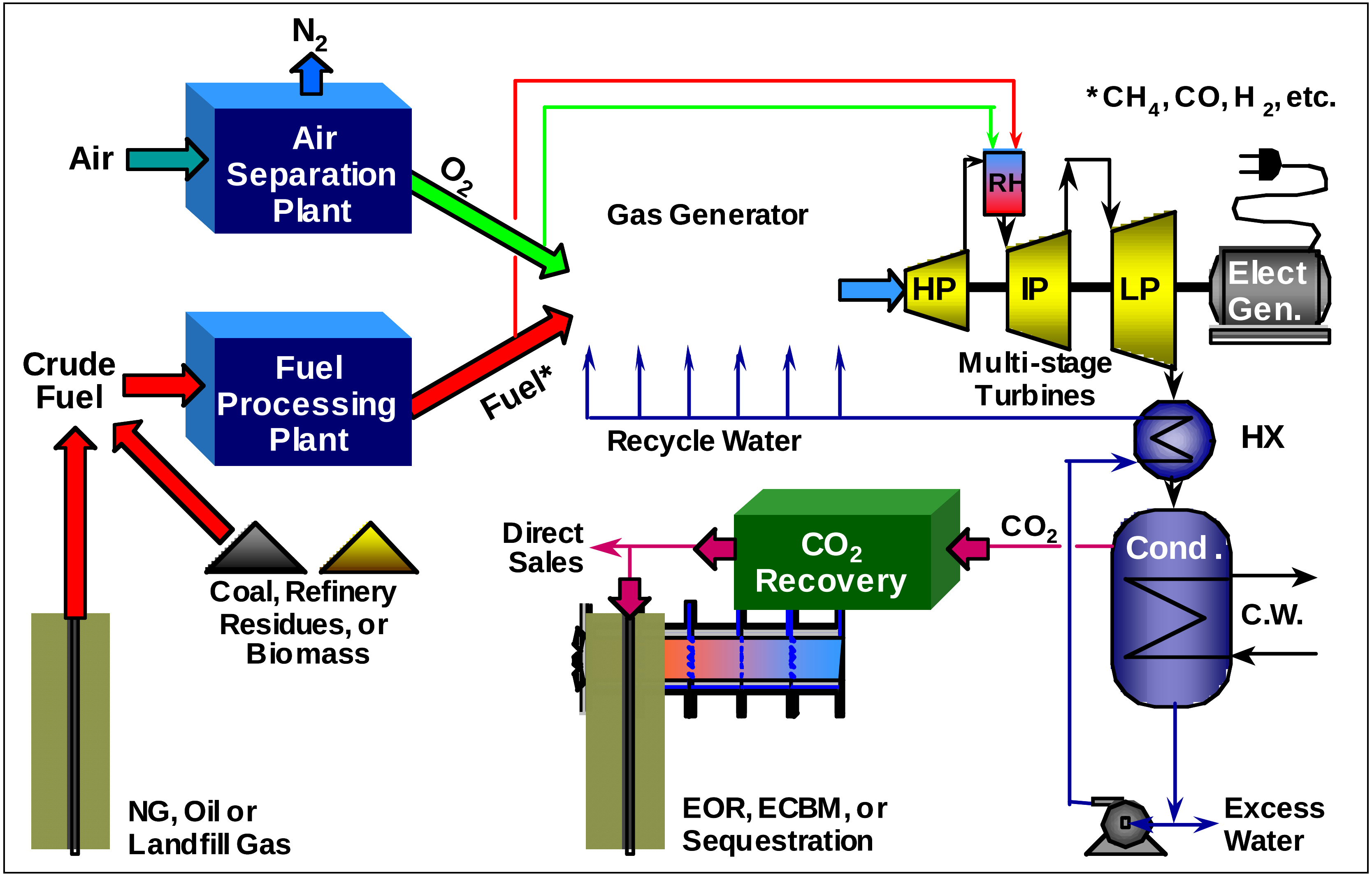
Outline

- ***Background***
- ***Objectives***
- ***Materials and experimental procedure***
- ***Alloys for evaluation***
- ***Corrosion performance of alloys***
- ***Data on creep properties in CO_2 environments***
- ***Project Summary***

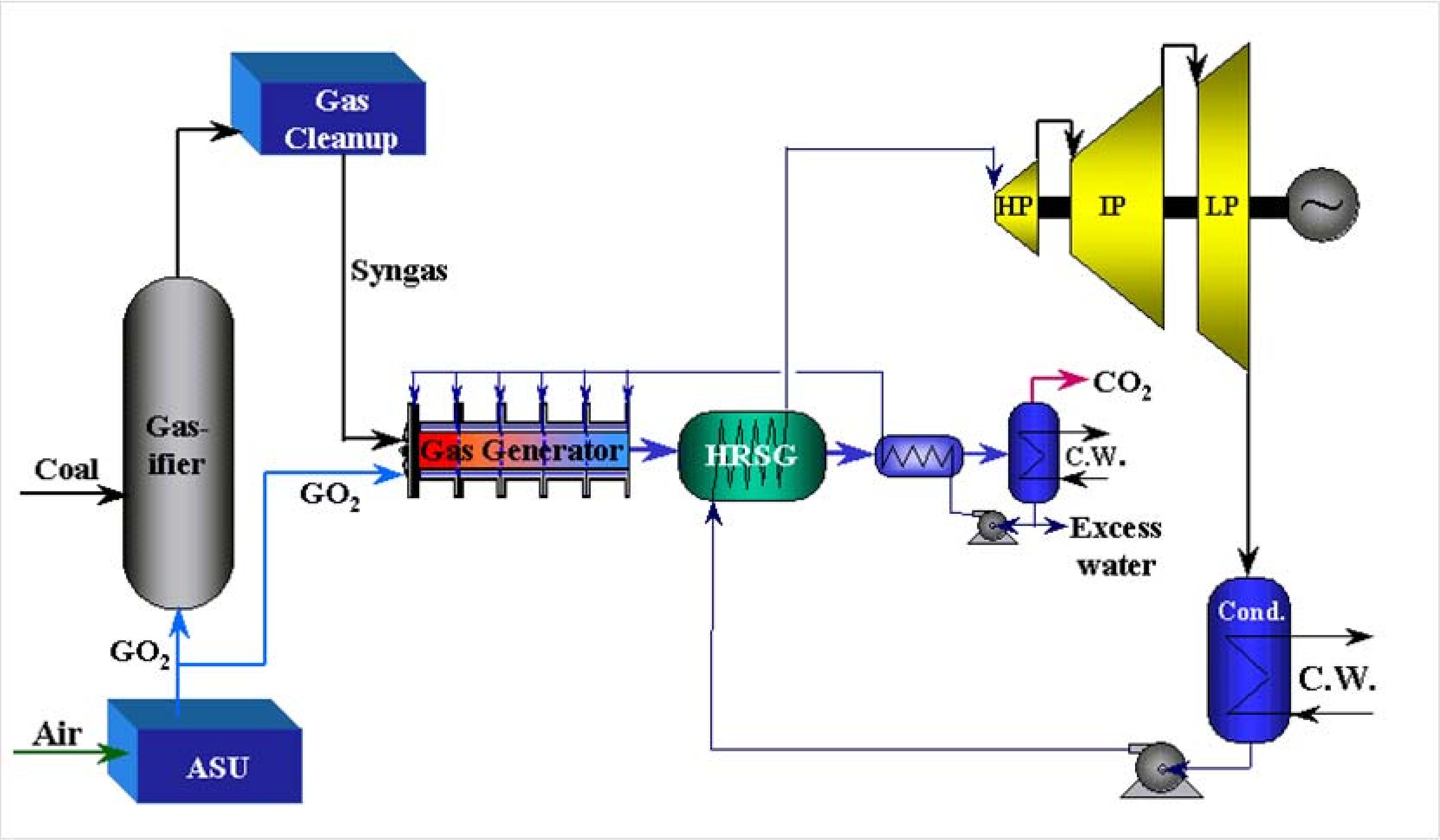
What and why Oxy-fuel Combustion

- ***Global climate change - One of the causes identified is CO_2 increase in atmosphere - one of the source for CO_2 is exhaust from fossil fuel combustion plants***
- ***Energy production (in particular, electricity) is expected to increase due to population increase and per capita increase in energy consumption***
- ***To meet the energy needs fossil fuels (coal, gas, oil, etc.) will play a major part in production even with a projected increase from alternate sources***
- ***To minimize CO_2 emission - current systems emphasize capture from power plants and sequestration***
- ***Oxy-fuel combustion systems - recycle CO_2 to the compressor, use novel gas turbines, and emphasize reuse***

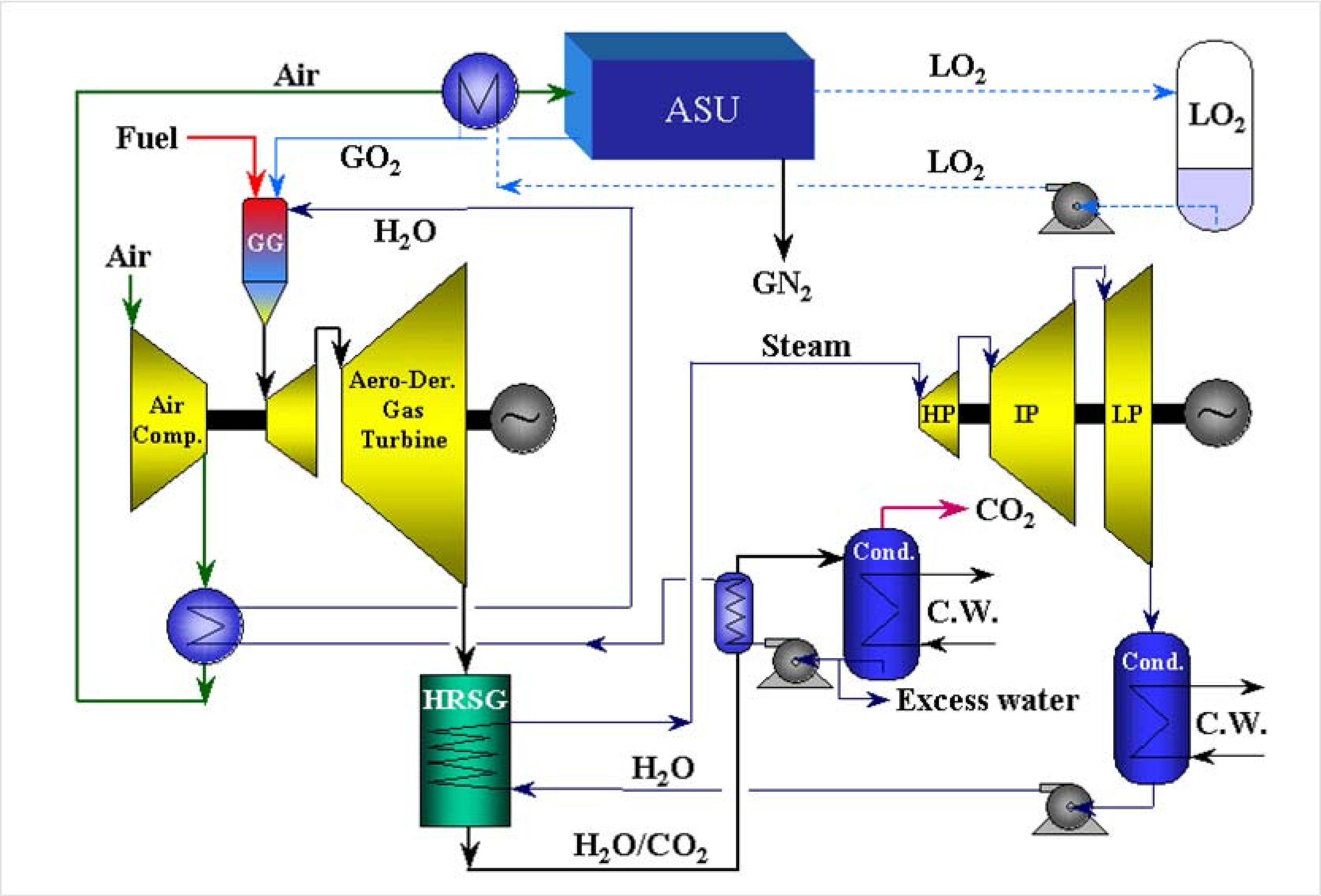
Clean Energy Systems Process



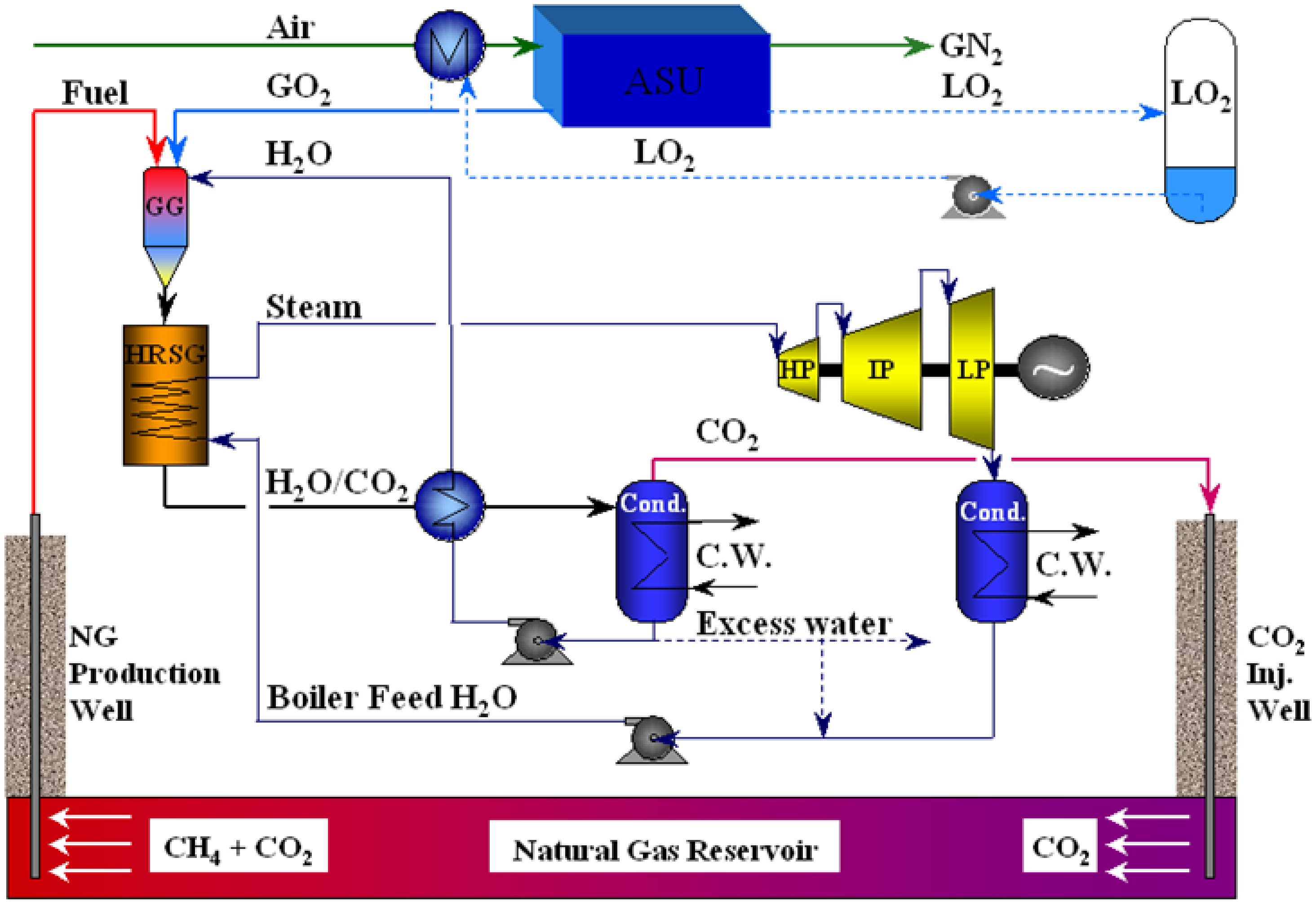
Coal Feed Demonstration at Kimberlina Facility in CA



Gas Turbine Demonstration at Kimberlina Facility in CA



Dutch Project



ANL Program Objectives

- **Evaluate oxidation/corrosion performance of metallic structural alloys in pure CO_2 and in CO_2-steam environments over a wide temperature range**
- **Establish the kinetics of scaling and internal penetration, if any, and develop correlations for long term performance**
- **Identify viable alloys for structural and gas turbine applications**
- **Evaluate the influence of exposure environment on the mechanical properties (especially creep, fatigue, and creep-fatigue) of the candidate alloys**

Current List of Alloys in the Study

Material	C	Cr	Ni	Mn	Si	Mo	Fe	Other
800H	0.08	20.1	31.7	1.0	0.2	0.3	Bal	Al 0.4, Ti 0.3
330	0.05	10.0	35.0	1.5	1.25	-	Bal	-
333	0.05	25.0	45.0	-	1.0	3.0	18.0	Co 3.0, W 3.0
617	0.08	21.6	53.6	0.1	0.1	9.5	0.9	Co 12.5, Al 1.2, Ti 0.3
625	0.05	21.5	Bal	0.3	0.3	9.0	2.5	Nb 3.7, Al 0.2, Ti 0.2
602CA	0.19	25.1	62.6	0.1	0.1	-	9.3	Al 2.3, Ti 0.13, Zr 0.19, Y 0.09
230	0.11	21.7	60.4	0.5	0.4	1.4	1.2	W 14, Al 0.3, La 0.015
693	0.02	28.8	Bal	0.2	0.04	0.13	5.8	Al 3.3, Nb 0.67, Ti 0.4, Zr 0.03
740	0.07	25.0	Bal	0.3	0.5	0.5	1.0	Co 20.0, Ti 2.0, Al 0.8, Nb+Ta 2.0
718	-	19.0	52.0	-	-	3.0	19.0	Nb 5.0, Al 0.5, Ti 0.9, B 0.002
MA956	-	20.0	-	-	-	-	Bal	Al 4.5, Ti 0.5, Y_2O_3 0.6

Laboratory Test Details

Key variables: Temperature, time, alloy composition

Materials: Fe- and Ni-base alloys, coatings

Environment: Pure CO_2 and CO_2-steam mixtures

Test temperature range: 650-1000°C

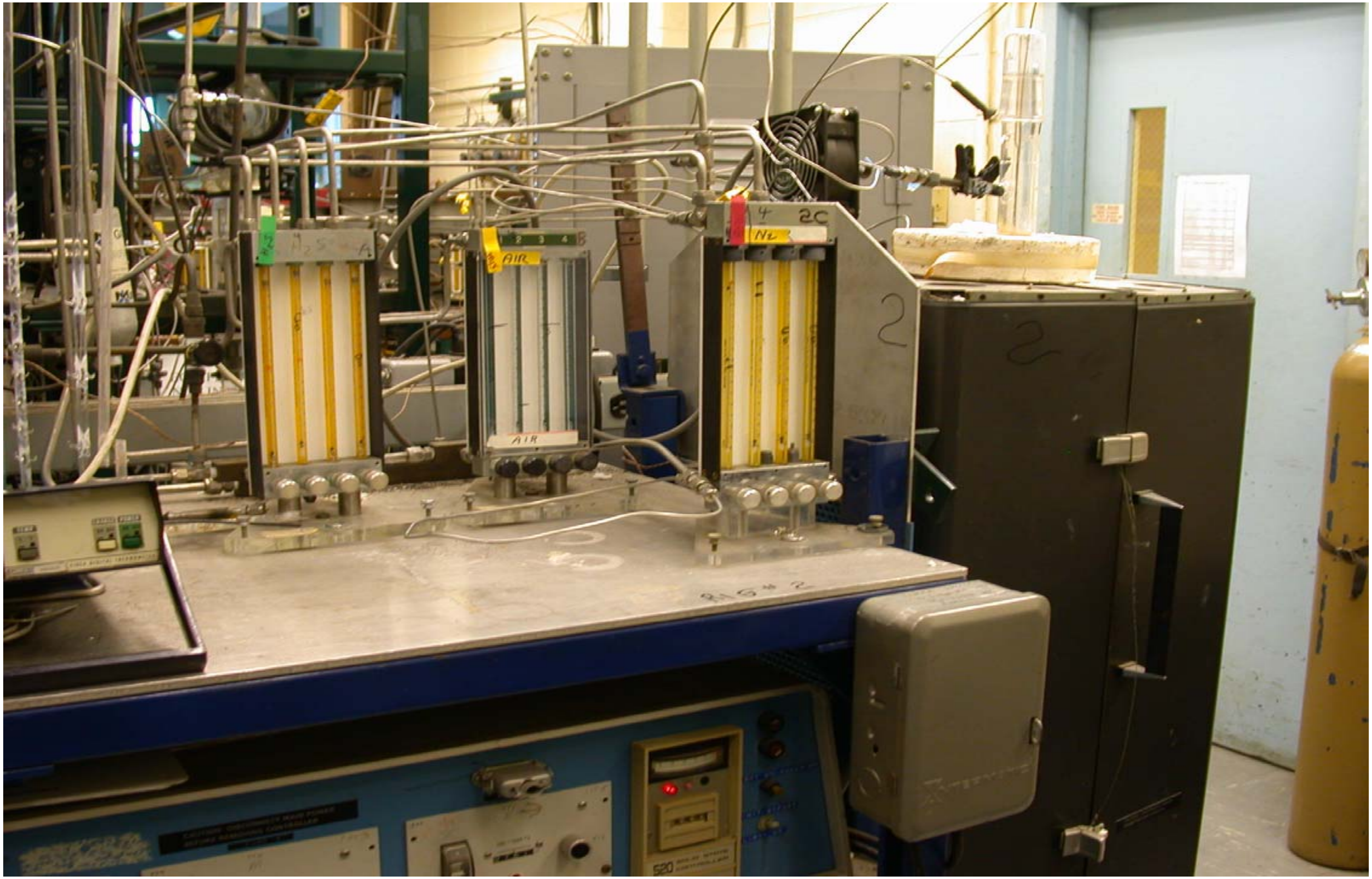
Test times: up to 10,000 h

Specimen evaluation: weight change
scanning electron microscopy
energy dispersive X-ray analysis
X-ray diffraction
synchrotron nanobeam analysis

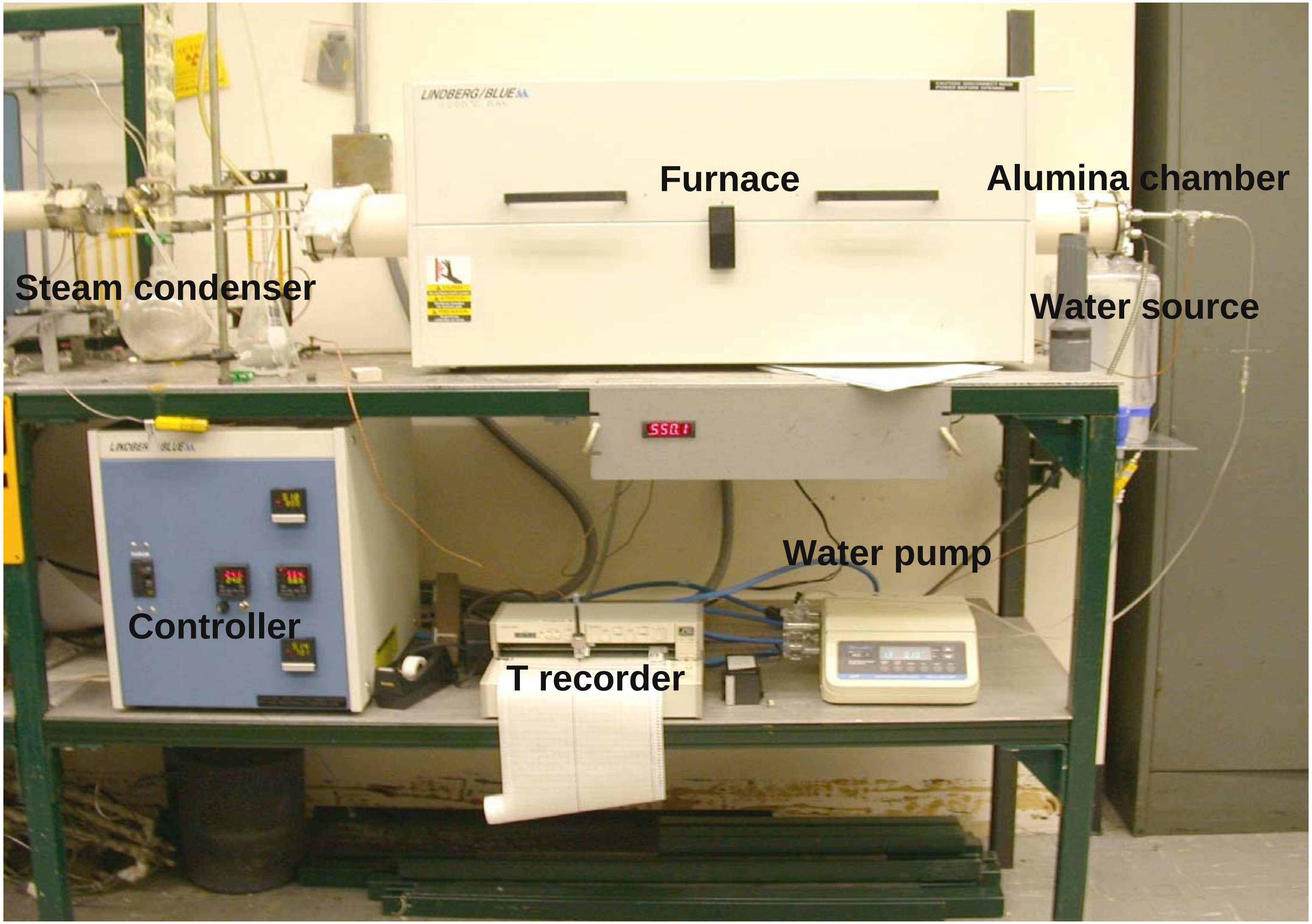
Specimen Exposure Environments

Environment	Exposure temperature (¡C)	Exposure time (h)
CO_2	650	1,865
	750	2,760
	850	5,426
	950	2,547
50% CO_2 Ğ50% Steam	650	10,090
	750	10,090
	850	1,400
Steam	750	1,220
	850	510
Air	750	3,000
	850	3,000

CO_2 Exposure Test Facility

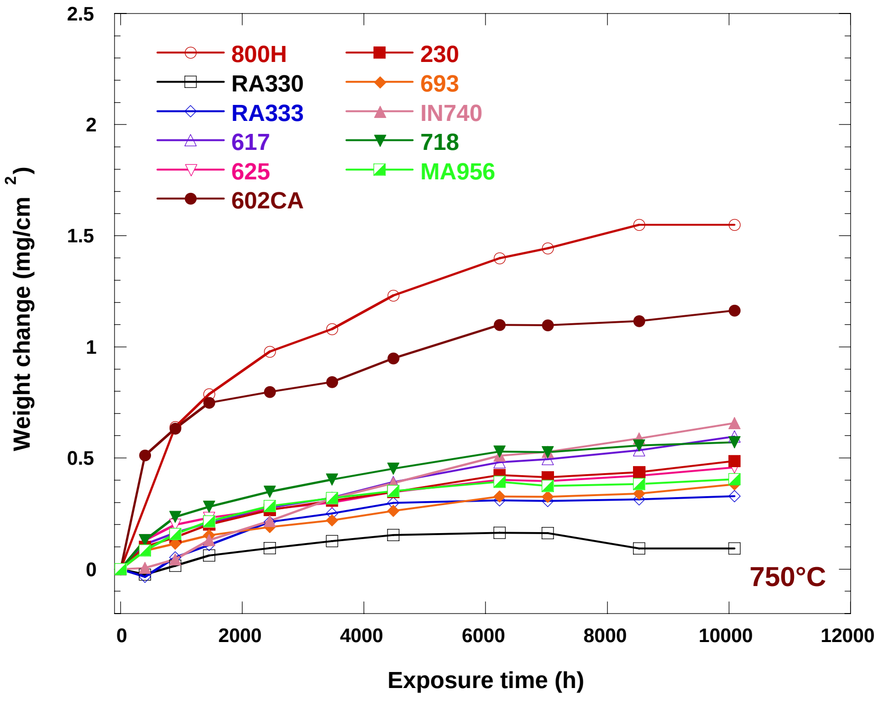


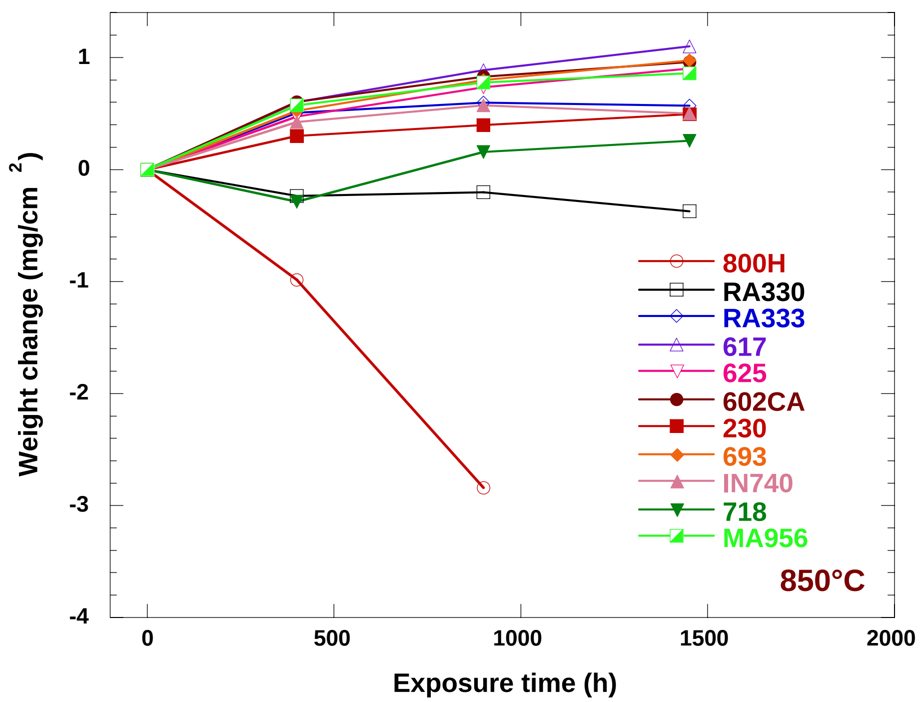
CO_2-Steam Exposure Test Facility



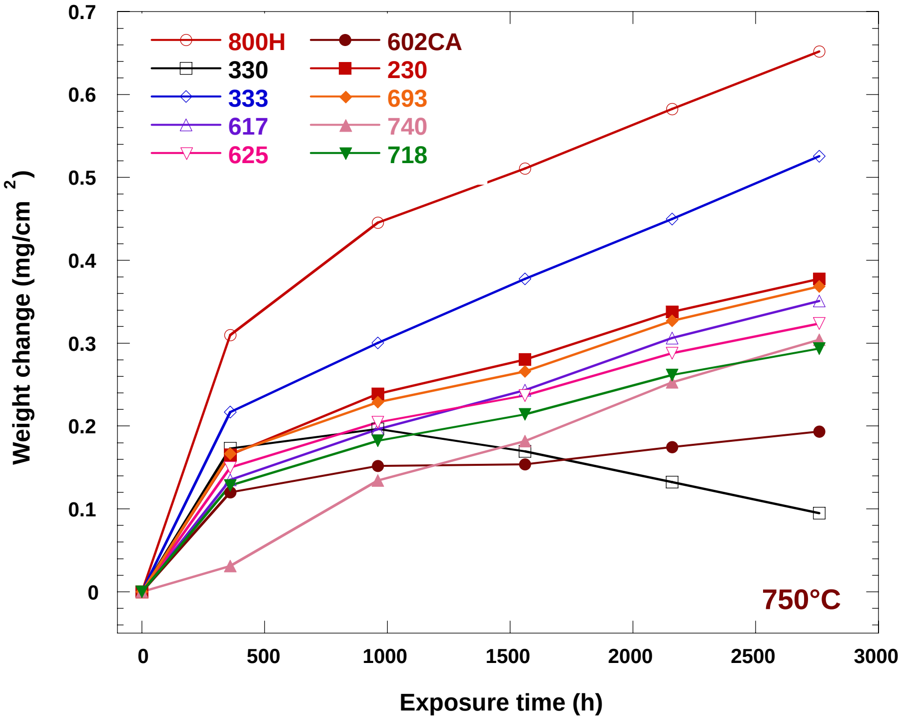
Creep Test Facility

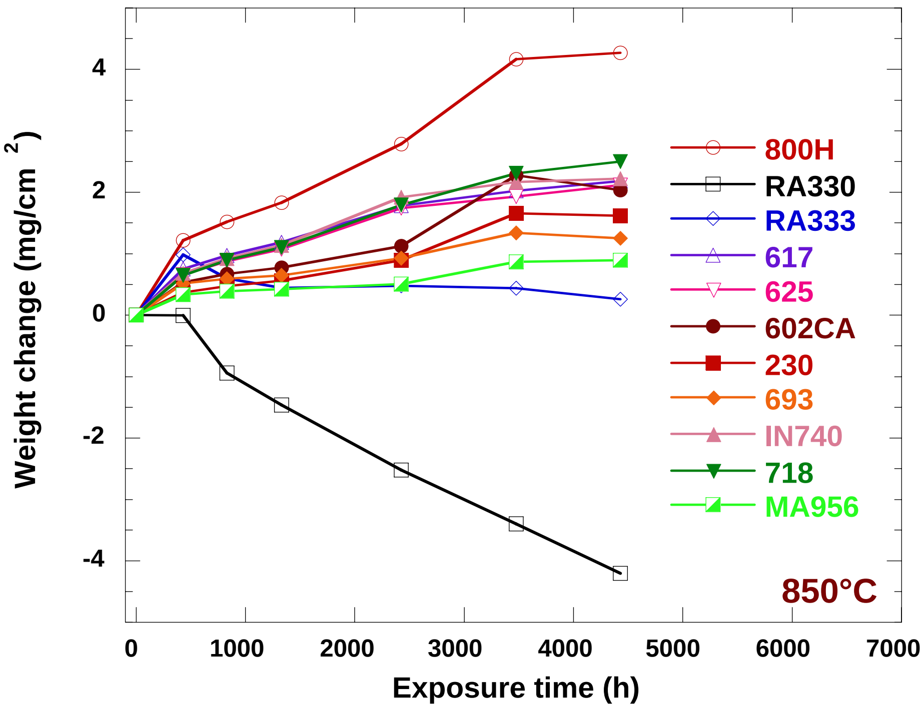
Oxidation Performance in Pure CO_2 at 750 and 850°C



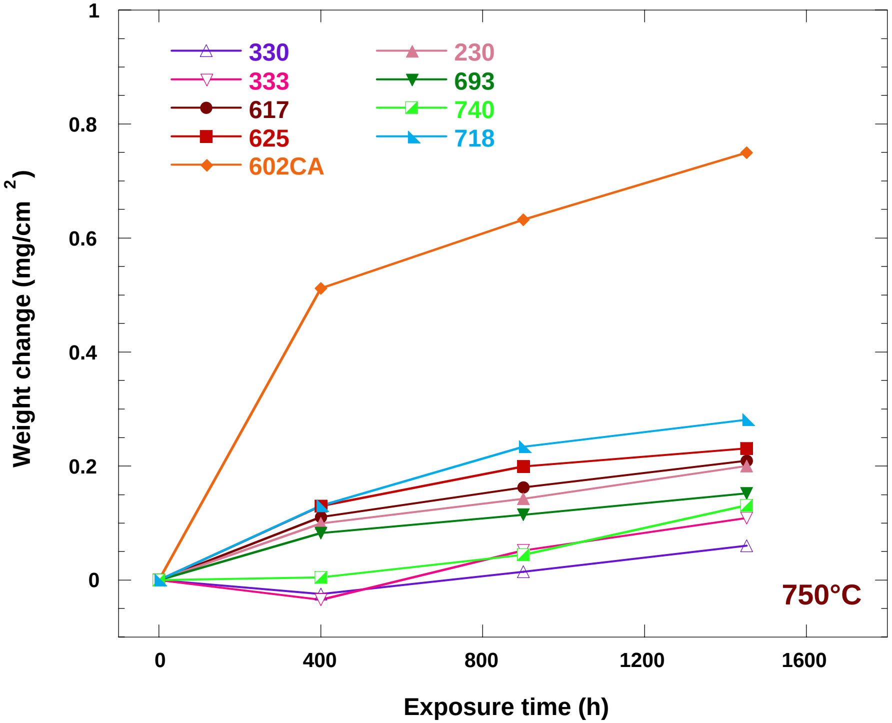


Oxidation Performance in 50% CO_2- 50% H_2O at 750 and 850°C

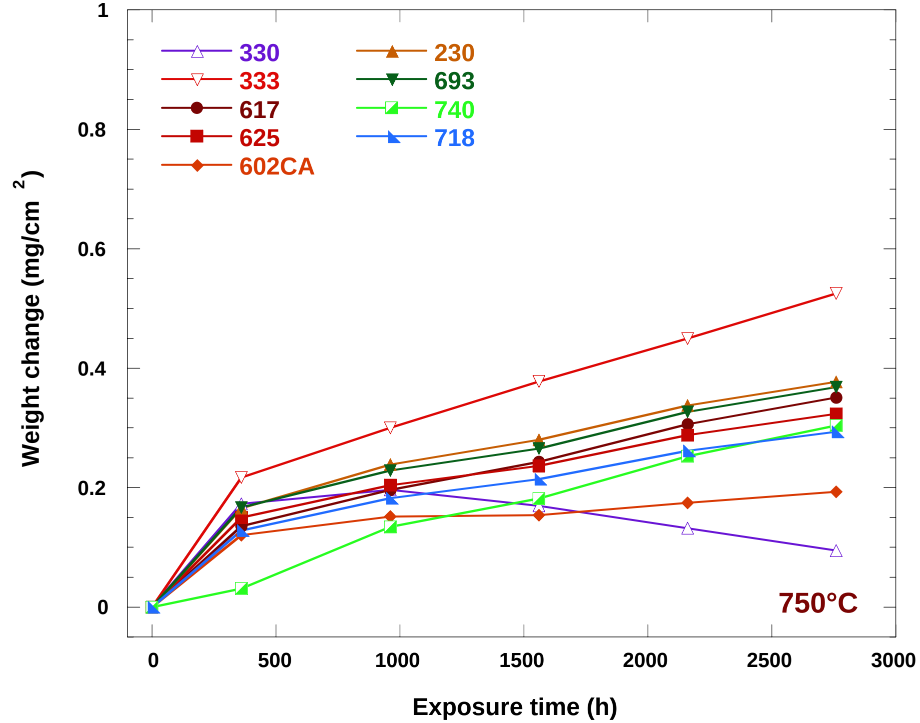




Oxidation Performance in CO_2 and in 50% CO_2-50% H_2O at 750°C



Pure CO_2



50% CO_2 -50% H_2O

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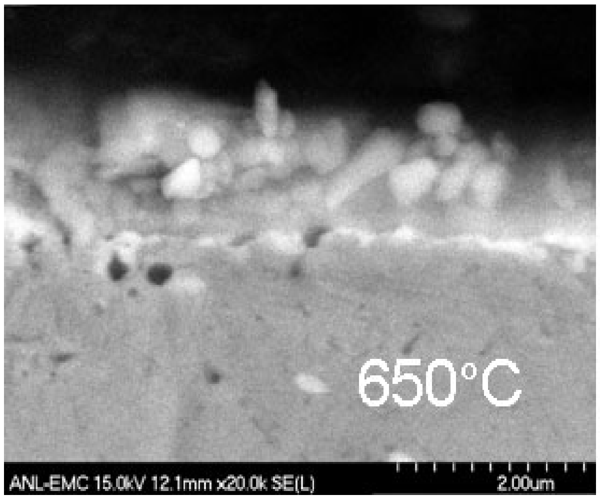
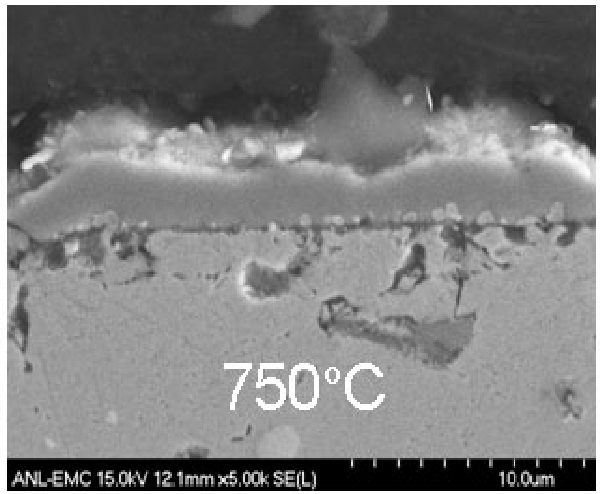
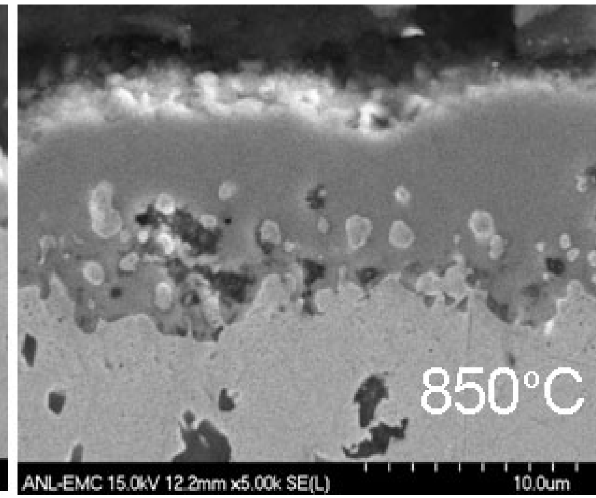
Alloy 617 exposed to pure CO_2



1452 h

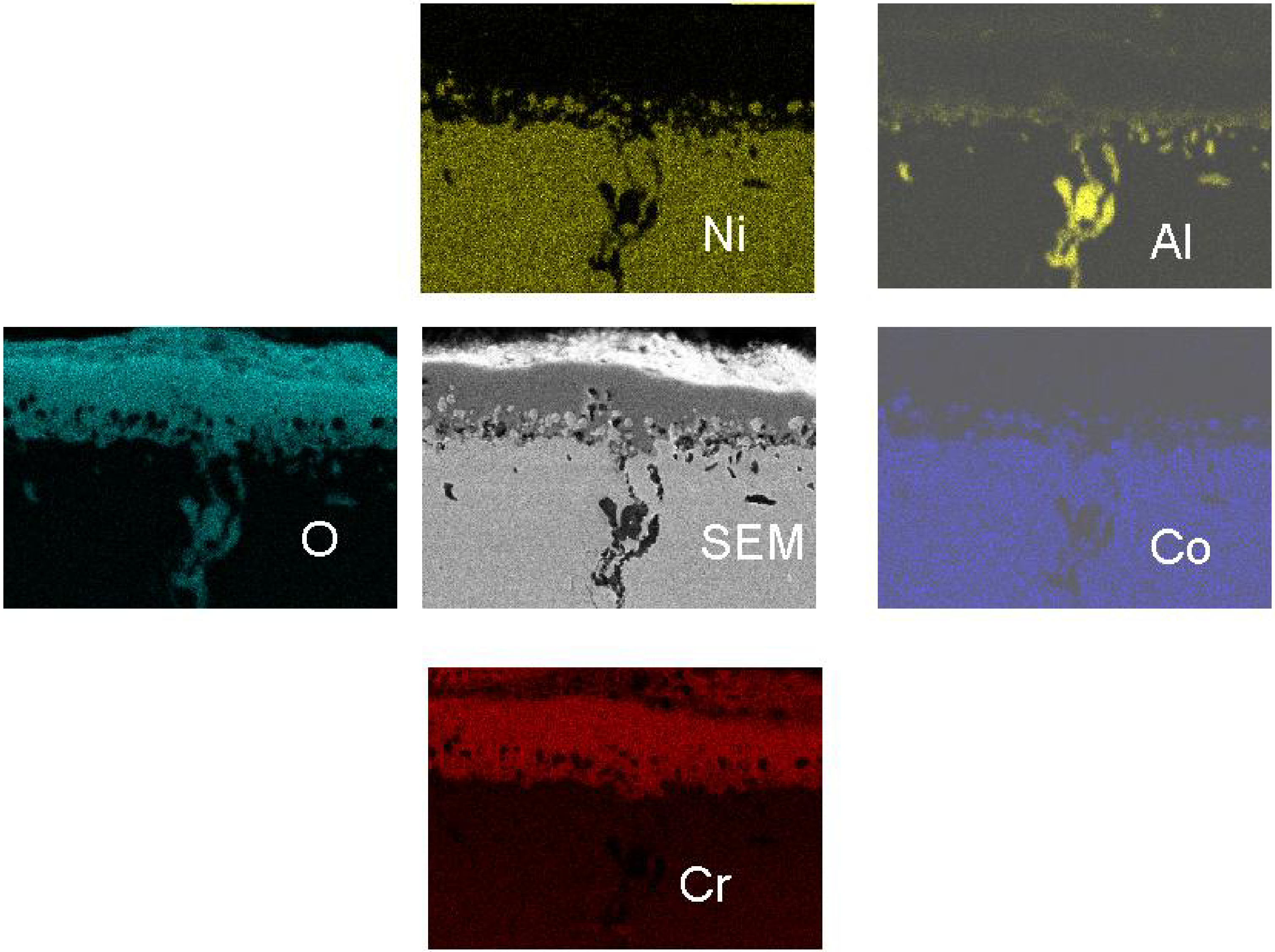


1452 h

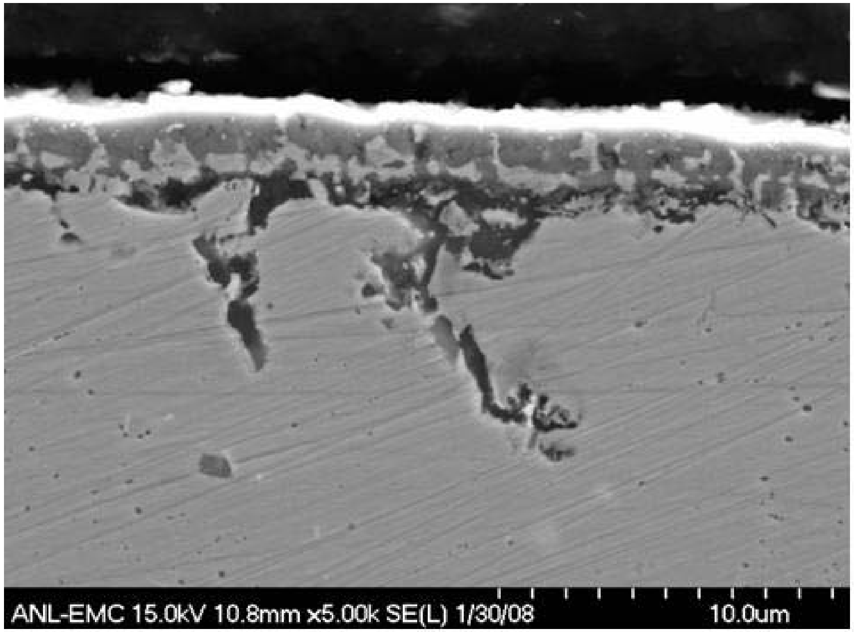


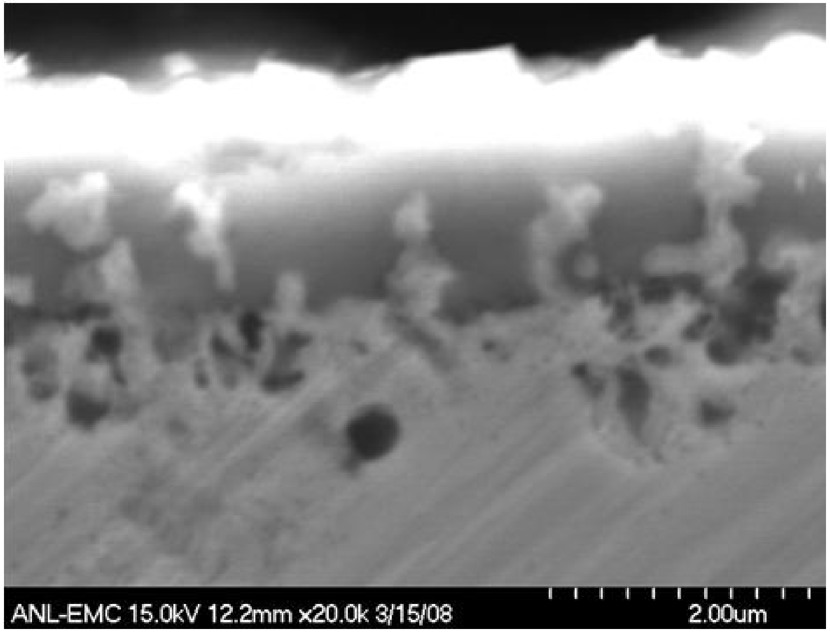
1400 h

EDX mapping: Alloy 617 exposed to pure CO_2 for 1,400 h at 850°C

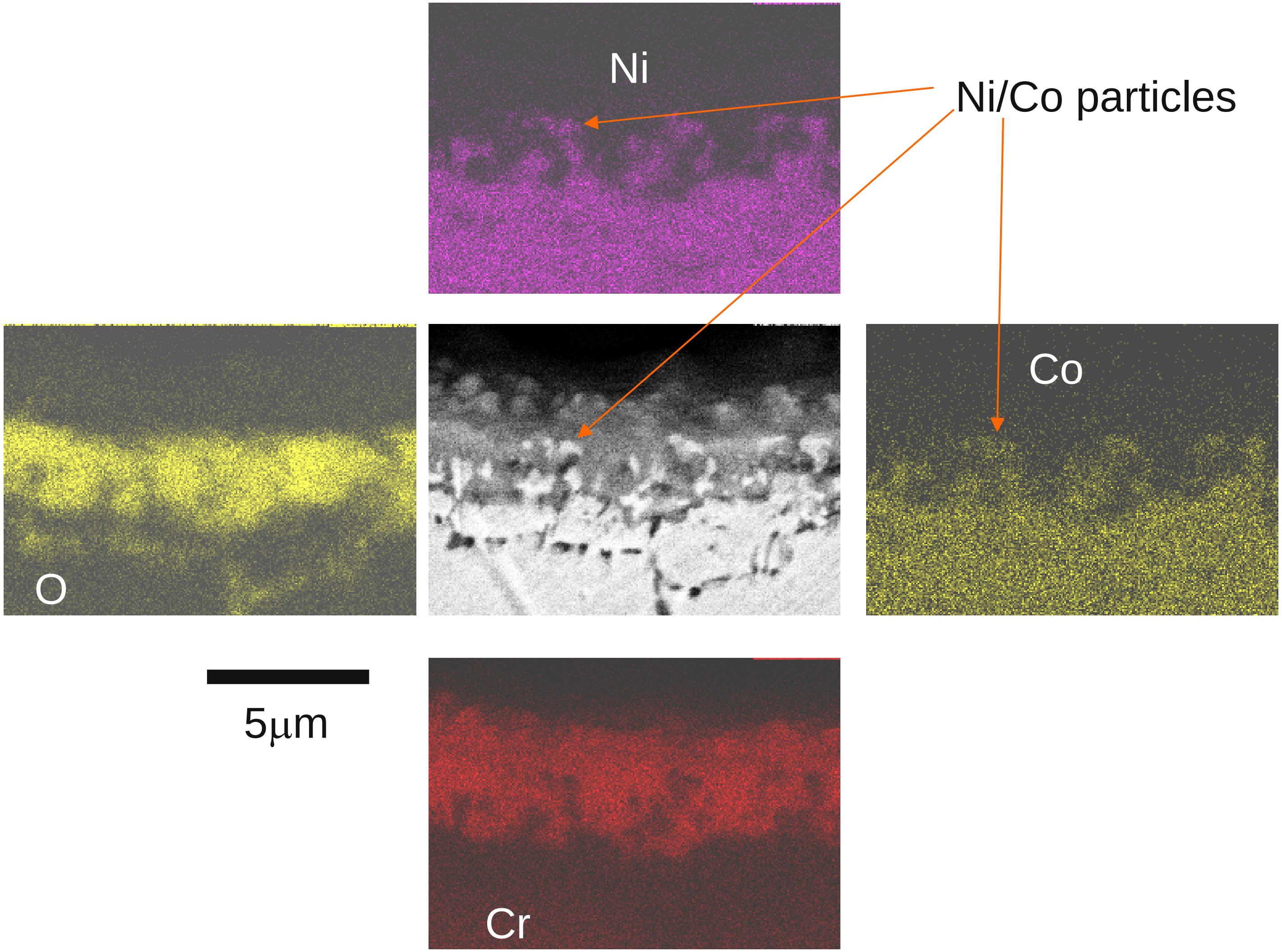


Alloy 617 after 2,760-h exposure to 50% CO_2-50% steam at 750°C

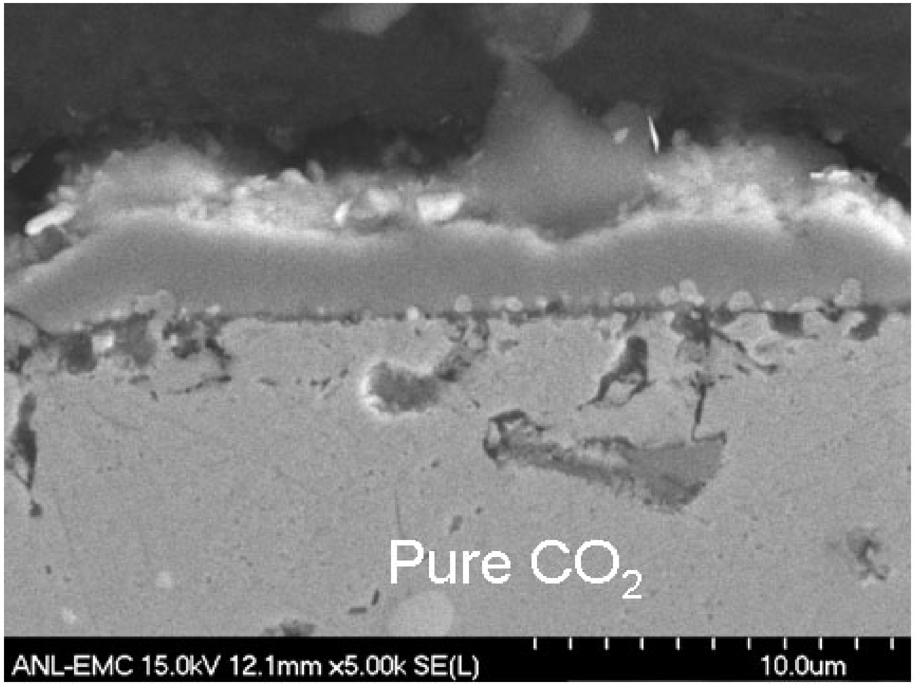




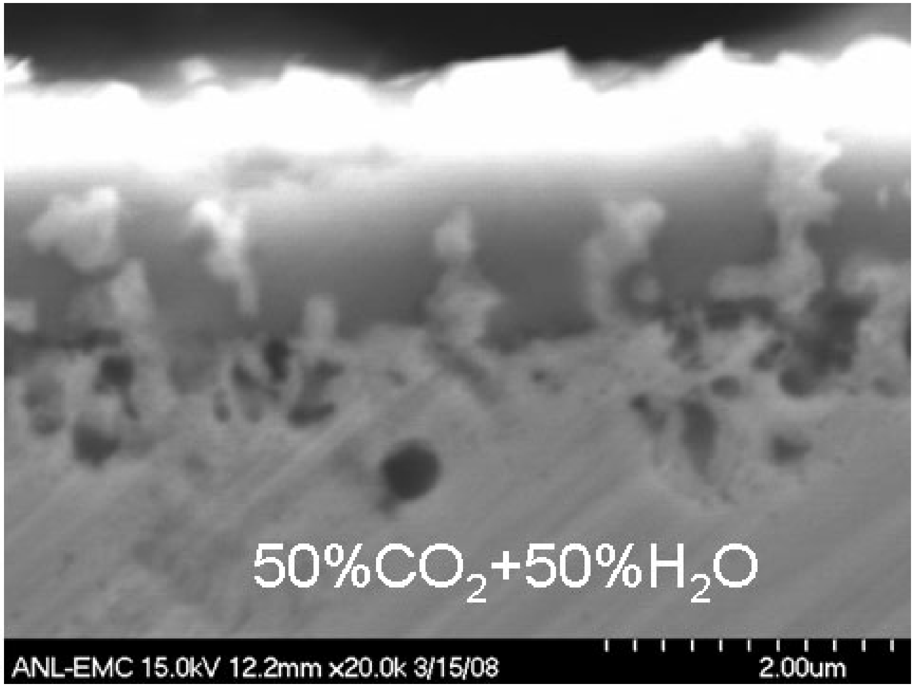
EDX mapping: Alloy 617 after 2,760-h exposure to 50% CO_2-50% steam at 750°C



Alloy 617 exposed to 50%CO_2-50%Steam at 750°C

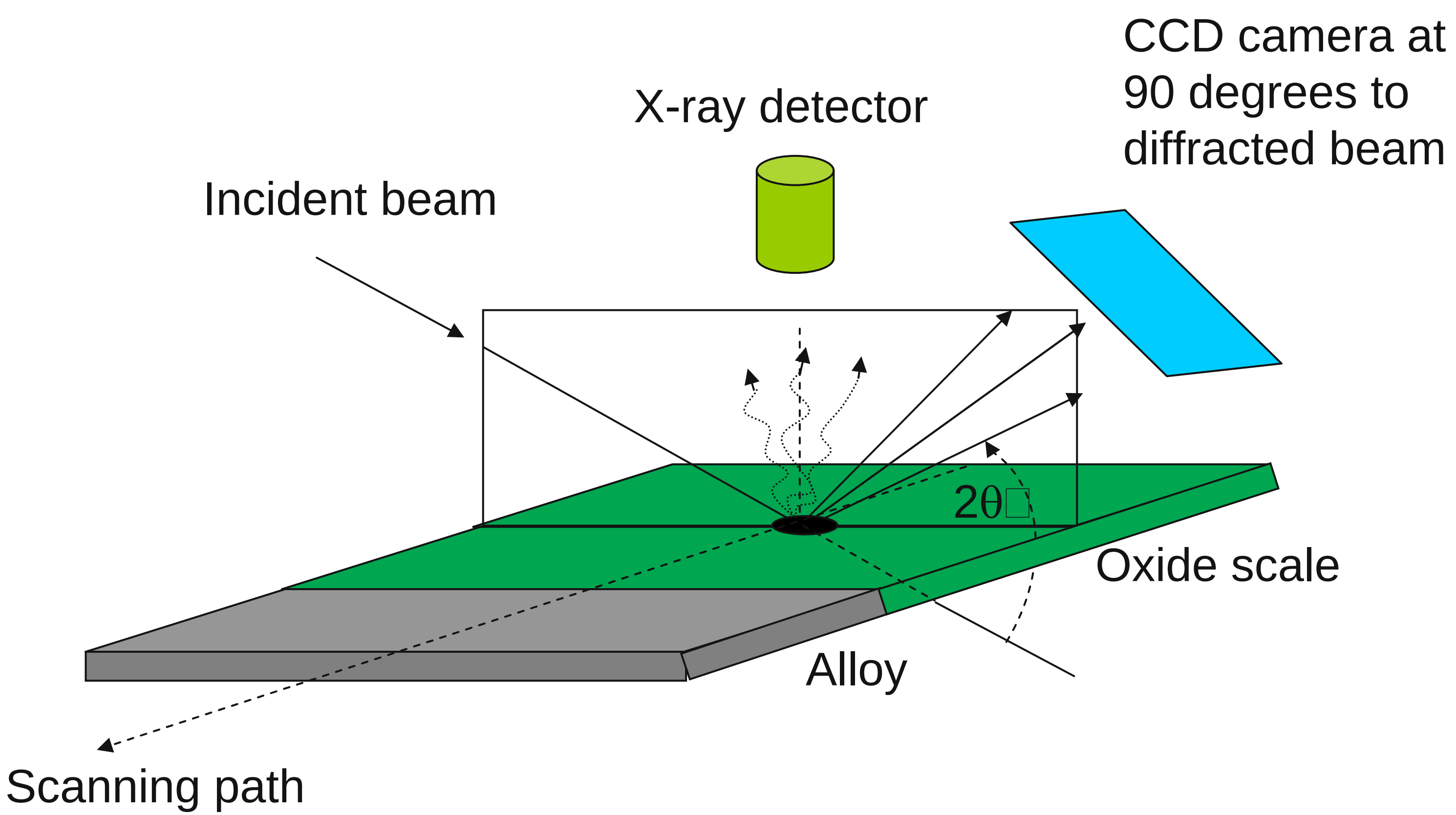


1452 h

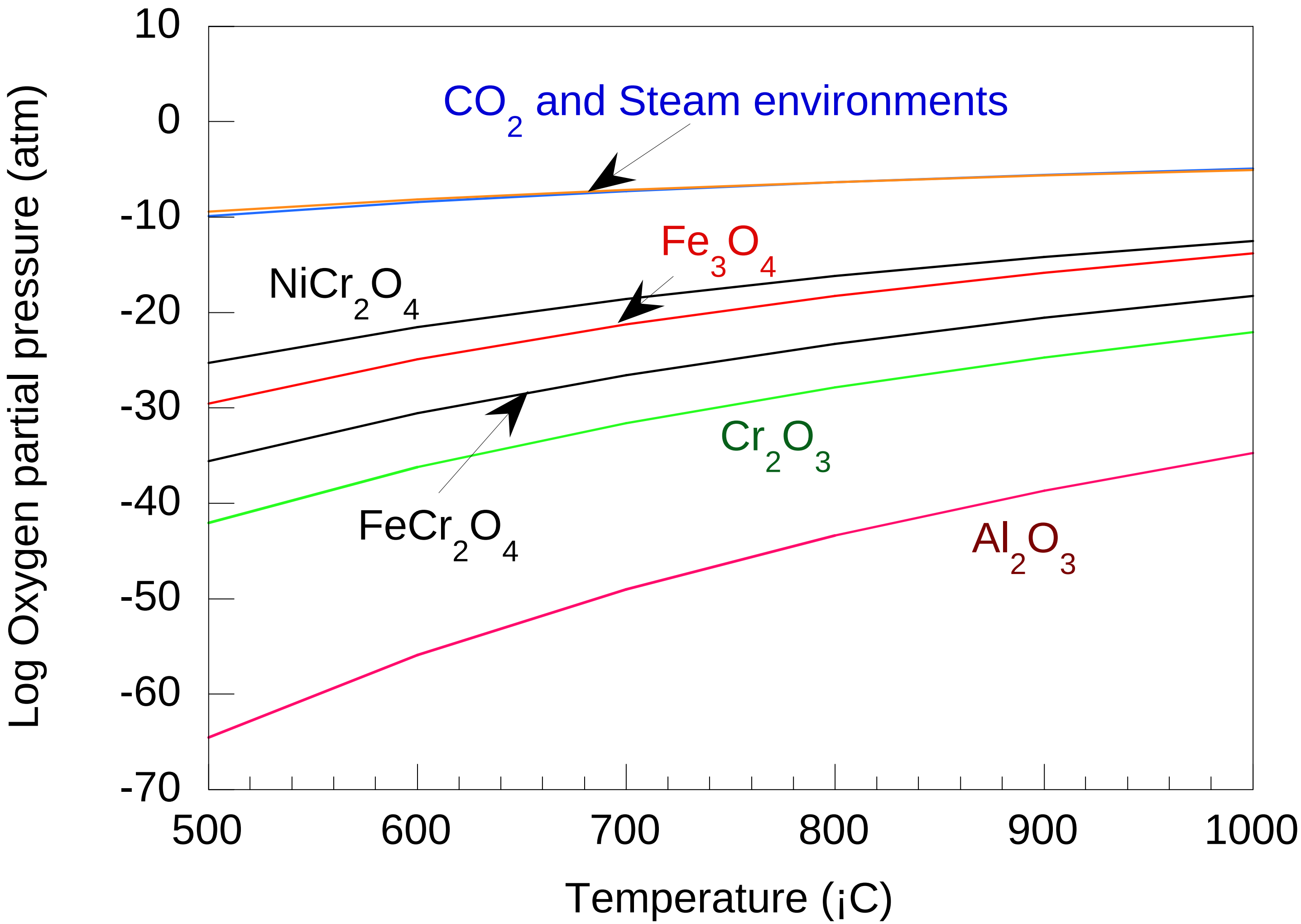


2760 h

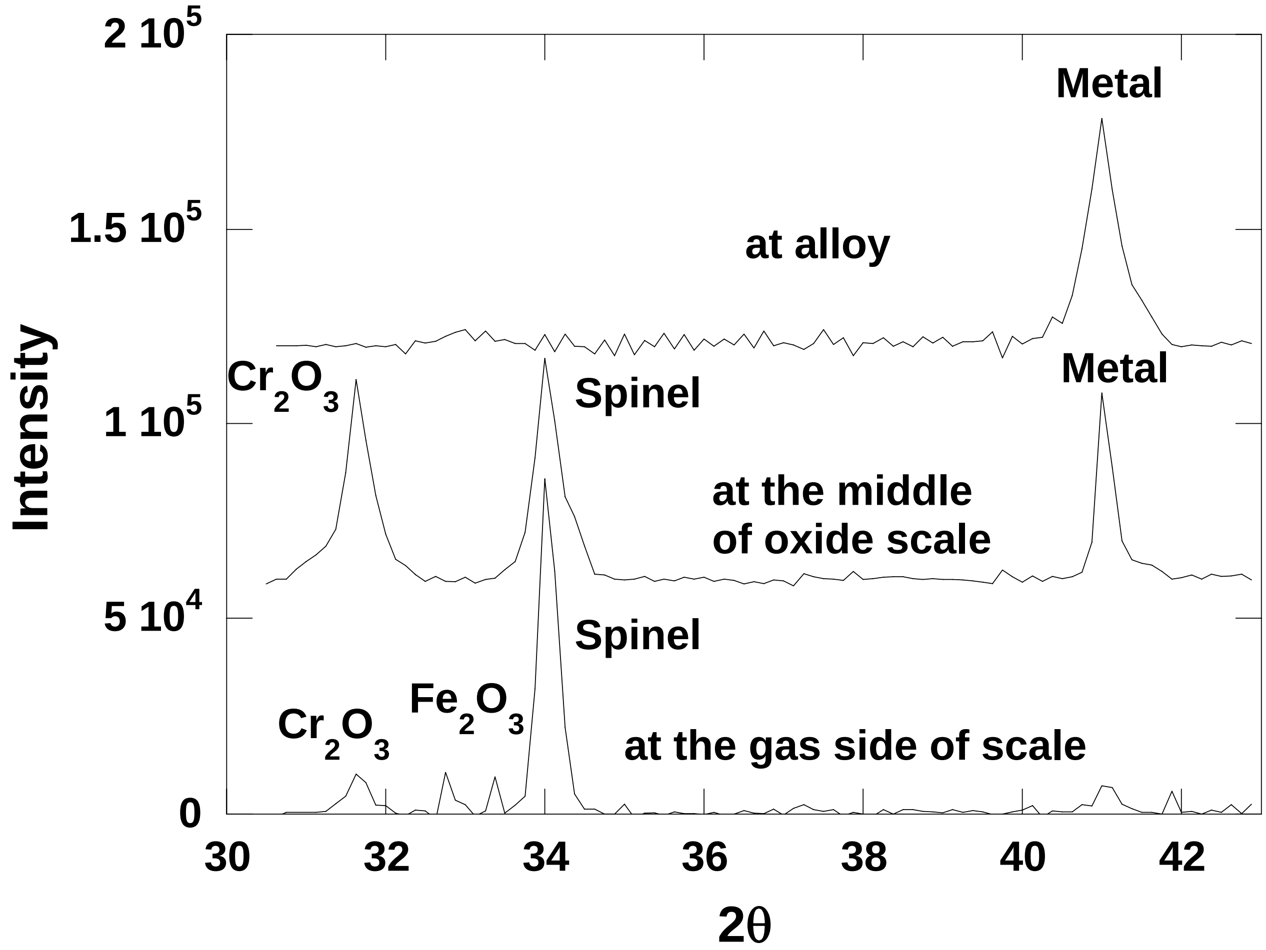
Alloy 617 exposed to 50%CO_2-50%Steam at 750°C



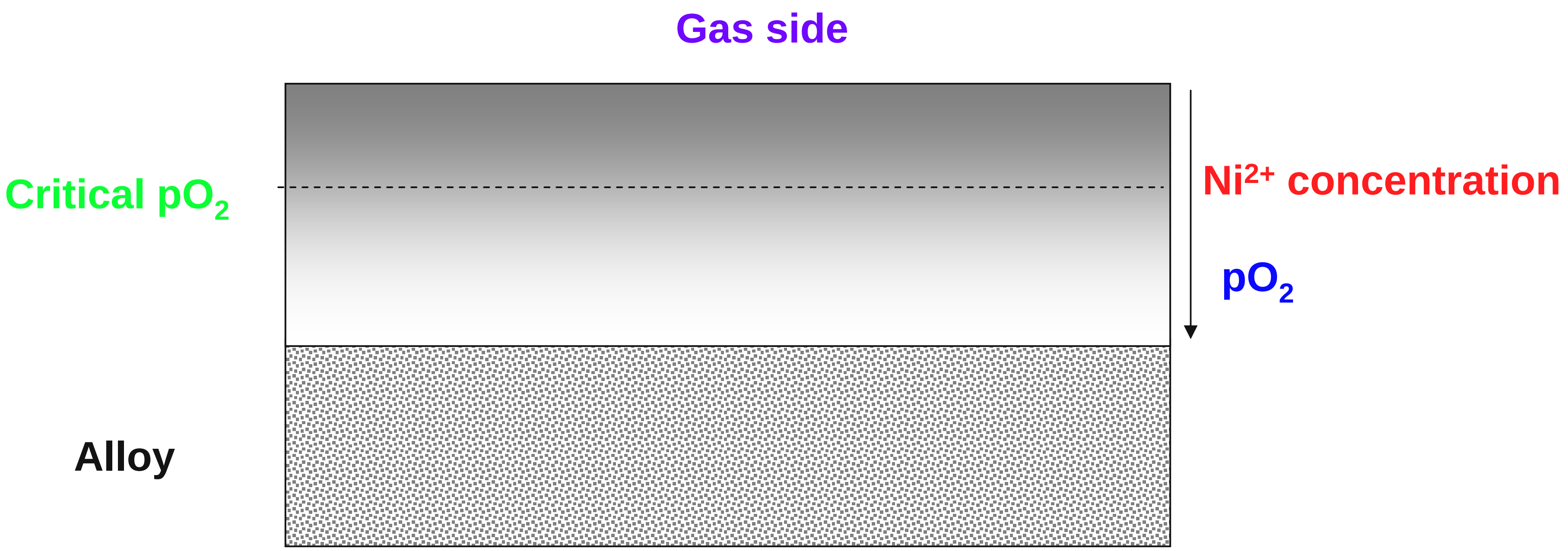
Thermodynamic stability of various oxide phases



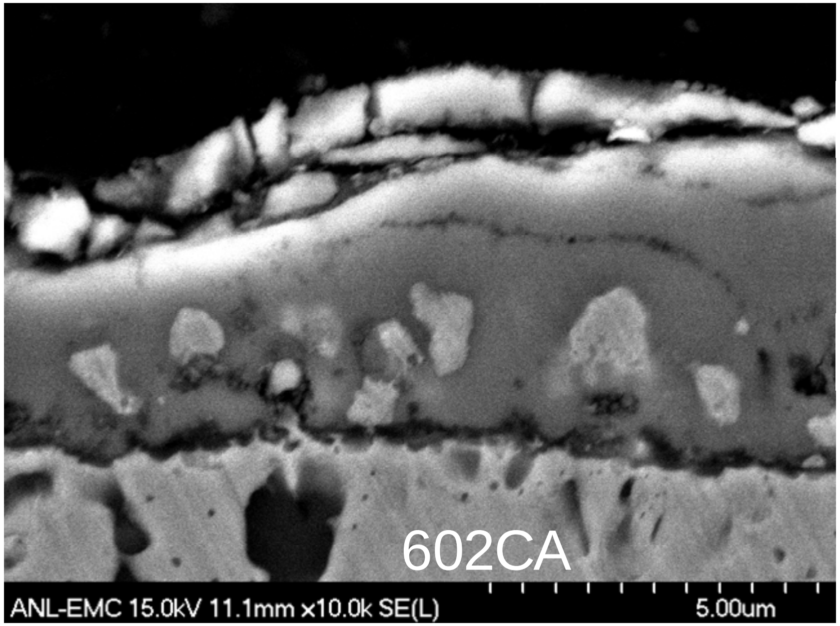
XRD at different locations of scale on the surface of Alloy 617 after 2,760-h exposure in 50%CO_2-50%Steam at 750°C



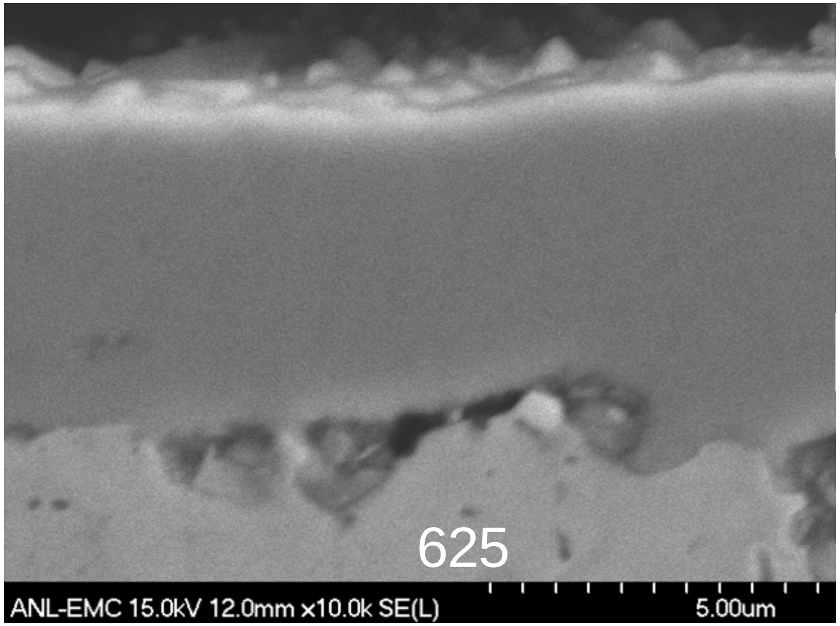
Effect of variation in p_{O2} on scale morphology



Effect of Fe content in alloy on the oxidation scale morphology

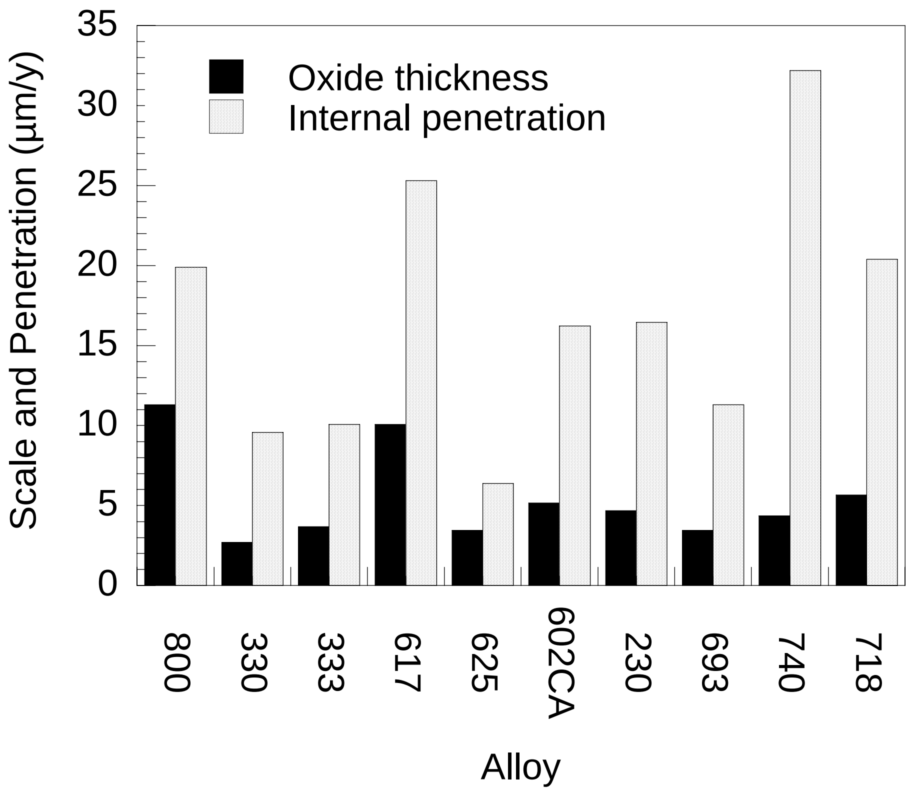


9.3 wt.% Fe

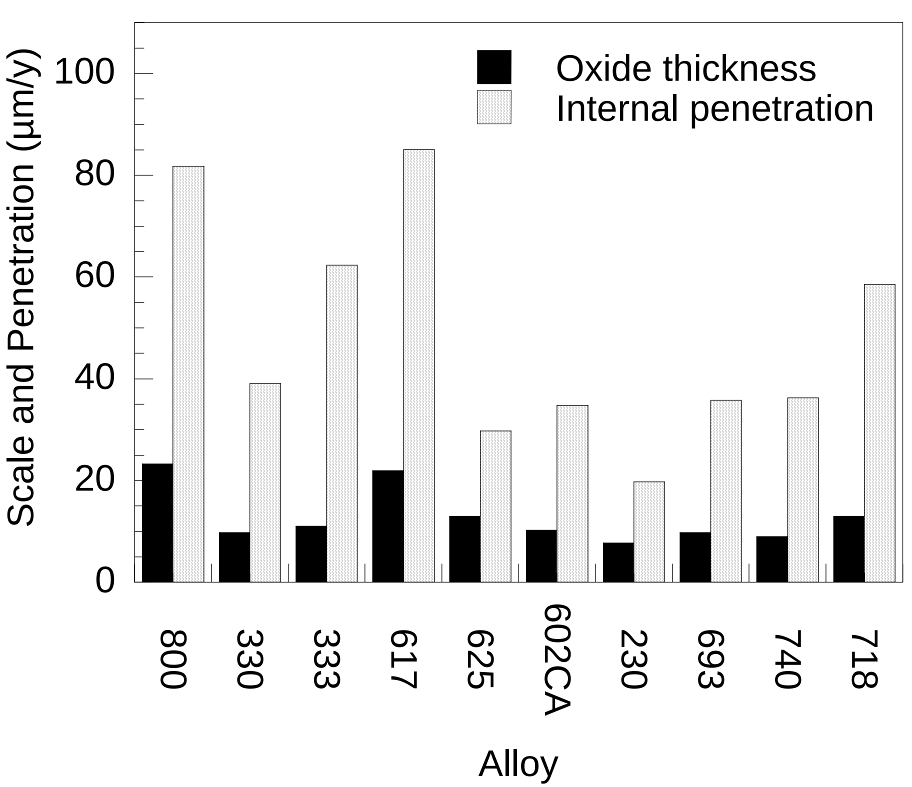


2.5 wt.% Fe

Scale growth and penetration rates in pure CO_2 (Parabolic kinetics)

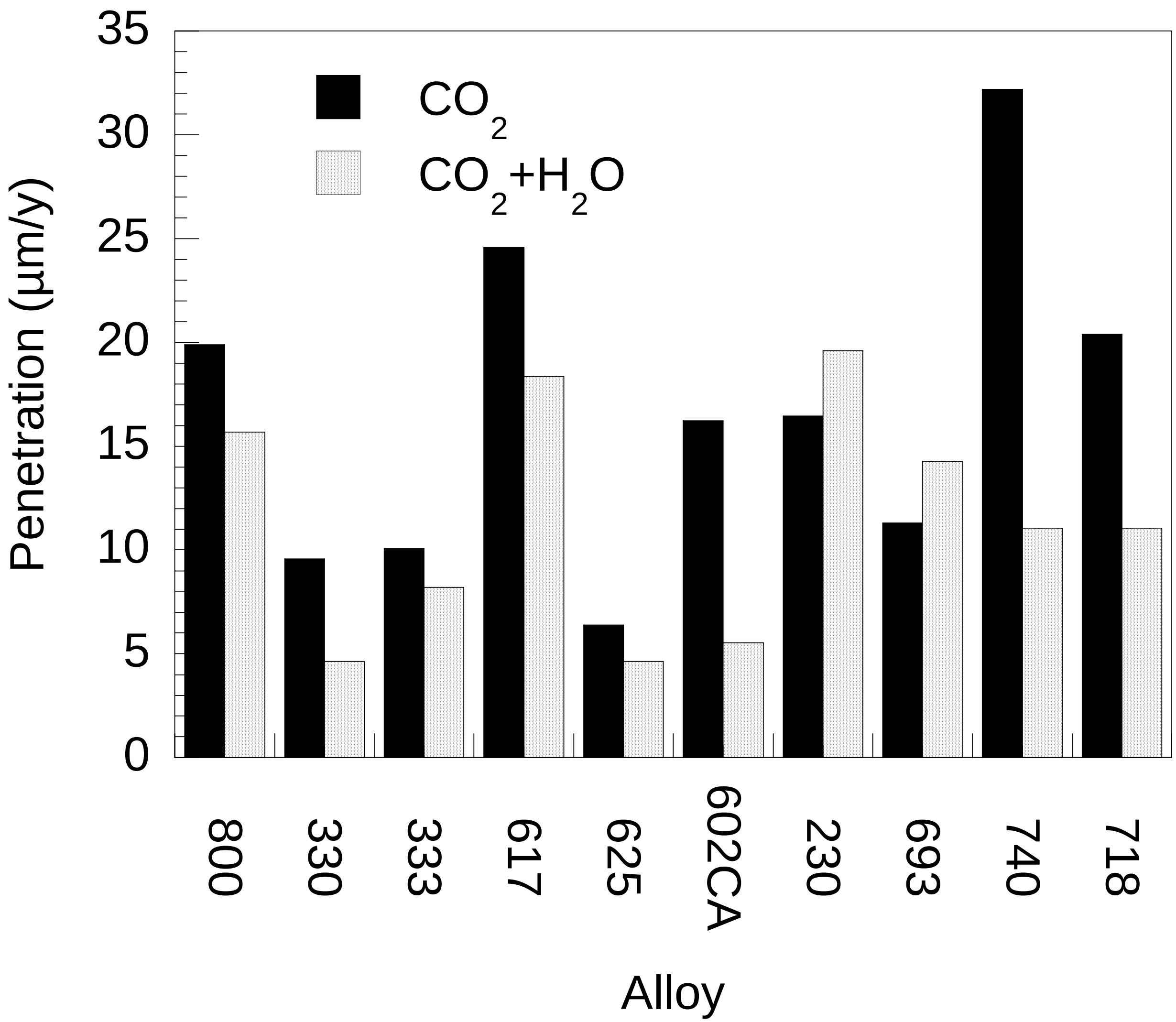


750°C

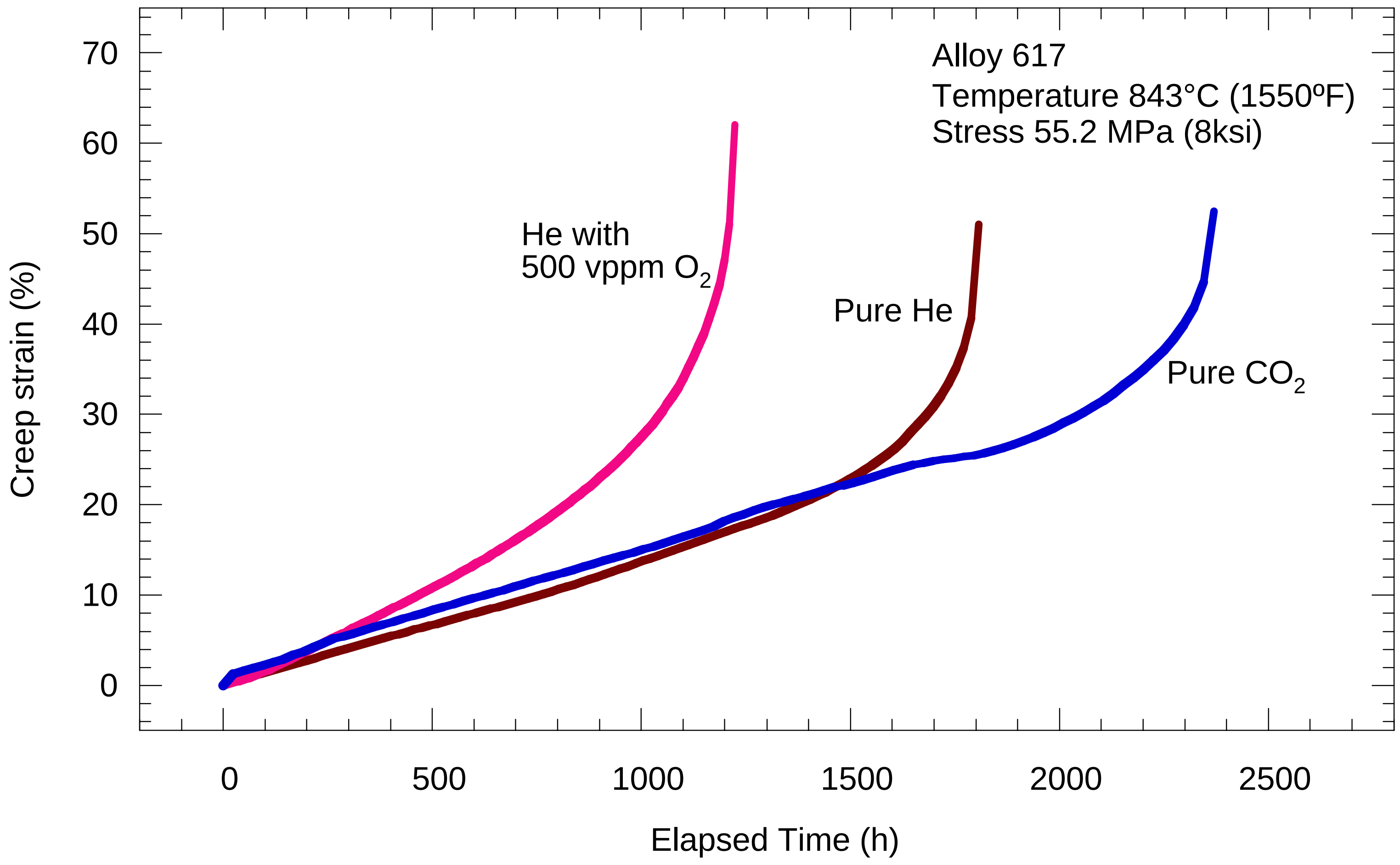


850°C

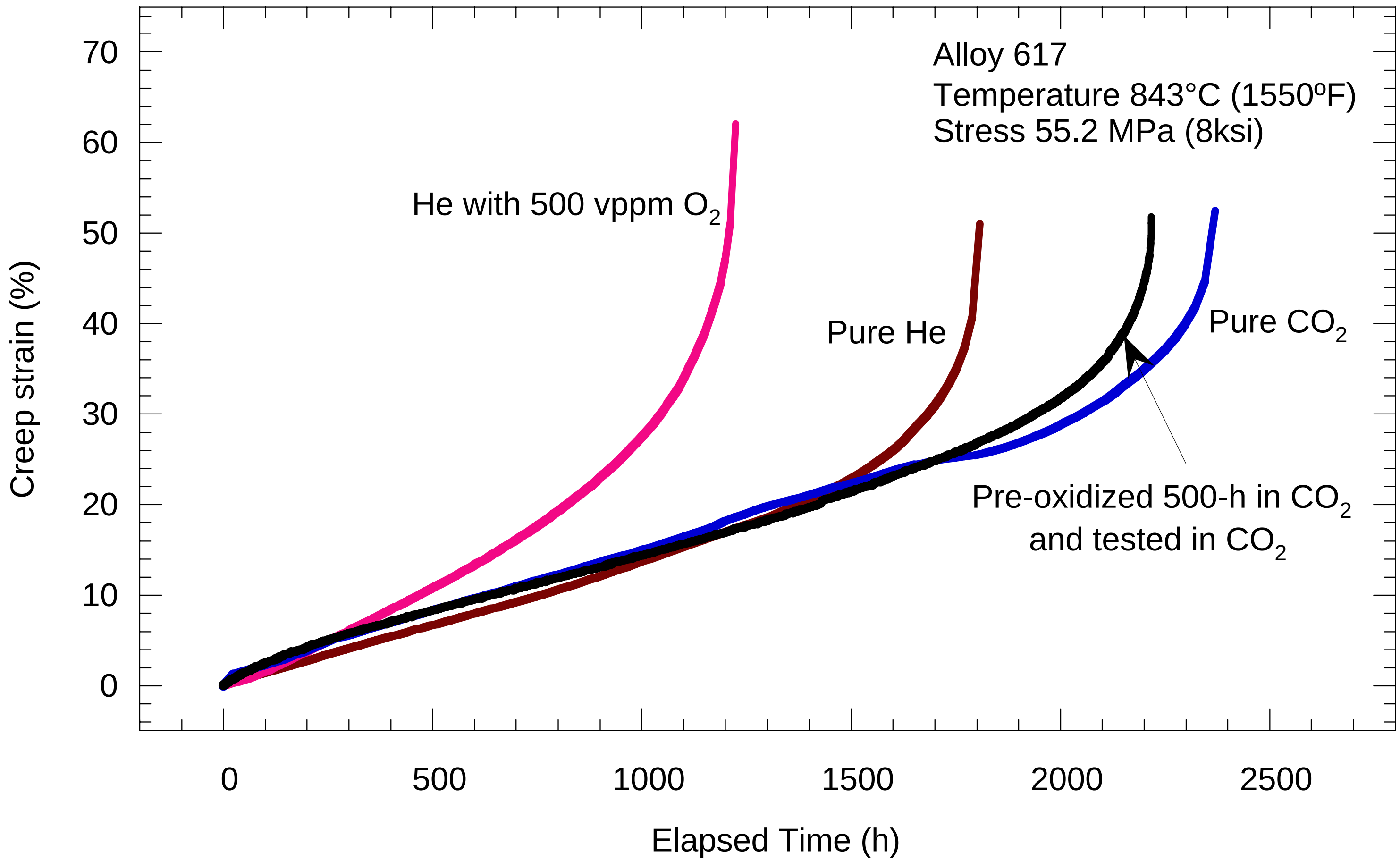
Alloy penetration rates at 750°C in CO_2 and in 50%CO_2-50%Steam



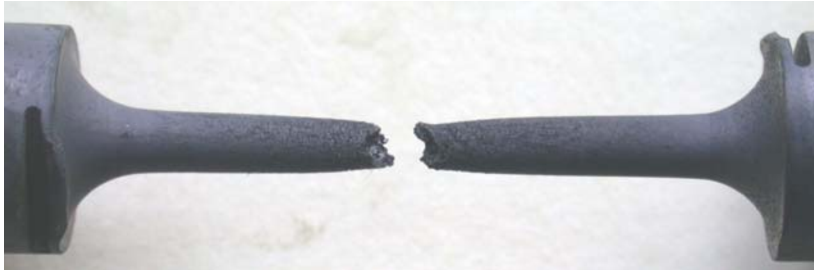
Creep performance of Alloy 617 at 843°C in several environments

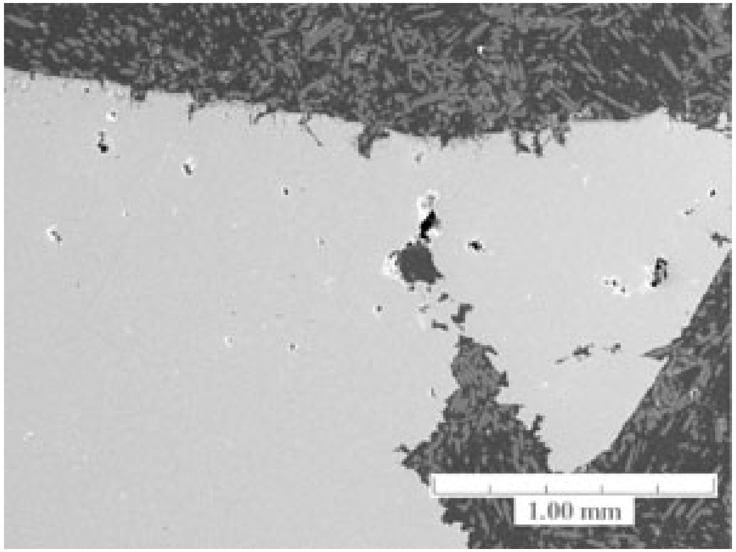


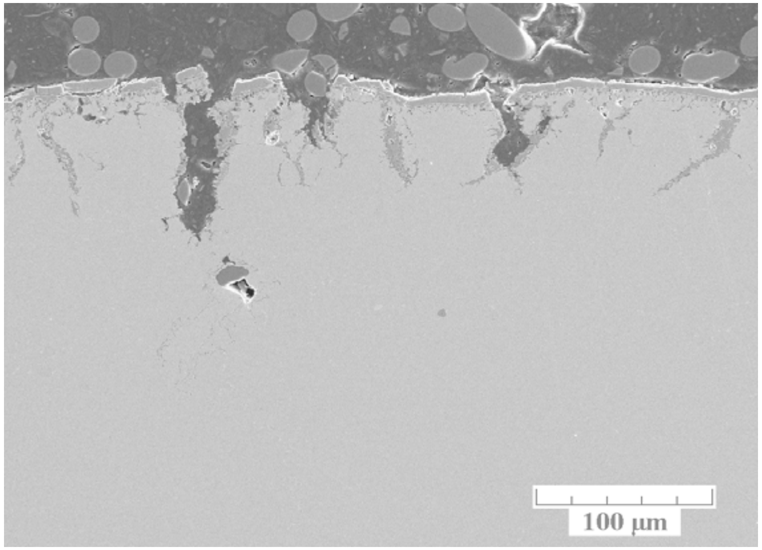
Creep performance of pre-oxidized Alloy 617 at 843°C

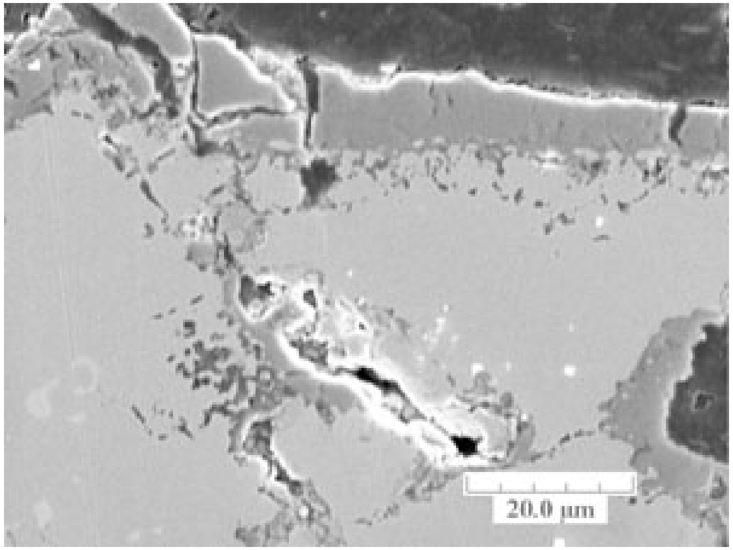


Alloy 617, 843°C, CO_2 environment
Applied stress 55.2 MPa
Rupture life 2,369 h

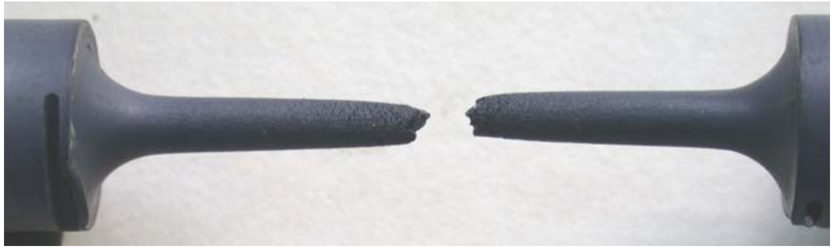


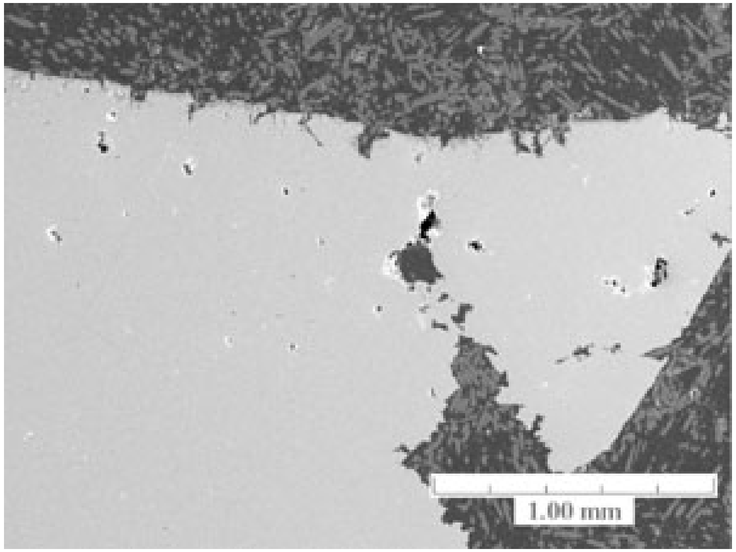


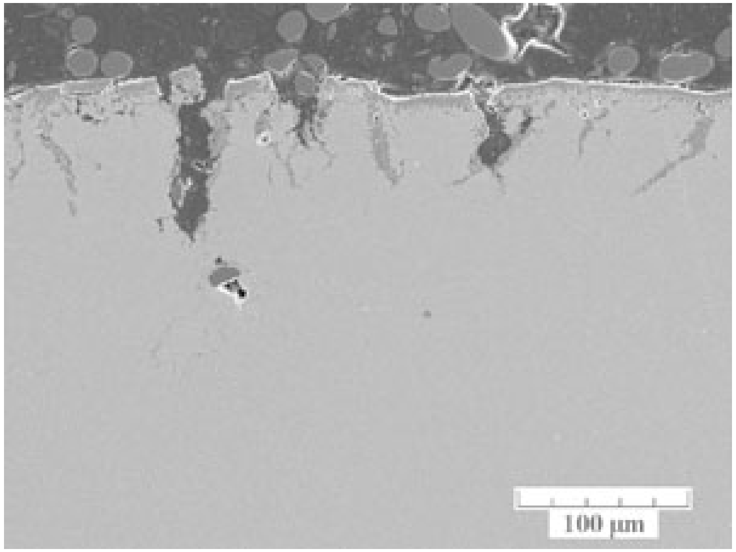


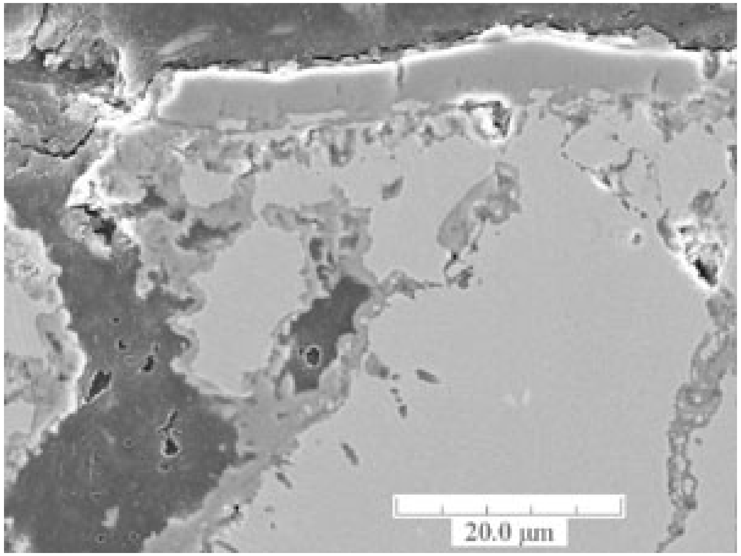


Alloy 617, 843°C, CO_2 environment
Applied stress 68.95 MPa
Rupture life 543.6 h

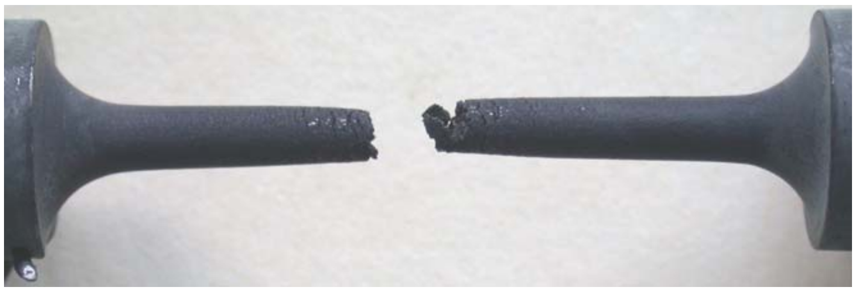


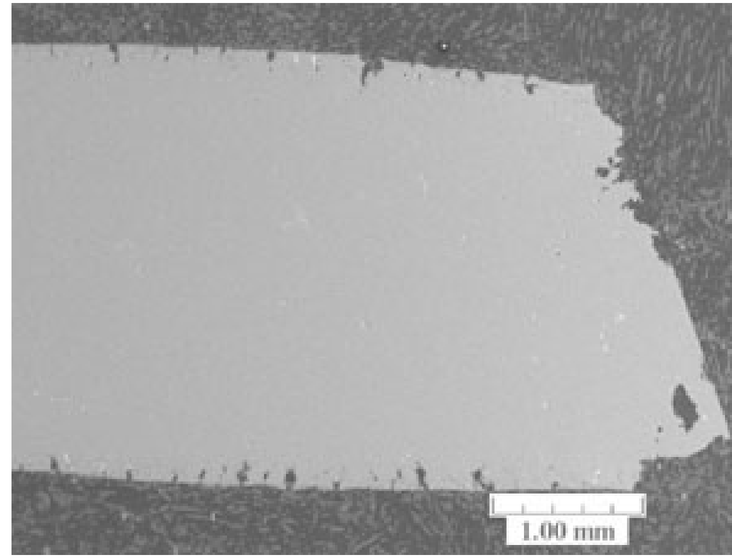


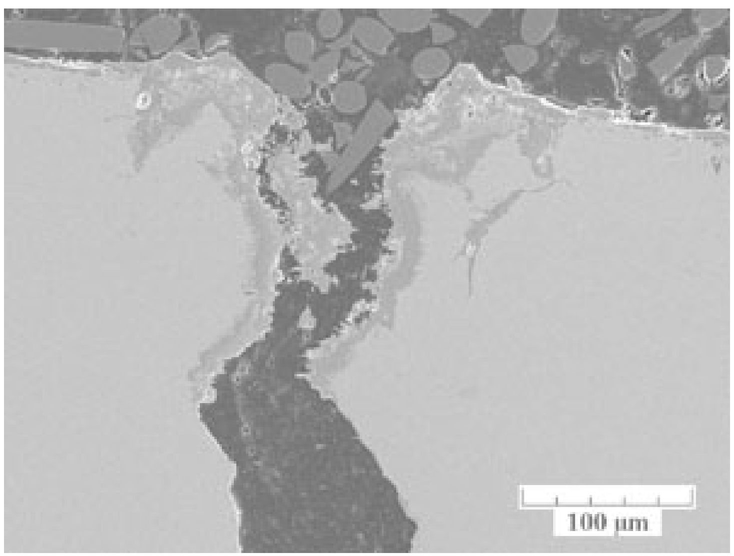


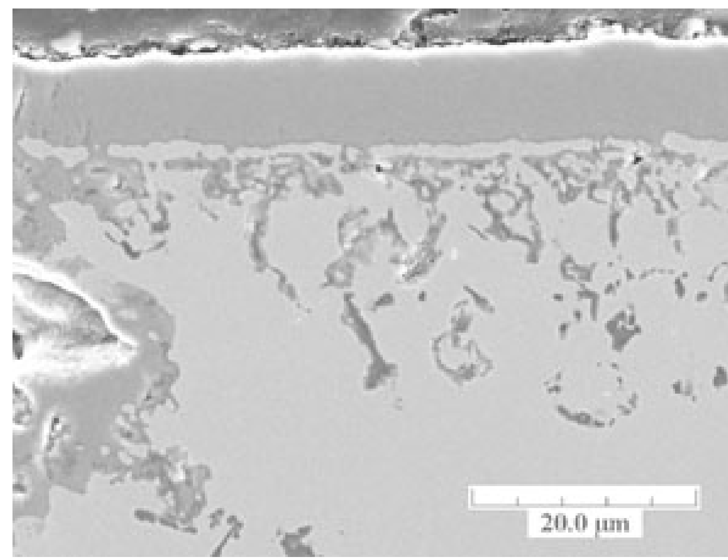


Alloy 617, Preoxidized 500 h in CO_2, 843°C, tested in CO_2 environment Applied stress 55.2 MPa Rupture life 2,217.6 h









Project Summary

- We have conducted a study to evaluate the oxidation performance of structural alloys in CO_2 and CO_2-steam environments at temperatures up to 1000°C
- We will incorporate additional gas-turbine alloys as they become available
- Results indicate that the oxide scales that develop on the alloys are not that protective and internal carburization of the substrate can occur
- The formation of nano-particles of metals such as Fe, Ni, and Co can act as continuous channels for the transport of carbon through the oxide scale
- Preliminary results on creep of Alloy 617 in pure CO_2 environment showed very little effect on the properties such as creep rupture strain and creep rupture life