Assessment of Materials Performance Data for Advanced Combustion Plants

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The Fuel and Energy Research Forum 2nd Annual Meeting and Inaugural Environment Interest Group Seminar,

11 April 2018

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Acknowledgements

- **EU Research Fund for Coal and Steel Project RFCS-2015/709954**
  - **“Preparation for Commercial Demonstration Plant for 700 °C Operation”**
  - **DP 700 – Phase 1**

Outline

- Introduction
  - Advanced coal/biomass combustion systems
  - Materials issues

- Fireside corrosion
  - Degradation mechanisms
  - Materials data sources - laboratory exposures

- Data gathering & Database development

- Summary

Introduction

Advanced solid fuel fired combustion plants

Higher efficiencies

- higher component operating temperatures and pressures √

Lower emissions

- CO_2, SOx, NOx, etc. √

Carbon capture systems

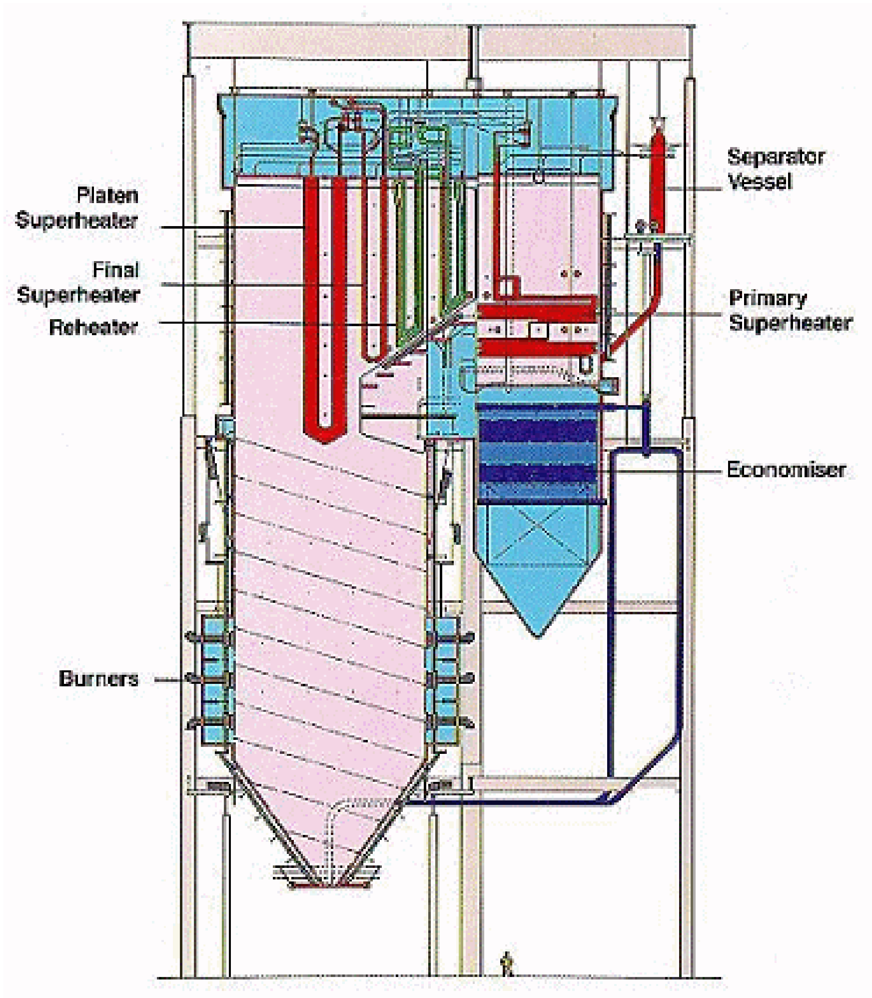
- post-combustion capture?
- oxy-firing?

Fuel flexibility

- wide range of coals √
- co-firing with biomass ?

Operational flexibility

- base load?
- cyclic operation √



Introduction

Materials issues in A-USC/HSC plants

Environmental

Steam-side oxidation:

- scale growth; scale spallation; erosion / blockages

Fireside corrosion:

- superheaters / reheaters; boiler walls

Fireside erosion

Mechanical

Creep

Fatigue (LCF, HCF and TMF)

Creep / fatigue interactions

Synergistic effects

Creep-corrosion

Corrosion-fatigue

How will the balance between these damage mechanisms differ in an A-USC/HSC plant?

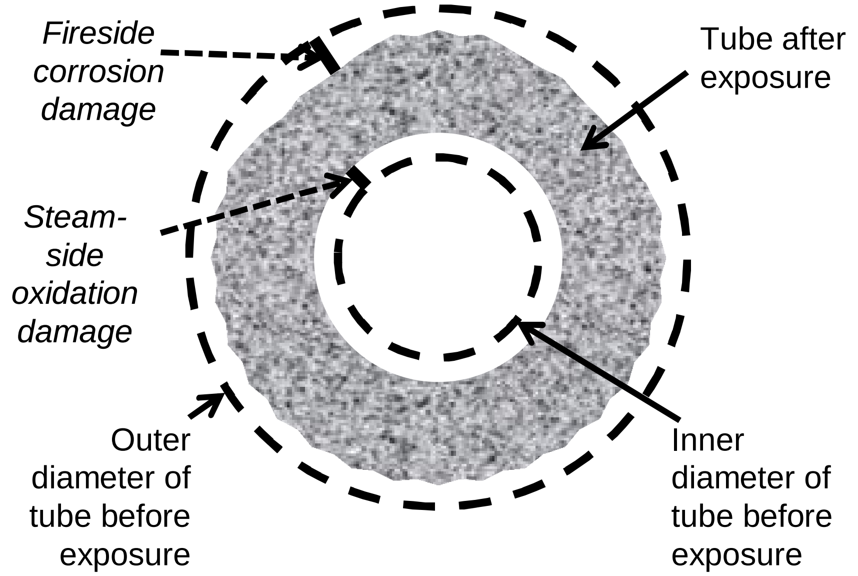
Steam-side oxidation and fireside corrosion might be expected to make a larger contribution at the higher temperatures and pressures **– focus on superheaters and reheaters**

Introduction

Candidate Materials

- **Base alloys:**
  - Ferritic steels: T24, T92
  - Austenitic steels: Sanicro 25, HR3C, 347HFG, 304HCu, 316L
  - Ni-based alloys: 740H, 282, 263, 617 (modified)

- **Coatings**
  - Fireside (HVOF application):
    - Ni-50Cr; NiCrAlY; FeCrAl; Alloy 625, etc
    - With and without sealants
  - Steam-side
    - Aluminising treatments
    - Application using slurry coating or liquid ionic plating



Fireside Corrosion

Fireside conditions for heat exchanger tubes

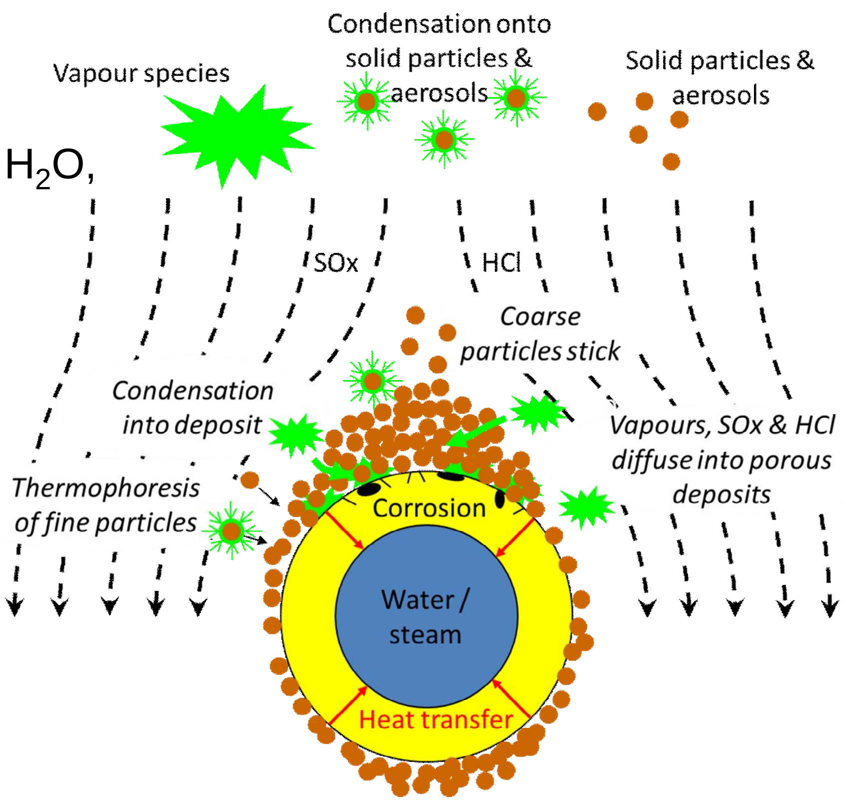
Fuel: coal / biomass

Gas stream characteristics:

- Gaseous species – e.g. SO_X, HCl, O_2, CO_2, H_2O, NO_X, N_2
- Vapour species – e.g. Na, K compounds
- Particles
  - from ash in fuel
  - condensed vapour species
- Gas temperature

Heat exchanger characteristics:

- Water / steam temperature (& pressure)
- Metal temperature (& heat flux)
- Deposit
  - rate of formation (flux)
  - composition



Fireside Corrosion

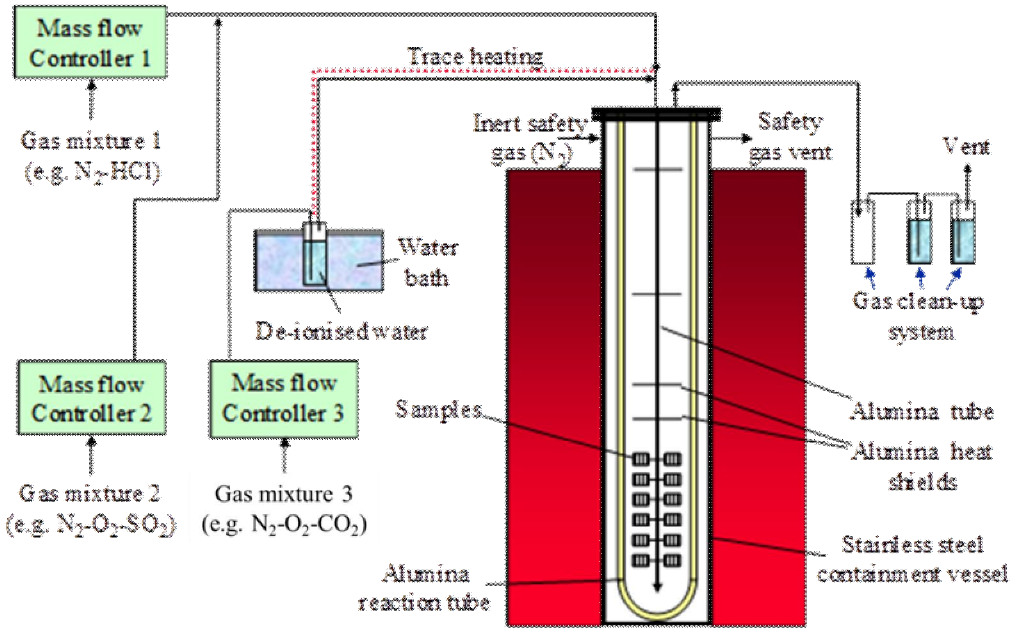
Laboratory Corrosion Tests

Critical parameters
- Metal temperatures
- Gas composition
- Deposit composition
- Deposition flux
- Coating / alloy compositions

Deposit recoat technique
- Simple ‘simulation’ of deposition flux
- Allows control of deposit composition
- Multiple deposit recoats (ideally >5)

Controlled atmosphere furnaces
- Specific gas compositions
- Alumina lined reactors
- Exposure temperatures controlled to +/- 3-5°C

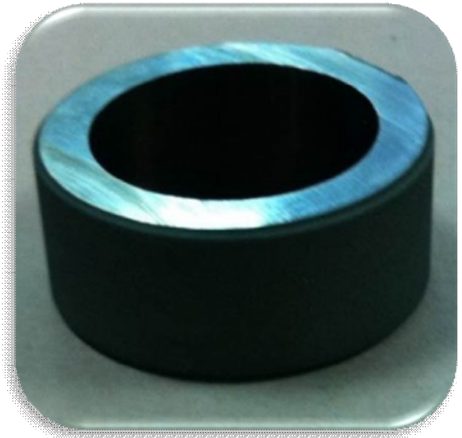
Samples manufactured from tubes / bars
- Machined
  - Standard surface finish
  - Precision for **dimensional metrology**
- Measurment of dimensions

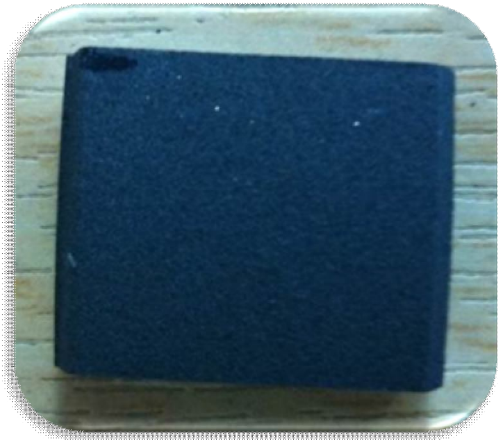


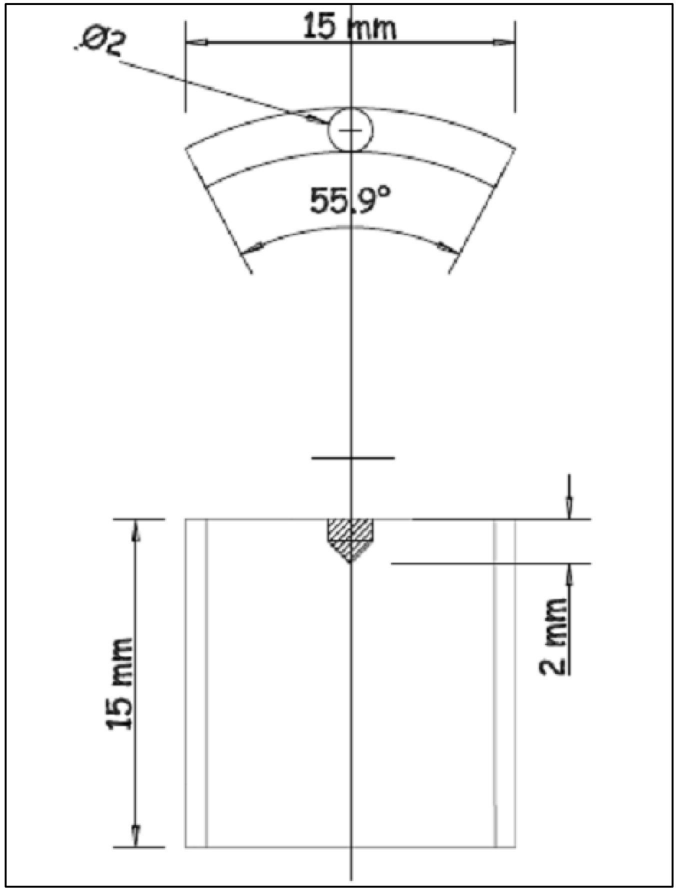
Fireside Corrosion

Sample Preparation

- Coated tubes cut into segments
- Reference samples also prepared
- Sample measured and weight prior to testing
- Now need to determine the test conditions



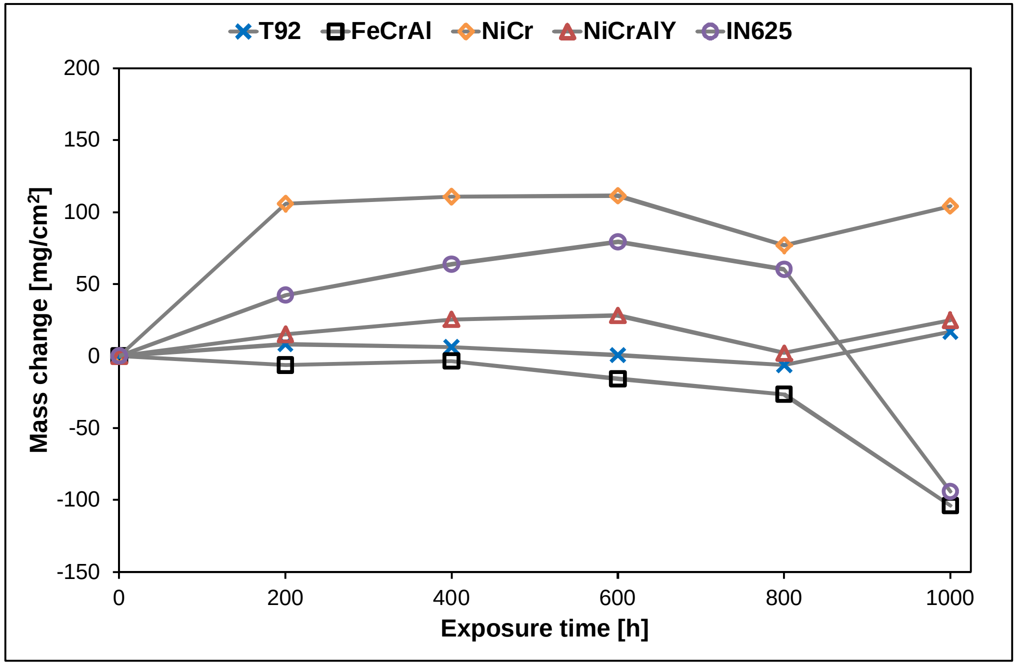




Fireside Corrosion

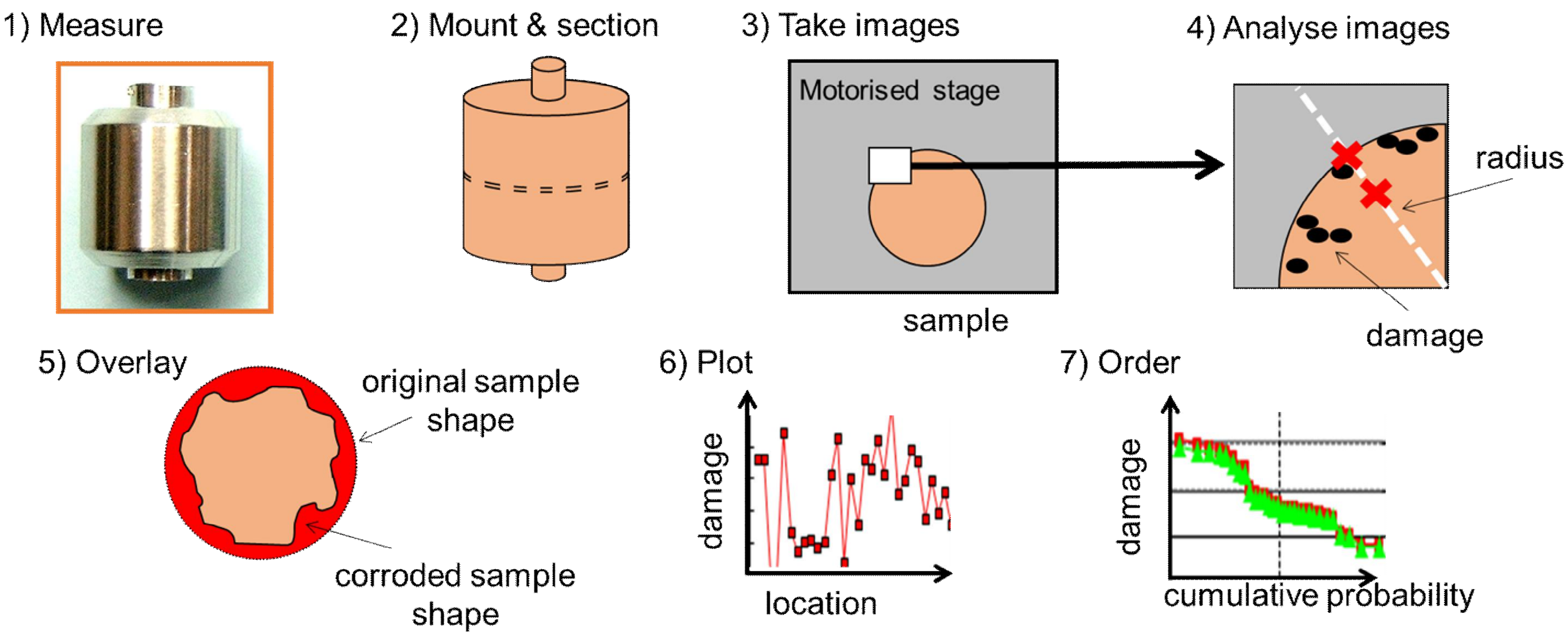
Net Mass Change

- Net mass change – mass of sample only
- How does this compare to gross mass change?
- There is a better way…



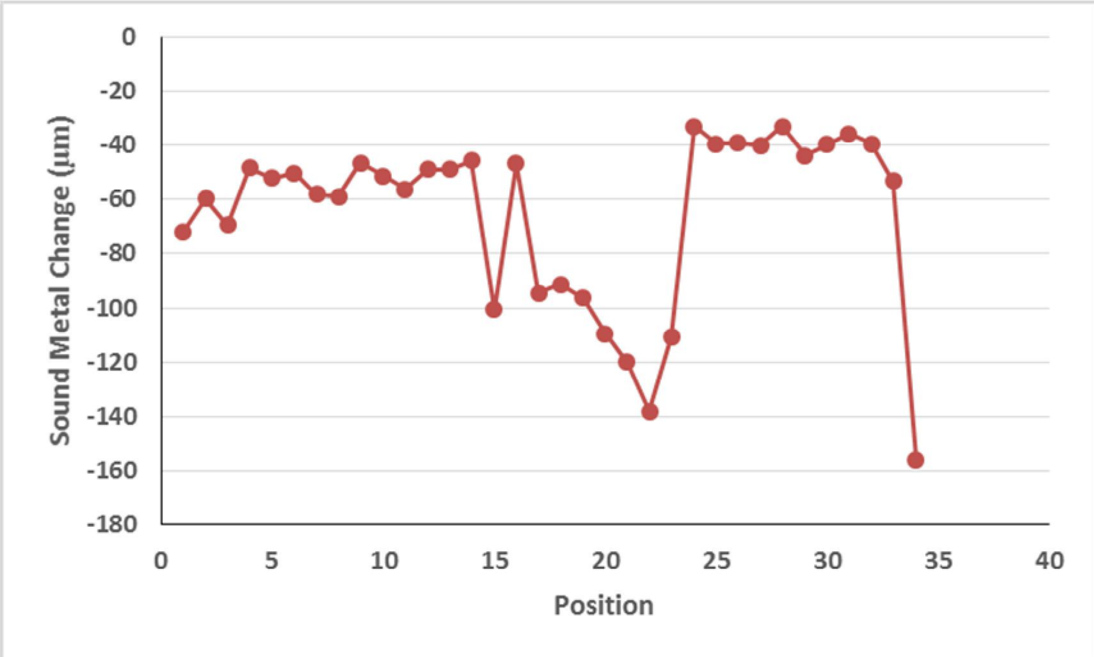
Fireside Corrosion

Dimensional Metrology



Fireside Corrosion

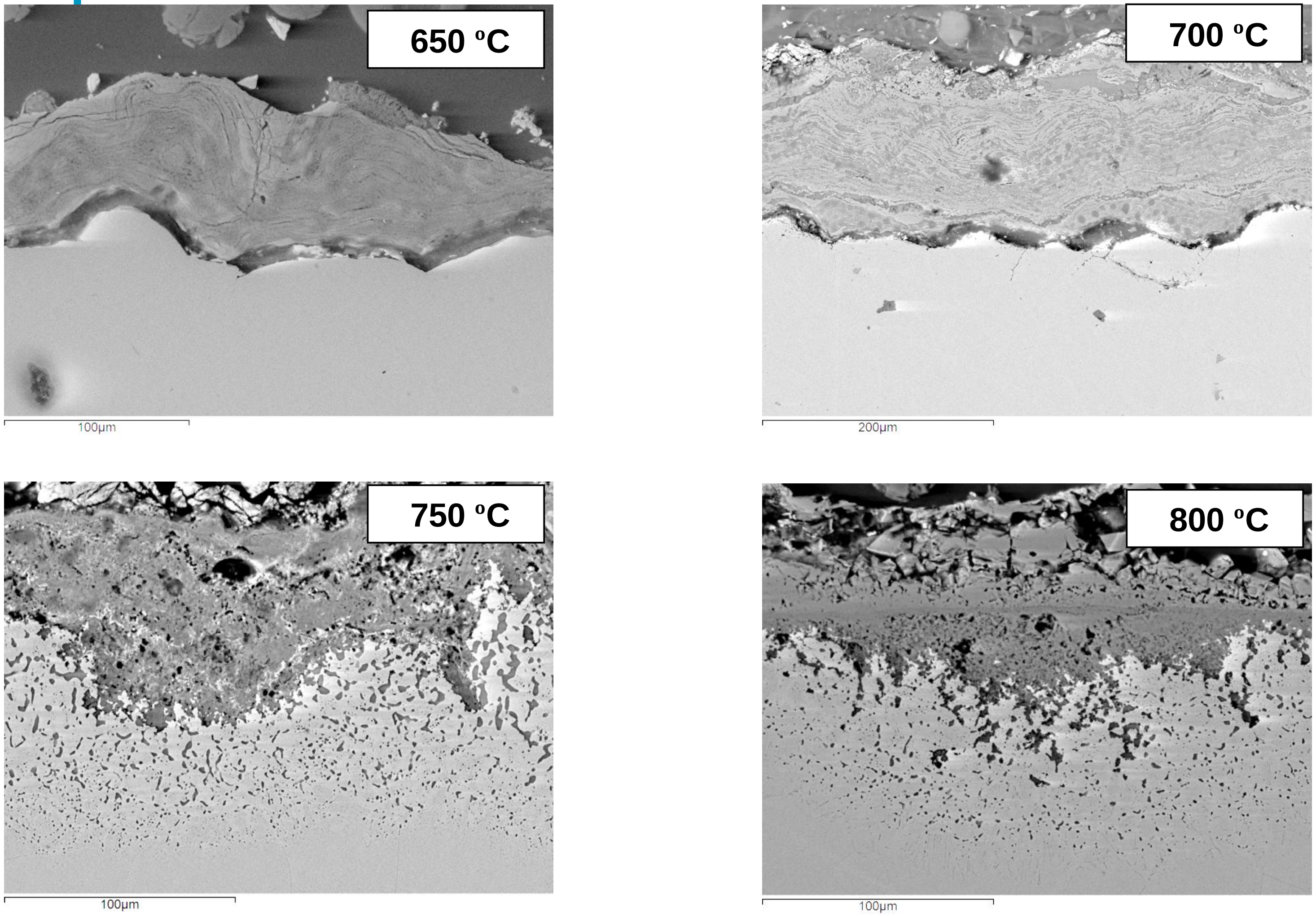
Example measured metal loss data – rectangular sample



- Measurements from selected zones of corrosion behaviour
- Measurements from random locations
- Subtraction of pre- and post- test data sets
- No ‘maximum’ or ‘typical’ subjective data
- Sound metal = that left unaffected by damage (surface and internal corrosion)

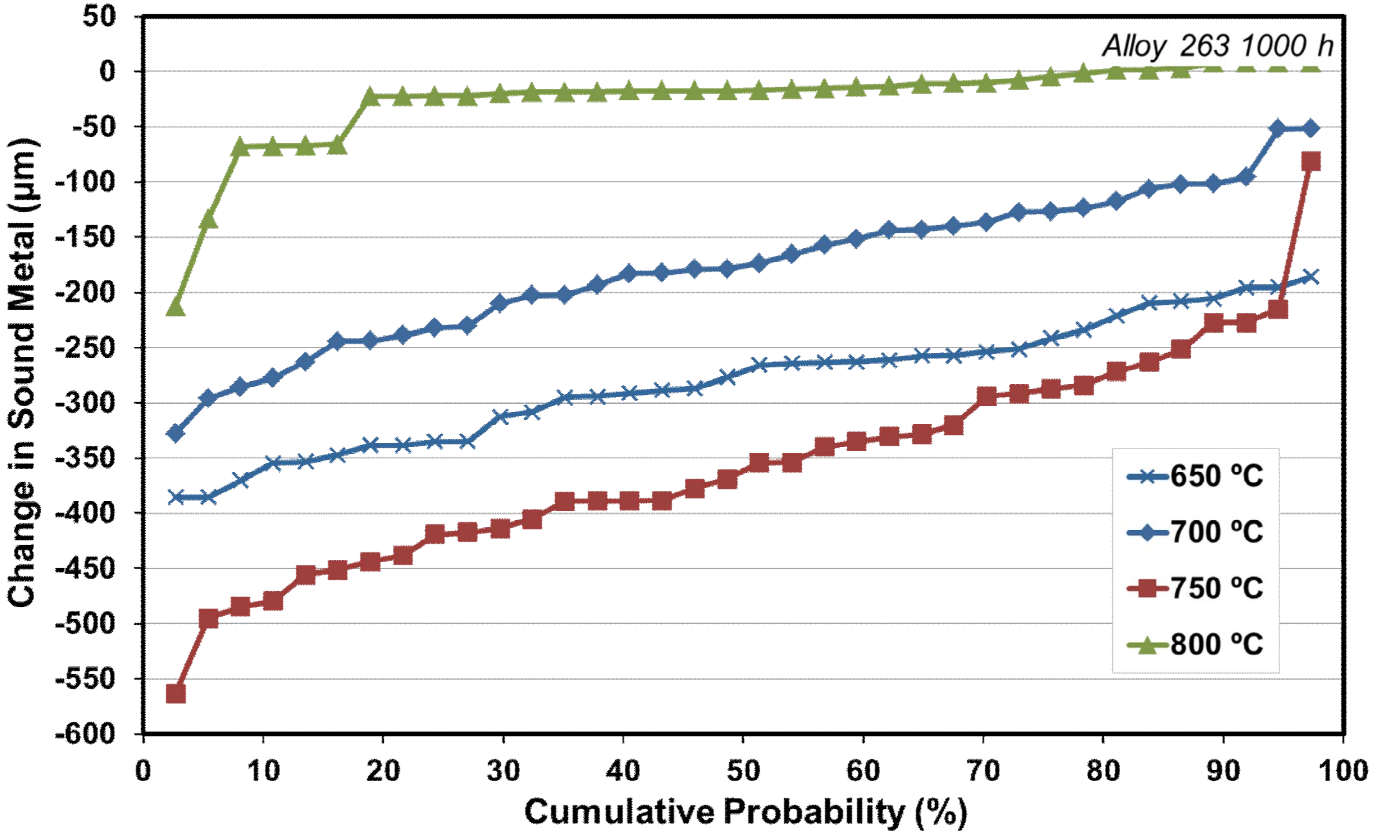
Fireside Corrosion

Alloy 263 – 1000 hours laboratory tests at each temperature with deposits



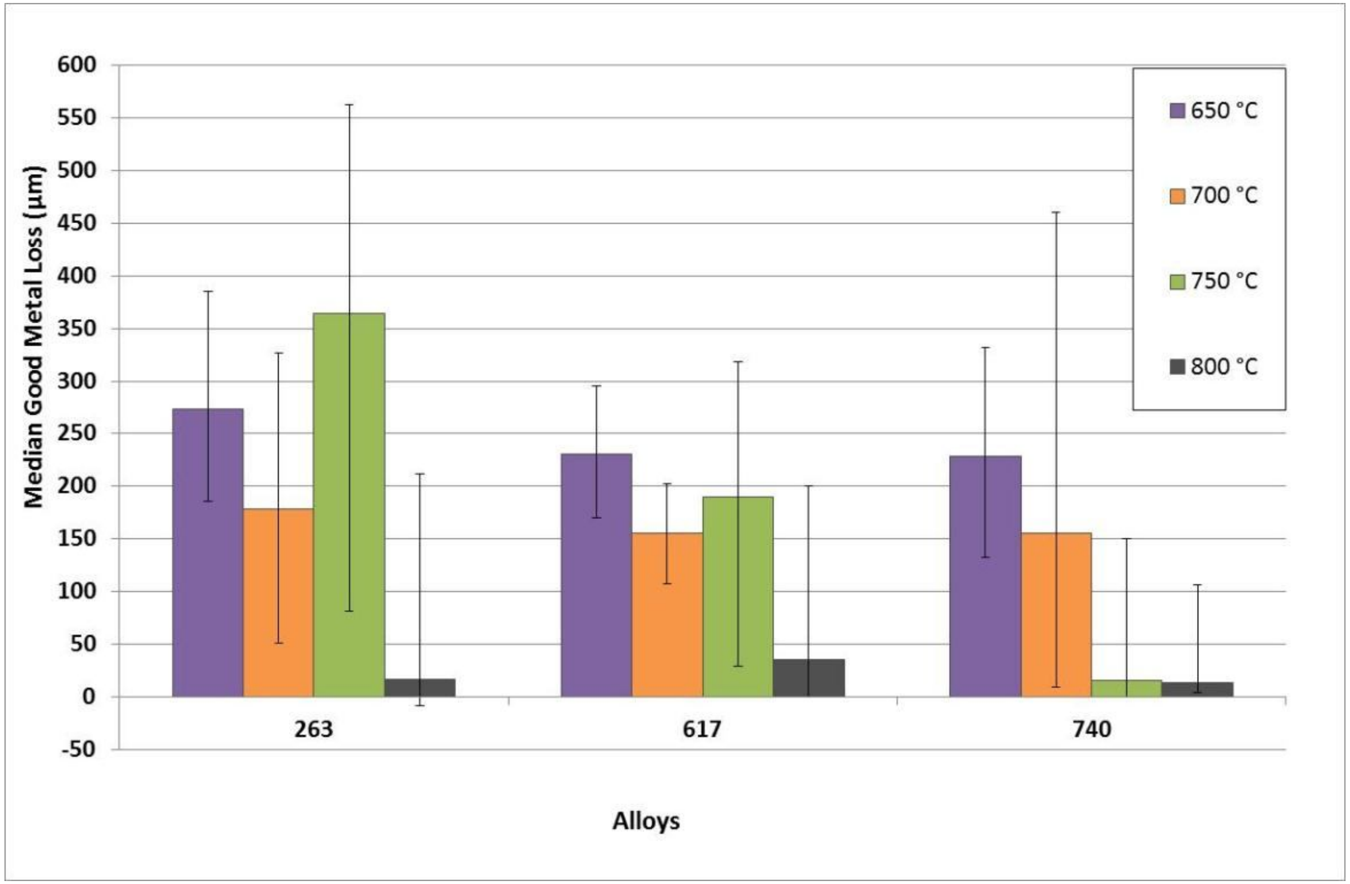
Fireside Corrosion

Probability plot for Alloy 263 fireside corrosion data



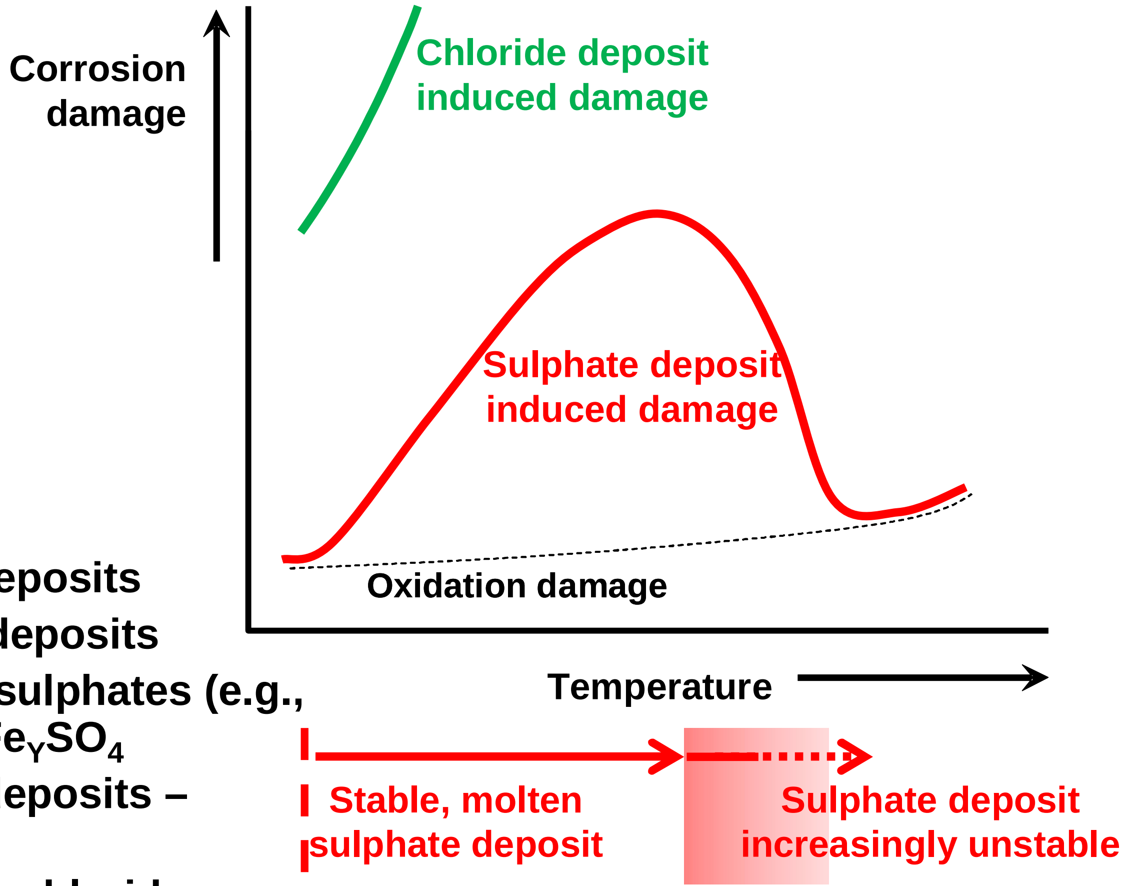
Fireside Corrosion

Median Metal Damage of Ni Alloys After 1000 h



Fireside Corrosion

Superheater / reheater fireside corrosion damage



Corrosive deposits

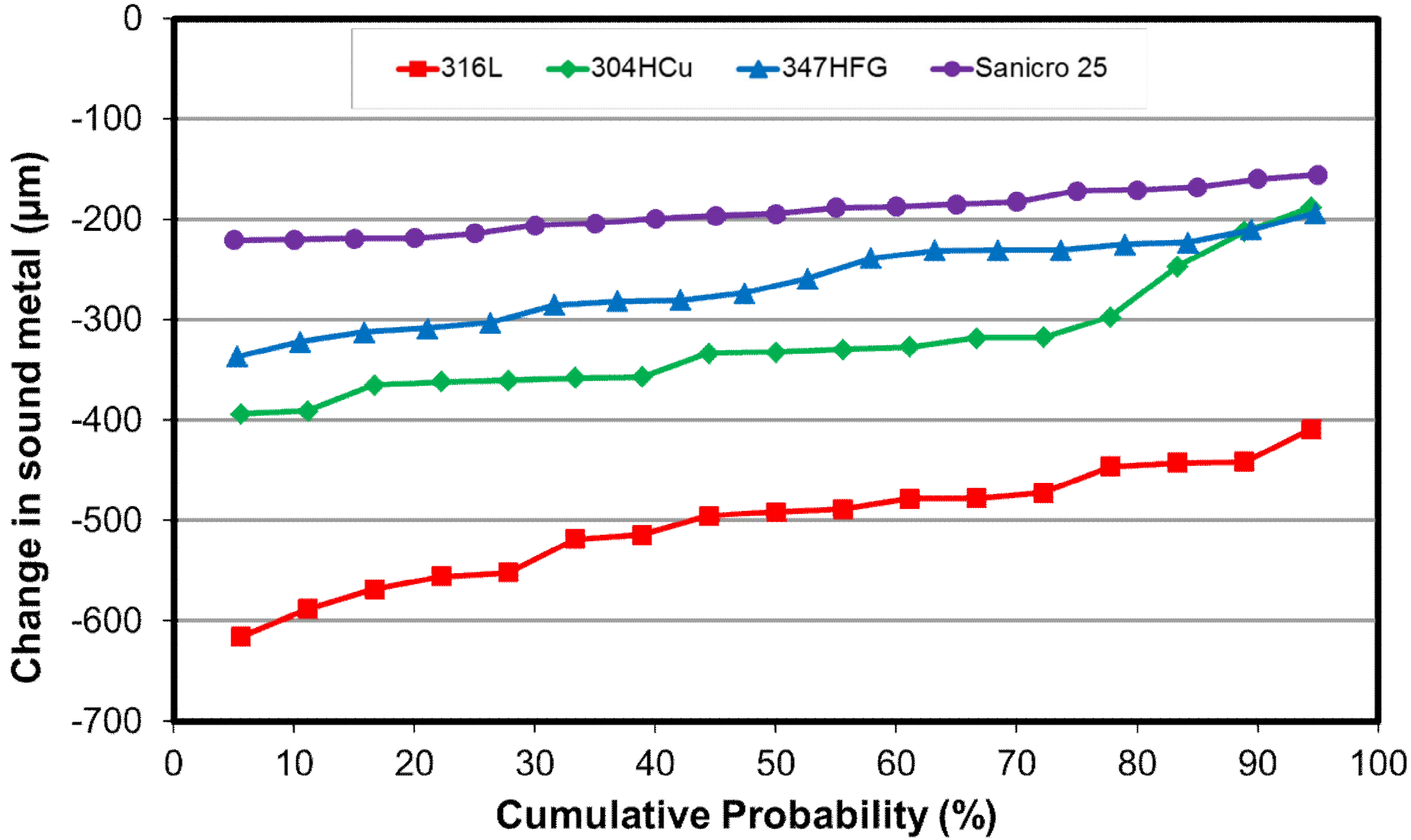
- Sulphate deposits
  - mixed sulphates (e.g., $(K,Na)_X Fe_Y SO_4$
- Chloride deposits – mixed
- Sulphate – chloride 'soup'
- Molten vs sticky vs solid

Deposit instability

- SO_3 needed to stabilise some sulphate phases & SO_3 favoured at lower temperatures
- Other phases more stable with change in deposit temperature

Fireside Corrosion

Fireside corrosion – examples of degradation of four stainless steels at 650 °C

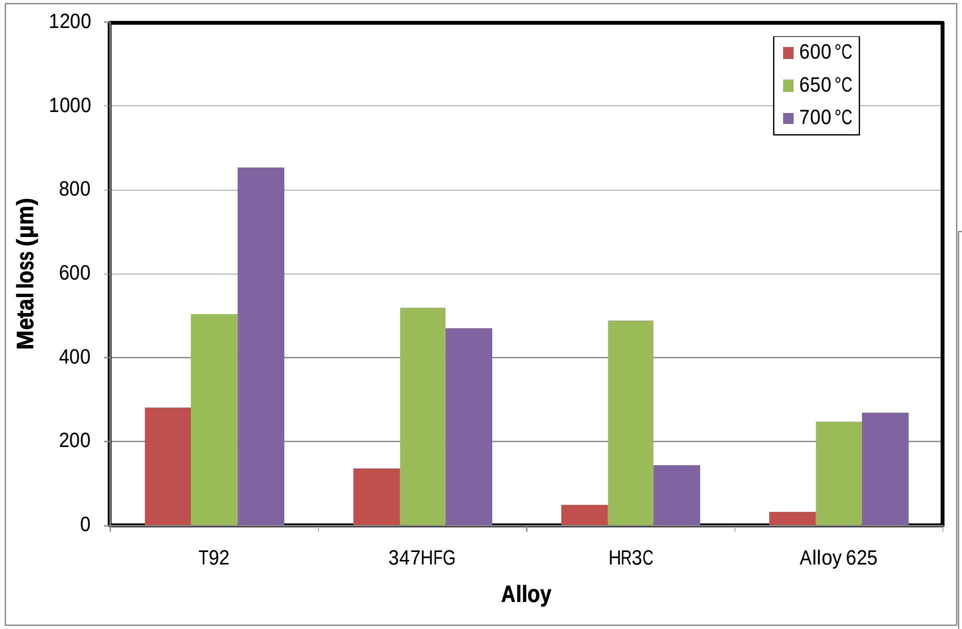


Alloys covered with alkali iron sulphate deposit (D1) in simulated air-fired combustion gases for 1000h

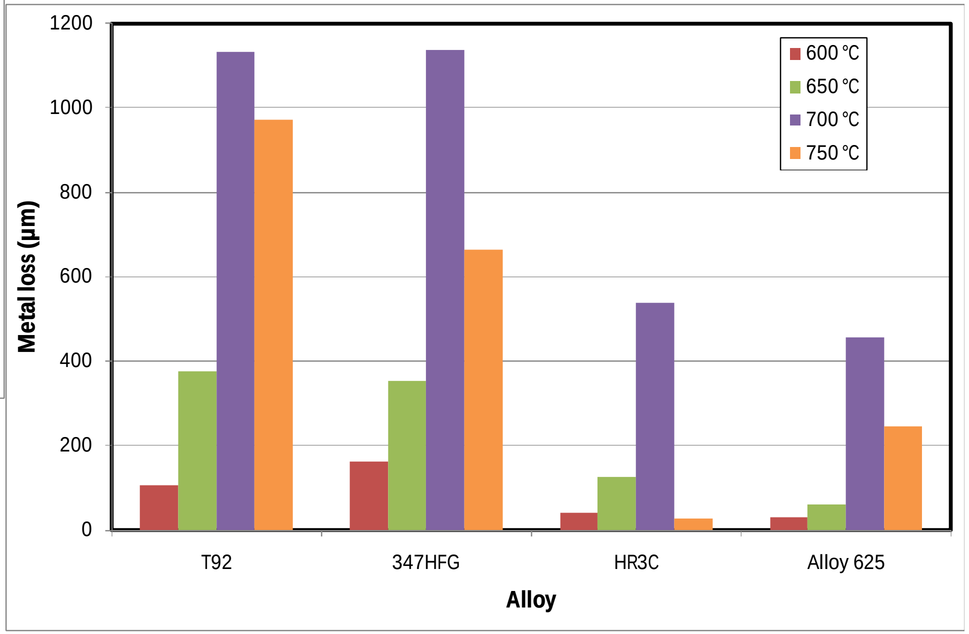
Fireside Corrosion

Fireside corrosion damage to alloys exposed with alkali iron sulphate (deposit D1)

(a) Simulated air-fired combustion gases

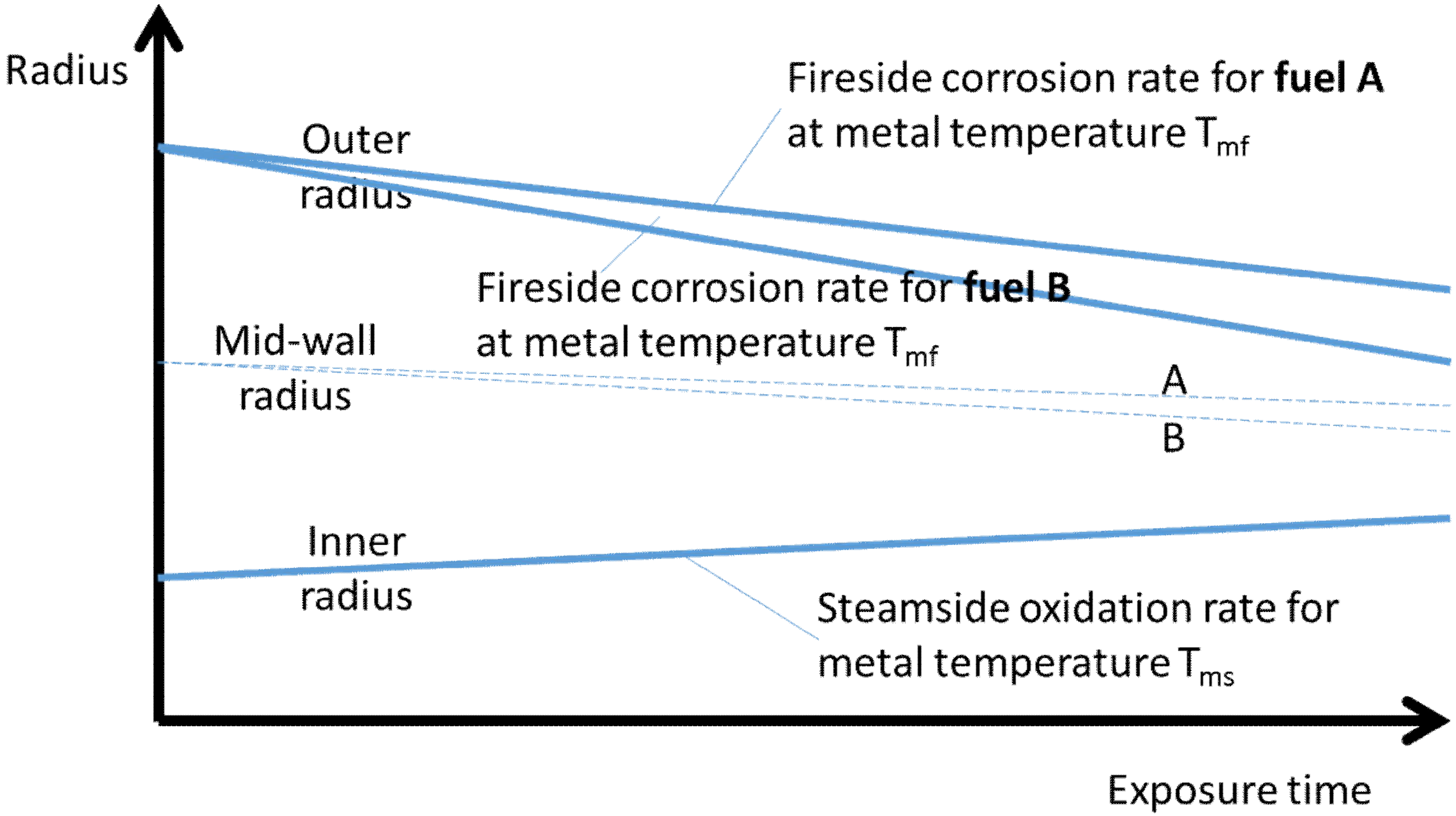


(b) Simulated oxy-fired combustion gases (hot gas recycle option)



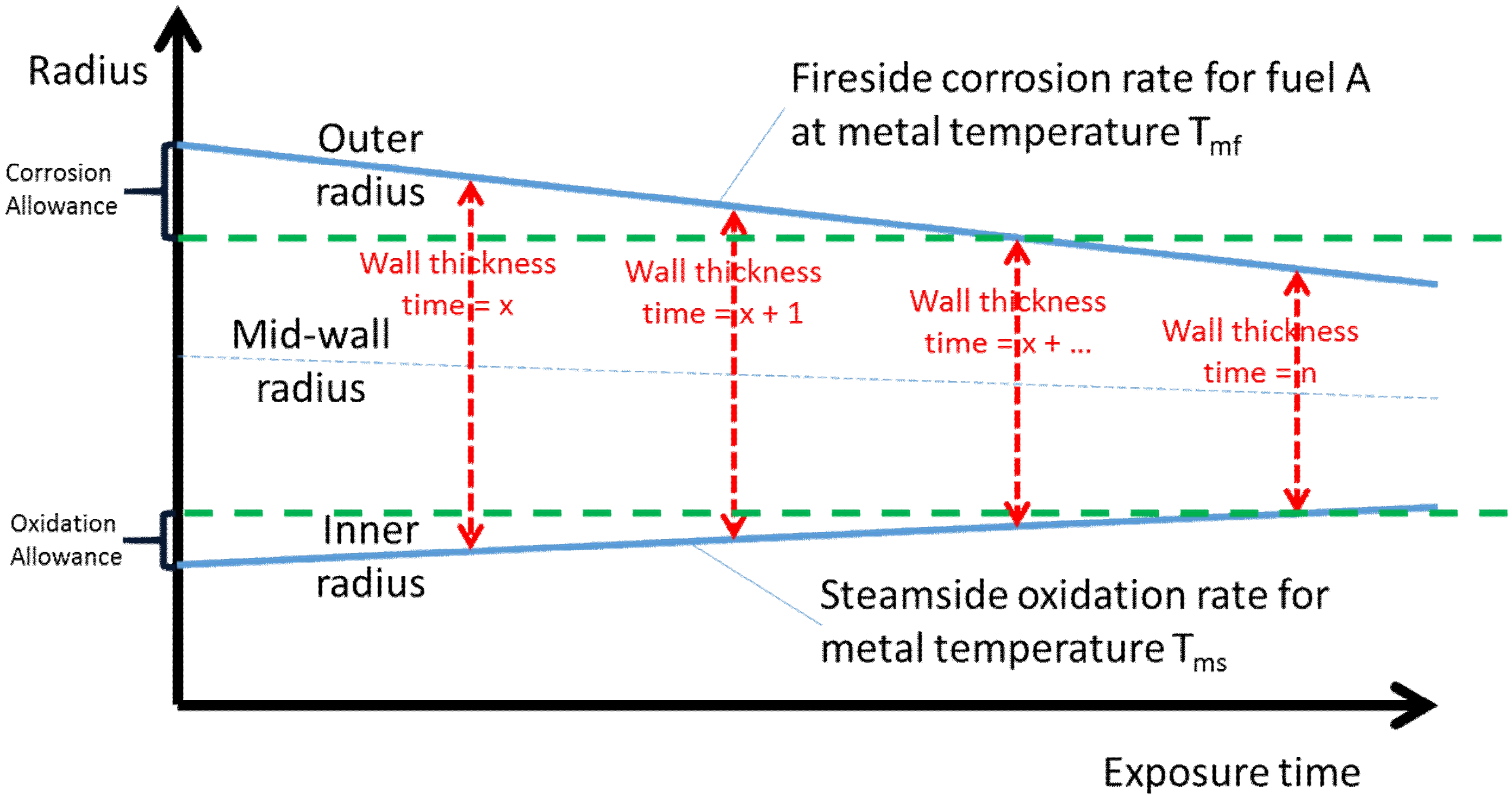
Fireside Corrosion

Corrosion Allowance



Fireside Corrosion

Corrosion Allowance



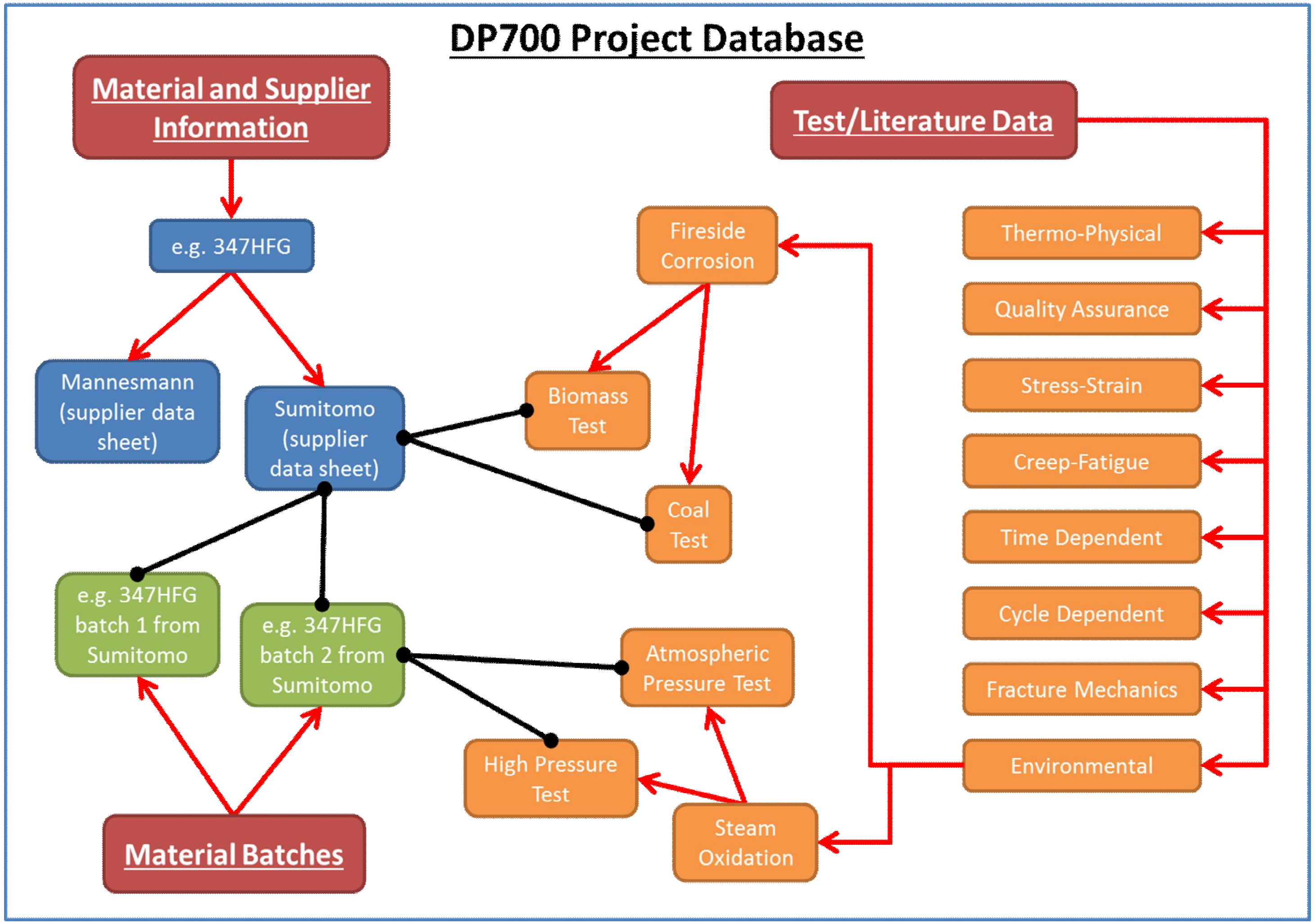
Data gathering and Database development

DP700 Materials Database

- Materials suitable for AUSC can be very expensive;
- Current approach in designing (design by code) too conservative;
- Need to develop a new approach to design (design by analysis);
- In order to change the approach a large amount of good quality data is needed;
- Large amount of data available in the literature;
- A lot of projects try to develop an AUSC (US, UK, India, China).

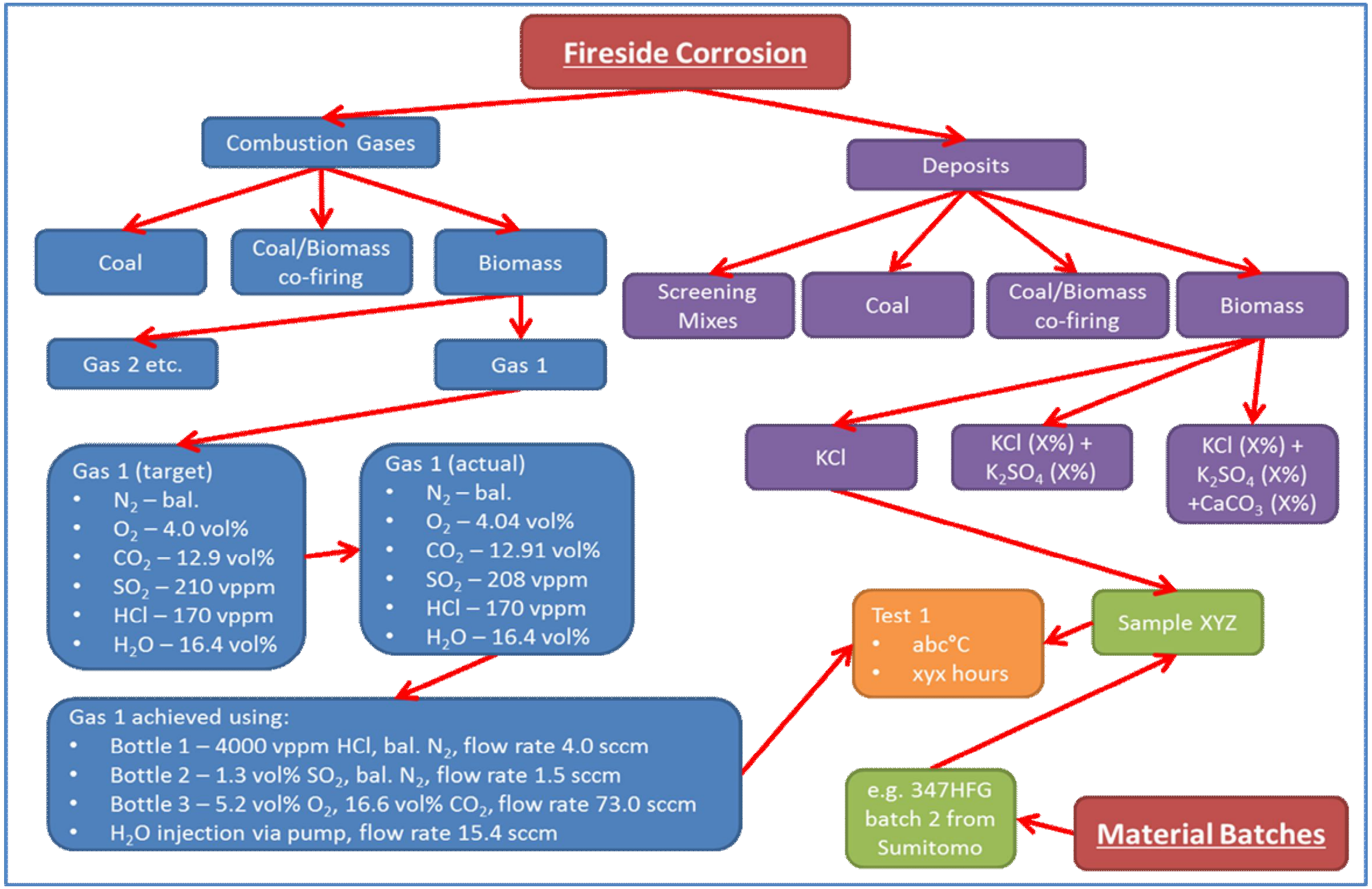
Data gathering and Database development

Design Database Layout



Data gathering and Database development

Example data for a fireside corrosion test



Data gathering and Database development

Data quality ratings – 5 levels

Level 5 (all the material pedigree data and production processing are provided) Highest Quality

- **chemical composition**
- **material production process: material Manufacturer, primary melt process, de-oxidation practice, secondary melt process, ingot or continue casting**
- **product manufacturing: hot/cold working process parameters**
- **product form and dimensions**
- **heat treatment: time, temperature and cooling medium**
- **microstructure**
- **test environment (this is valid for corrosion/oxidation)**

Level 4 (as Level 5 but information on material production/processing is not complete)

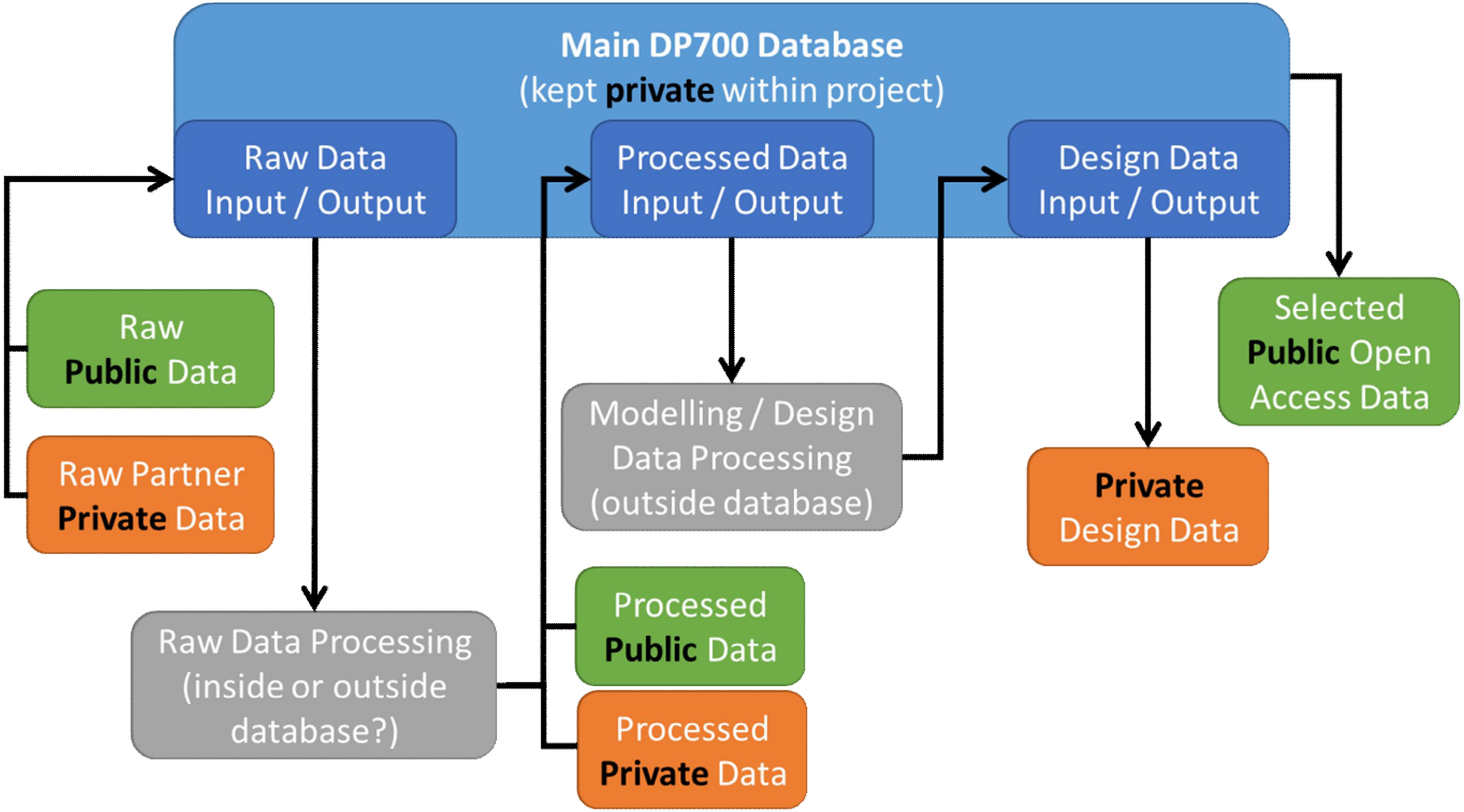
Level 3 (as Level 4 but the microstructure is not provided)

Level 2 (as Level 3 but the chemical composition and the product form/dimensions are not complete)

Level 1 only the indication of the name of the material is reported. Chemical analysis not provided, or only partially provided. Lowest Quality

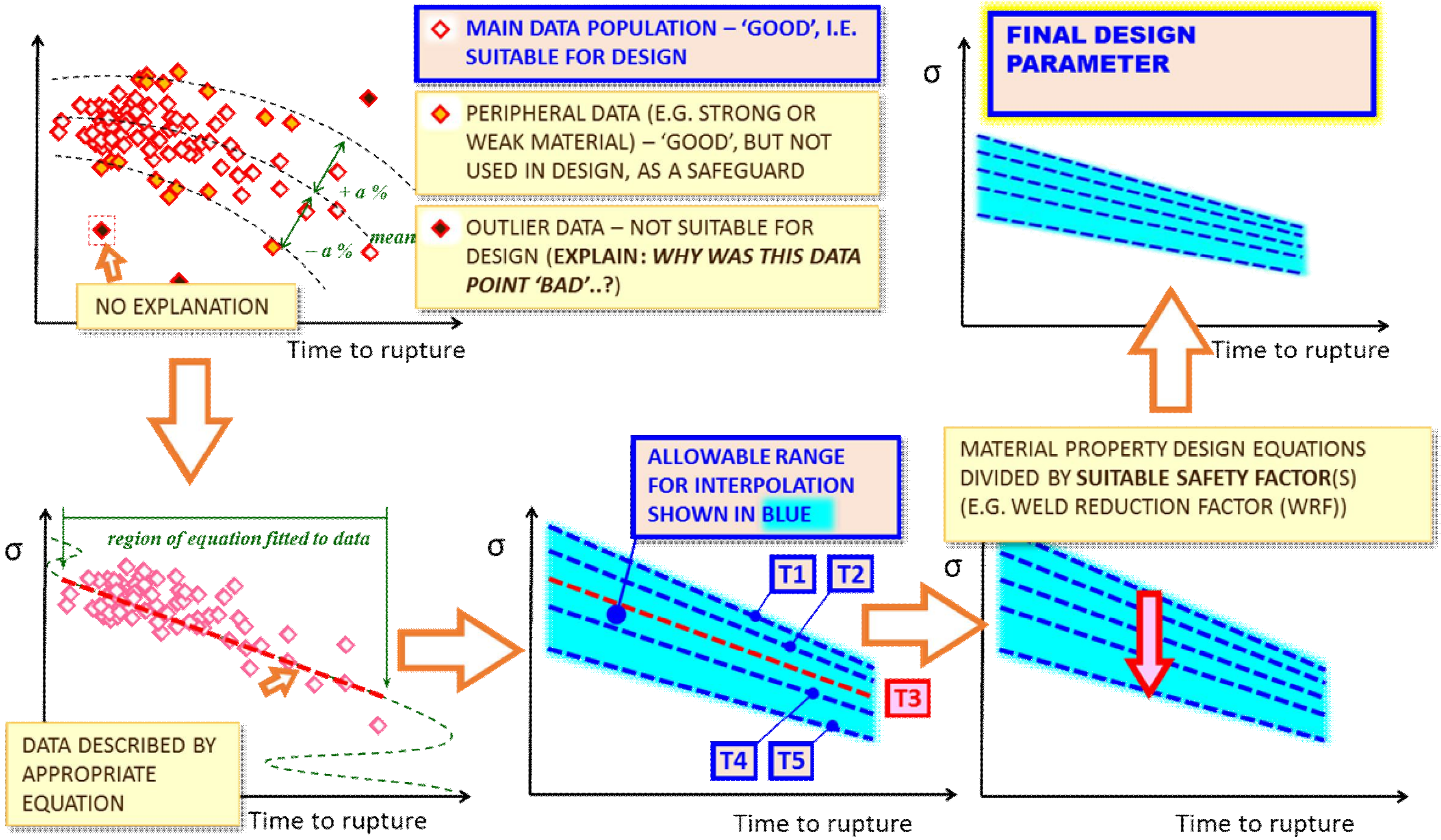
Data gathering and Database development

Strucure of the Database



Data gathering and Database development

Use of the qualified data



Summary

- AUSC will require high spec materials;
- Some of these materials need to be studied;
- The way to assess the properties is crucial;
- Key point is the assessment of the corrosion allowance;
- One possible way is *via* Dimensional Metrology;
- Reduce the costs of these materials is also vital;
- One way is to change the approach to the design (Design by Analysis);
- A lot of good quality data and the building of a database is crucial for this point.

Thank you for your attention

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