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Air Oxidation Modelling at PSI

Presented at the Second European MELCOR User Group, Prague, 1-2 March 2010

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Outline

- Air oxidation model development at PSI
  - background
  - summary description of model
  - comparison with test data
- OECD Spent Fuel Programme
- Current plans

Technical background

Background – effect on accident evolution

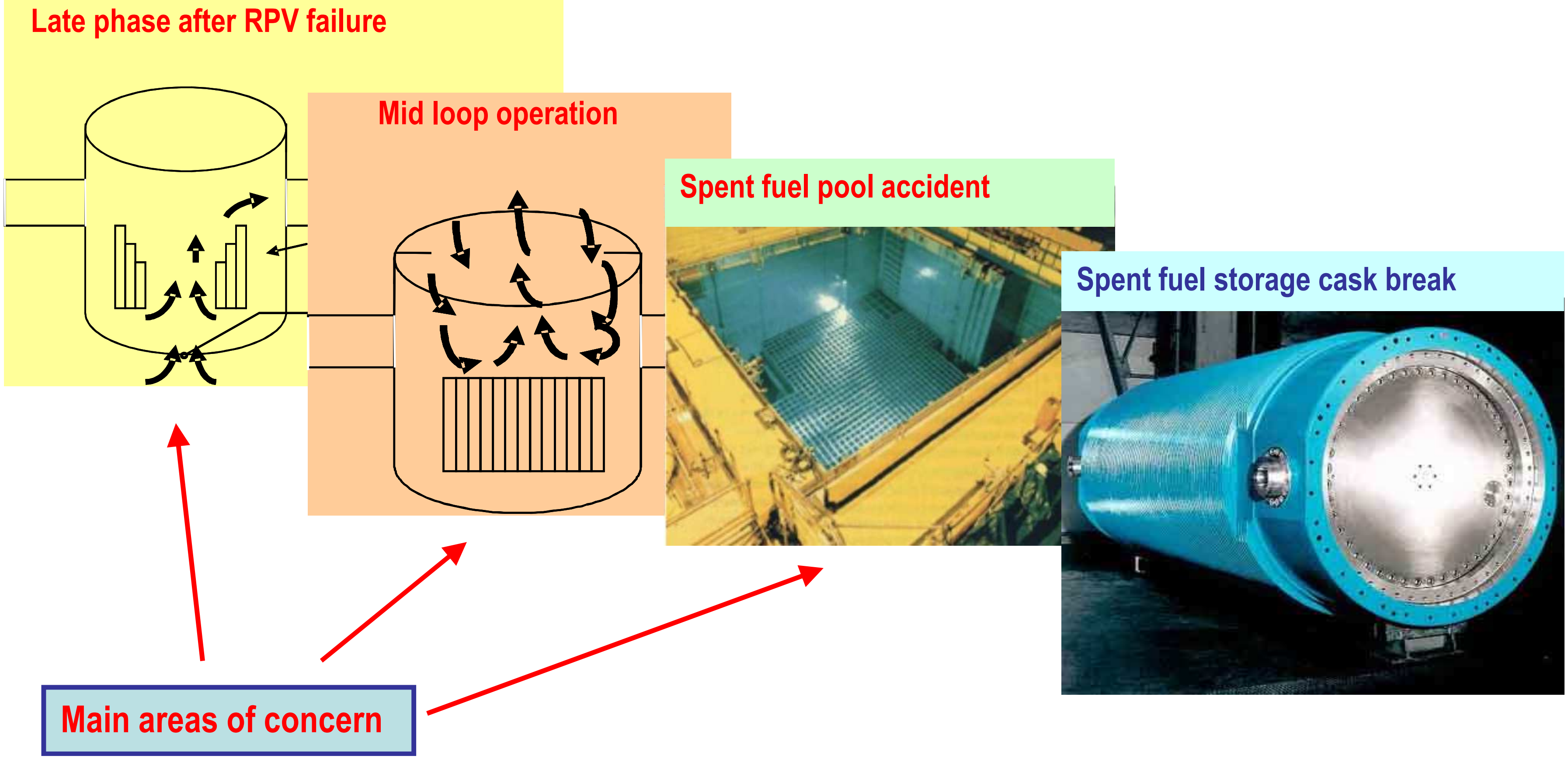
Strong exothermal reaction
($\Delta_R H^{air} >> \Delta_R H^{steam}$)
+ Less cooling effect
→ **Temperature escalation**

Detrimental effect of nitrogen on oxide scales
→ **Enhanced cladding degradation**

Higher oxygen activity in the core
→ **Oxidation of fuel**
FP release and transport

Air oxidation is important in determining boundary conditions for FP release

Background – air oxidation scenarios



Late phase after RPV failure

Mid loop operation

Spent fuel pool accident

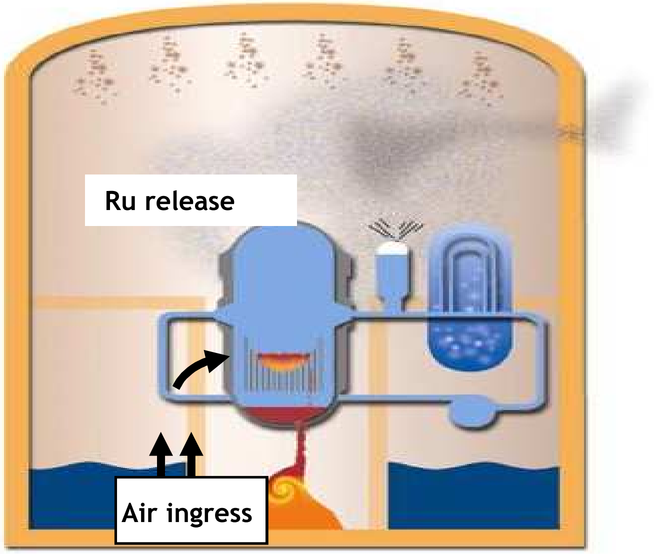
Spent fuel storage cask break

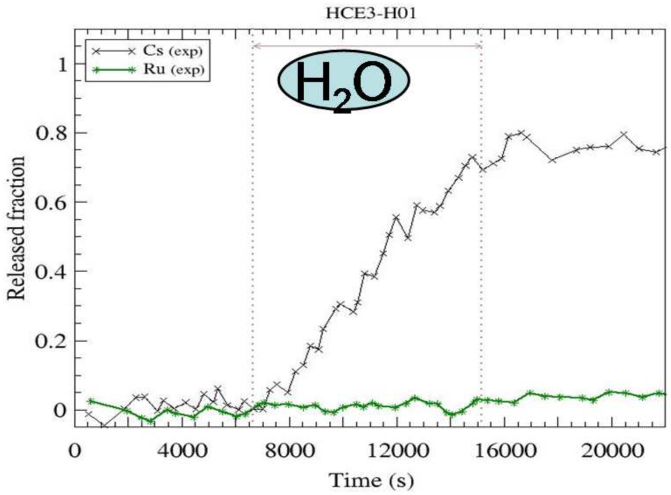
Main areas of concern

Technical background

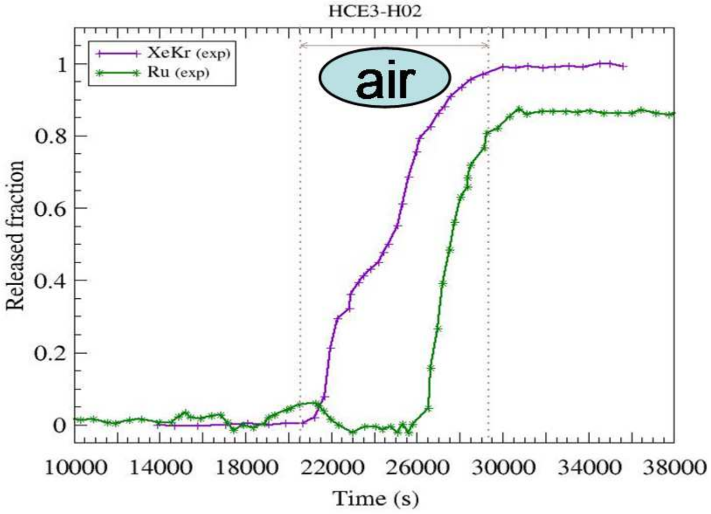
Background – ruthenium release

- Air ingress into a damaged reactor core may lead to increased FP release, especially that of ruthenium, e.g. shown by AECL HCE data
- Ru release and transport were extensively studied experimentally and by modelling in the EU SARNET 6th FW project
- Effect of air on Ru release modelled, also persistence of volatile forms in the containment was demonstrated
- Further expts and modelling to conclude the study in the EU 7th FW SARNET2 project, starts early 2009 for 4 years





Test	HCE3-H01	HCE3-H02
Max. temperature (K)	2200	2160
Oxidation temperature (K)	1770	1790
Oxidation duration (s)	8500	8740
Gas phase	90% H2O 10 % Ar 0.2% Ar	Air



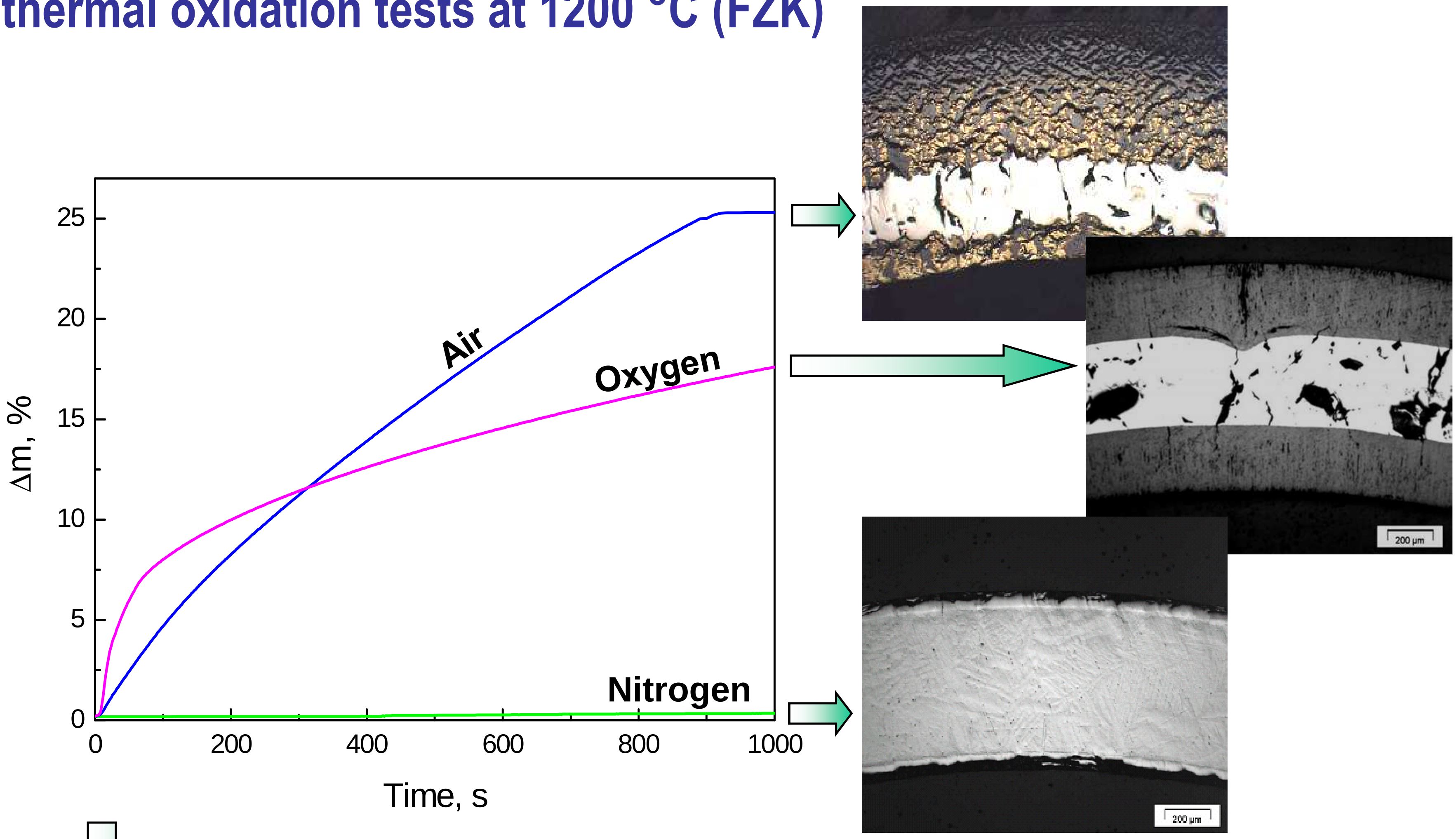
Technical background

Summary of air oxidation phenomena

- Exposure to air degrades the oxide layer and promotes transport of oxidant to the metal surface
  - oxide scale has higher porosity and may be broken away
- Reaction with oxygen takes precedence over reaction with steam
  - oxygen and steam kinetics similar
  - nitrogen enhances oxidation by both steam and oxygen
- Kinetics are influenced by many factors
  - may be dependent on temperature, previous oxidation history (fading memory effect), cladding alloy, …
- Existing correlations typically overestimated oxidation rate
  - calculated oxygen starvation at the key location may be non-conservative
- A more complete treatment is required to provide essential boundary conditions for the fission product release and transport models

Technical background

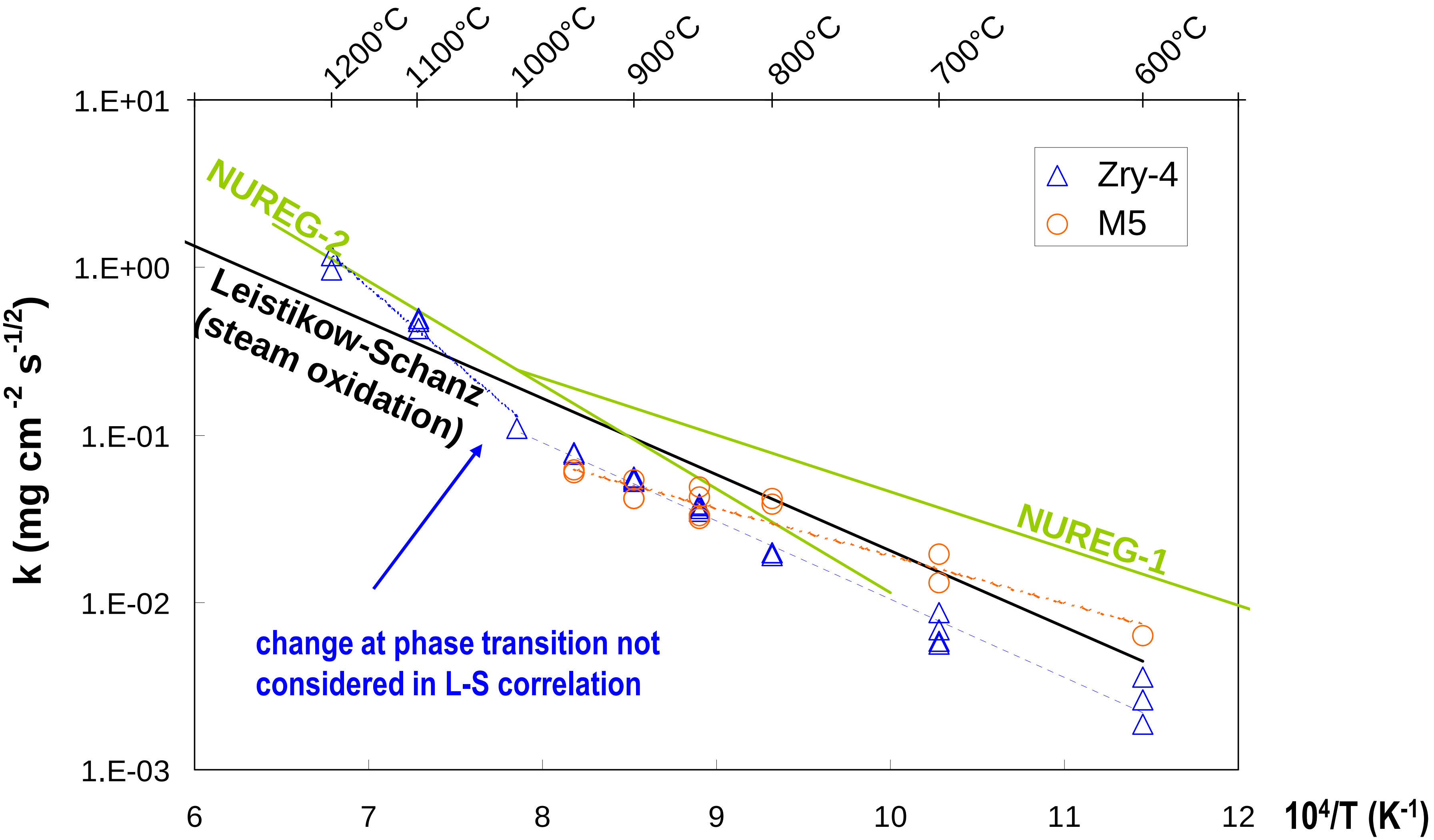
Isothermal oxidation tests at 1200 °C (FZK)



Significant nitride formation in air but not in nitrogen

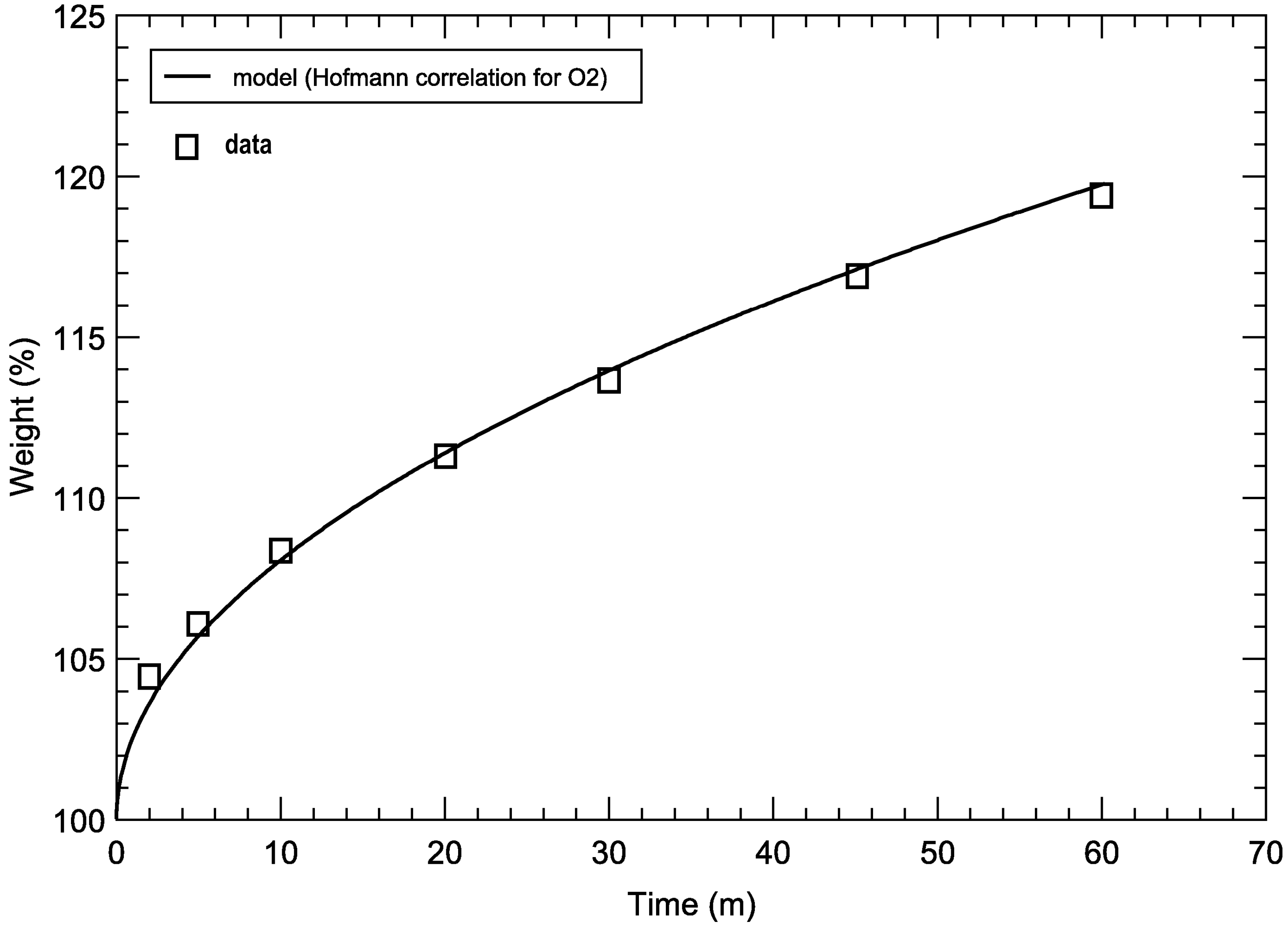
Technical background

Classical models for pre-transition air oxidation



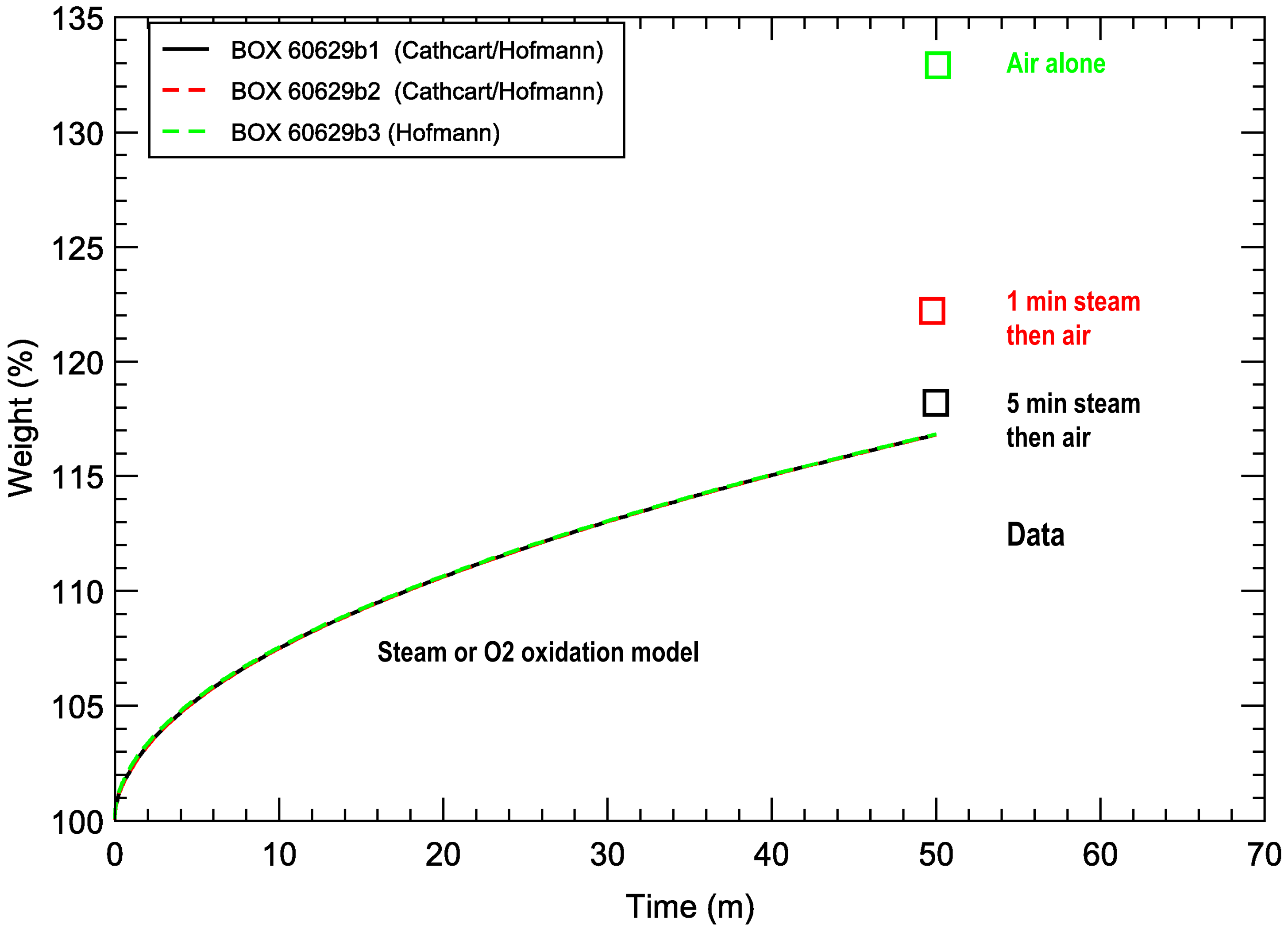
change at phase transition not considered in L-S correlation

Comparison with data test in 25% O_2/75% Ar mixture at 1200 ºC



Air oxidation modelling

Comparison with BOX test in air and steam then air at 1200 ºC

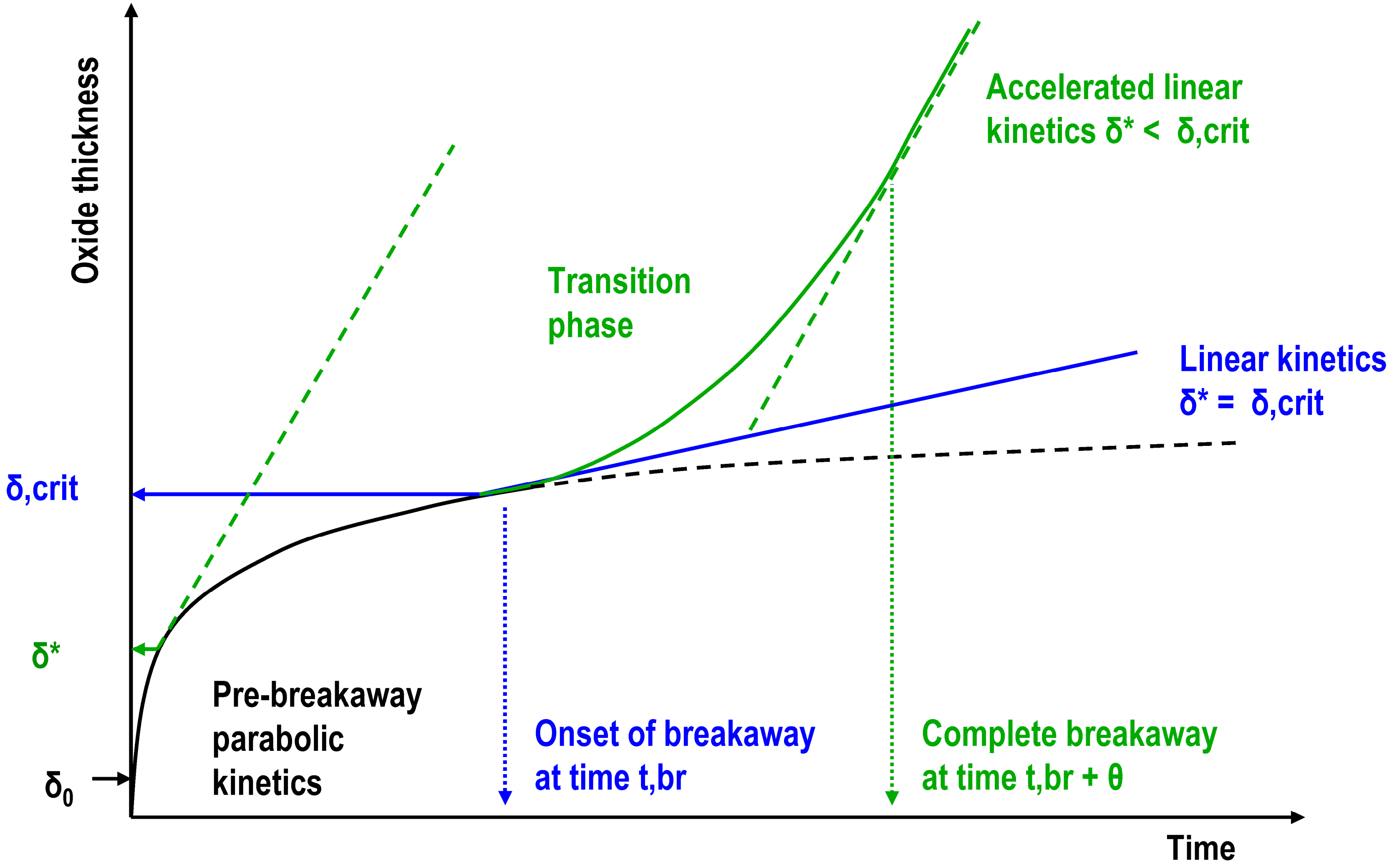


Air oxidation modelling

Outline of model concept - 1

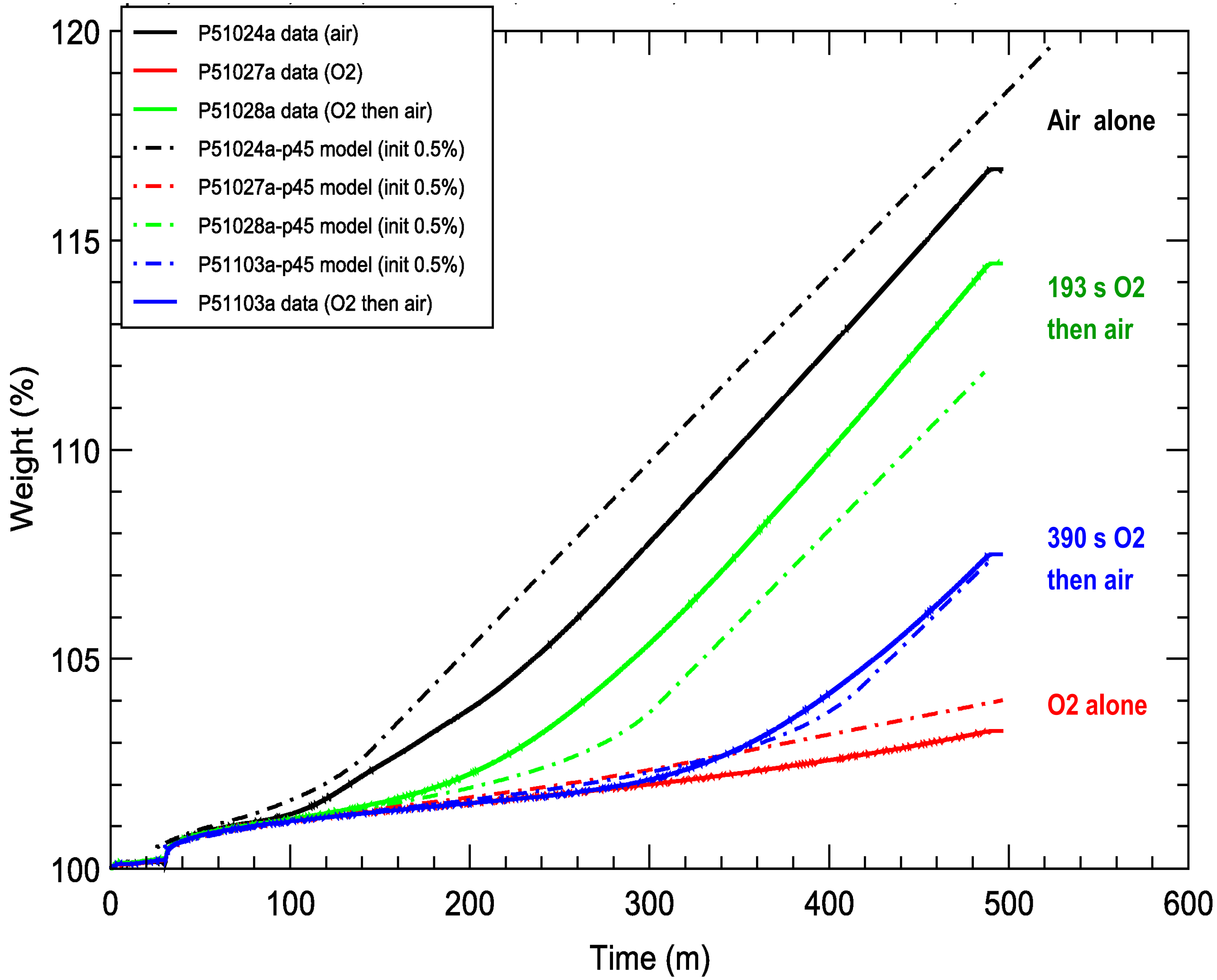
- Define breakaway condition as an upper limit on effective oxide thickness
  - cladding oxidation rate/area: $R = \rho_{Zr}\, d(\delta)/dt \sim A \exp(-B/T) / \delta^*$
  - where $\delta^* = \max(\delta_0 , \min(\delta, \delta^*))$
  - δ_0 is some minimum ($\ll \delta^*$)
  - and δ = true oxide thickness
- Separate values of δ^* are defined for air and steam
  - typically $\delta^*_{air} < \delta^*_{steam}$
- In general δ^* is a function of temperature, material and possibly other factors
- We also define a criterion for onset of breakaway δ,crit ($\geq \delta^*$) and timescale τ over which the limit value δ^* is applied
- Model parameters δ,crit, δ^*, τ will be mostly based on results of recent and current separate-effects experiments

Outline of model concept - 2



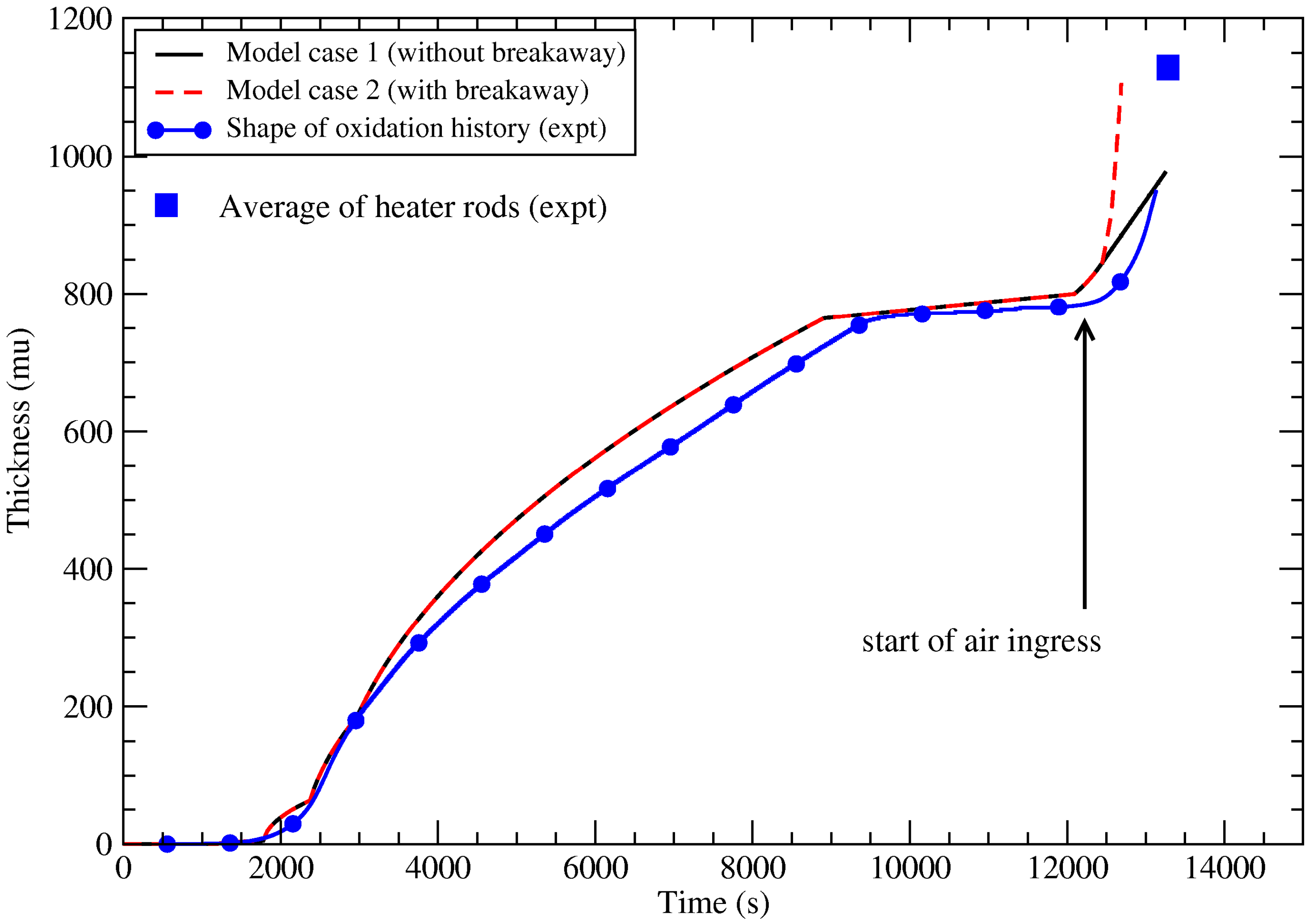
Air oxidation modelling

Comparison with thermal balance tests in O_2 and air (T = 800 ºC)

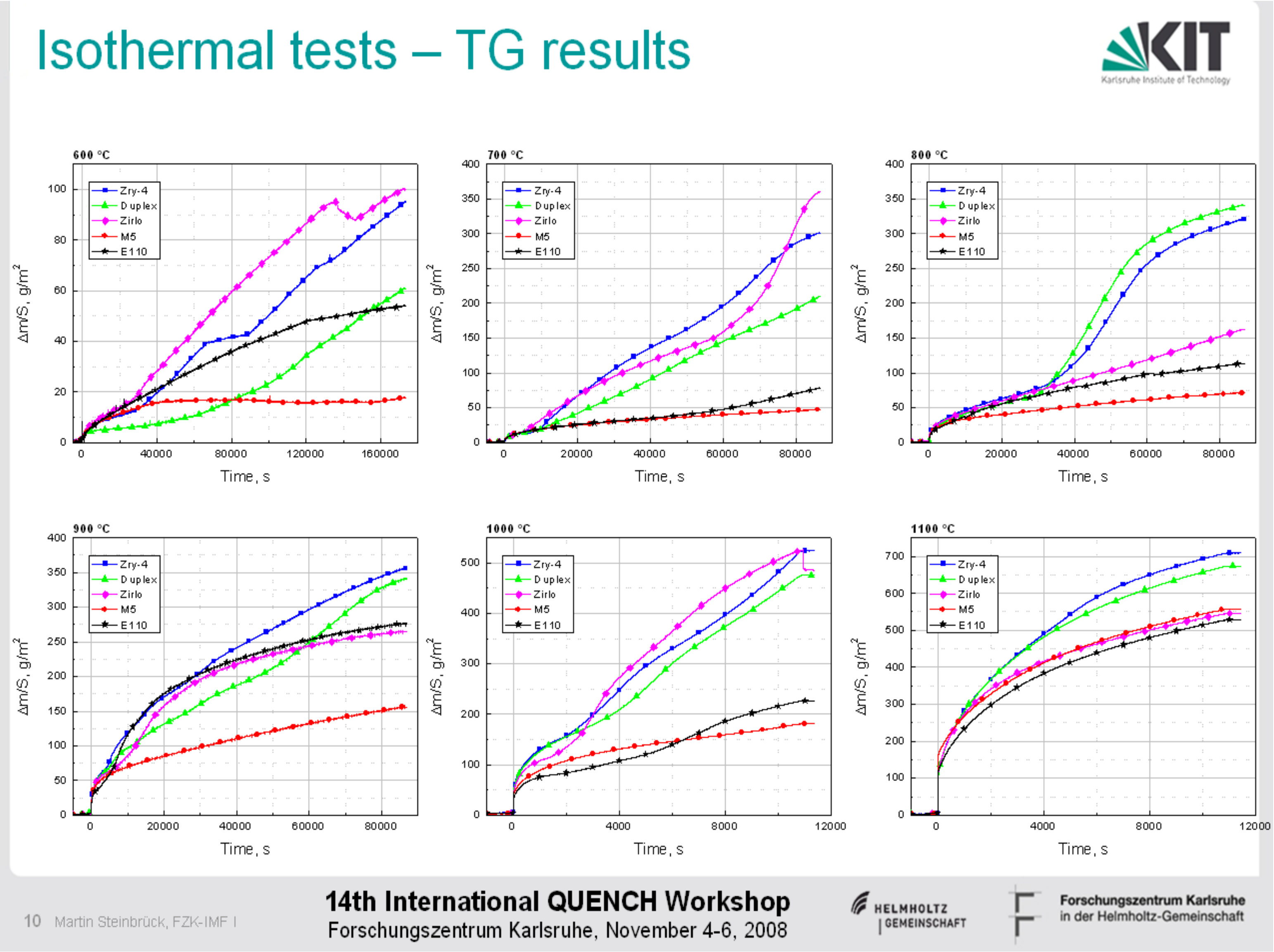


Air oxidation modelling

Reconstruction QUENCH-10 oxide layer growth



Effect of different cladding types



Isothermal tests – TG results

10 Martin Steinbrück, FZK-IMF I

14th International QUENCH Workshop
Forschungszentrum Karlsruhe, November 4-6, 2008

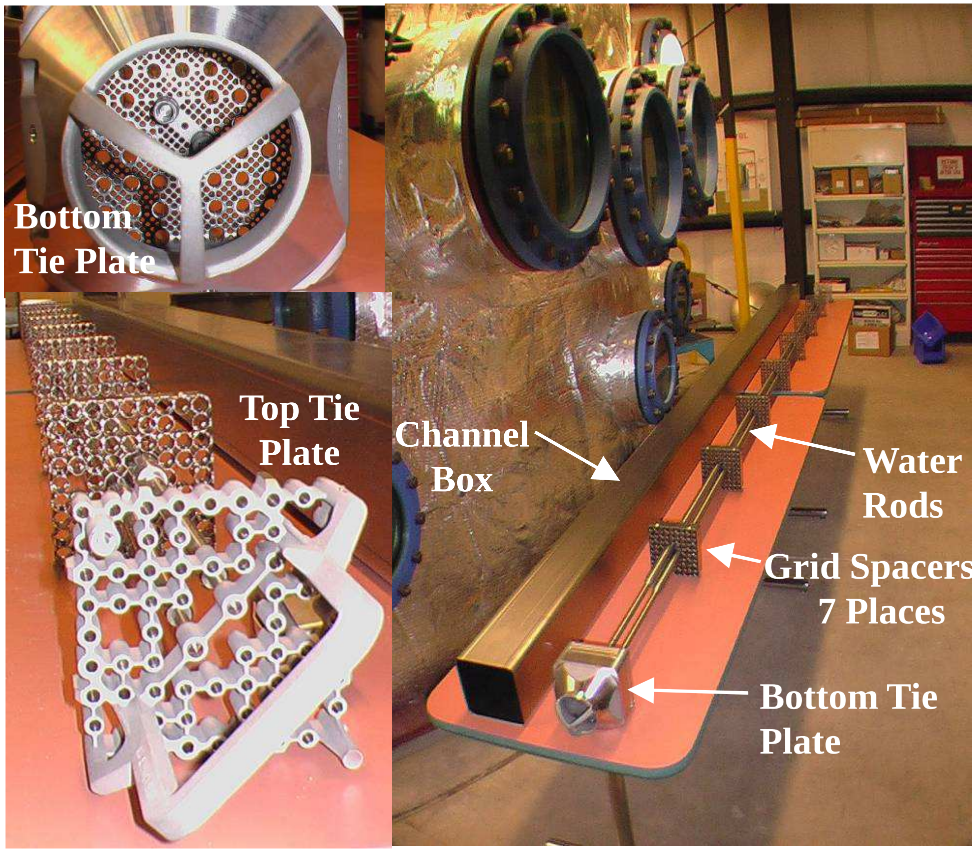
HELMHOLTZ GEMEINSCHAFT

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

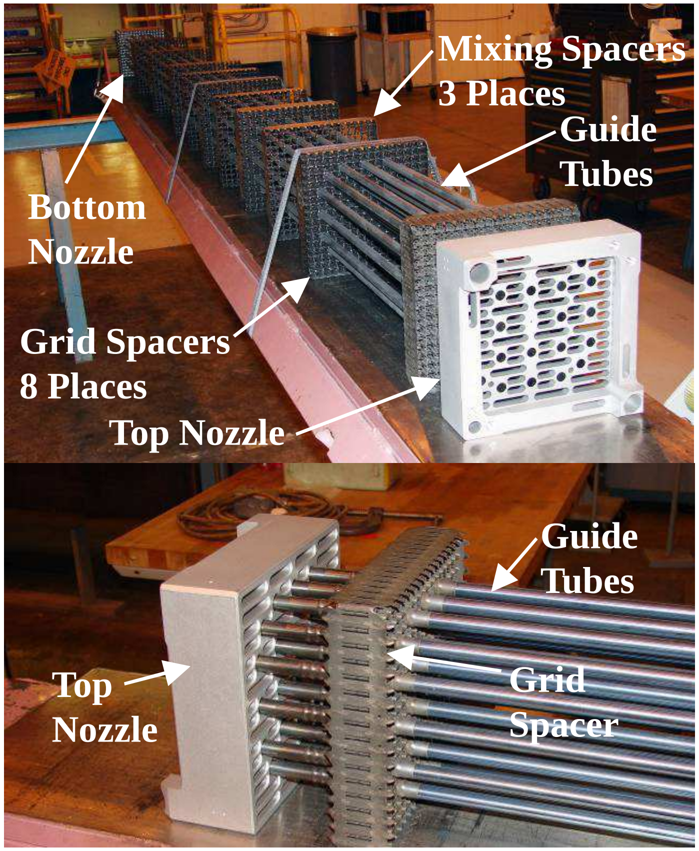
M Steinbrück, "Oxidation of diferent cladding alloys in steam at temperatures 600-1200 ºC", 14th QUENCH Workshop, Forschungszentrum, Karlsruhe, November 2008

Prototypic BWR and PWR Hardware

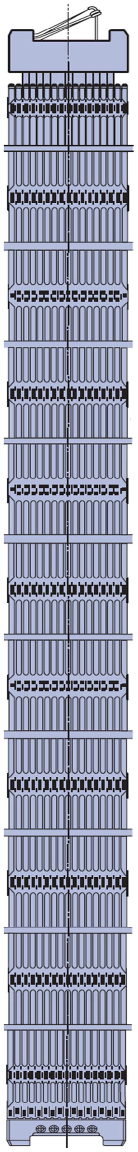
GNF 9 × 9 BWR
- SNL/NRC

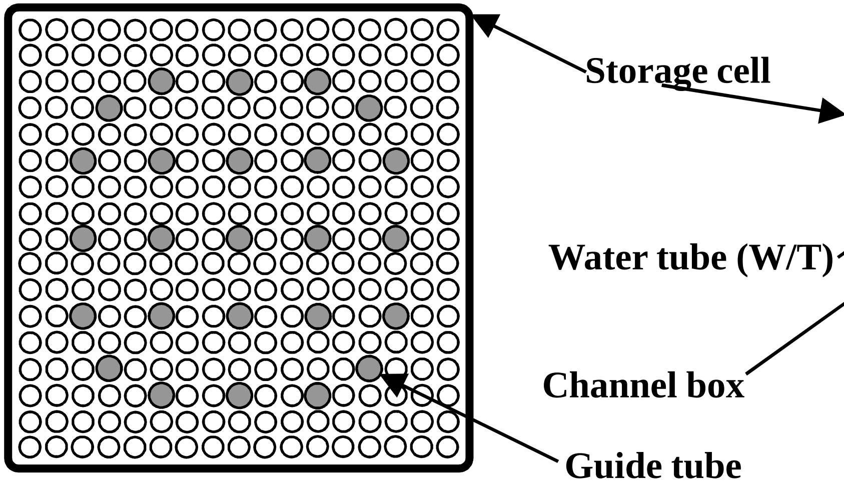


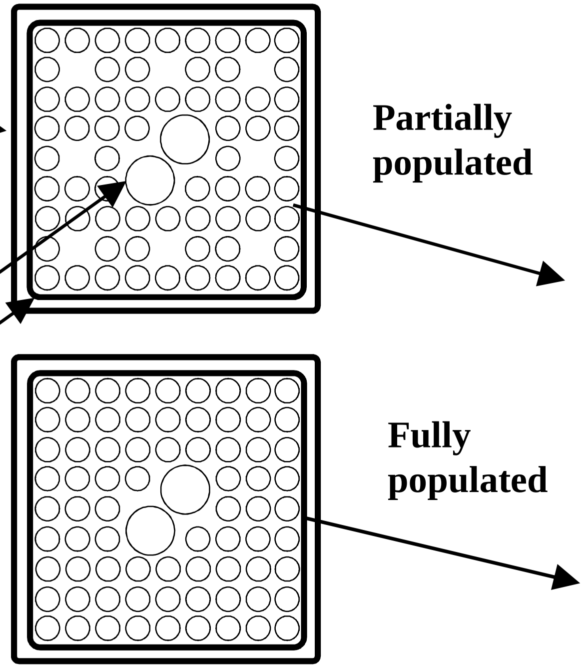
Westinghouse 17×17 PWR
- SNL/OECD

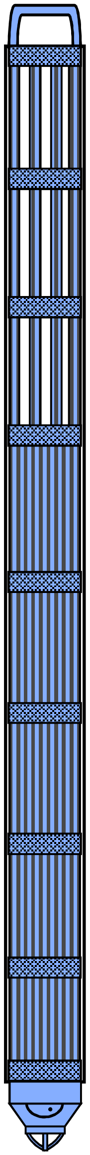


PWR and BWR Assembly Geometries









PWR 17×17

- 264 Fuel rods
- 24 Guide tubes
- 1 Instrument tube
- 11 spacers

Storage cell

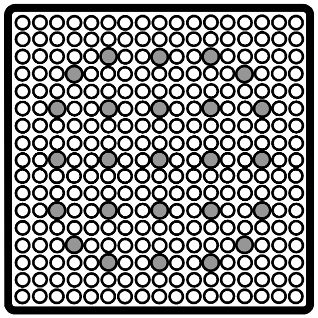
BWR 9×9

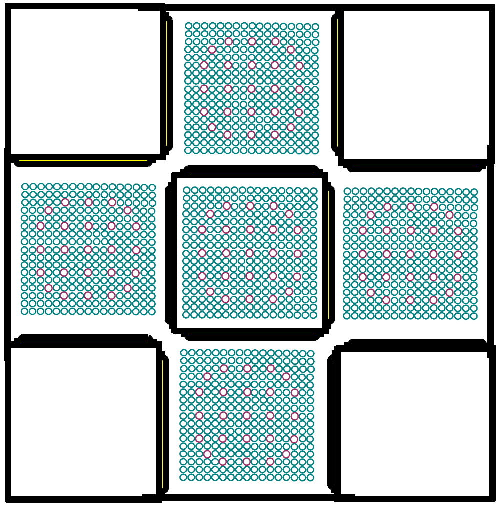
- 74 Fuel rods (8 partial length)
- 2 Water tubes
- 7 spacers

Channel box

Storage cell

PWR testing program





- Phase 1
- Axial Ignition
  - Temp profiles measurements
  - Buoyancy induced flow measurements
  - Axial O_2 profile measurements
  - Nature of fire

- Phase 2
- Radial Propagation in a 1 + 4 arrangement
  - Determine nature of radial fire propagation
  - Effect of fuel rod ballooning

Current plans for 2009-2012

- Implement in MELCOR
  - *in progress in local version of MELCOR 1.8.6*
- Validation against independent data
  - *bundle tests: QUENCH-10 and PARAMETER SF4: 2010*
  - *data from Spent Fuel Pool Programme*
- Further developments
  - *implementation in MELCOR 2*
    - ***requires active collaboration among SNL, NRC and PSI***
  - *possible extension to alternative cladding alloys (M5, Zirlo, E-110)*

Acknowledgments

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- The authors gratefully acknowledge material provided by FZK and IRSN in preparing this presentation
- Thank you for your attention

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