In-situ neutron radiography investigations of the hydrogen absorption of zirconium alloys during steam oxidation

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  - Data processing

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Introduction

Context

Possible dangers and accidents in nuclear fission reactors

- Loss Of Coolant Accidents (LOCA)
  - Rod temperature rises quickly, Core dries out
  - Re-flooding the reactor core with water or steam
  - Severe Fuel rod Damage (SFD)
Reaction between hot nuclear fuel rod cladding and steam:

\[
2 \text{H}_2\text{O} + \text{Zr} + 2\text{V}_0^{(2+)} + 4\text{e}^- \rightarrow \text{ZrO}_2 + 4\text{p}^+ 4\text{e}^- \\
4\text{p}^+ + 4\text{e}^- \rightarrow 2\cdot\text{x} \text{H}_2\uparrow + 4(1\cdot\text{x}) \text{H}_{\text{abs}}
\]

- risk of hydrogen detonation
- change of the time dependence of H release
- embrittlement of the cladding material
Currently the following two topics are being investigated

- The hydrogen absorption of zirconium alloys during steam oxidation
- The temperature dependence of $\Sigma$ of hydrogen solute in $\beta$-zirconium
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Hydrogen determination by means of neutron radiography

X-ray radiography

neutron radiography

Objects

- with small total cross section have a high transmission (bright),
- with high total cross section have a low transmission (dark)
Hydrogen determination by means of neutron radiography

Calibration

Dependence of total macroscopic neutron cross section on hydrogen concentration and on oxide layer thickness.
Hydrogen determination by means of neutron radiography

In-situ NeutronenRadiographie ReaktionsOfen

Gas and steam flow controller

Nb resistance heater

H2O cooling

Sample

Beam window

Neutron beam

Off-gas

Air lock

Neutron camera system
Hydrogen determination by means of neutron radiography
Hydrogen determination by means of neutron radiography

\[
T = \frac{I}{I_0} = e^{-\Sigma x} \quad \rightarrow \quad \Sigma = \frac{-\ln(T)}{x}
\]
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Hydrogen uptake by Zirconium alloys/Results

Temperature dependence of Hydrogen total neutron cross section in ZrH2

Hydrogen absorption at 1000°C with 2,4 and 8 g/h
Hydrogen uptake by Zirconium alloys/Results

In-situ steam oxidation experiment in Zircaloy 4

Steam oxidation in Zry-4 at 1000°C
Hydrogen uptake by Zirconium alloys/Results

Diffusion of hydrogen in an oxygen coated Zry-4 cylinder

Hydrogen diffusion at 900°C

Hydrogen diffusion at 550°C
Content

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➤ Hydrogen uptake by Zirconium alloys/Results
  • Temperature dependence of Hydrogen total neutron cross section in ZrH$_2$
  • Oxygen absorption by pre-oxidized Zry-4 alloys
  • Diffusion of hydrogen in an oxygen coated Zry-4 cylinder

➤ Summary and Conclusions
Summary and Conclusions

Neutron radiography is a powerful tool for a fast, non-destructive, and quantitative determination of the hydrogen content in zirconium alloys with high lateral resolution (< 30 µm). In-situ investigations are possible.

The hydrogen uptake at the beginning of steam oxidation is very fast. After about 600s the maximal hydrogen concentrations seems to be reached.
Thanks

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Thank you for your attention