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Aspects of Modeling a Spent Fuel Pool

M. Loeffler, M. Braun
AREVA GmbH

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Content

1. **Hydraulic diameter of a fuel assembly**
2. **Evaporation of a spent fuel pool**
3. **Transition between different CVs inside the SFP**

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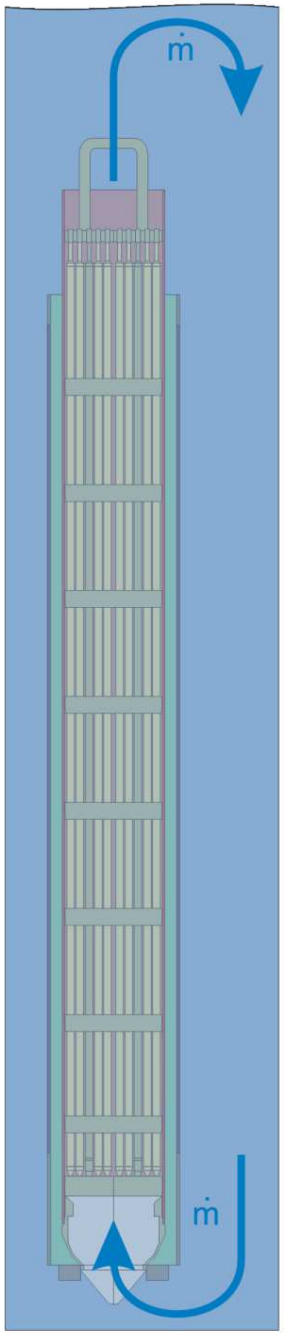

1.) Hydraulic diameter of a fuel assembly

- **Convection driven by stack-effect inside fuel assembly (FA)**

$$\Delta p_{stack} = g \cdot \rho(T(0)) \cdot (z_{top} - z_{bottom}) \quad - g \int_{z_{bottom}}^{z_{top}} \rho(T(z))\, dz$$

- **Water flow: Reynolds number ~1000 ➡ more laminar flow**
- **Air flow: Reynolds number ~1-10 ➡ only laminar flow**

- **Flow limited by wall friction inside fuel assembly**

$$\Delta p_{friction} = \frac{64 \cdot \mu}{2 \cdot \rho} \cdot \frac{L_{FA}}{d_{FA}^{2} \cdot A_{FA}} \cdot \dot{m}$$

- **MELCOR**
  - **FLnnn03 FRICFO FRICRO is unimportant**
  - **FLnnnSk SAREA SLEN SHYD dominates**

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1.) Hydraulic diameter of a fuel assembly

MELCOR 1.8.6 notation:

- **FLnnn03 FRICFO FRICRO**
- **FLnnnSk SAREA SLEN SHYD SRGH SLAM**

$$\Delta P^{f}_{j,\varphi} = \frac{1}{2} K_{j,\varphi}\rho\left|v_{j,\varphi}\right|v_{j,\varphi} + \sum_{S} \frac{2 f_{\varphi,S} L_S}{D_S}\rho_{\varphi,S}\left|v_{\varphi,S}\right|v_{\varphi,S}$$

Laminar flow coefficient, control function possible: According our experience for FAs in SFP not necessary

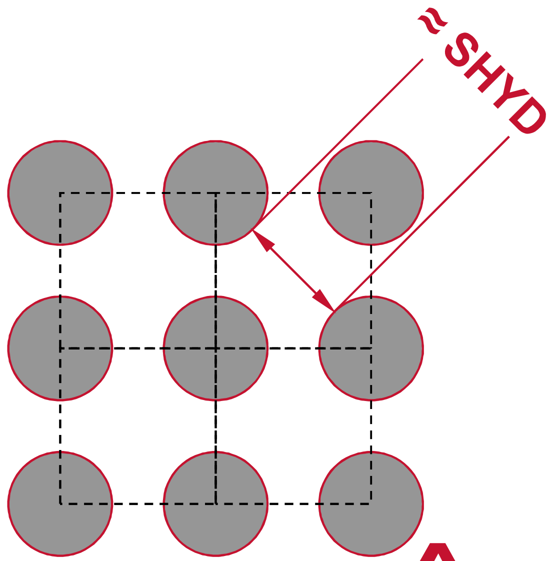
- **Single-Phase Friction Factor (SLAM = 16.0 for tubes)**

$$f = \frac{16.0}{\mathrm{Re}}$$

- **Conventional definition of hydraulic diameter (for tube like geometries)**

$$D_S = \frac{4 \cdot area}{wetted\ \ perimeter}$$

$$D_S = \sqrt{2} \cdot PITCH - 2 \cdot RCLAD$$



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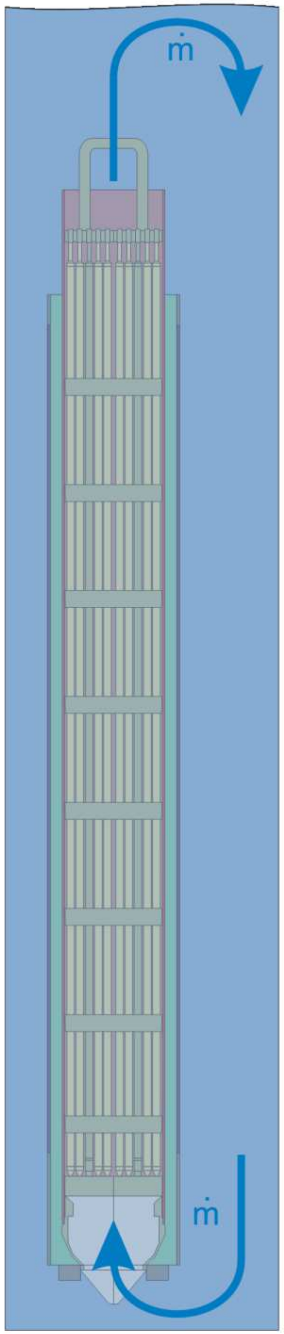


1.) Hydraulic diameter of a fuel assembly

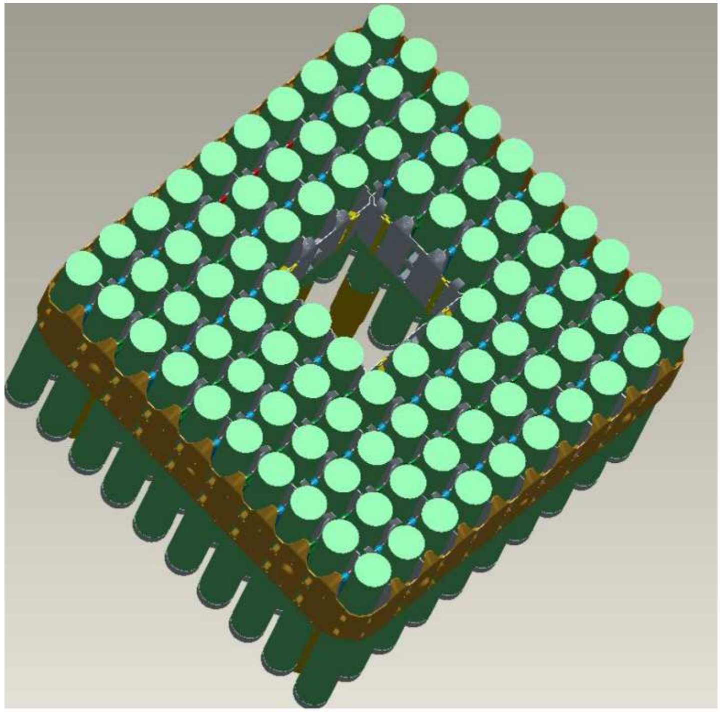
- **CFD-Analysis to determine hydraulic diameter (SLAM = 16.0)**
  - **Cross section of a complete BWR fuel assembly**
  - **Rod bundle**

$$\frac{4 \cdot area}{wetted\ \ perimeter} > \textbf{SHYD} > \sqrt{2} \cdot PITCH - 2 \cdot RCLAD$$

  - **Grid spacer**

    SHYD ≈ 38 % of Bundle-SHYD
  - **Fuel guard**

    SHYD ≈ Spacer-SHYD



Spacer with part of fuel rods (water channel and canister faded-out)

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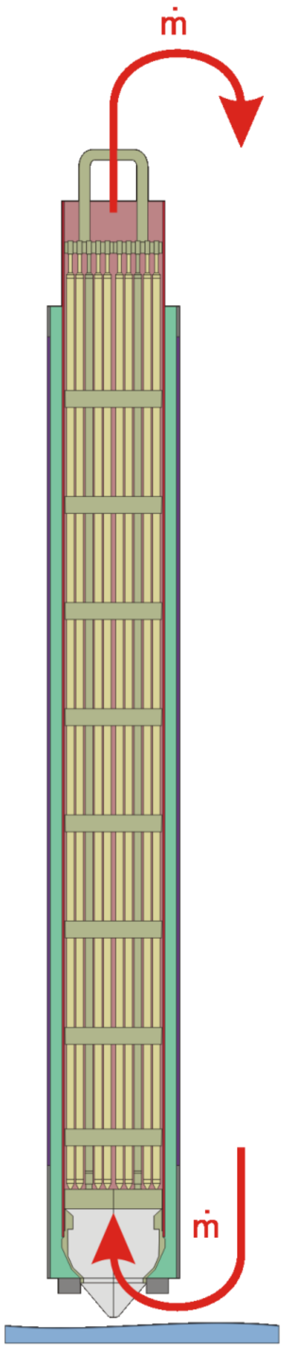
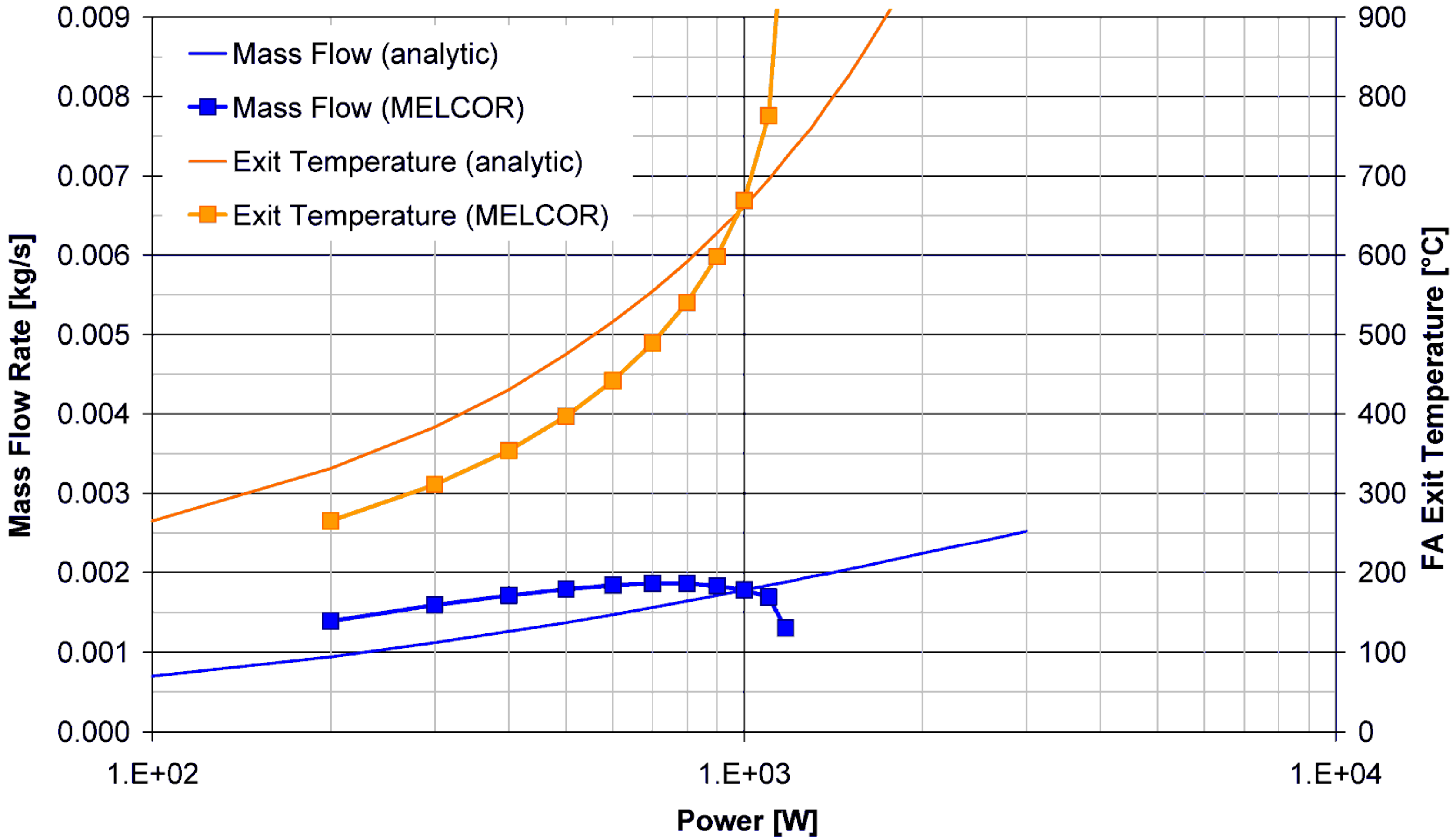
1.) Hydraulic diameter of a fuel assembly



- **Air-coolability of FA after dryout of the SFP**



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Content

1. Hydraulic diameter of a fuel assembly

2. **Evaporation of a spent fuel pool**

3. Transition between different CVs inside the SFP

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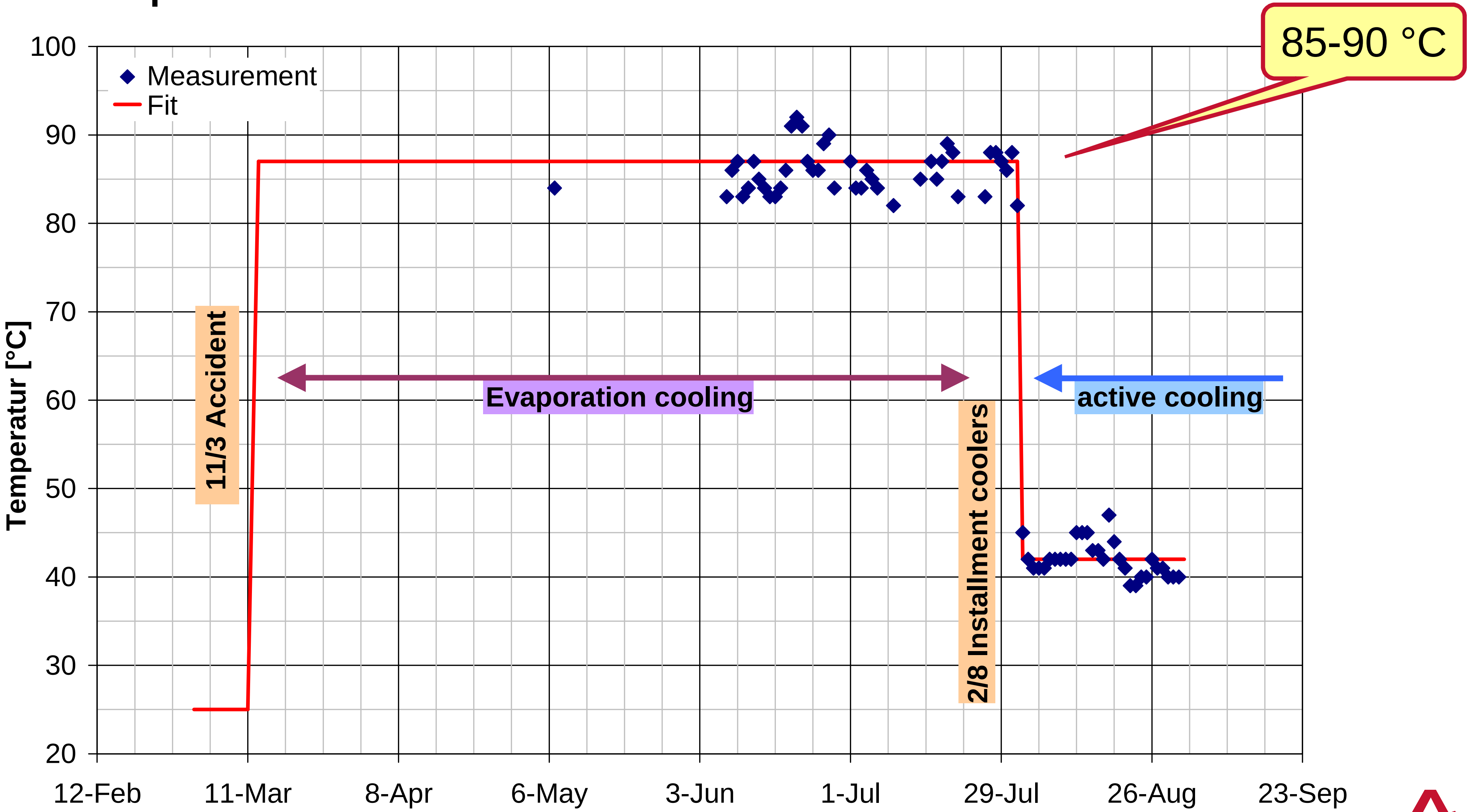
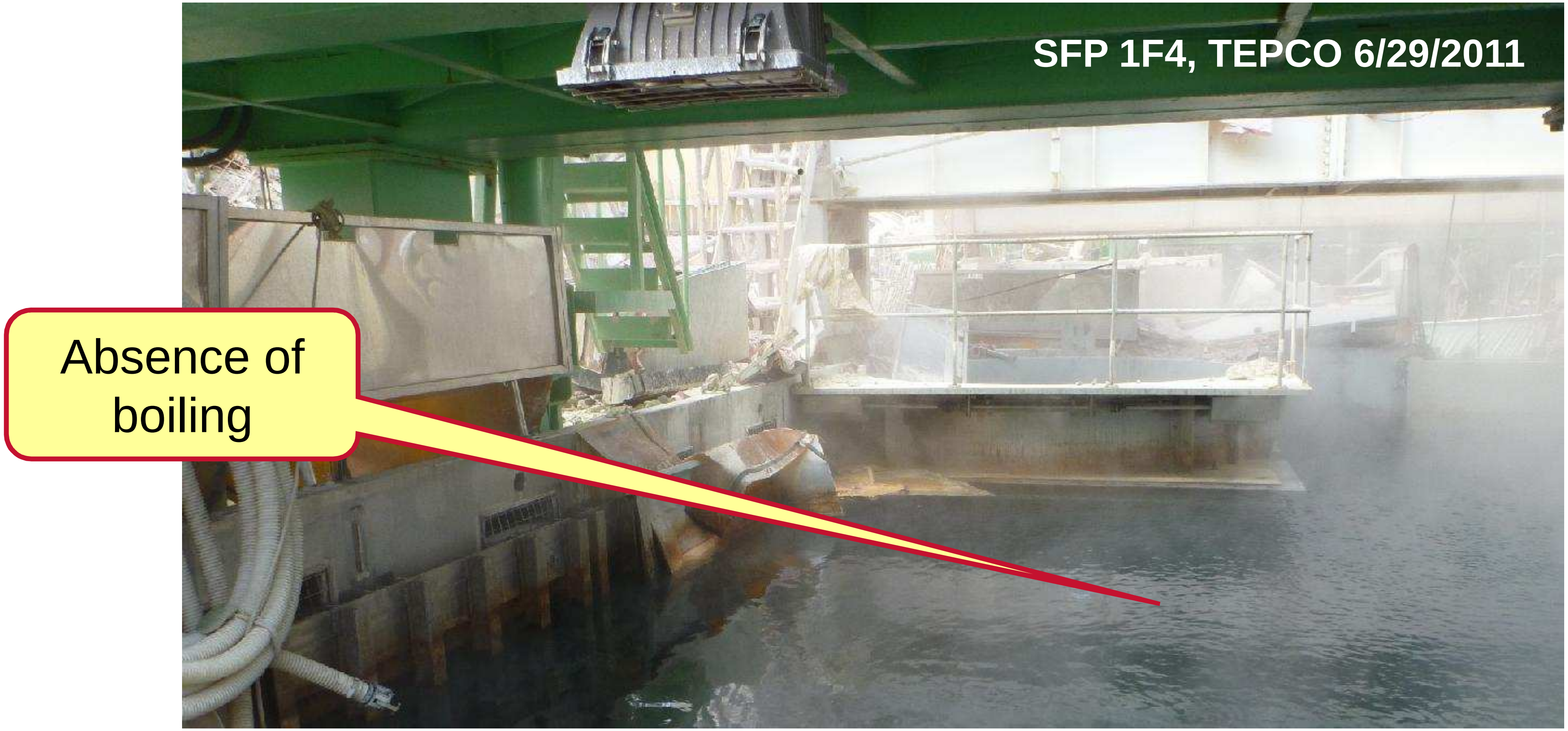
2.) Evaporation of a spent fuel pool

- **SFP temperature of Fukushima Unit 4**



2.) Evaporation of a spent fuel pool

- **Why does Fuel Pool not boil?**
  - **Low total decay power (1.58 MW @ 6/1/2011)**
  - **Large water surface (11 m x 12 m)**
  - ➔ **Evaporation from sub-cooled water surface sufficient to cool pool**



2.) Evaporation of a spent fuel pool

- **Problem – Weak experimental basis**
  - **Small scale experiments**
    Boelter, Gordon, Griffin
    Free Evaporation into Air of Water from a Free Horizontal Quiet Surface,
    Ind. Eng. Chem. 38 (1946) 596–600
  - **Low temperature observations**
    Z. Li, P. Heiselberg,
    CFD Simulations for Water Evaporation and Airflow Movement in Swimming Baths, April 2005,
    ISSN 1395-7953 R0503)

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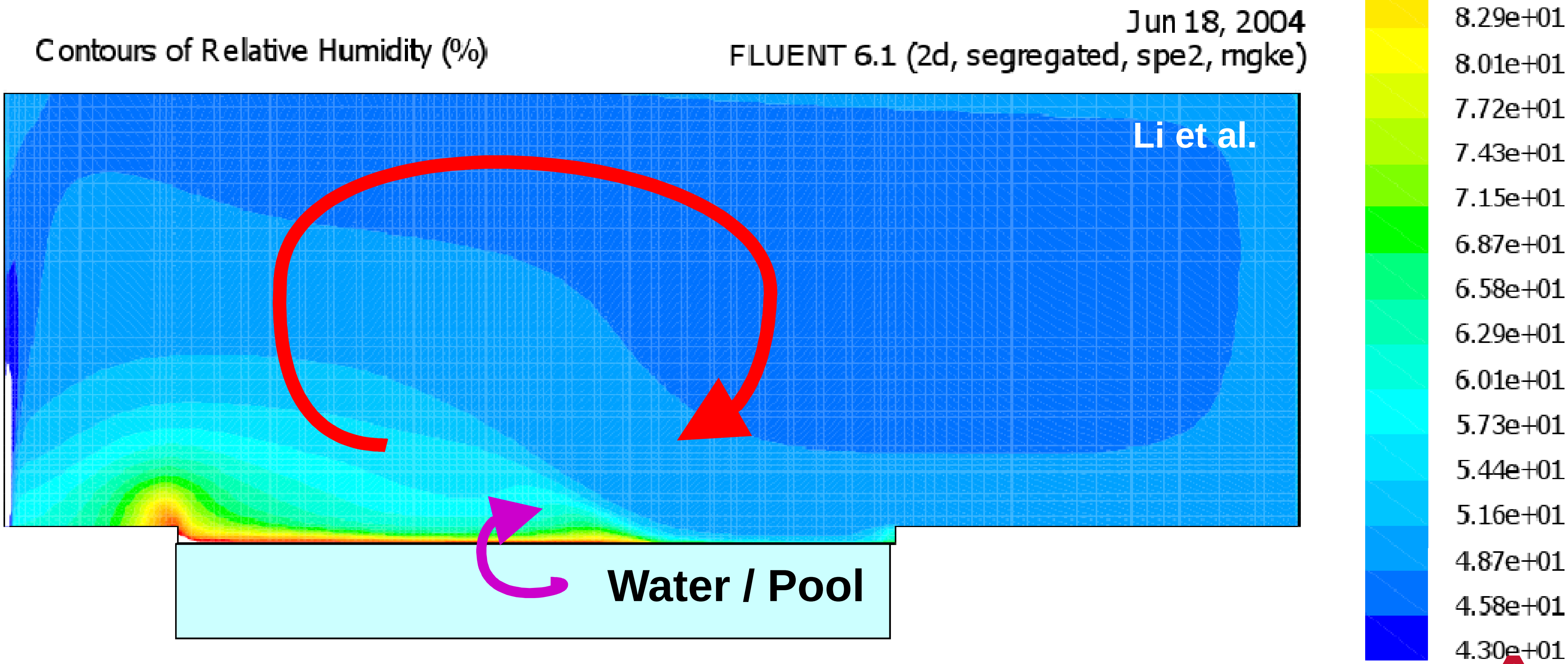
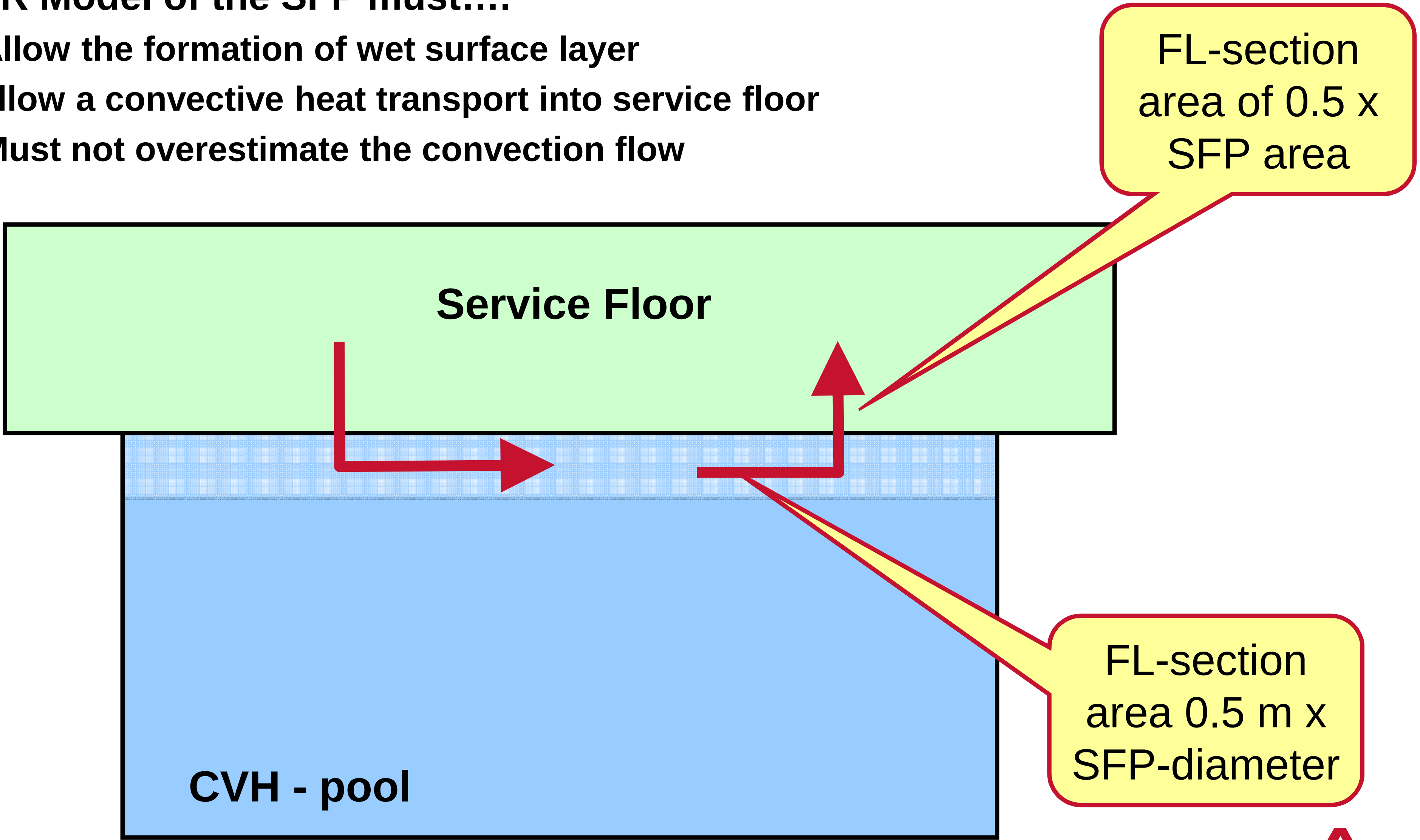
2.) Evaporation of a spent fuel pool

- Evaporation of water is driven by diffusion (fast)
- Wet hot gas layer forms above water pool
- Convection transports vapor away from water-gas-interface (slow)



2.) Evaporation of a spent fuel pool

- **MELCOR Model of the SFP must….**
  - **… Allow the formation of wet surface layer**
  - **... Allow a convective heat transport into service floor**
  - **… Must not overestimate the convection flow**



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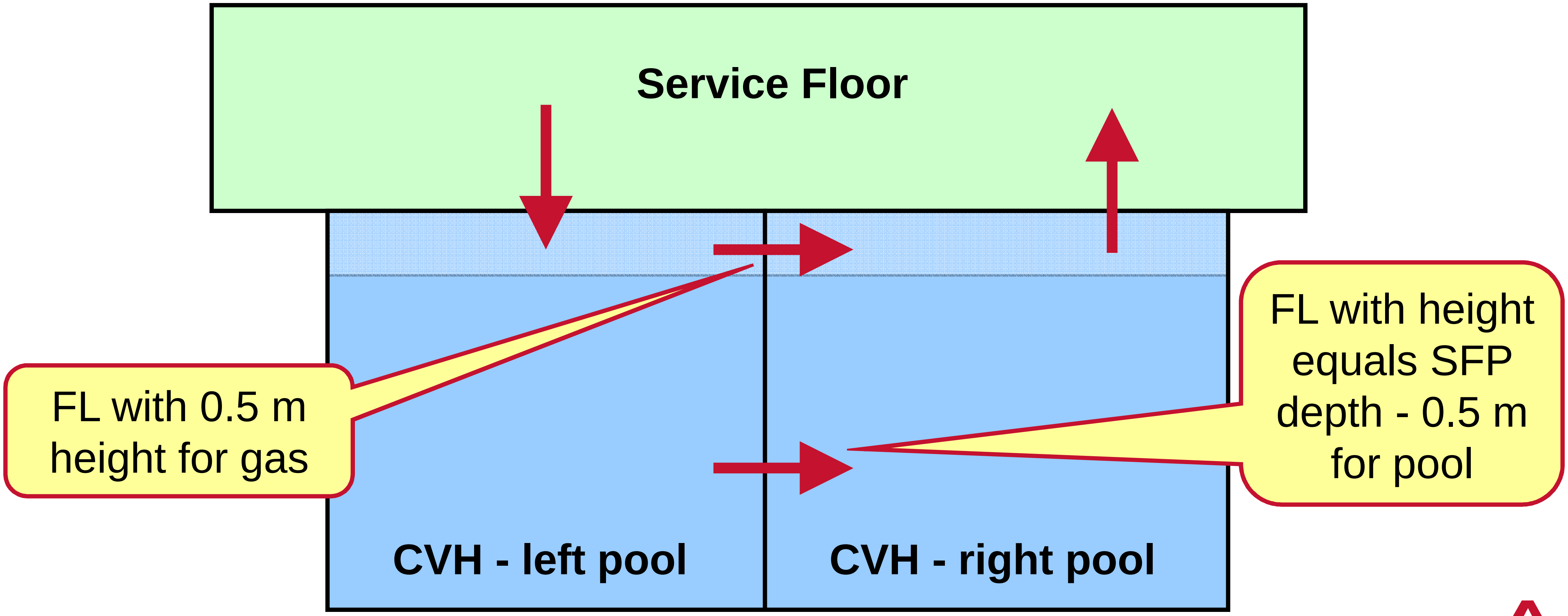
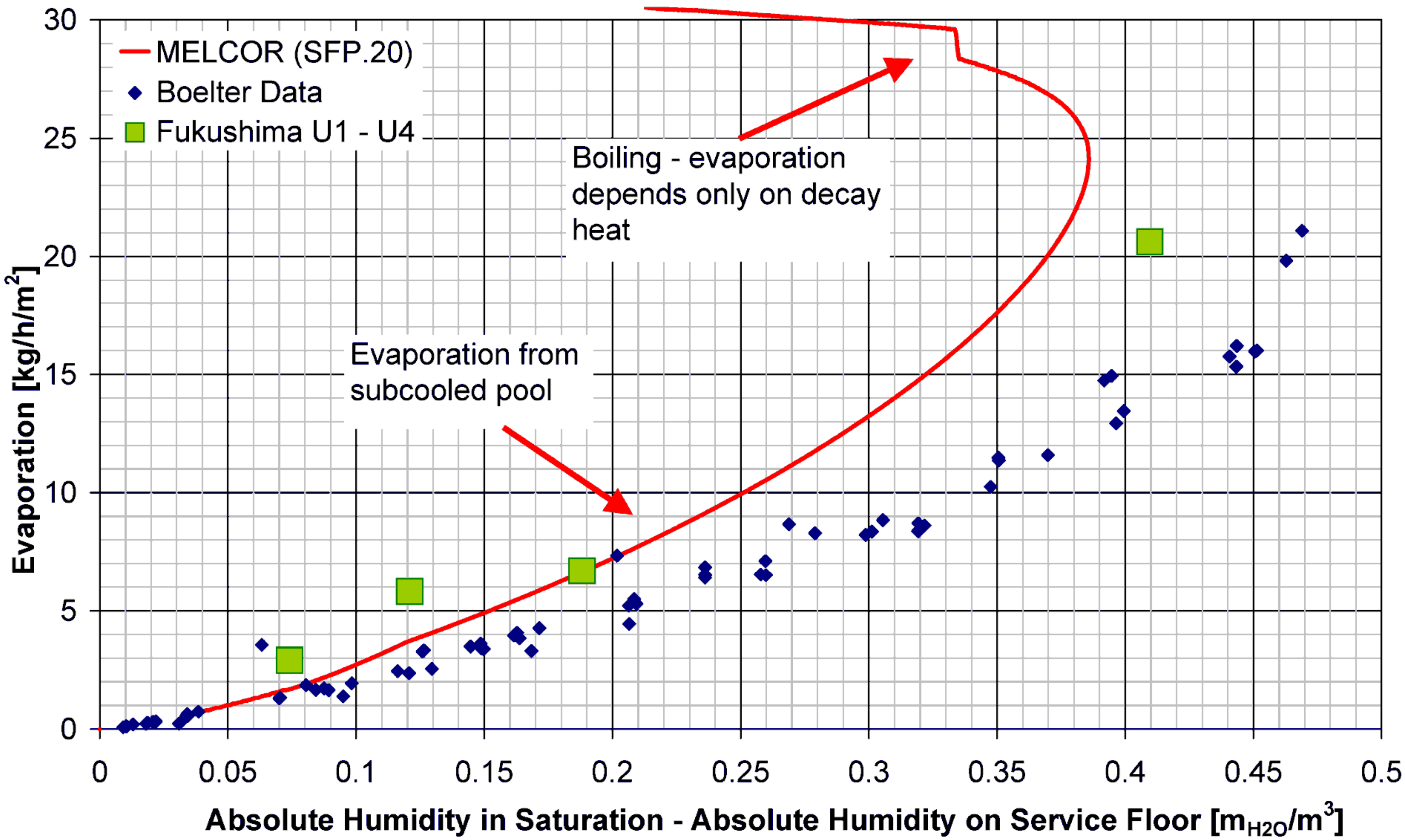


2.) Evaporation of a spent fuel pool

- **Resulting evaporation rates in comparison to literature**



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2. Evaporation of a spent fuel pool

3. **Transition between different CVs inside the SFP**

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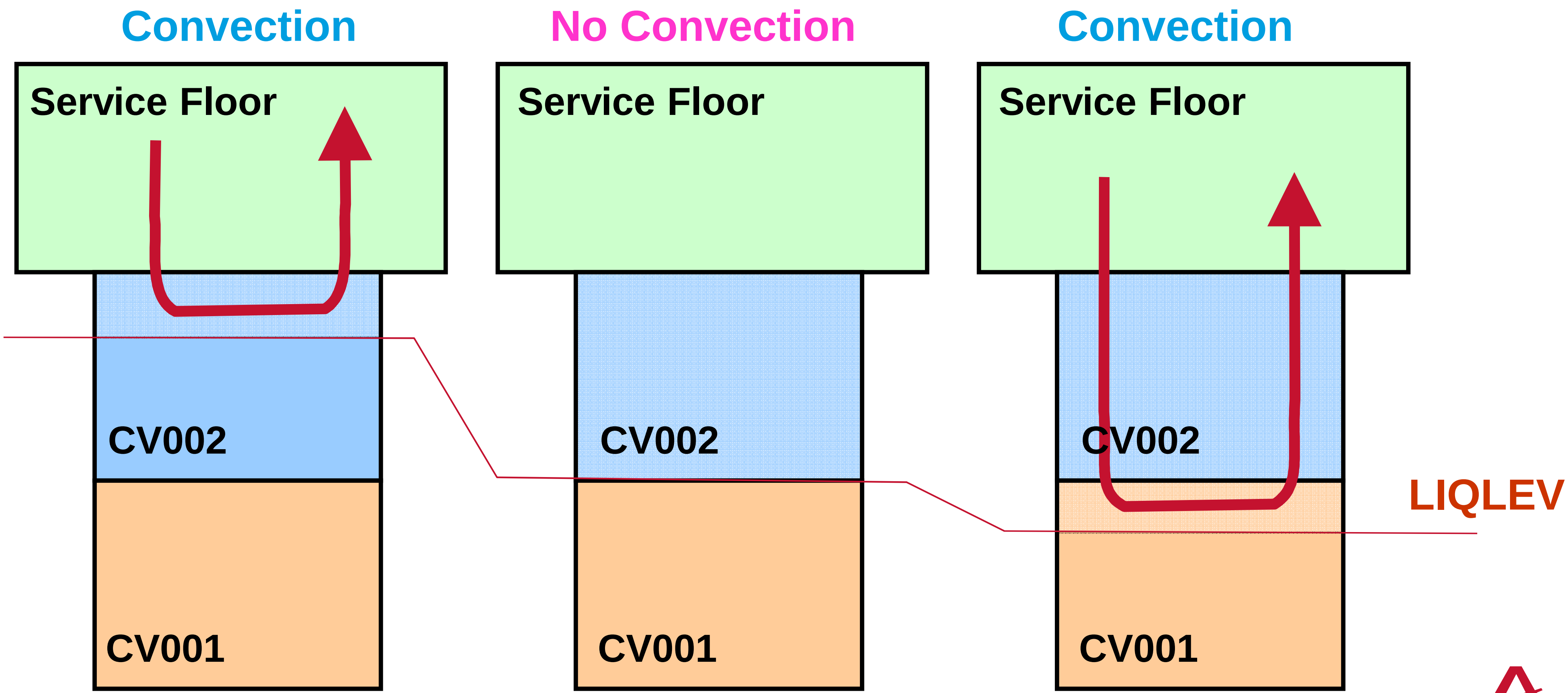
3.) Transition between different CVs inside the SFP

- **Problems when SFP is axially separated in different CVH**
  - **No evaporation when LIQLEV equals to a CVH boundary**
  - **Only known fix: Do not axially split SFP**



Conclusions

- **Hydraulic diameter of a fuel assembly**
  - **For small Reynolds numbers hydraulic diameter is very important for accurate pressure losses**
  - **Determination of hydraulic diameter is not straight forward**
  - **Whole range of Reynolds numbers can be satisfactory modeled with appropriate combination of Loss Coefficients and Hydraulic Diameters**
- **Evaporation of a spent fuel pool**
  - **The convection from a layer above the in the spent fuel pool to the service floor limits the evaporation**
  - **0.5 m layer thickness seams to be reasonable**
- **Transition between different CVs inside the SFP**
  - **Horizontal separation of a spent fuel pool is challenging if the level drops**
  - **We recommend no horizontal sub-division**

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THANK YOU

End of presentation: Aspects of Modeling a Spent Fuel Pool

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