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HTGR simulations in PSI using MELCOR 2.2

10th Meeting of the European MELCOR User Group (EMUG), 25-27 April, Zagreb, Croatia

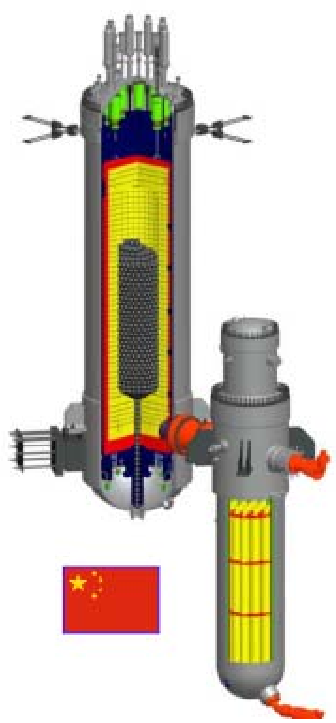
Introduction

- Since the code version 2.1, MELCOR includes several features for modeling of accident scenarios in High Temperature Gas-cooled Reactors (HTGRs)
  - Models for both prismatic block and the pebble bed fueled HTGR designs.
  - In the previous investigation, Corson (2010) conducted an extensive study on Pressurized and De-pressurized Loss of Forced Cooling accidents in the South African PBMR-400 design using the MELCOR 2.1 code
  - Also, a previous modified version of the MELCOR code has been used for example, on an air ingress accident analysis of a pebble bed reactor (Merrill, 2010).

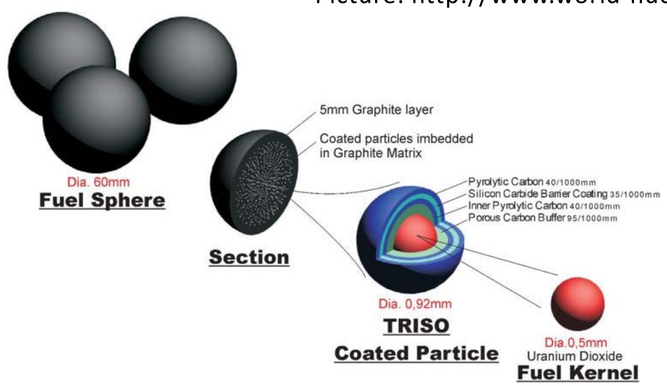
Introduction

- We have used MELCOR 2.2 code to simulate Pressurized and De-pressurized loss of forced flow accidents (PLOFC/DLOFC) in the HTR-PM
  – HTR-PM is a 250 MWth twin unit, modular pebble bed reactor, currently being build in Shandong province, China

Picture: http://www.world-nuclear-news.org/



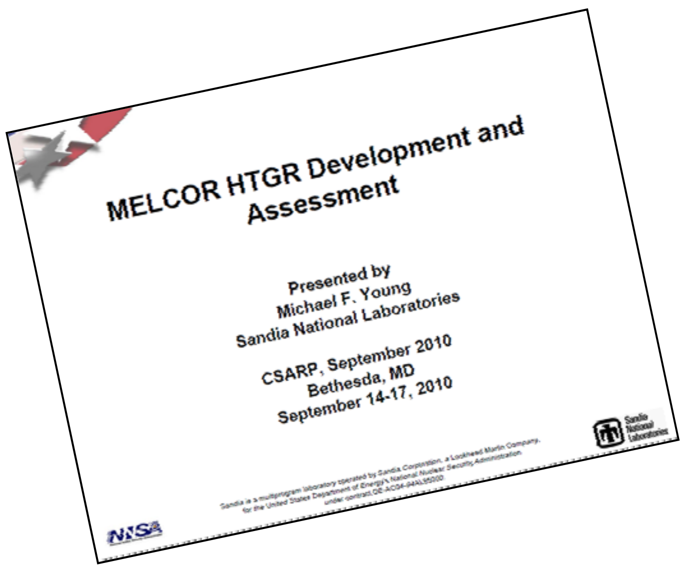
Picture: IAEA I3-TM-50156



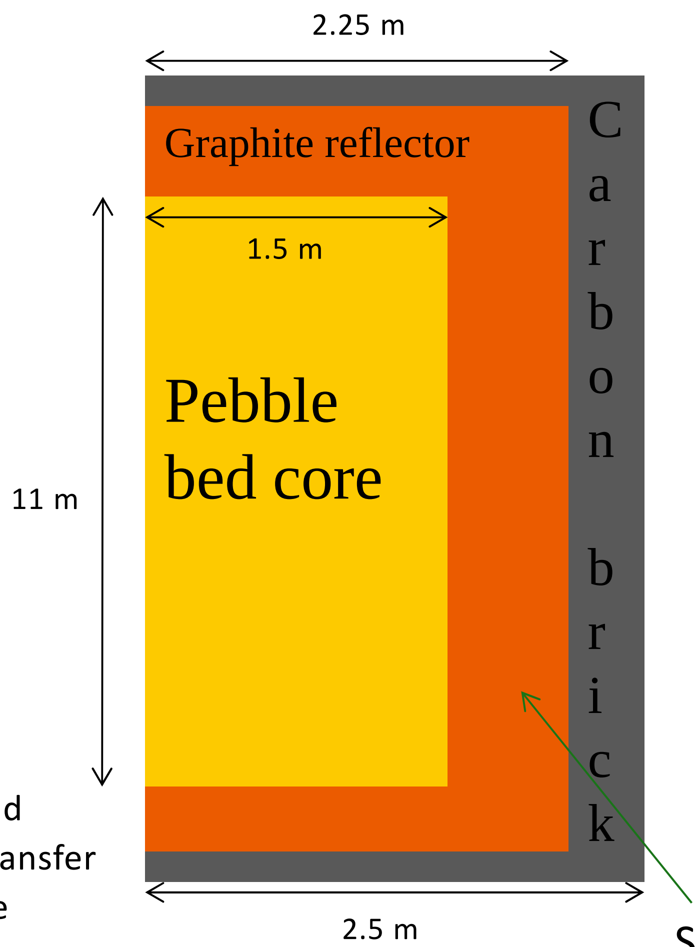
Picture: https://nuclearstreet.com/

Introduction

- We have used MELCOR 2.2 code to simulate Pressurized and De-pressurized loss of forced flow accidents (PLOFC/DLOFC) in the HTR-PM
  - The input was prepared with the help of the old open literature HTGR work performed on MELCOR and an open literature description of the HTR-PM pebble bed core, side and bottom reflectors, internal carbon structures, reactor pressure vessel and the residual heat removal system.
  - Some input, like the reactor power distribution and decay heat obtained from previous PSI HTGR work

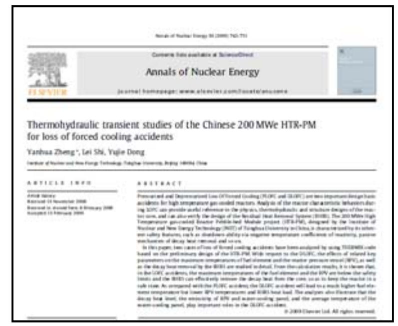


MELCOR model of the HTR-PM



Following Corson and Zheng et al., Heat transfer coefficient at pebble surface set to:

$$\mathrm{Nu} = 1.27\frac{\mathrm{Pr}^{1/3}}{\varepsilon^{1.18}}\mathrm{Re}^{0.36} + 0.033\frac{\mathrm{Pr}^{1/2}}{\varepsilon^{1.07}}\mathrm{Re}^{0.86}$$


Annals of Nuclear Energy

Thermohydraulic transient studies of the Chinese 200 MWe HTR-PM for loss of forced cooling accidents

Yanhua Zheng *, Lei Shi, Yujie Dong

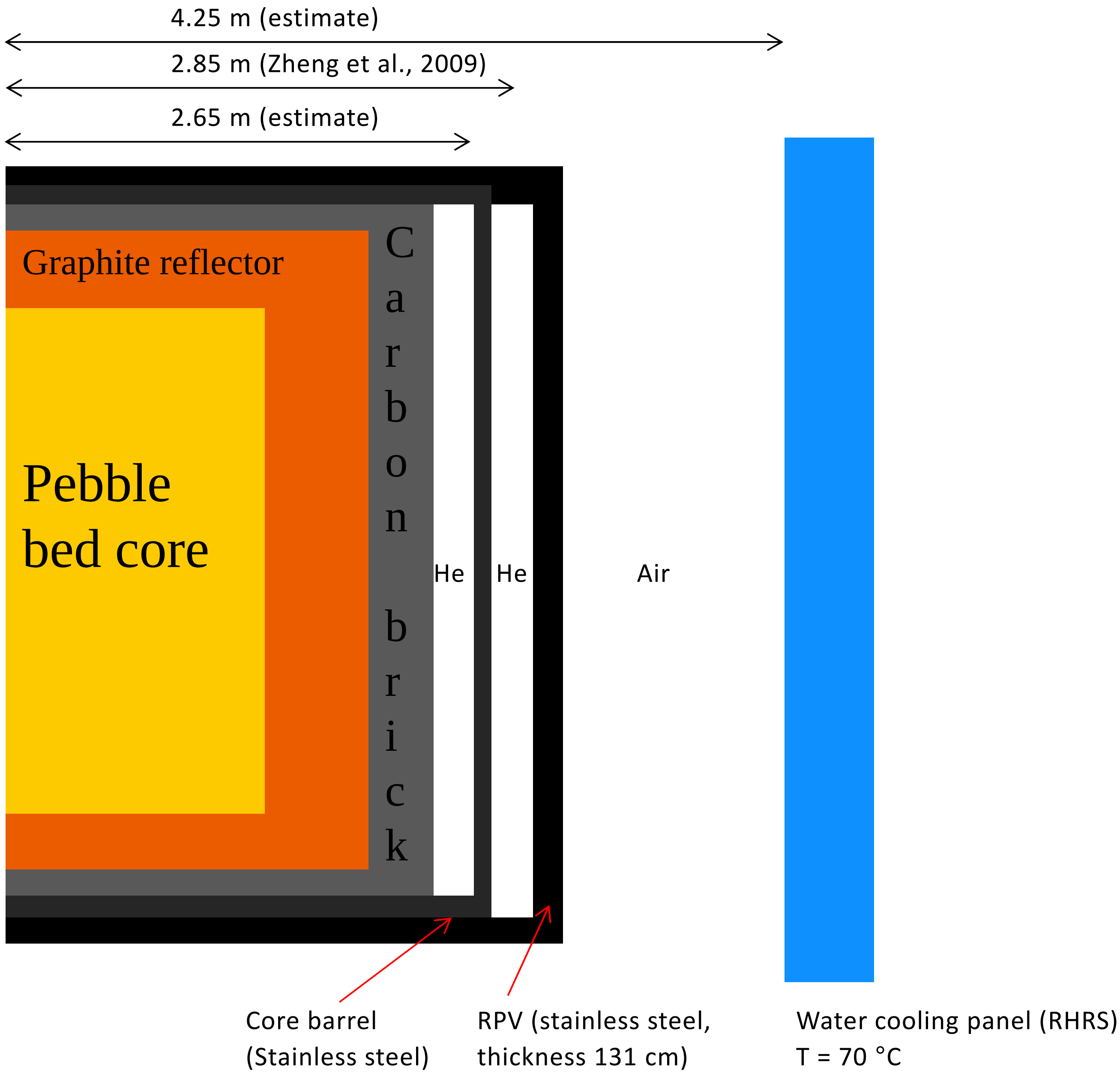
- Most of the information on HTR-PM geometry + material properties
  – Zheng et al., Ann. Nucl. Energy 36 (2009)

Side and bottom/top reflectors porous

- With coolant channels, control rods…

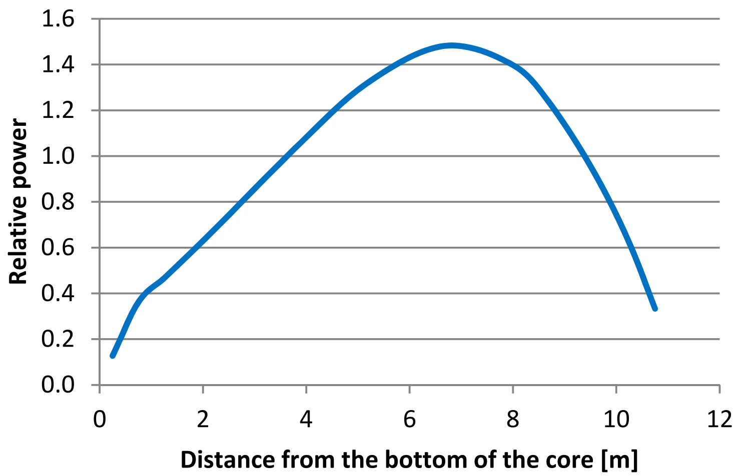
MELCOR model of the HTR-PM

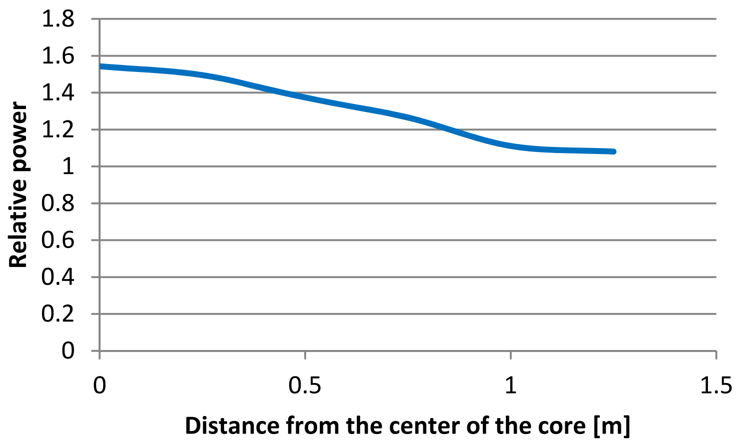
- Size of the RPV obtained from Zheng et al.
- Other distances estimated from various HTR-PM open literature sources
- Radiation heat transfer from the carbon brick to RHRS

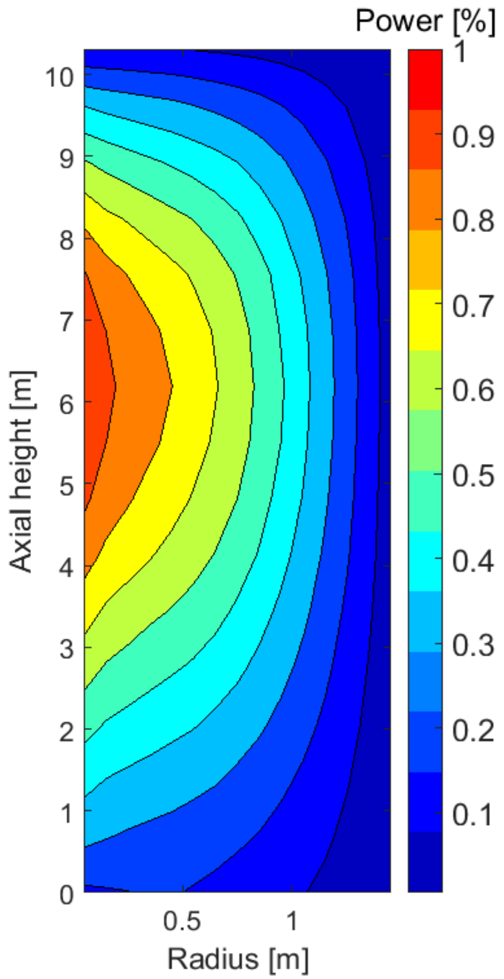


MELCOR model of the HTR-PM: Power distribution

- The power distribution of the core was obtained from the Serpent 2, a 3D continuous-energy Monte Carlo code calculation of the HTR-PM, performed as a part of previous MSc work in PSI

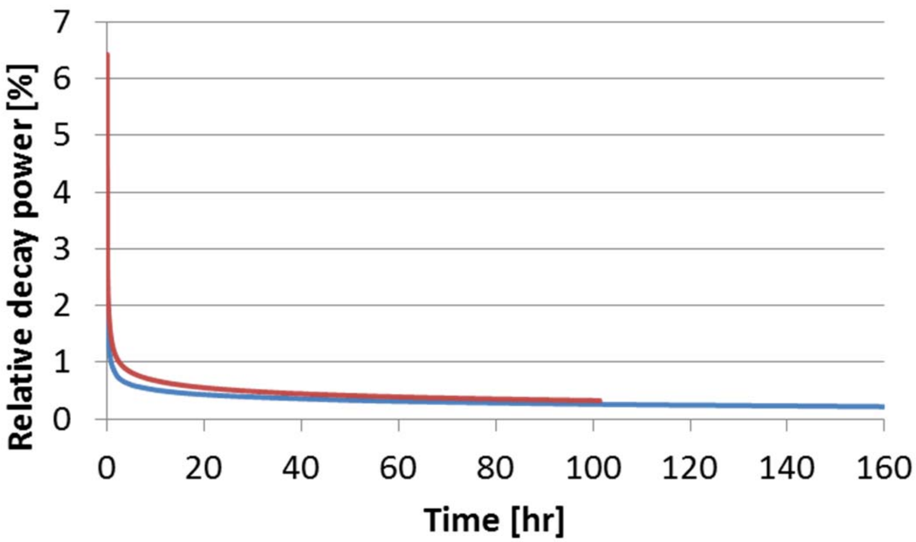






MELCOR model of the HTR-PM: Decay heat

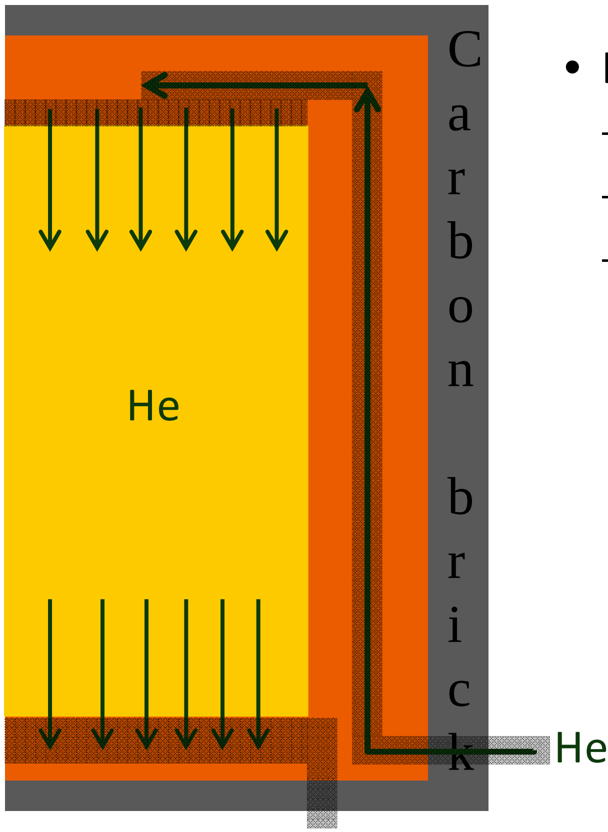
- Decay power also obtained from a Serpent 2 simulation
  - Average flux over the whole lifetime of a pebble in core
  - Burnup: 90 MWd/kg_{HM}
  - Compared to one used by Zheng et al.



1 h: ~72 %
10 h: ~75 %
100 h: ~80 %

- Decay heat used in the MELCOR simulation
- Zheng et al., Ann Nucl Energy 36 (2009)

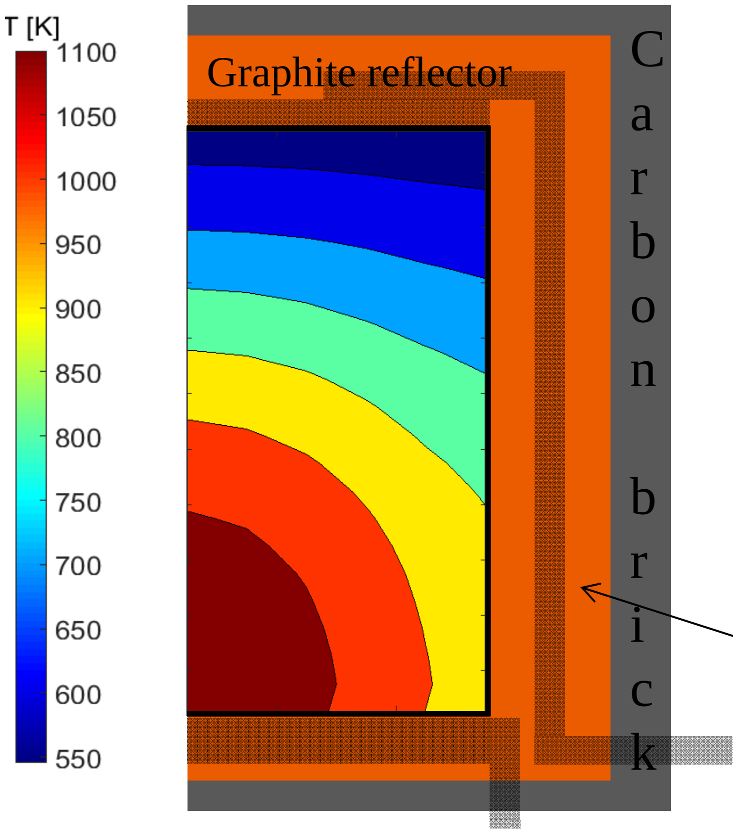
Results: Normal operation



- In normal operation:
  - He mass flow rate 96 kg/s
  - He pressure in primary loop 7 Mpa
  - He temperature:
    - T_{in}: 523 K
    - T_{out} = 1022 K

Results: Normal operation

- Melgen flag: EXEC_SS
  - Heat capacities in COR and HS reduced with a factor of 0.01
  - Steady state reached in approx. 5000 s.



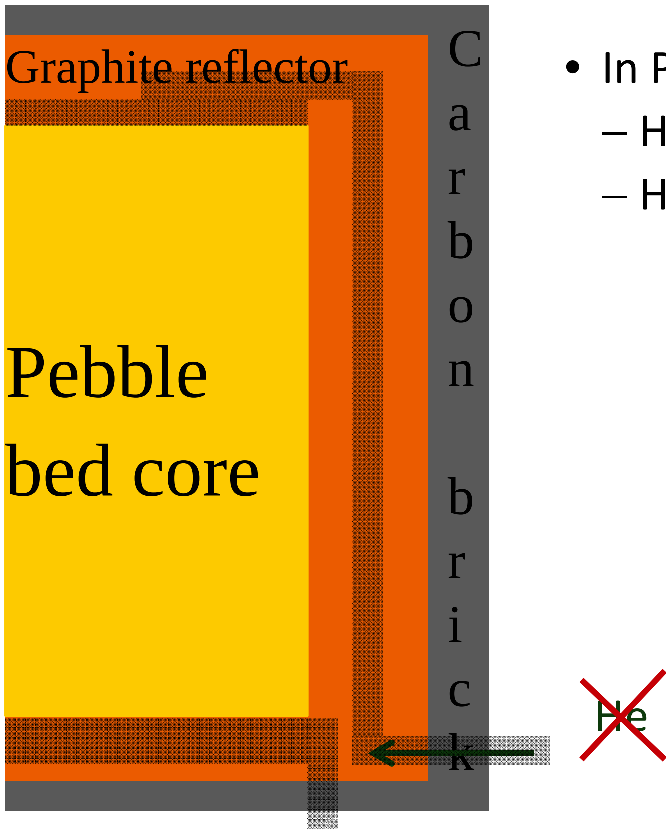
Average fuel element temperature in the pebble bed

- In normal operation:
  - He mass flow rate 96 kg/s
  - He pressure in primary loop 7 Mpa
  - He temperature:
    - T_{in}: 523 K
    - T_{out} = 1022 K

Side reflector graphite temperature:
$T_{max} \approx 620$ K

Results: PLOFC accident

- Pressurized Loss of forced cooling (PLOFC) accident
  - Helium flop disrupted (e.g. He blower failure)
  - Primary circuit kept intact

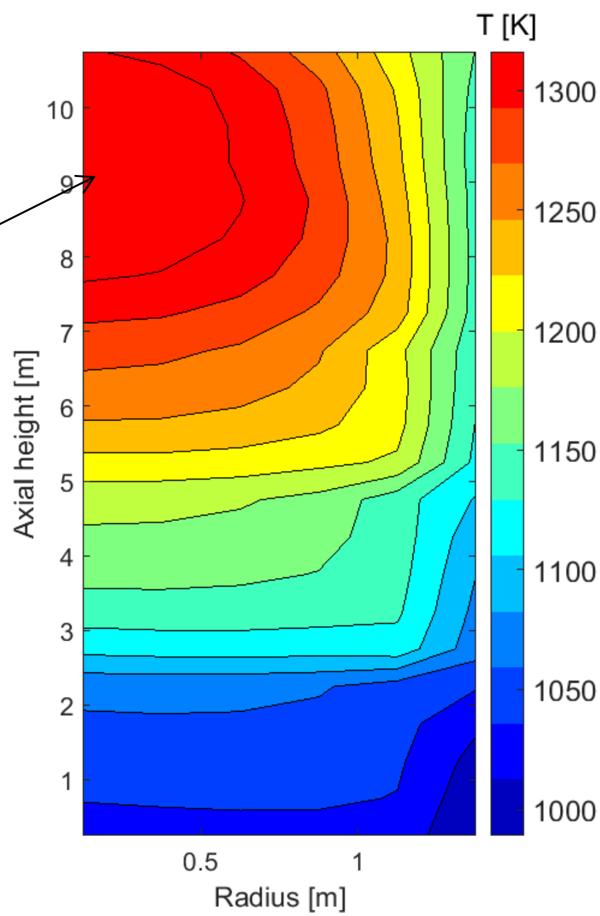


- In PLOFC:
  - He flow rate reduced to 0 kg/s in 30 s
  - He pressure in the primary loop 7 Mpa

Results: PLOFC accident

- Pressurized Loss of forced cooling (PLOFC) accident
  - Helium flow rate reduced to 0 in 30 s.
- Max. fuel temperature at approx. 145000 s

T_{max} ≈ 1342 K,
Height ≈ 9 m



High density of the high pressure He

- Buoyancy lifts high temperature He up in the core
- Natural circulation established in the pebble bed

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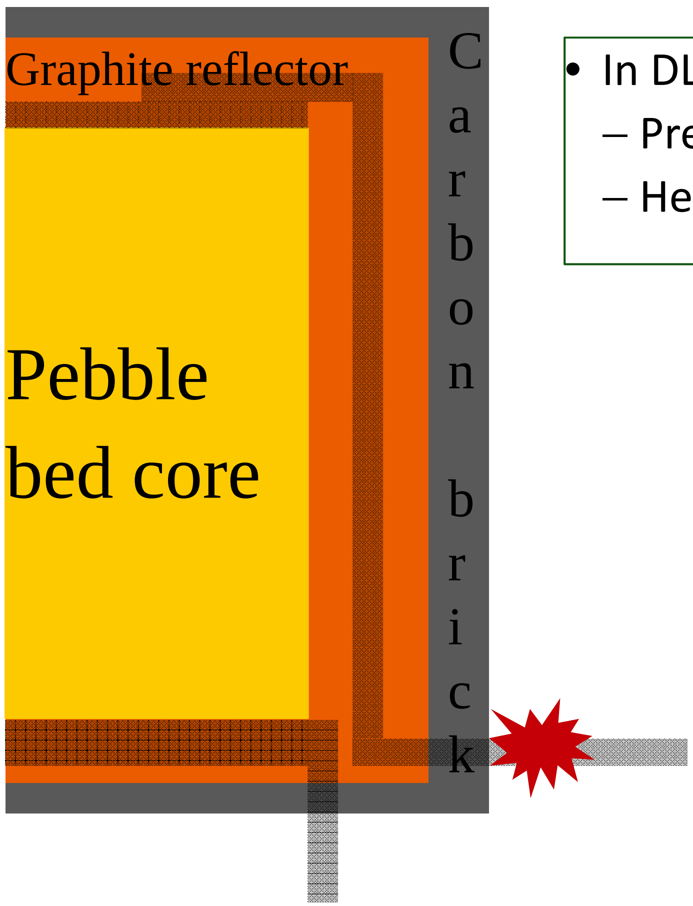
Results: DLOFC accident

- De-pressurized Loss of forced cooling (DLOFC) accident
  - Break in the primary circuit

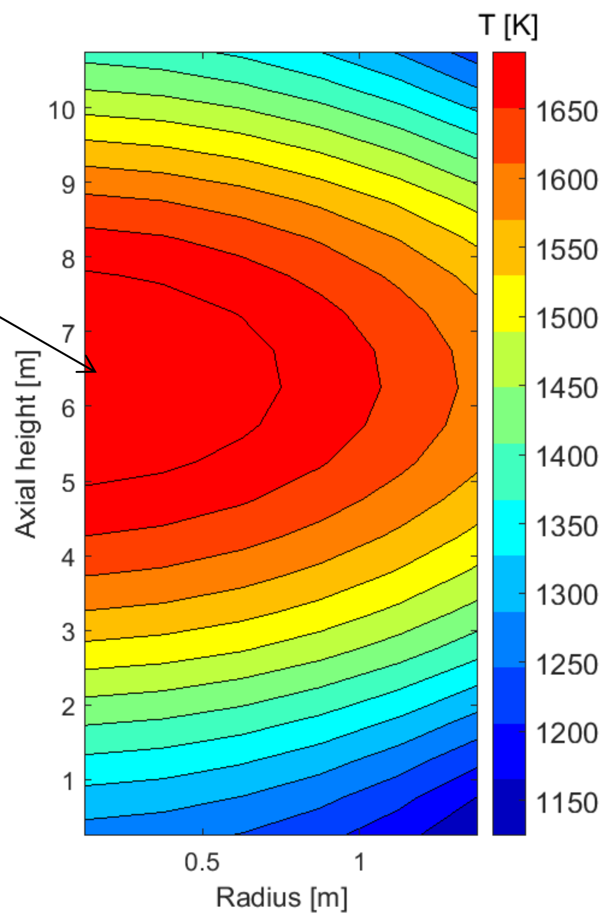


- In DLOFC:
  - Pressure decreased to 0.1 Mpa in approx. 20 s.
  - He flow simultaneously decreased to 0 kg/s

Results: DLOFC accident

- De-pressurized Loss of forced cooling (DLOFC) accident
  - Pressure decreased to 0.1 Mpa in approx. 20s.
- Max. fuel temperature approx. at 570000 s

T_{max} ≈ 1732 K,
Height ≈6.5 m

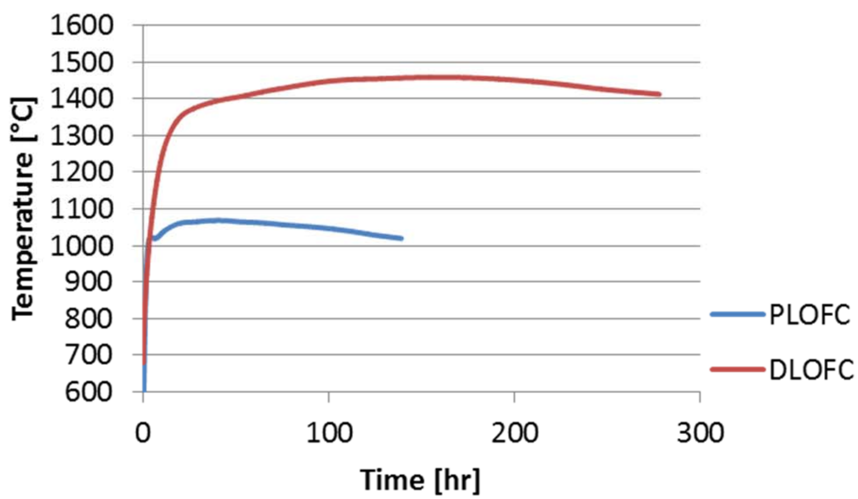


Low density of He in low pressure:

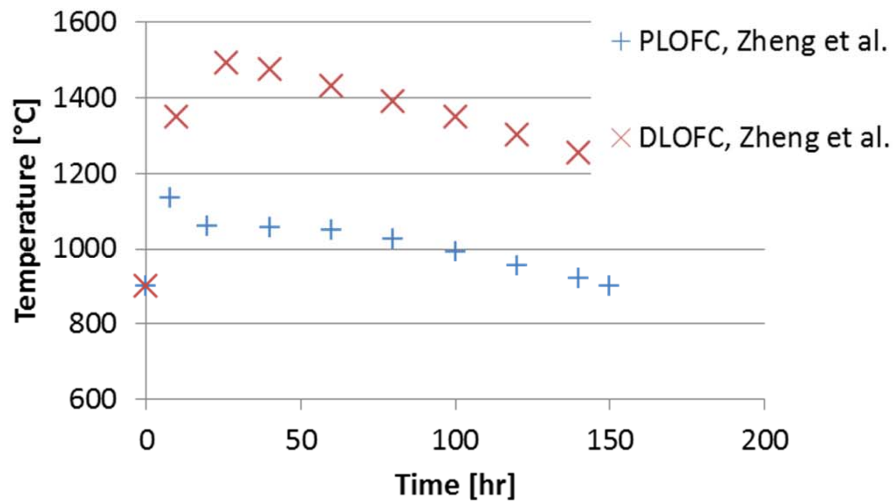
- No significant convection
- Heat transfer mainly by conduction and radiation

Results: Comparison with a reference

- Comparison to analysis by Zheng et al., Ann Nucl Energy 36 (2009)
  - Zheng et al. simulated P/DLOFC in HTR-PM using a THERMIX code
    - Thermohydraulics steady state and transient code for pebble bed reactor primary circuit, including a neutron point kinetics and graphite corrosion models
- Max fuel temperature DLOFC: 1458 °C (MELCOR), 1492 °C (Zheng et al.)
- Max fuel temperature PLOFC: 1069 °C (MELCOR), 1134 °C (Zheng et al.)



Maximum fuel temperature from the MELCOR simulation

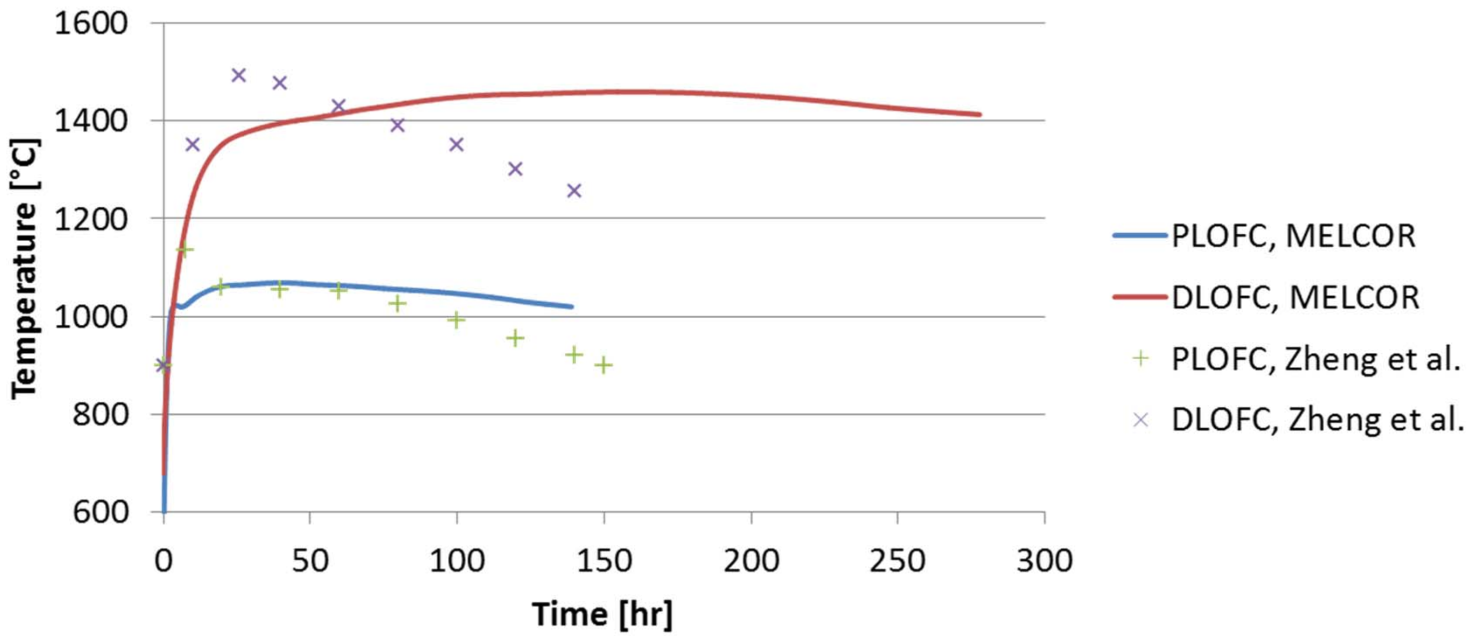


Maximum fuel temperatures

Zheng et al., Ann Nucl Energy 36 (2009)

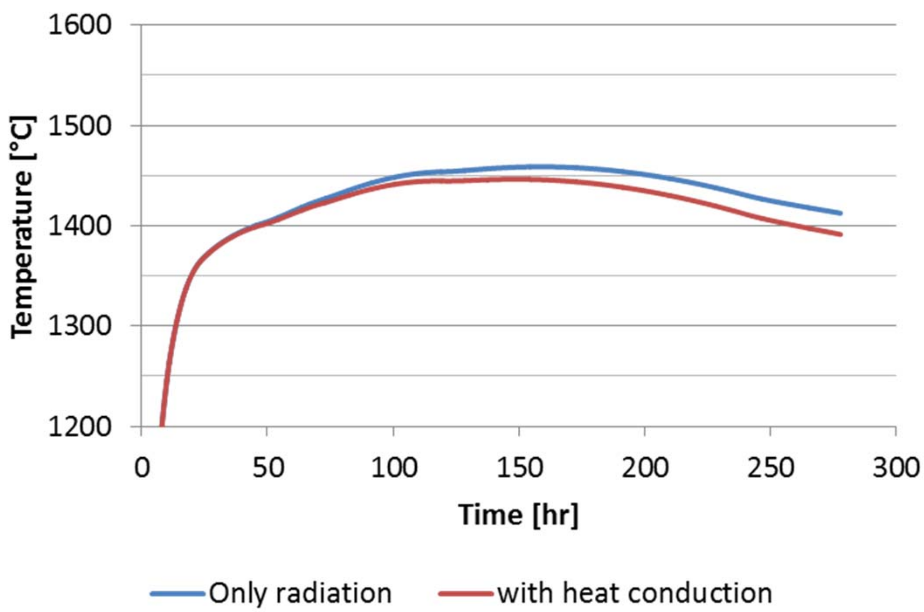
Results: Comparison with a reference

- Comparison to analysis by INET (Zheng et al., Ann Nucl Energy 36 (2009)
  - Max fuel temperature DLOFC: 1458 °C (MELCOR), 1492 °C (Zheng et al.)
  - Max fuel temperature PLOFC: 1069 °C (MELCOR), 1134 °C (Zheng et al.)
- The maximum fuel temperatures quite close in DLOFC, with PLOFC the fast increase and cooling (at 10 hr) missing in MELCOR result
  - Could be partly due to the lower decay heat
- Slow heating period to reach T_{max} much longer in MELCOR



Results: heat transfer to the water panel

- Currently, heat transfer through conduction from core barrel to RPV is not considered in the simulations
  - Important according to Zheng et al.
  - Conduction added in a very recent simulation to DLOFC case
    - Max. temperature of the fuel decreased only approx. 10 K -> no significant difference on the results



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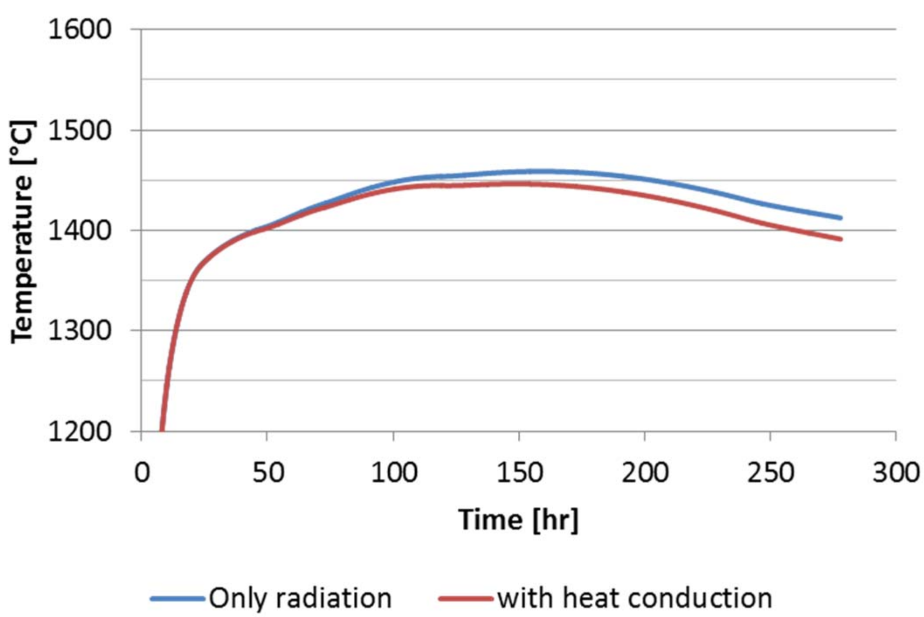

- Also, due to insufficient data the bottom and top reflector models lack detail in current model
  - Could have an effect on the results
  - To be improved in the future

Conclusions and future work

- MELCOR model of an HTR-PM was developed
  - Mainly open source literature was used for the geometry details -> uncertainties remain
  - Power distribution and decay heat obtained from previous simulations of the HTR-PM in PSI
- Two accident scenarios, PLOFC and DLOFC were investigated
  - Maximum fuel temperatures remained below the pebble fuel safety limit of 1600 °C.
  - Fuel temperature changes slowly compared to the reference simulation by Zheng et al..
- Future work:
  - Improvement of the reactor geometry (especially core barrel and RHRS placement)
  - MELCOR code also includes models for fission product release from the fuel elements during normal operation and in accident conditions of the HTGR
  - In the future work, also the study of FP release and transport during different accident scenarios is envisioned

Thank you!