Coupling MELCOR 1.8.6 and GASFLOW for Enhanced Simulation of Hydrogen Distribution During Accident Analysis

Institute for Nuclear and Energy Technologies (IKET)
Karlsruhe Institute of Technology (KIT)

Tobias Szabó

5th Meeting of the European MELCOR User Group (EMUG)
Mai 02-03, 2013, Stockholm

Outline

1. Introduction
2. GASFLOW code
3. MELCOR–GASFLOW coupling
4. Test of MELCOR-GASFLOW coupling
5. Conclusion

1. Introduction

- Severe loss of coolant accident in PWR with H_2 generation in core
- Temporarily inhomogeneous H_2 distribution in containment
- Danger of fast deflagration or Deflagration to Detonation Transition

→ 3D-CFD approach to resolve local flow

- PSA-2
  - Integral analyses with MELCOR → enveloping scenarios
  - Detailed analyses of H_2 distribution with 3D-CFD code (e.g. GASFLOW)
  - Combustion simulations with 3D-CFD code (e.g. COM3D)

1. Introduction

- Subsequent MELCOR and GASFLOW analyses
- GASFLOW predicts different and more realistic containment pressure compared to MELCOR (result of International Standard Problem 47)
- Inconsistency during subsequent MELCOR and GASFLOW analyses:
  - → different containment pressure
  - → different leak flow rate
  - → effect accident progression
- If the more realistic containment pressure from GASFLOW is used in MELCOR, the accident progression predicted by MELCOR will differ.

→ **Coupling of MELCOR and GASFLOW**

2. GASFLOW code

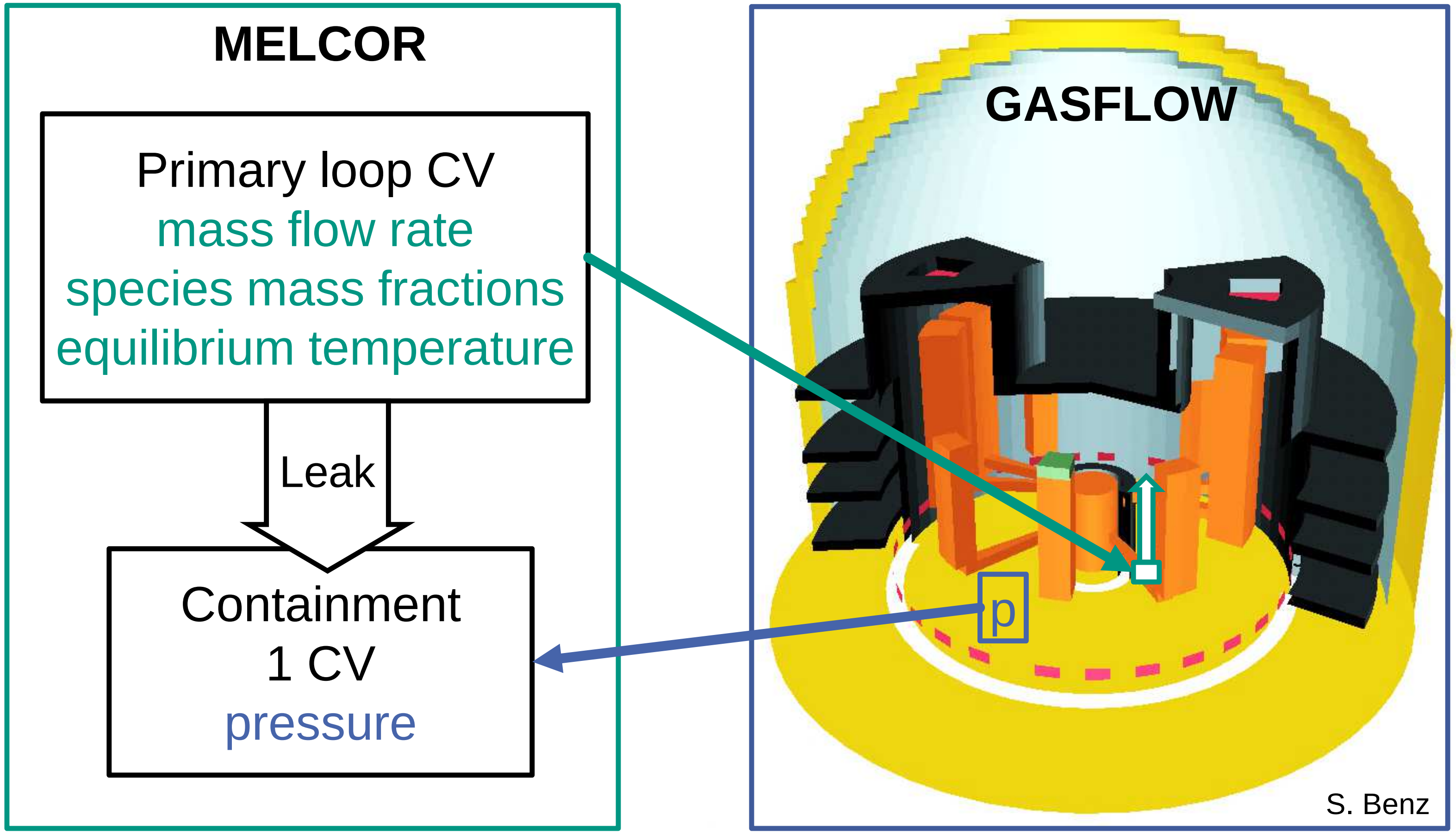
Karlsruhe Institute of Technology

- Developed at KIT
- 3D-CFD, Finite Volume Method
- Local distribution of H_2 in containment
- Evaluation of combustion criteria (σ, λ)
- Simple combustion simulation
- Heat transfer at structures
- Turbulence modelling
- Mitigation
- Successfully validated: PANDA, MISTRA, TOSQAN, THAI, PHEBUS, HDR, BMC, HYJET, etc.
- Application: KONVOI, EPR, KPC, APR1400, VVER1000

→ **Reliable prediction of local H_2 distribution and containment pressure**

3. MELCOR–GASFLOW coupling

- Coupling MELCOR accident and GASFLOW containment TH analyses
- Data exchange at leak in coolant pipe



3. MELCOR–GASFLOW coupling

- Similar coupling interfaces in codes
  - MELCOR 1.8.6 coupling interface (mexpvi, mexpvs, mexpvt, mexpvx, mexsnd, mexrcv)
  - New GASFLOW coupling interface
- Coupling is
  - external: codes are separate, GASFLOW not included into MELCOR
  - explicit in time: boundary conditions remain constant between coupling time points → coupling error
  - asynchronous: codes use their own time steps

4. Test of MELCOR-GASFLOW coupling

- Check correct functioning of the coupling
- Analysis of a severe accident
  - Coupled MELCOR and GASFLOW calculation
  - Severel stand-alone calculations for comparison
  - Coupled calculation first, stand-alone calculations afterwards

Primary, secondary systems	Containment
Coupled MELCOR	Coupled GASFLOW
Stand-alone MELCOR	Stand-alone GASFLOW
	MELCOR Containment

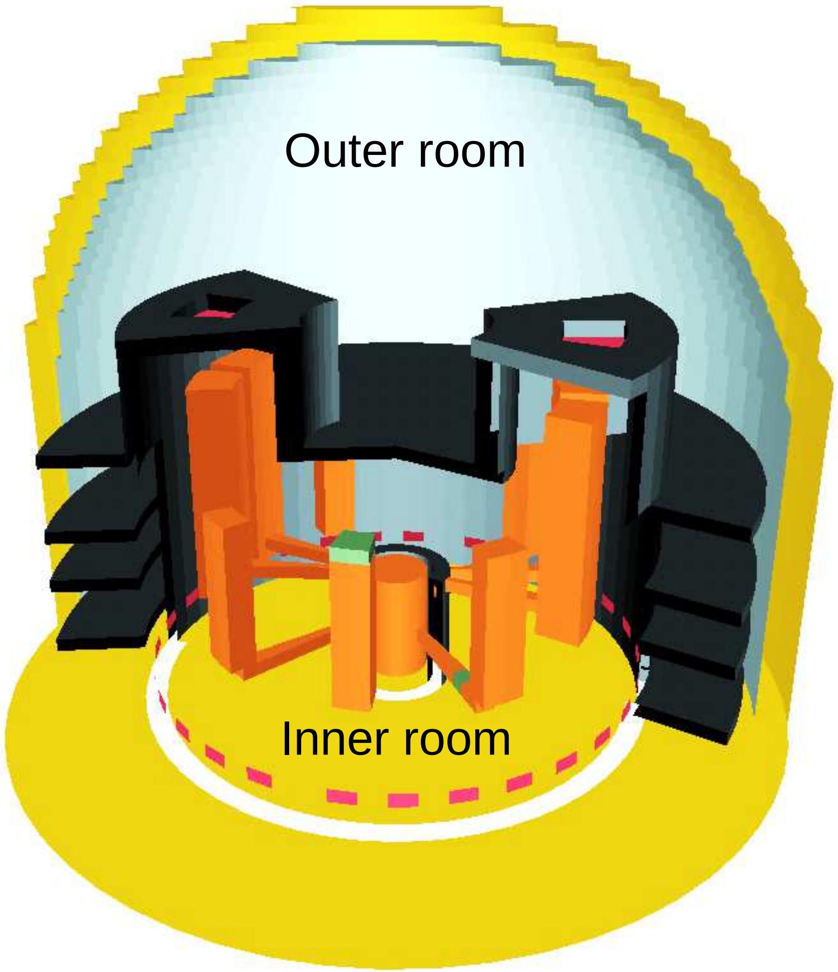
- Stand-alone containment calculations obtain their **source term** from coupled MELCOR (data table)
- Stand-alone MELCOR calculation obtains **containment pressure** from coupled GASFLOW (data table)
- Coupling time step of 0.1 s, data table time step 0.1 s

4. Test of MELCOR-GASFLOW coupling

Scenario

- Severe LOCA
- 150 cm² leak in hot leg of PWR

- Simplified, generic containment
  - Inner room, 18 000 m³
  - Outer room, 50 000 m³
  - Separated by rupture disks

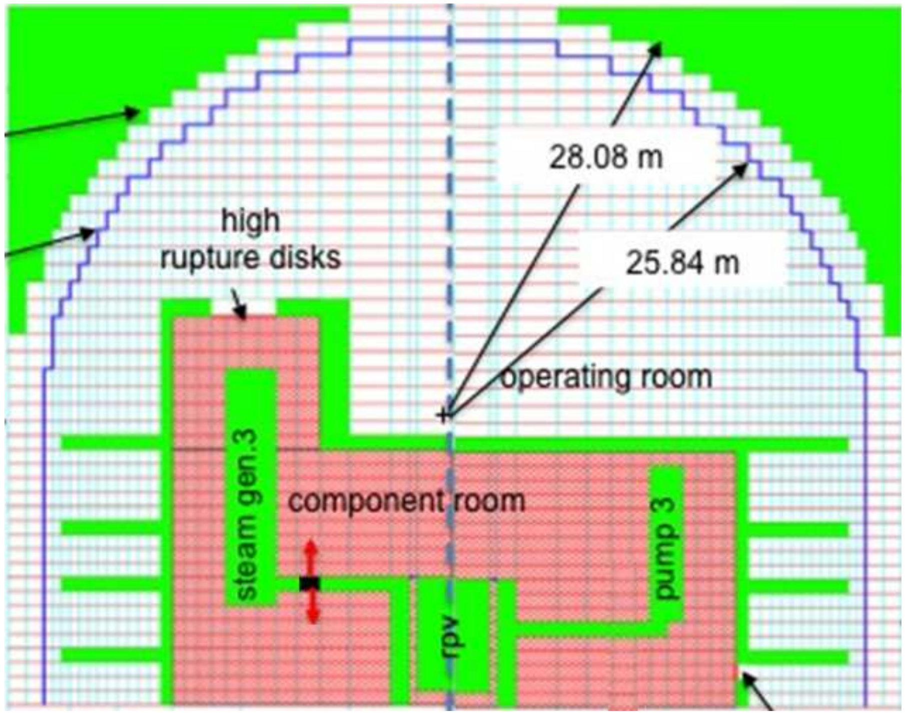


S. Benz

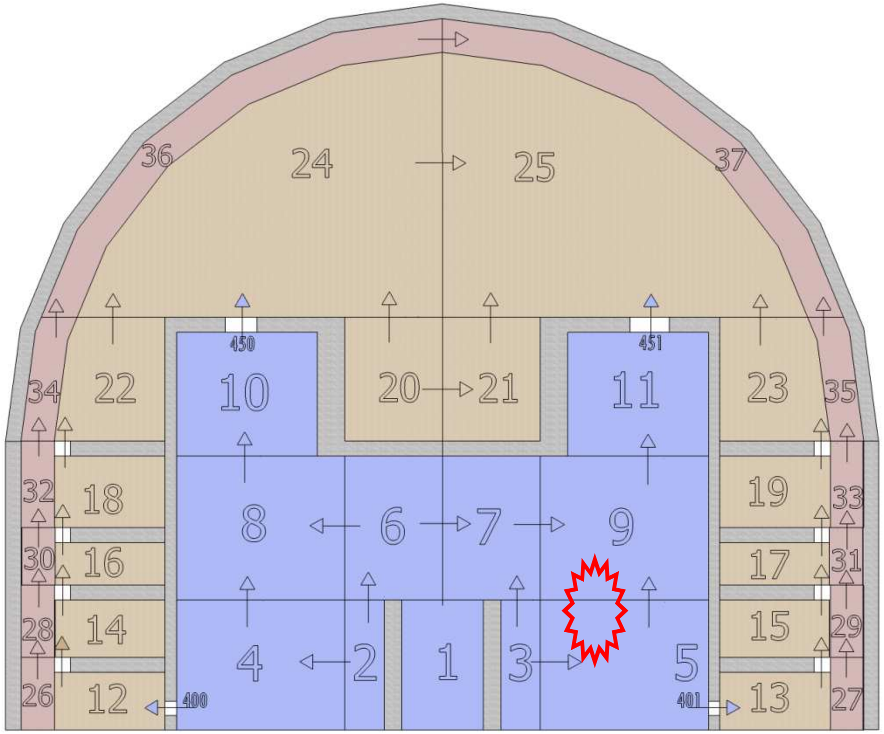
4. Test of MELCOR-GASFLOW coupling

Generic containment

GASFLOW Containment	MELCOR Containment (stand-alone)



S. Benz



37 CV, 55 FL, 52 HS

4. Test of MELCOR-GASFLOW coupling

Steam mass flow rate through leak

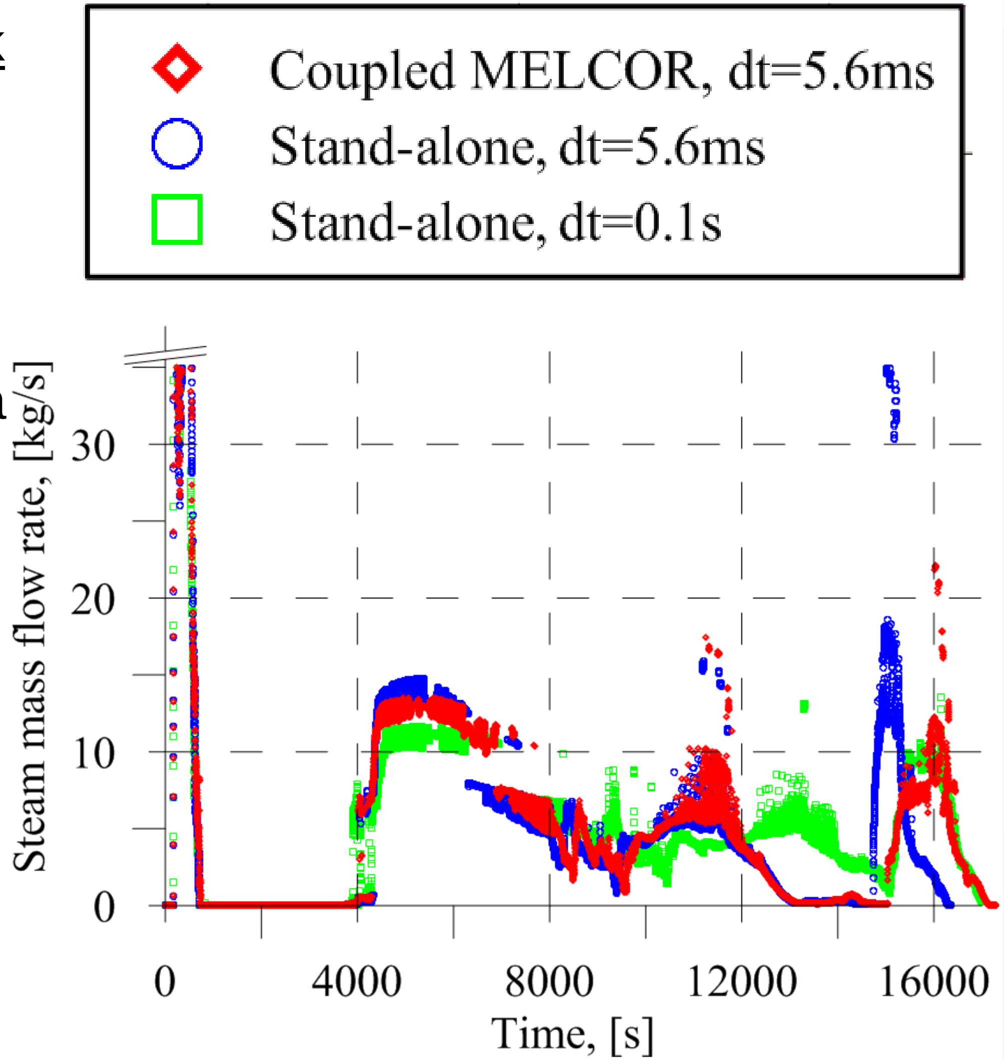
- Differences between Coupled MELCOR and Stand-alone, dt=5.6ms

→ Coupling error from explicit data exchange

- Major differences between Stand-alone calcualations, dt=6.5ms – dt=0.1s

→ Coupling error smaller than ordinary MELCOR uncertainty

→ **Coupling functions correctly enough**



4. Test of MELCOR-GASFLOW coupling

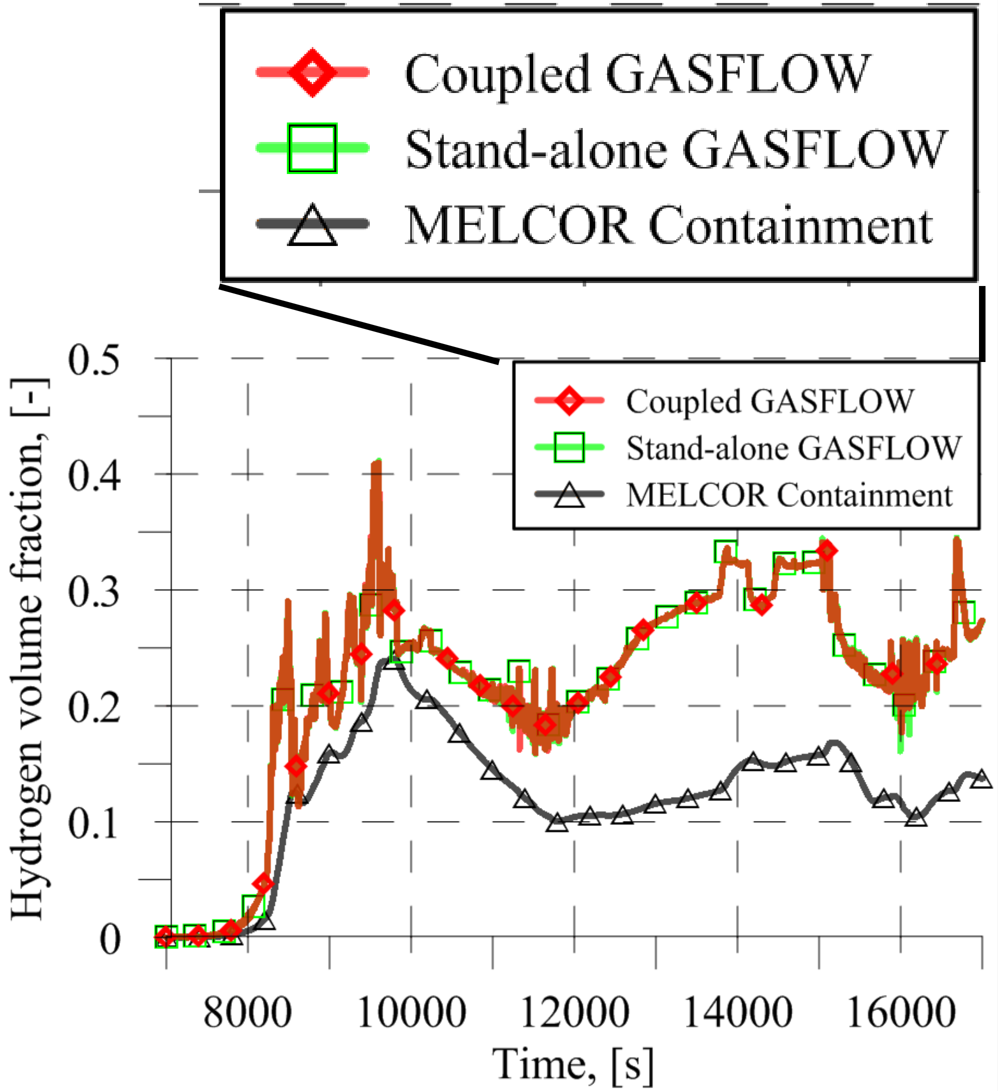
Local H_2 distribution

- Coupled GASFLOW and Stand-alone GASFLOW agree

→ **Coupling functions correctly**

- GASFLOW vs. MELCOR Containment (stand-alone)
- H_2 fraction in corresponding CV differs considerably

→ **Coupling provides more exact H_2 distribution**



4. Test of MELCOR-GASFLOW coupling

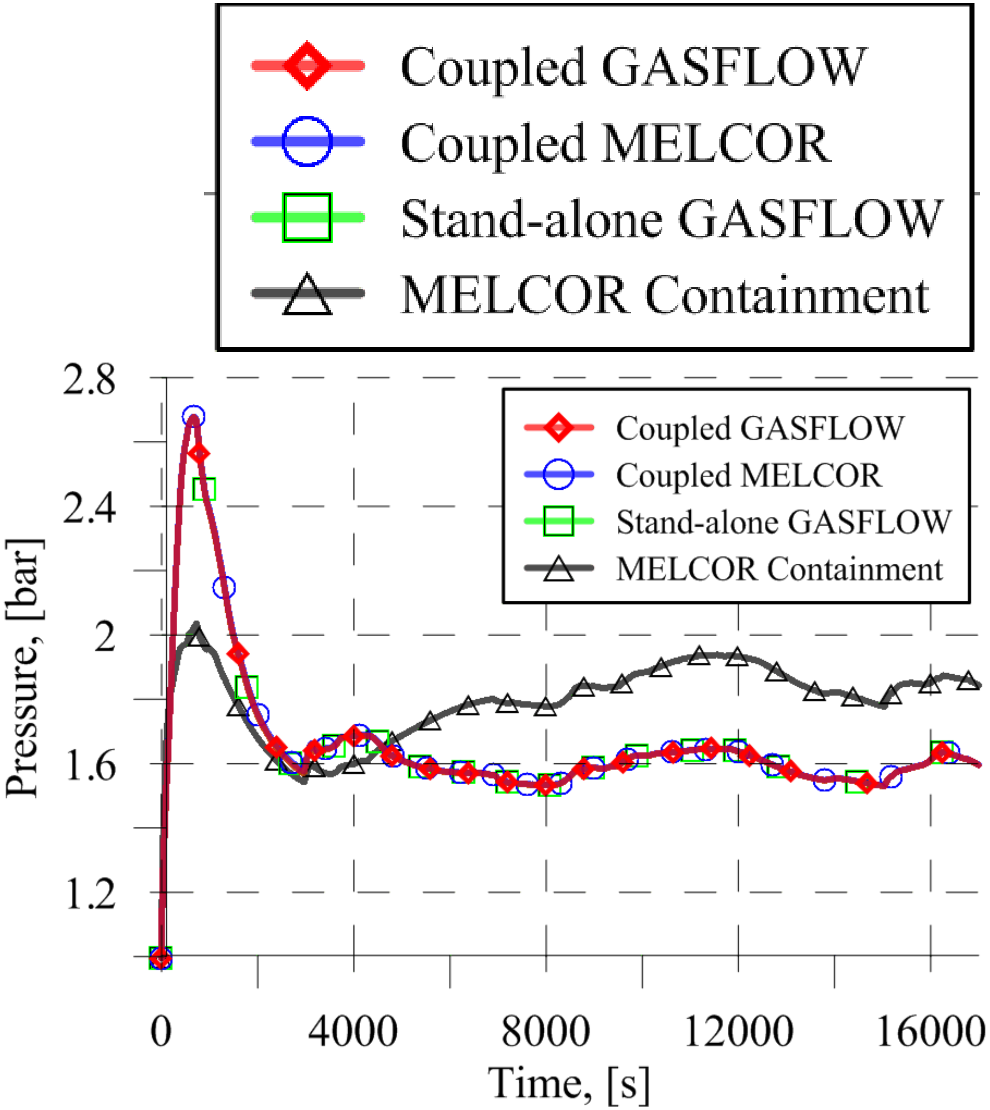
Containment pressure

- Coupled GASFLOW and Coupled MELCOR agree
- Coupled GASFLOW and Stand-alone GASFLOW agree

→ **Coupling functions correctly**

- MELCOR Containment (stand-alone) differs considerably as regards to GASFLOW pressure
- Rather trust in GASFLOW pressure (very good results in ISP-47)

→ **Effect accident progression calculated by MELCOR**



5. Conclusion and outlook

- MELCOR and GASFLOW coupled: external, explicit, asynchronous
- Coupled MELCOR vs. Stand-alone MELCOR
  - Overall agreement
  - Deviations from coupling smaller than ordinary uncertainty in MELCOR
- Coupled GASFLOW vs. Stand-alone GASFLOW
  - Perfect agreement

→ **MELCOR-GASFLOW coupling functions correctly**

- GASFLOW vs. MELCOR Containment (stand-alone)
  - Different H_2 distribution, large LP volumes in MELCOR homogenize H_2
  - More realistic containment pressures in GASFLOW
  - Feedback of realistic containment pressure to accident progression accounted for in MELCOR-GASFLOW coupling

→ **MELCOR-GASFLOW coupling more realistic and exact results**

5. Conclusion and outlook

Outlook

- Comparison of integral MELCOR calculation and integral coupled MELCOR-GASFLOW calculation
- Other coupling project: in-vessel retention, Philipp Dietrich
  - Validate MELCOR against LIVE experiments (behaviour of core melt in lower plenum)
  - Coupling of enhanced models for behaviour of core melt in lower plenum

Thank you for your attention.

Contacts:

Tobias Szabó (Dipl.-Ing.)
Phone: +49 721 608-28320
Email: tobias.szabo@kit.edu

Frank Kretzschmar (Dipl.-Phys.)
Phone: +49 721 608-22436
Email: frank.kretzschmar@kit.edu

Additional slides

<u>Accident scenario</u>

- 150 cm² leak in hot leg of PWR
- High and low pressure injection
- Recirculation mode not available (no sump water injection)
- No additional water sources available → loss of cooling

Inst. Nuclear and Energy Technologies
Karlsruhe Institute of Technology (KIT)

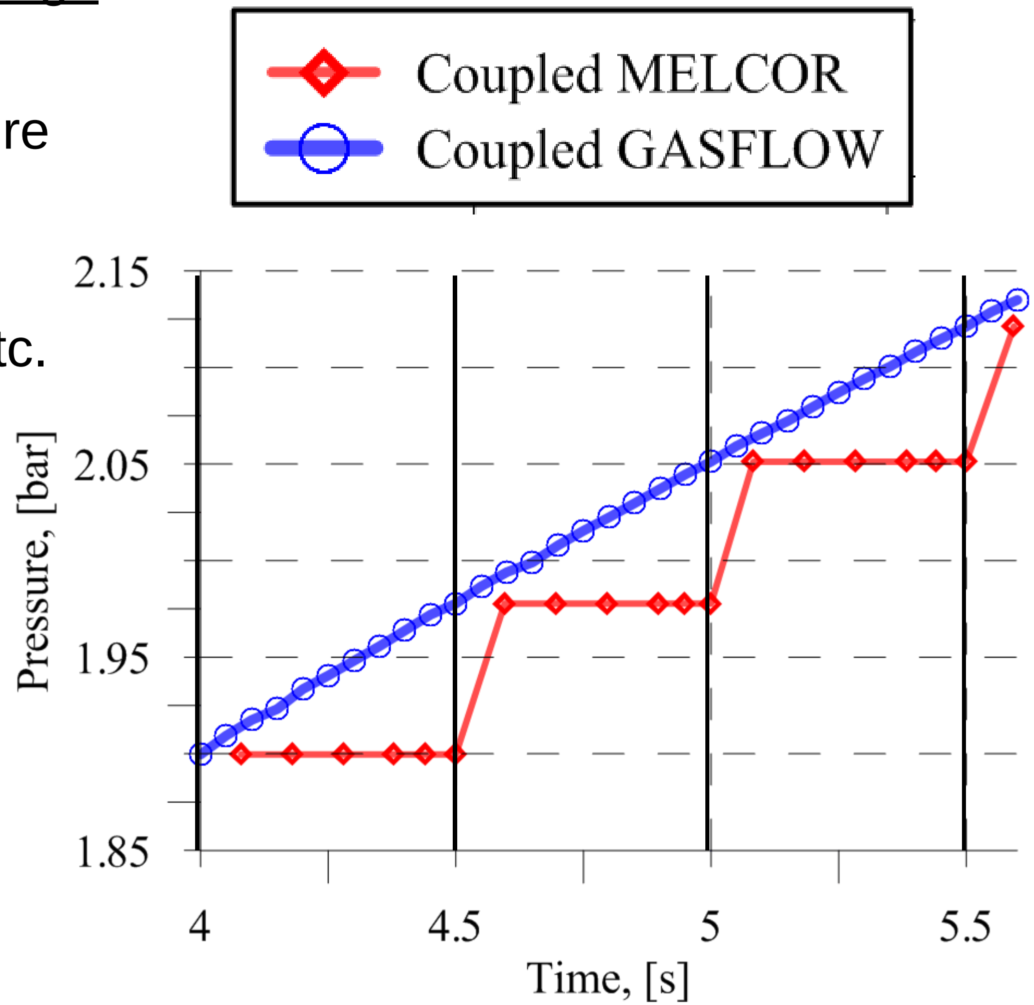
Additional slides

Verification of correct data exchange

- Example: containment pressure GASFLOW → MELCOR
- Coupling time step 0.5 s
- Data exchanges at 4 s, 4.5, etc.
- New value available for plot at next plot time point
- Explicit in time → constant value in MELCOR

→ Data exchange correct

→ Coupling error depending on coupling time step

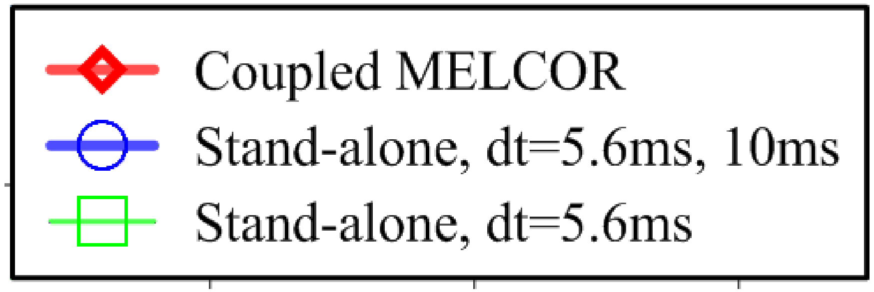


Additional slides

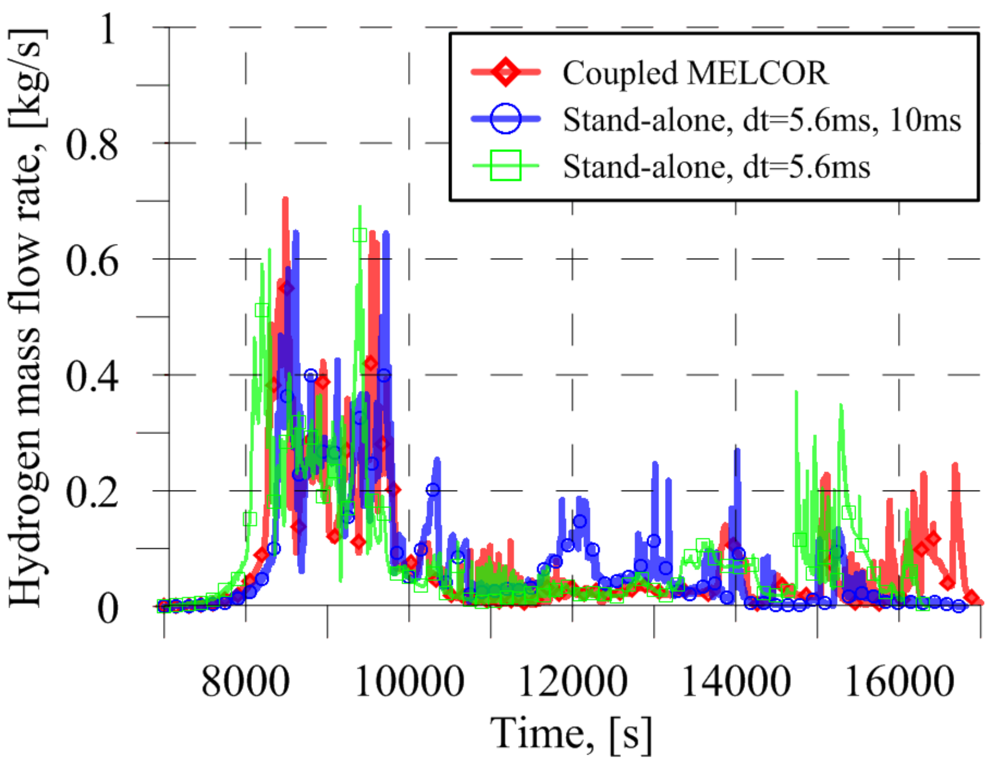
<u>H_2 outflow into containment</u>

integral

Simulation	Mass [kg]	Δ
Coupled MELCOR	748	-
Stand-alone MELCOR	740	-1%

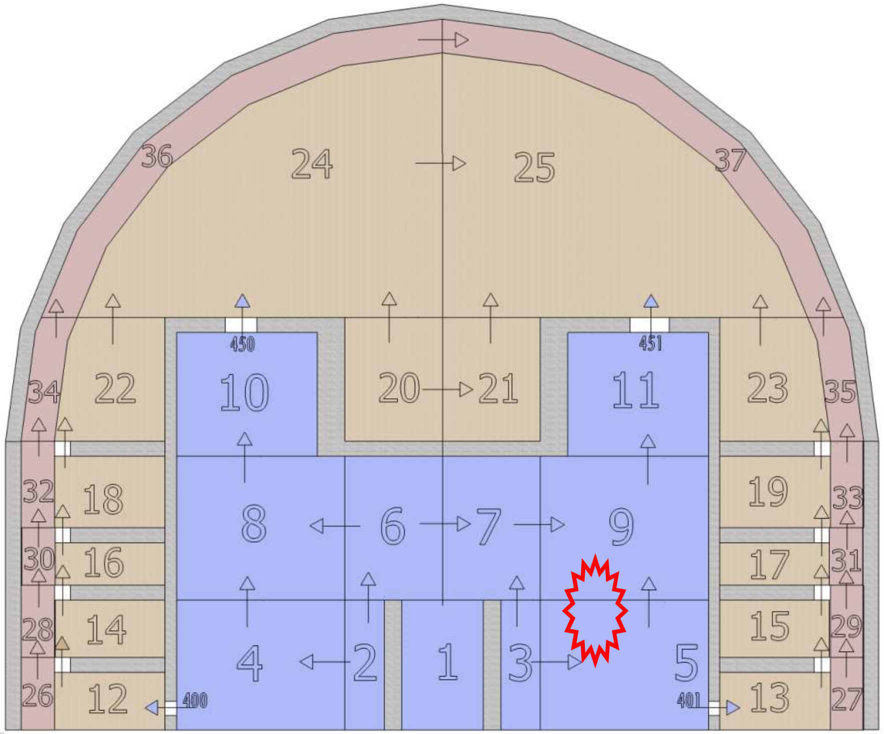


Mass flow rate

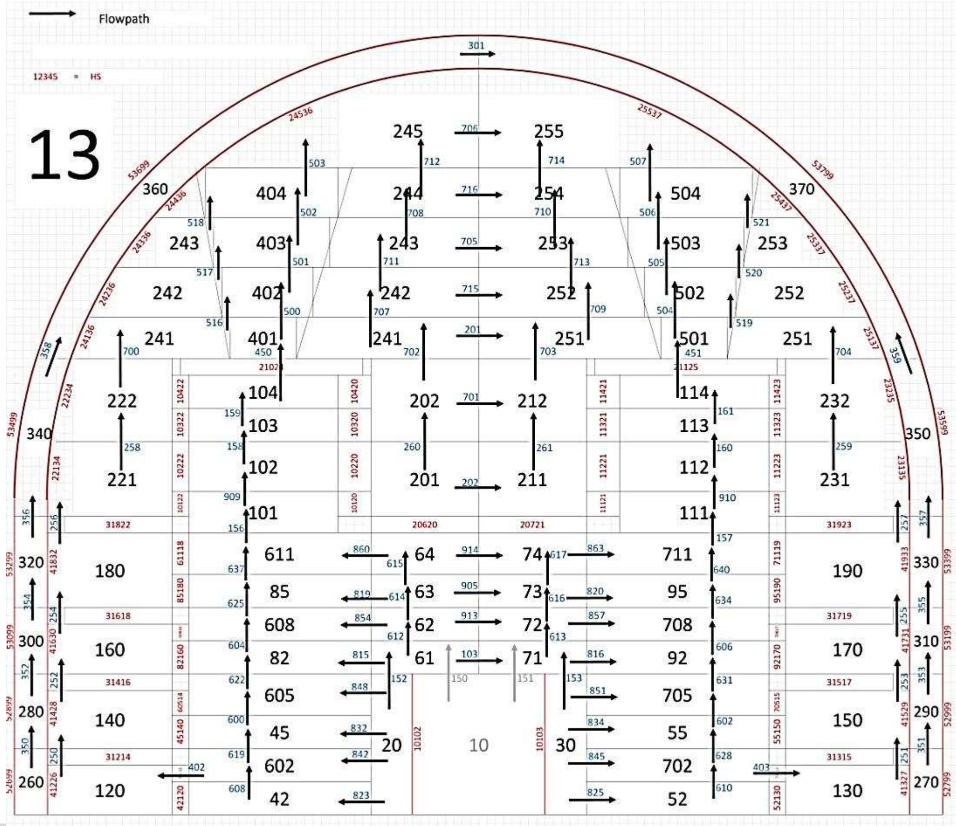


Additional slides

- Typical, very coarse nodalization for integral analyses



- Advanced nodalization
  - Refined vertical and horizontal Nodalization
  - Jet zones



Additional slides