Jožef Stefan Institute

Reactor Engineering Division

Loss of cryostat vacuum in DEMO fusion reactor due to large ingress of He gas

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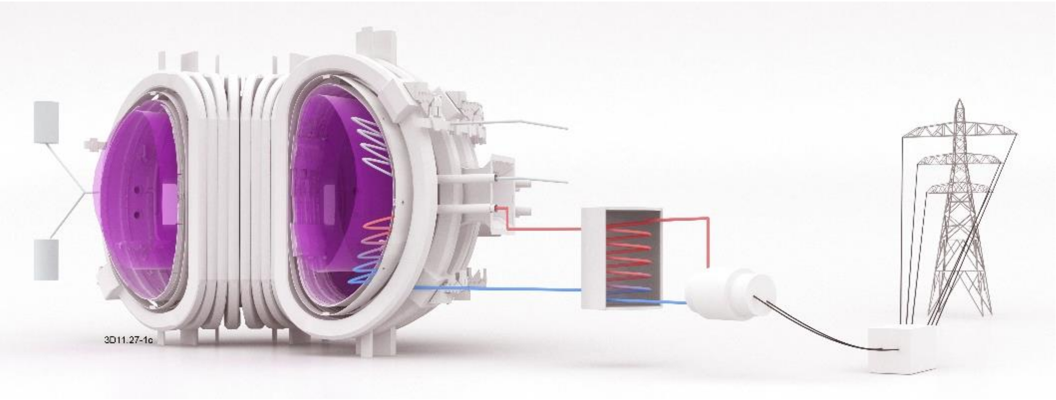
Outline

- Introduction
- Accident scenario
- MELCOR model
- Analyzed cases
- Simulation results
- Conclusions

Introduction

- EUROfusion – European Consortium for the Development of Fusion Energy
  - Loss of cryostat vacuum in DEMO fusion reactor due to large ingress of He gas
- DEMO – DEMOnstration power plant
  - To demonstrate necessary technologies for controlling powerful plasma, for safe generation of consistent electricity, and for regular, rapid, and reliable maintenance of the plant
  - Net electricity power output: 300 MW – 500 MW
  - Magnetic confinement fusion
  - Current status: conceptual design (till 2030)
    - Engineering design phase (2030-2040)
    - Construction phase (2040-operation in 2050s)



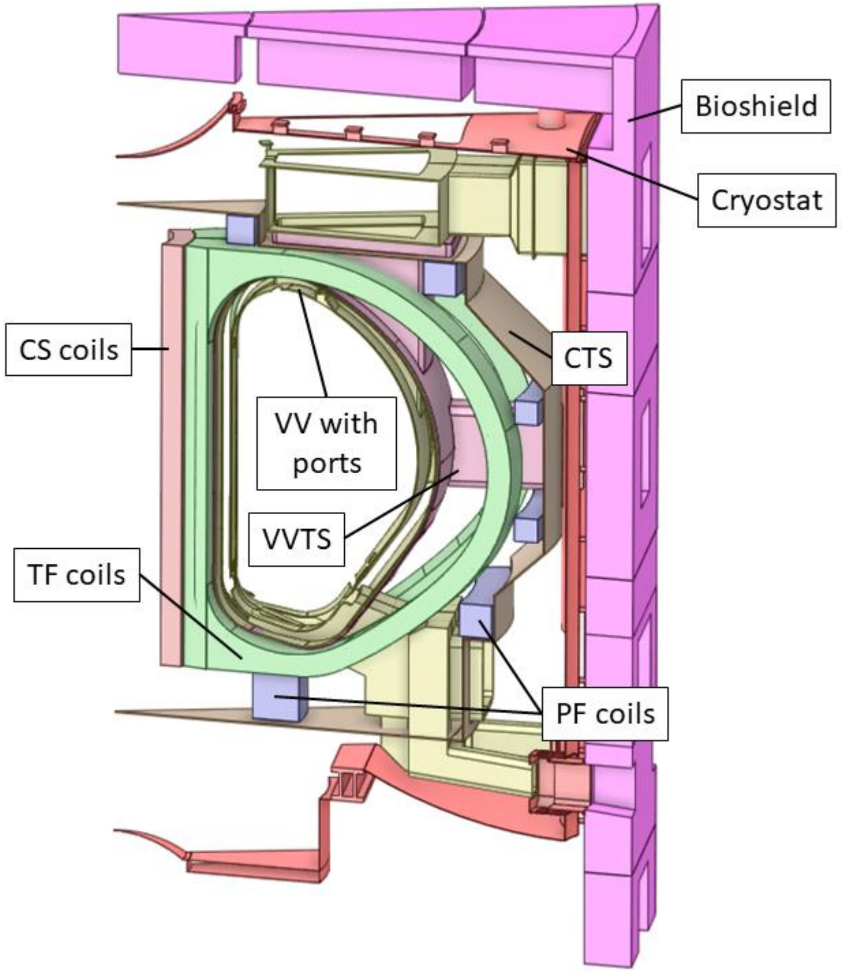
Simplified artistic impression of a tokamak connected to the grid (source: euro-fusion.org)

Accident scenario

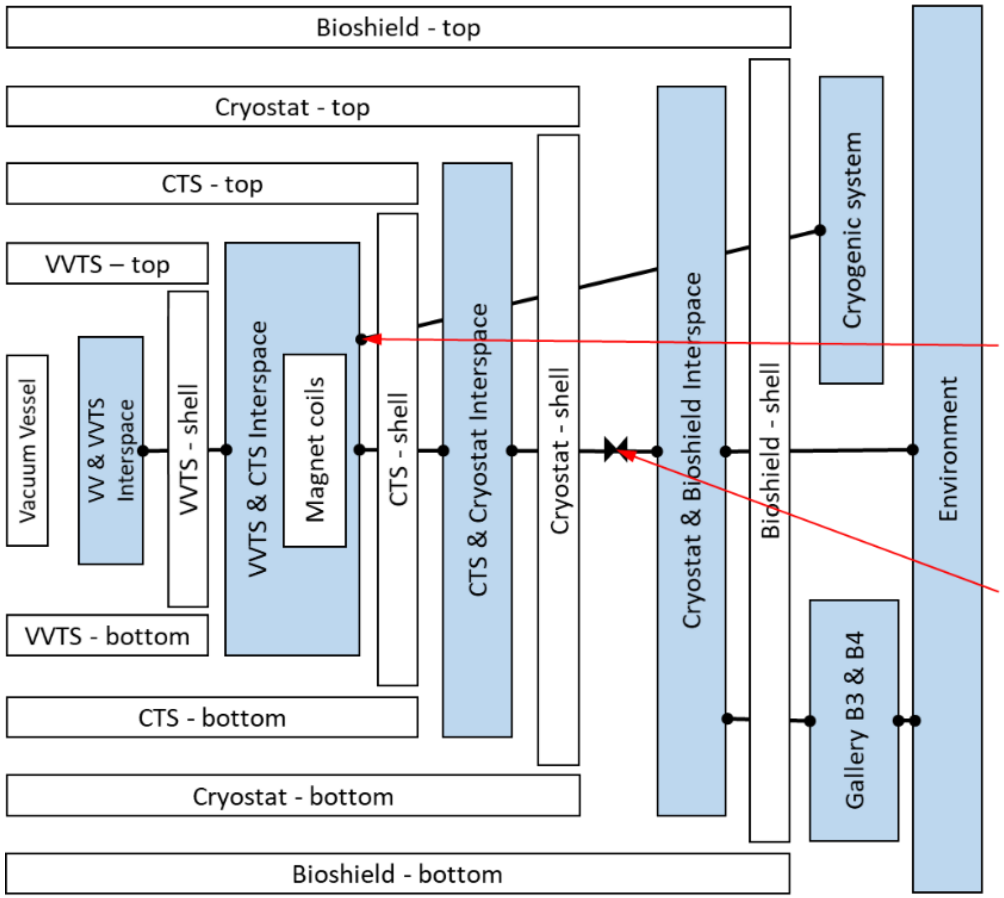
- Postulated Initiating Event
  - Break in the cryogenic lines used for cooling the superconductive magnets and large spill of helium gas into interspace between vacuum vessel thermal shield and cryostat thermal shield

- System assumptions
  - Vacuum vessel: T = 473 K (constant)
  - Break diameter: PF = 0.269 m, CS = 0.1345 m, TF = 0.1345 m, Thermal Shields = 0.266 m
  - Base case: 16 rupture discs in cryostat with 0.1 m diameter
  - Pressure set point of the cryostat rupture discs is set to 5 kPa overpressure
  - Cryostat pressure limit 109 kPa (9 kPa overpressure)

- Parameter study
  - Different temperatures of magnets (4.2 K and passive) and thermal shields (75 K and passive)



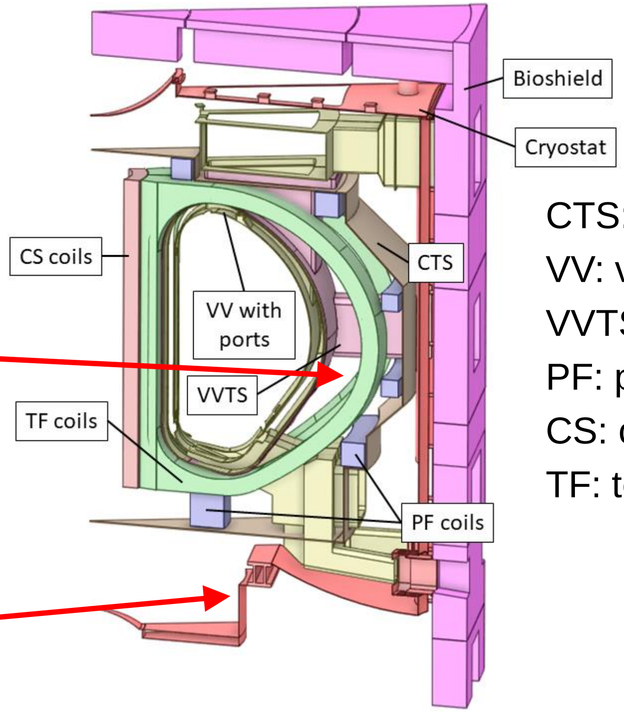
Cryostat: MELCOR model



Heat structure
Control volume

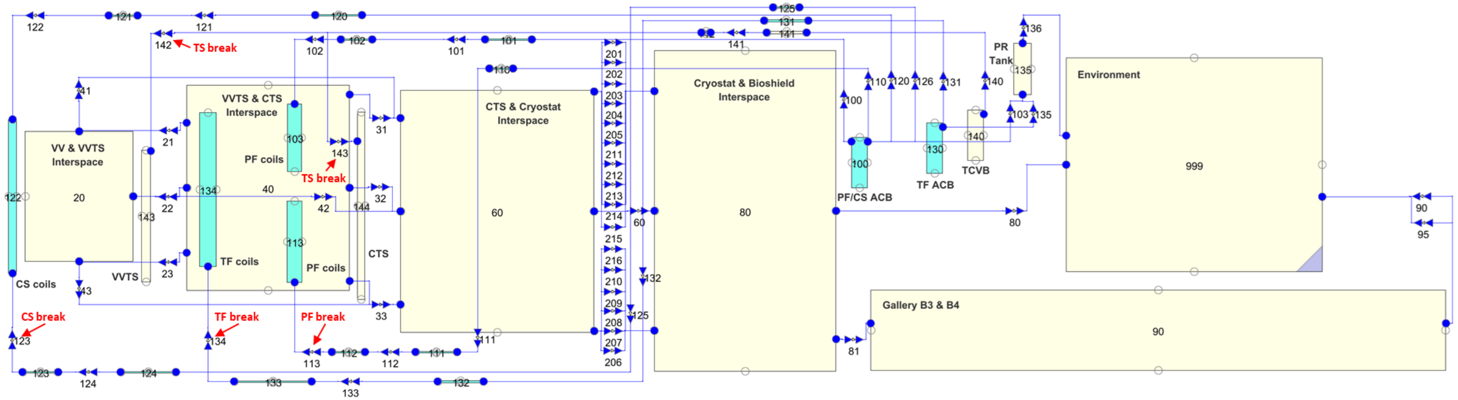
Double guillotine break

Rupture discs

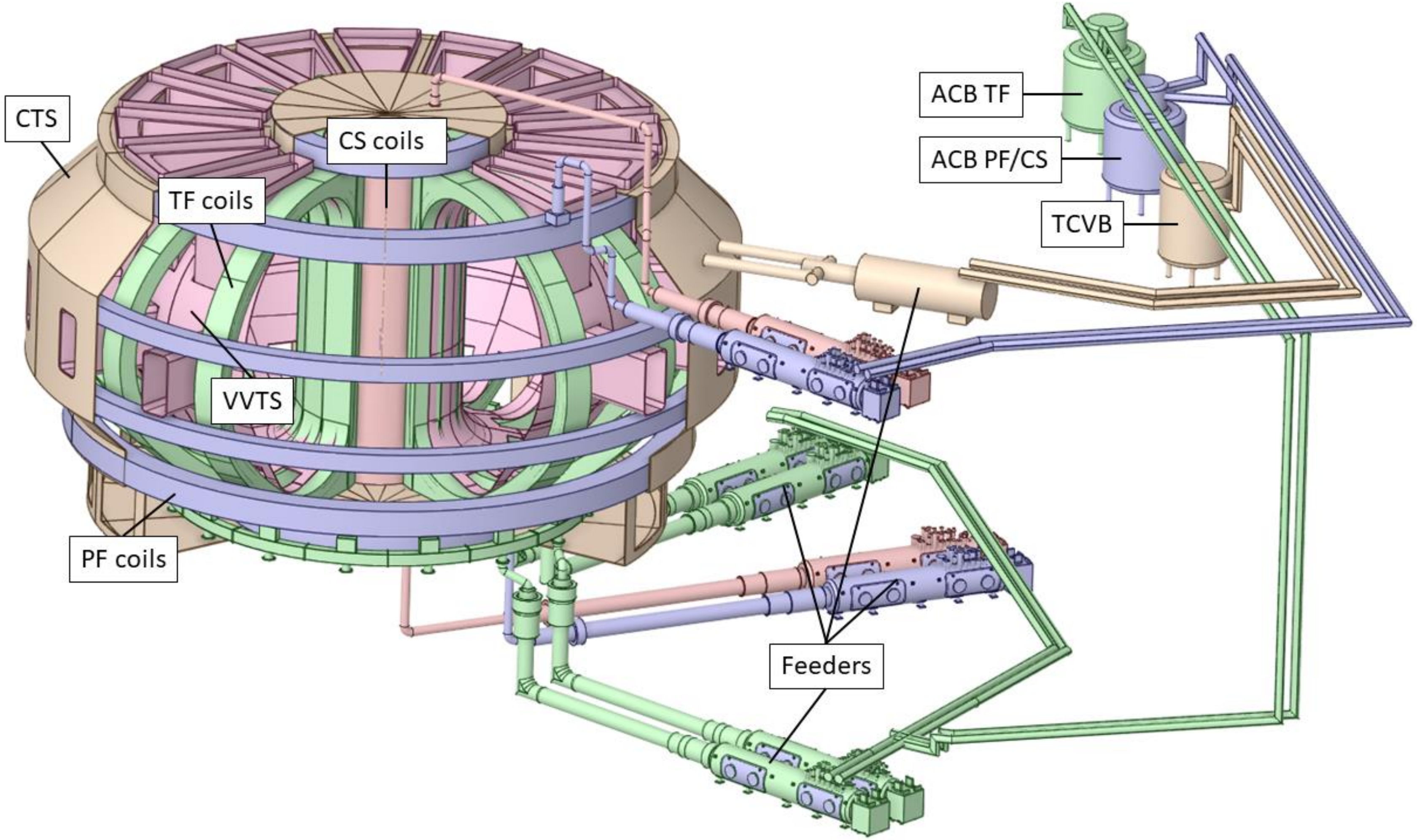


CTS: cryostat thermal shield
VV: vacuum vessel
VVTS: vacuum vessel thermal shield
PF: poloidal magnetic field
CS: central solenoid
TF: toroidal magnetic field

MELCOR nodalization

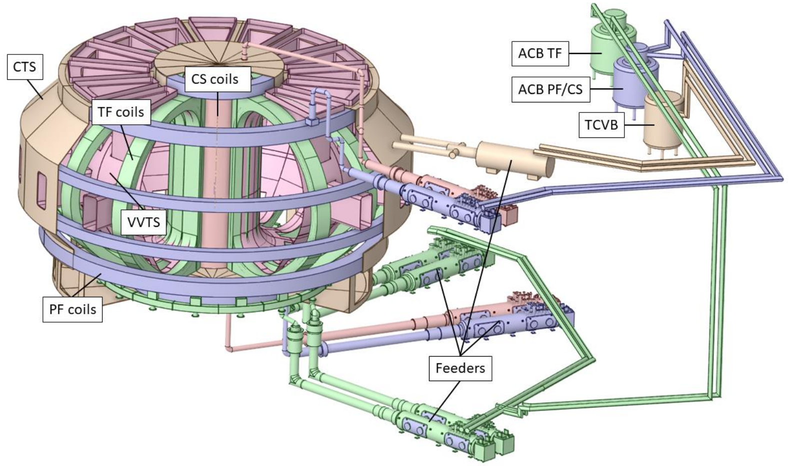


Cryogenic systems



CTS: cryostat thermal shield
VV: vacuum vessel
VVTS: vacuum vessel thermal shield
PF: poloidal magnetic field
CS: central solenoid
TF: toroidal magnetic field

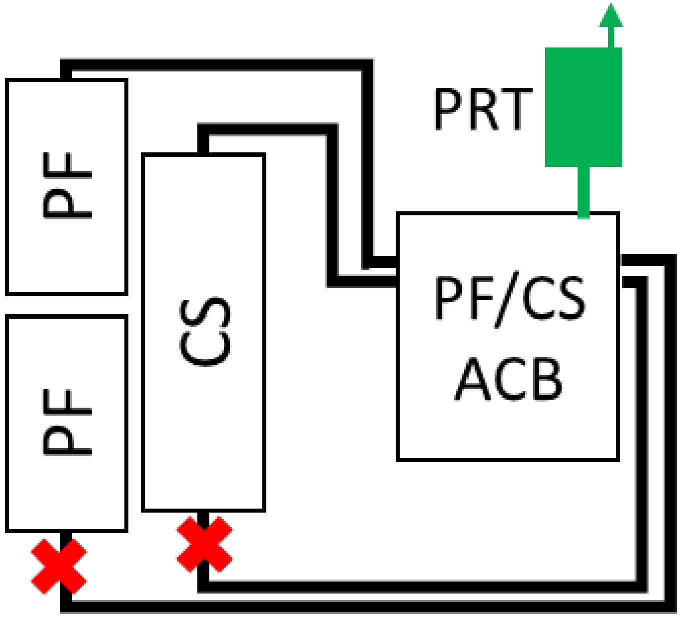
ACB: auxiliary cold box
TCVB: thermal shields control valve box



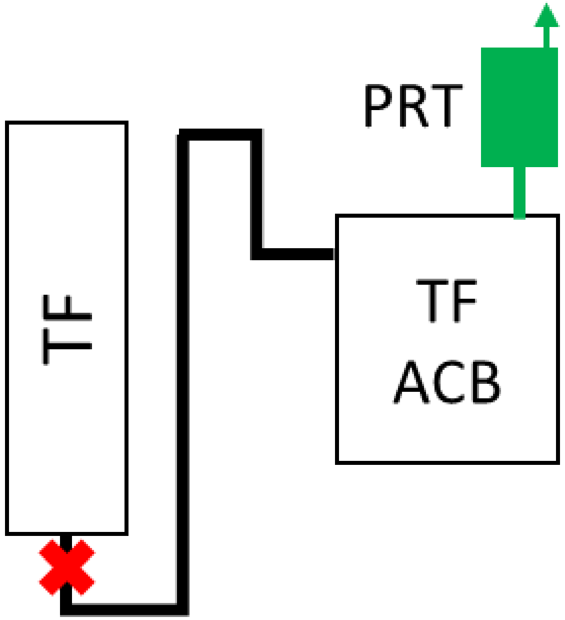
Cryogenic systems: MELCOR model

- Three cooling subsystems

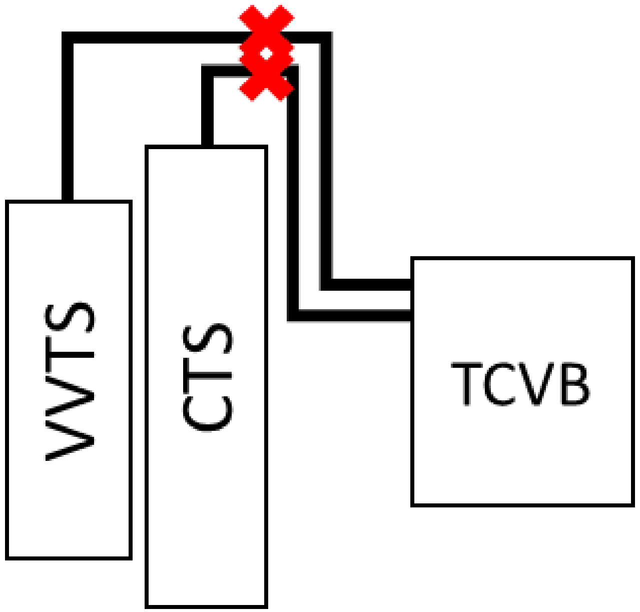
Central solenoid and Poloidal field magnets cooling system



Toroidal field magnets cooling system



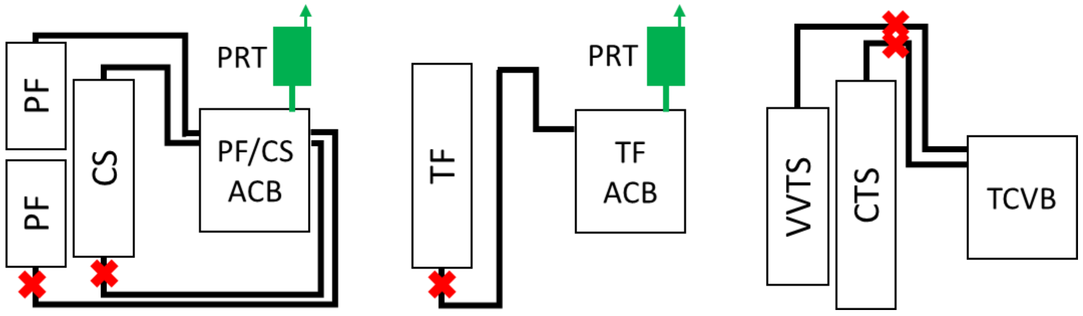
Thermal shields cooling system for vacuum vessel and cryostat



Break location marked with ✖

Analyzed cases

- Accident scenarios

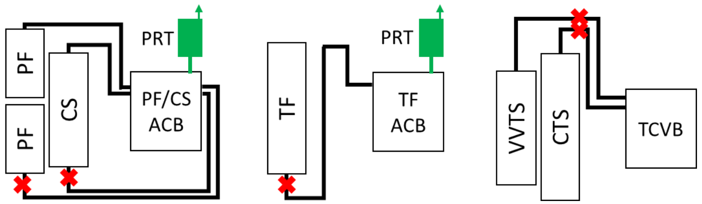


- MELCOR for Fusion
  - Based on MELCOR v1.8.6
  - Developed by Idaho National Laboratory

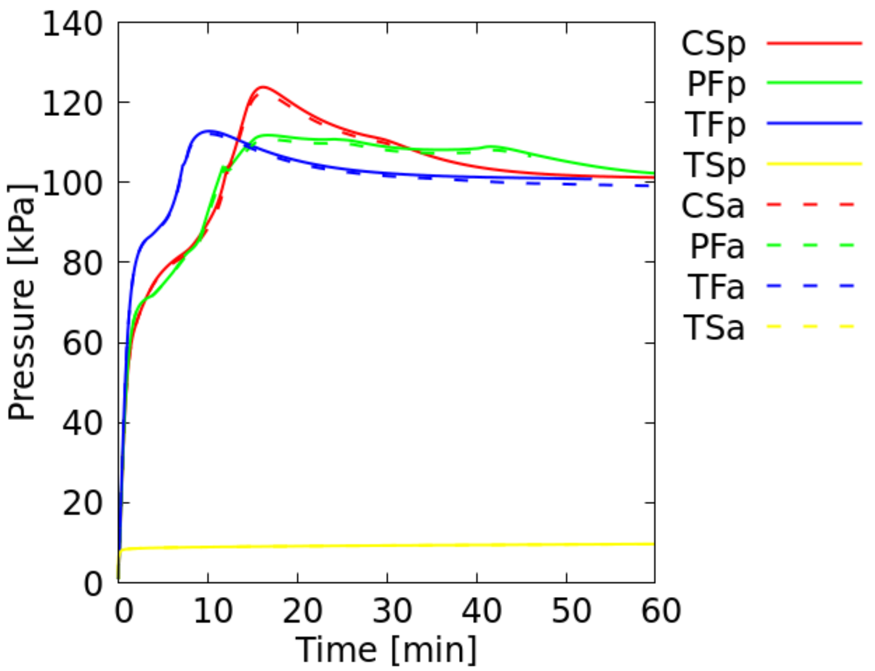
Case	Break location	Other cooling systems
CSp	CS	Passive
PFp	PF	Passive
TFp	TF	Passive
TSp	TS	Passive
CSa	CS	Active
PFa	PF	Active
TFa	TF	Active
TSa	TS	Active

Simulation results

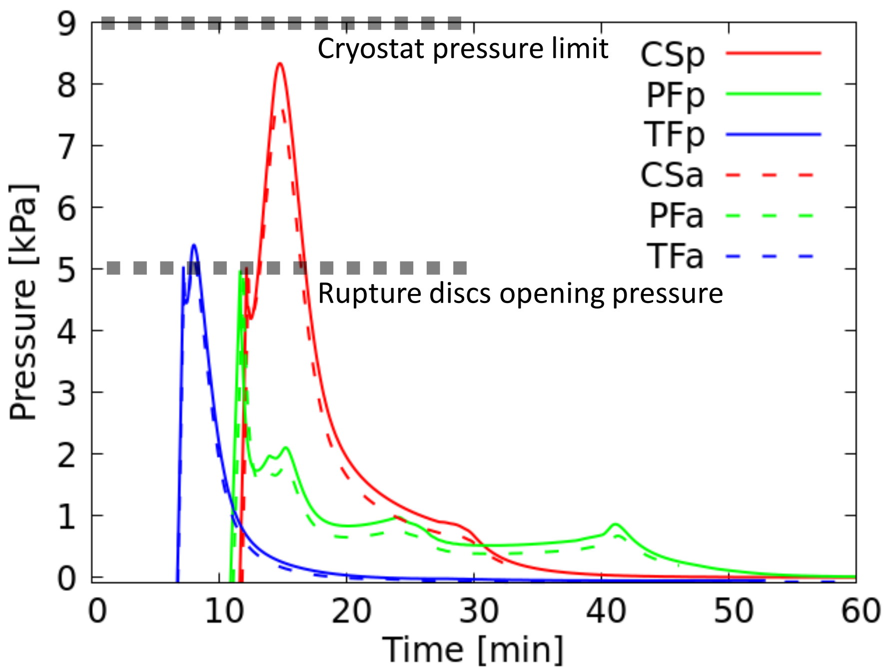
Case	Break location	Other cooling systems
CSp	CS	Passive
PFp	PF	Passive
TFp	TF	Passive
TSp	TS	Passive
CSa	CS	Active
PFa	PF	Active
TFa	TF	Active
TSa	TS	Active



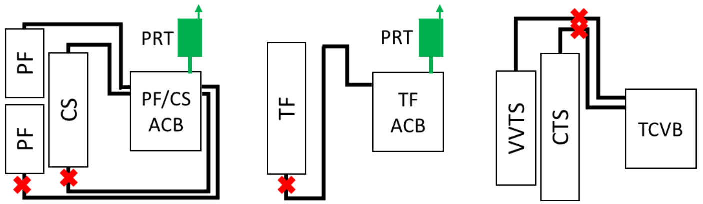
Pressure in cryostat



Pressure difference inside/outside cryostat

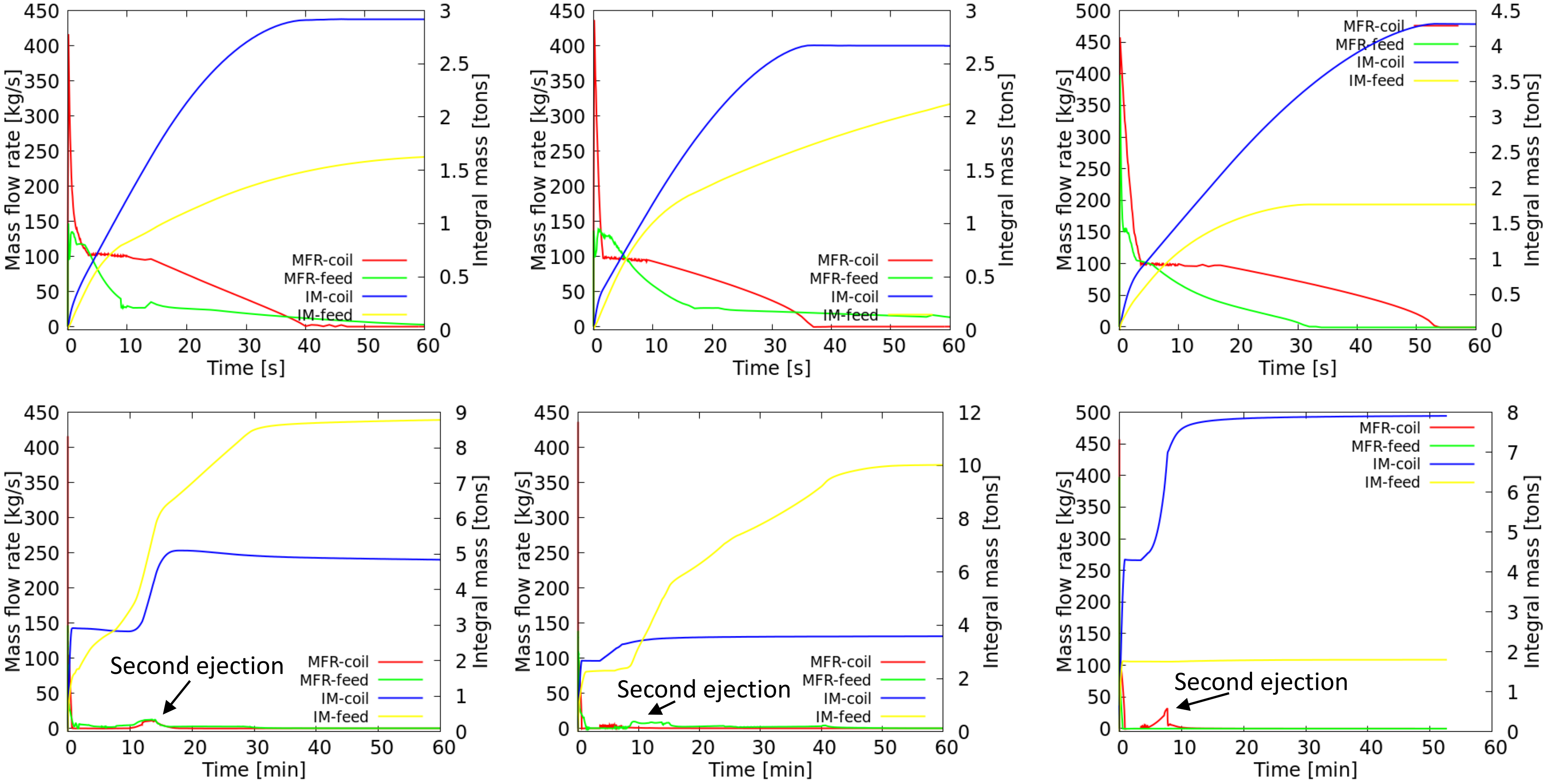


- Pressure increase in TS cases small
- Difference between passive and active cases small
- CS cases bounding



He mass flow rate and Integral released mass

Scenario: CSp PFp TFp



- In all cases initial mass flow rate is large on both break sides (coil, feeder), up to 500 kg/s.
- Second ejection after 5-15 min due He boiling inside failed cryogenic subsystem.
- In CS case second ejection occurs simultaneously through both break sides
  ⇒ large pressure difference inside/outside cryostat.

Temperature of CV in DEMO tokamak building

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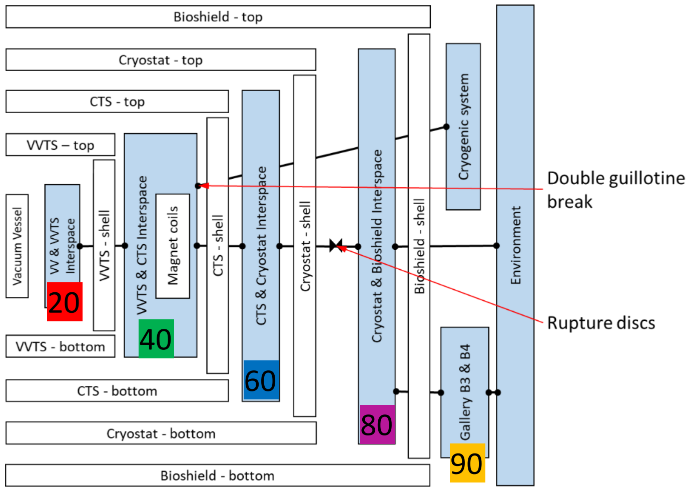
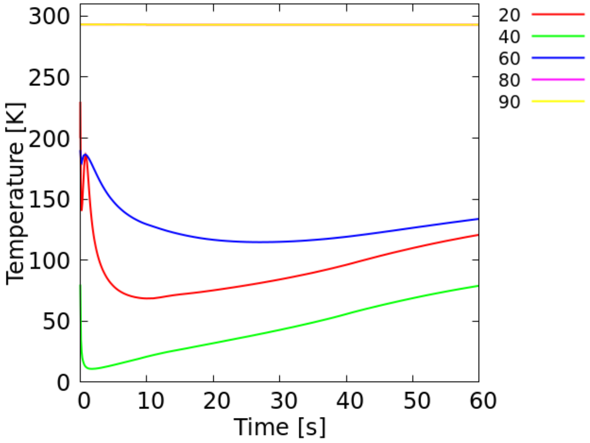
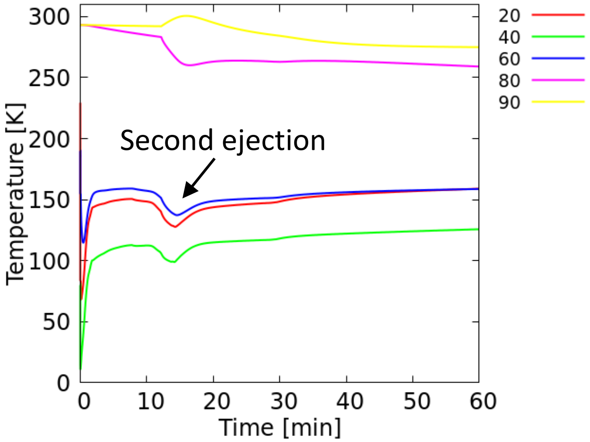
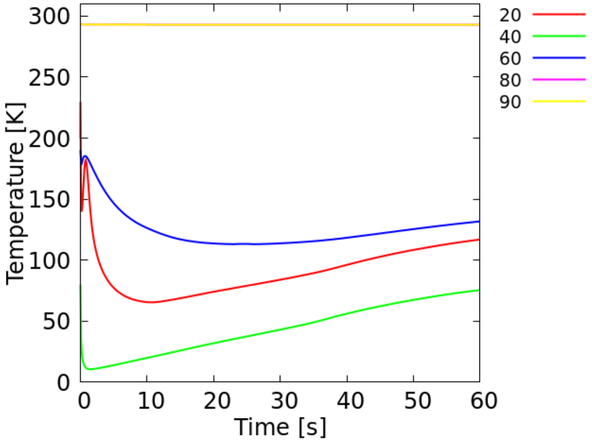


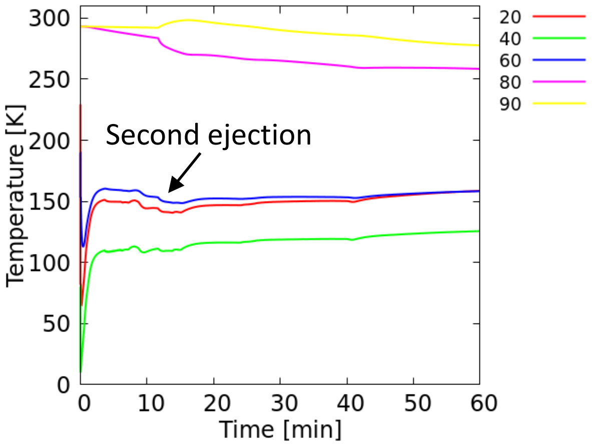
Scenario: CSp



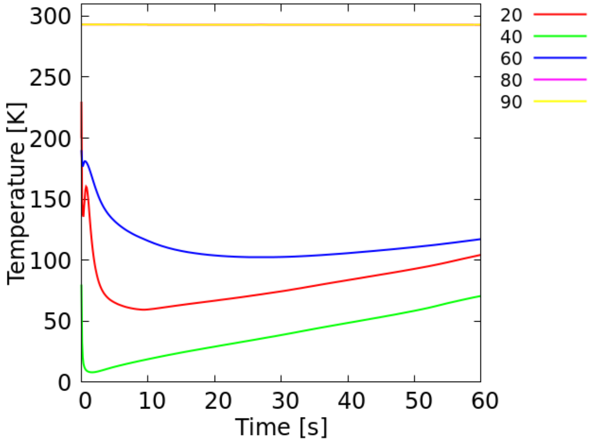


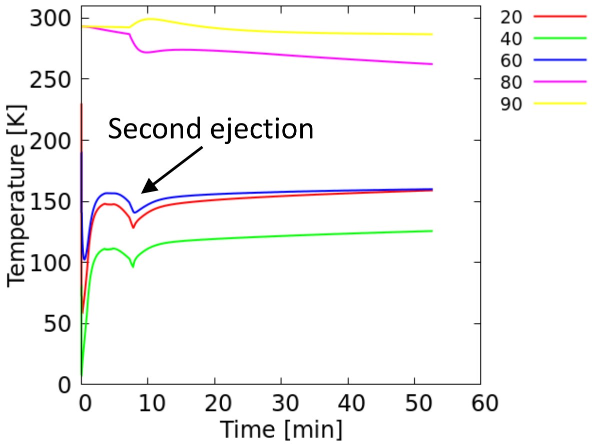
PFp





TFp





- Temperature evolution for all scenarios quite similar.
- Initially temperature drops due to cryogenic He outflow through break (the most in break location CV40). Then starts to rise due to heat transfer from heat structures.
- During second He ejection temperature decreases again.

Conclusions

- MELCOR model of DEMO fusion power plant was developed
- Transient process after break in cryogenic system and ingress of helium gas analyzed
  - Simulations of various cases performed considering different break locations and other cooling systems being passive/active
- Simulation results show that break in central solenoid cooling system is bounding regarding maximal pressure difference inside/outside cryostat
  - Second He ejection occurs simultaneously through both break sides
  - Difference between passive and active cases minimal
  - Number of needed rupture discs to maintain pressure difference inside/outside cryostat below design limit calculated

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