EUROfusion

MELCOR for Fusion Application for Cryogenic Helium Spill in Fusion Power Plant

The 14th Meeting of the European MELCOR and MACCS User Group

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Rok KRPAN

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Jožef Stefan Institute

Reactor Engineering Division

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MELCOR for Fusion

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- Based on MELCOR v1.8.6.
- Developer: Idaho National Laboratory Fusion Safety Program, Thermal Sciences and Safety Analysis Department
- Modifications:
  - oxidation of beryllium, carbon, or tungsten in steam and oxygen (air) environments,
  - condensation and freezing of air, water, or helium in cryogenic environments,
  - flow boiling heat transfer correlations,
  - air, helium or lithium as the working fluid,
  - turbulent and centrifugal aerosol deposition and,
  - enclosure radiant heat transfer.

Merrill et al., Modifications to the MELCOR code for application in fusion accident analyses, Fusion Eng. Des, 51-52, 2000.

Introduction

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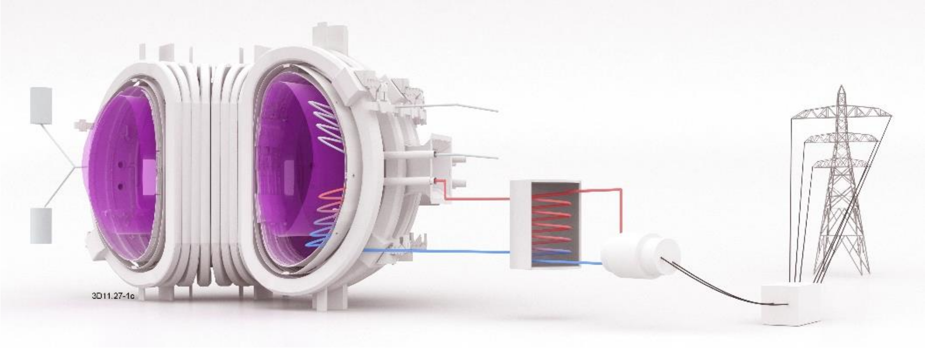
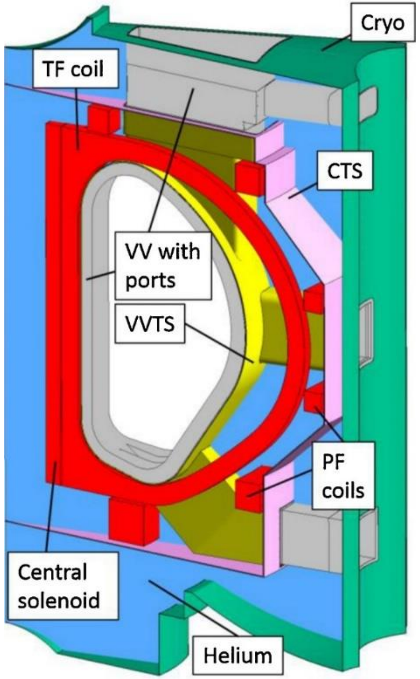
- DEMOnstration power plant DEMO
  - To demonstrate necessary technologies for controlling powerful plasma, for safe generation of consistent electricity, and for regular, rapid, and reliable maintenance of the plant.
  - Net electricity power output: 300 MW – 500 MW.
  - Magnetic confinement fusion.
  - Current status: conceptual design.



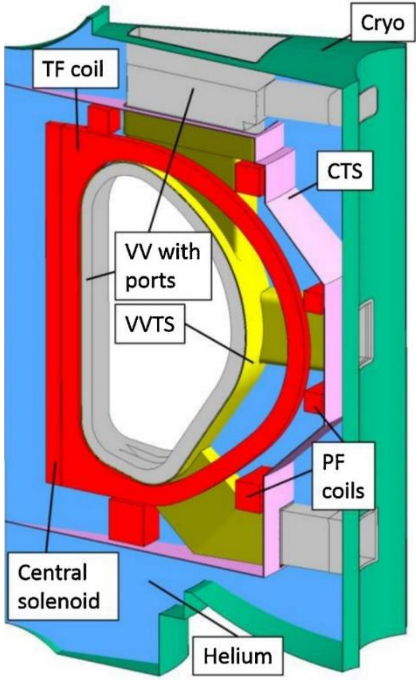
Simplified artistic impression of a tokamak connected to the grid
(source: euro-fusion.org)

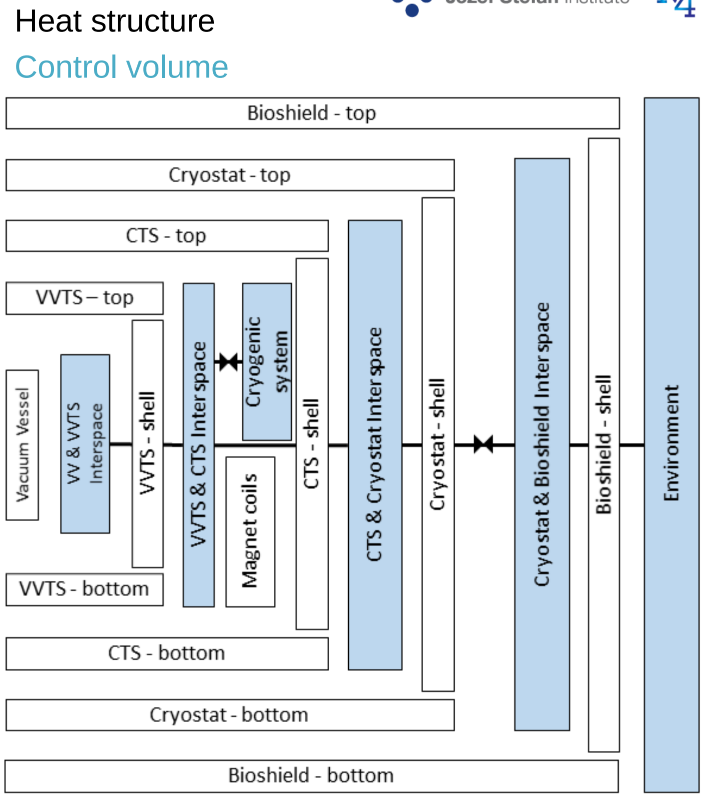
Accident Scenario

- 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 0.1 m.
  - Pressure set point of the cryostat rupture disk is set to 5 kPa overpressure.
  - Cryostat pressure limit 109 kPa (9 kPa overpressure).
- Parameter studies
  - Different temperatures of magnets (4.2 K and passive).
  - Up to 20 tons of released helium.
  - Different diameters of rupture disc in cryostat.



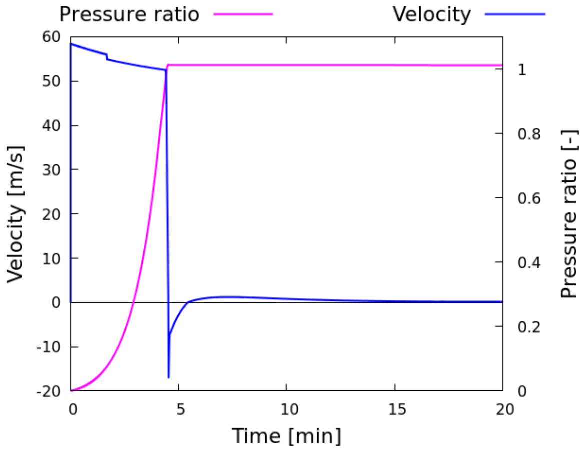
MELCOR model



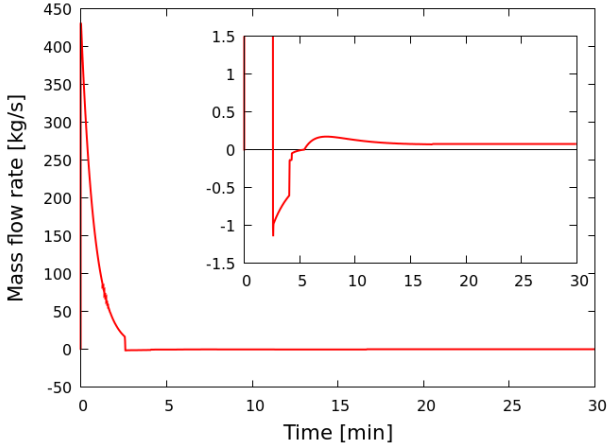


Results – Helium as NCG

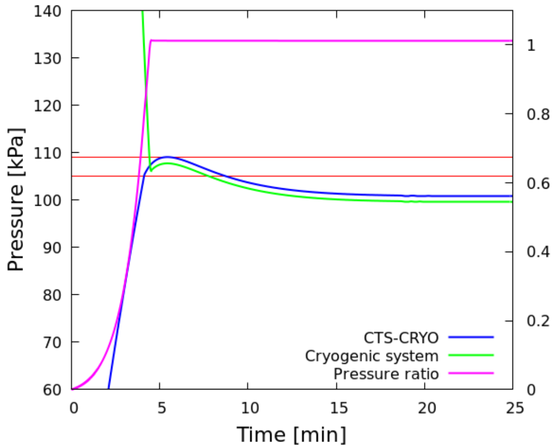
Flow through break with D = 0.1 m



Helium velocity through the break.



Helium mass flow through the break.



Pressure inside cryostat.

Conditions in cryostat during accident

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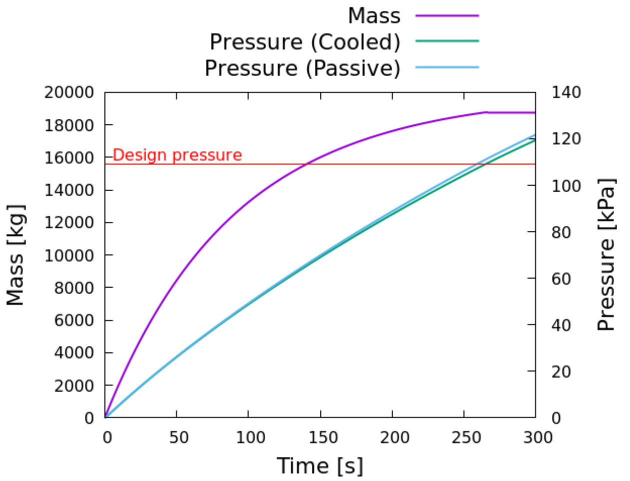
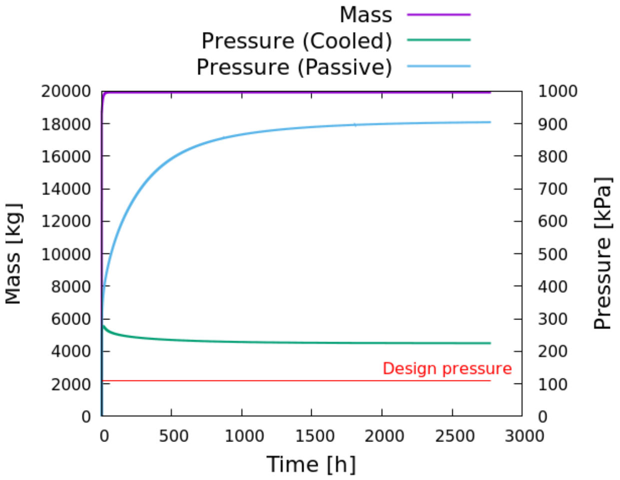
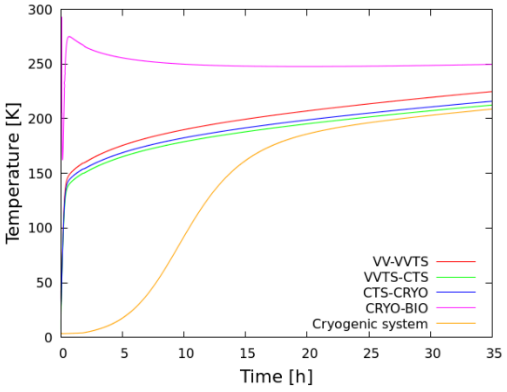




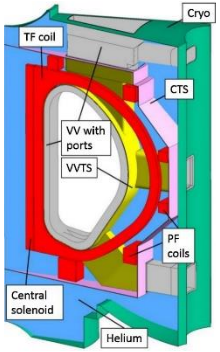
Leaked helium mass into the interspace between VVTS and CTS and the pressure inside the cryostat.

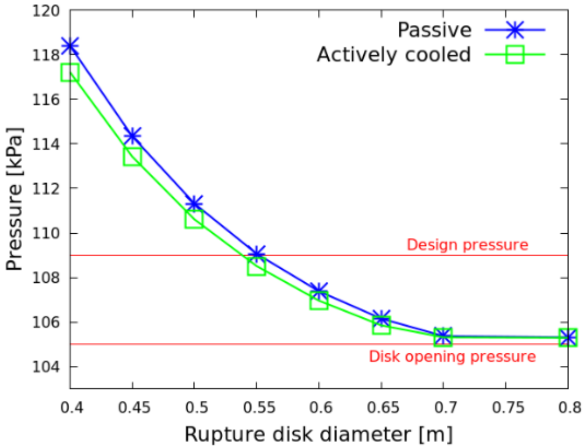


Atmosphere temperature in different control volumes.

Results – Helium as NCG

Parametric studies

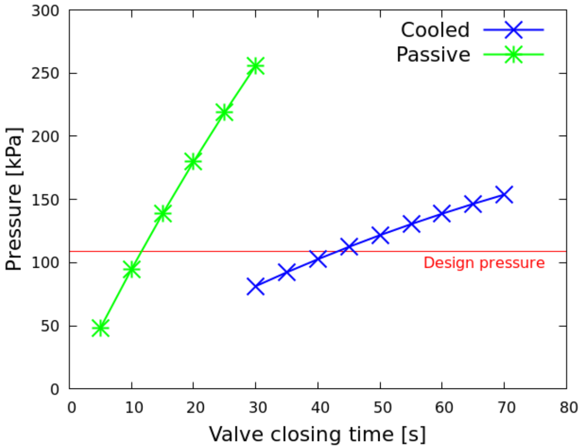




Maximal pressure inside the cryostat with different cryostat pressure relief system diameters.

blue: passive superconducting magnets,

green: magnets at a constant temperature.



Maximal pressure value inside cryostat regarding the closing time of cryogenic system isolation valve.

Helium as working fluid (1)

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- Numerical instability:

  <Diagnostic Message> Time= 3.5910E+01 Dt= 1.0000E-09 Cycle= 559023 (CVH)

  Error in CVTSVE for pool

  Called from near-equilibrium thermo routine CVTNQE

  For Volume 101, with NCG in a very small atmosphere

  THERMO ERROR 21 IN VOLUME 100

  THERMO ERROR AT 'NEW' STATE, VOLUMES 100

Helium as working fluid (2)

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- “Solution”

```
*           TIME   DTMAX   DTMIN     DTEDT   DTPLT  DTREST
time1        0.0  5.0e-8   1.e-9      10.0    0.01    10.0
time2     5.0e-3  5.0e-5   1.e-8      10.0     0.1    10.0
time3      100.0     1.0   1.e-6     100.0     1.0   100.0
time4     1000.0   100.0   1.e-4   10000.0    10.0 10000.0


tend       1.0e6
```

```
*           TIME   DTMAX   DTMIN     DTEDT   DTPLT  DTREST
time1        0.0  5.0e-8   1.e-9      10.0    0.01    10.0
time2     5.0e-3  5.0e-5   1.e-8      10.0     0.1    10.0
time3       10.0     1.0   1.e-9     100.0     0.1   100.0
time4       30.0     1.0   1.e-9     100.0     0.1   100.0
time5      100.0     1.0   1.e-6     100.0     1.0   100.0
time6     1000.0   100.0   1.e-4   10000.0    10.0 10000.0
tend       1.0e6
```

Helium as working fluid (3)

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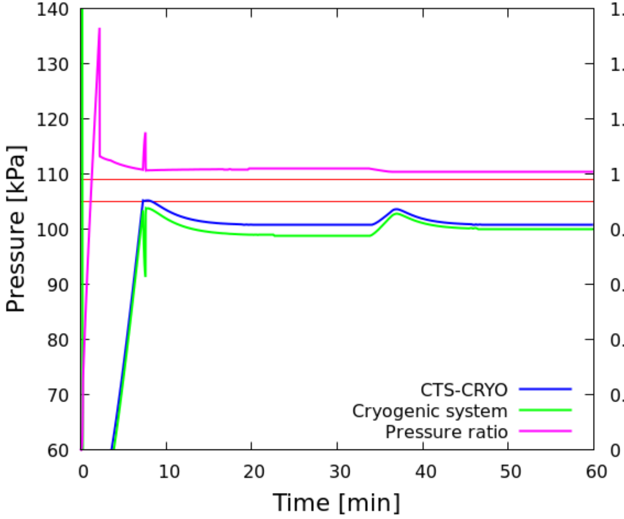

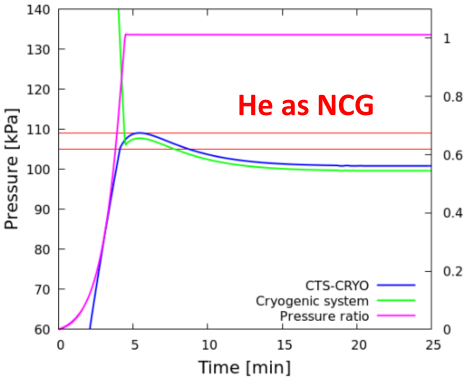

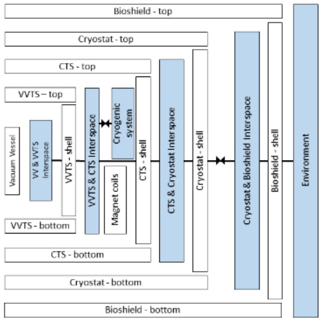

Pressure in the cryostat and in the cryogenic system, and the ratio between these pressure values.

Helium as working fluid (4)

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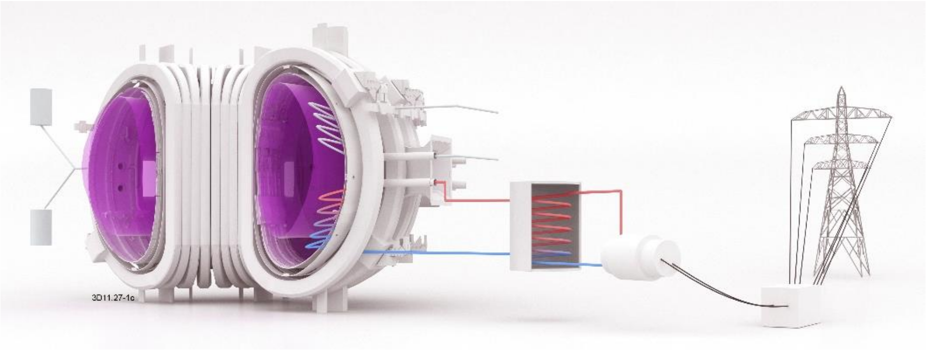
- Numerical instability: [External correspondence]:
    - Li-EoS external file: ‘THERMO ERROR 11’
        - related to converge a thermodynamic state at the beginning of a time step.
    - Very low amounts of Li vapour (10^(-10) kg) in concerned volumes.
    - Problem occurs also with no flow paths.

Conclusions

- MELCOR for Fusion.
- DEMOnstration power plant DEMO:
  - PIE: Break in the cryogenic lines and large spill of helium into cryostat.
- He as NCG: ✓
- He as working fluid: ✗



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