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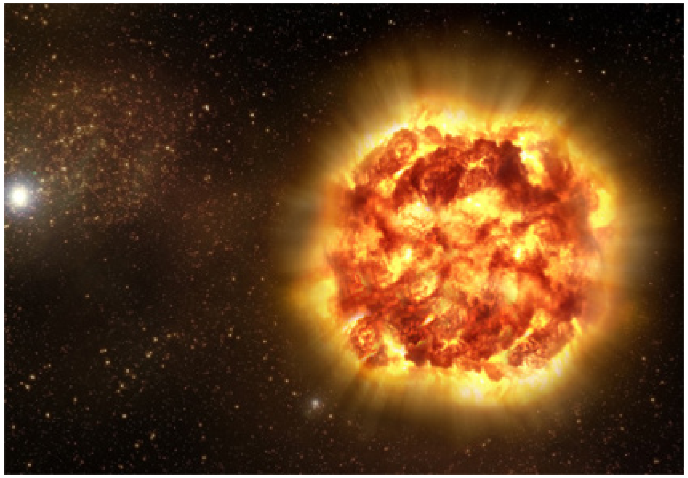
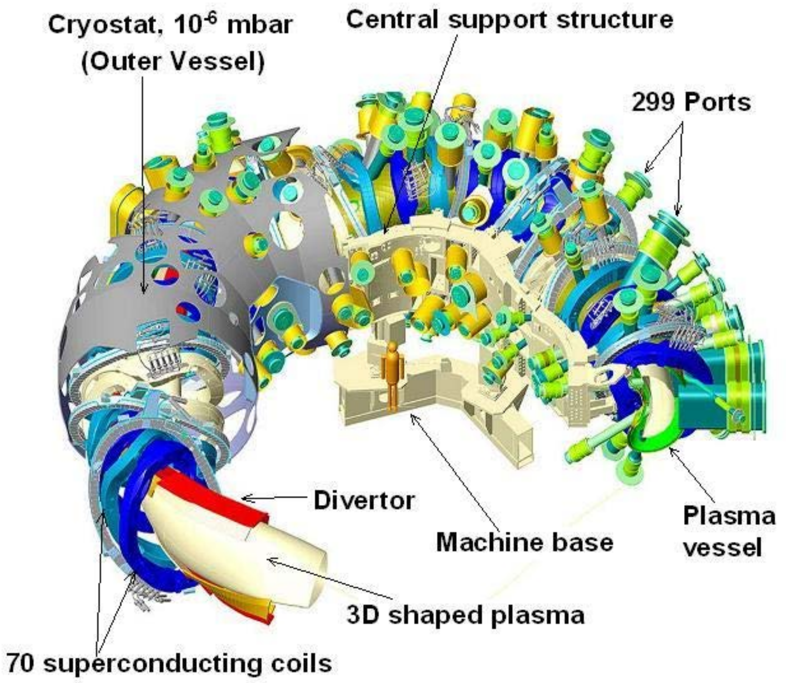
Safety assessment of Wendelstein 7-X Experimental Nuclear Fusion Facility in the case of LOCAs

Outline

- Introduction. W7-X torus
- Safety aspects of W7-X
- Purpose of the analysis
- Modelling of processes in the Cooling System, Vacuum Vessel and Pressure Increase Protection system
- Results of analysis:
  - Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe
  - Analysis of small break LOCA inside vacuum vessel – break of 1 mm^2 cross section
- Conclusions

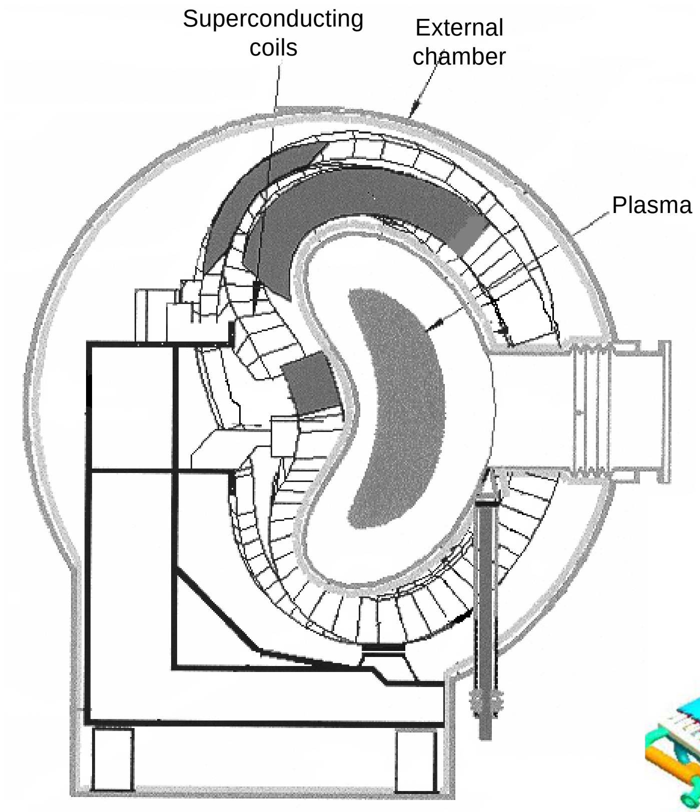
Introduction

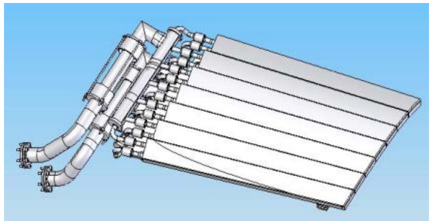


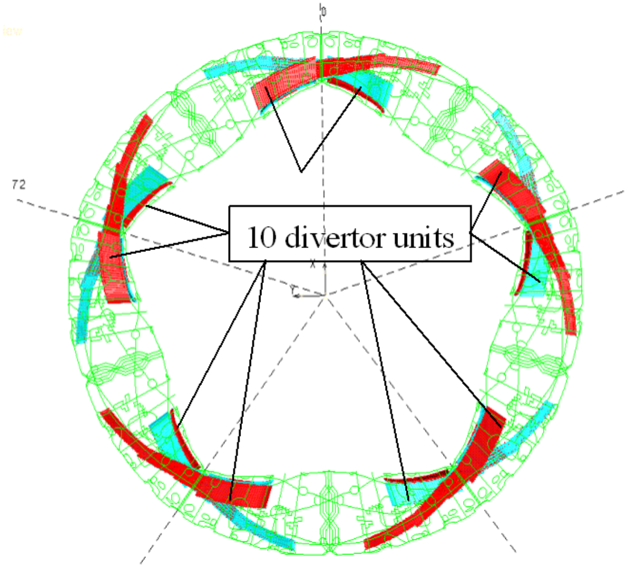


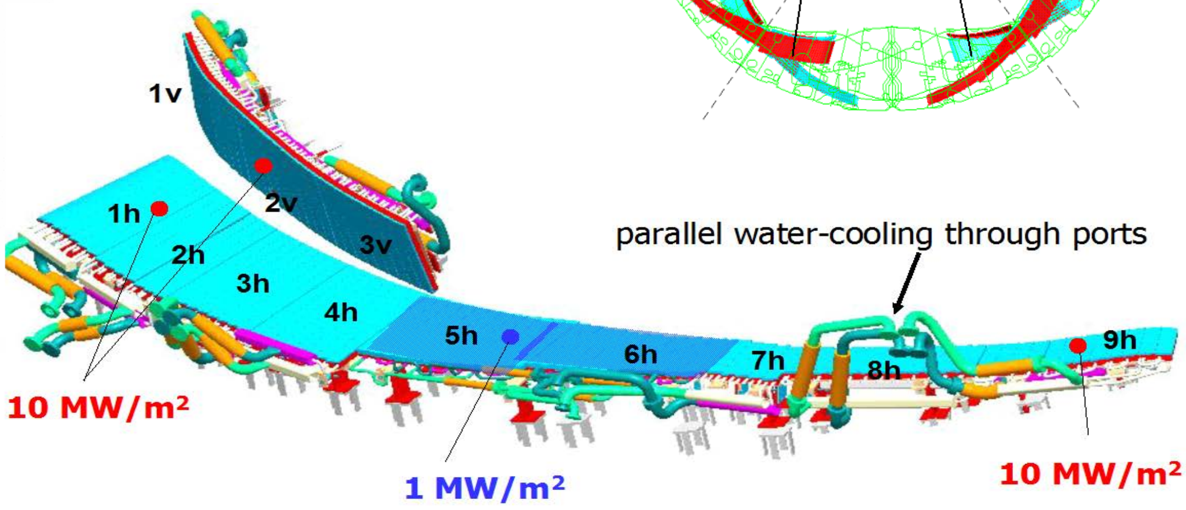
- W7-X is an experimental fusion device of stellarator type, which is currently being developed and built by Max Planck plasma physics institute (IPP, Germany).
- The purpose of the W7-X device is to demonstrate the feasibility of the stellarator devices for the creation of stable plasma conditions for as long as half an hour.
- In 2007 - 2012 Lithuanian energy institute (LEI) within the frame of European Fusion Development Agreement (EFDA) cooperated with (IPP) in performing safety analysis for fusion device W7-X.

Introduction. W7-X torus









W7-X torus and single divertor unit with horizontal (1h-9h) and vertical (1v-3v) target modules

Safety aspects of W7-X

The nuclear hazards, related to the radioactive source terms, in the fusion devices:

- neutron produced during the burn phase
- the activated material of the plasma facing components
- the active corrosion production in the cooling circuits
- the activated dust produced by plasma-wall interaction in the Vacuum Vessel (VV)
- the availability of a small amount of Tritium in the VV

Safety barriers of W7-X:

- divertor units cooling system
- vacuum vessel

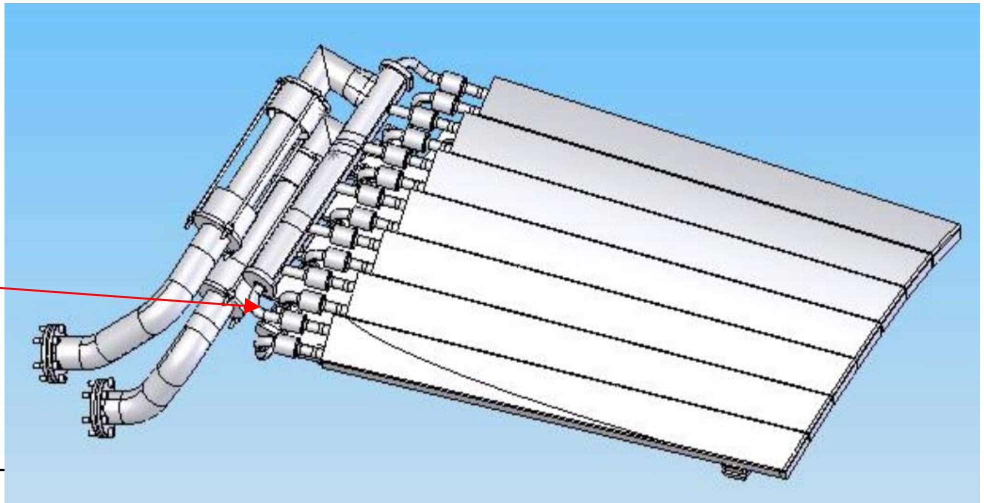
Acceptance criteria fort W7-X:

- pressure in divertor units cooling system < 5 MPa (integrity of bellows, connecting in-vessel components with the piping outside vacuum vessel)
- pressure in vacuum vessel < 50 kPa above the atmospheric pressure (integrity of ports)

Purpose of the analysis (1)

- The most severe accident for the stelarator device - pressure increase in plasma (vacuum) vessel
- This can occur in the case of rupture of pipeline, which provides the coolant to the divertor units. This will lead the discharge of steam – water mixture through the break into plasma vessel.
- A rupture of the 40 mm pipe connected to target module could lead to the loss of vacuum condition up to overpressure of the plasma vessel and damage of in-vessel components – loss of integrity of VV.

40 mm pipe



Purpose of the analysis (2)

- To decrease the pressure in VV (to decrease the amount of discharged water in VV) – closure of automatic valves is foreseen
- But, the fast closure of automatic valves could lead the water hammer phenomenon – loss of integrity of divertor units cooling system.

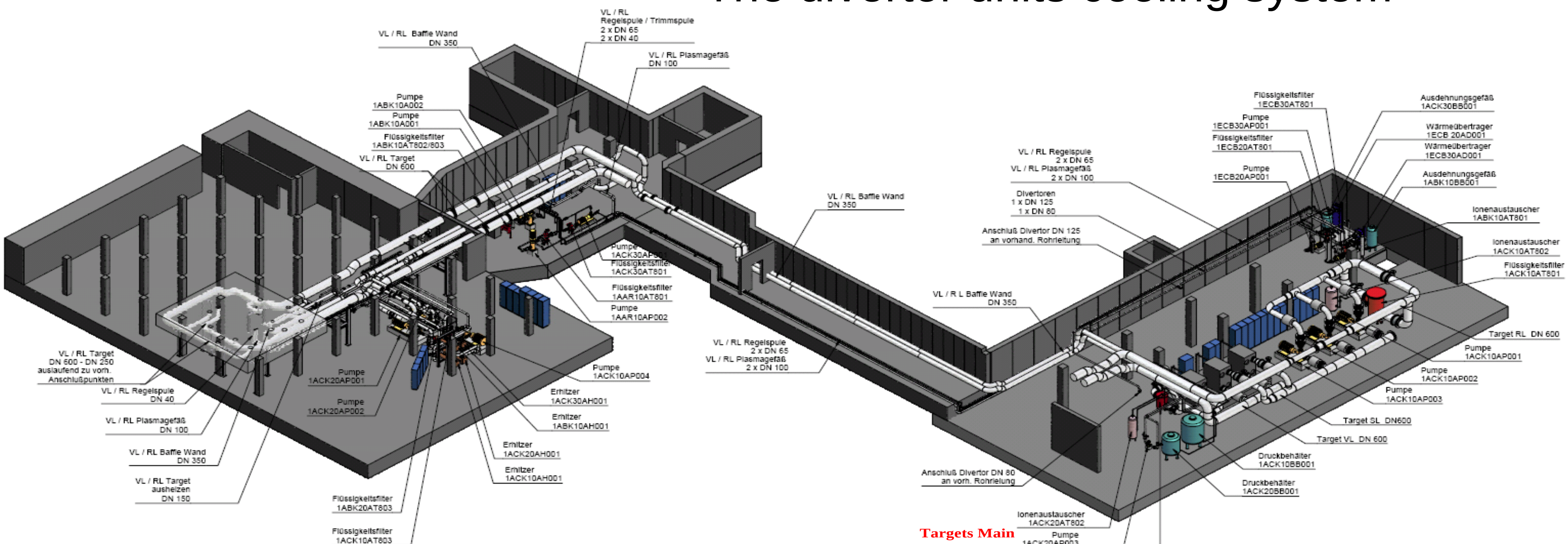
- Thus, the close rate of valves should be selected, taking into account:
    - minimum possible amount of water discharge in VV
    - possibility of occurrence of water hammer phenomena.

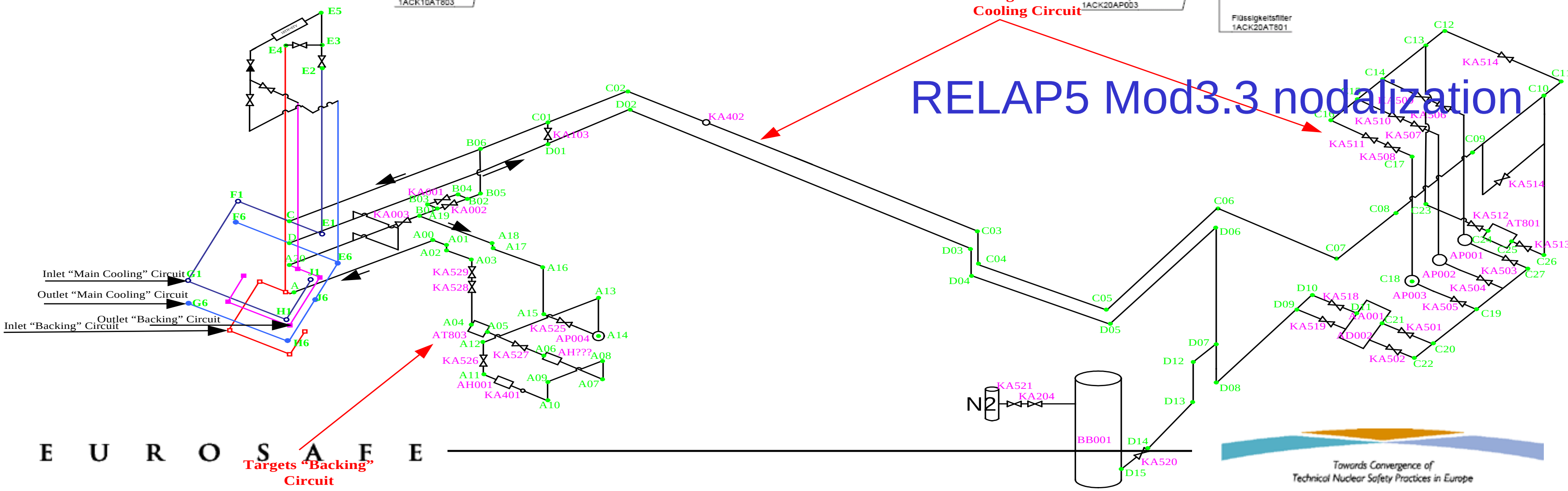
- **In this paper the detailed safety assessment of Wendelstein 7-X experimental nuclear fusion facility in the case of small and large LOCAs is presented.**

Modelling of processes in the Cooling System

Development of calculation model

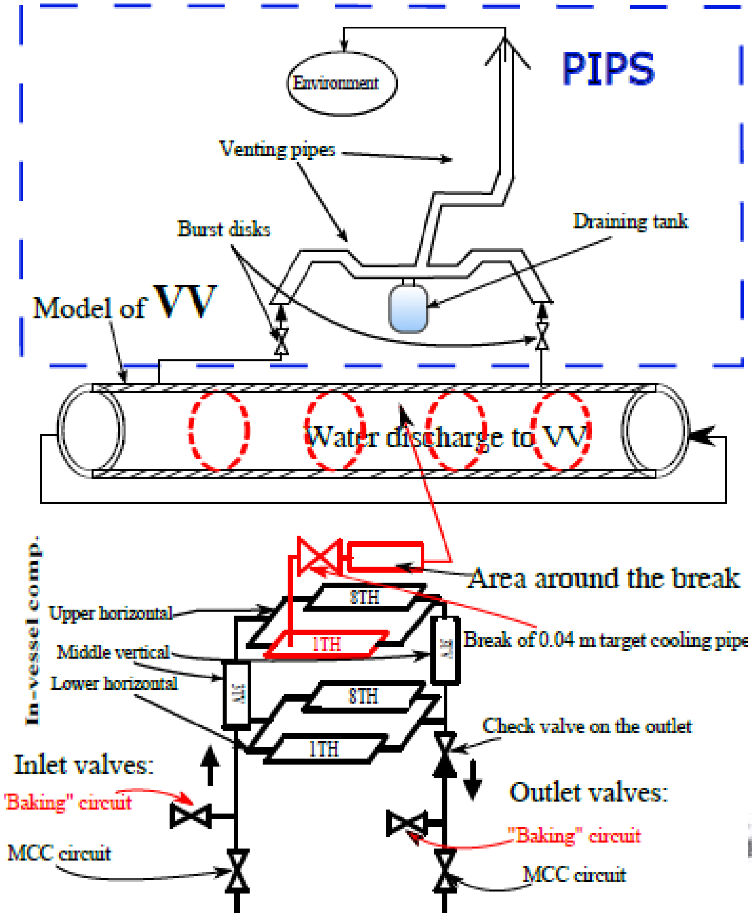
The divertor units cooling system

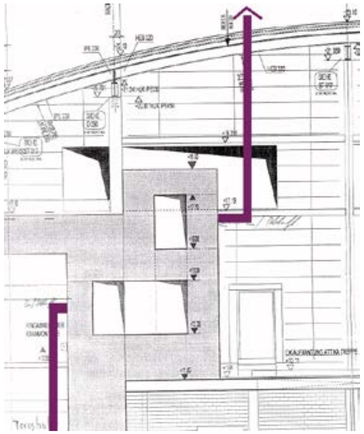


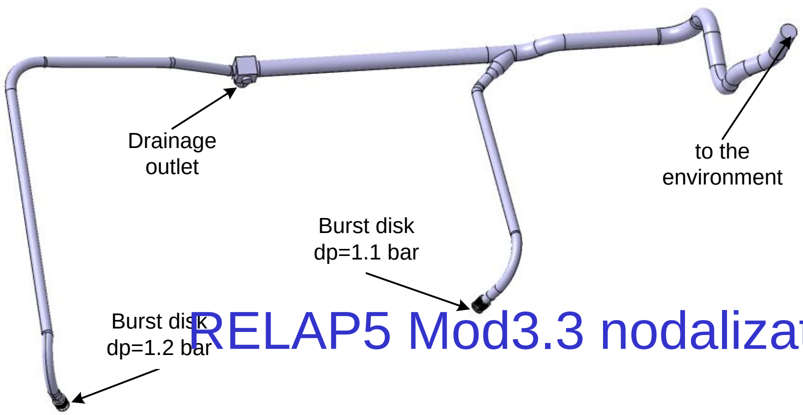


Modelling of processes in the Vacuum Vessel and Pressure increase Protection system

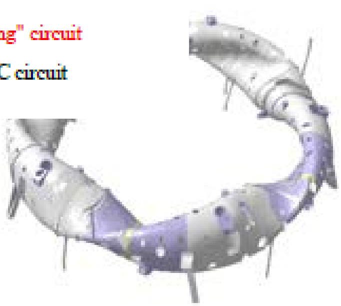
Development of calculation model

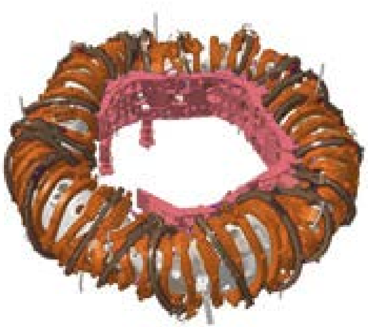




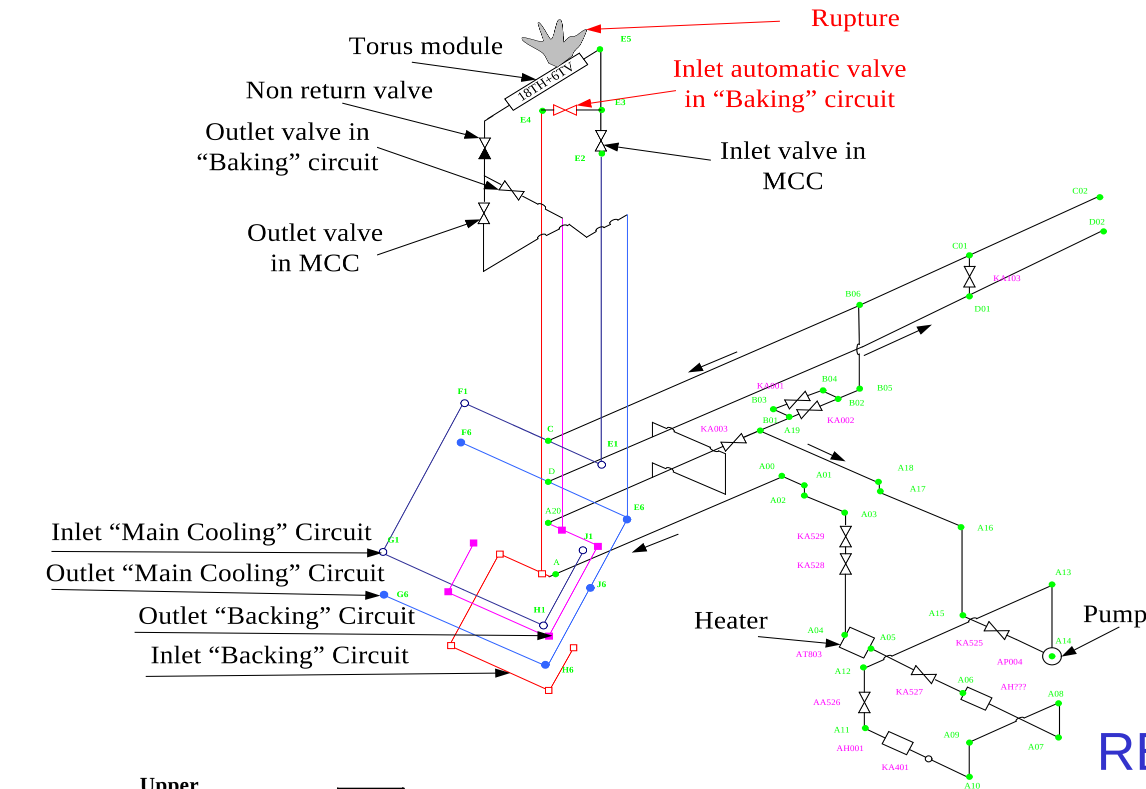


RELAP5 Mod3.3 nodalization





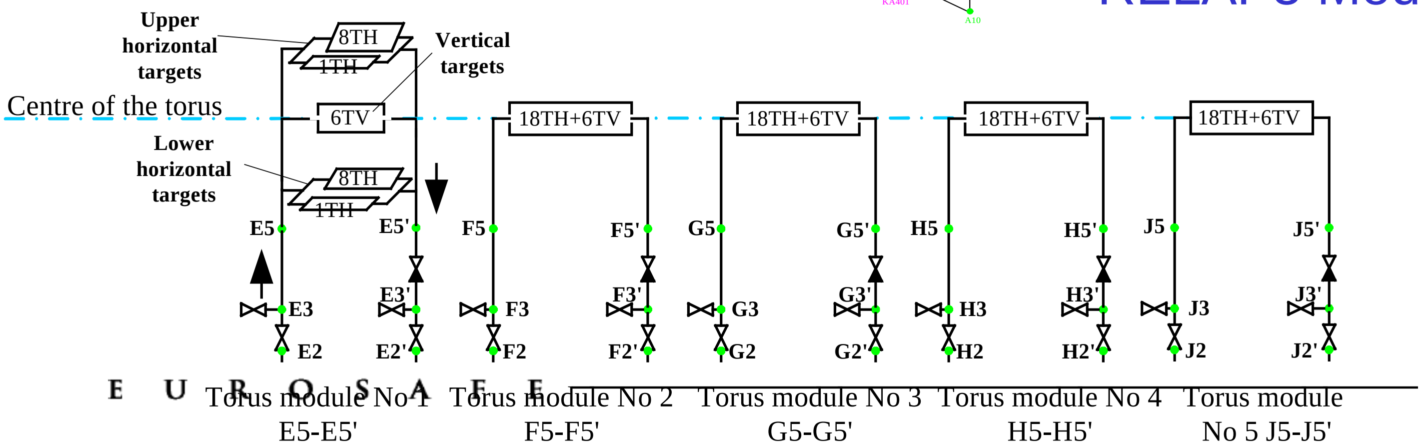
Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (1)



The initial conditions (in “baking” operation mode):

- Water temperature 160 °C
- Water flow rate 177 m^3/h
- Pressure in plasma vessel 1000 Pa
- Pressure in “Baking” circuit ~1.0 MPa

RELAP5 Mod3.3 nodalization



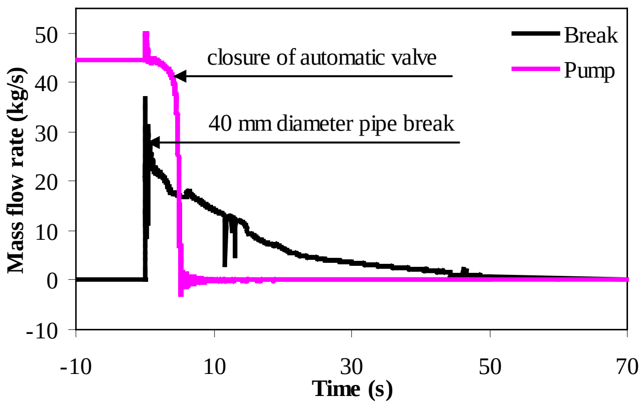
Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (2)

Consequence of events

0.0 – 0.01 s	Double ended guillotine rupture of 40 mm diameter feeder pipe, connecting single upper horizontal target module.
0.14 s	The pressure in plasma vessel reaches 2000 Pa.
0.14 + 0.5 = 0.64 s	Signals for actuation of automatic valves and trip of pumps are generated.
0.64 + 1.0 = 1.64 s	The automatic valves start to close. The pumps in "baking" circuit are stopped.
1.64 + 5.0 = 6.64 s	The automatic valve on target module inlets are fully closed
30 s	The pressure inside the plasma vessel reaches value of 110 kPa. The burst disk opens to discharge the steam to the torus hall.
~50 s	The discharge of steam-water mixture from the ruptured 40 mm diameter feeder pipe terminated.

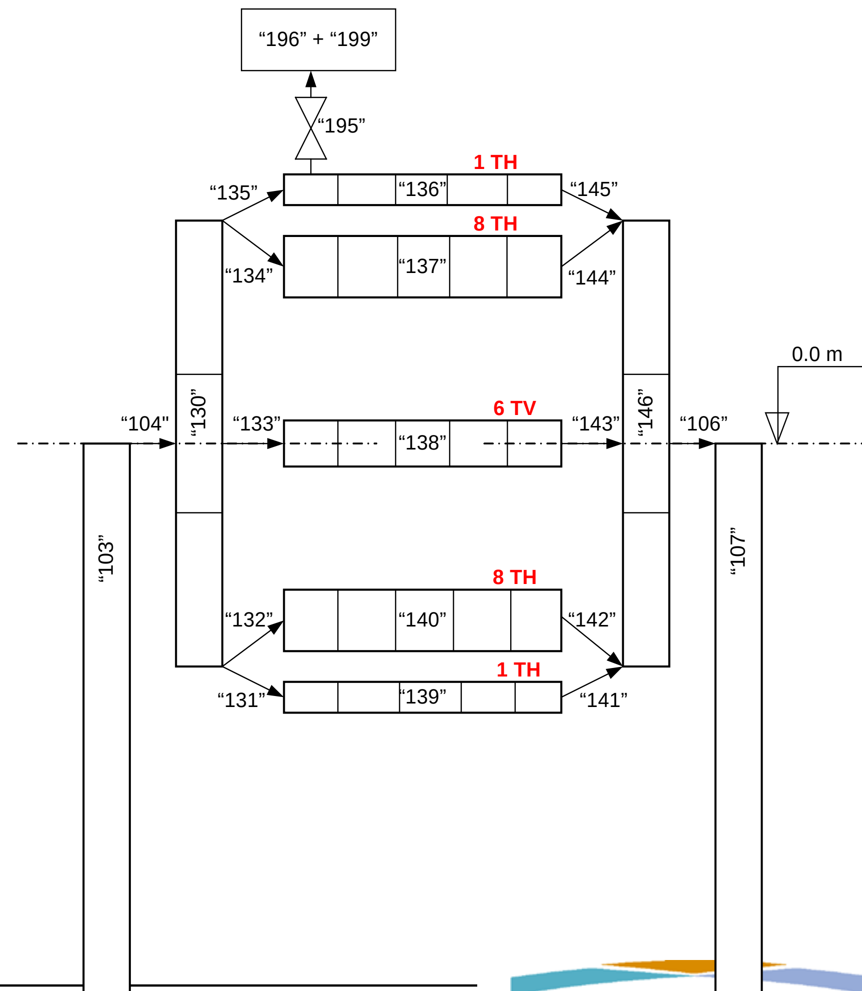
Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (3)

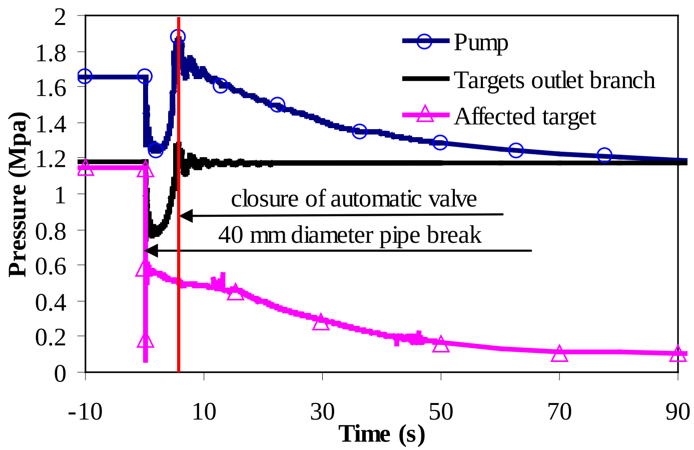
Response of cooling system – discharge of water



Water flow rate through the pump and discharge of coolant through the rupture

RELAP5 Mod3.3 calculations

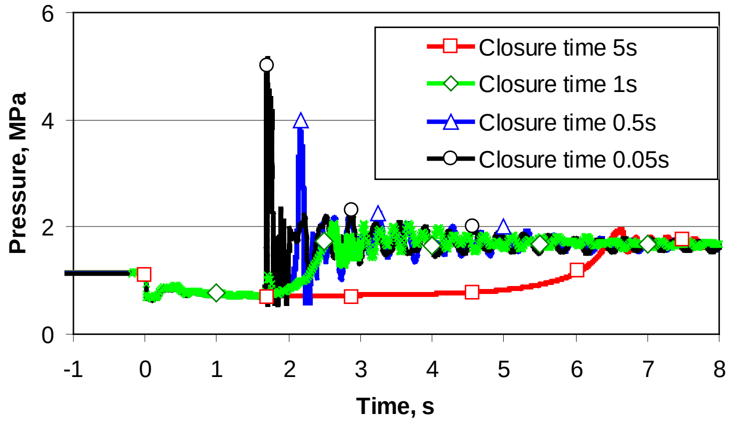




Pressure in “baking” circuit

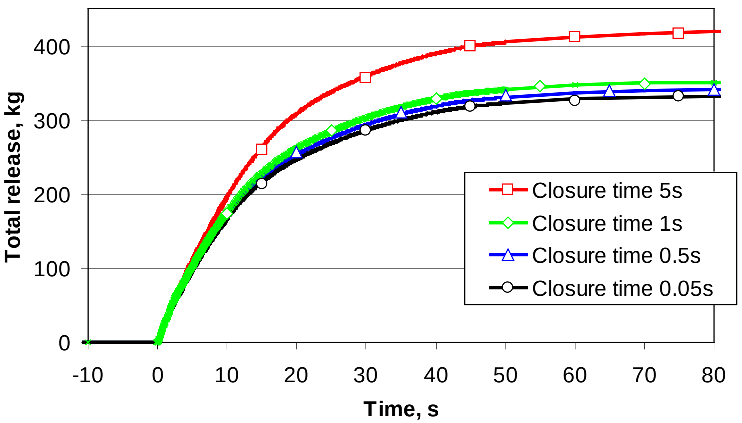
Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (4)

Response of cooling system – Analysis of the possible pressure surge in cooling system



Pressure peak in the segment upstream automatic valves

RELAP5 Mod3.3 calculations



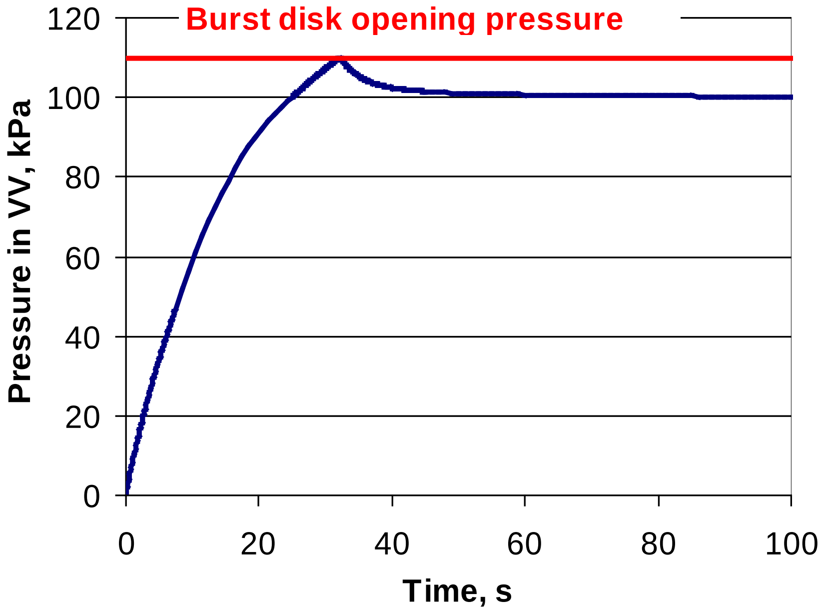
Total coolant release through the break

The recommended time for automatic valves closure should be between 1 – 5 s

Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (5)

Response of vacuum vessel – Analysis of the pressure increase

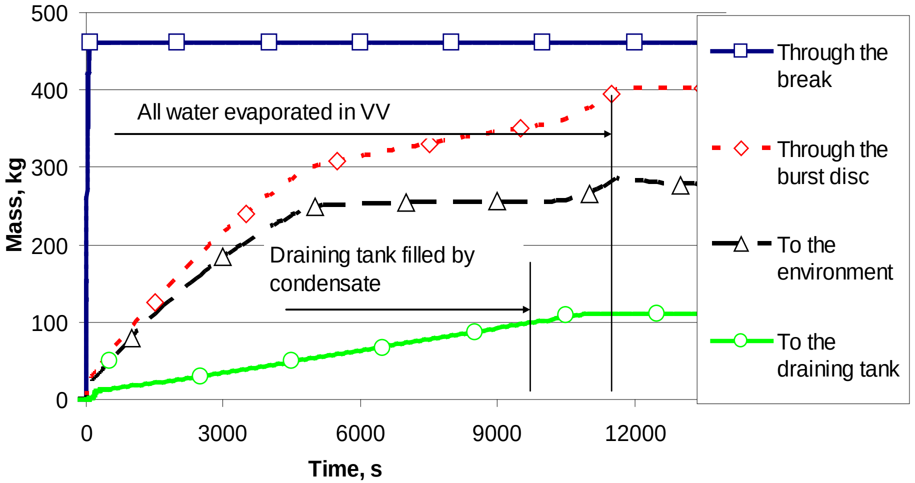
RELAP5 Mod3.3 calculations



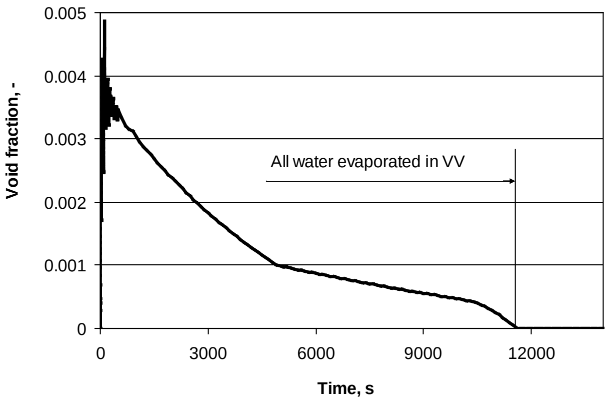
Pressure increase in vacuum vessel

Analysis of LOCA inside vacuum vessel – guillotine break of 40mm diameter water supply to single target module pipe (6)

Response of the PIPS – Analysis of the steam discharge and condensation in pipelines



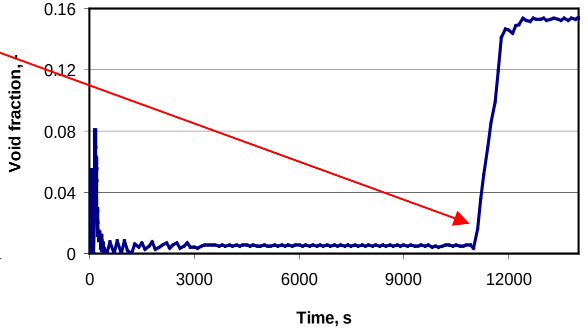
RELAP5 Mod3.3 calculations



Calculation results of water mass in vacuum vessel and pressure increase protection system

Fraction of liquid in vacuum vessel

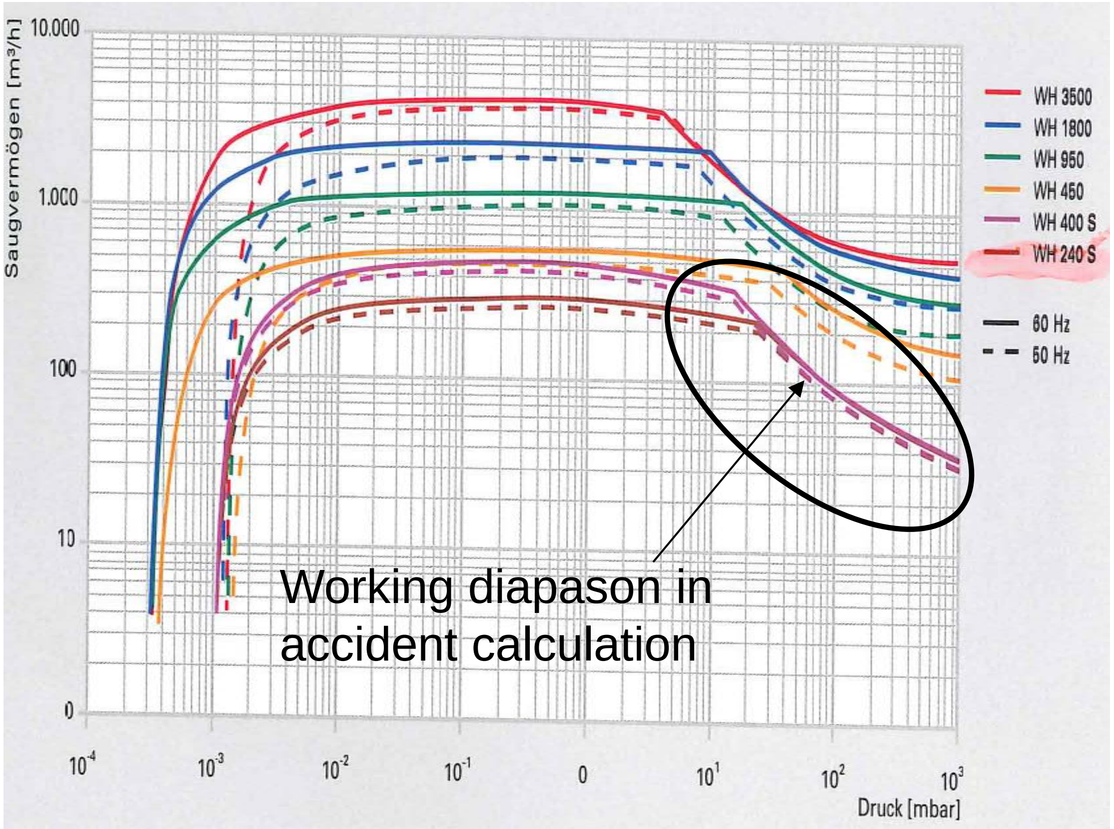
The draining tank is overfilled



Fraction of water in the horizontal part of the venting pipe connected to a draining tank

Analysis of small break LOCA inside vacuum vessel – break of 1 mm^2 cross section (1)

System of Vacuum Pumps WH240S



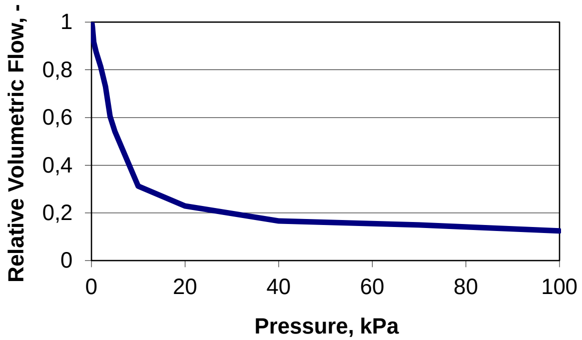
Analysis of small break LOCA inside vacuum vessel – break of 1 mm^2 cross section (1)

Consequence of events

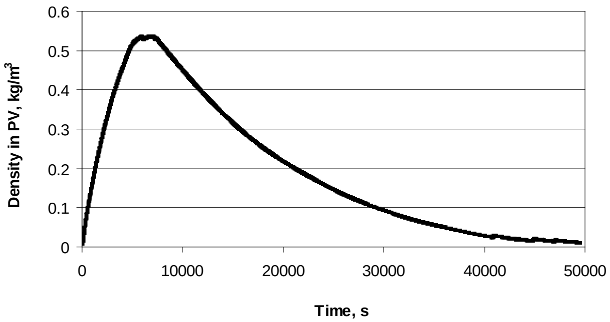
0 – 0.1 s	Small break with the 1 mm^2 cross section area in the target module feeder pipe
48 s	The pressure in VV reaches 2000 Pa
48.5 s	The signal for automatic actuation of valves on targets inlet is generated.
49.5 s	Start of automatic valve actuation Trip of pump in “baking” circuit Actuation of vacuum pump
54 s	The automatic valves are fully closed The nominal flow rate through the vacuum pump is reached
7200 s	The pressure in VV starts to decrease slowly

Analysis of small break LOCA inside vacuum vessel – break of 1 mm^2 cross section (2)

Response of the pressure in vacuum vessel – evaluation of capacity of the vacuum pump

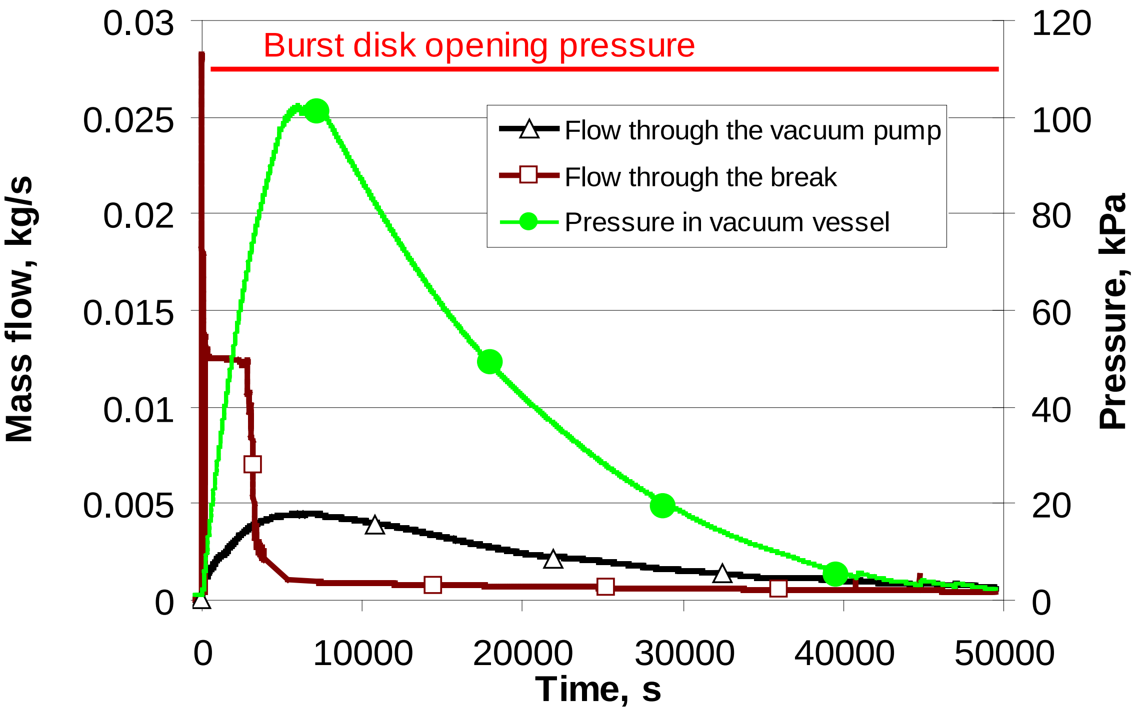


Relative volumetric flow dependency from pressure in vacuum vessel



Density of air-steam mixture in vacuum vessel

RELAP5 Mod3.3 calculations



Mass flow rate through the vacuum pump and break, pressure in vacuum vessel

Conclusions

- The integral thermal-hydraulic analyses of processes in divertors cooling system, vacuum vessel and the pressure increase protection system were performed using thermal-hydraulic state-of-the-art RELAP5 Mod3.3 code for the partial and guillotine 40 mm diameter in-vessel pipe break in W7-X.
- The calculations showed that the automatic valve closure time 1 s is the most acceptable: the pressure peak in pipelines reaches 2.1 MPa (only 2 times higher than initial pressure), total coolant release through the break is ~17% lower than in the case of 5 s closure time of automatic valves and only 5% higher comparing to fastest (0.05s) valves closure cases.
- The pressure increase protection system ensures that the pressure in vacuum vessel remains below the acceptable pressure limit in the case of 40 mm diameter water supply to single target module pipe
- For the case of partial break of in-vessel components – the calculation results shows, that the burst disc does not open, and the vacuum pump is capable to maintain required vacuum in the vacuum vessel if the partial rupture of in-vessel cooling system is not larger than 1 mm^2.
- The calculation results showed that in the case of guillotine 40 mm diameter pipe break, draining tank is filled with condensed water. At the time moment ~11,000 s after the break, condensed water starts to accumulate in the horizontal venting pipeline section, which is connected to the draining tank. At the end of calculation ~16% of the total volume of this pipe section is already occupied by water.

Thank you for your attention

Questions?