Analysis of the Consequences in the Loss-of-Coolant Accident in Wendelstein 7-X Experimental Nuclear Fusion Facility

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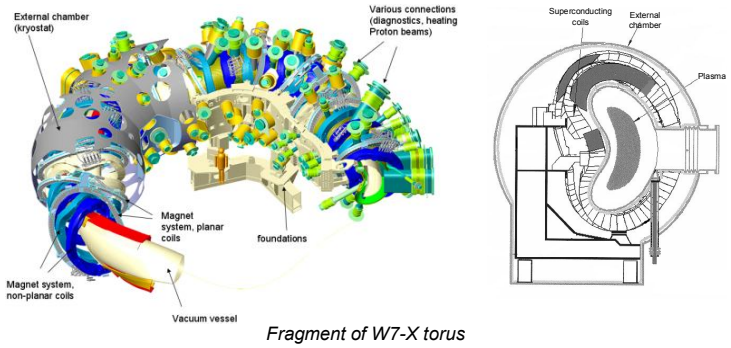
1. Introduction

At present, several experimental fusion reactors are under construction, among them ITER, which is built in France, KSTAR in South Korea, Wendelstein 7-X (W7-X) in Germany. Wendelstein 7-X (W7-X) is an experimental stellarator currently being built in Greifswald, Germany by the Max-Planck-Institut für Plasmaphysik (IPP). W7-X is an optimized stellarator, i.e. the magnetic field has been tailored to meet several physical optimization criteria. The superconducting magnet system enables continuous operation, limited by the cooling water system whose capacity to remove the plasma heat load onto the wall components is designed for 30 minutes full power operation.



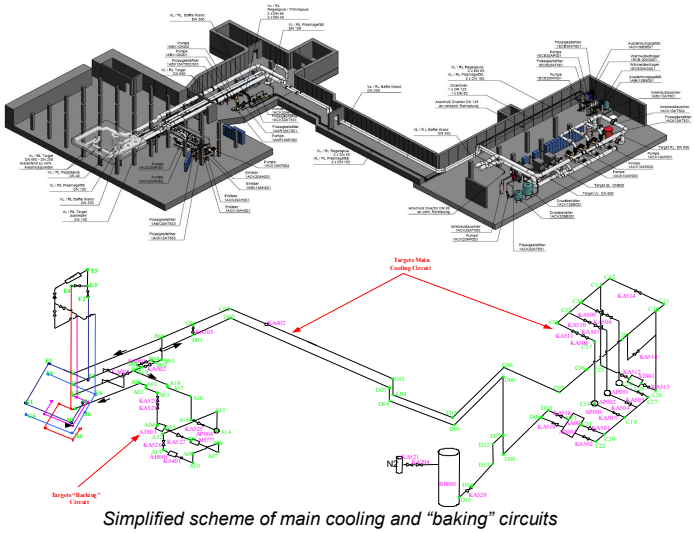
Fragment of W7-X torus

Lithuanian energy institute (LEI) in the frames of European Fusion Development Agreement program is cooperating with Max Planck Institute for Plasma Physics by performing safety analysis of W7-X Experimental Nuclear Fusion Facility. In this paper the consequences of the Loss-of-Coolant Accident (LOCA) in the cooling system of W7-X facility are analysed. The ingress of water during the W7-X no-plasma "baking" operation mode into the plasma vessel represents one of the critical failure events, since primary and secondary steam production leads to a rapid increase of the inner pressure in the vacuum (plasma) vessel. A rupture of the 40 mm target module cooling pipe could lead to the loss of vacuum condition up to an overpressure in the plasma vessel, damage of in-vessel components (for example: the bellows of the ports). The pressure behaviour in the plasma vessel depends on the amount of discharged water through the leak. Thus, the processes both in the target modules cooling system and plasma vessel should be modelled. The analysis was performed using thermal-hydraulic RELAP5 Mod3.3 code.

2. Modelling of W7-X target modules cooling system

The W7-X facility target modules cooling system consists of two coolant circuits:

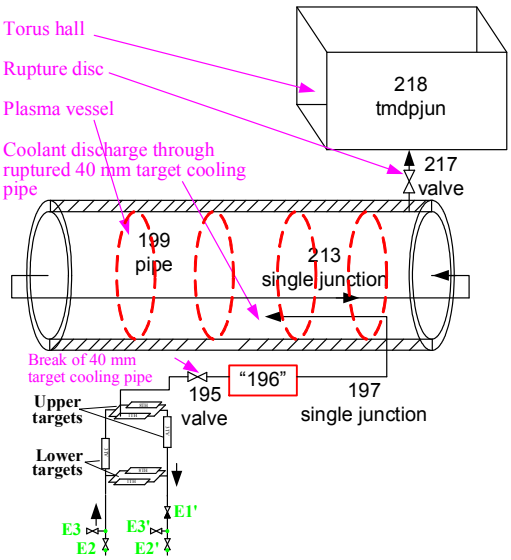
- The Main Cooling Circuit is used for cooling of the target modules when the W7-X facility under normal operation.
- The "Baking" circuit is used for the heated up in-vessel components in order to 'clean' the surfaces by thermal desorption and the subsequent pumping out of the released volatile molecules.



Simplified scheme of main cooling and "baking" circuits

The amount of water in all pipelines, connecting the target modules with both MCC and the "baking" circuits is 1.66 m^3. The amount of water in the MCC – 63.1 m^3, while the amount of water in "baking" circuit is very small – 1.06 m^3. The volume of plasma vessel is 108 m^3.

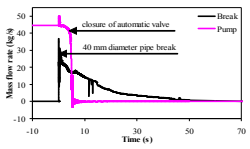
- Under the W7-X operation in "baking" mode the maximum water temperature is 160°C, the water pressure is about 1.0 MPa.
- The corresponding mass flow of water in the "baking" circuit is 177 m^3/h (44.6 kg/s), the flow velocity through the cooling tubes of the target modules during "baking" operation mode is about 1 m/s.
- The designed working pressure in the plasma vessel is about 10^{-2} Pa (deep vacuum), but (due to limitation of RELAP5 code) it was assumed that the pressure in plasma vessel is equal to 1000 Pa – the lowest possible pressure used in RELAP5 computer code.



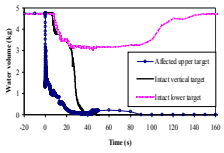
Nodalization scheme of stellarator with rupture in 40 mm diameter feeder pipe

3. Analysis of double-ended guillotine rupture of 40 mm pipe in upper target module

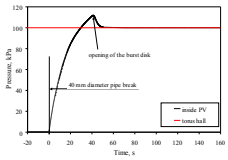
- t = 0 s – double ended guillotine rupture of 40 mm pipe in upper target module.
- t = 0.14 s – pressure in plasma vessel reaches 2000 Pa. Signal for automatic actuation of valves on the inlets to each torus segments is generated. Delay between parameter reaches the set-point and signal generation – 0.5 s. Delay between signal generation and start of valve actuation – 1 s. Time to full closure of automatic valve on target module inlets – 5 s. t = 6.64 s – the torus segment inlet automatic valves are fully closed.
- t = 1.14 s – trip of pump in "baking" circuit (due to signal of pressure increase in plasma vessel).
- t = 42 s – pressure in plasma vessel exceeds 1100 kPa (the absolute pressure). The burst disk is opened and steam from the plasma vessel is discharged to the torus hall.



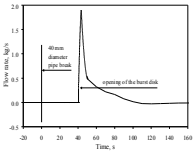
Water flow rate through the pump and discharge of coolant through the rupture



Water volume in the single targets of affected torus segment



Pressure behaviour in the plasma vessel



Mass flow rate through the burst disk

4. Conclusions

- The analysis of accident with water ingress into the plasma vessel in Wendelstein nuclear fusion device W7-X was performed. The rupture of the 40 mm target module cooling pipe was selected as one of the critical failure events with loss of coolant, since primary and secondary steam production leads to a rapid increase of the inner pressure in the vacuum (plasma) vessel.
- The model of W7-X divertors, main cooling and "baking" circuits and the plasma vessel were developed using thermal-hydraulic state-of-the-art RELAP5 Mod3.3 code.
- The performed analysis of rupture of 40 mm diameter pipe in the single upper horizontal target module demonstrate that the area of burst disk is sufficient to prevent pressure inside the plasma vessel exceeding 110 kPa in the case of simulated accident.
- The prepared models will be used for further analyses of other accidents to prove safety of W7-X fusion facility.

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