PhD Candidate: D. Carloni (Pisa University, KIT)

Thesis Title: Thermal Hydraulics and Safety Analyses for Fusion Reactors Primary Heat Transfer Systems

Abstract

The objective of this PhD thesis work is the computational thermal hydraulic analysis of ITER and DEMO fusion reactors PHTSs; the performances of the cooling loops have been evaluated during normal operation pulsed condition (ITER) and accidental scenario (DEMO).

The fusion reaction, which is at the basis of current tokamak machines, is briefly reported together with a description of the current design status for ITER and DEMO fusion reactors. Also some existing experimental facilities, aimed to test some of the fusion reactors cooling system features, are briefly presented.

Then the ITER in-vessel components PHTS (IBED PHTS) is analyzed through the RELAP5 code during plasma pulse scenario. During the pulsed plasma operation, the pressure and temperature variation within the IBED PHTS shall be controlled and maintained within an acceptable range of values to avoid both potential dangerous pressure fluctuation within the circuit and thermal fatigue to the loop piping and equipment. A set of countermeasure to control the IBED PHTS pressure and temperature and mitigate their fluctuation during the plasma operation is simulated through RELAP5 and obtained results are shown and discussed.
Finally, a temperature and pressure control strategy is proposed, also addressing possible criticalities to be carefully evaluated during the design activities.

The reference PHTS layout for DEMO HCPB concept is analyzed, together with its auxiliaries systems, through a novel analytical method, the Functional Failure Mode and Effect Analysis at component level with evaluation of loss of function. The objective of the FMEA is to analyze the system and its functions and identify possible failure mode associated to the loss of function and hence define representative accidental scenarios to be further investigated. As result of this analysis a set of Postulated Initiating Events is identified and the possible accidental chain sequences discussed in detail, also specifying the severity of the events (e.g. Large and Small Break LOCA).

Hence the DEMO PHTS ex-vessel LOCA, one of the identified Postulated Initiating Event in the FMEA, is analyzed by means of MELCOR code. The purpose of the analyses is to evaluate the influence of size and location of the break in terms of pressurization of the pressure confinement system of DEMO.
In this section, together with the reference PHTS layout, an alternative loop configuration, whose design has been entirely developed within the thesis activities, is proposed and modeled. Here the dynamic behavior of the pressure and flow rate of the two PHTS layouts is compared, highlighting in which cases (i.e. for which break size and layout) mitigating actions, such as prompt loop isolation through safety valve activation or atmosphere detritiation, can be performed effectively.

In the conclusions a rationale for the future fusion reactors PHTS is formulated on the basis of the consideration rising from the results collected in this work. Here The PHTS control strategy to be adopted to cope with the pulsed regime is discussed; some remarks on potential critical aspect associated to the pulsed operation are highlighted.
Emphasis is given also to the preventive PHTS design features which might enhance the overall safety of the reactor.