EUROFUSION WPSAE-CP(16) 15611

D N Dongiovanni et al.

Parametric explorative study of DEMO galleries pressurization in case of ex-vessel LOCA

Preprint of Paper to be submitted for publication in Proceedings of 29th Symposium on Fusion Technology (SOFT 2016)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Parametric explorative study of DEMO galleries pressurization in case of ex-vessel LOCA

Danilo Nicola Dongiovanni[a], Sergio Ciattaglia[b], Maria Teresa Porfiri[a]

[a] *ENEA, FSN Department, via E. Fermi 45, 00044 Frascati (Roma), Italy*
[b] *EUROFUSION Programme Management Unit, Boltzmannstrasse, Garching, Germany*

Radioactive toxins confinement is a main safety function for fusion power plants, hence the importance of confinement design parameters optimization. Moving from this perspective, present work focuses on two Loss of Coolant Accidents (LOCAs), Vacuum Vessel (VV) Primary Heat Transfer System (PHTS) water cooling loop and to Toroidal Field (TF) helium cooled coils. The importance of such accident investigation resides in the fact that these two LOCAs may impact galleries design parameters, as they constitute a second confinement boundary for radioactive toxins. In particular, based on publicly available ITER data (2000 baseline design), a first approximation scaling to DEMO is obtained and a set of sensitivity simulation analyses are performed on main variables (coolant inventories, enthalpy, rooms volume, etc.) in order to derive resulting galleries pressure and temperature conditions.

As first feedback to the design of the systems considered to keep gallery pressure below an assumed design pressure of 1.2 bar, the VV PHTS LOCA requires pressure reduction (e.g. increase expansion volume, inventory partitioning, sprinkler), while TF He LOCA requires releasable inventory to be limited at about 4.4 tons and Cryo-systems designed against Common Mode Failure (e.g. seismic and fire, quench valve failure).

Keywords: DEMO SAFETY EX-VESSEL LOCA GALLERIES

---

author's email: danilo.dongiovanni@enea.it

1. Introduction

Radioactive toxins confinement is a main safety function for fusion power plants, hence the importance of confinement design parameters optimization. In this context, performing parametric assessments of variables thought to be relevant for confinement design can help at better framing the option design space.

The goal of the present work is to investigate the pressurization of DEMO galleries deriving from the possible occurrence of LOCA into gallery, i.e. the rupture of one VV cooling loop (water cooled) or the failure of the TF magnets cooling (helium cooled). These two accidents are chosen since considered relevant for thermal energy inventory loss into gallery rooms. The importance of such accidents investigation resides in the fact that galleries around the tokamak implement a second confinement boundary for radioactive toxins. Moreover these volumes surrounding the tokamak commonly have a lower design pressure limit (1.2 bar assumed in this work) with respect to expansion volumes such as ITER Tokamak Water Cooling System (TWCS) vault (2 bars pressure design limit) devoted to cooling systems with higher tritium content (e.g. breeding blanket cooling system). The purpose of the work is to investigate under which design parameters configuration (amount of inventories for VV Heat Transfer System (HTS) water and TF coils helium, available building volume), the pressurization of galleries may exceed the design pressure limit with consequent violation of plant operating boundary assumptions. Note that such a violation would in turn compromise the plant licensing, unless further mitigating actions are undertaken, so that providing an early feedback on the issue for DEMO would be important. Finally the combination of the studied LOCAs presents potentially interesting mixture of condensable (water vapors) and incondensable gases (cryogenic He).

2. Materials and methods

To investigate gallery pressurization and provide early feedback on safety feasible design space at early stage of plant design as for DEMO, one must deal with the lack of a detailed layout and design information necessary for simulation model setup. To overcome this issue, at first a model exploiting ITER layout derived from publicly available safety analysis data [1][2] has been set up. Then the model has been scaled to DEMO parameters exploiting currently available data: coolant inventories, operating pressure, operating temperature. In case of no available data, a working value has been assumed and sensitivity analyses have been carried out to gain insight on the design space.

A fast running code, CONSEN5 [3] was judged suitable for the analysis given its flexibility to deal with low detailed layout design and its ability to model cryogenics [4]. The specific objective of the analysis is the verification of peak pressure resulting from the expansion of the coolant in the gallery volume, so that radioactive toxins content and mobilization is not considered. The acceptability criterion for the accident consequences is to maintain the maximum pressure below 1.2 bars, assumed as design target for the gallery.

2.1 LOCAs description

The first accident considered (labeled as H2O-LOCA in the following) is the loss of coolant from VV cooling loop into galleries. The volumes considered are: i) VV cooling loop, ii) Gallery volume including cryostat space room (CSR); iii) Environment volume to account for uncontrolled gaseous leakage in the accident sequence and exchanging heat with gallery volume through walls. As initiating event a double break of water cooling pipe, occurring during normal operation, is considered. The co-occurrence of a loss of site power is assumed, implying that HVAC system is not working. The transient sequence foresees the water coolant discharged into galleries volume, leading to its pressurization. Heat is exchanged through gallery walls between gallery volume and surrounding environment. The cooling layout has been assumed similar to the ITER one, while a working hypothesis value has been assumed for the inventory.

The second accident considered (labeled as He-LOCA in the following) is the loss of coolant from TF coil helium cooling loop into galleries. The volumes considered are: i) CSR volume ii) Gallery volume; iii) Environment volume accounting for gaseous uncontrolled leakage losses and heat exchange through walls structures. The initiating event is the double break of cooling loop with the loss of half of available inventory. Again the co-occurrence of a loss of site power is assumed. In the transient sequence: helium coolant is discharged into CSR volume, leading to its pressurization. Helium blow down is modeled as a constant gas flow rate for 60s before the safety valves operation prevent further spillage. Half of total TF coils helium inventory is assumed to spill in such time interval. Helium inventory was estimated [4] from approximate volume of 60 m^3, at 4.5 K - 9 bar: 146.3 kg/m^3. Since the connection of 2 square meters between CSR and Galleries (junction J.2-3, Fig. 1), both volumes are pressurized. Heat is exchanged through gallery walls between gallery volume and surrounding environment. The cooling layout and inventory have been estimated on the base of TF coils design proposal in [4]. Table 1 summarizes the inventory details for both accidents, based on engineering judgment estimates for current design [5][6][7].

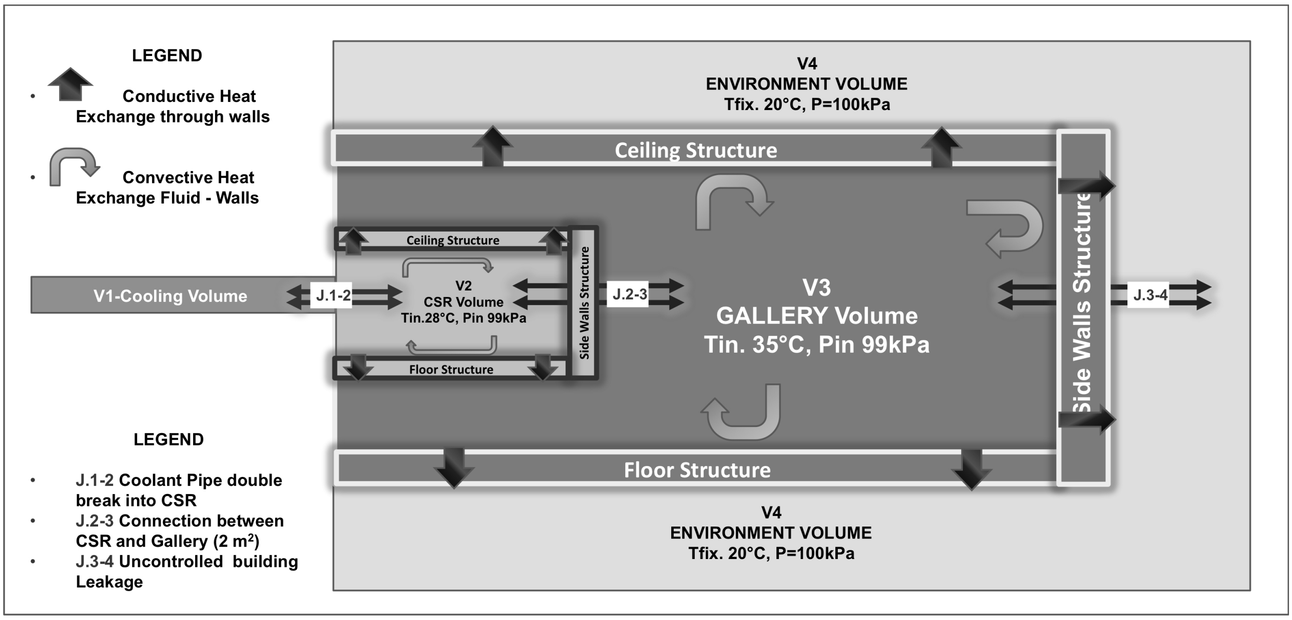

Fig. 1. CONSEN5: model layout representation for VV LOCA.

Table 1. Considered coolant inventories.

Accident	ITER2000	DEMO
VV cooling loop (H2O)	2 loops, ≈150tons each, T=125°C, P= 1.5MPa	2 loops, ≈260 tons each, T=200°C, P= 3.15MPa
TF coil cooling loop (He)	2.6 tons releasable in single failure T=4.5°K, ≈6 bar	4.4 tons releasable in single failure T=4.5°K, ≈6 bar

2.2 Layout considered

The considered layout has been derived from ITER public documents. In particular, the data used in the accident analysis have been collected from ITER SADL-3 2000 [1]. The Cryostat Water and Helium ingress analysis reported in Tab VII-3.8.2-2 in the ITER GSSR 2001 [2] report has also been partially exploited as source of information.

The COSEN model implemented assumes the coolant release to occur in the CSR (volume 5095 m^3, transversal area 439 m^2), which is in turn connected by means of a 2 m^2 aperture to Gallery (volume 60000 m^3, transversal area 3444 m^2), allowing for masses exchange. The CONSEN model for H2O-LOCA is graphically represented in Fig.1. An environment volume has also been considered allowing Gallery volume to exchange heat through structures. Moreover a building leak rate proportional to square root of differential pressure is assumed according to [1] (junction J.3-4, Fig. 1). For gallery temperature, the maximal allowed temperature, i.e. 35°C, has been conservatively considered. Galleries are kept de-pressurized (-100 Pa) with respect to atmosphere pressure to favour in-leakage against out-leakage. Fluid mass has been calculated considering a density of 939,72 Kg/m^3 for water at given pressure and temperature and a density of 1,14 Kg/m^3 for air at given pressure and temperature. Environment was modeled as an arbitrarily big volume with high mass of air at 20°C. Moving from ITER2000 layout a proportional scaling based on TF coils height has been performed to approximate DEMO volumes dimensioning. In particular TF coils height is about 2/3 galleries height and DEMO TF coils have a dimension (height x width) of about 16,3 x 10 m [6][7].

3. Results

A total reference volume of ≈ 2 x ITER2000 for CSR and galleries was assumed in simulations. As shown in Fig.2 VV loop rupture results in highest pressurization peak between the two considered LOCAs (1.52kPa H2O-LOCA vs 1.18 kPa for He-LOCA). Note that DEMO is operated at ITER baking-equivalent condition (200 °C) resulting in higher enthalpy for VV coolant.

Fig.3 shows the pressurization results in the Beyond Design Basis Accident (BDBA) case considering the simultaneous loss of both VV coolant and TF coils coolant. The resulting pressurization in the simulation was 175.0 kPa. Also a simulation considering the complete loss of TF coils inventory was performed, resulting in a pressurization of 124.3 kPa.

Given the arbitrariness of some assumptions, sensitivity analyses were performed to gain insight in the design space. In particular, in Fig.4 the pressurization results sensitivity to gallery volume was investigated, observing a pressure peak of 1.93 kPa reached in case of H2O-LOCA for ITER2000 gallery rooms volume, while in Fig.5 the sensitivity of pressurization to coolant inventory was investigated by increasing the number of cooling loops for VV and supposing only one loop broken. Finally the use of sprinkler (spray water 30 °C) was simulated to mitigate the consequences of H2O-LOCA as shown in Fig. 6.

4. Conclusion

Despite being based on ITER2000 design scaling and not related either to the final ITER layout (not publicly available), nor to that being developed for EU DEMO (design still undefined on proposed layout), the presented work is meant to exemplify a safety integrated design approach supporting upcoming design decision with early feedback on selected safety observables. Both LOCAs are possibly no-recovery accident with fast evolution, reaching the pressure peak in about 300s, therefore precluding the possibility to credibly rely on prompt human intervention. To keep gallery pressurization under 1.2 bar design limit a volume of about 2 x ITER2000 (Gallery + CSR) is hypothesized. Notwithstanding the assumed gallery volume H20-LOCA needs pressure reduction (e.g. increase expansion volume, inventory partitioning, sprinkler). The volume is indeed sufficient for the considered cryogenic helium releasable inventory (required to be limited at about 4.4 tons). At any rate the cryo-systems shall be designed against Common Mode Failure (e.g. seismic and fire, quench valve failure).

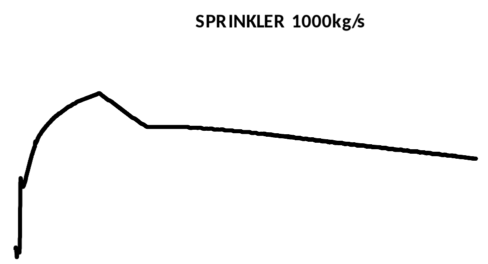

Fig. 6. Simulation of sprinkler mitigating action in case of H2O-LOCA.

Acknowledgments

Authors acknowledge Dr. Luigi Muzzi and Dr. Christian Bachman for information provided on DEMO design. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] ITER SADL-3, H.-W. Bartels et al., Safety Analysis Data List-3, Version 2.0, 4. July 2000

[2] ITER Generic Site Safety Report (Gssr), Volume Vii, Analysis Of Reference Events, G 84 Ri 6 01-07-10 R 1.0, 2001

[3] Caruso G., Bartels H.W., Iseli M., Meyder R., Nordlinder S., Pasler V., Porfiri M.T., Simulation of cryogenic He spills as basis for planning of experimental campaign in the EVITA facility, (2006) Nuclear Fusion, 46 (1), pp. 51-56.

[4] Caruso G., Vitale Di Maio D., Porfiri M. T., Numerical study on Ingress of Coolant Event experiments with CONSEN code, Fusion Engineering and Design 100 (2015) 443–452

[5] L. Muzzi, Design of TF Winding Pack Option2 (WP#2) and of "ENEA" LTS Cable, EFDA_D_2L2W6Z, 2015

[6] B. Meszaros, DEMO geometry derivation from PROCESS code based on current knowledge, 2014 EFDA_IDM_2LFUG2

[7] C. Bachmann, DEMO Pant Description Document, EFDA_D_2KVWQZ

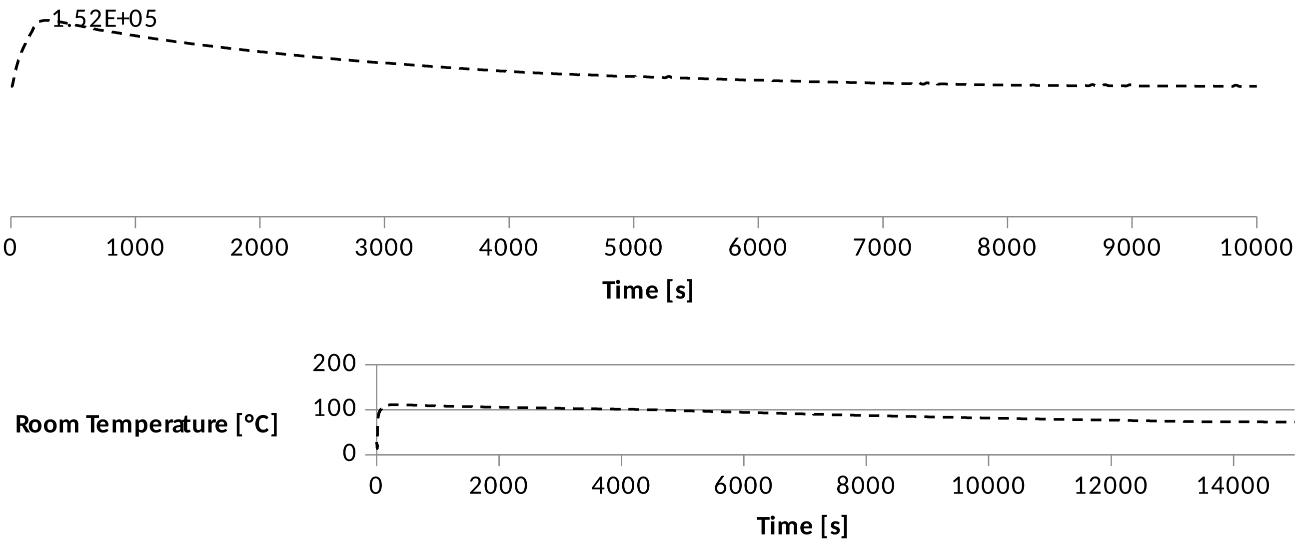

Fig. 2. Pressure and temperature in the gallery rooms for H2O-LOCA (dashed line) and He-LOCA respectively.

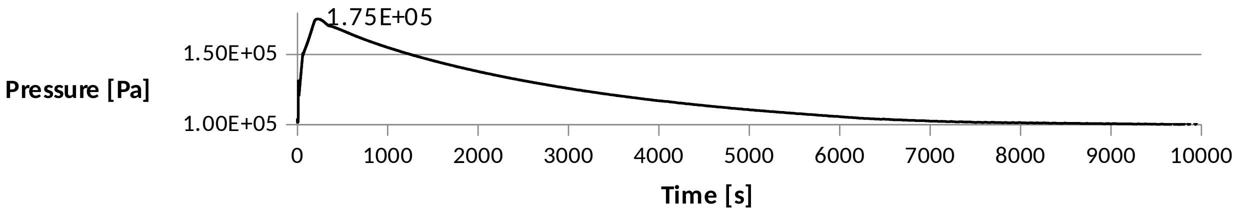

Fig. 3. Pressurization simultaneous occurrence of H2O-LOCA and He-LOCA

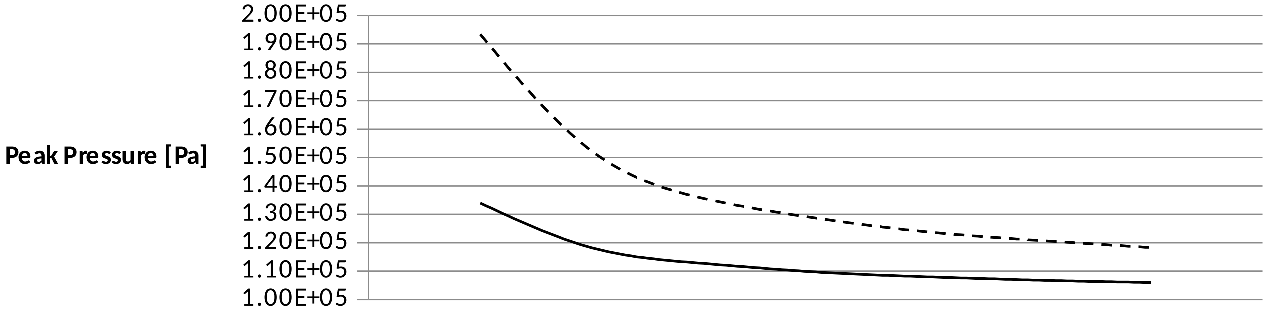

Fig. 4. Pressure peak sensitivity to available expansion volume for H2O-LOCA (dark blue) and He-LOCA (light blue) respectively.

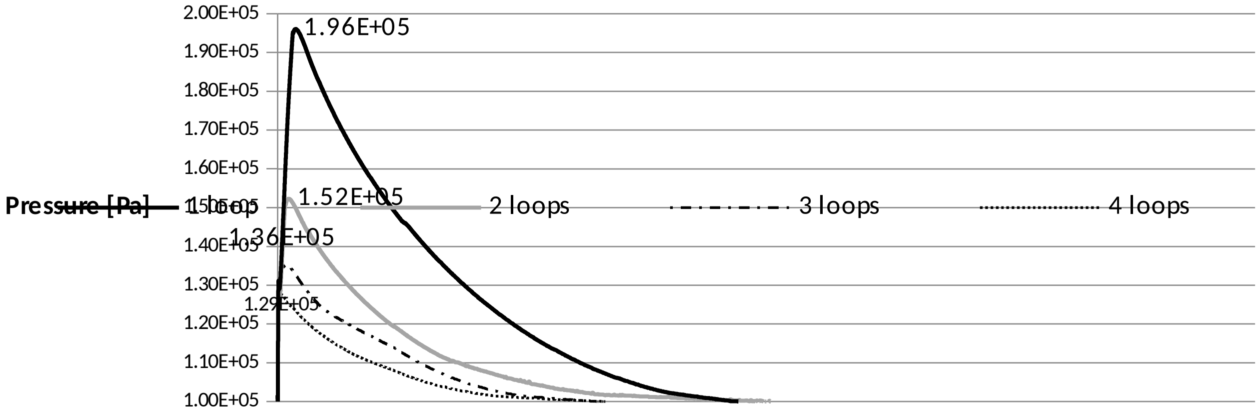

Fig. 5. Pressurization sensitivity to inventory partitioning for H2O-LOCA.