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Studio preliminare dell'ottimizzazione della configurazione del Target Assembly di IFMIF

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STUDIO PRELIMINARE DELL'OTTIMIZZAZIONE DELLA CONFIGURAZIONE DEL TARGET ASSEMBLY

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Progetto: B.3.2 – Attività di Fisica della Fusione Complementari a ITER
Obiettivo: Progettazione e qualifica ingegneristica del target IFMIF – subtask b2. Forniture ed implementazioni comuni per sviluppo e qualifica di sistema di manipolazione remotizzata e della progettazione completa del target asssembly di IFMIF
Responsabile del Progetto: A. Pizzuto, ENEA

Index

Abstract

Within the framework of IFMIF design activities, a research campaign has been launched in 2017 at the Department of Energy, Information Engineering and Mathematical Models (DEIM) of the University of Palermo, in close cooperation with ENEA-Brasimone, to theoretically investigate the thermo-mechanical behaviour of an alternative configuration of the IFMIF Target Assembly (TA) under nominal steady state conditions. This research campaign is aimed to promote and support the theoretical investigation of the Target Assembly, properly integrated with its support framework and the Lithium inlet pipe, thermo-mechanical performances under nominal steady state loading scenario envisaged for it. In particular, this alternative configuration mainly foresees a TA endowed with an integrated Back-Plate (BP) instead of the "bayonet-concept" adopted till now. Particular attention has been paid to the potential onset of significant deformations, which may deeply change Lithium channel lay-out inducing flow instability, cause interferences with the Test Module or generate a misalignment between deuteron beams and Lithium footprint. Moreover a stress linearization procedure has been performed in order to assess the fulfilment of the SDC-IC structural safety rules within the most critical regions of the domain investigated.

A theoretical-computational approach based on the Finite Element Method (FEM) has been followed and a quoted commercial FEM code, qualified for the numerical simulation of thermo-mechanical behaviour of solids and already widely adopted within the international scientific community involved in fusion technology, has been adopted to perform the study.

Results have shown that, from the thermal point of view, no particular concerns seem to arise for the components investigated.

Furthermore, mechanical results have shown that SDC-IC design rules for level A criteria have resulted to be generally fulfilled with comfortable margins except for that one relevant to the immediate plastic flow localization in a particular heavily stressed region located approximately on the back-plate middle section, suggesting the potential need of a back-plate design revision.

1 Introduction

The International Fusion Materials Irradiation Facility (IFMIF) is a joint effort of the international scientific community within the framework of the Fusion Materials Implementing Agreement of the International Energy Agency. It is mainly devoted to test and qualify candidate materials to be used in fusion reactors, allowing, in particular, the development of a material irradiation database for the design, construction, licensing and safe operation of the DEMOnstration fusion reactor [1].

IFMIF mainly consists of two 40 MeV continuous linear accelerators which deliver two 125 mA current beams of deuterons on a flowing liquid Lithium target, where D-Li stripping reactions take place, providing an intense neutron flux of ~10^{18} $m^{-2}s^{-1}$ characterized by an energy spectrum peaked at 14 MeV, which enables materials testing up to a damage rate of 50 dpa/y [1]. With the aim of having a stable liquid Lithium flow, a target system, consisting in a Target Assembly (TA) properly integrated with a Lithium loop, has been designed. It is mainly devoted to house the beam footprint, to remove the 10 MW heat power released by deuteron beams and to produce a stable Lithium jet 25 mm thick with a wave amplitude less than 1 mm at a speed of 10–20 m/s [2]. A detailed description of the Lithium loop lay-out may be found in [1,2].

Within the framework of IFMIF design activities, several research campaigns have been performed in these years at the Department of Energy, Information Engineering and Mathematical Models (DEIM) of the University of Palermo, in close cooperation with ENEA-Brasimone, to theoretically investigate the thermo-mechanical behaviour of the IFMIF TA under both steady state and transient conditions [3-5]. As a further development of the study reported in [3-5], a research campaign has been launched in 2017, aimed at promoting and supporting the theoretical investigation of the thermo-mechanical performances of an alternative TA configuration, properly integrated with its support framework and the Lithium inlet pipe, undergoing the nominal steady state loading scenario envisaged for it.

In particular, the thermo-mechanical behaviour of an alternative configuration of the IFMIF TA, endowed with an integrated BP, instead of the replaceable “bayonet-concept” BP adopted till now, has been investigated, taking also into account the thermo-mechanical action of the TA support framework and Lithium inlet pipe. Particular attention has been paid to the potential onset of significant deformations, which may deeply change Lithium channel lay-out inducing flow instability, cause interferences with the Test Module or generate a misalignment between deuteron beams and Lithium footprint. Moreover a stress linearization procedure has been performed in order to assess the fulfilment of the SDC-IC structural safety rules within the most critical regions of the domain investigated.

A theoretical-computational approach based on the Finite Element Method (FEM) has been followed and a quoted commercial FEM code, qualified for the numerical simulation of thermo-mechanical behaviour of solids and already widely adopted within the international scientific community involved in fusion technology, has been adopted to perform the study.

Results obtained are herewith presented and critically discussed.

2 IFMIF TARGET SYSTEM

IFMIF Lithium Target system is mainly intended to remove the 10 MW heat power deposited by the deuterium beams, to allow a stable Lithium jet 25 mm thick, with a wave amplitude less than 1 mm at a speed of 10 - 20 m/s, to control impurity levels, to guarantee a sufficient safety with respect to Lithium hazard and Tritium release from the Lithium loop and, and last but not the least, to achieve the required system availability during plant lifetime [2]. The concept of the IFMIF Target system is reported in figure 1.

It mainly consists of the Target Assembly (TA), the Support structure and the Lithium loop. The TA is devoted to provide a fast, reliable and stable flow of Lithium, mainly characterized by a jet thickness of 25 ± 1 mm, a flow velocity of 10-20 m/s and a Lithium temperature ranging from 250 to 300 °C, with a reference inlet value of 250 °C [2,6]. The TA is maintained in its position by means of a Support structure fixed to the

Test Cell (TC) ground by a proper bolt system. Finally, the Lithium loop is articulated in a main loop and purification loop and it is intended to feed Lithium to the TA by ElectroMagnetic (EM) Pumps, routing it through the Heat exchange system and the Lithium purification loop, consisting of cold and hot traps.

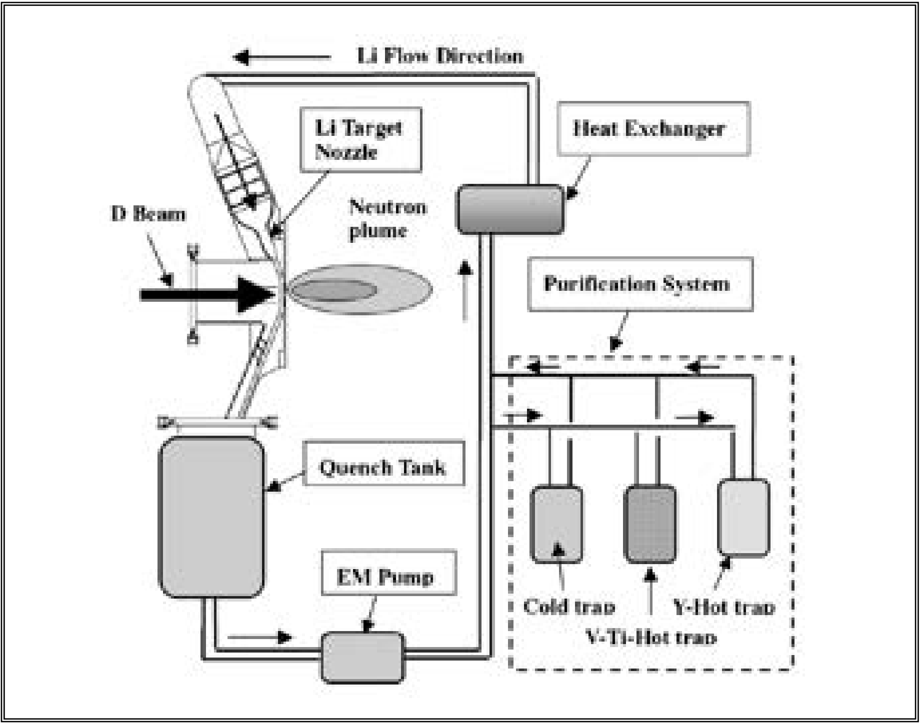

Figure 1. Concept of IFMIF Target system.

The design of the new integrated IFMIF Target System (Fig. 2) reproduces the TA (Fig. 3), its Support structure (Fig. 4) and the main components of the Lithium circuit. In particular, the whole Target system is composed by the following components:

- the Lithium inlet pipe and its support;
- the Interface Inlet Shield Plug (IISP);
- the Fast Disconnecting System (FDS);
- the Beam duct;
- the Inlet nozzle;
- the Back-Plate;
- the Target chamber;
- the Outlet nozzle;
- the Quench Tank (QT);
- the Lithium outlet pipe;
- the Support structure.

The TA, entirely composed of EUROFER steel, is welded to the Lithium inlet pipe and it is supported by the Target chamber arms laying on the Support structure, directly fixed to the ground by means of a proper bolt system. Both the Target chamber and the Outlet nozzle are connected with the Beam duct and the QT, respectively, by means of a FDS.

Concerning the Lithium inlet pipe, it can be divided in two regions connected by means of a further FDS. The former, represented in yellow in Fig. 1, is made of EUROFER steel and will be removed with the TA, whereas the latter, coloured in green, is made of AISI 316 L steel and it will not be replaced during the TA maintenance and/or replacement operations.

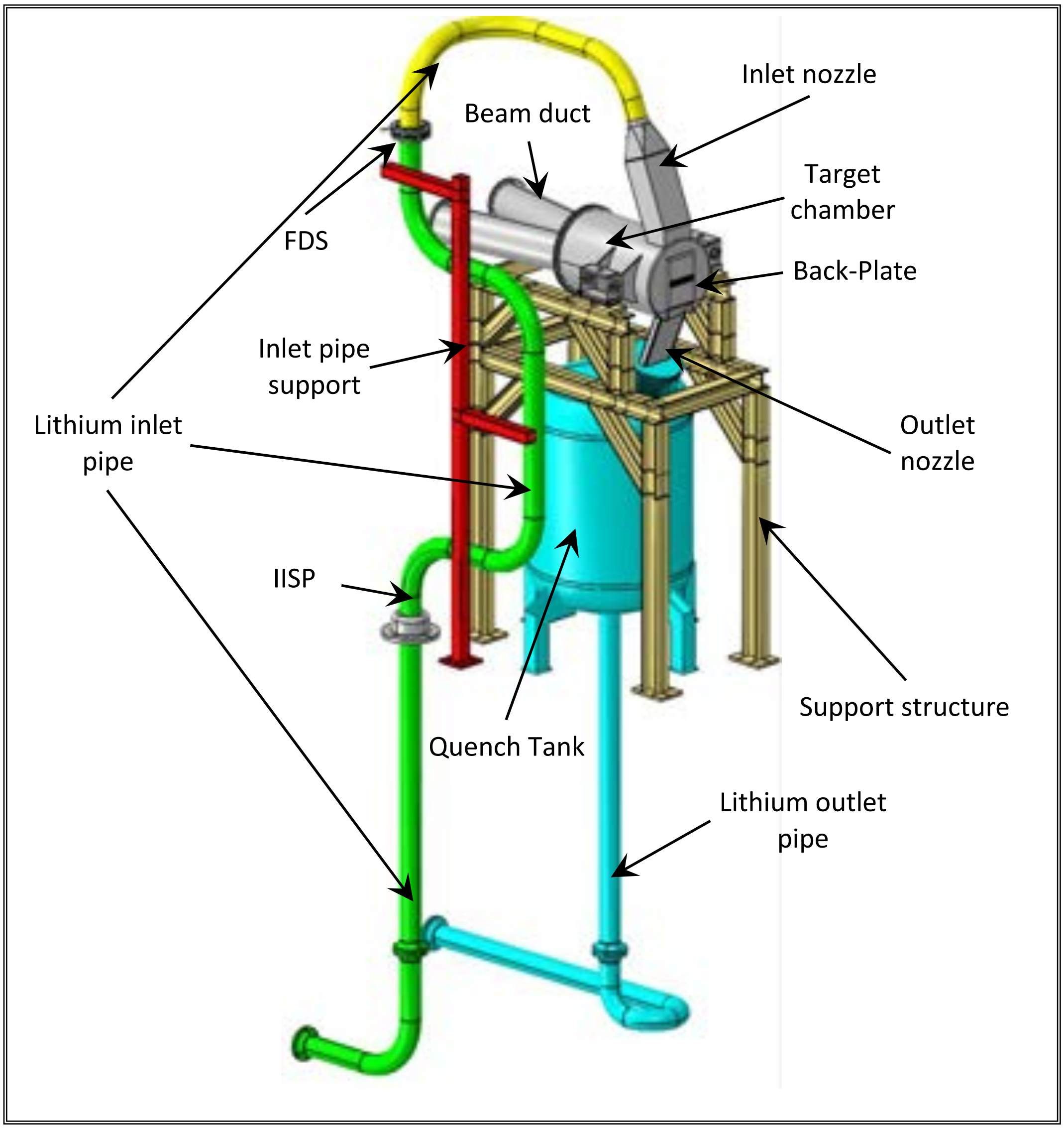

Figure 2. The new IFMIF Target system.

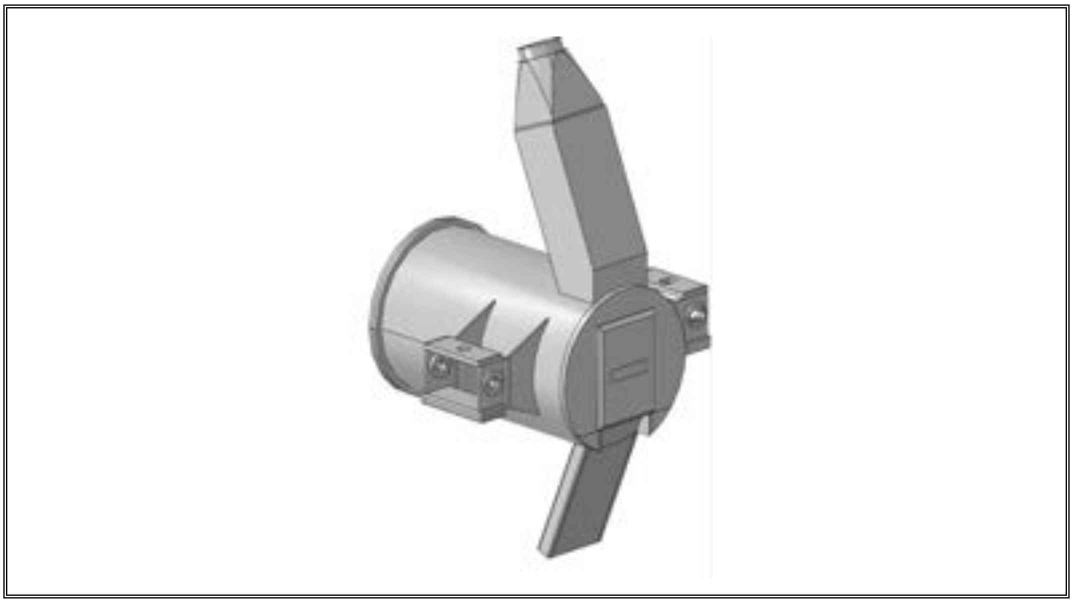

Figure 3. IFMIF Target system - Target Assembly.

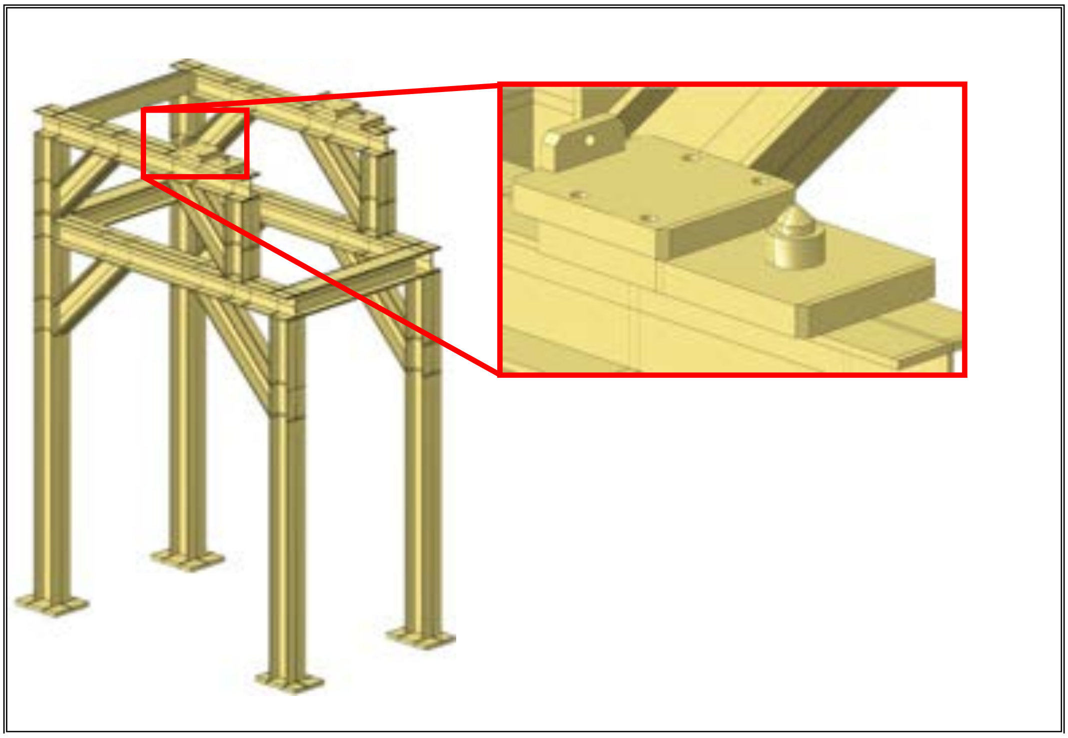

Figure 4. IFMIF Target system - Support structure.

3 Thermo-mechanical analysis

Within the framework of the IFMIF R&D activities and in close cooperation with ENEA-Brasimone, a research campaign has been launched at DEIM to theoretically investigate the thermo-mechanical performances of the IFMIF Target system integrated with its Support structure and the Lithium inlet pipe.

The research campaign has represented the further development of previous activities performed at DEIM in cooperation with ENEA-Brasimone in the past years. The present research has been aimed at the assessing of the thermo-mechanical behaviour of an alternative TA layout foreseeing an integrated BP when subjected to the nominal steady state loading scenario envisaged for IFMIF. The main goal of the research activity has been to verify whether the components might safely withstand the thermo-mechanical loads the TA undergoes without incurring in significant deformations, which may warp Lithium channel inducing flow instability, cause interferences with the Test Module or generate a misalignment between deuteron beams and Lithium footprint. Attention has been focussed also on the fulfilment, in the most critical area of the domain investigated, of the SDC-IC structural safety criteria. The research campaign has been performed adopting a theoretical-numerical approach based on the Finite Element Method (FEM) and a qualified commercial FEM code has been used to perform the study.

3.1 Steady state loading scenario

The reference nominal steady state scenario that the TA, integrated with its support framework and the Lithium inlet pipe, is envisaged to experience, is mainly characterized by Lithium flowing within the Lithium inlet pipe and through the TA, where it enters the Lithium straightener at 250 °C and at a static pressure of ~60 kPa, up to the outlet nozzle, where it reaches ~300°C and a static pressure of 10^{-3} Pa, prior to be discharged in the Quench Tank [7]. During this phase, deuteron accelerators remains under full-power irradiation conditions (two 125 mA current beams), allowing heat power to be deposited by deuterons, neutrons and photons within Lithium coolant, TA components, support framework and Lithium inlet pipe.

The neutron swelling induced within the structural material has not been taken into account in the present research campaign, because it has been aimed to preliminary assess the thermo-mechanical behaviour of this alternative design of the IFMIF TA.

3.2 The FEM model

A realistic 3D FEM model, reproducing the TA integrated with the Support structure and the Lithium inlet pipe, has been developed and a mesh independency analysis has been performed to select an optimized spatial discretization which allows accurate results to be obtained saving calculation time. A mesh composed of ~500k nodes connected in ~930k both tetrahedral and hexahedral linear elements has been selected, whose views are reported in Figs. 5-8.

The QT with its Lithium outlet pipe have not been taken into account in the FEM model since they are connected with the rest of the structure by means of a bellow that allows mechanical effects on the TA to be decoupled. Neither the FDS connecting the EUROFER section of the lithium inlet pipe with the AISI 316L one, nor the clamp system connecting the different parts of the AISI 316L Lithium inlet pipe section, have been directly modelled, but their mechanical effects have been simulated imposing appropriate contact models that permits to consider the tightened flanges as perfectly tied. Finally, although the beam duct has not been directly modelled, its thermomechanical effect on the whole TA has been properly simulated.

Concerning the lithium, only the flow domain flowing through the BP and the outlet nozzle has been directly modelled, even though its thermomechanical effects on the Target system have been properly taken into account.

Materials have been considered homogeneous, uniform and isotropic. Their thermo-mechanical properties have been assumed to depend uniquely on temperature as indicated in [8-12] and a linear elastic model has been adopted for EUROFER and AISI 316L steels.

Figure 5. FEM model - Target Assembly.

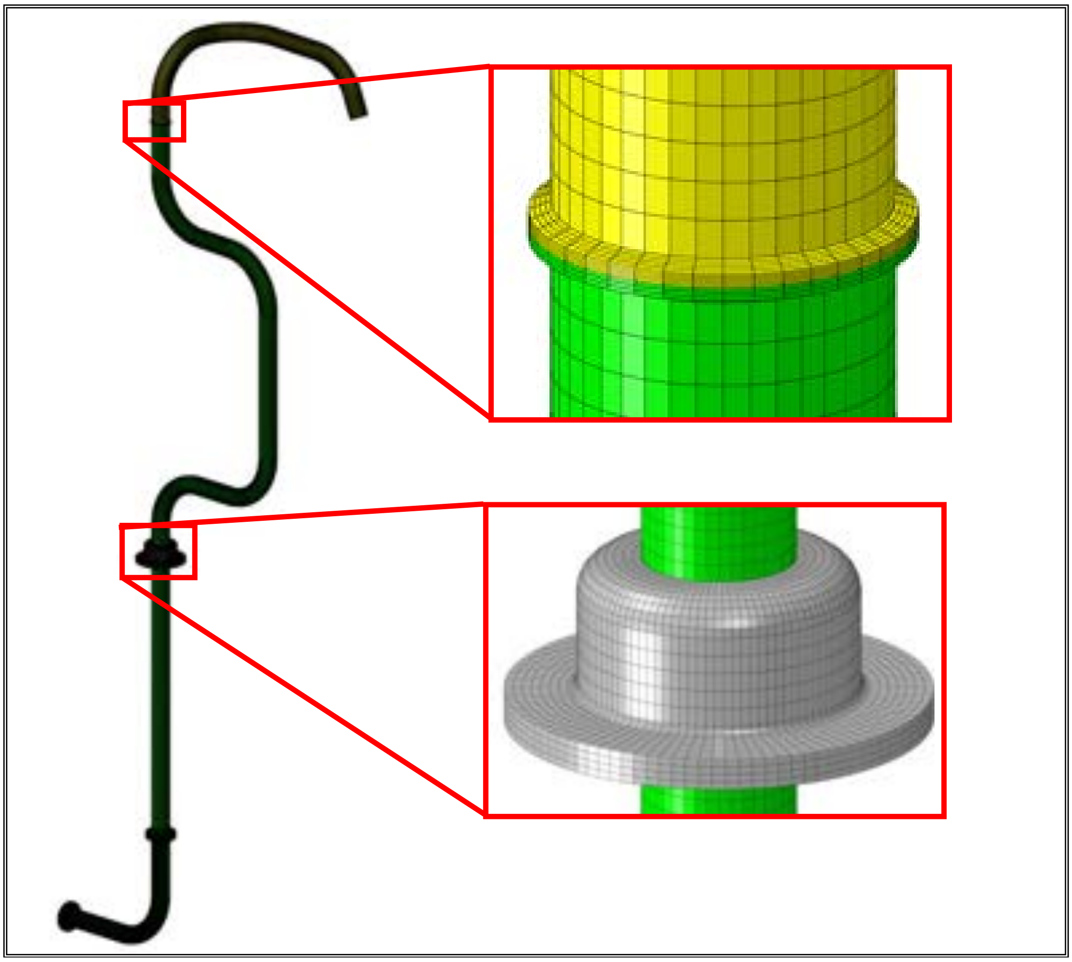

Figure 6. FEM model - Lithium inlet pipe with details.

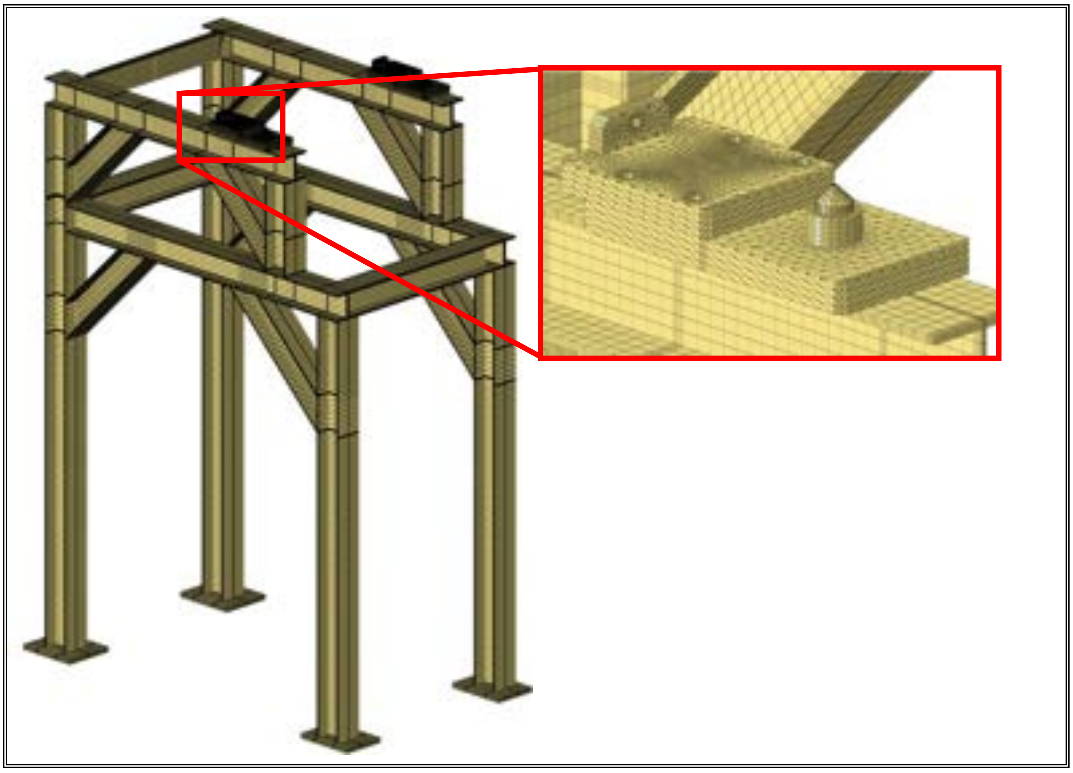

Figure 7. FEM model - Support structure with details.

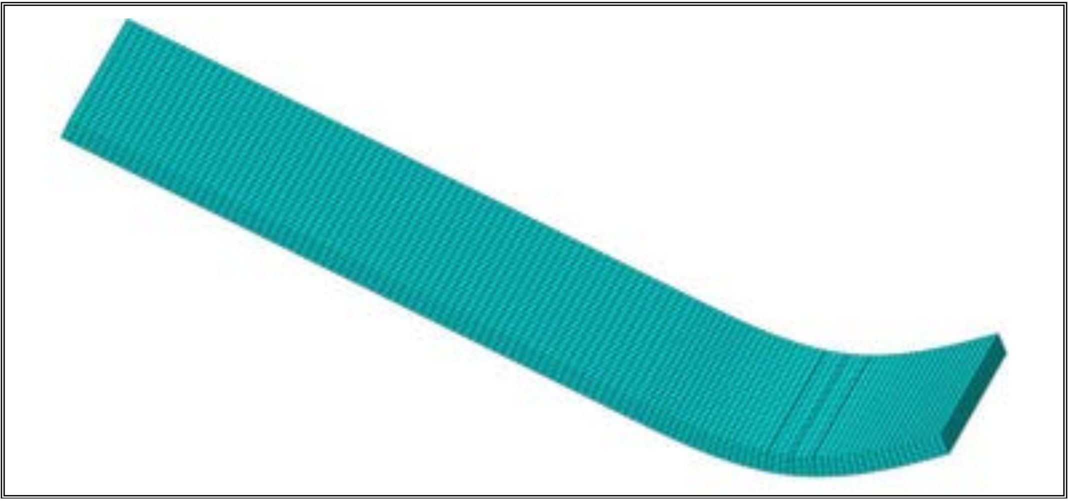

Figure 8. FEM model - Lithium flow domain.

3.3 Thermal interactions, loads and boundary conditions

The following thermal interactions, loads and boundary conditions have been assumed to simulate the TA, integrated with its Support structure and Lithium inlet pipe, thermal behaviour under nominal steady state loading scenario:

- thermal contact interactions;
- volumetric heat power deposited within Lithium by deuterons;
- volumetric heat power deposited within TA by neutrons and γ-rays;
- TA natural convective cooling;
- external irradiation;
- internal irradiation;
- forced convection with flowing Lithium;
- thermal interaction between BP and High Flux Test Module (HFTM).

Thermal interactions occurring between the TA arms and the Support structure, as well as between the Target chamber and the Beam duct have been modelled by means of thermal contact models characterized by a thermal conductance of 2000 W/m² °C [13] and 15.8 W/m² °C [7], respectively. For this latter interaction a proper 1D model has been developed at DEIM in order to reproduce the spatial distribution of the Beam duct flange (not modelled) sink temperature, that has been already adopted in previous studies.

The 10 MW power deposited by the accelerated D^+ ion beam [14], interacting with Lithium nuclei, has been supposed to be uniformly distributed within the Lithium flow domain delimitated by the 20 x 5 cm² beam foot-print. A value of 4.0E+10 W/m³ has been, therefore, imposed to elements highlighted in red in Fig. 9.

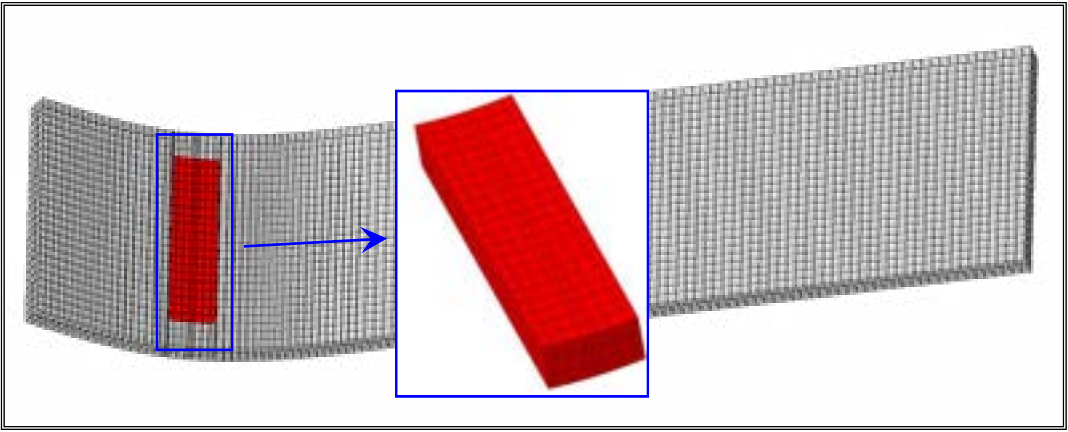

Figure 9. Detail of Lithium flow domain beam footprint region.

A volumetric density of nuclear heat power (q''') has been assumed within the TA, the Support structure and the Lithium inlet pipe in order to properly simulate the heat power deposition process due to interactions of both neutrons arising from D-Li interactions and γ photons produced by (n,γ) reactions with the nuclei of their structural material.

In particular, regarding TA, the non-uniform spatial distribution of nuclear-deposited heat power volumetric density, calculated by ENEA adopting the Monte Carlo method [15] (Fig. 10), has been assumed and implemented in the FEM model by means of a specific user subroutine.

Furthermore, since no data have been directly calculated for nuclear-deposited heat power volumetric density within the Support structure and the Lithium inlet pipe, its spatial distribution has been extrapolated assuming a $1/r^2$ dependence. In particular, the following formula has been adopted:

$$q'''(r) = \frac{q_0'''}{4\pi r^2} \tag{1}$$

where $q_0''' = q'''_{BP,centre}/200$ and r is the distance between a generic point and the BP centre. The q''' value at the BP centre has been divided by the factor 200 in order to obtain an acceptable agreement for the nuclear-deposited heat power volumetric density values at the boundary between the geometric domain in which q''' values have been directly calculated by ENEA and the domain where they have been extrapolated.

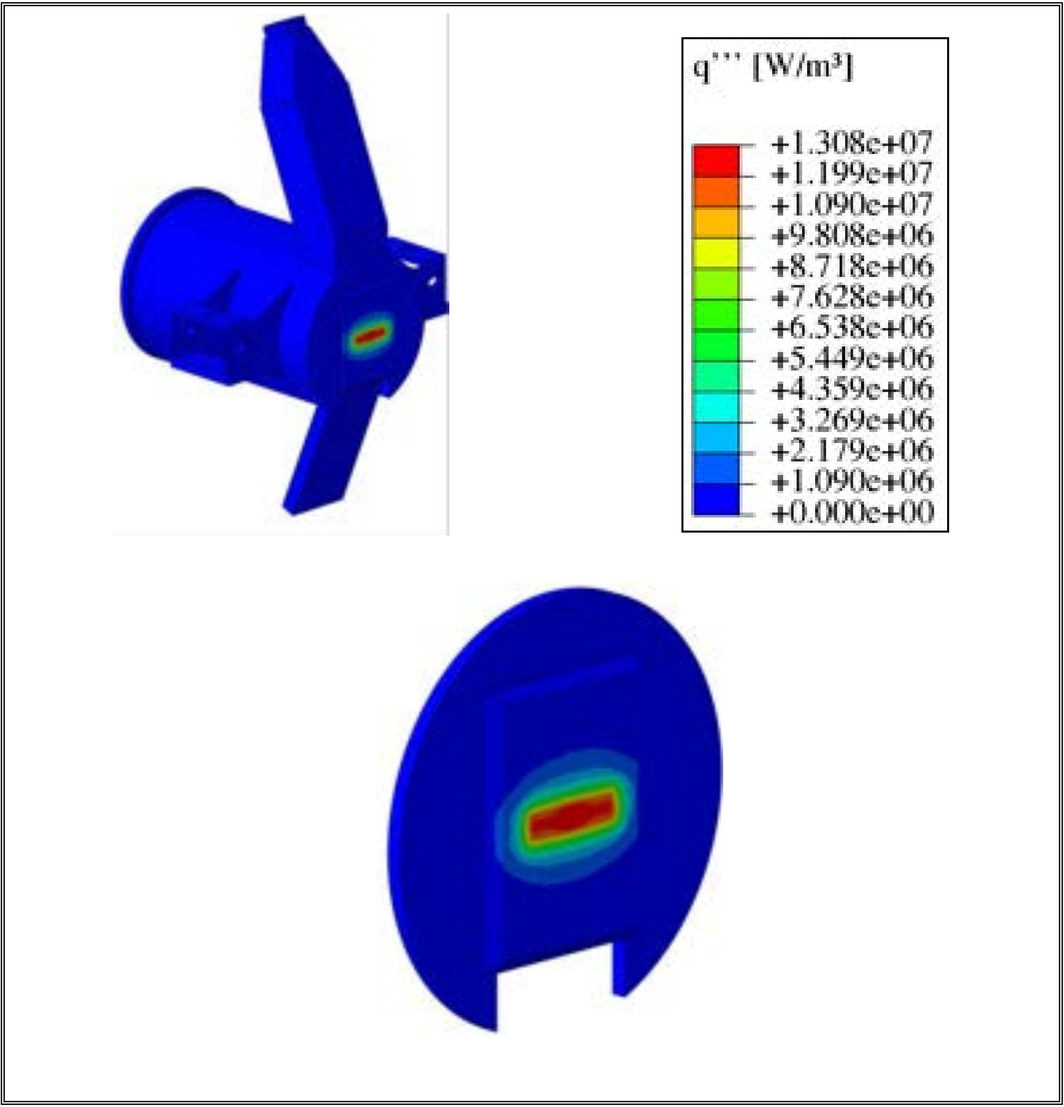

Figure 10. Spatial distribution of heat power volumetric density within TA.

A radiative and convective heat transfer condition has been imposed to all un-insulated surfaces of the model (Fig.11). They have been supposed to radiate towards the TC walls, set at a temperature of 50 °C with an emissivity value of 0.3, and to be cooled by the helium filling the TC, at 50 °C and 5 kPa, with a heat transfer coefficient calculated according to the formula [16] reported in Appendix I. Concerning the internal irradiation, a proper radiation cavity has been implemented composed of the internal TA surfaces and the upper Lithium one. Emissivity values of 0.3 and 0.06 have been considered for EUROFER and Lithium, respectively.

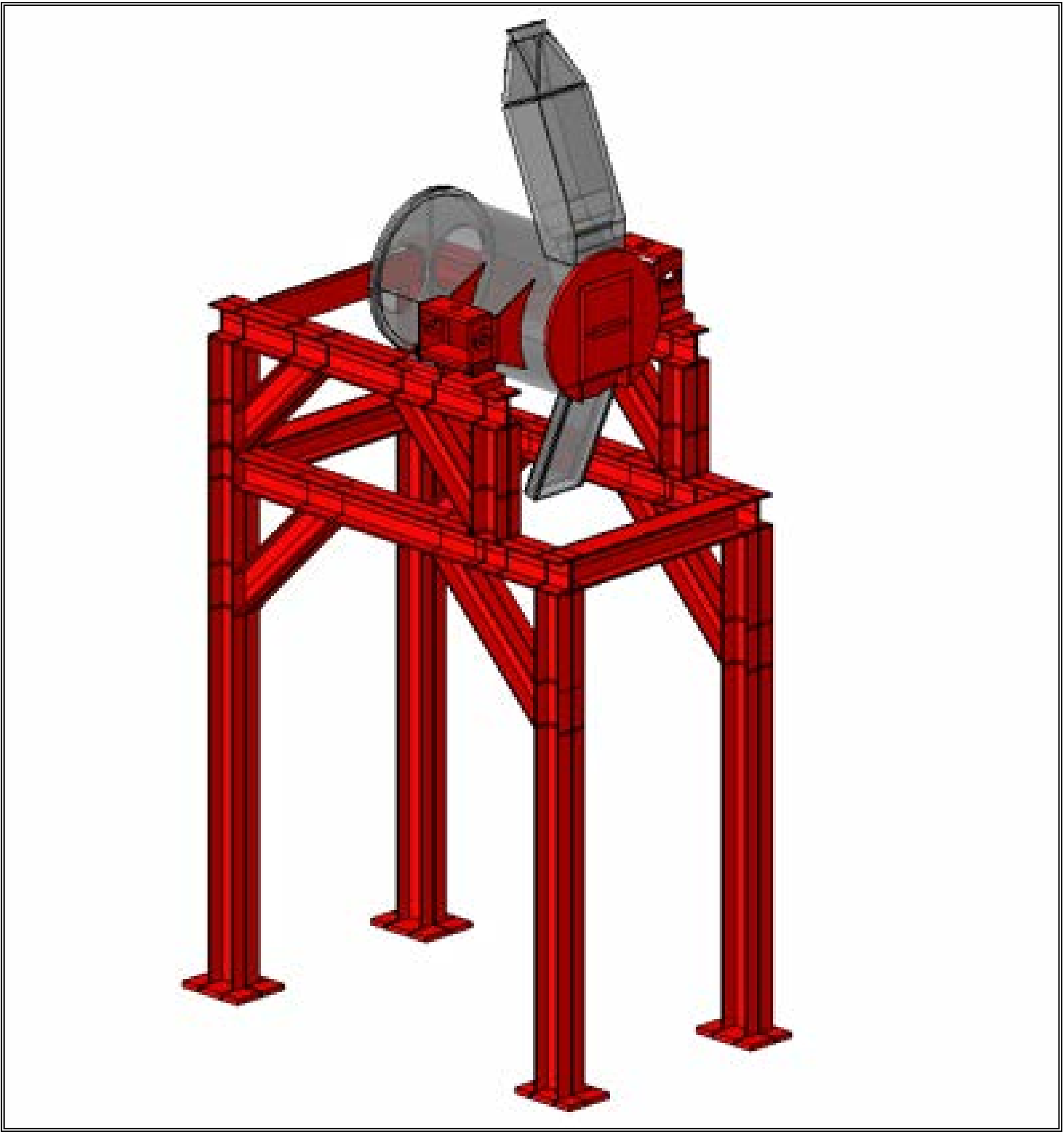

Figure 11. External radiation surfaces.

Forced convection with Lithium has been taken into account imposing a convective heat transfer condition onto Lithium inlet pipe and Inlet nozzle characterized by a heat transfer coefficient of 34000 W/m² °C [13] and a bulk temperature of 250 °C. Concerning BP and Outlet nozzle Lithium wetted surfaces, a contact model with Lithium flow domain has been implemented assuming a thermal conductance of 34000 W/m² °C.

The thermal interaction between BP and High Flux Test Module (HFTM), mainly consisting in a diffusive heat transfer due to the narrow thickness of their helium gap, has been simulated by implementing a Cauchy's boundary condition at the BP coloured surfaces in Fig. 12. It is characterized by a HFTM sink temperature of 50°C and a heat transfer coefficient calculated as the helium conductivity (λ) @5 kPa and 50 °C divided by the gap thickness (d).

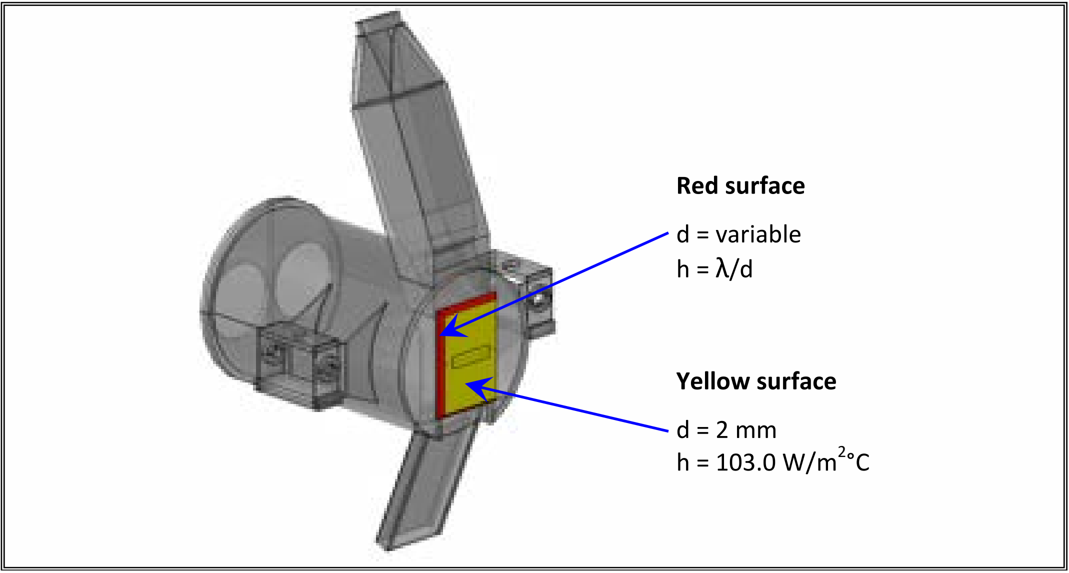

Figure 12. BP and HFTM thermal interaction surfaces.

3.4 Mechanical interactions, loads and boundary conditions

The following mechanical interactions, loads and boundary conditions have been assumed to simulate the Target System thermo-mechanical behaviour under the nominal steady state loading scenario:

- mechanical interactions between TA and its Support structure;
- thermal deformations;
- Lithium induced pressure loads;
- internal and external pressures;
- weight force;
- mechanical restraints.

Mechanical interactions between TA and its Support structure, considered as dry lubricated, as well as between Lithium inlet pipe and IISP have been simulated by mechanical contact models envisaging Coulombian friction interactions characterized by a uniform friction factor of 0.03 and 0.74, respectively. A detail of the contact surface between TA and its Support structure where sliding is allowed is reported in Fig. 13. All other components have been considered as tied.

As to thermal deformations, the non-uniformly distributed thermal deformation field arising within the Target System as a consequence of its thermal field and its isotropic thermal expansion tensor have been applied to the FEM model.

The effect of gravity has been taken into account for the whole model. In particular for TA, Support structure and Lithium inlet pipe a proper mechanical load has been imposed, while regarding the Lithium flow its weight force has been included in the pressure applied onto Lithium wetted surfaces.

According to the results reported in [7], a non-uniform internal pressure load has been applied to Lithium wetted surfaces of Lithium inlet pipe, nozzles and BP. In particular, the pressure load onto the Lithium inlet pipe wetted surface (p_{IP}) has been imposed as uniformly equal to 60 kPa, while a further uniform pressure load (p_{IN}) of 31.125 kPa, calculated as the average value between the 60 kPa at the entrance of the inlet nozzle and the 2.250 kPa at its exit (in red in Fig. 14), has been imposed to the inlet nozzle internal surfaces. Moreover, according to [7], the pressure load onto the BP Lithium wetted surface, p_{BP}, has been assumed to depend linearly on the z coordinate, reaching its maximum (~12 kPa) at the beam footprint centre and decreasing till to 10^{-3} Pa at the BP channel exit, remaining vanishing ($p_{ON} \approx 0$ Pa) along the Outlet nozzle channel (in blue in Fig. 14). Moreover, according to [7], a pressure of 5 kPa has been assumed for the containment vessel helium atmosphere and it has been applied as an external pressure to the whole external surface of the FEM model.

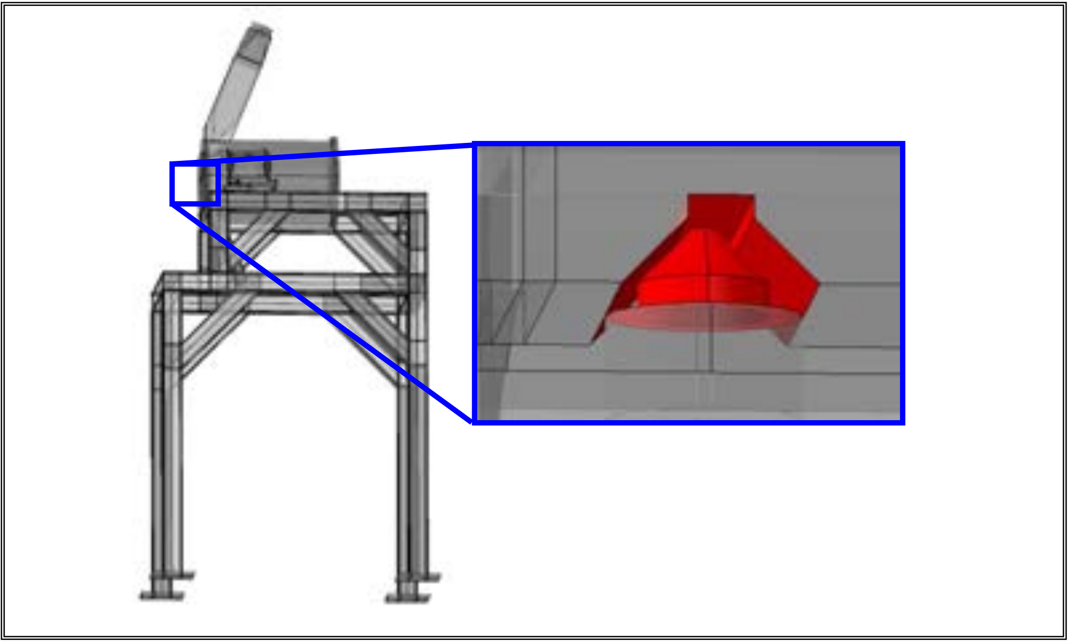

Figure 13. Contact surfaces between TA and its Support structure - Detail of sliding pin.

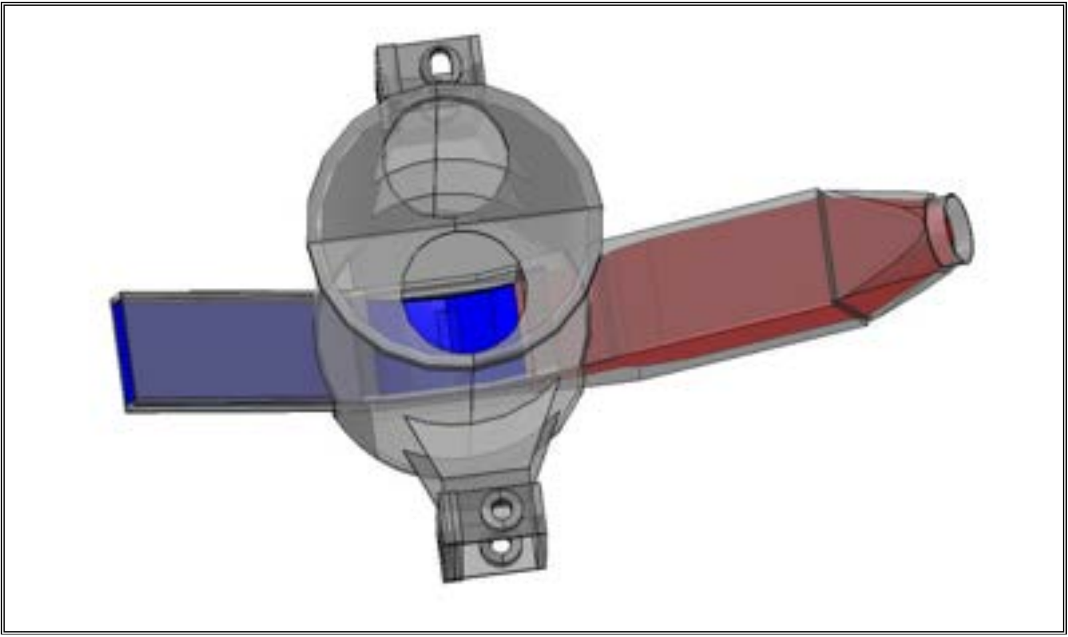

Figure 14. TA Lithium wetted surfaces.

As far as Support structure mechanical restraints are concerned, all displacements (u_x, u_y, u_z) of nodes lying on bottom surfaces of the Support structure feet have been prevented, in order to simulate the effect of the connection with the TC floor. The same condition has been imposed to nodes of the lower Lithium inlet pipe flange, in order to simulate the fixed connection located in the TLIC, and in correspondence of the lower flange of the IISP to reproduce its junction with the TC liner (Fig. 15).

Regarding the TA system constraints, displacements along Z direction have been prevented to nodes highlighted in red in Fig. 16a, in order to simulate the effect of the pins devoted to avoid gap openings between the TA and its Support structure. Moreover, in order to properly take into account the mechanical effect of the FDS devoted to connect the Target chamber to the Beam duct, displacements along Y and Z directions of the nodes highlighted in yellow and blue in Fig. 16b, respectively, have been prevented.

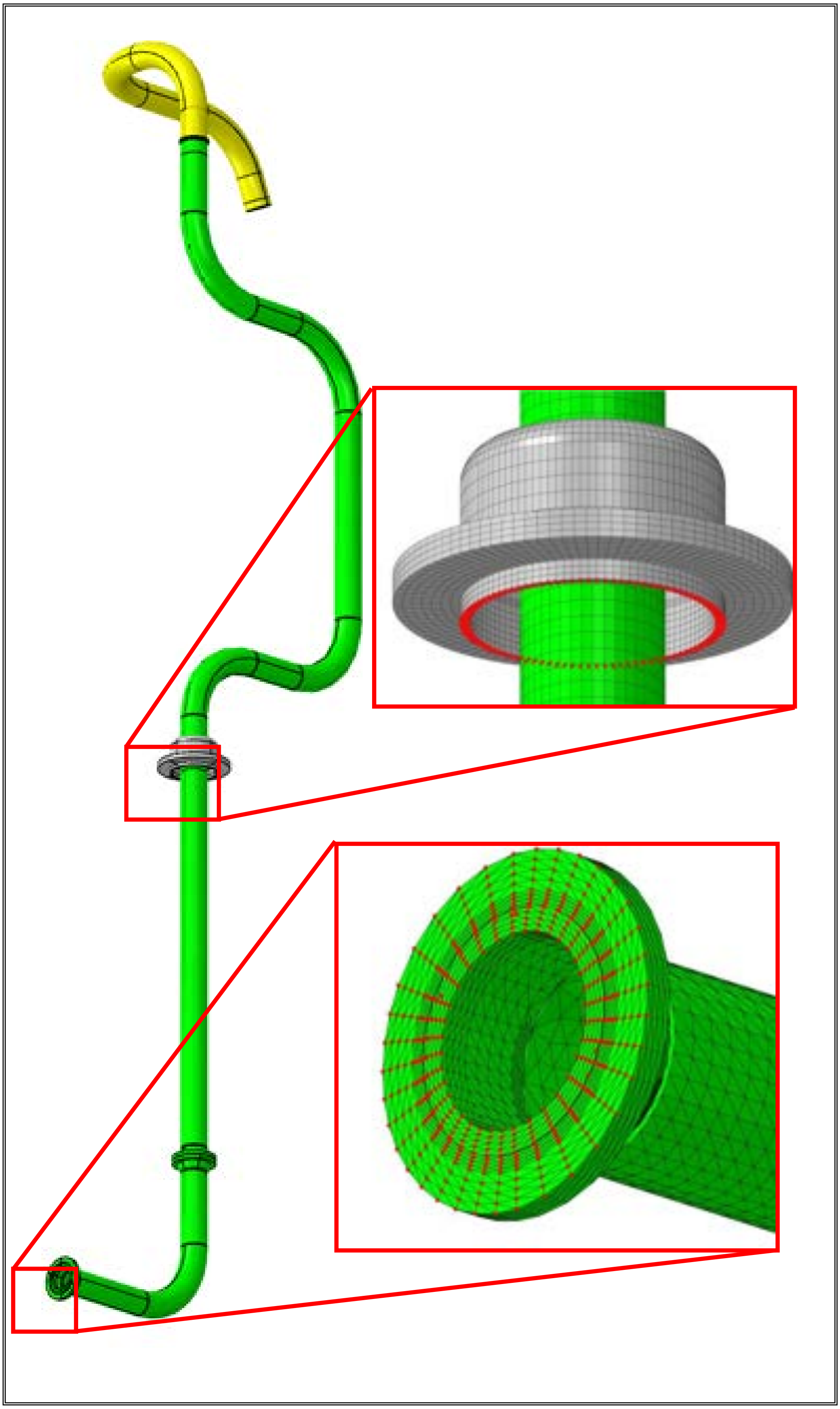

Figure 15. Lithium inlet pipe constraints.

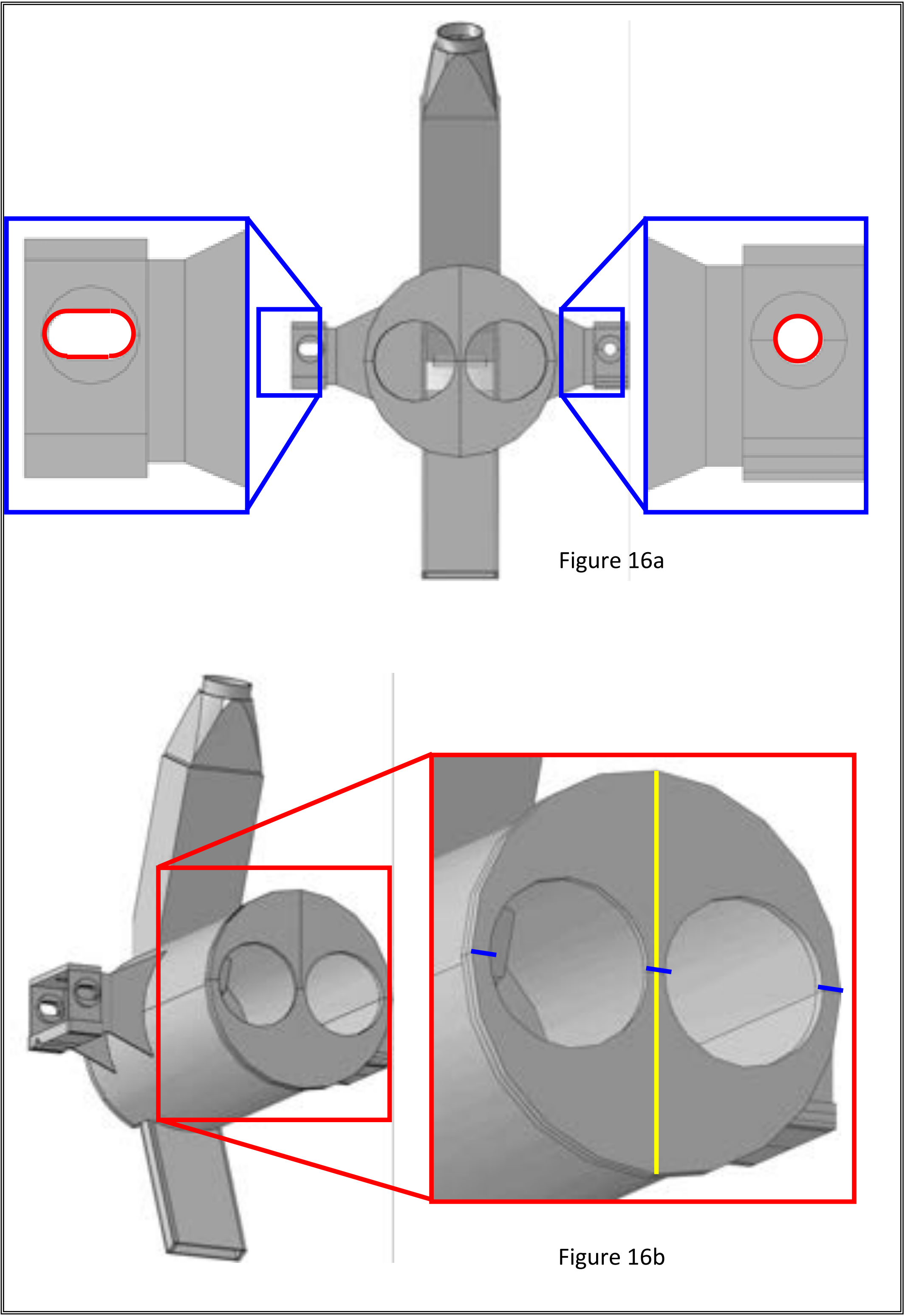

Figure 16a

Figure 16b

Figure 16. Target chamber constraints.

3.5 Steady state analysis results

Un-coupled steady state analyses have been launched in order to assess the thermo-mechanical behaviour of the IFMIF TA, equipped with its Support structure and Lithium inlet pipe, under its envisaged nominal operating scenario.

Results obtained from the thermal analysis have shown that the maximum temperature reached within the structure is always well below the maximum EUROFER allowable temperature of 550 °C (Fig. 17). In particular, the maximum temperature of 442.7 °C is predicted to be reached within the TA domain (Fig. 18), in correspondence of the Lithium channel guides. Concerning the BP (Fig. 19), it experiences a maximum temperature of ~360 °C, calculated on the internal surface in correspondence of the aforementioned Lithium channel guides. As far as Lithium inlet pipe and Support structure are concerned, a uniform temperature distribution is foreseen for the former, whereas a maximum temperature value of ~145 °C is predicted for the latter (Fig. 20) in correspondence of the contact with the TA arms, whereas a significantly lower temperature (~70 °C) is predicted in the rest of the component.

From the mechanical point of view an acceptable stress field is generally predicted within the structure (Figs. 21-24). Anyway, it has to be highlighted that very high von Mises stress values are calculated, but uniquely in those regions where too conservative boundary conditions have been imposed (i.e. fixed points in correspondence of Lithium inlet pipe and IISP flanges). Focussing the attention on the TA, and particularly on its BP, it can be observed that the von Mises stress distribution is quite similar to that obtained in analogous analyses performed on the TA equipped with the removable bayonet-BP, but von Mises stress values result to be lower with respect to those calculated in [5], with a maximum stress value of ~380 MPa (Fig. 23).

As far as displacement field is concerned, obtained results allow to exclude both a significant Lithium beam footprint misalignment (Figs. 25-26) and the overlapping between BP and HFTM. Moreover, values coherent with applied loads and boundary conditions are observed, with maximum displacement of ~2 cm reached in the bend region of the Lithium inlet pipe (Fig. 27), whereas displacements of few millimetres are predicted for the Support structure (Fig. 28).

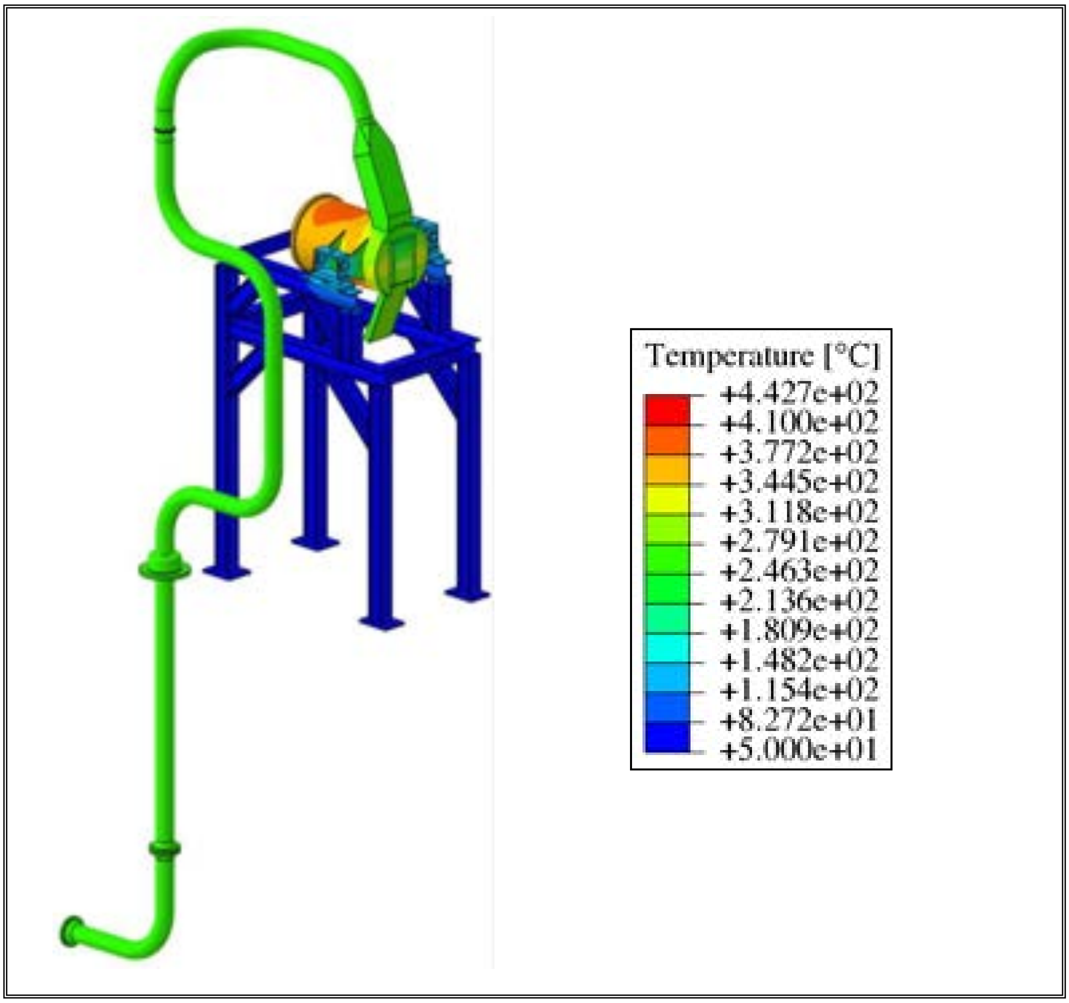

Figure 17. Thermal field.

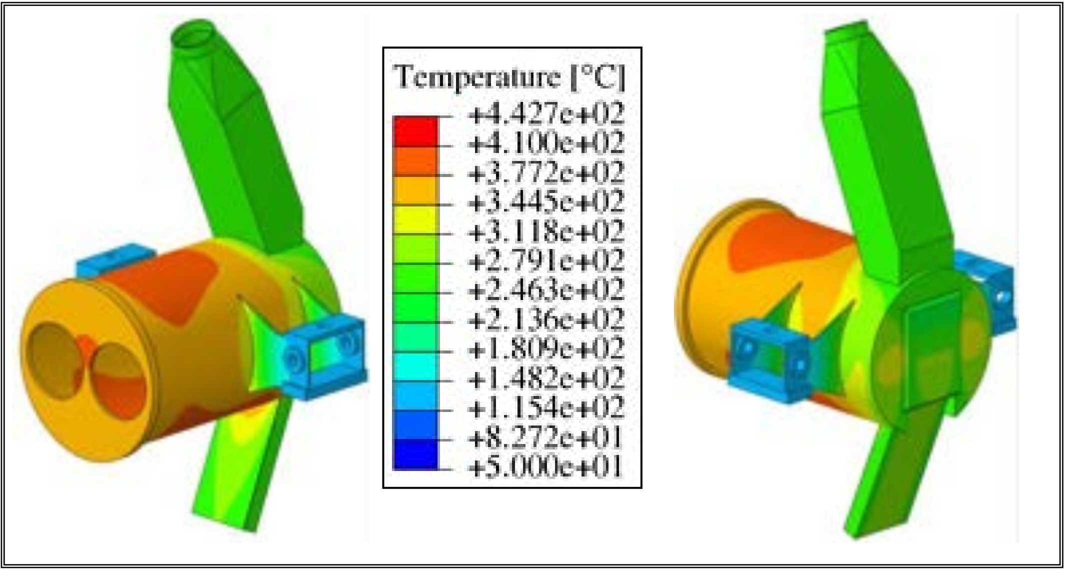

Figure 18. Thermal field - Detail of the TA.

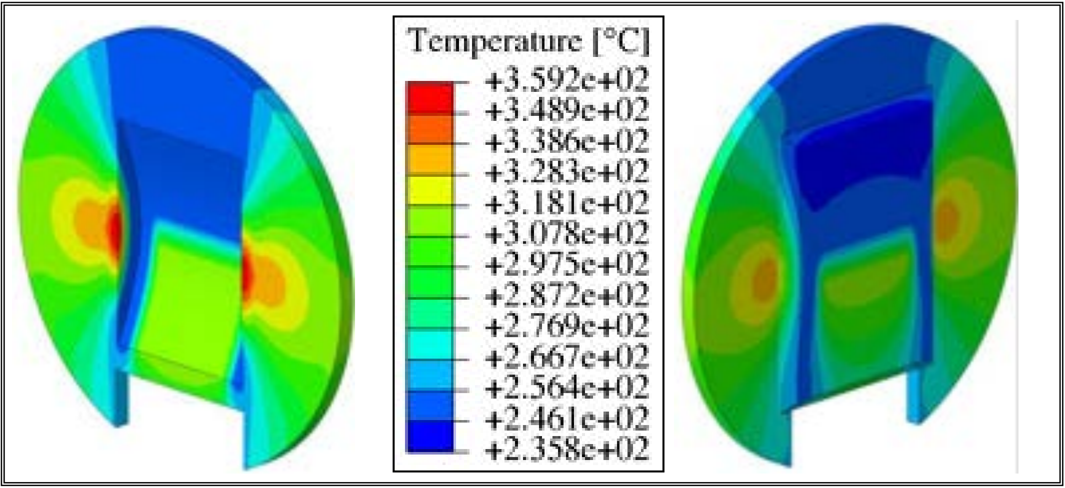

Figure 19. Thermal field - Detail of the BP.

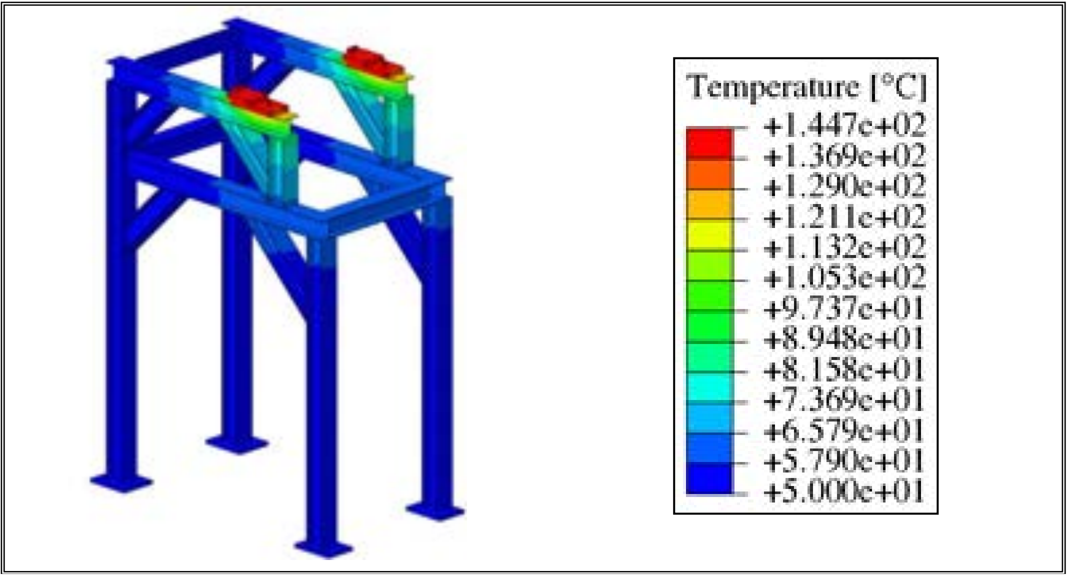

Figure 20. Thermal field - Detail of the Support structure.

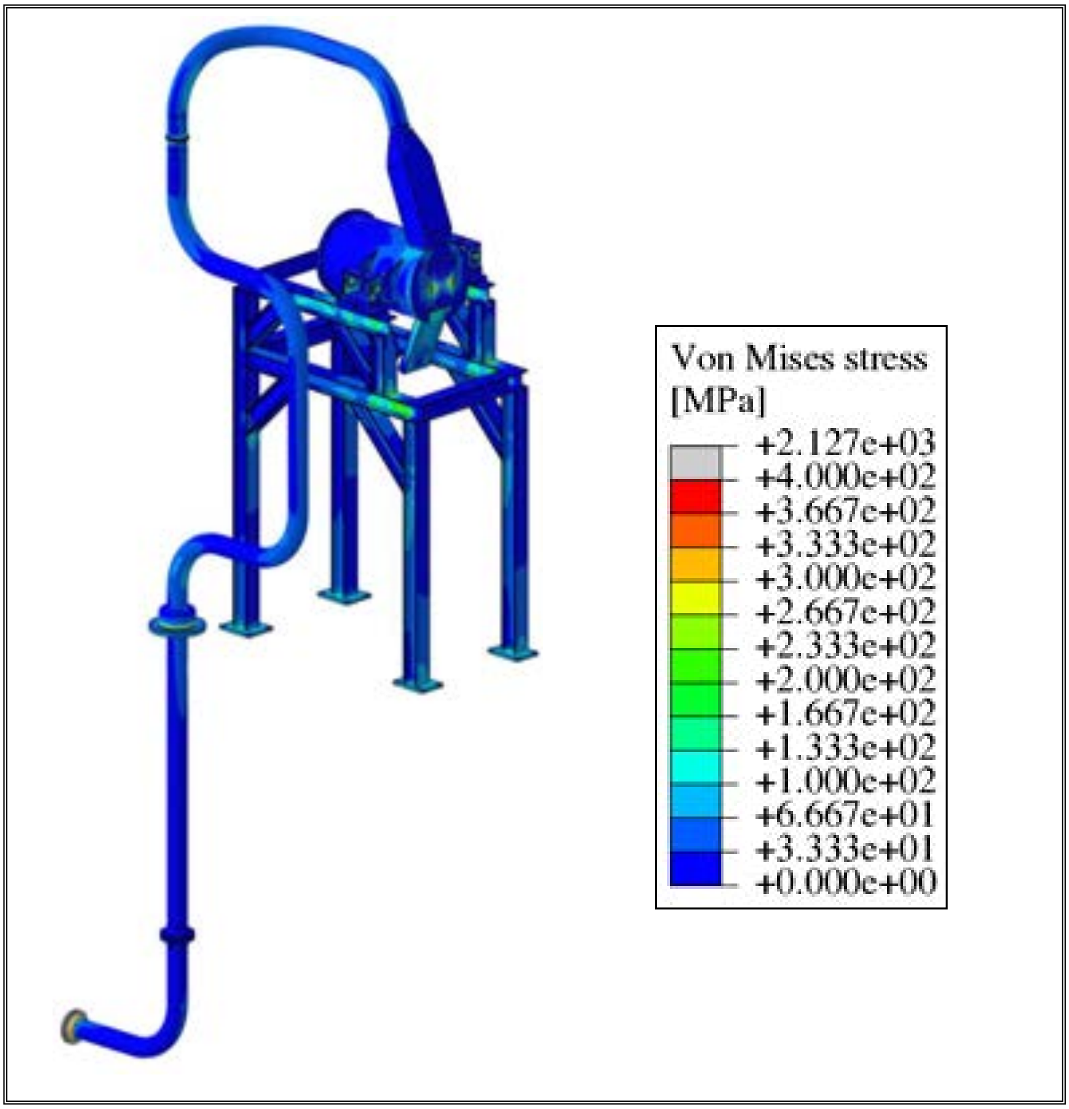

Figure 21. Von Mises stress field.

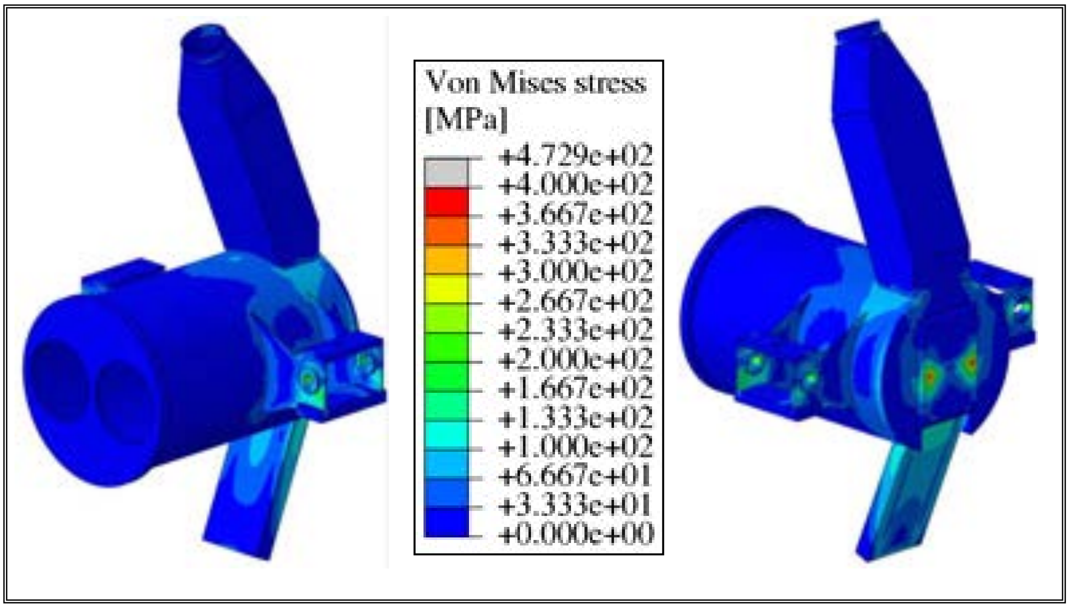

Figure 22. Von Mises stress field - Detail of the TA.

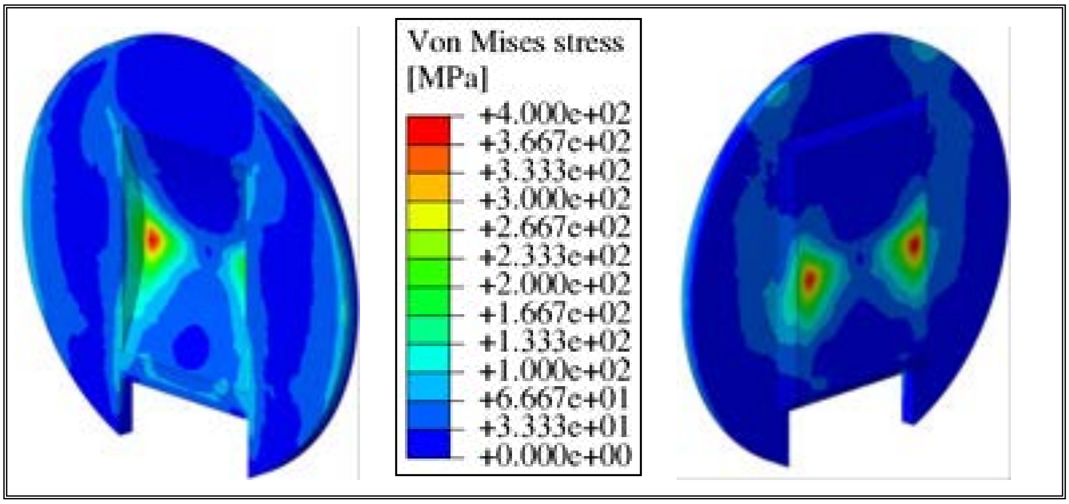

Figure 23. Von Mises stress field - Detail of the BP.

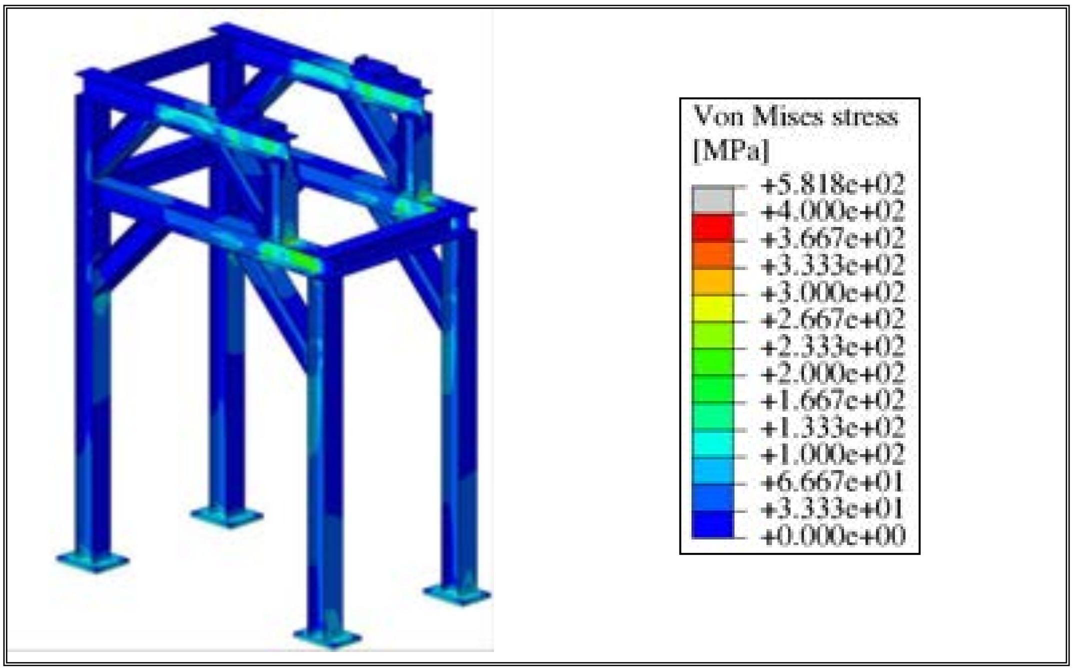

Figure 24. Von Mises stress field - Detail of the Support structure.

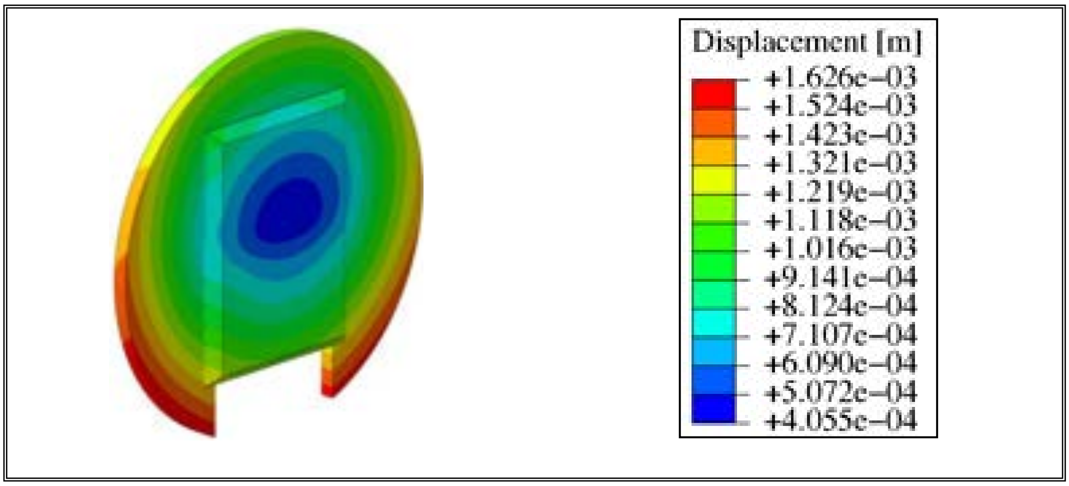

Figure 25. Displacement field.

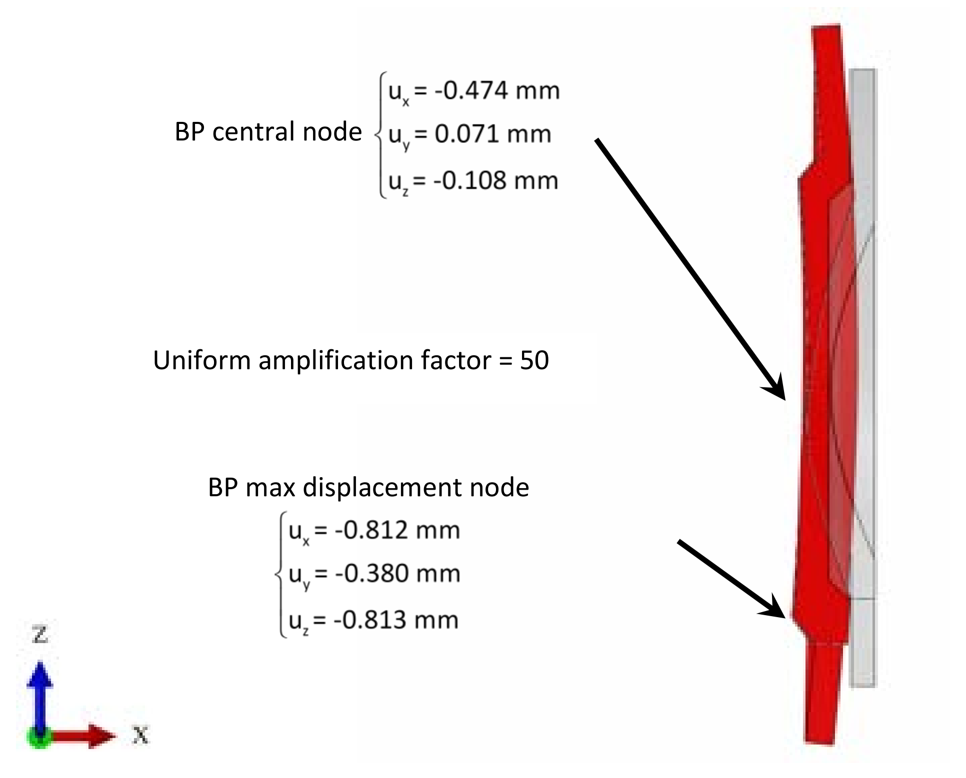

Figure 26. Deformed vs. Un-deformed view - Back-Plate.

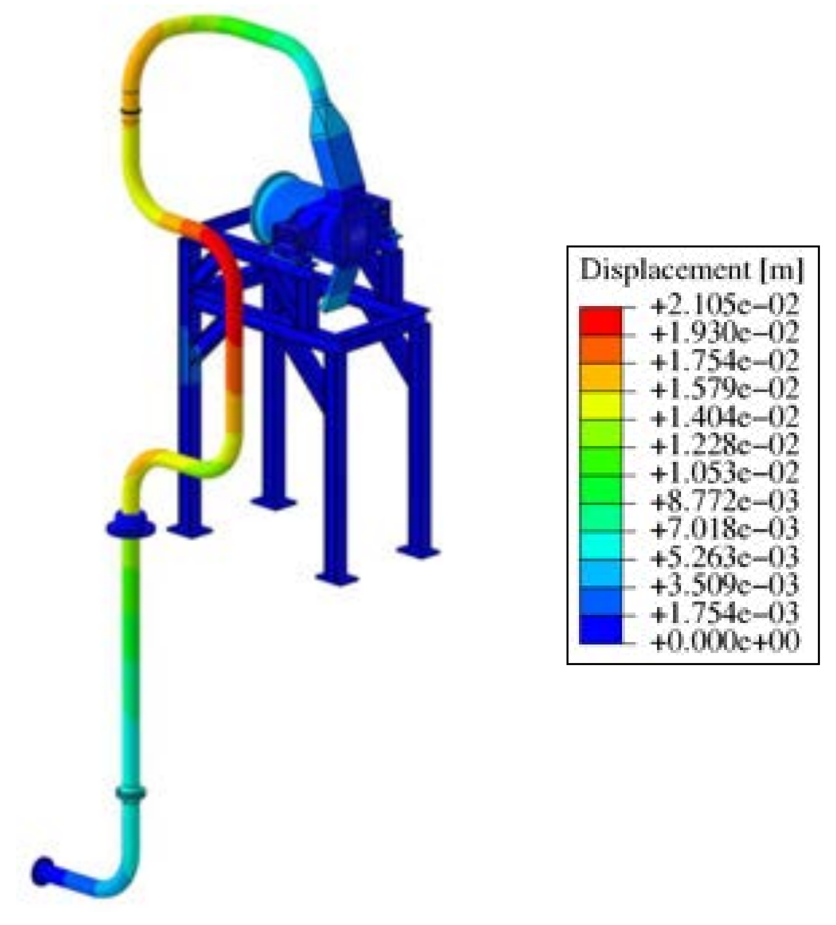

Figure 27. Displacement field.

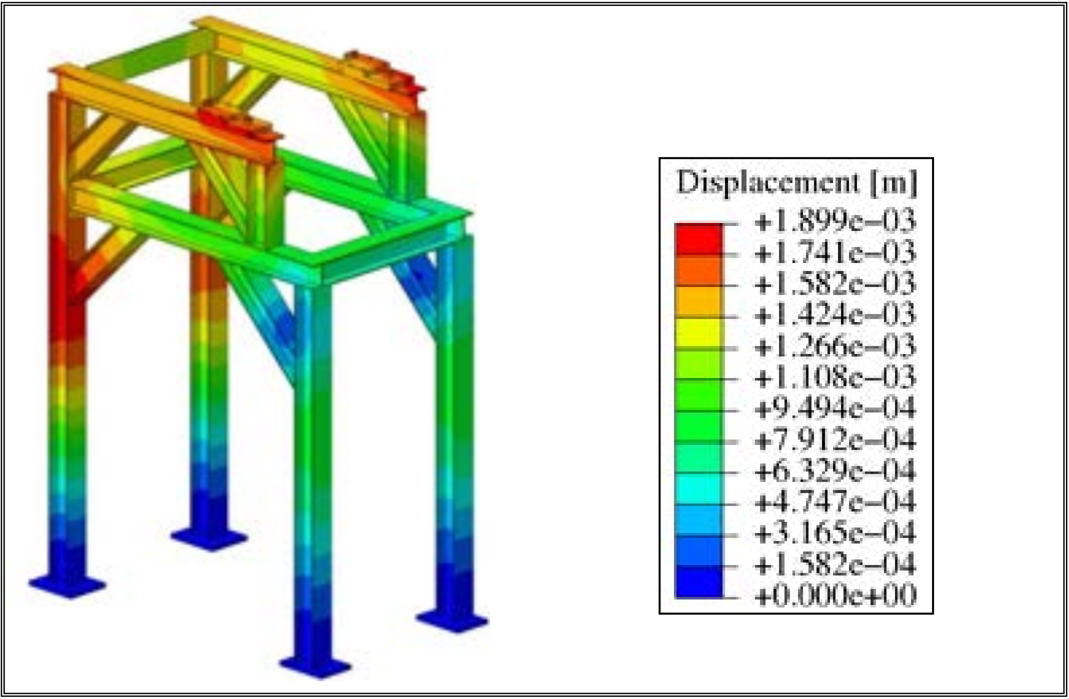

Figure 28. Displacement field - Detail of Support structure.

Finally, a stress linearization procedure has been performed along three significantly loaded paths, two located in the middle plane of the BP Lithium channel and one within a bend region of the Lithium inlet pipe. The SDC-IC [17] criterion against the immediate plastic follow-up, which normally is the most severe in this kind of analysis, has been checked adopting EUROFER maximum allowable stress values reported in [18]. The criterion fails to be fulfilled only in correspondence of the BP path located in the most heavily loaded region of the BP (Fig. 29).

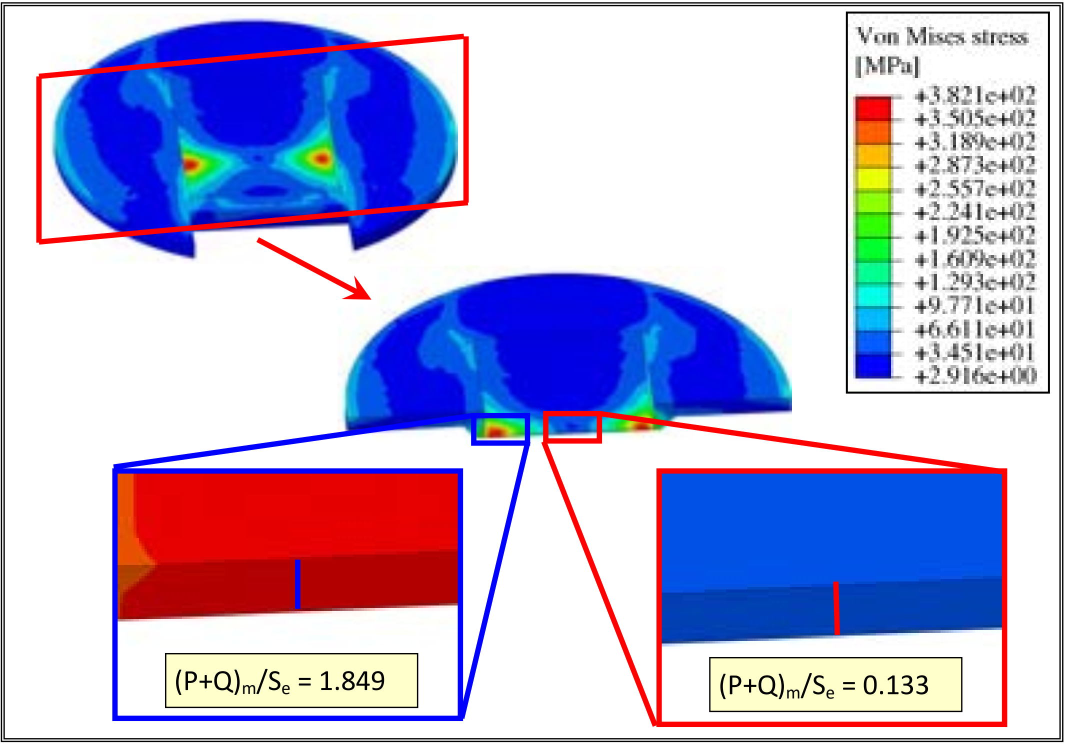

Figure 29. BP stress linearization paths and SDC-IC criterion verification.

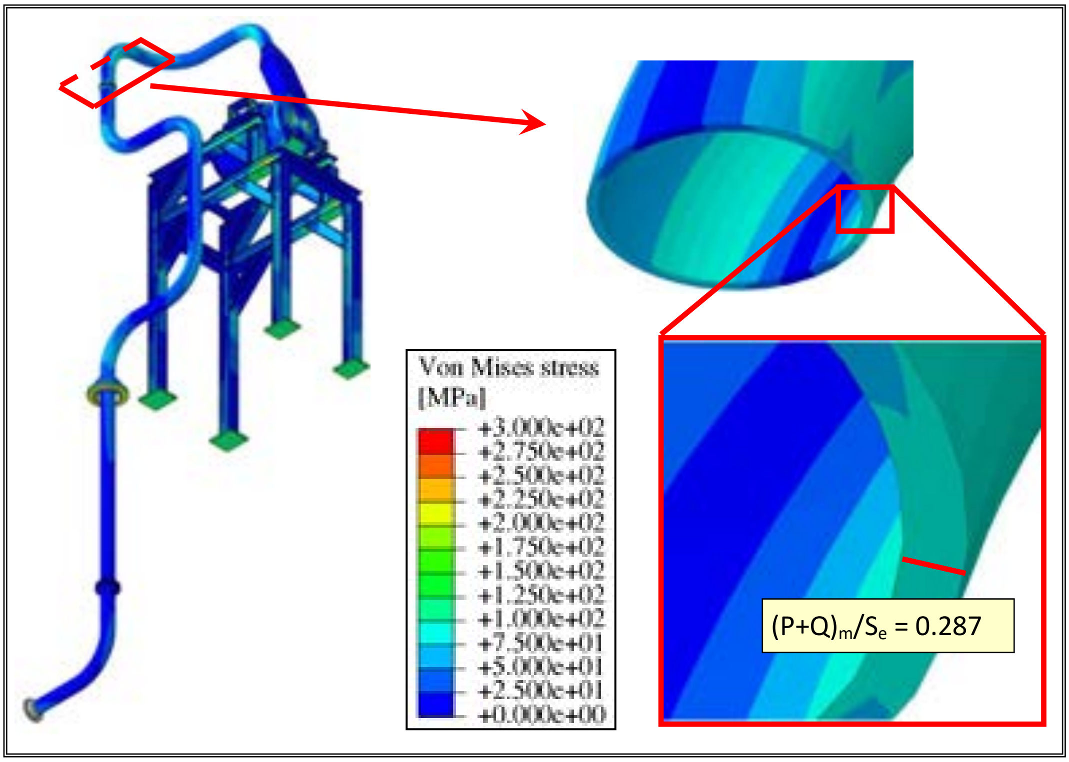

Figure 30. Lithium inlet pipe stress linearization path and SDC-IC criterion verification.

4 Conclusions

Within the framework of IFMIF design activities, a research campaign has been launched in close cooperation by ENEA-Brasimone and the Department of Energy, Information Engineering and Mathematical Models of the University of Palermo to theoretically investigate the thermo-mechanical behaviour of an alternative layout of the IFMIF Target Assembly integrated with its support framework and the Lithium inlet pipe, to verify whether this component might safely withstand the thermo-mechanical loads it undergoes without incurring in significant deformations.

A theoretical approach based on the Finite Element Method (FEM) has been followed and a qualified commercial FEM code has been adopted to perform the study.

Thermal results have indicated that the EUROFER critical temperature of 550 °C is never reached within the model, since a maximum temperature slightly lower than 450 °C is predicted to be reached within the lithium guides.

Mechanical results have shown that an intense Von Mises equivalent stress field is predicted at the edges of the back-plate flow channel, due to both thermal induced stresses and geometrical discontinuity.

Mechanical results have also indicated that the maximum BP external surface displacement towards the HFTM is predicted to be 0.8 mm, excluding the potential interference between the two components. Also an excessive misalignment between the deuteron beam and the Lithium footprint seems to be avoided. On the other hand, SDC-IC criterion against immediate plastic flow localisation has resulted to be not satisfied along a particularly loaded path of the BP, suggesting the need of a partial review of the BP layout.

5 References

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6 Abbreviations and acronyms

BP	Back-Plate
DEIM	Dipartimento di Energia, Ingegneria dell’informazione e Modelli matematici
EM	ElectroMagnetic
FDS	Fast Disconnecting System
FEM	Finite Element Method
HFTM	High Flux Test Module
IFMIF	International Fusion Materials Irradiation Facility
IISP	Interface Inlet Shield Plug
LS	Lithium System
QT	Quench Tank
SDC-IC	Structural Design Criteria for In-vessel Components
TA	Target Assembly
TC	Test Cell
TLIC	TC-LS Interface Cell

Appendix I

In order to reproduce in a detailed way the natural convective heat transfer between the un-insulated Target system surfaces and the helium filling the TC, a proper model has been set up. This model takes into account the Churchill and Chu correlation [16]:

$$Nu = \left\{ 0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + \left(0.496/Pr \right)^{9/16} \right]^{8/27}} \right\}^2 \tag{2}$$

where the Nusselt number (Nu) is calculated in function of the Prandtl (Pr) and Rayleigh (Ra) numbers. Ra is defined as:

$$Ra_L = \frac{gL^3 \left(T_W - T_\infty \right)}{\nu \alpha T_\infty} \tag{3}$$

where g is acceleration of gravity, T_W and T_∞ the wall and fluid bulk temperatures, respectively, ν is the cinematic viscosity, α is the thermal diffusivity and L is the characteristic length of the plate.

Finally, the convective heat transfer coefficient (h) is derived from the Nusselt number with the equation (4):

$$h = \frac{Nu \cdot L}{\lambda} \tag{4}$$

where λ is the thermal conductivity of the helium.

For the Target system three main regions, with three different mean wall temperature values, have been identified (Fig. 31). The first is that of the Support structure (highlighted in red in Fig. 31), where a T_W of 80 °C and a characteristic length of 3 m have been imposed. The second is the surface belonging to the TA arms which connect the TA to the Support structure (coloured in light blue in Fig. 31). A mean wall temperature of 100 °C and a L value of 0.5 m has been set up. Finally, the third surface taken into account is the BP surface farther from the HFTM (in blue in Fig. 31) , where a T_W of 270 °C and a L of 0.5 m have been adopted. The heat transfer coefficient values so calculated are reported in Fig. 31.

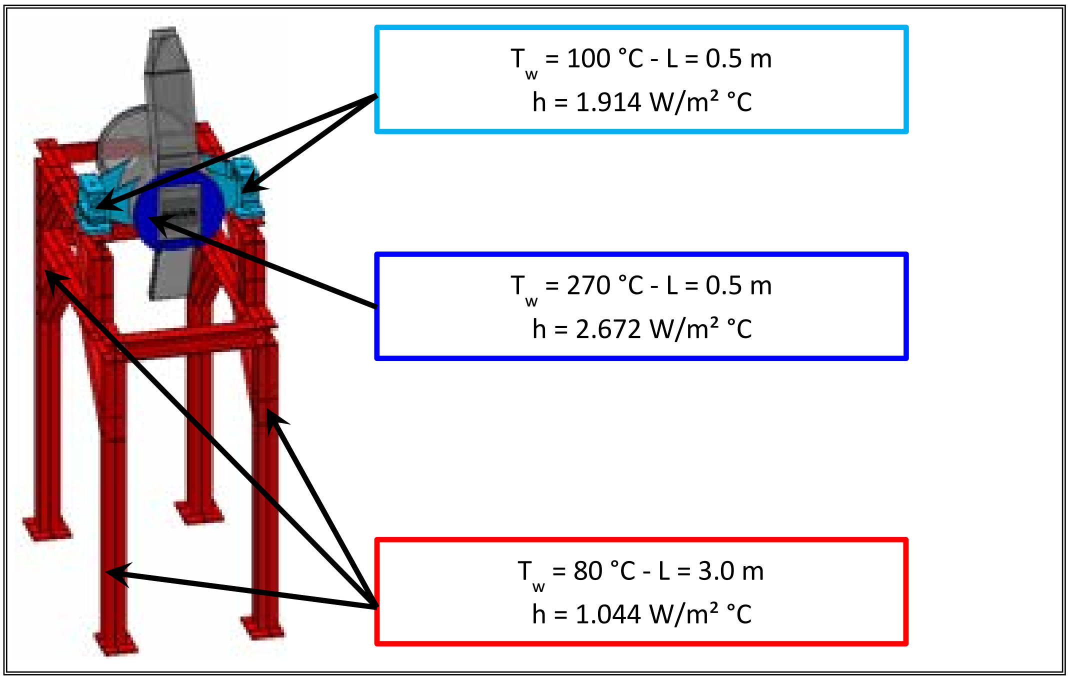

Figure 31. Target system un-insulated surfaces.