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Ricerca di Sistema elettrico

Caratterizzazione termo-meccanica e neutronica del target assembly di IFMIF in condizioni di scostamento dal funzionamento nominale

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CARATTERIZZAZIONE TERMO-MECCANICA E NEUTRONICA DEL TARGET ASSEMBLY DI IFMIF IN CONDIZIONI DI SCOSTAMENTO DAL FUNZIONAMENTO NOMINALE

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Index

Abstract

Within the framework of IFMIF design activities, a research campaign has been launched in 2016 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 Target Assembly (TA) under non-nominal steady state conditions. This research campaign is the development of the study performed in 2014 and it is placed in the framework of the activities of the ENEA research contract ref. 11768/2016 - CIG ZDD1B3BBB0, 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 non-nominal steady state loading scenario envisaged for it. In particular, the investigation of some non-nominal steady state scenarios, foreseeing the failure of one of the two accelerators and the change of the beam footprint size, have been taken into account. 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 and the natural convective heat transfer between the vacuum vessel atmosphere and the support framework non-insulated surfaces allows a significant cooling for the whole TA.

Furthermore, mechanical results have shown that SDC-IC safety 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 $\sim 10^{18}$ $m^{-2}s^{-1}$ 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 [3-4]. As a further development of the study reported in [3-4], a research campaign has been launched in 2016 at DEIM, within the framework of the activities of the ENEA research contract ref. 11768/2016 - CIG ZDD1B3BBB0, aimed to promote and support the theoretical investigation of the TA, properly integrated with its support framework and the Lithium inlet pipe, thermo-mechanical performances under two non-nominal steady state loading scenarios envisaged for it.

In particular, the thermo-mechanical behaviour of the IFMIF TA, integrated with its support framework and the entire Lithium inlet pipe, has been investigated when one of the two 5 MW accelerators fails and the beam footprint size changes. Particular attention has been paid a 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) and the Lithium Loop. The former 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 200 to 300 °C, with a reference inlet value of 250 °C [2,5]. The latter is articulated in a main loop and purification loop and it is intended to feed Lithium to the TA by ElectroMagnetic Pumps, routing it through the Heat eXchange system and the Lithium purification loop, consisting of one cold and two hot traps.

TA and Lithium Loop are connected each other by means of three Fast Disconnecting Systems (FDSs), two located in the TA Lithium inlet pipe and one devoted to attach the TA Lithium outlet duct to the Quench Tank.

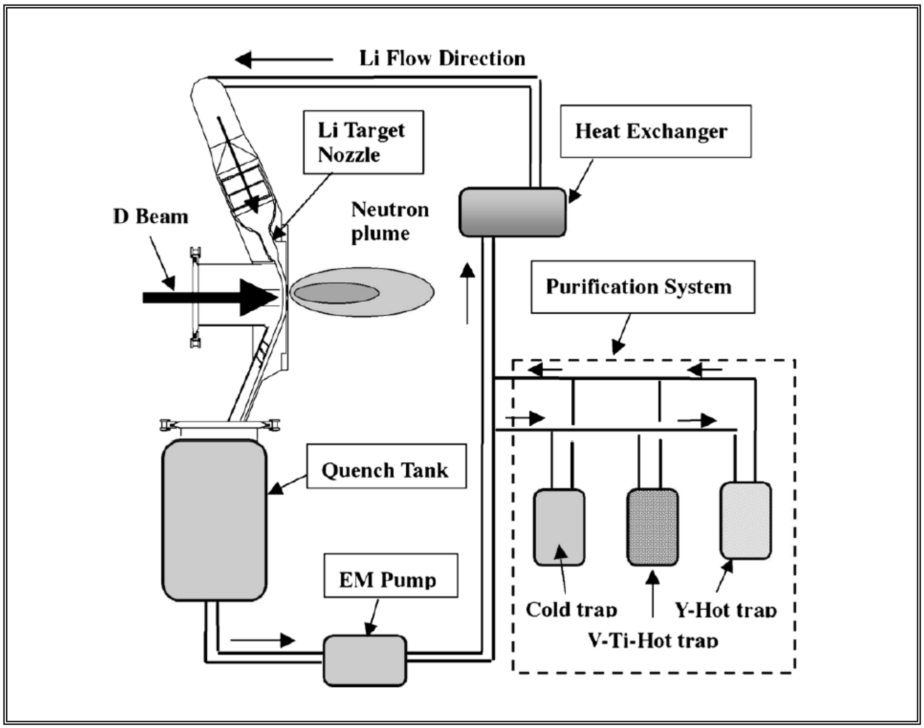

Figure 1. Concept of IFMIF target system.

2.1 *Target Assembly*

The Target Assembly (Figs. 2-3), made of reduce activation steel (EUROFER), is approximately 2.5 m tall and 600 kg heavy. It has to be located in the test cell as close as possible (~2 mm) to the High Flux vertical Test Module (HFTM), being supported by arms laying on a proper support framework. It mainly consists of a flow straightener, a nozzle, a back-plate, a target chamber, a frame, drain baffles and flanges. A more detailed description of its lay-out may be found in [1,2].

The flow straightener, located inside the inlet nozzle, is provided to change Lithium flow regime from turbulent to laminar.

The inlet nozzle is placed at the exit of the straightener to realize a stable Lithium flow. In particular, since the IFMIF target nozzle is required to contract Lithium flow with a contraction ratio of 10, from 1.5 m/s to 15 m/s, and no nozzle exists with a contraction ratio higher than 4 which operates at the required high speed of 15 m/s, a two steps contraction Shima type nozzle has been selected. It is characterized by contraction ratio values of 4 for the first nozzle and 2.5 for the second nozzle and it allows the transverse component of flow velocity to remain under the prescribed limit (±0.1m/s).

The back-plate (BP) is the most heavily loaded TA component (Fig. 4). It is devoted to house the beam footprint, resulting to operate, in IFMIF, under severe conditions of neutron irradiation damage (~50 dpa/y) [5]. Its expected lifetime under irradiation is estimated to be less than 1 year and, although the required replacement period will be defined considering irradiation effects on material properties, it should be significantly shorter than 11 months. Therefore, the reference TA design is conceived with a remotely replaceable back-plate.

A curved profile has been envisaged for the back-plate in the beam footprint region in order to allow, thanks to centrifugal forces arising within Lithium flow, the pressure of the liquid Lithium to be increased and, consequently, also the saturation temperature, avoiding the risk of vaporization under the 10 MW power deposition due to the interaction with deuterons.

Two design options are currently under investigation as far as IFMIF TA back-plate is concerned. The first option is based on the so-called integral TA which is conceived to be replaced during the planned maintenance stages of the system. The second option foresees a removable BP, so that it can be easily replaced using a remote handling device without removing the whole TA. This latter concept, proposed by ENEA, is based on the adoption of a so-called BP "bayonet" design, which consists in a replaceable back-plate that can be inserted to and removed from the TA fixed frame by means of a sliding-skate mechanism [6]. The TA arms are connected to the support framework (Fig. 5), made of EUROFER steel too, directly fixed to the vacuum vessel ground by means of a proper bolt system. The support framework allows the sliding of one of the TA arms during the nominal operational phase in order to allow the TA deformation and maintain the alignment between the deuteron beams and the Lithium footprint.

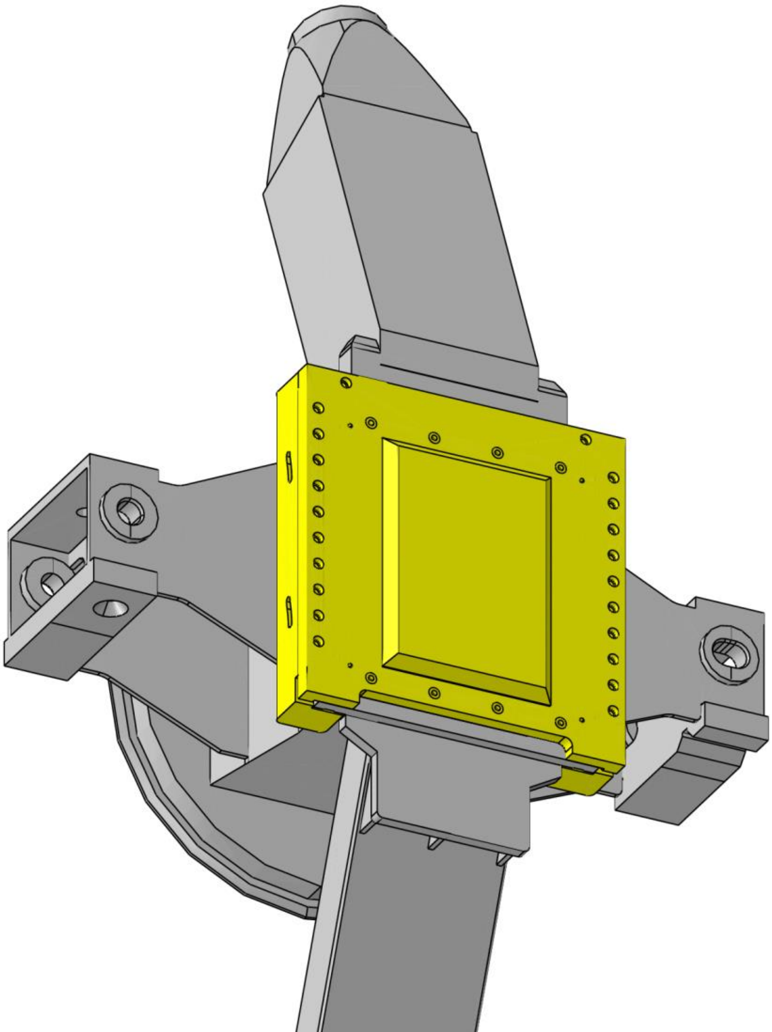

Figure 2. IFMIF Target Assembly.

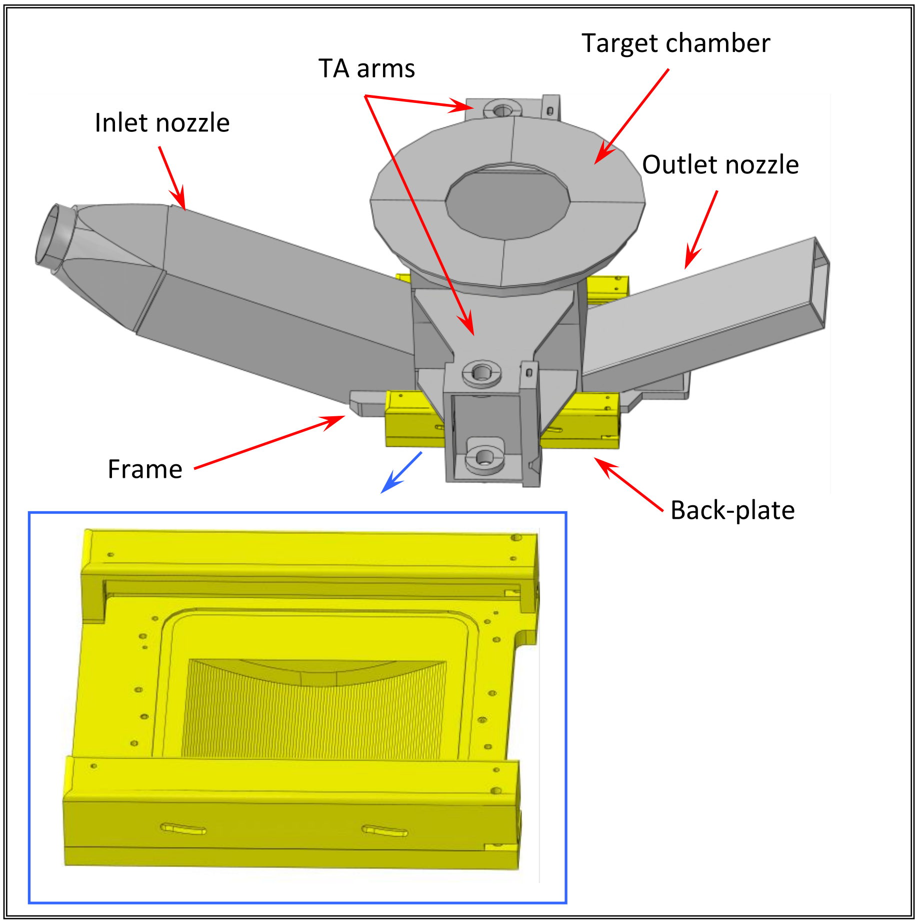

Figure 3. IFMIF Target Assembly exploded view.

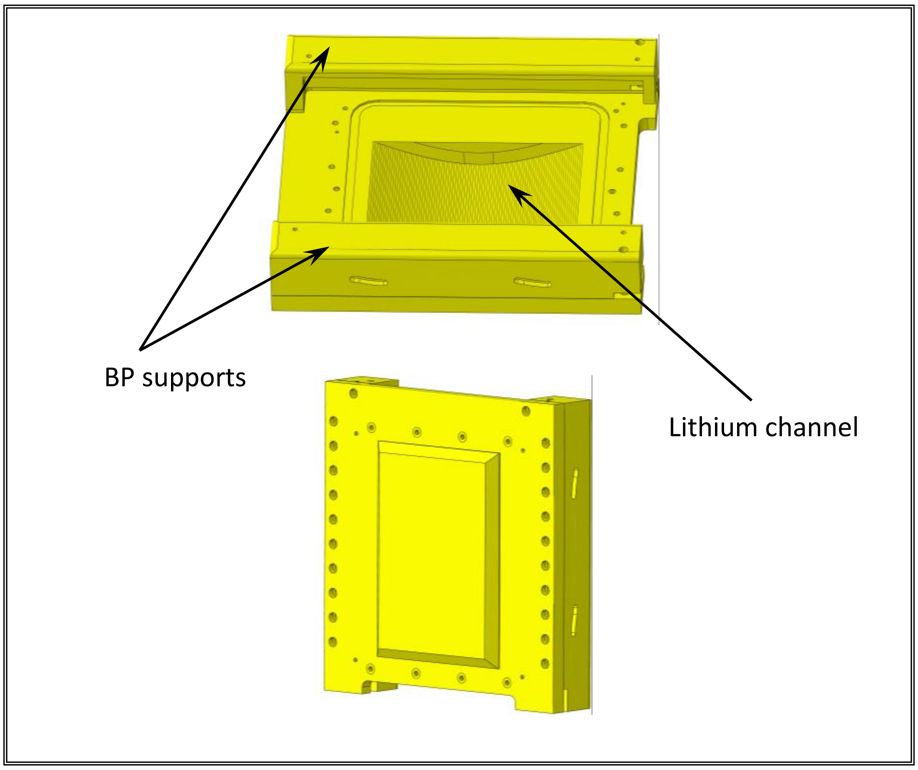

Figure 4. IFMIF Target Assembly back-plate (Front and back views).

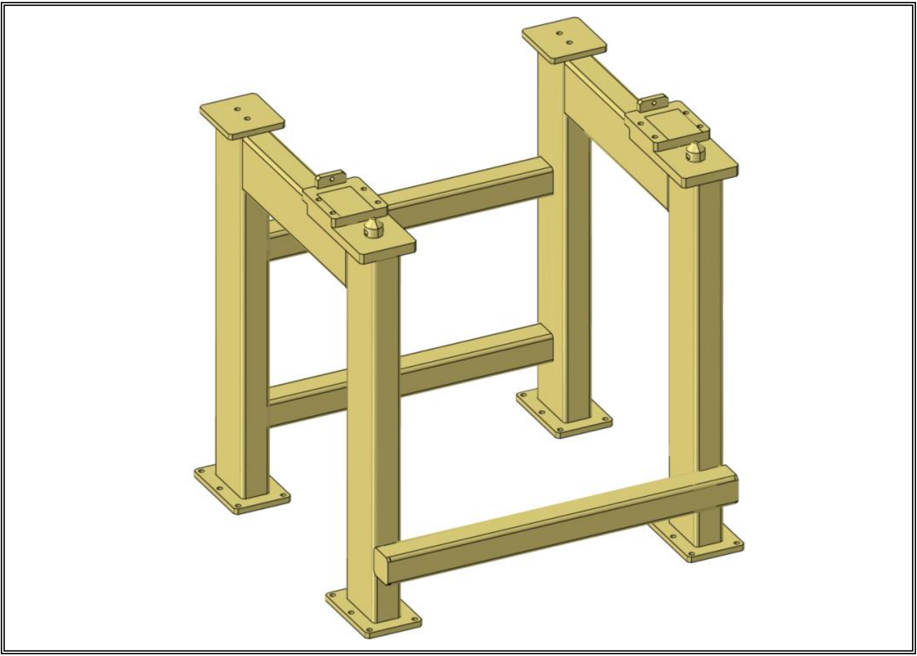

Figure 5. TA support framework.

2.2 Lithium Loop

The Lithium Loop is articulated in a main loop and a purification loop. Its design specifications are reported in Table 1. Further details may be found in [1,2]. The main loop stably supplies liquid Lithium of the adequate flow rate and temperature to the TA. It mainly consists of the quench tank, the overflow tank, the Lithium dump tank, the organic dump tank, the main electromagnetic pump and two heat exchangers. There are, in addition, a trace heating system (to maintain the temperature throughout the loop above the melting point of the Lithium at all times the liquid Lithium is present in the loop), thermal insulation, valves, electromagnetic flow meters, instrumentation and connections to vacuum and argon headers [2]. Among the main loop components, in order to investigate the thermo-mechanical performances of the IFMIF Target Assembly, attention has been paid to the Lithium inlet pipe, made of EUROFER steel, devoted to supply Lithium to the inlet nozzle straightener. The Lithium inlet pipe is articulated in two sections, connected each other by means of two Fast Disconnecting Systems (FDSs) and a gimbal expansion joint (Fig. 6).

Table 1. Main Lithium loop specifications [7].

Lithium inventory	9 m^3
Lithium flow rate	130 l/s (maximum)
Lithium flow velocity	10 – 20 m/s (at the target section)
Lithium temperature	250 – 300 °C (nominal conditions)
	≤ 350°C (emergency)
	400 °C (design limit)
Lithium pressure	10^{-3} Pa (at vacuum interface in the target chamber)
	12 kPa (maximum value at BP interface)
	10^{-3} Pa (target quench tank under operation)

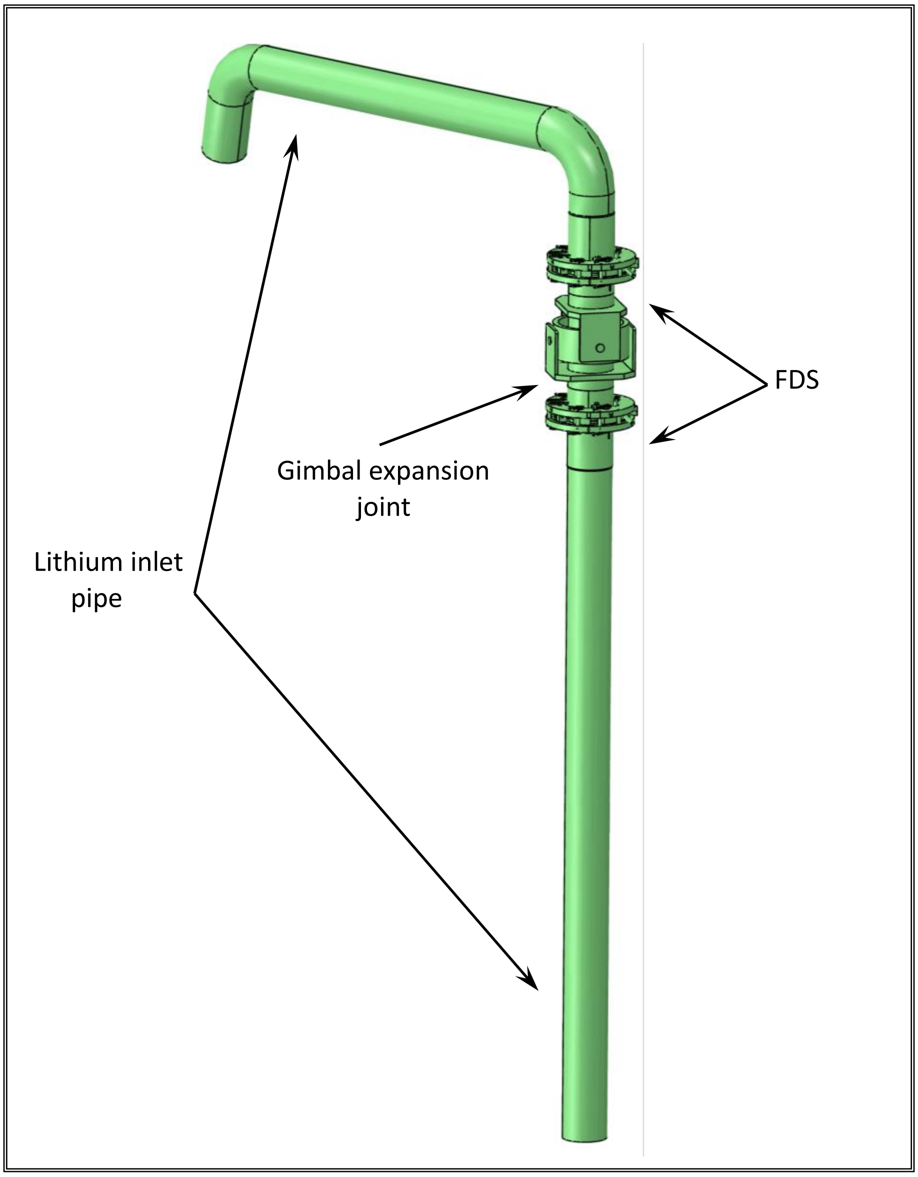

Figure 6. Lithium inlet pipe.

Each FDS permits to easily and quickly connect and disconnect base and removable flange by simply acting (by remote) on only one screw. The seal is the heart and most delicate item of the FDS project, and it is ensured by a metallic gasket operating by axial pressure mode.

Apart from the removable flange and the gasket which are removed together with the TA, the rest of the FDS is attached to the fixed part of the Lithium loop. The FDS is equipped with a leak detection system, used to get an alarm in case the liquid Lithium would flow out of the two flanges connected. A more detailed description of FDS, leak detection system components and of the detachment system functioning is reported in [7].

The gimbal expansion joint is able to compensate angular movements between the flanges of the two inlet pipe sections. It is aimed to compensate thermal expansions during IFMIF normal operation phase and misalignments during target system installation. Further details on the gimbal expansion joint foreseen for the Lithium inlet pipe may be found in [7].

The purification loop consists of a cold trap and two hot traps, to remove various impurities, and of auxiliary supporting equipment. Major impurities are Protium (H), Deuterium (D), Tritium (T), 7Be, activated corrosion products and other species (C, N, O) [2].

3 TA 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 TA, whether endowed with the bayonet type replaceable back-plate, integrated with its support framework and the Lithium inlet pipe.

The research campaign, funded by ENEA-Brasimone with the research contract ref. 11768/2016 - CIG ZDD1B3BBB0, 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 to assess the TA thermo-mechanical behaviour under two different non-nominal steady state scenarios, in order to verify whether the components might safely withstand the thermo-mechanical loads it 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 scenarios

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 loading scenarios assessed in this campaign of research represent a deviation from the reference conditions and they concern two non-nominal steady state scenarios, named A and B, in which the loss of one of the two deuteron accelerators is taken into account. In the loading scenario A the presence of only one accelerator has been considered, while as far as scenario B is concerned, the loss of one accelerator together with the halving of the beam footprint size (10 x 5 cm^2) has been investigated.

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 investigate exclusively the thermo-mechanical response of the structure during some deviations from the nominal steady state operational phase.

3.2 The FEM model

A realistic 3D FEM model, reproducing the TA integrated with its support framework 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 ~$4.0 \cdot 10^5$ nodes connected in ~$1.55 \cdot 10^6$ linear tetrahedral elements has been selected, whose views are reported in Figs. 7-14. The so formed spatial discretization allows numerical simulations to be carried out in about 4 hours. The two FDS and the gimbal expansion joint of the Lithium inlet pipe have not been directly modelled, but their mechanical effects have been simulated imposing, for the former, an appropriate contact model that permits to consider the flanges tightened by the FDS as perfectly tied while, for the latter, a proper kinematic model, that allows the coupling of the rotational and translational displacements of the two Lithium inlet pipe sections connected by the gimbal expansion joint.

According to the IFMIF Comprehensive Design Report [1] and its subsequent modifications relevant to the EU TA concept, EUROFER steel has been assumed as the TA, support framework and Lithium inlet pipe structural material. Lithium flowing onto BP and outlet nozzle surfaces has been modelled too in order to properly simulate its thermal interaction with TA. To this purpose a flow velocity at the inlet nozzle exit amounting to 15 m/s has been adopted. 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, in particular, EUROFER mechanical behaviour has been simulated adopting a linear elastic model.

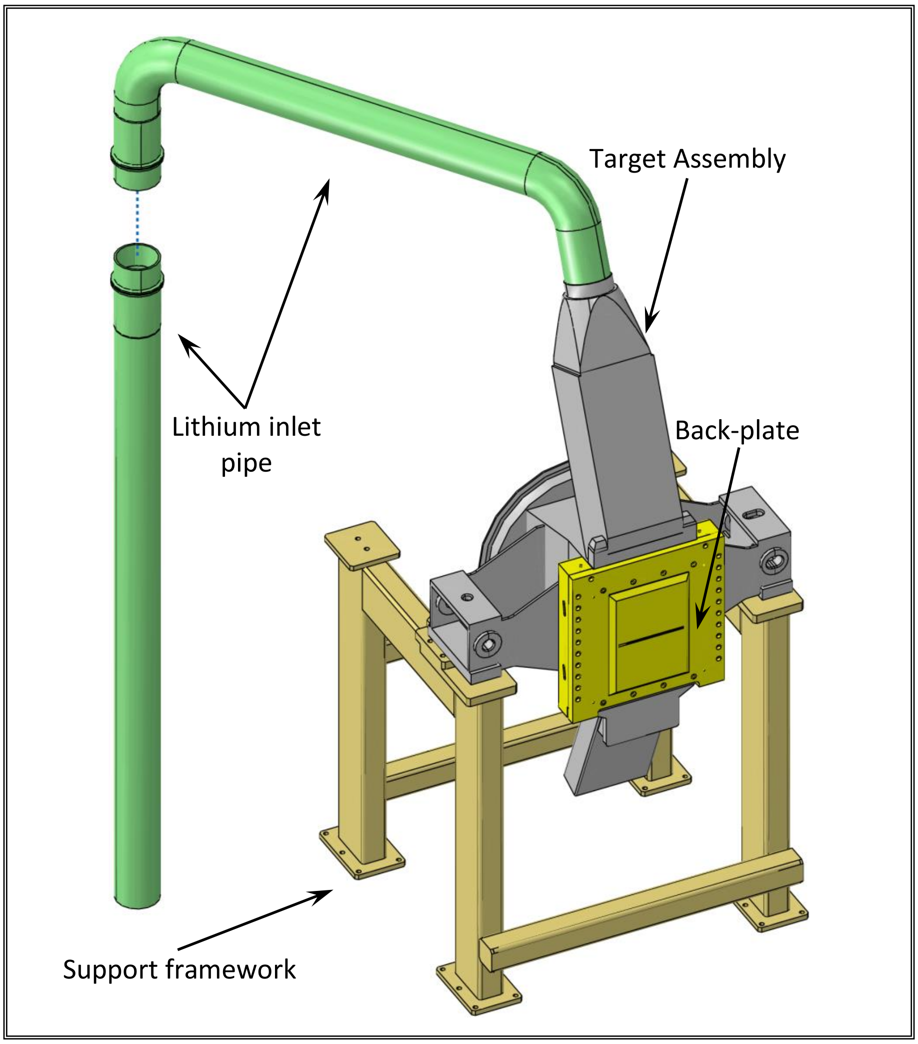

Figure 7. FEM model.

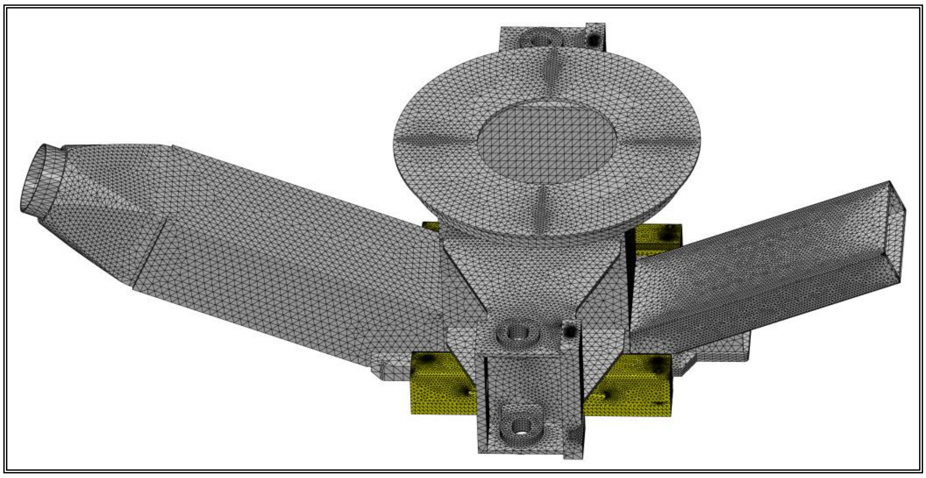

Figure 8. FEM model. Target Assembly lateral view.

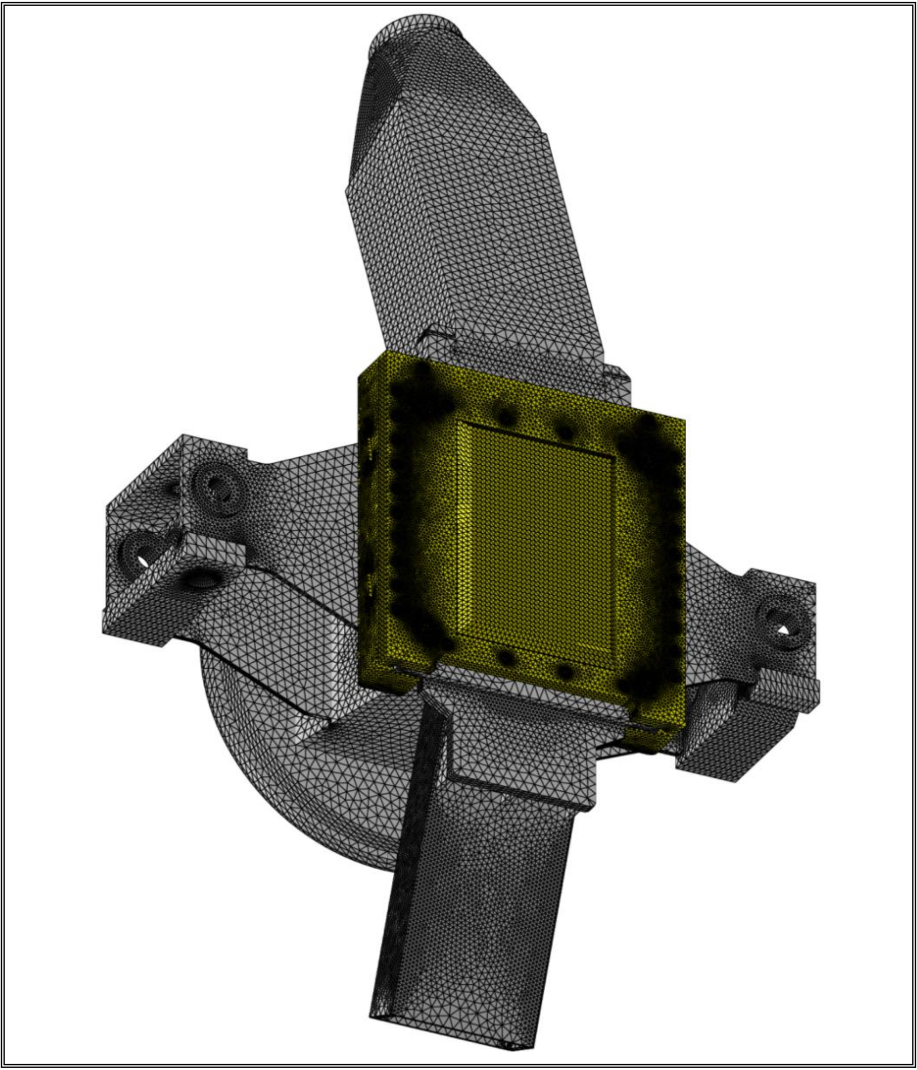

Figure 9. FEM model. Target Assembly front view.

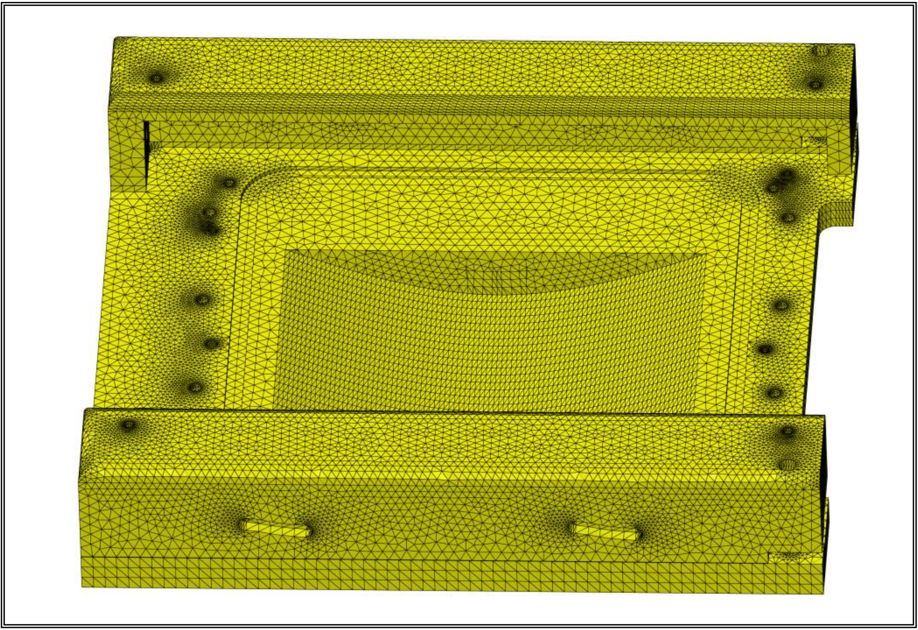

Figure 10. FEM model. Particular of the back-plate.

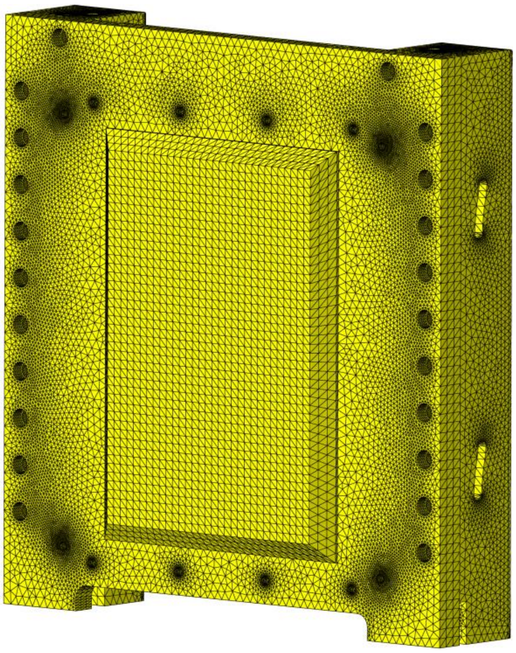

Figure 11. FEM model. Particular of the back-plate.

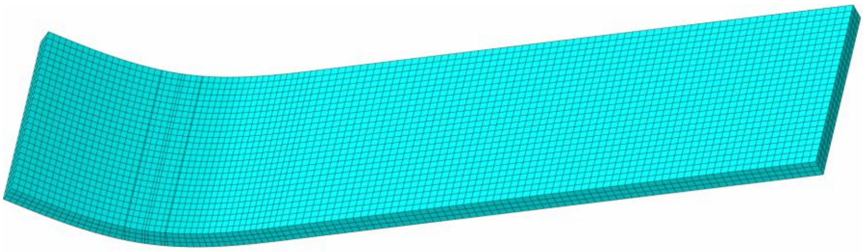

Figure 12. FEM model. Particular of the Lithium flow domain.

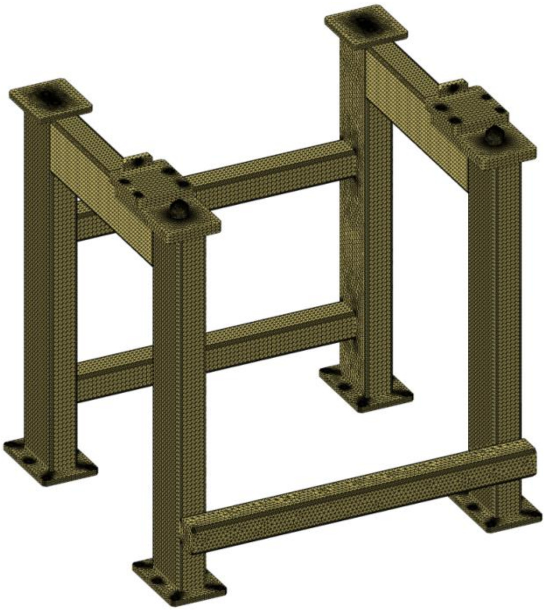

Figure 13. FEM model. Particular of the support framework.

Figure 14. FEM model. Particular of the Lithium inlet pipe.

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 framework and Lithium inlet pipe, thermo-mechanical behaviour under the two non-nominal steady state loading scenarios:

- thermal interactions between the IFMIF target system components;
- volumetric density of heat power deposited in the Lithium flow footprint region;
- volumetric density of heat power deposited within TA, framework and inlet pipe;
- forced convection with Lithium;
- heat transfer between BP and High Flux Test Module (HFTM) through helium gas;
- heat transfer between target chamber and beam duct;
- internal irradiation;
- external irradiation;
- TA and support framework natural convection cooling.

In particular, the volumetric density of nuclear deposited heat power has been supposed to be uniformly distributed within the beam footprint region of Lithium flow domain to model heat power deposition due to interactions between deuterons and Lithium. Two different values, according to the loading scenarios investigated, have been taken into account. A volumetric density of heat power value of 20 GW/m³ has been adopted for the loading scenario A, where only one deuteron beam interacts with the nominal footprint (Fig. 15a). As far as scenario B is concerned, a value of 40 GW/m³ has been imposed on the halved nominal beam footprint region (Fig. 15b).

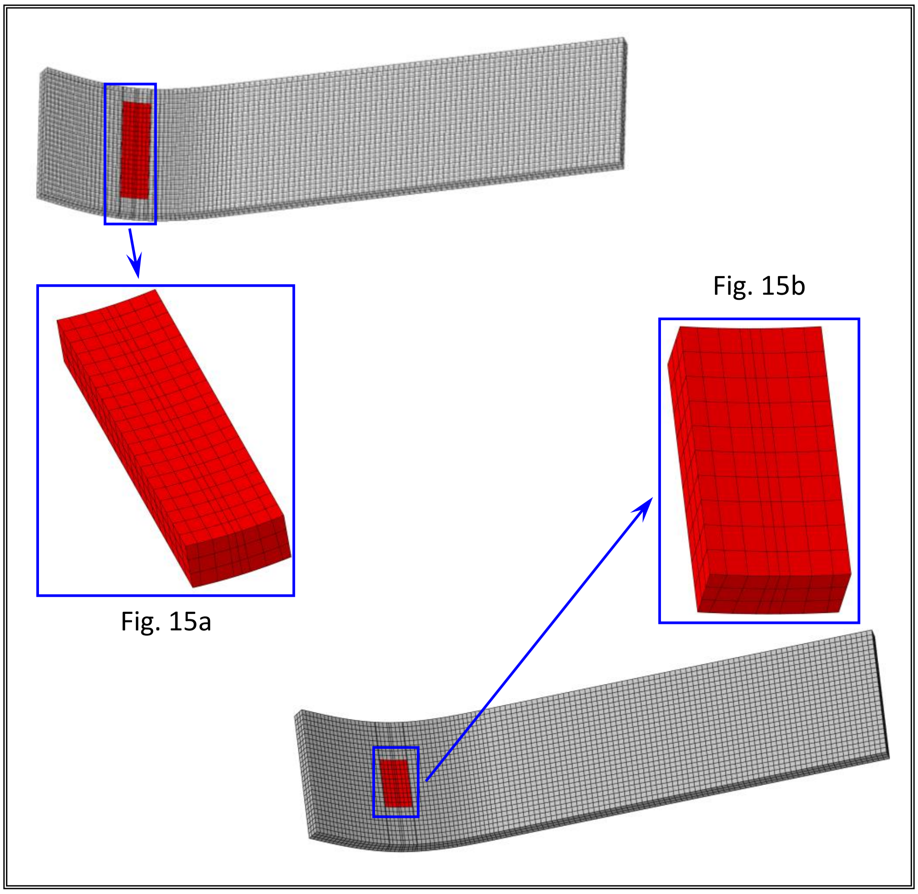

Fig. 15a

Fig. 15b

Figure 15. Detail of Lithium flow domain beam footprint regions.

3.4 Mechanical interactions, loads and boundary conditions

As far as the mechanical analysis is concerned, the following mechanical interactions, loads and boundary conditions have been assumed to simulate the TA thermo-mechanical behaviour under the two non-nominal steady state loading scenarios:

- thermal deformations according with the loading scenario;
- mechanical interactions between the TA components;
- weight force;
- internal and external pressures;
- tightening screw loads;
- skate-based clamping system loads;
- support framework constraints;
- Lithium inlet pipe constraints;
- TA system constraints;
- Lithium inlet pipe gimbal expansion joint.

A more detailed description of the mechanical interactions, loads and boundary conditions listed in this section can be found in [4].

3.5 Steady state analysis

Uncoupled thermo-mechanical steady state analyses have been carried out in order to investigate the TA, integrated with its support framework and the Lithium inlet pipe, thermo-mechanical behaviour under two non-nominal loading scenarios in order to assess the potential aptitude of this system to safely withstand the loads it undergoes without incurring in significant deformations and structural crisis of the structure, with a particular attention on its replaceable back-plate.

Two steady state thermal analyses, one for each thermal condition taken into account, have been carried out to obtain the corresponding thermal field distribution. Every thermal analysis has been followed by two independent steady state mechanical analyses intended to assess separately the distributions of total and secondary stresses and to derive that of primary stresses, as the difference.

In order to study the structure thermal behaviour, attention has been mainly focussed on the assessment of the spatial distribution of its thermal field. On the other hand, in order to investigate its mechanical behaviour, attention has been paid to the assessment of the spatial distribution of the Von Mises equivalent stress field, σ_{VM}. Moreover, in order to verify that no significant deformations occur which might warp BP channel inducing Lithium flow instability and cause an overlapping between BP external surface and HFTM, a particular attention has been paid also to the analysis of the BP deformation field and to the displacements of its surface directly faced to HFTM. Finally, the potential insurgence of a misalignment between deuteron beams and Lithium footprint, due to excessive BP displacements on the plane normal to the beams direction, have been investigated too.

Since the design of TA has to be based on a consistent set of rules taking into account, at the same time, regulation requirements for nuclear components, the peculiarities of EUROFER mechanical behaviour and the specific operating conditions foreseen for IFMIF environment, a stress linearization procedure has been carried out, with the specific aim to evaluate general or local primary membrane stress tensor (P_m or P_L), primary bending stress tensor (P_b), general or local secondary membrane stress tensor (Q_m or Q_L), secondary bending stress tensor (Q_b) and peak stress (F) in some particularly significant paths of the Target Assembly BP (Fig. 16). Stress values calculated have been adopted to verify if the TA thermo-mechanical stress state complies with requirements prescribed by SDC-IC rules [13], that are both the most conservative and comprehensive of all possible damage modes for level A criteria. In particular, in SDC-IC as in conventional codes, primary stresses are limited in order to guarantee the components against M (monotonic) type damages, while secondary stresses are limited to preserve them against C (cyclic) type damages, namely the progressive deformation and the time independent fatigue [14]. A complete description of the SDC-IC rules adopted in the present study are available in [13].

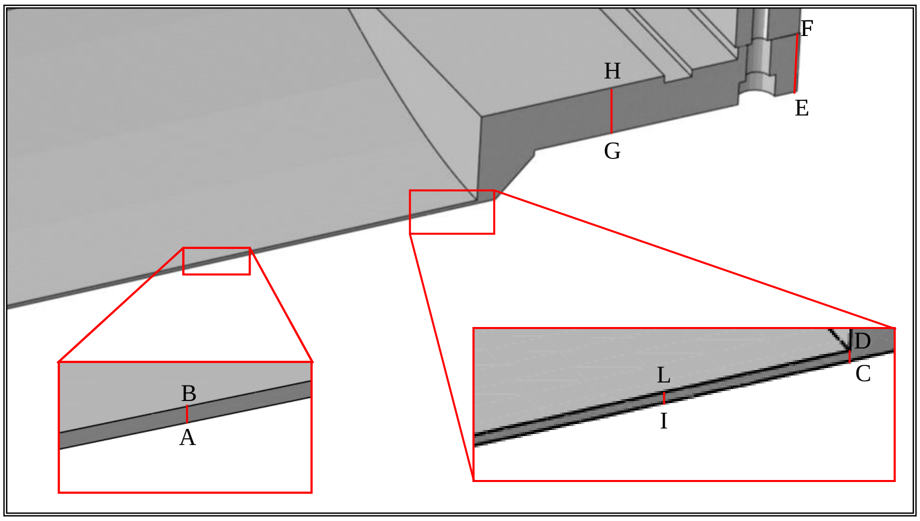

Figure 16. Stress linearization paths.

Results obtained in terms of thermal and displacement fields are summarized in tables 2-4. As it can be observed, the maximum temperatures, the maximum misalignment (u_x and u_z) between the deuteron beam and the Lithium footprint, as well as the maximum displacement of the BP external surface toward the HFTM ($u_{y,Max}$) are predicted in Scenario B. Therefore, results of thermo-mechanical analysis in term of thermal, Von Mises equivalent stresses and displacement field, are reported in the following (Figs. 17-22) only for this loading scenario.

In particular, from the thermal point of view, results obtained for Scenario B show that neither the limit temperature for thermal activated phenomena of 450°C [13] nor the maximum EUROFER allowable temperature of 550°C is overcame. Consequently, SDC-IC high temperature rules have not been considered and only low temperature SDC-IC safety criteria has been performed.

As far as the mechanical results are concerned, it can be observed that the highest values of the Von Mises equivalent stress are reached in a very small area, probably due to numerical singularities within the FEM model. In fact, the whole structure experiences Von Mises equivalent stress values lower than 400 MPa in a widely diffused region of the geometric domain investigated.

As for the displacement field, the deformed (in red) vs. un-deformed (in grey) configuration of the whole model and a detail of the BP are reported in Figs. 23-24, adopting an isotropic amplification factor equal to 50 for the deformed configuration in order to amplify the structure displacements respect to the initial configuration. Particular attention has been paid to the potential misalignment between the deuteron beams and the Lithium footprint, the slipping that may occur between the TC arms and the support framework and finally to the BP external surface displacements, in order to check that no overlapping with the HFTM surface takes place. Results obtained highlight that neither overlapping between BP and HFTM external surfaces nor a pronounced misalignment between the deuteron beam and the Lithium footprint should occur.

Finally, a stress linearization procedure has been performed along the most significant paths already highlighted. The fulfilment of safety verifications prescribed by the SDC-IC safety rules has been checked along these paths and results obtained for both scenarios have been reported in Table 5. Results show that all criteria are widely verified in all paths except for the one against the immediate plastic flow localization in case of Scenario B, where a value slightly above 1 is predicted.

Table 2. Maximum and minimum component temperatures.

Maximum temperatures [°C]				
Scenario	BP	TA	Inlet pipe	Framework
A	289.9	315.6	250.0	65.4
B	311.7	319.5	250.0	65.5
Minimum temperatures [°C]				
Scenario	BP	TA	Inlet pipe	Framework
A	169.6	60.0	250.0	50.8
B	170.3	60.3	250.0	50.8

Table 3. External central BP node displacements.

Scenario	u_x [mm]	u_y [mm]	u_z [mm]
A	-0.260	0.664	0.036
B	-0.266	0.712	0.042

Table 4. Maximum BP displacement along the beam direction ($u_{y,Max}$).

Scenario	$u_{y,Max}$ [mm]
A	0.720
B	0.746

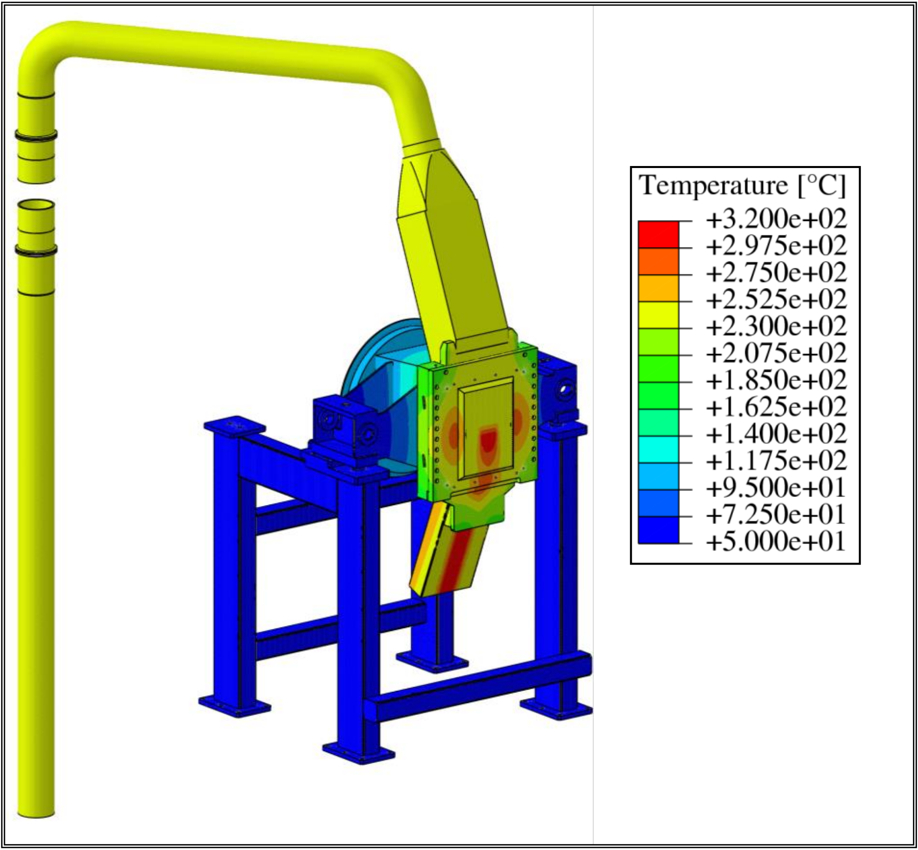

Figure 17. Scenario B – Thermal field.

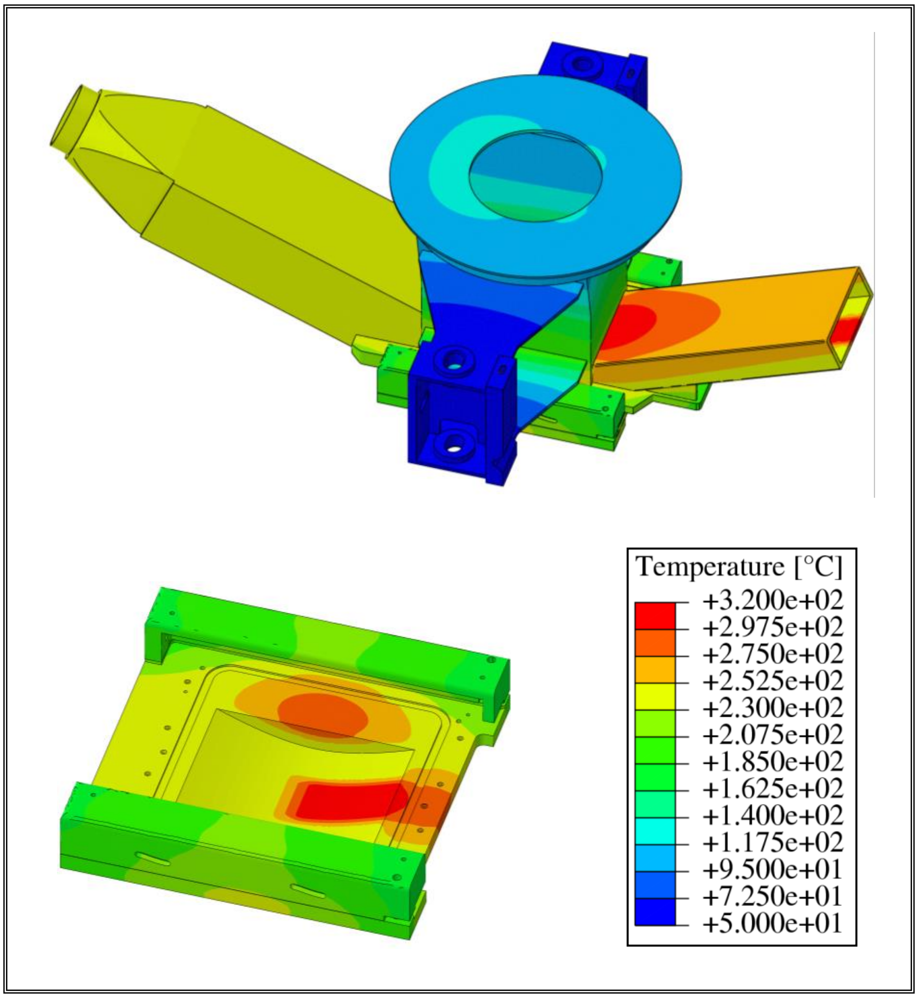

Figure 18. Scenario B – TA and BP thermal field.

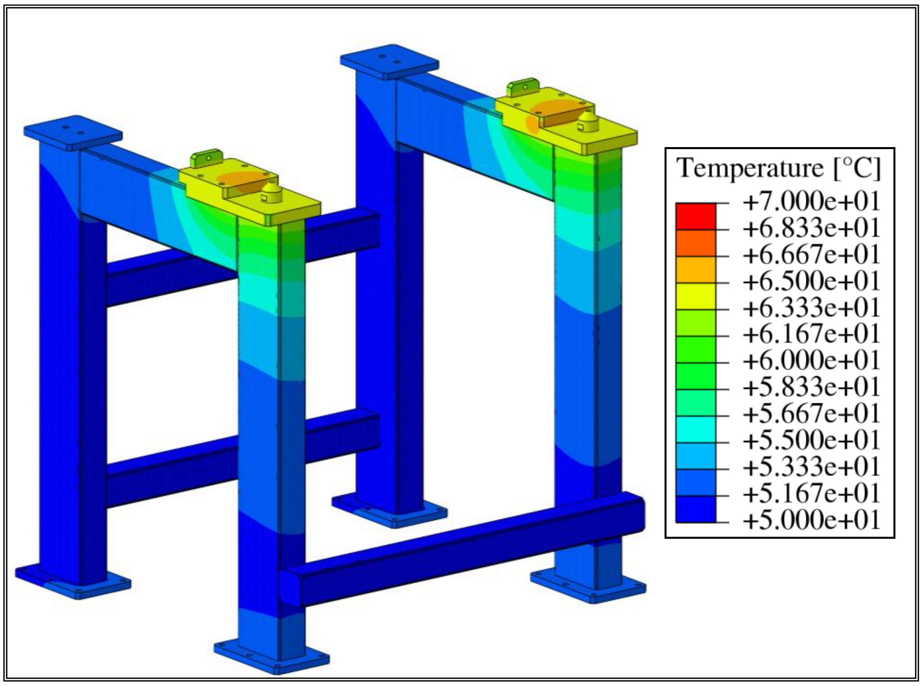

Figure 19. Scenario B – Support framework thermal field.

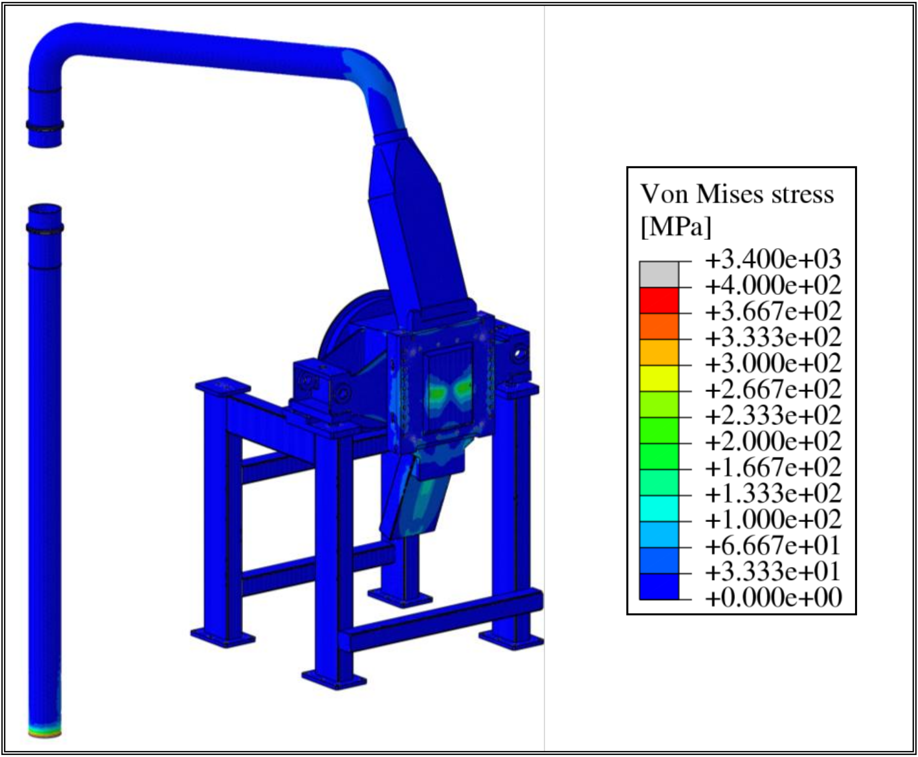

Figure 20. Scenario B – Von Mises stress field.

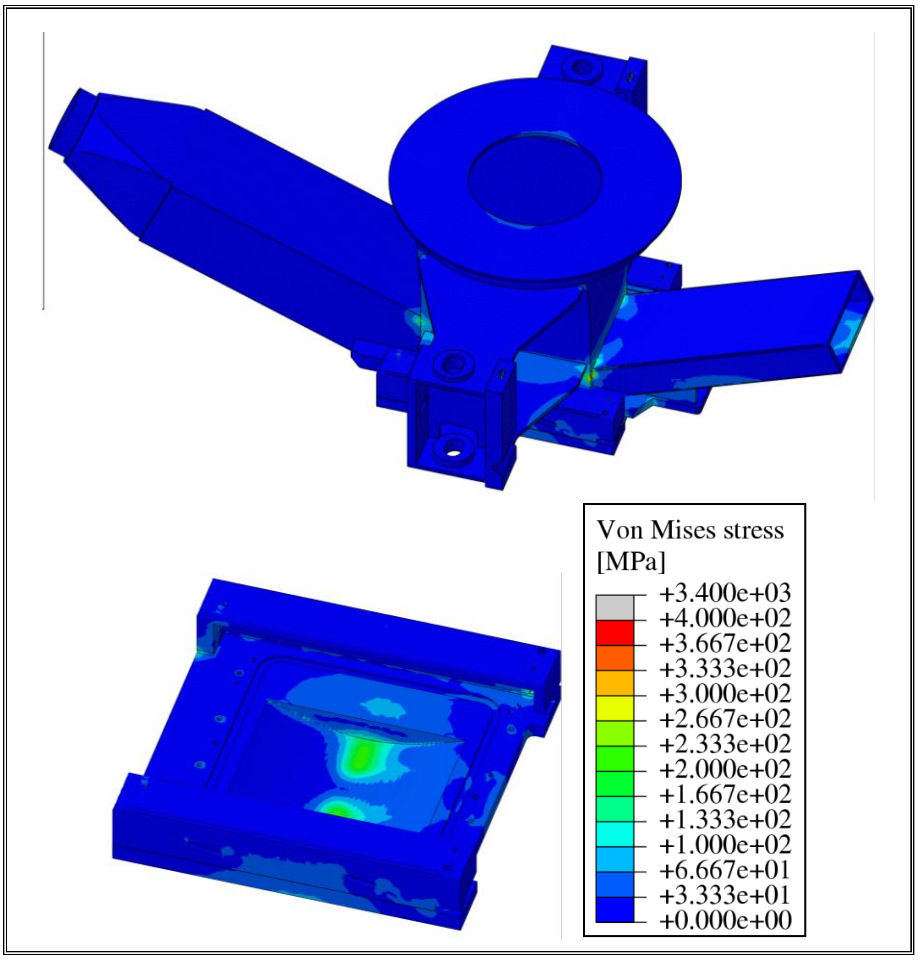

Figure 21. Scenario B – TA and BP Von Mises stress field.

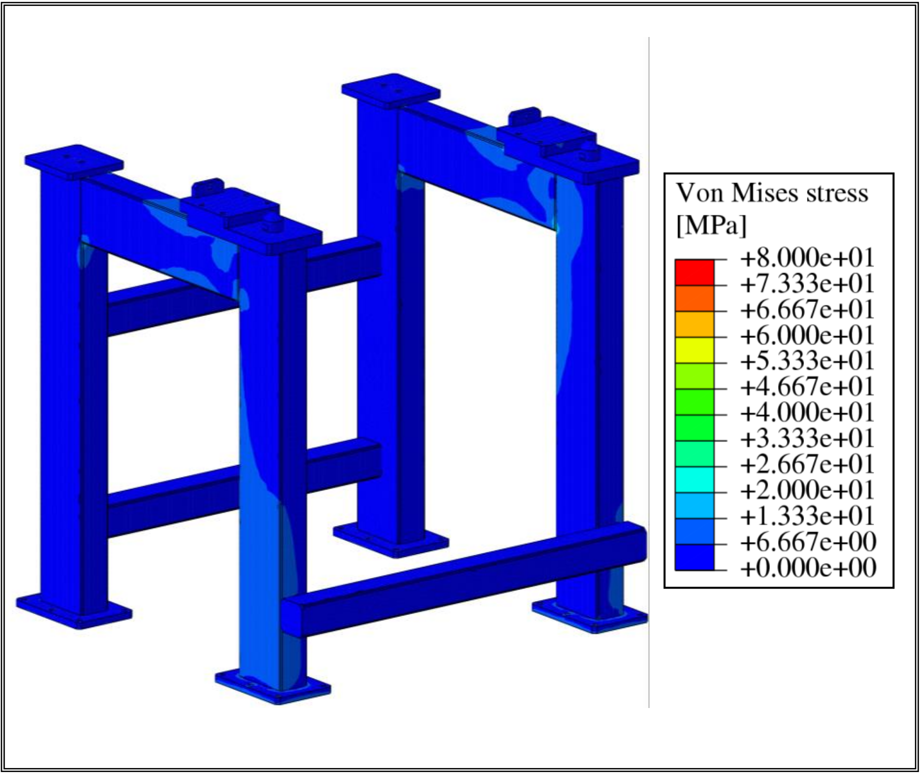

Figure 22. Scenario B – Support framework Von Mises stress field.

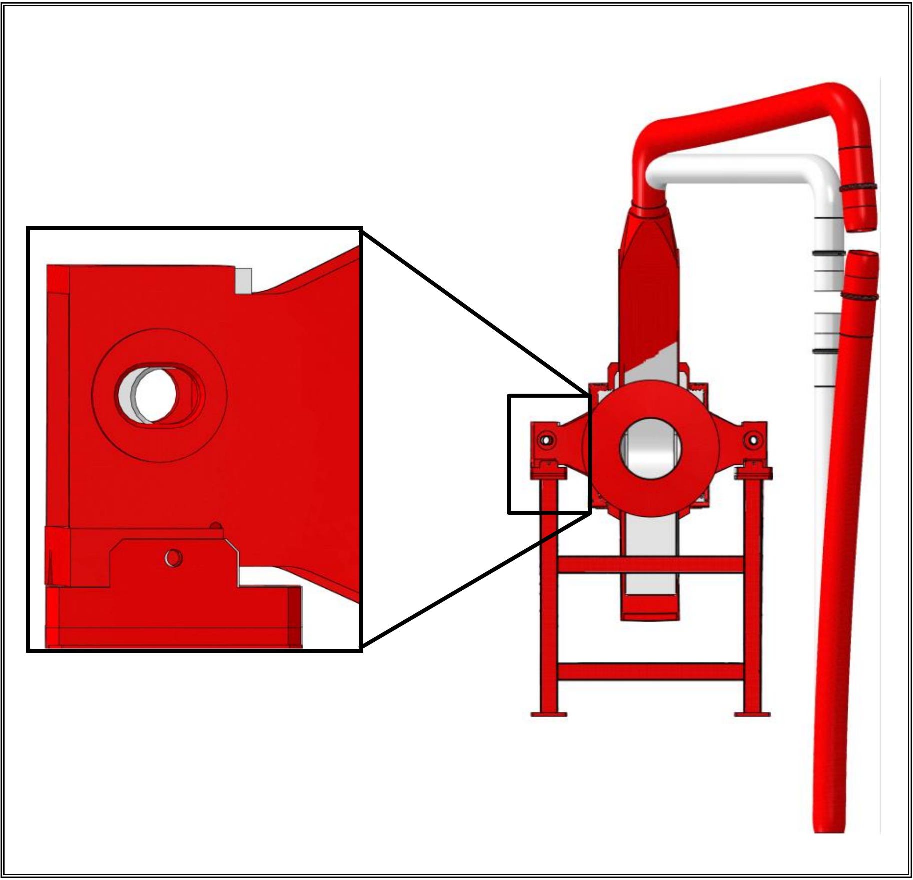

Figure 23. Scenario B – Deformed vs. un-deformed configuration.

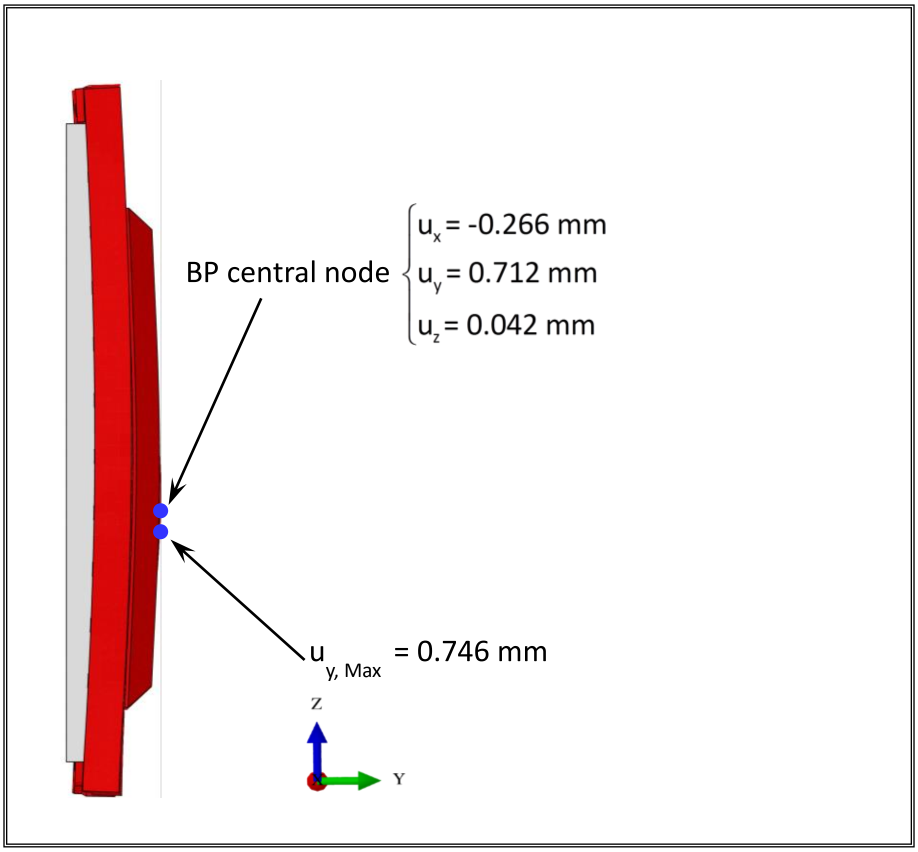

Figure 24. Scenario B – BP deformed vs. un-deformed configuration.

Table 5. SDC-IC low temperature safety rules.

	Path AB	Path CD	Path EF	Path GH	Path IL
Scenario A					
$T_{Max\text{-}Path}$ [°C]	266	250	231	283	250
P_m/S_m	0.0040	0.0015	0.0002	0.0005	0.0020
$(P_m+P_b)/(K_{eff}*S_m)$	0.0027	0.0011	0.0003	0.0006	0.0014
$(P_m+Q_m)/S_e$	0.3915	0.6689	0.2775	0.2154	0.9028
Scenario B					
$T_{Max\text{-}Path}$ [°C]	266	250	231	283	250
P_m/S_m	0.0038	0.0014	0.0002	0.0005	0.0018
$(P_m+P_b)/(K_{eff}*S_m)$	0.0026	0.0011	0.0003	0.0006	0.0012
$(P_m+Q_m)/S_e$	0.1049	0.7208	0.2797	0.2417	1.0190

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 the IFMIF Target Assembly integrated with its support framework and the Lithium inlet pipe under two different non-nominal loading scenarios, 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 320 °C is predicted at localized region of the target chamber at the edge with the frame and the back-plate, in both loading scenarios assessed.

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 in Scenario B the maximum value of the misalignment (u_x and u_z) between the deuteron beams and the Lithium footprint and the highest maximum displacement of the BP external surface toward the HFTM ($u_{y,Max}$) are predicted. In particular, the maximum BP displacement along the beam direction amounts to be 0.746 mm towards the HFTM. Therefore, BP and HFTM contact can be excluded, being 2 mm their nominal gap under room temperature.

Finally, SDC-IC safety rules have resulted to be generally fulfilled with comfortable margins except for that one relevant to the immediate plastic flow localization in case of Scenario B. Indeed, the verification of this criterion is not fulfilled in a particular heavily stressed path lying approximately on the BP middle section along the beam direction, suggesting the potential need of a BP design revision.

5 References

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6 Abbreviations and acronyms

BP	Back-Plate
DEIM	Dipartimento di Energia, Ingegneria dell'informazione e Modelli matematici
FDS	Fast Disconnecting System
FEM	Finite Element Method
HFTM	High Flux Test Module
IFMIF	International Fusion Materials Irradiation Facility
SDC-IC	Structural Design Criteria for In-vessel Components
TA	Target Assembly