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Rapporto sulla progettazione del prototipo del target per L'EVEDA loop

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RAPPORTO SULLA PROGETTAZIONE DEL PROTOTIPO DEL TARGET PER L'EVEDA LOOP

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Sommario

The present report describes the engineering design of the Target Assembly with bayonet Back-Plate for the EVEDA lithium test loop, carried out during the reference period December 2010 – November 2011.

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Index

Introduction

The EVEDA Lithium Test Loop (ELTL) is a lithium facility recently built at Oarai in Japan [1] to test and validate many of the thermohydraulics features and engineering solutions proposed for the Lithium Target Facility design of the IFMIF plant.

As for IFMIF, the main objective of the Lithium Target system of the ELTL is to provide a fast, reliable and stable flow of lithium on the Back Plate (BP) of the Target Assembly (TA). To be representative of the IFMIF target, all the characteristics of the Li flow in the ELTL (e.g., Li channel geometry, flow velocity, jet thickness,…) are similar to the ones foreseen for the IFMIF target, except for the channel width on the back plate that is reduced to 100 mm, i.e., about 1/3 of the IFMIF one (260 mm).

Main specifications common to ELTL and IFMIF target assemblies in normal operation are the followings [2]:

Li speed at nozzle exit: 10-20 m/s
Li flow thickness: 25 ±1 mm
Li inlet temperature: 250 °C
Vacuum pressure: 10^{-3} Pa (at free-surface during operation)

In IFMIF, the BP operates under severe conditions of neutron irradiation damage (up to 60 dpa/fpy), therefore it must be designed for replacement after a certain number of months [3]. To meet this goal, two different design options have been considered:

- the so called integral target assembly which is conceived to be entirely replaced during the planned maintenance stages of the system.
- the TA with a removable BP that can be easily replaced using a remote handling device without removing the whole target body.

To validate both options, two different TA systems have been proposed for the ELTL TA:

1) an integral target in SS316 to be developed by JAEA in Japan

2) a TA with replaceable BP completely made of Reduced Activation Ferritic Martensitic (RAFM) steels (BP in EUROFER and TA body in F82H) to be developed in collaboration between Europe and Japan

Within the second option, ENEA is in charge of the engineering design of the replaceable BP in EUROFER material to be integrated with the F82H target body designed by ENEA and manufacture by JAEA.

The solution adopted by ENEA to implement the replaceable BP concept is based on the so called bayonet concept that is also envisaged in the design of the IFMIF TA. In such a concept, the BP is equipped with two sliding skate mechanisms that allow to insert, remove and rigidly connect it to the the fixed part of the TA [4].

With respect to the integral target, the bayonet BP allows to:

- simplify the replacement of the BP from Remote Handling (RH) point of view
- reduce the time required for its substitution
- minimize the contaminated wastes, since only the BP and not the entire target is replaced

On the contrary, the TA with bayonet BP is more complex than the integral TA.

The present report describes the engineering design of the bayonet BP carried out by ENEA during the reference period.

1. The bayonet concept backplate design

1.1 General description and design requirements

A 3D model of the system is shown in Figs. 1 and 2. The concept is based on the possibility to vertically insert and remove the BP from the interface frame permanently fixed to the TA body, without dismounting the target itself.

The closure system between the BP and the frame consists of a combined solution of sliding skates and tightening bolts which provides the force required on the gasket to maintain the necessary sealing capability between the volume inside the TA and the environment outside.

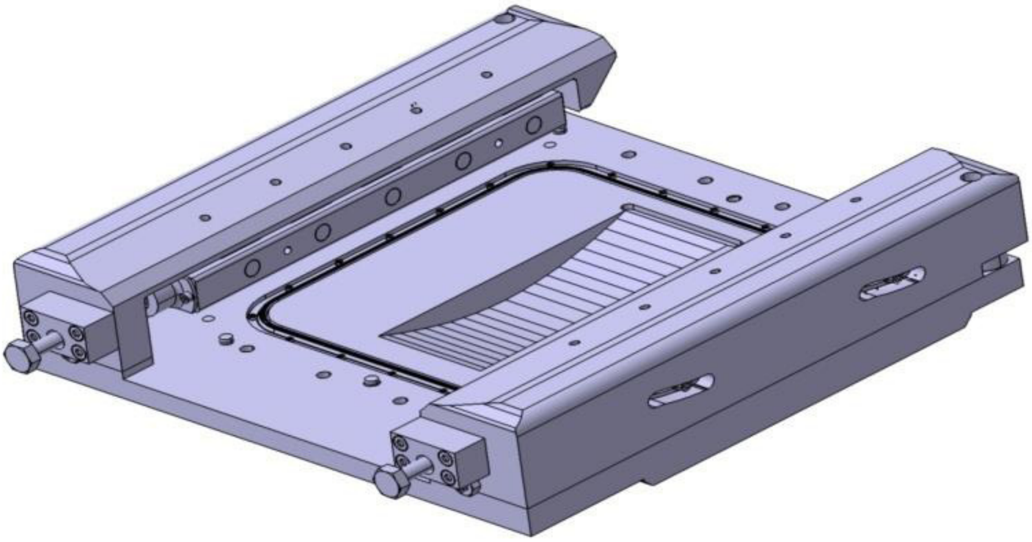


Figure 1 – 3D model of the bayonet BP (front view)

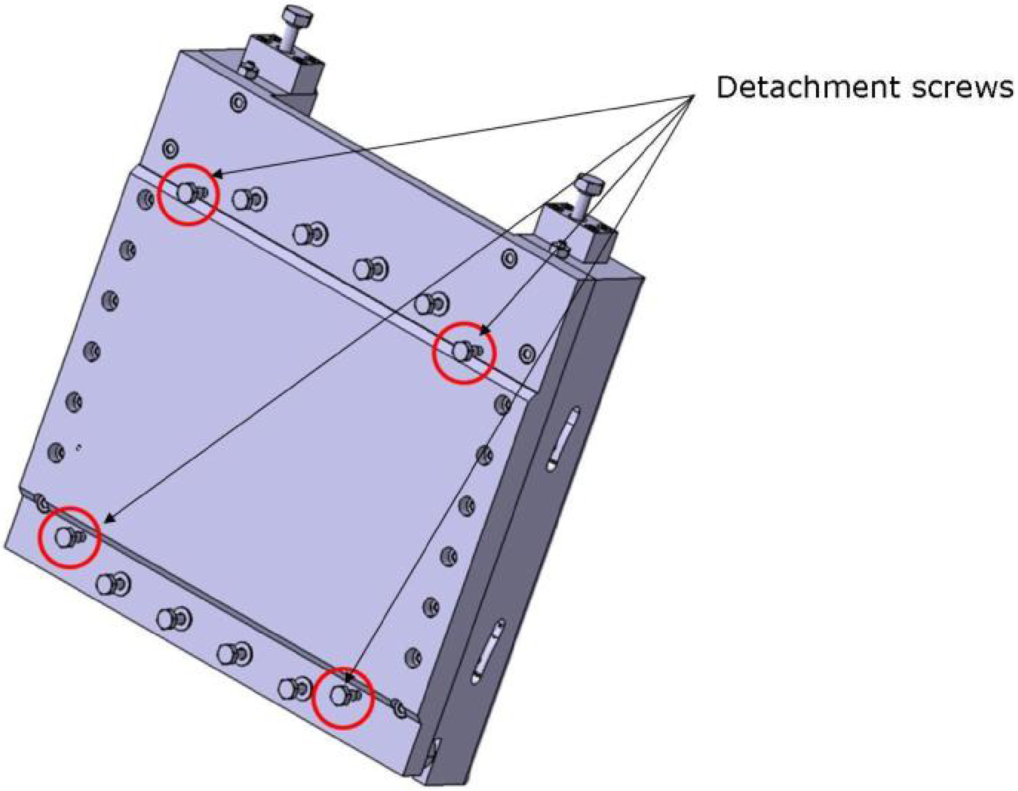


Figure 2 – 3D model of the bayonet BP (back view)

The removable BP is characterized by a rectangular inner concave profile [5] on which the liquid lithium runs in the deuterons bombardment area. The present bayonet concept foresees the introduction of the BP from the top of the fixed frame, by sliding it along the vertical direction, as can be seen in Fig. 3.

The back-plate is locked by a skate system and at the end of its travel it is rigidly connected to the frame by means of four bolts (two in the upper part and two in the bottom part, see Fig 3).

The locking system must provide a force of up to 24 tons on the gasket in order to guarantee the sealing and maintain the required vacuum gradient between the target chamber (10^{-3} Pa) and the vessel where the TA is installed (10^{-1} Pa).

The gasket must ensures a maximum leak rate of 10^{-10} Pa $*m^3/s$, and is fitted into a rectangular groove between the front face of the back-plate and its matching surface on the permanent interface frame.

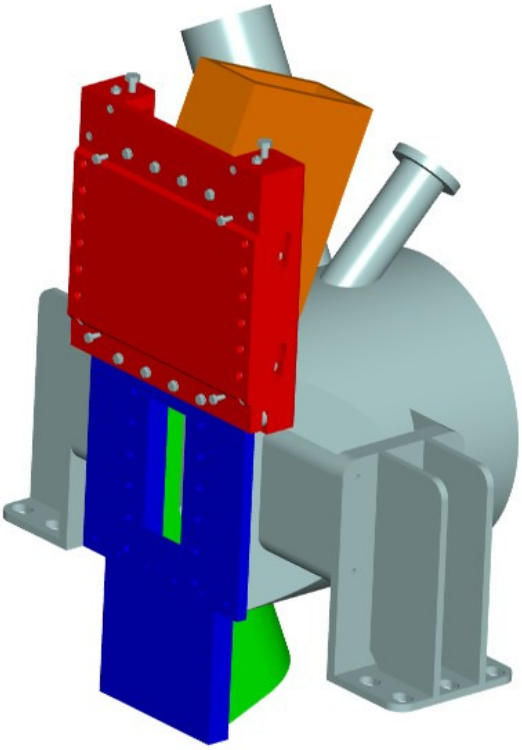


Figure 3 – Fixed frame (blue), removable BP (red) and TA body (grey)

The design of the bayonet BP has been accomplished taken into account the following aspects:

- the capability of the skate system to transmit the load required by the sealing gasket was proved in the past on dedicated experimental mock-ups at ENEA Brasimone
- the skate system is exchanged each time together with the BP;
- the use of a rectangular gasket (instead of a circular one) reduces the load necessary for the sealing, thus potentially reducing also the force required for the detachment of the BP from the frame during replacement operation;

The TA system is made up of three main components:

- the interface frame
- the removable back-plate
- the closure system

1.2 The interface frame

The interface frame consists in a centrally perforated element to be welded to the target body on one side and to be clamped to the BP on the other side (Fig. 4). The welded connection between the frame and the target assembly, in correspondence of the lithium channel, has to be successively machined in order to assure a surface continuity without any step.

The frame consists of a rectangular plate with two lateral shapes which constitute, once that the BP is correctly inserted, the rolling surface for the sliding skates.

In the centre of the plate one rectangular aperture is provided such that when the back plate is positioned, it forms the complete flow channel for the liquid lithium.

A specific isostatic system for the centering of the BP with respect to the frame has been conceived (Fig. 5). It consists mainly of two pins (one in the upper part and one in the bottom part of the BP) which engage in calibrated slots created on the interface frame. The lower pin engages in a circular slot and blocks the displacements of the BP with respect to the frame in horizontal and vertical directions while allowing rotation around it. The upper pin engages in an elliptical slot and blocks the remaining degree of freedom (rotation) while permitting the vertical BP expansions caused by differential thermal dilatations. This permits to avoid dangerous stresses arising from temperature variations during transients.

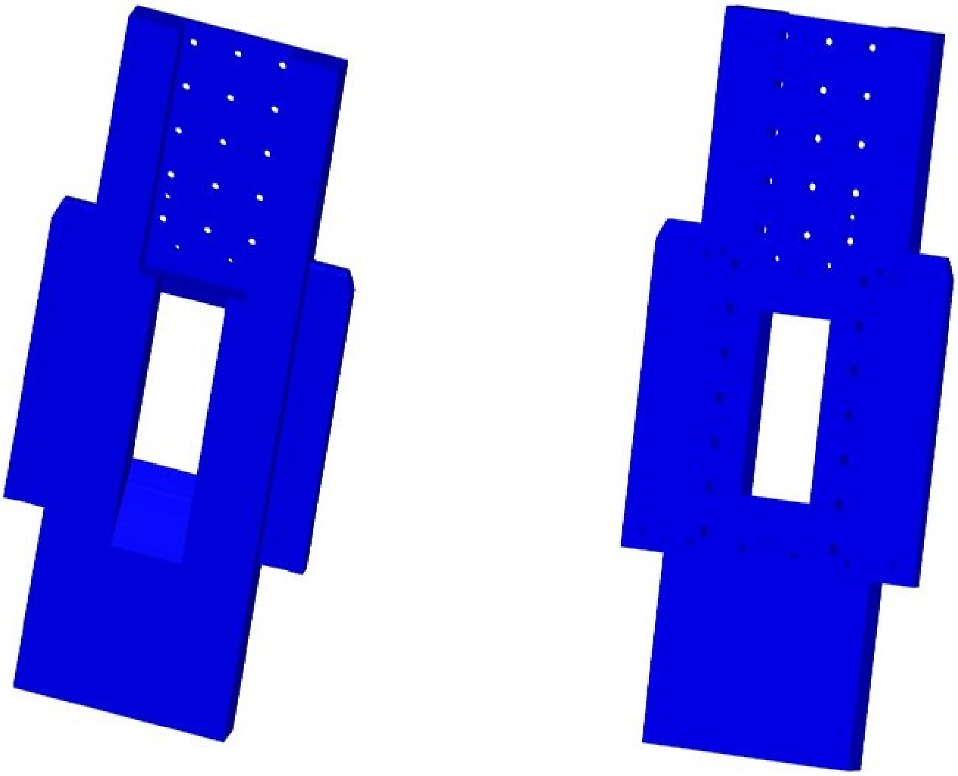


Figure 4 – Front (left) and back (right) view of the fixed frame

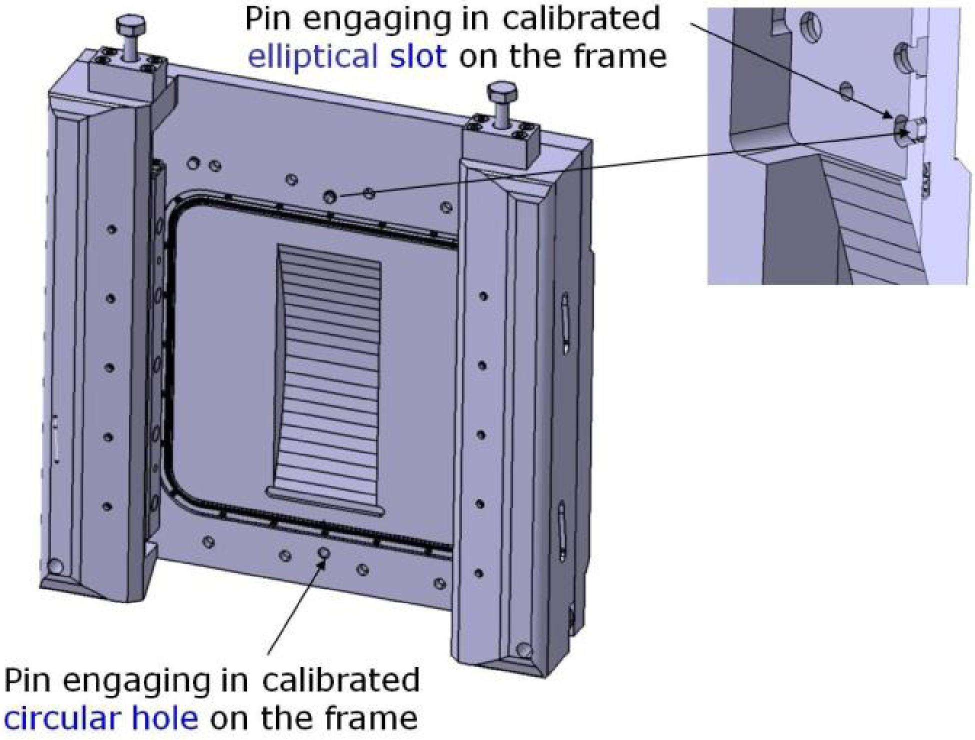


Figure 5 – Centering system between BP and frame

1.3 The back-plate

The removable back-plate is a solid plate (see Fig. 6) suitably designed to create, once inserted on the fixed frame, the channel for the lithium flow, leaving enough material at the point of minimum thickness to guarantee correct operations (including pressure tests) for the necessary time period.

On the front side of the back-plate, suitable holes and pins are provided to match the holes and pins present in the fixed frame for the alignment of the two elements.

A rectangular-shaped groove is machined on the front side of the BP to house the gasket, together with the holes for fastening the clips which hold the gasket firmly in place during insertion and extraction of the back plate.

The sealing between the fixed frame and the removable BP is assured by a high performance HELICOFLEX® gasket manufactured by Garlock company. This gasket is an energized rectangular-shaped C ring.

Since the required tightening force of the clamping system is proportional to the gasket perimeter, it is clear that a rectangular gasket assures the tightening of the interface with a smaller force than the circular one. For this reason and also to avoid sticking phenomena, a rectangular gasket was preferred. The gasket manufacturer can produce rectangular gaskets of any dimension assuring the same performances of the circular type.

The HELICOFLEX® gasket, shown in Fig. 7 for a circular type (but the same holds for the rectangular type), is composed of an helicoidal spring, an inner lining in high strength elastic material and an external C-profiled jacket. The outer jacket is made of soft iron, in order to assure a good deformability under tightening load without the risk of marking the steel surfaces of the flanges. The inner spring is normally made in Nimonic steel and assures the necessary elastic response even at 300℃. Since, due to its high content in Cobalt (21%), the Nimonic steel can be dangerously activated by neutron irradiation, it has been replaced by Inconel X750 which presents the same elastic properties at 300°C but has better neutronic performances.

The lining is made of AISI 304 stainless steel.

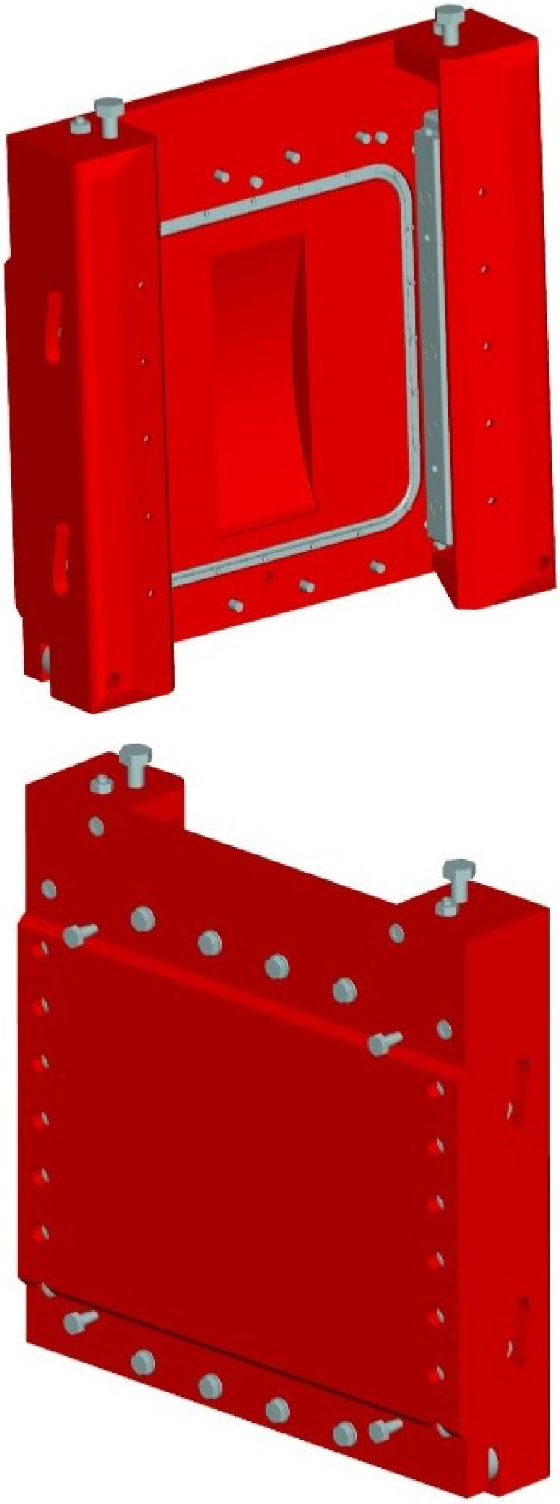


Figure 6 – Front (top) and back (bottom) view of the removable BP

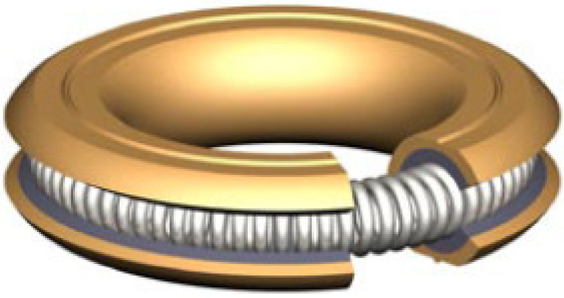


Figure 7 – Garlock HELICOFLEX® gasket (with circular geometry)

1.4 The closure system

The closure system comprises the skate clamping system and the tightening bolts. The clamping system relies on the forced coupling between rollers and wedges which produce (Fig. 8) a compressive force proportional to their relative sliding position.

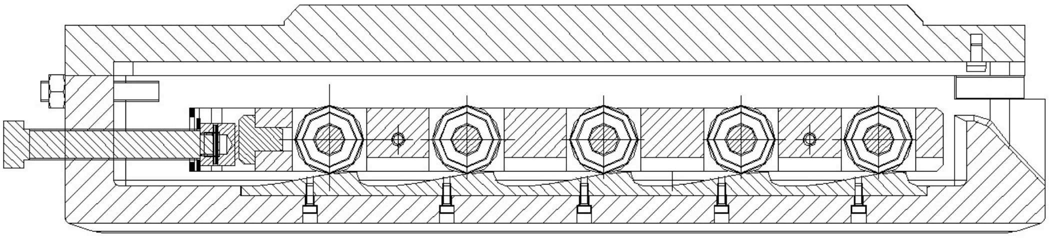


Figure 8 - Clamping system based on rollers and wedges

The force application and accurate positioning of the roller skates with respect to the wedges is operated by means of an adjustable screw. The possibility to adjust only one screw for each roller skate represents the operational advantage of this solution. In order to use the compressive force distribution in an efficient way, a rectangular gasket is preferred.

The skate system is made up of two “L” shapes (see Fig. 9) attached to the BP, each carrying a series of inclined cams upon which the skates run to provide the closure motion of the back plate.

The advantage of this solution is that also the whole skate system can be completely replaced together with the BP, since the two elements forms a single removable component.

The cams are manufactured in 100Cr6 steel to give better support to the closure thrust. The “L” shapes are threaded to support the interface screws which provide the force required by the gasket. The threads are made of CuBe 2% to reduce the friction coefficient during handling.

Each “L” shape consists of a frame (Fig. 10) with 5 triple bearings on six parallel axes. Each bearing is made up of two caged needle-rollers INA RSTO 15 which are seated at the two sides of one needle-roller INA NATV15 (Fig. 11). The lateral rollers act on the sliding surface of the fixed frame, while the central roller runs on the inclined cams present on the “L” shape. The relative rolling motion between the carriages central rollers and the cams first creates the thrust movement and then the force necessary for the closure of the back plate. As in the IFMIF extreme operating conditions (vacuum, radioactivity, high temperature) lubrificant is not allowed, all the bearing surfaces of the rollers are covered with a anti-seizure coating material called “dicronite”.

During the opening of the system, the skates are driven and consequently forced to contact the cams through two lateral pins which move in grooves reproducing the profile of the cam (see Fig.). In each cam a ground and hardened steel plate takes the force of the screw. To minimize the friction and guarantee non-deformation of the contacting surfaces, the tip of the screw contains a ground and hardened steel insert with a spherical surface profile.

The skate-based clamping system has been successfully tested and qualified on experimental mock-ups realized at ENEA Brasimone.

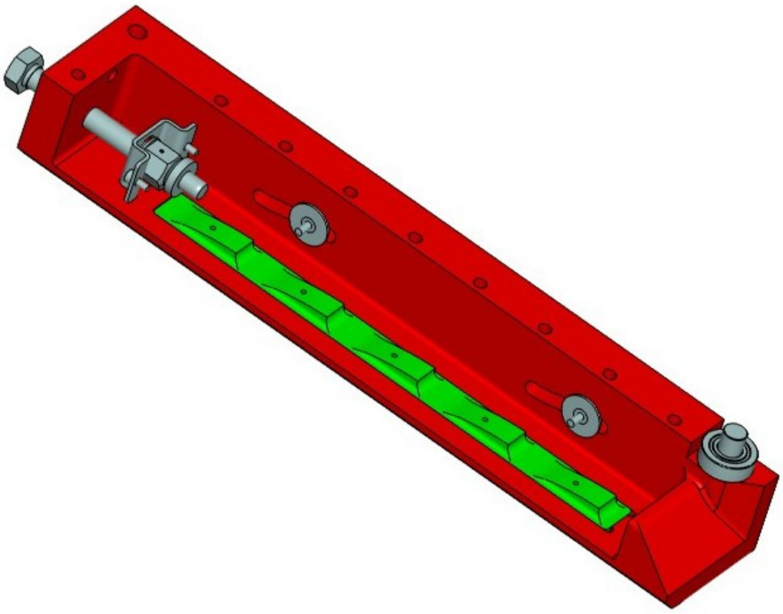


Figure 9 – “L”-shapes (red) with inclined cams (green) of the clamping system

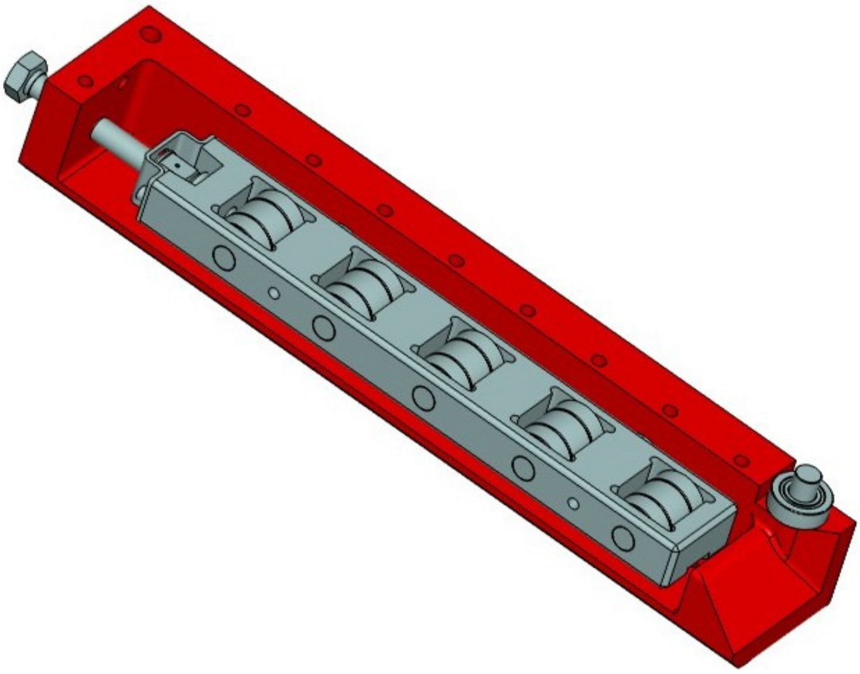


Figure 10 – Skate frame with bearings (gray) inserted in the L-shape structure

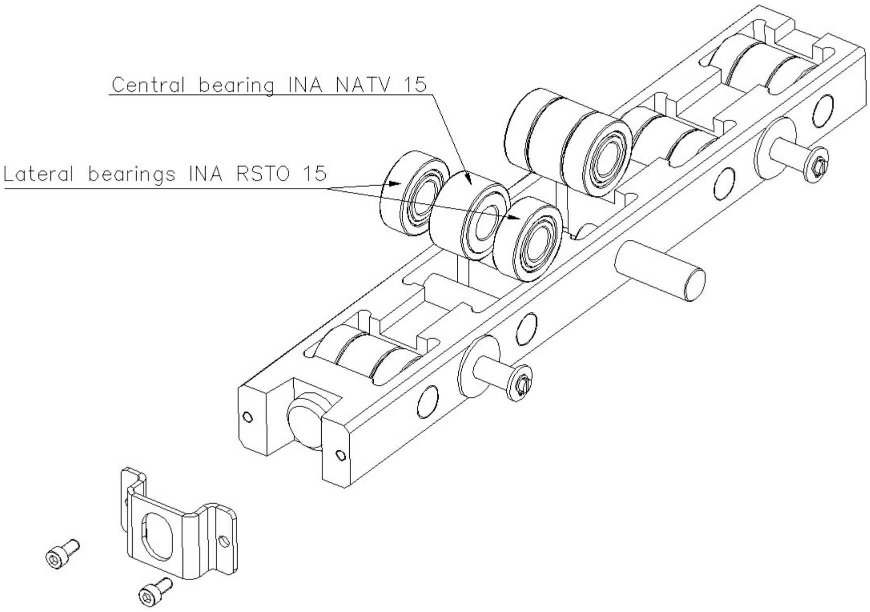


Figure 11 - Rollers skate

1.5 Materials

The material selected for the BP is the Reduced Activation Ferritic-Martensitic (RAFM) steel EUROFER 97. The first reason of this choice is its better resistance to the high lithium velocity erosion/corrosion with respect to the 316L stainless steel. A second interesting reason is the opportunity to test and demonstrate the manufacturing of the back plate prototype.

As already explained, the BP profile is partially carved in the connection frame and partially in the removable BP. This configuration presents an important drawback represented by the mechanical step resulting by non perfect matching of the two interfacing parts. The risk of discontinuity in the profile would be enhanced by temperature in case that the components were made in different metals. To prevent this occurrence, it was decided to build in RAFM steel even the BP supporting frame.

For this reason, the F82H steel was chosen as the material for the frame. The TA body is also made of F82H.

2. Thermomechanical analysis

A research campaign has been launched to investigate the thermo-mechanical performances of the Target Assembly system with bayonet back-plate, under steady state conditions.

The research campaign has been mainly focussed on the assessment of the back-plate thermo-mechanical behaviour under selected steady state scenarios.
In particular, attention has been paid to the potential onset of significant deformations, which may deeply change lithium channel layout inducing flow instability, and yielding, which could led to the system structural crisis.
A theoretical approach based on the Finite Element Method (FEM) has been followed and the qualified ABAQUS FEM code has been adopted to perform the study.
The following loading scenarios have been taken into account:

- **Nominal scenario**
  Lithium flowing at 275°C and internal pressure of 0.18 MPa

- **Design scenario**
  Lithium flowing at 400°C and internal pressure 0.75 MPa

A realistic three-dimensional FE model of the whole Target Assembly (Fig. 12) has been developed and a mesh independency analysis has been performed to select an optimized mesh which allows accurate results to be obtained saving calculation time.
A mesh composed of ~280000 nodes connected in ~$1.2 \cdot 10^6$ tetrahedral elements has been selected, which allows numerical simulations to be carried out in about 6 hours.

Thermo-mechanical contact models have been implemented to properly take into account both thermal and mechanical interactions among frame, back-plate and gasket.

As to the thermal contact model, a uniform gap conductance equal to 2000 W/m^2°C has been considered.

Concerning the mechanical contact model, an ideal Coulombian friction interaction has been supposed with a uniform friction factor amounting to 0.74.

All the other components of the Target Assembly system have been considered as tied from both thermal and mechanical point of view.

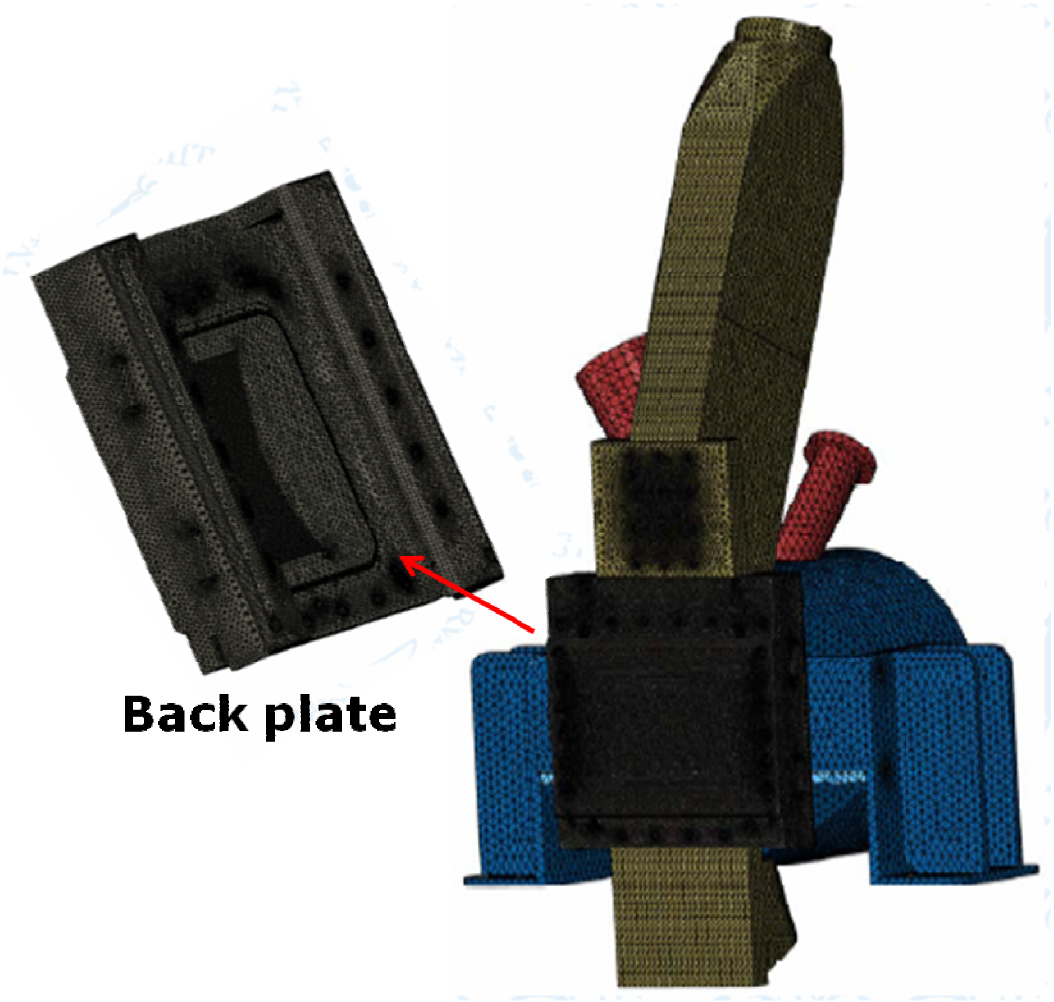


Figure 12 – 3D FE model of the whole TA

The following loads and boundary conditions have been assumed to model the Target Assembly thermomechanical behaviour according to the loading scenarios considered.

Thermal loads and boundary conditions

- Forced convection with Lithium
- Internal irradiation
- External irradiation

Mechanical loads and boundary conditions

- Internal and external pressures
- Tightening screws loads
- Skate-based clamping system loads
- Target Assembly system constraints

Uncoupled thermo-mechanical steady state analyses have been carried out to investigate the thermo-mechanical behaviour of the Target Assembly system under each loading scenario considered.

The following field variables have been calculated:

- Thermal field
- Displacement field
- Von Mises equivalent stress field
- ω field, representing the local ratio between Von Mises equivalent stress and Yield stress fields

Attention has been paid mainly to the thermo-mechanical behaviour of the back-plate and, particularly, to the relevant distribution of ω field, to assess that it does not overcome the unit value which is representative of material incipient yielding.

2.1 Nominal scenario

A selection of the most significant results in terms of thermal, stress and displacement fields in the BP for the nominal conditions scenario are summarized in Figs. 13, 14 and 15, respectively

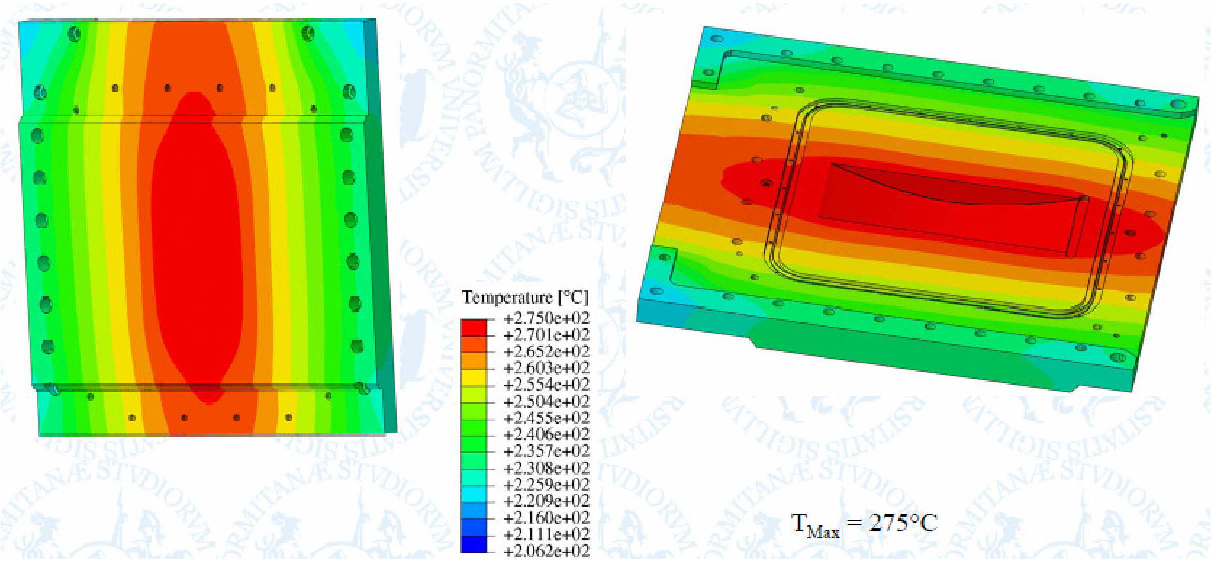


Figure 13 – Thermal field in the BP (nominal scenario)

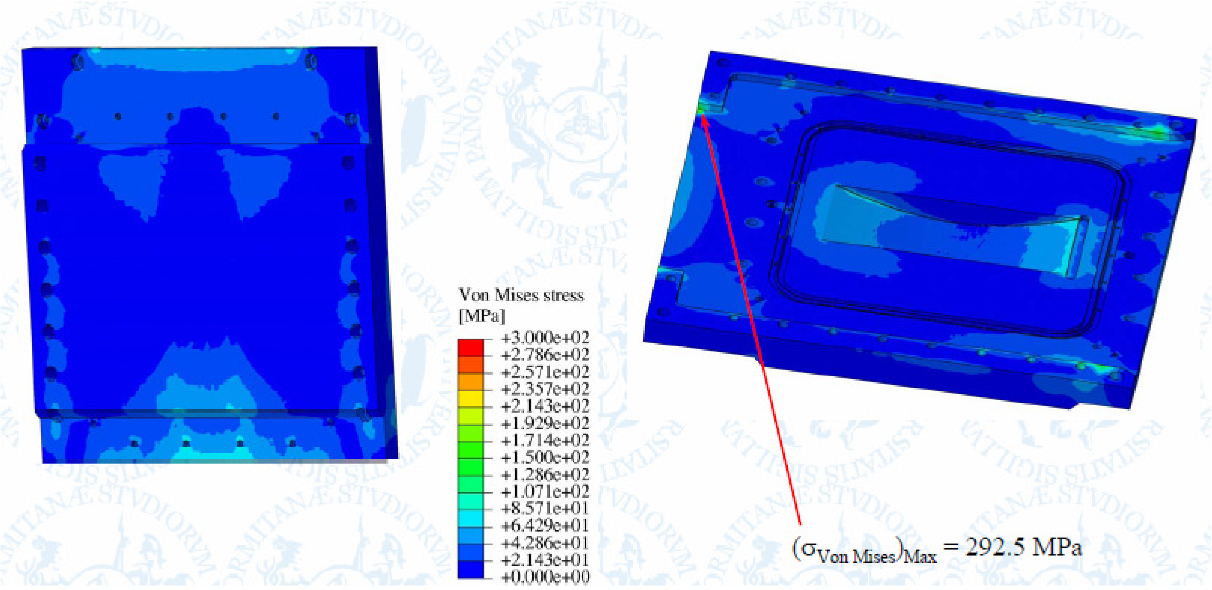


Figure 14 – Von Misis stress field in the BP (nominal scenario)

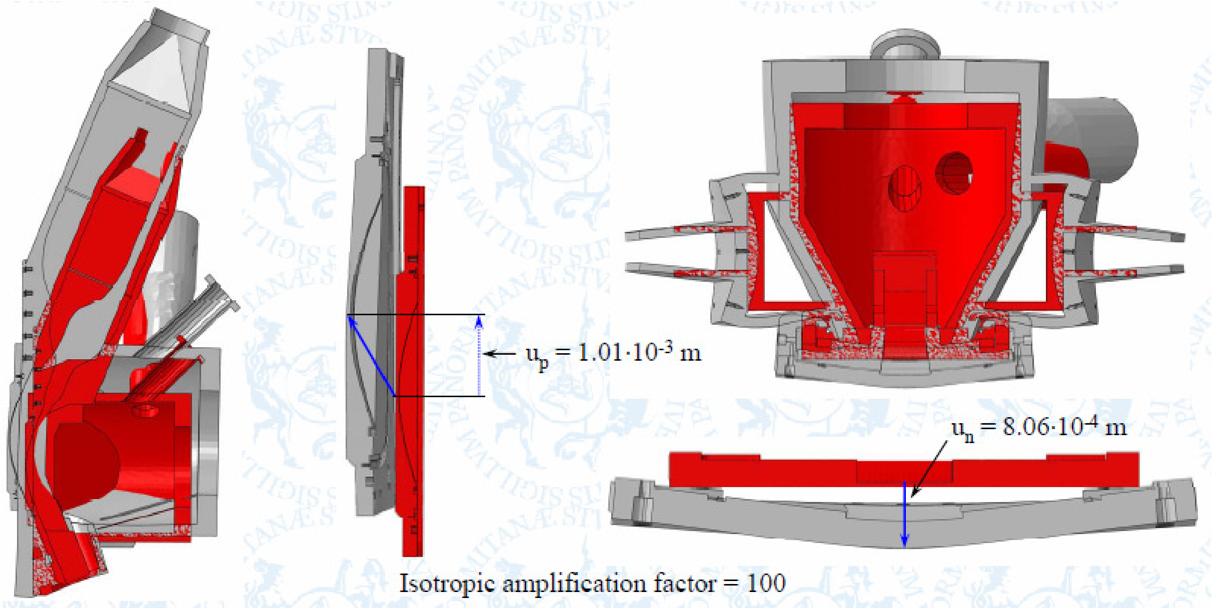


Figure 15 – Displacement field in the BP (nominal scenario)

2.2 Design scenario

A selection of the most significant results in terms of thermal, stress and displacement fields in the BP for the design conditions scenario are summarized in Figs. 16, 17 and 18, respectively.

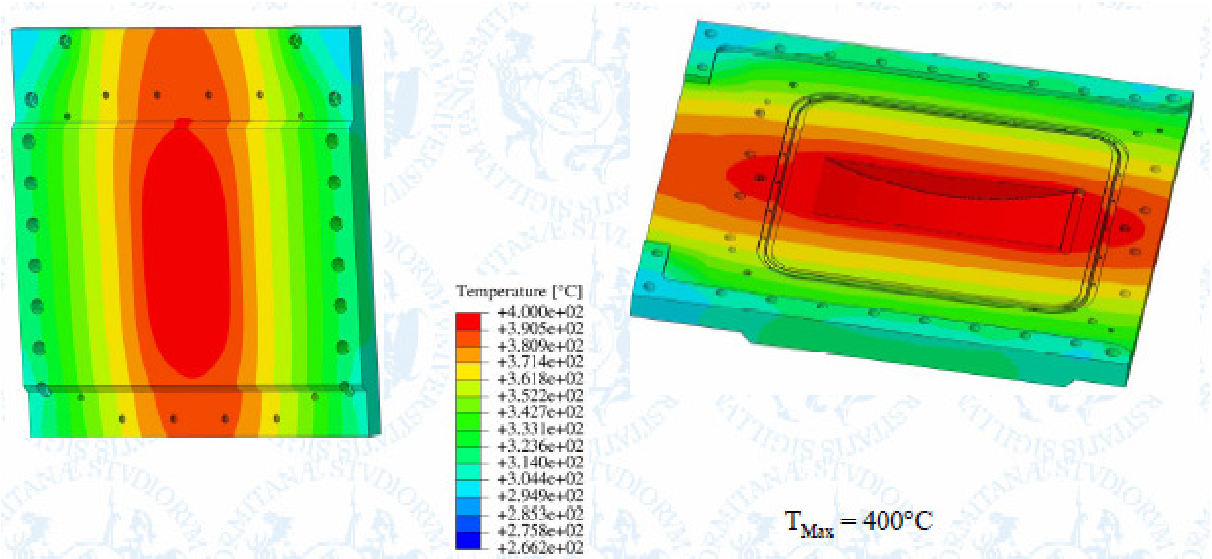


Figure 16 - Thermal field in the BP (design scenario)

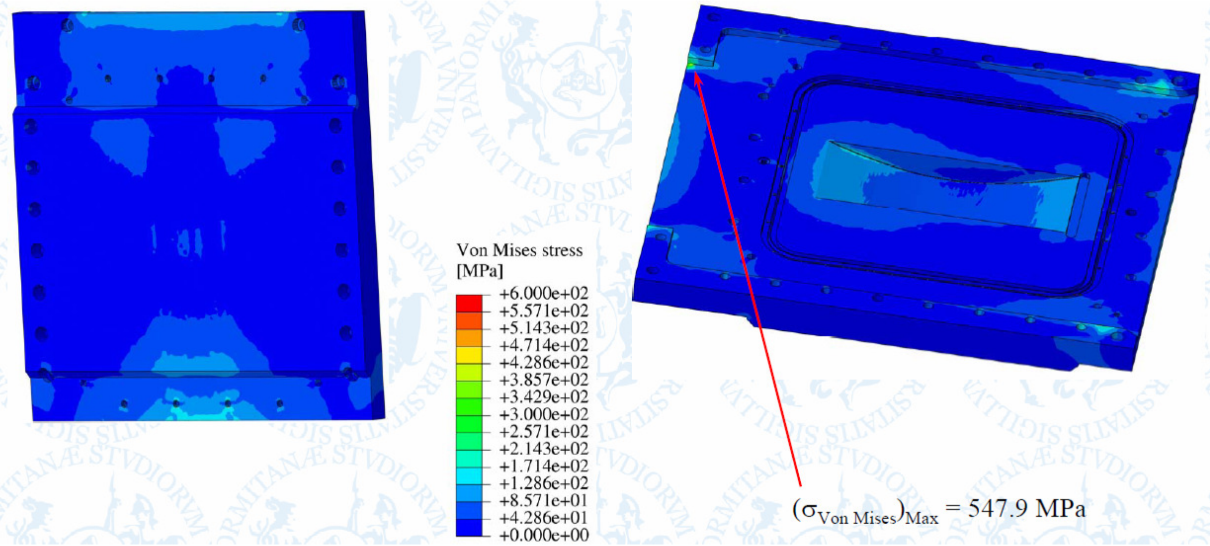


Figure 17 – Von Misis stress field in the BP (design scenario)

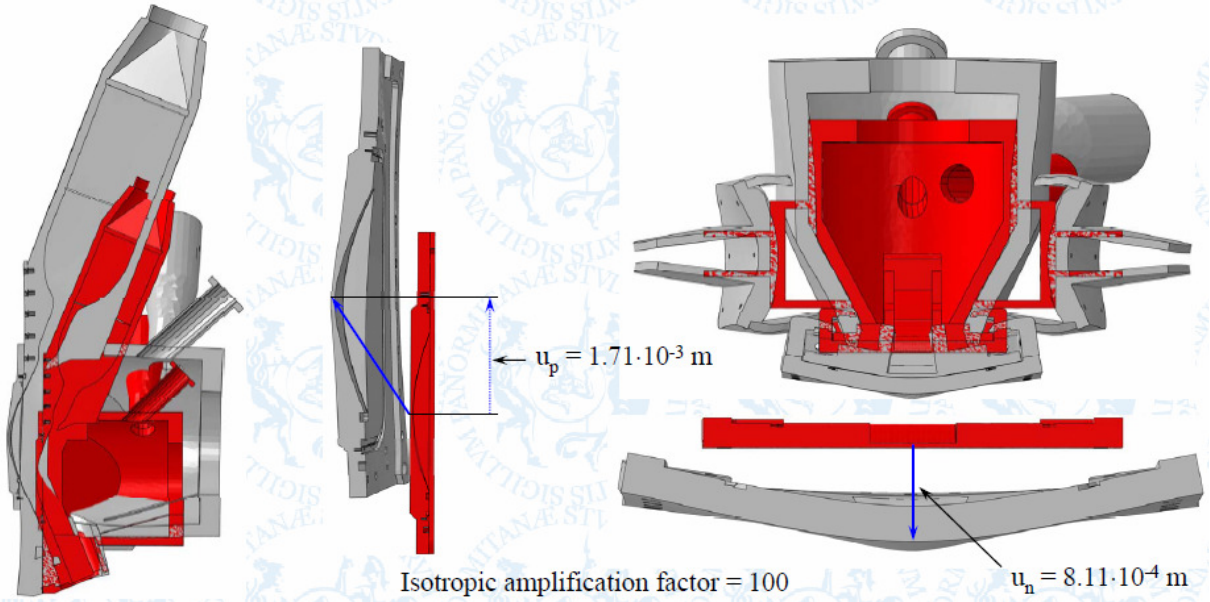
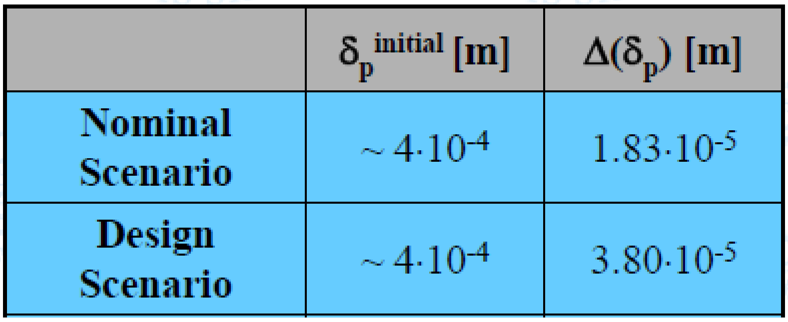


Figure 18 – Displacement field in the BP (design scenario)

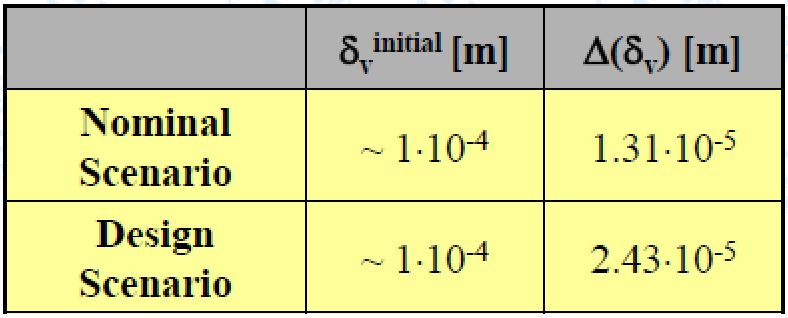
2.3 Interface frame – BP displacements

The displacements between the interface frame and the BP under applied loadings for both nominal and design scenarios have been calculated and are reported in Tab. 1 and 2 which correspond to the points shown in Fig. 19.



	$\delta_p^{initial}$ [m]	$\Delta(\delta_p)$ [m]
Nominal Scenario	$\sim 4\cdot10^{-4}$	$1.83\cdot10^{-5}$
Design Scenario	$\sim 4\cdot10^{-4}$	$3.80\cdot10^{-5}$

Table 1 – Calculated values for the δp displacement (see Fig. 19)



	$\delta_v^{initial}$ [m]	$\Delta(\delta_v)$ [m]
Nominal Scenario	$\sim 1\cdot10^{-4}$	$1.31\cdot10^{-5}$
Design Scenario	$\sim 1\cdot10^{-4}$	$2.43\cdot10^{-5}$

Table 2 – Calculated values for the δv displacement (see Fig. 19)

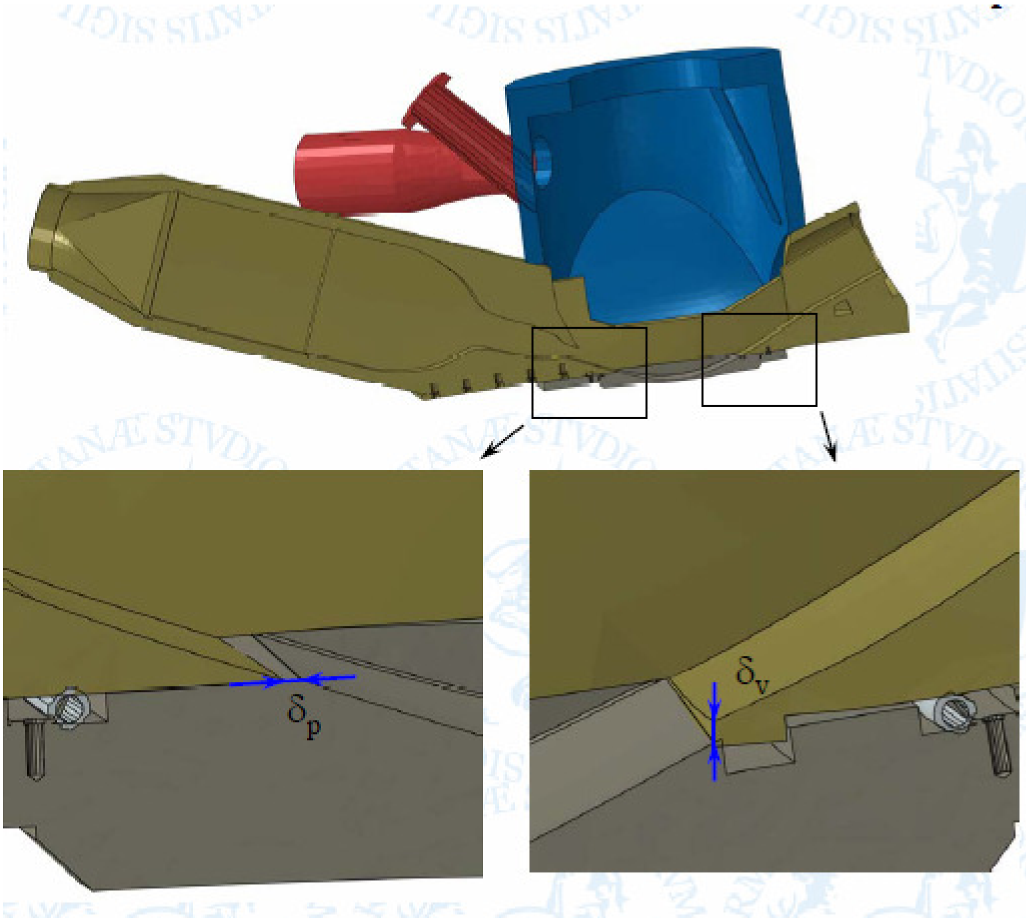


Figure 19 – Displacements between interface frame and BP

Conclusions

In the present report, the engineering design of the Target Assembly system with bayonet Back Plate representing one of the two TA options to be tested in the EVEDA Lithium Test Loop Facility in Oarai (Japan) has been documented.

A description of the system including the various design solutions developed by ENEA during the reference period has been presented.

Themomechanical calculations have been performed to assess the capability of the TA design to withstand the applied thermal and mechanical loadings during nominal and design scenarios.

Results have indicated that under nominal scenario the Back-plate seems able to withstand both thermal and mechanical loads it undergoes without incurring in any plastic deformation.

As to the design scenario, results obtained have shown that the Back-plate experiences yielding in a very small region, localized nearby the sharp edge of the components. Variations up to 25% in the distance between Frame and Back-plate have been predicted at their interface next to Lithium channel.

References

[1] LF 1.3.2 *EVEDA Lithium Test Loop Engineering Design Report*, IFMIF DMS, 229N6V

[2] LF01-EU *Procurement Arrangement*, IFMIF DMS

[3] IFMIF *Comprehensive Design Report* (CDR), IFMIF International Team, IEA Report, 2004

[4] P. Agostini, F.S. Nitti, G. Miccichè, M. Serra, L. Sansone, *Definition Report of the EVEDA Bayonet Back Plate*, Deliverable LF1.2, IFMIF DMS, 2009

[5] F.S. Nitti, *Termofluidodinamica di un getto di Litio*, Ph.D. Thesis, 2010, available on-line at: http://amsdottorato.cib.unibo.it/2793/