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Studio del comportamento termomeccanico del target assembly nelle condizioni transitorie di start up

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STUDIO DEL COMPORTAMENTO TERMOMECCANICO DEL TARGET ASSEMBLY NELLE CONDIZIONI TRANSITORIE DI START UP

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Abstract

In the framework of the engineering design activities of the International Fusion Materials Irradiation Facility (IFMIF), ENEA is engaged in the design of the liquid lithium target assembly (TA) with bayonet backplate whose development has recently progressed up to a well advanced stage which culminated in the construction of a full-scale prototype at ENEA Brasimone laboratory. However, many aspects still remain to be addressed to finalize the TA design. One of the most important is concerned with the pre-heating of the system at start-up (before lithium injection at 250 °C) which is needed in order to avoid lithium freezing and unacceptable thermal stresses in the structures. This is accomplished by means of electric heaters arranged around the TA external surfaces. With the aim of identifying the most suitable electric heaters configuration and powers as well as to select the optimized operating procedure which allows to achieve the final temperature as much uniformly as possible, a thermal analysis of the start-up transient behavior of the ENEA TA prototype has been performed in collaboration with the University of Palermo by means of a finite element (FE) model implemented through a qualified software package. The temperature distribution resulting from the analysis will be also used as a reference to validate the FE model by comparison with the experimental data obtained from the heating tests to be performed on the TA prototype. By means of the performed analysis, an optimized electric heaters time-dependent load profile which allows to increase the temperature of the TA mock-up components in a quite uniform way has been identified. Moreover, the results obtained have shown that the heat flux provided by the electric heater placed on the BP needs to be increased as the BP cannot reach a sufficiently high temperature over large zones, particularly in the Lithium channel.

1 Introduction

The International Fusion Materials Irradiation Facility (IFMIF) is a joint effort of the international scientific community within the framework of the Broader Approach Agreement established between Europe and Japan. IFMIF is an accelerator-based neutron source which is devoted to test and qualify candidate materials to be used in future fusion reactors, allowing, in particular, the development of a material irradiation database for the design, construction, licensing and safe operation of the DEMO fusion power reactor. The IFMIF neutron source 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 about 10^{18} $nm^{-2}s^{-1}$ characterized by an energy spectrum peaked at 14 MeV, which enables materials testing up to a damage rate of more than 20 dpa/y [1]. With the aim of having a stable liquid Lithium flow, a target system, consisting of a Target Assembly (TA) properly integrated with a Lithium loop, has been designed. The TA is mainly devoted to create, within its removable component, called bayonet Back-Plate (BP), a stable Lithium jet flowing at a nominal speed of 15 m/s to remove the 10 MW heat power released by deuteron beams and produce the desired neutron flux. A detailed description of the Lithium loop layout and of the target assembly can be found in [1,2]. The IFMIF project is currently in the Engineering Validation and Engineering Design Activities (EVEDA) phase which foresees the execution of experimental campaigns aimed at validating the main components and subsystems of the machine (e.g., accelerator sections, target system, lithium purification loop…). In particular, a mock-up of the target system with bayonet BP has been realized at ENEA Brasimone [3] in order to perform experimental activities aimed at assessing different aspects of the target design, with particular attention to the replaceable BP. The experimental activities which will be conducted on the target system mock-up will mainly concern the achievement of two principal goals.

The first goal regards the qualification of the remote handling devices designed to perform the maintenance operations on the target assembly.

The second goal consists in the reproduction of the initial phase (the so called pre-heating phase) of the IFMIF target system start-up [4], characterized by a time-dependent action of the electric heaters placed on the target structure, aimed at demonstrating the effectiveness of the foreseen pre-heating system as well as at determining the thermal field arising in the BP.

In order to support the activities aimed at reproducing the pre-heating phase of the IFMIF target system, a research campaign has been launched within the framework of the present Annual Realization Plan (*Piano Annuale di Realizzazione*, PAR 2014) of the ENEA-MSE Agreement by ENEA Brasimone in collaboration with the Department of Energy, Information Engineering and Mathematical Models (DEIM) of the University of Palermo to theoretically and numerically investigate the thermal behavior of the target system mock-up under transient loading conditions [5], with the aim of setting up a proper electric heaters load profile able to avoid the insurgence of thermal gradients of unacceptable entity within the mock-up structure. A theoretical-computational approach based on the Finite Element Method (FEM) has been followed and a qualified commercial FEM code has been adopted to perform the study. An iterative procedure, based on the analysis of the maximum temperature achieved within the mock-up most critical components, has been followed in order to determine the electric heaters load profile. These results will also be validated during the experimental activities to be conducted on the target mock-up at ENEA Brasimone laboratory, allowing a benchmark of the theoretical-numerical procedure followed.

2 IFMIF Target System Mock-up

A schematic overview of IFMIF is shown in Fig. 1, where the main facility sections are reported. The European concept of the IFMIF target system, proposed by ENEA [6], is characterized by a replaceable Back-Plate (BP) and it mainly consists of the Target Assembly (TA), the Support Framework and the Lithium pipes.

The TA is devoted to provide a fast, reliable and stable flow of Lithium and it is connected to the Support Framework by the TA arms and to the Lithium Loop 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. The TA mainly consists of an inlet and an outlet nozzle, a Back-Plate, a Target chamber, an interface frame and connecting flanges. A more detailed description of its lay-out may be found in [6].

It has to be underlined that the BP is the most heavily loaded TA component, both from neutronic and thermo-mechanical point of view. In fact, it is devoted to house the beam footprint, resulting to operate, in IFMIF, under severe conditions of neutron irradiation damage. Therefore, its replacement, defined considering irradiation effects on material properties, is expected to occur once a year. For this reason, the reference European Target Assembly design is conceived with a remotely replaceable “bayonet” Back-Plate so that it can be easily replaced, thanks to a purposely designed skate system, using a remote handling device without removing the whole Target Assembly.

The Support Framework, directly fixed to the ground of the Test Cell by means of a proper bolt system, allows the sliding of one of the TA arms during all operation phases in order to allow the TA deformations and, at the same time, maintain the alignment between the deuteron beams and the Lithium footprint, ensuring the stability of the neutron flux generated in the beam footprint region by the deuteron-lithium interactions.

The Lithium Loop is articulated in a main loop and a purification loop, designed to operate for 30 years. The main loop stably supplies liquid Lithium at the adequate flow rate and temperature to the TA. It mainly consists of the target system, the quench tank, the electromagnetic pump, the dump tank and the primary heat exchanger. Inside the Test Cell, the Lithium inlet pipe is articulated in two sections, connected each other by means of two FDSs and a gimbal expansion joint which are placed just before the TA system.

The connection of the Lithium inlet pipe sections by FDSs is one of the main characteristic of the IFMIF target system European concept. In fact, each FDS permits to easily and quickly connect and disconnect flanges by simply acting on only one screw, using a purposely designed remote handling device. Furthermore, a FDS is conceived with a passive Lithium leak detection system which continuously checks the sealing of the flanges connected. A more detailed description of FDS, the Lithium leak detection system and its components is reported in [6-7].

The gimbal expansion joint is able to compensate angular movements between the flanges of the two Lithium inlet pipe sections. It is aimed to compensate thermal expansions during all IFMIF operational phases and misalignments during target system installation. Further details on the gimbal expansion joint foreseen for the Lithium inlet pipe may be found in [6].

The purification loop consists of a cold trap and two hot traps, to remove various impurities, and of auxiliary supporting equipment devoted to perform the Lithium make up. Further details about the Lithium Loop may be found in [1].

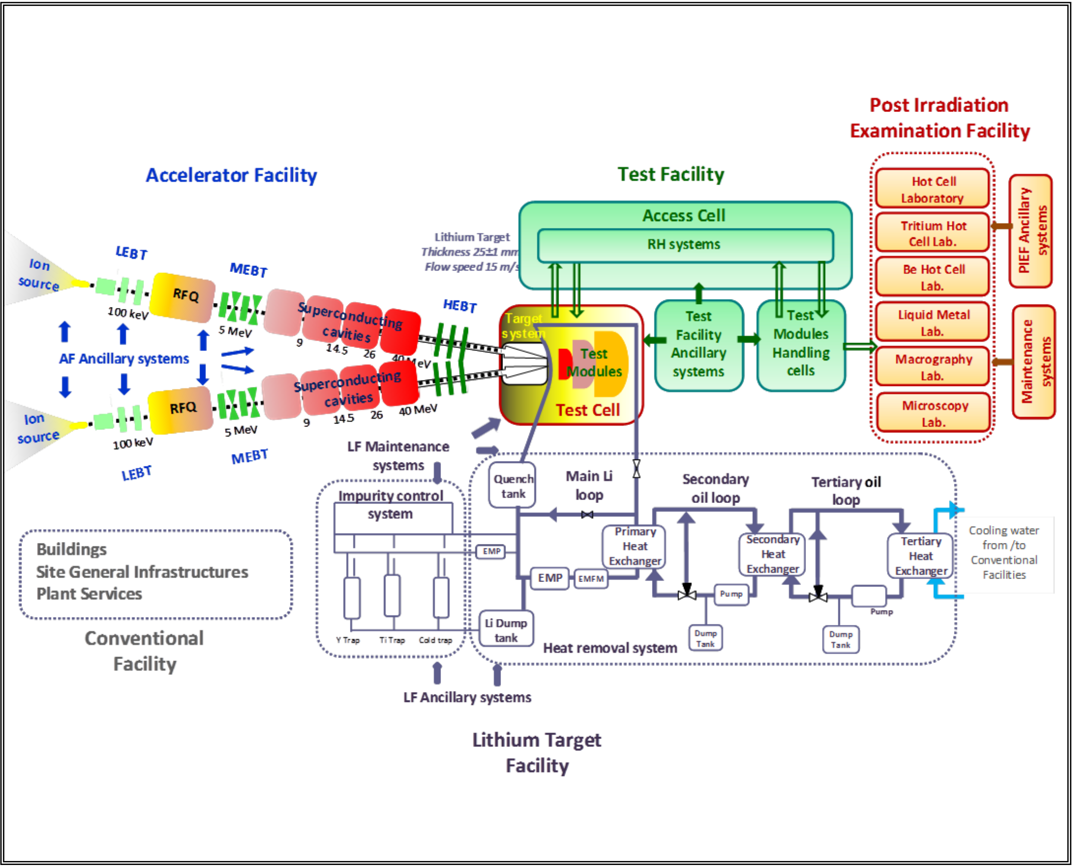

Figure 1. IFMIF schematic overview.

It has to be underlined that all the design solutions adopted by the IFMIF project team for the acceleration system, the target system and the test cell need to be validated and, if necessary, further modified during the next phases of the IFMIF project.

Within the framework of the EVEDA phase, some validation activities are planned with the aim of conducting experimental campaigns in order to qualify the design solutions adopted for IFMIF, using purposely designed mock-ups of the critical subsystems and components (accelerator, target system, Lithium loop, test modules, ect…).

Results obtained from these experimental activities will be carefully assessed and the most promising design solutions will be adopted to achieve the final IFMIF design, which will be developed during the next phases of the project.

In order to qualify the design of the IFMIF target system , a mock-up of the European concept of the TA has been realized at ENEA Brasimone [3]. It realistically reproduces the most recent design of the IFMIF Target Assembly, properly integrated with its Support framework and the entire Lithium inlet pipe, and it includes the following main components (Figure 2):

- the Lithium inlet pipe;
- the gimbal expansion joint;
- the FDSs;
- the Beam Duct;
- the Inlet Nozzle;
- the Back-Plate;

- the Interface Frame;
- the Target Chamber;
- the Outlet nozzle;
- the Support Framework.

The TA is supported by the Target Chamber arms laying on the Support Framework, directly fixed to the ground by means of a proper bolt system, and it is welded to the Lithium inlet pipe.

Regarding structural materials employed for the mock-up construction, it has been realized using AISI 316 steel for the Back-Plate and AISI 304 steel for all the remaining components, differently from the IFMIF target system in which the European reduced activation ferritic/martensitic (RAFM) steel EUROFER has been selected as structural material for almost all the components.

A more detailed description of the target system mock-up realized at ENEA Brasimone can be found in [3].

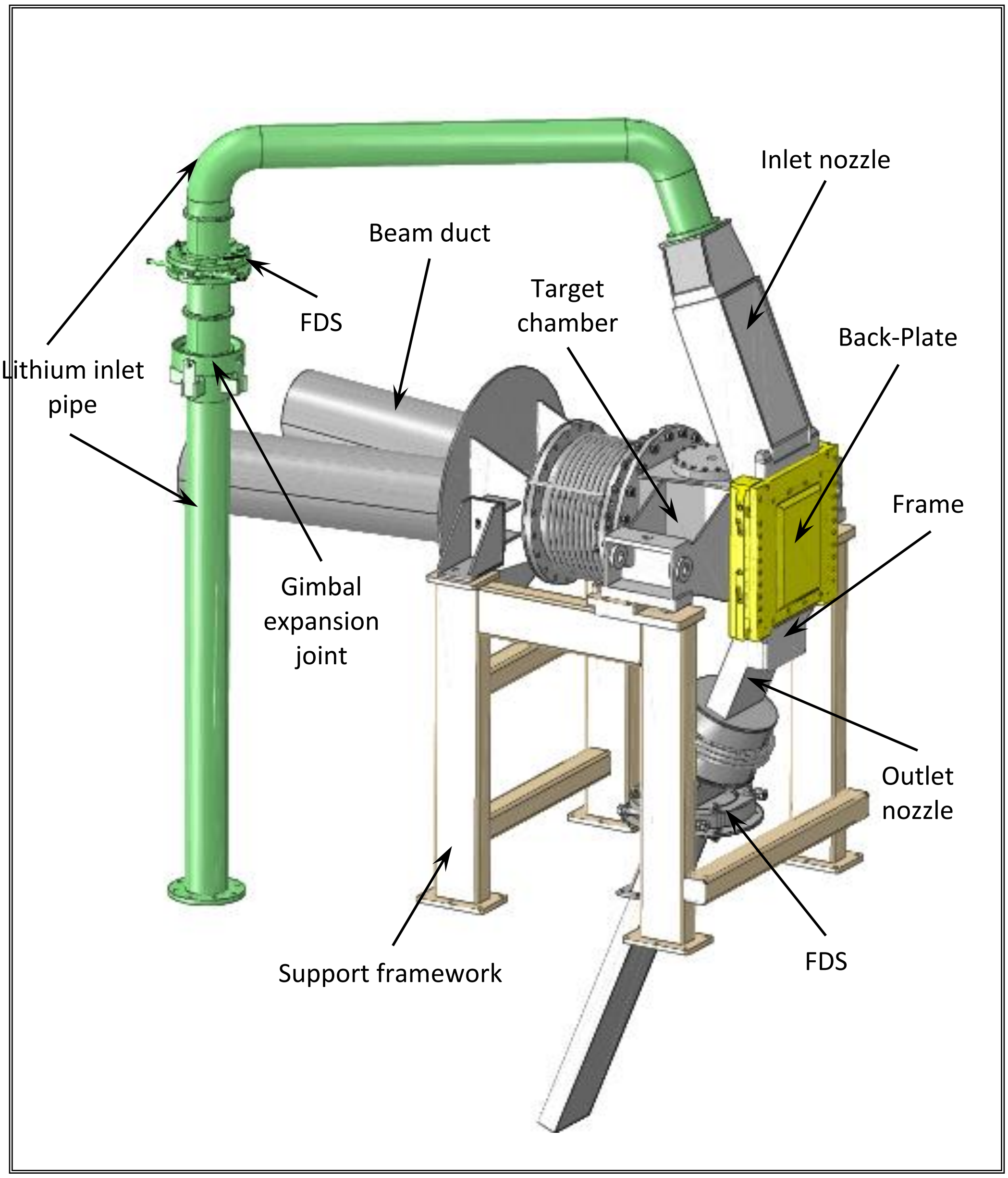

Figure 2. The mock-up of the IFMIF target system realized at ENEA Brasimone.

Differently from the IFMIF target system design, the mock-up realized at ENEA Brasimone is endowed with only one FDS in the Lithium inlet pipe region. Moreover, the presence of the accelerator system has been taken into account by constructing a double pipe, connected to the Target Chamber by a proper bolt system, which represents the Beam Duct foreseen in IFMIF.

It has to be underlined that the mock-up of the target system does not reproduce the whole IFMIF Lithium Loop, except for the TA Lithium inlet pipe. In fact, the target system mock-up does not foresee the presence of the liquid Lithium, being envisaged to allow the achievement of two main goals: the validation of the remote handling devices devoted to perform the maintenance operations on the target system and the reproduction of the electric heaters action foreseen during the initial phase of the IFMIF target system start-up.

As far as the remote handling procedures are concerned [8-9], they play a fundamental role in IFMIF maintenance phase, due to the high dose rate predicted in the Test Cell housing the target system. In fact, nuclear activation reactions will take place between neutrons, generated within the beam footprint region, and structural materials nuclei, making the Test Cell internals hostile to human presence. Therefore, the periodic BP substitution and any maintenance activity foreseen for the target system must be executed using robotic devices governed by remote. Hence, experimental campaigns will be carried out on the target system mock-up in order to validate all the remote-governed devices, and the pertinent operative procedures, devoted to execute the BP insertion to and removal from the fixed interface frame of the Target Assembly and the FDSs tightening and detachment mechanical operations [8-9].

As far as the reproduction of the IFMIF start-up is concerned, and in particular the first of the three sub-phases in which it is articulated, named pre-heating phase [4], a proper set of electric heaters is necessary to perform the pre-heating of the structure before the Lithium begins to flow into the target system, in order to avoid the insurgence of particularly intense thermal gradients between the Lithium, that enters the target system at 250 °C, and the structure at room temperature. In fact, large thermal gradients may originate particularly intense stresses within the structure, jeopardizing the leak-tightness of the sealing gasket interposed between the Back-Plate and the frame. For this reason, particular attention should be paid to the thermal field arising within BP at the end of the pre-heating phase, since it is the most critical component of the entire target system and therefore an excessive temperature difference between the BP Lithium channel surface and the Lithium flow should be avoided in order to minimize the thermal induced stress within the component.

Furthermore, during the pre-heating phase, the electric heaters action needs to be properly tuned adopting a purposely set-up time-dependent load profile, in order to avoid a non-homogeneous increase of the temperature within the structure, that may cause the insurgence of high thermal gradients between adjacent components. For these reasons, the experimental activity performed on the target system mock-up, aimed at reproducing the pre-heating phase, will be mainly focussed onto the testing of electric heaters action and the mapping of the thermal field arising within BP.

It is obvious that the execution of the experimental activity aimed at reproducing the TA pre-heating phase has to be based on the knowledge of a purposely set-up electric heaters time-dependent load profile, able to allow the mock-up temperature increase within the different components as uniformly as possible during the entire pre-heating phase of the transient operational start-up.

The research activity performed in the framework of the present ENEA-MSE Agreement for the current Annual Realization Plan (*Piano Annuale di Realizzazione*, PAR 2014) has been aimed at determining the time-dependent load profile of the electric heaters acting on the external surfaces of the IFMIF target system mock-up.

The electric heaters load profile obtained from this analysis will be adopted for the experimental campaign to be performed at ENEA Brasimone laboratory using the purposely constructed mock-up. Hence, the results of these experimental activities will allow the validation of the models and the procedure adopted in the present study.

3 Target System Mock-up Thermal Analysis

As already mentioned, the present analysis has been aimed at assessing the thermal behaviour of the IFMIF target mock-up under the pre-heating phase of the start-up transient scenario [4], in order to set-up the time-dependent load profile of the electric heaters purposely arranged on the mock-up external surfaces with the aim to perform the heating of the structure before the Lithium begins to flow.

In order to determine the optimized electric heaters load profile, an iterative procedure has been followed, assessing the maximum temperature values achieved within the mock-up components. Attention has been focused on the maximum temperature achieved within the BP, since the pre-heating main goal is to increase, as uniformly as possible, its temperature up to the Lithium inlet temperature value of 250 °C. The research campaign has been performed adopting a theoretical-numerical approach based on the Finite Element Method (FEM) implemented through a qualified commercial software package.

3.1 Pre-heating phase of the start-up transient scenario

The pre-heating phase is the first of the three sub-phases in which the IFMIF start-up transient scenario is articulated. Further details about the IFMIF start-up loading conditions can be found in [4].

The pre-heating phase, in which no Lithium flows within the target system, is characterized by the action of a set of electric heaters arranged on the target system external surfaces, devoted to supply heat power to the structure in order to increase its temperature, as uniformly as possible, up to the Lithium inlet value of 250 °C. This strategy is mainly devoted to minimize the potential insurgence of intense thermal gradients within the structure when the Lithium at 250 °C will begin to flow. During the pre-heating phase, the action of the electric heaters has to be suitably tuned, by imposing an intermittent functioning (so as to reproduce the actual experimental conditions that will be realized in the ENEA laboratory), in order to avoid non-homogenous time evolution of the thermal field arising within the target system, which may lead to the insurgence of intense thermal gradients between adjacent components. Hence, the determination of an electric heaters load profile becomes fundamental to correctly define the pre-heating phase transient loading scenario.

An iterative approach, based on the assessment of the maximum temperature reached in the Lithium inlet pipe, the Inlet nozzle, the Target chamber, the Outlet nozzle and the Back-Plate of the mock-up, has been followed. In particular, a discontinuous functioning of the electric heaters has been assumed, making sure that the maximum temperature of the components could increase as uniformly as possible up to the value of 250 °C and, once reached this reference value, it could range between 240 °C and 260 °C, allowing the further heating of the structure.

As explained in the following, three different transient loading configurations, differing each other for the electric heaters spatial arrangement and for the BP external irradiation conditions, have been simulated, and a relevant load profile has been assessed for each configuration taken into account, following the aforesaid iterative procedure.

3.2 The FE model

A realistic 3D FEM model of the IFMIF target system mock-up realized at ENEA Brasimone has been developed. The model reproduces the Target Assembly integrated with its Support Framework and the entire Lithium inlet pipe. An overview of the 3D geometric model is reported in Figs. 3-4.

It has to be noted that the two FDSs, the gimbal expansion joint of the Lithium inlet pipe and the Beam duct, foreseen in the target system mock-up design (Fig. 2), have not been directly included in the 3D geometric model. Nevertheless, their thermal effects have been simulated, as explained in the following, imposing appropriate thermal boundary conditions and contact models which permit to simulate the thermal effects of the geometric regions not included in the 3D model on the calculation geometric domain. This simplifying assumption leads to a reduction in terms of calculation time without incurring in a significant loss of information.

A mesh independence analysis has been preliminarily performed to select an optimized spatial discretization which allows accurate results to be obtained saving calculation time. A mesh composed of about 5×10^5 nodes connected in some 2×10^6 tetrahedral elements, listed within FEM codes libraries, has been selected.

The most representative views of the selected spatial discretization are reported in Figures 5-7. The so formed spatial discretization allows numerical simulations to be carried out in a time ranging from 40 to 100 hours, depending on the load configuration taken into account.

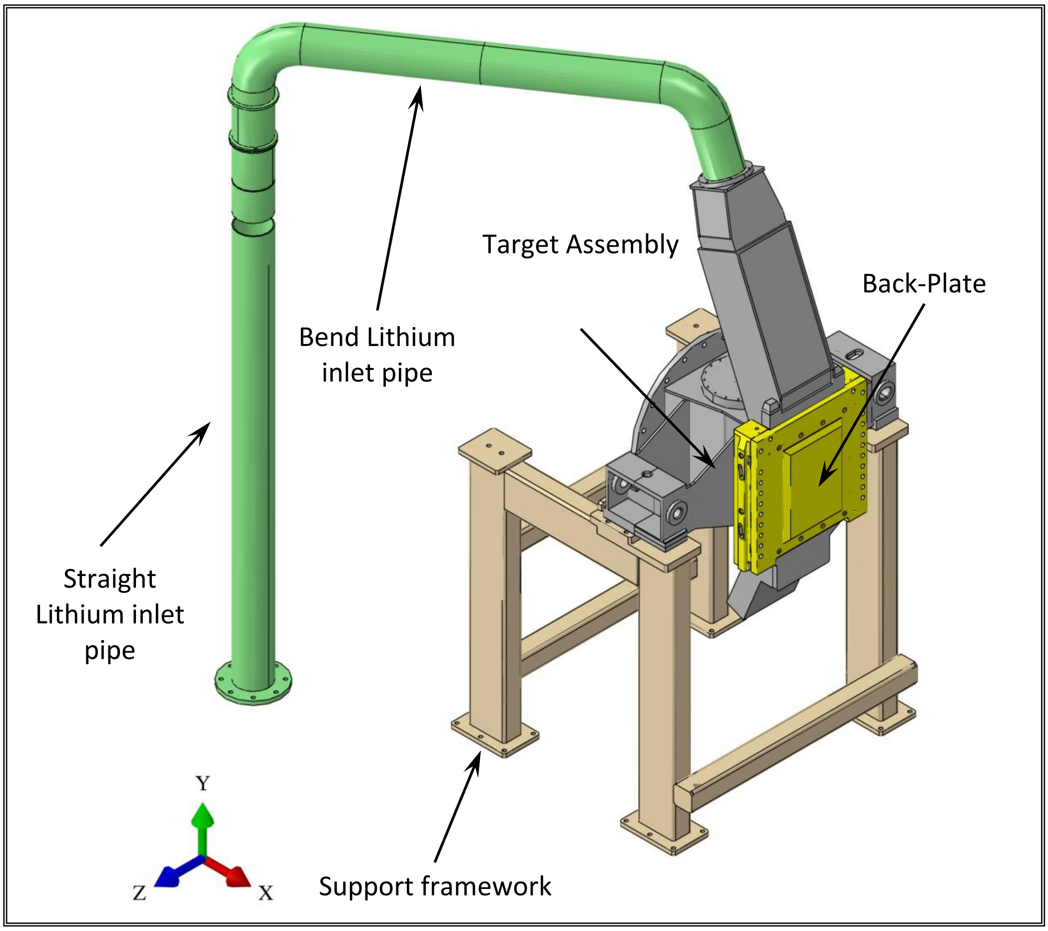

Figure 3. Mock-up 3D geometric model. General overview.

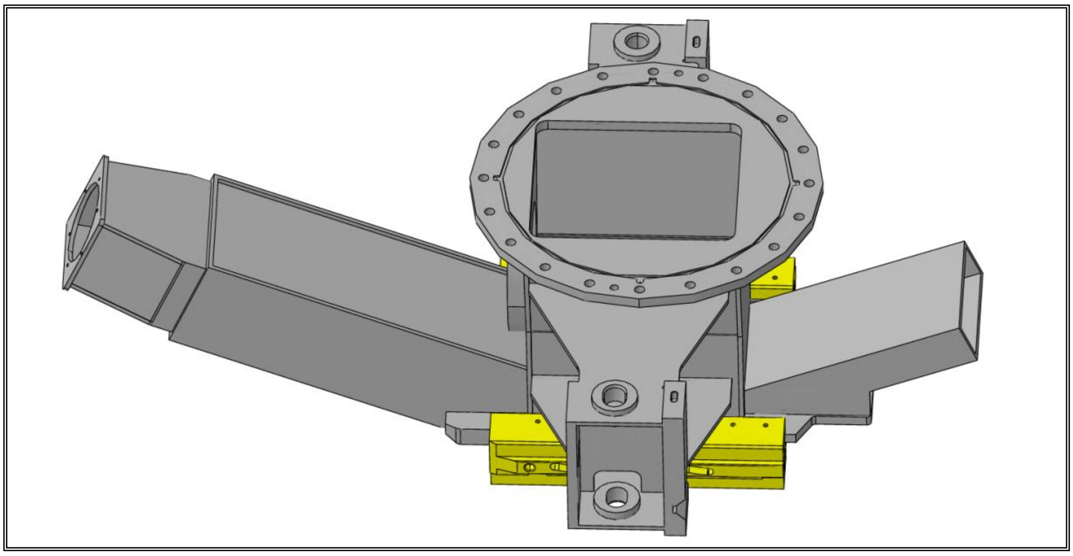

Figure 4. Mock-up 3D geometric model. Target Assembly and Back-Plate lateral view.

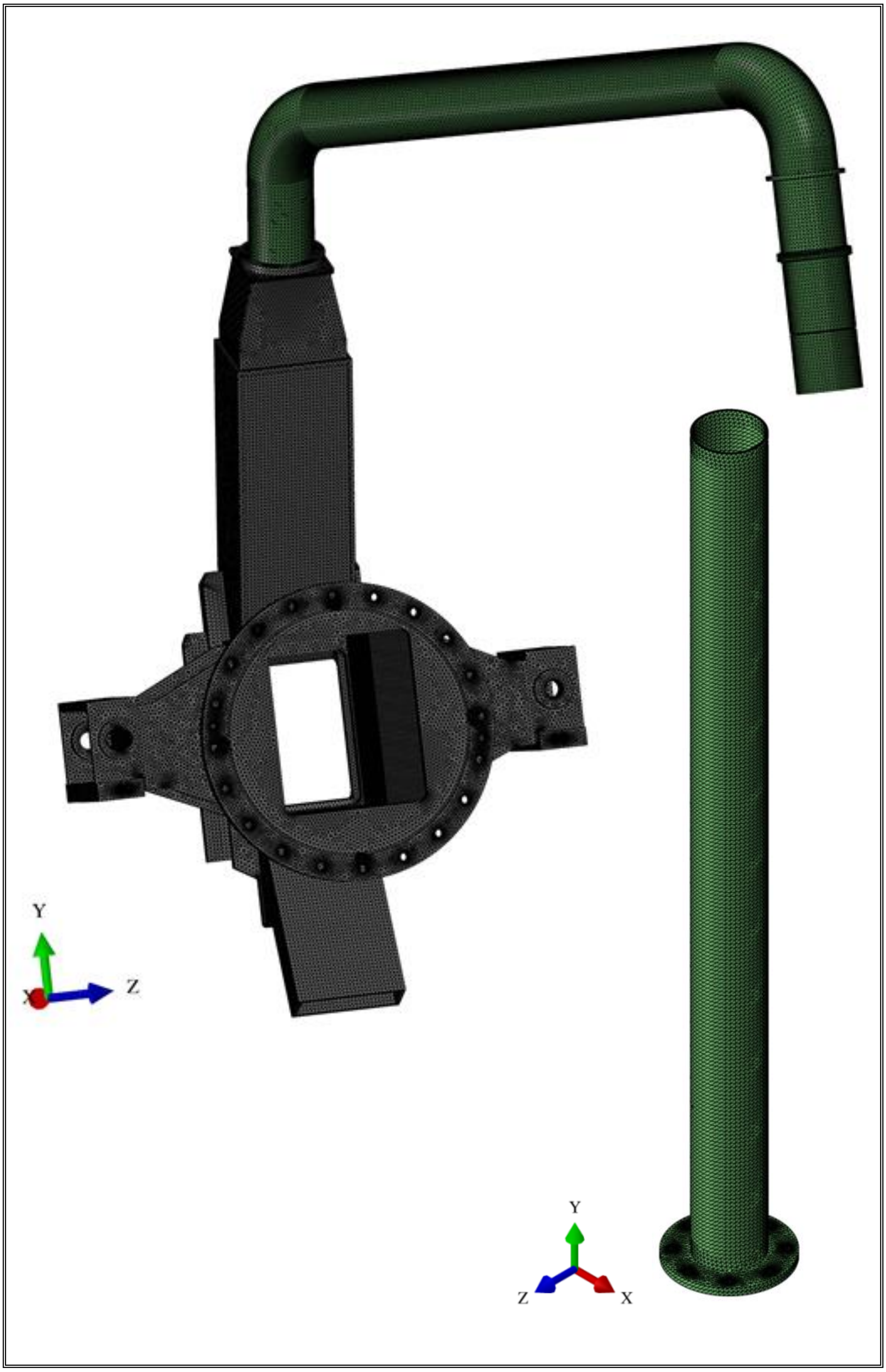

Figure 5. Mock-up FEM model. Target Assembly and Lithium inlet pipe exploded view.

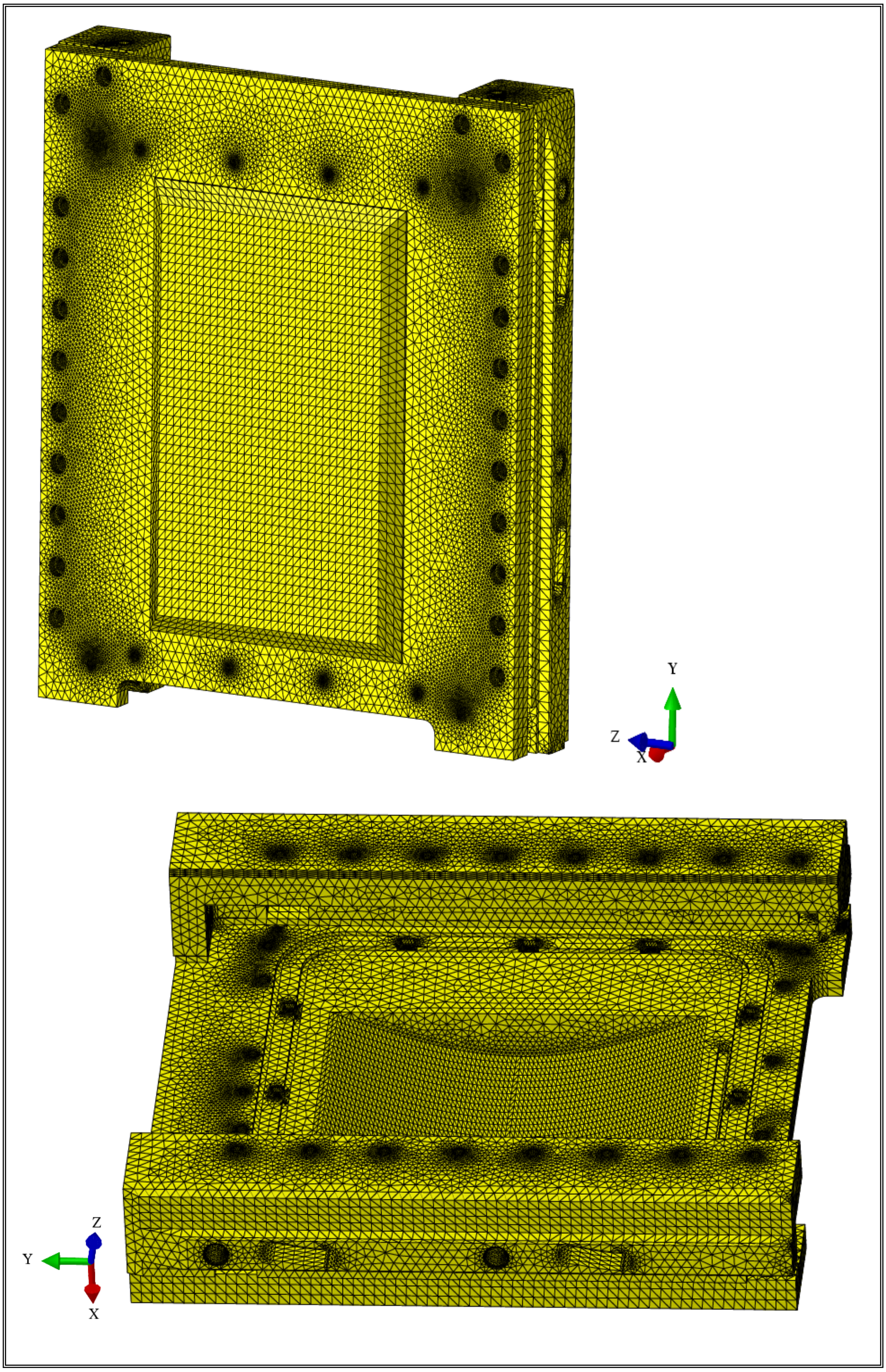

Figure 6. Mock-up FEM model. Particular of the Back-Plate.

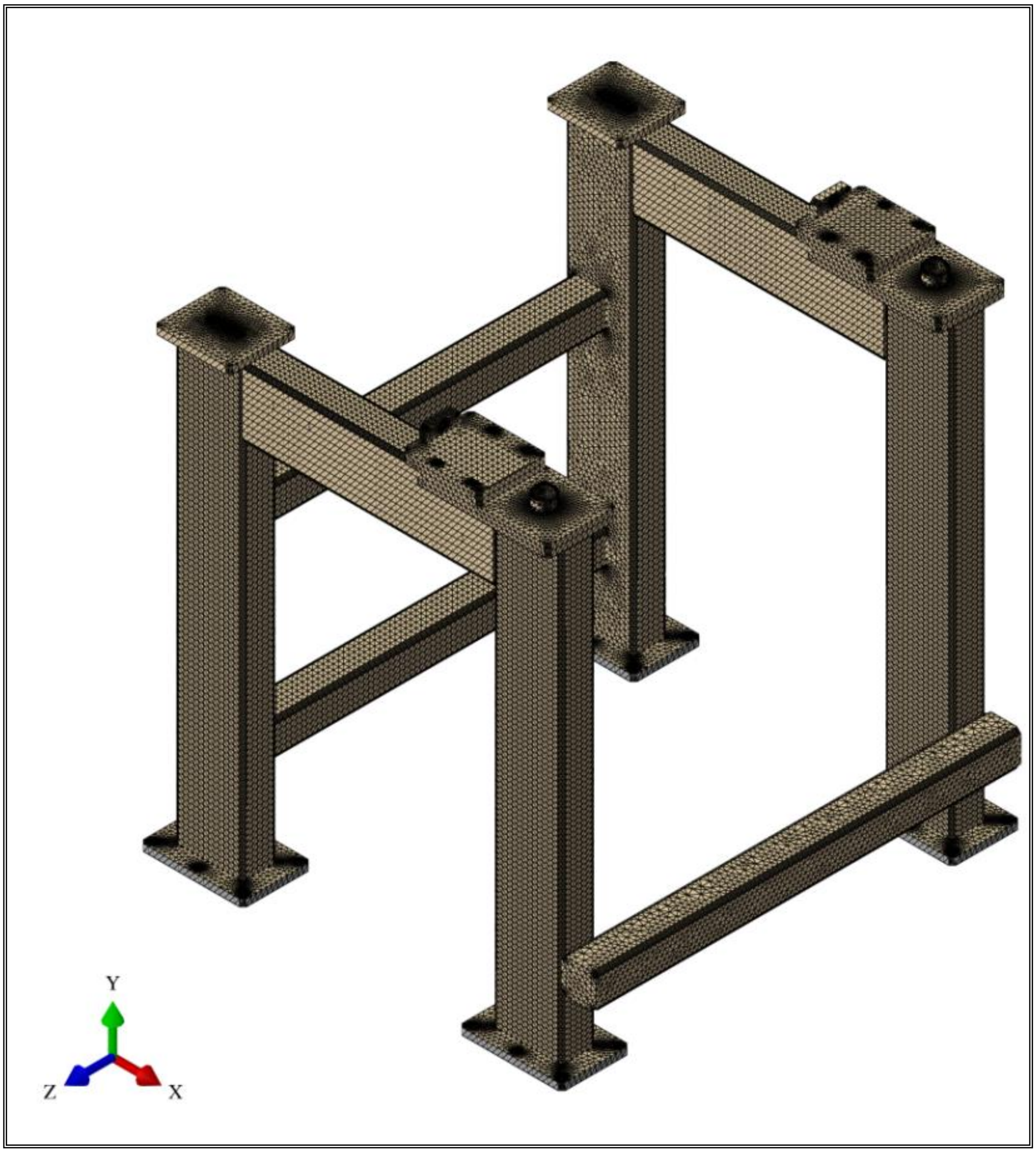

Figure 7. Mock-up FEM model. Particular of the Support framework.

3.2.1 Materials

According to the design of the IFMIF target system mock-up installed at ENEA Brasimone laboratory, AISI 304 steel has been assumed as the Target Assembly, Support framework and Lithium inlet pipe structural material. As far as the Back-Plate is concerned, it has been considered to be made of AISI 316 steel. The structural materials thermo-physical properties have been assumed to depend uniquely on temperature, as indicated in [10-12]. The thermo-physical properties values at room temperature of 20 °C are summarized in Tables 1 and 2, while temperature-dependent behaviour of the considered materials thermo-physical properties, normalized at the room temperature value, can be deduced from Figures 8-9.

Table 1. AISI 304 steel thermo-physical properties at 20°C [10].

AISI 304 STEEL	
λ_0	14.28 W/m K
c_{p0}	472 J/kg K
α_0	$1.53 \cdot 10^{-5}$ K^{-1}
ρ_0	7930 kg/m^3

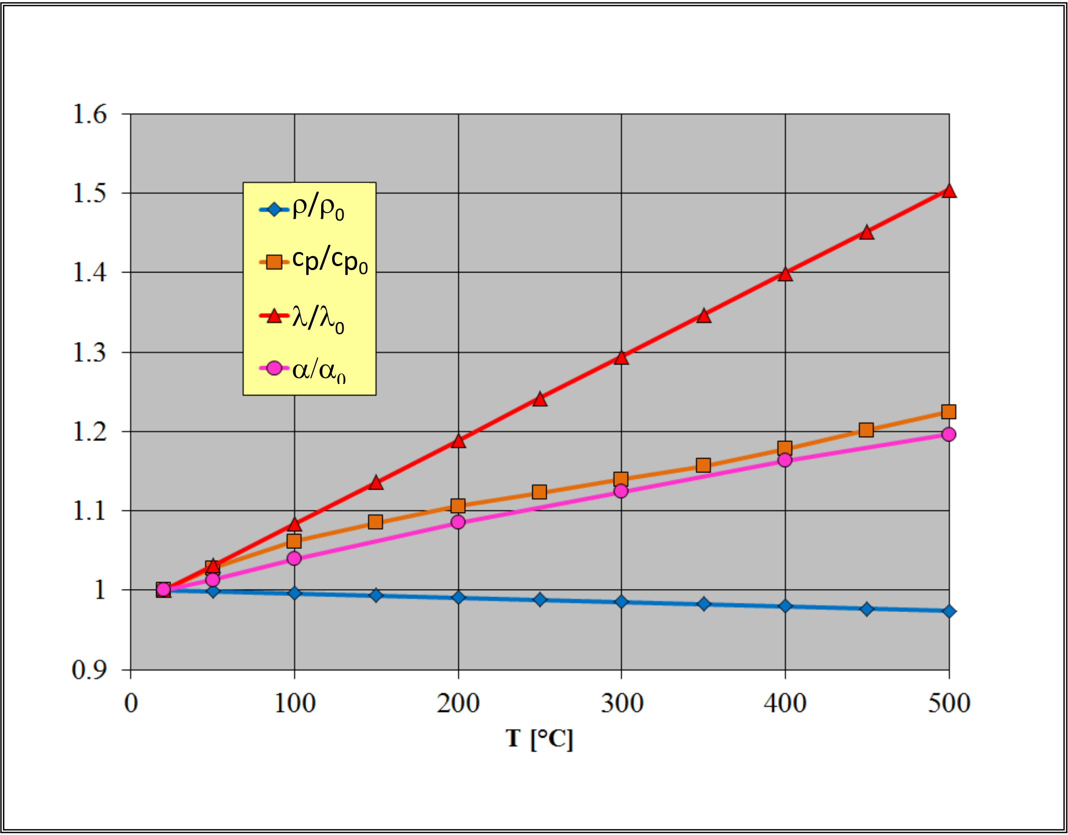

Figure 8. AISI 304 steel temperature-dependent thermo-physical properties.

Table 2. AISI 316 steel thermo-physical properties at 20°C [11-12].

AISI 316 STEEL	
λ_0	15 W/m°C
c_{p0}	452 J/kg°C
α_0	$1.54 \cdot 10^{-5}$ K^{-1}
ρ_0	7950 kg/m^3

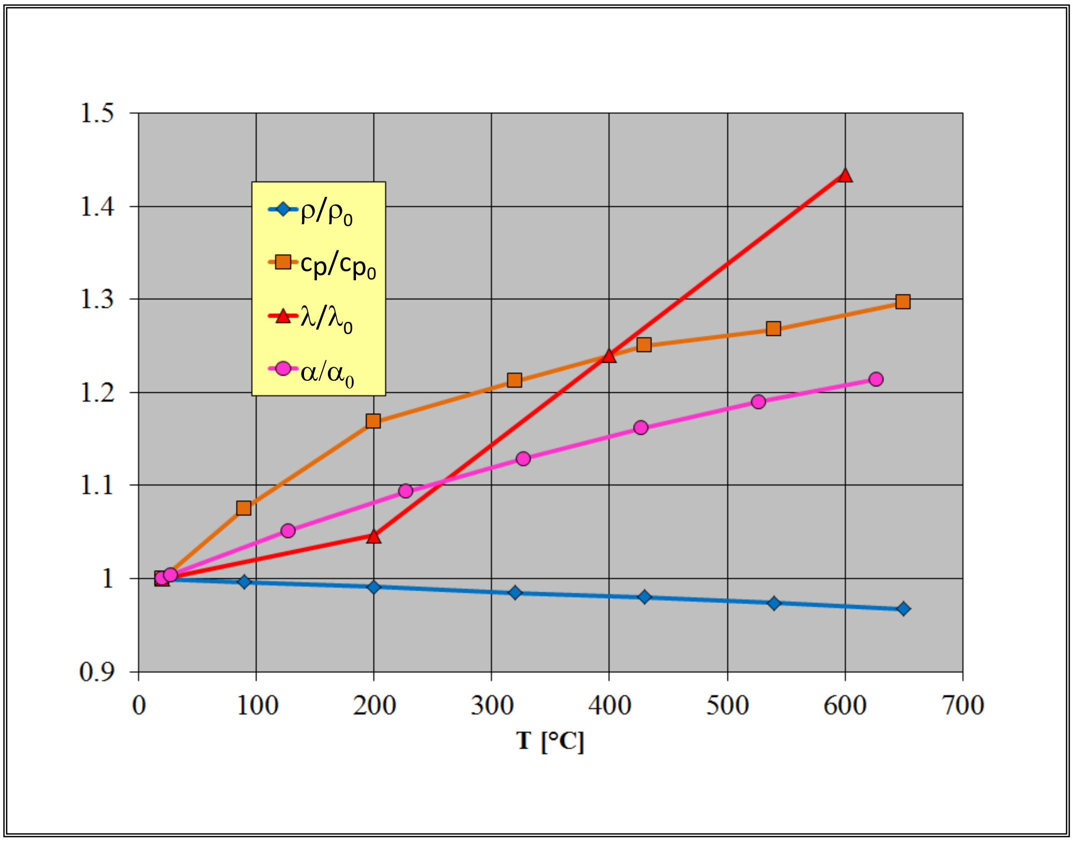

Figure 9. AISI 316 steel temperature-dependent thermo-physical properties.

3.2.2 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 framework and Lithium inlet pipe, thermal behaviour under pre-heating phase transient scenario:

- thermal interactions;
- heat transfer between Target chamber and Beam duct;
- time-dependent heat fluxes;
- internal irradiation;
- external irradiation;
- Target Assembly and Support framework natural convective cooling.

Thermal interactions between frame and Back-Plate have been simulated by a thermal contact model which foresees the following functional dependence of the heat flux between two coupled nodes i and j, q_{ij}, on their temperatures, T_i and T_j:

$$q_{ij} = H\left(T_i - T_j\right) \quad (1)$$

where H represents the thermal conductance between the two interacting components, which has been set to 2000 W/m^2°C [13,14]. All the other components of the model have been considered as a continuum from the thermal point of view. As to the gimbal expansion joint simulation, a proper coupling thermal model between straight and blend Lithium inlet pipe sections has been taken into account, as already done in [15].

Heat transfer between Target chamber and Beam duct has been simulated by imposing, according to [6], an effective convective heat transfer coefficient equal to 15.8 W/m^2°C on the Target chamber flange surface (red surface in Fig. 10) and a non-uniform bulk temperature, T_L, analytically derived from a 1-D simplified model of the beam duct conductive-radiative heat transfer, purposely set-up at DEIM for the previous research activities [4,15] developed within the framework of IFMIF R&D activities.

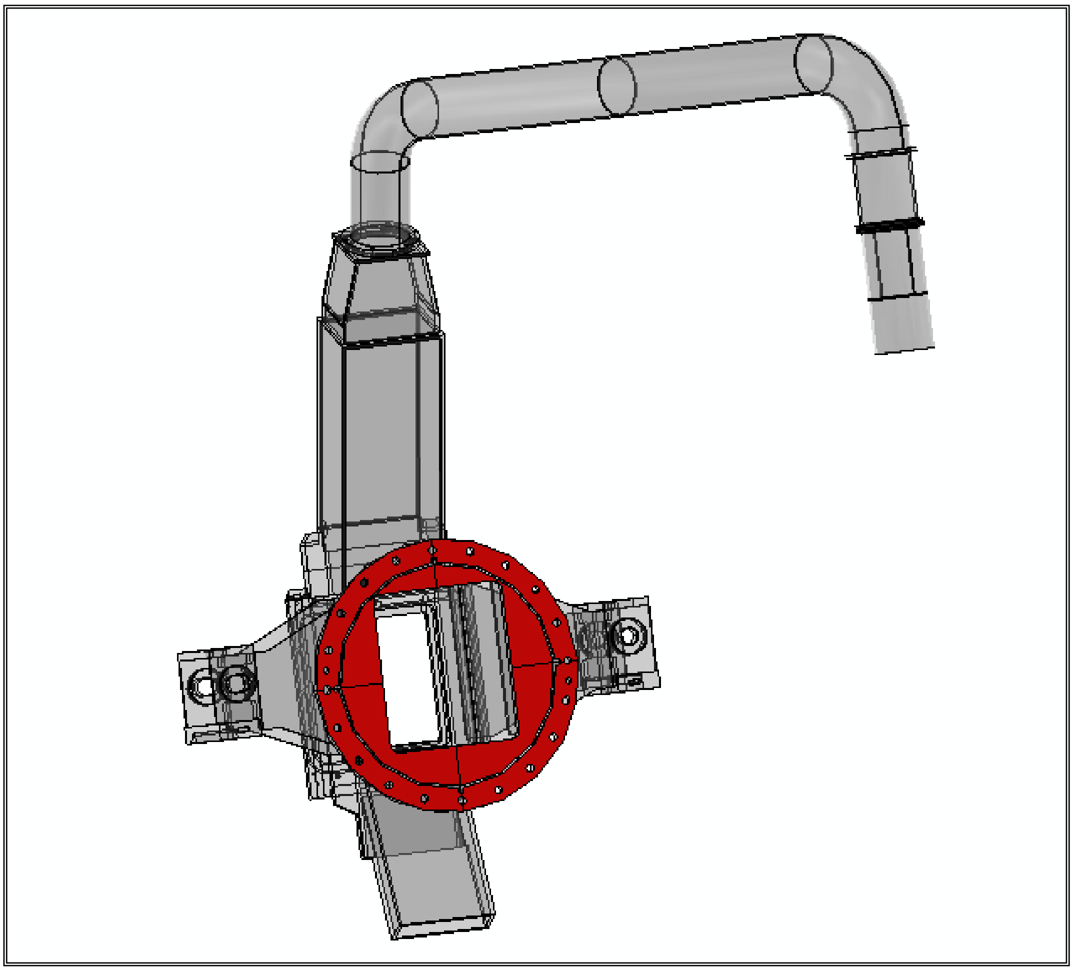

Figure 10. Target chamber flange surface.

In order to simulate the discontinuous electric heaters action in the pre-heating phase of the start-up transient loading scenario [4], a proper set of time-dependent heat fluxes has been imposed, by a purposely set-up FORTRAN routine, to the mock-up external surfaces, on the basis of the electric heaters spatial arrangement foreseen for the experimental campaigns on the TA mock-up. In particular, two different arrangements, named respectively Configuration 1 and Configuration 2, have been simulated (Figures 11-12) in order to investigate the influence of an electric heater laying onto the BP external surface on its thermal field time evolution. The values of the heat fluxes have been assumed on the basis of the technical specifications of the electric heaters devoted to perform the experimental campaigns on the TA mock-up. As for BP external surface heat flux, the value of 1500 W/m^2 has been inferred from the study, carried out ad DEIM, reported in [4] and aimed at investigating the IFMIF TA thermo-mechanical performances in the start-up transient loading scenario.

Since the present study has been devoted to set-up the electric heaters load profile able to ensure a temperature increase within the structure as uniform as possible, an iterative approach has been followed in order to determine the most appropriate electric heaters load profile in all the configurations taken into account. The iterative procedure has been based on modifications of the FORTRAN routine whenever a specific criterion, described in the following, based on the maximum temperature achieved within the most critical components has not been met.

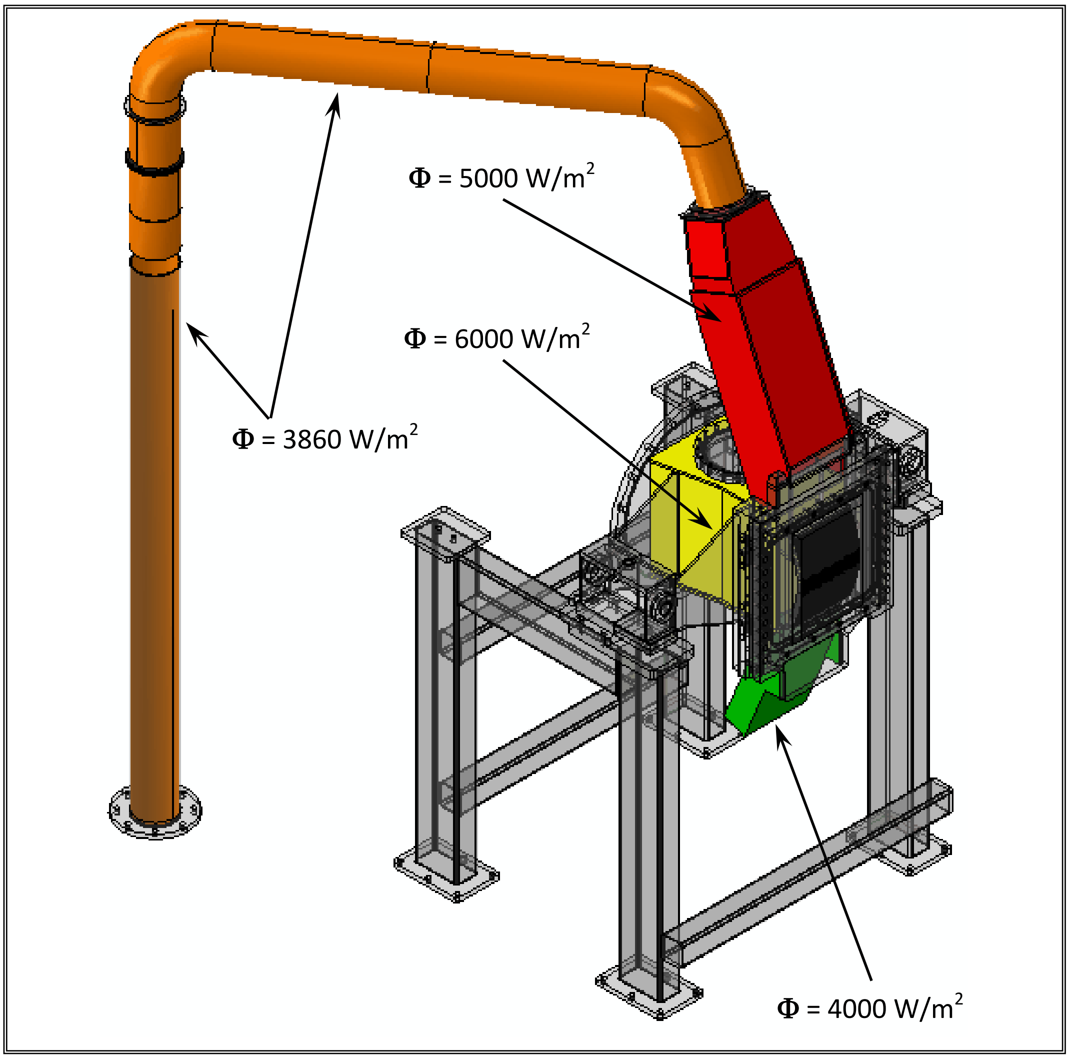

Figure 11. Heat fluxes. Configuration 1.

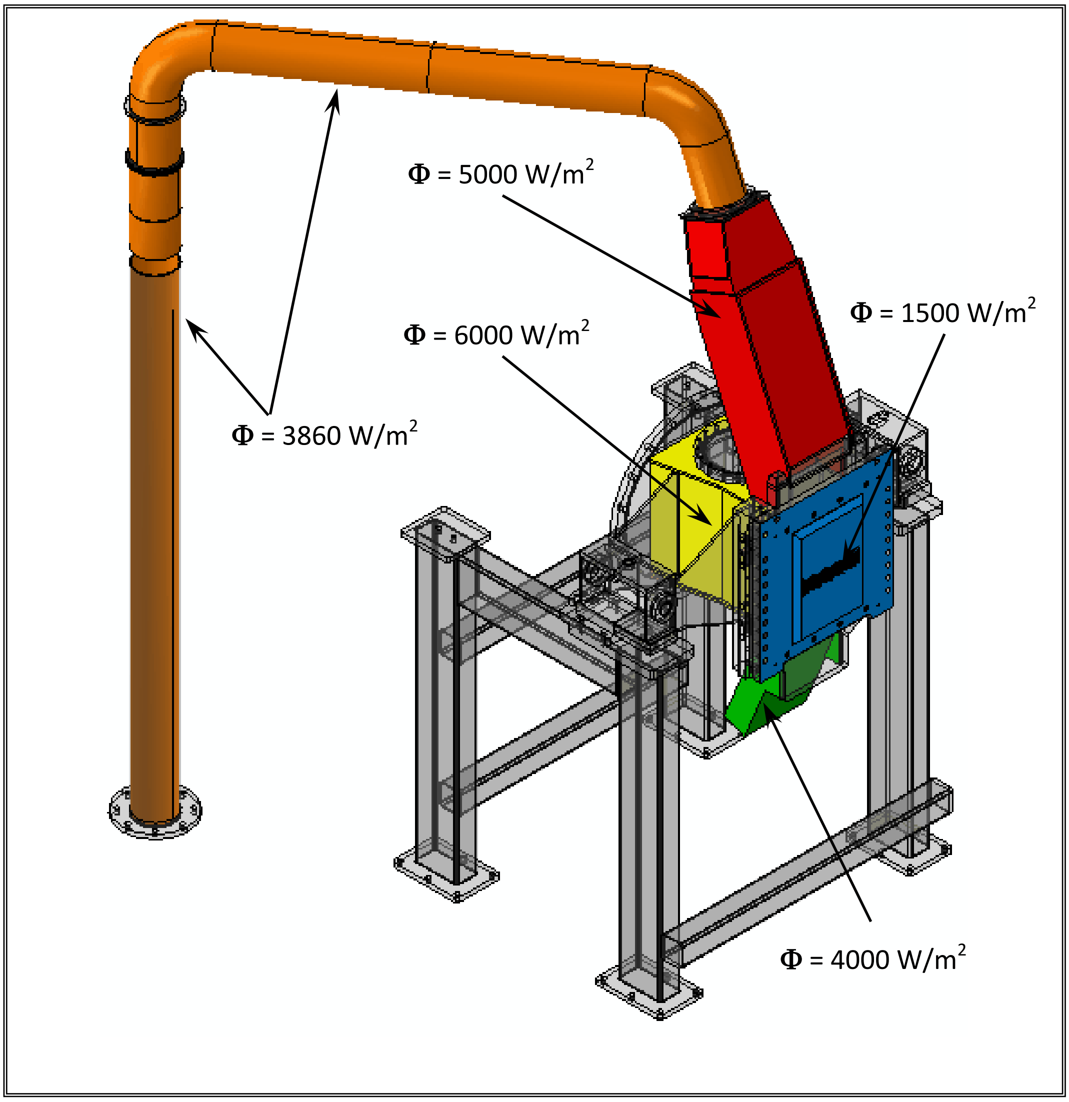

Figure 12. Heat fluxes. Configuration 2.

Radiation heat transfer occurring internally, between the internal walls of mock-up, has been modelled adopting the cavity radiation formulation widely described in [16,17]. It is based on the definition of a proper cavity articulated in mutually radiating surfaces, which result to be composed of collections of element facets.

Assuming that grey body radiation theory holds, considering only diffuse and, consequently, non-directional reflection from facets and neglecting radiation attenuation in the cavity medium, it is possible to derive, under the further hypothesis of isothermal and iso-emissive facets, the following analytical expression for the radiation heat flux, q_i, that the i-th facet receives from the rest of the facets belonging to the same cavity:

$$q_i = \frac{\sigma \varepsilon_i}{A_i} \sum_j \varepsilon_j \sum_k F_{ik} C_{kj}^{-1} \left(\theta_j^4 - \theta_i^4 \right) \quad (5)$$

where σ is the Stefan-Boltzmann constant, A_i is the area of i-th facet, ε_i and ε_j are the emissivities of the i-th and j-th facets, F_{ik} is the viewfactor between the i-th and k-th facets, θ_i and θ_j are the absolute temperatures of the i-th and j-th facets and C_{kj} is given by:

$$C_{kj} = \delta_{kj} - \frac{(1-\varepsilon_k)}{A_k} F_{kj} \quad (6)$$

with δ_{kj} representing the Kronecker's delta.

Since the mock-up structure is internally divided in six regions by means of internal plugs, a proper set of six radiation cavities, each reproducing one of the mock-up internal regions, has been defined in the 3D FEM model. The six radiation cavities set-up does not mutually interact from the radiation heat transfer point of view, due to the presence of the afore-mentioned dividing plugs.

The surfaces forming the six radiation cavities have been highlighted, using different colours, in Figure 13.

It has to be noted that no radiation has been allowed through the cavity opening at the top of the target chamber, since it is envisaged to be closed by the pipe simulating the presence of the beam ducts, and through the outlet nozzle exit section, since it is envisaged to be closed by a plug which reproduces the presence of the quench tank flange. Emissivity value of 0.3 has been adopted for all steel walls, as indicated in [18].

Radiation heat transfer occurring externally between the mock-up un-insulated external surfaces and the atmosphere of the containment building has been modelled applying the following simplified condition to element facets which are supposed to be un-insulated during the pre-heating phase of the start-up transient scenario:

$$q_{i0} = \sigma\varepsilon_i \left(\theta_i^4 - \theta_0^4\right) \quad (7)$$

where q_{i0} and ε_i are, respectively, the radiation heat flux and the emissivity of the i-th element facet, set to 0.3 both for AISI 304 and AISI 316, while θ_0 is the absolute temperature of the Test Cell atmosphere, set to 293 K.

In the present study, all the surfaces housing the electric heaters have been assumed as not radiating towards the containment building atmosphere. In particular, within Configuration 1, two different external irradiation conditions, named A and B, have been investigated. Surfaces able to radiate towards mock-up containment building atmosphere in Configuration 1-A and Configuration 1-B are shown in red in Figures 14-15. It has to be noted that the difference between the Configuration 1-A and Configuration 1-B is represented by the external irradiation condition assumed for the BP, which has been considered free to radiate only in Configuration 1-A.

On the other hand, also in Configuration 2 the surfaces devoted to house the electric heaters have been considered as not-radiating, as it has already been adopted in Configuration 1. Therefore, since in Configuration 2 has been assumed the presence of an electric heater on the BP external surface, the external irradiation condition imposed in this Configuration 2 corresponds to Configuration 1-B one (Fig. 15).

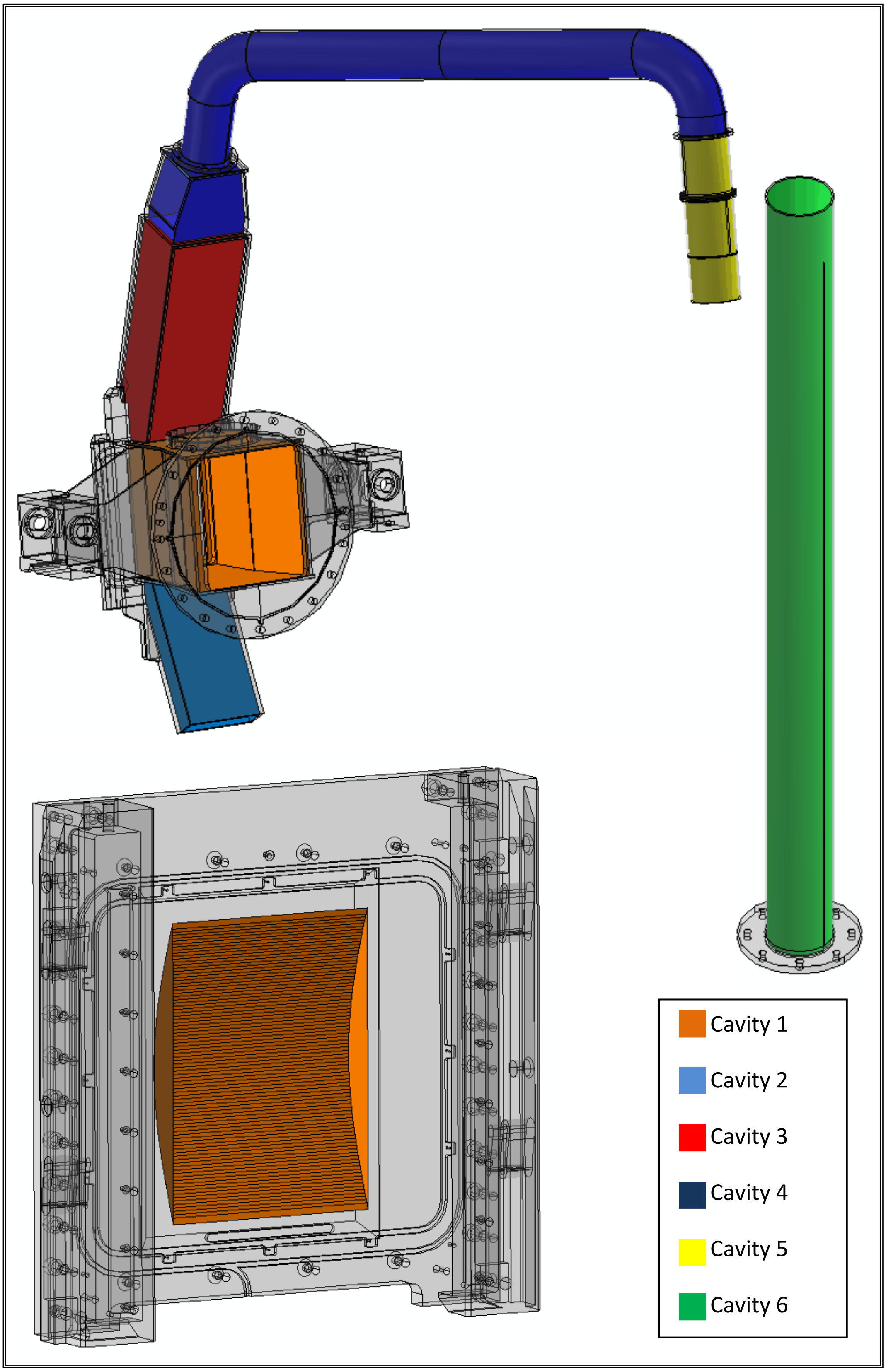

Figure 13. Radiation cavities surfaces.

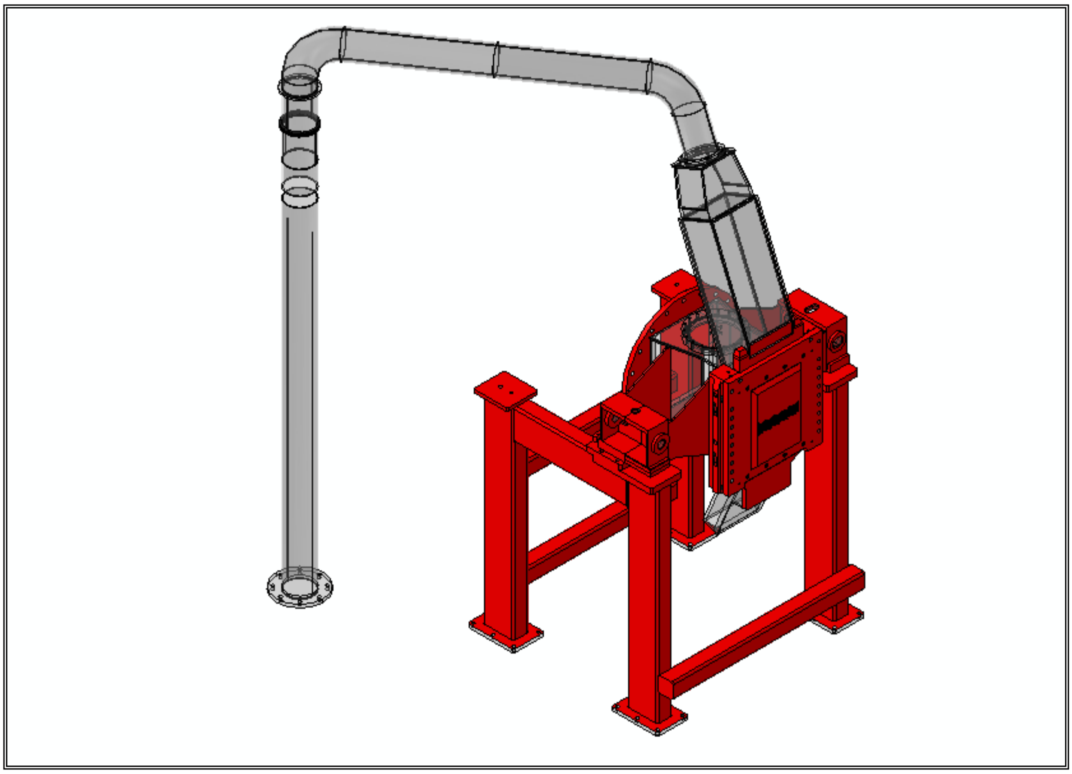

Figure 14. Radiating surfaces. Configuration 1-A.

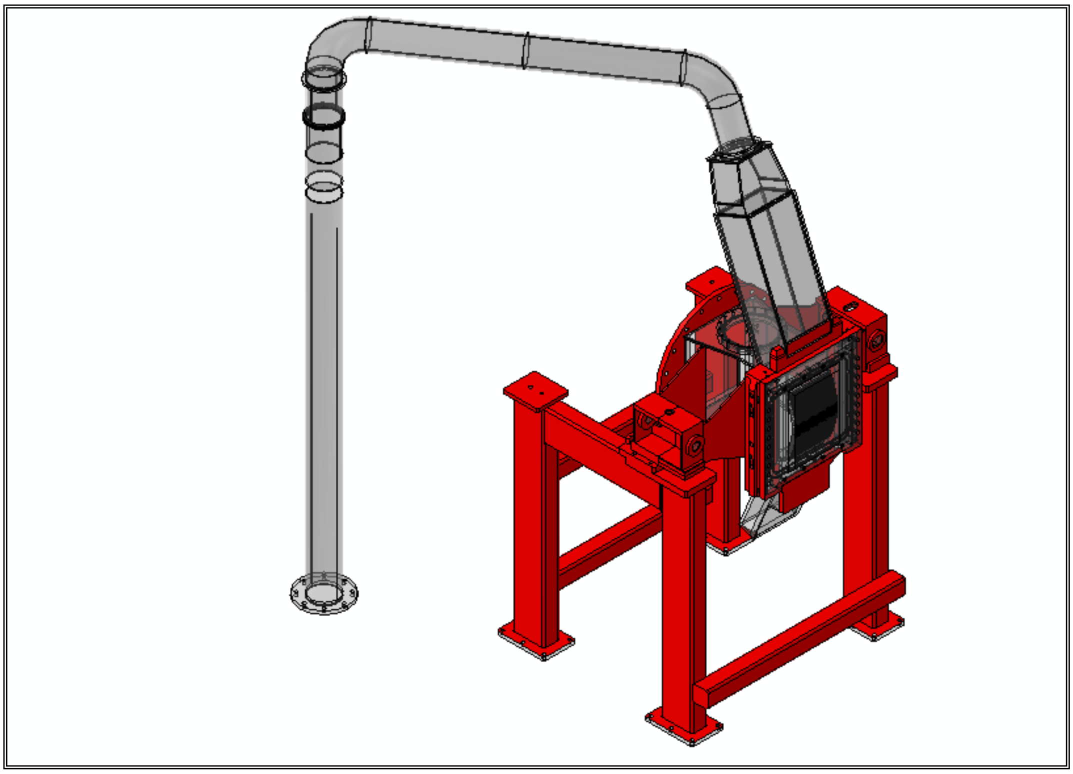

Figure 15. Radiating surfaces. Configurations 1-B and 2.

Regarding Target Assembly and Support framework natural convective cooling, the following Cauchy's boundary condition has been imposed to the nodes laying on the mock-up non-insulated surfaces (Figs. 14-15), as already adopted in [15]:

$$q_j = h\left(T_j - T_{atm}\right) \qquad (8)$$

where q_j is the normal heat flux at the j-th node of the mock-up non-insulated surfaces, T_{atm} is the uniform bulk temperature of the containment building atmosphere, set to 20°C, and h represents the convective heat transfer coefficient, which has been properly assumed equal to 10 W/m^2°C [15].

3.3 Transient analysis and results

A campaign of thermal transient analyses has been carried out to investigate the target system mock-up thermal behaviour under the pre-heating phase of the IFMIF start-up loading scenario, in order to set-up the electric heaters load profile able to allow a structure heating as uniform as possible. Three transient thermal analyses, one for each thermal configuration taken into account, have been carried out to obtain the corresponding electric heaters load profiles, which have been set-up following an iterative procedure based on the analysis of the time evolution of the maximum temperature achieved within Lithium inlet pipe, Inlet nozzle, Target chamber, Outlet nozzle and Back-Plate. In particular, the electric heaters load profile have been modified whenever the maximum temperature increase within the above-said components has not been sufficiently uniform. Moreover, once the maximum temperature of a component has raised up to the reference value of 250 °C, the load profile has been further modified whenever the maximum temperature has not ranged between the 240 °C - 260 °C interval, allowing the heating of the others components up to 250 °C. Adopting this criterion in each of the three configurations assessed, it has been possible to assess the relevant electric heaters load profiles.

Analyses results have shown that thermal Configurations 1-A and 1-B, in which no electric heater is foreseen on the BP, do not allow the BP maximum temperature to increase up to 250 °C. In particular, in these two configurations, the BP maximum temperature achieves a steady-state value well below 200 °C. For this reason, both thermal results and electric heaters load profiles relevant to Configurations 1-A and 1-B have not been reported in the following.

As a consequence of conclusions drawn from the results obtained as to Configurations 1-A and 1-B, the only heating strategy able to lead the BP maximum temperature up to 250 °C is that one foreseeing an electric heater on its external surface, as assumed in Configuration 2.

Results obtained from Configuration 2 in terms of maximum temperature time distributions are shown in Figures 16-24, while the thermal field arising at the end of the pre-heating phase is shown in Figures 25-26. The electric heaters load profile has been reported in Tables 3-11.

It can be observed that Configuration 2 ensures the achievement of a BP maximum temperature of ~244 °C, so very close to 250 °C, after a pre-heating phase of 720 minutes. Furthermore, it has to be noted that this is possible only assuming the BP electric heater to be switched-on for the entire pre-heating phase duration.

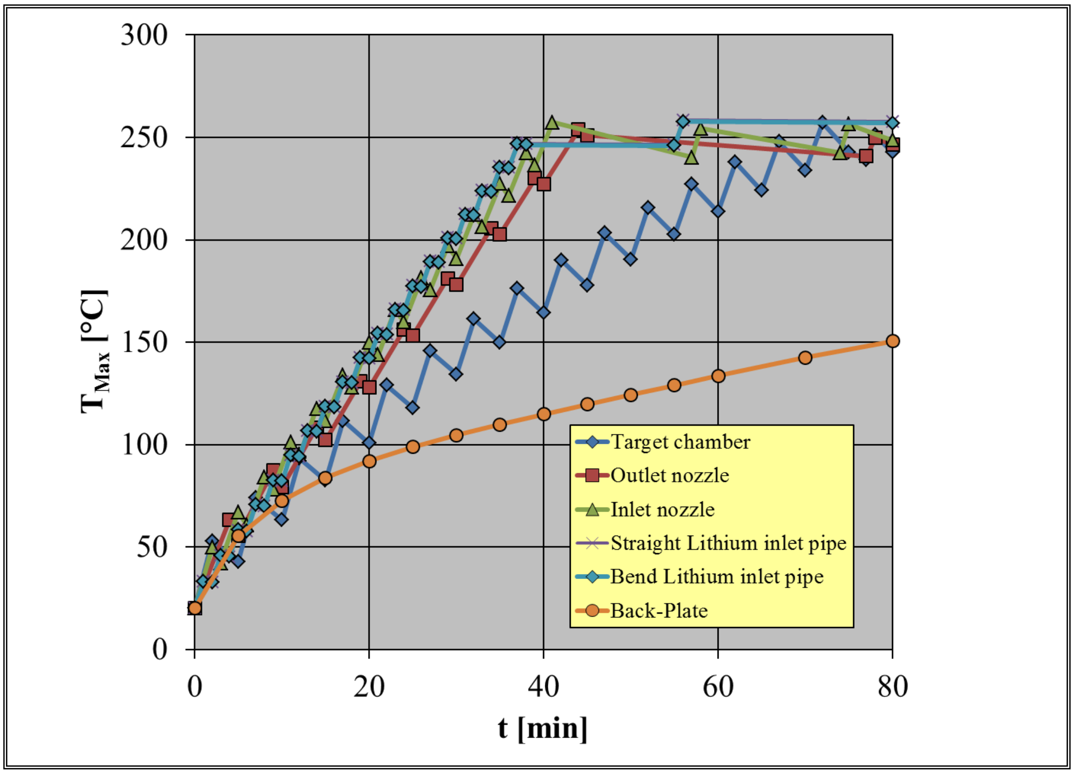

Figure 16. Configuration 2. Maximum temperature vs time. 0-80 minutes.

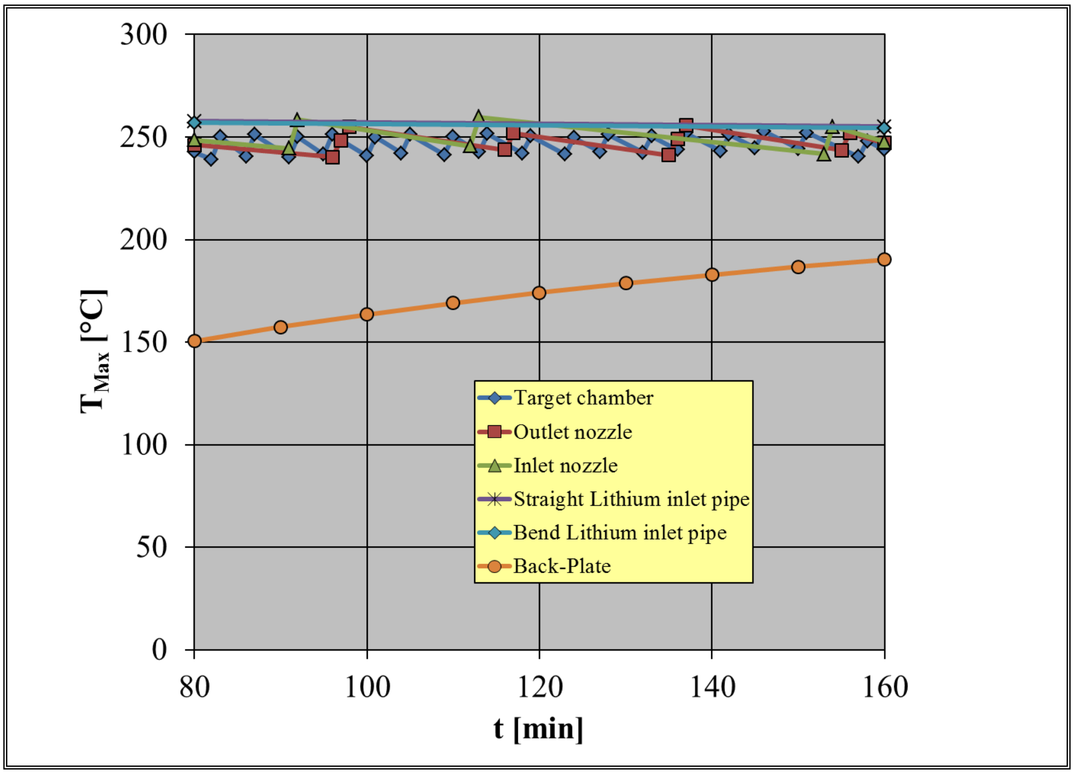

Figure 17. Configuration 2. Maximum temperature vs time. 80-160 minutes.

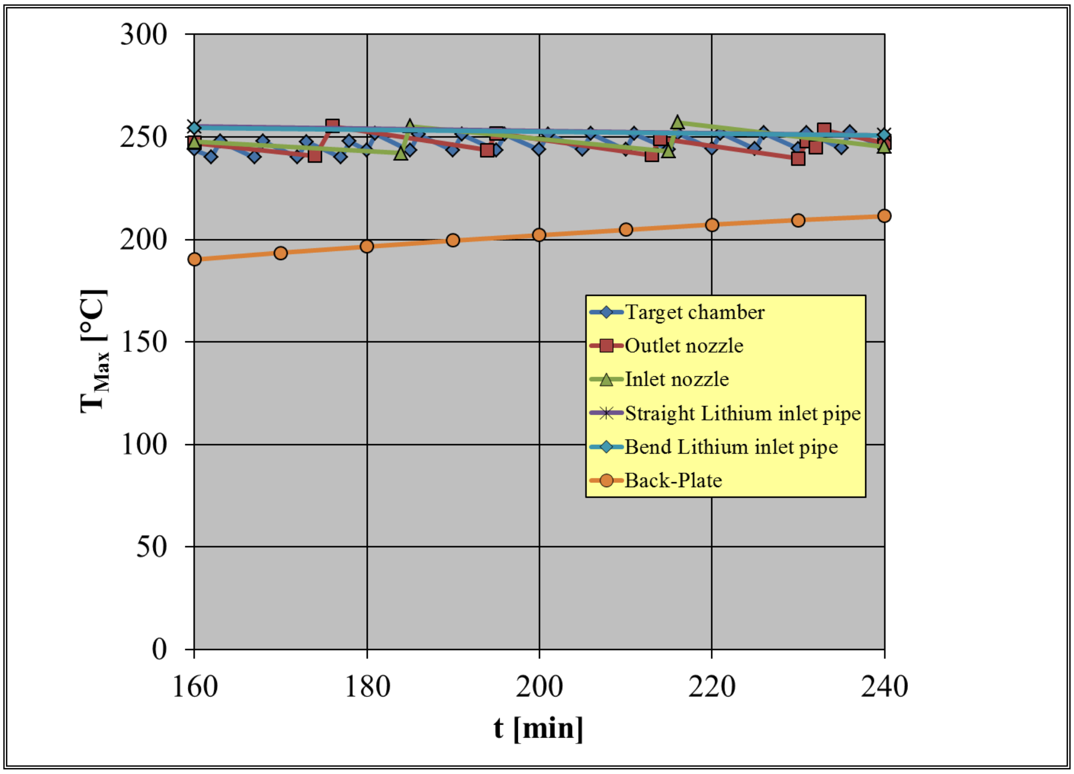

Figure 18. Configuration 2. Maximum temperature vs time. 160-240 minutes.

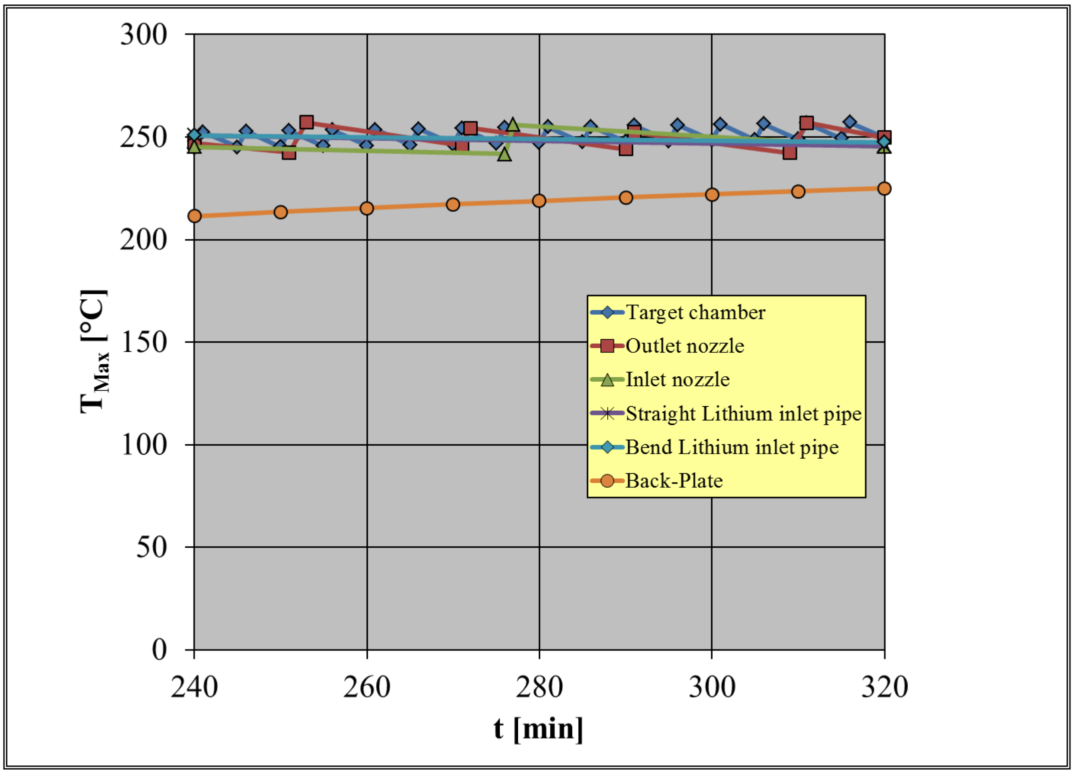

Figure 19. Configuration 2. Maximum temperature vs time. 240-320 minutes.

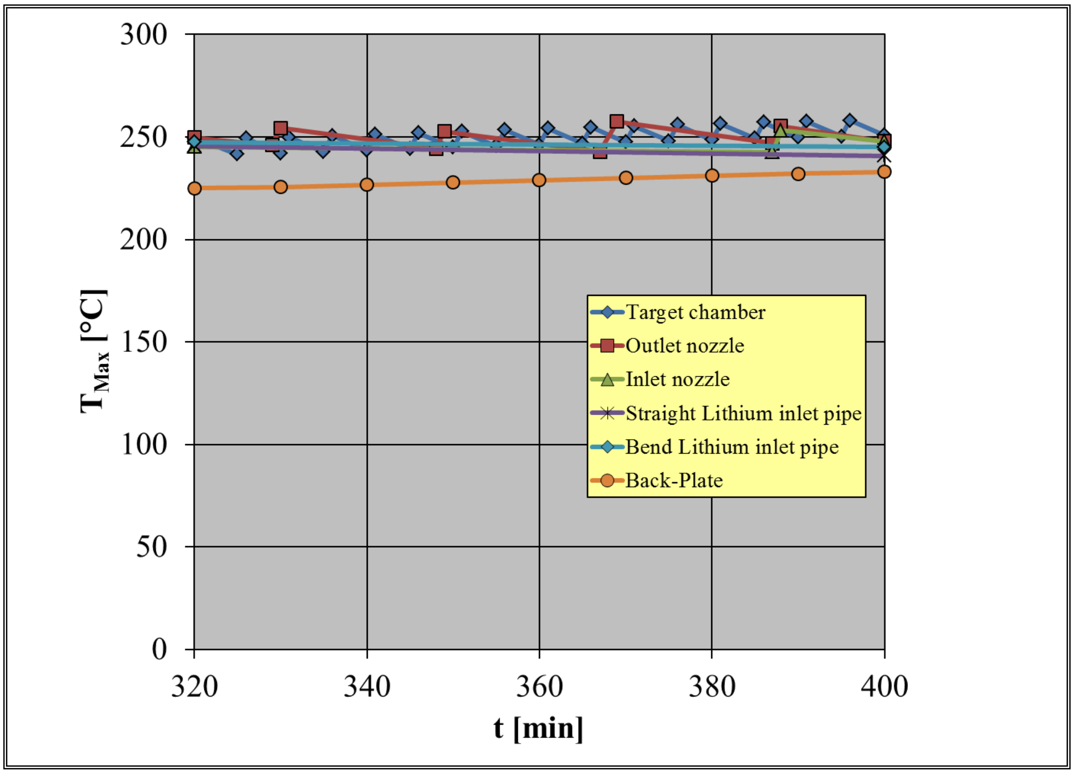

Figure 20. Configuration 2. Maximum temperature vs time. 320-400 minutes.

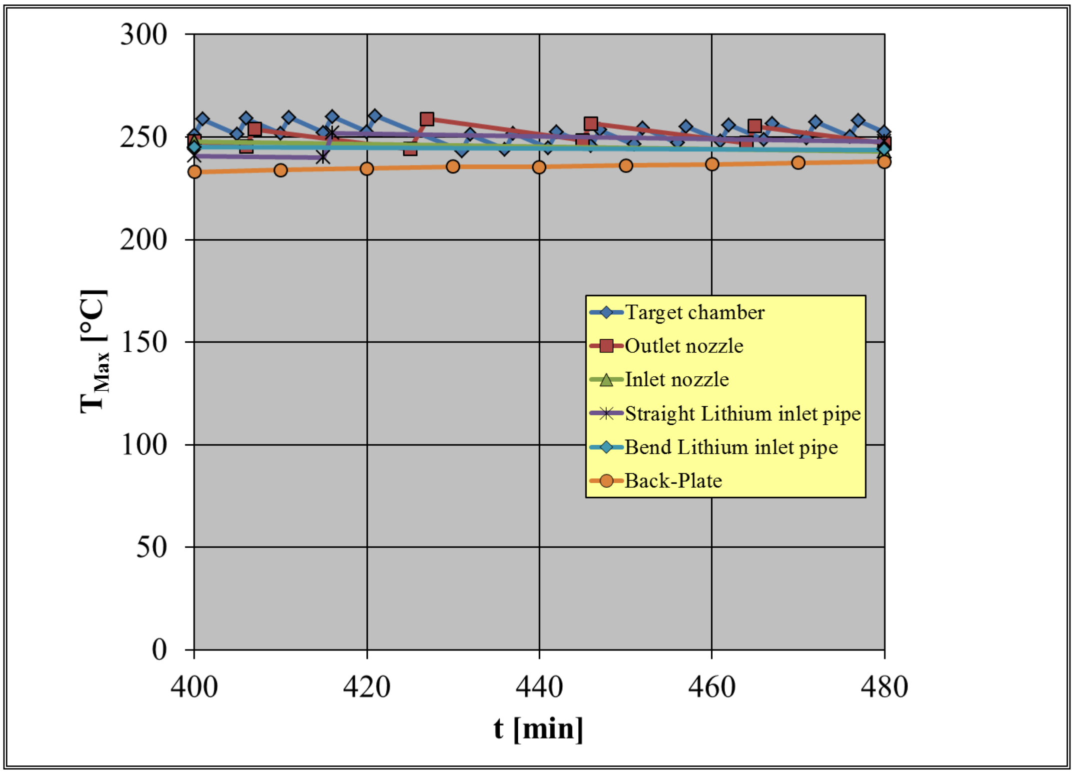

Figure 21. Configuration 2. Maximum temperature vs time. 400-480 minutes.

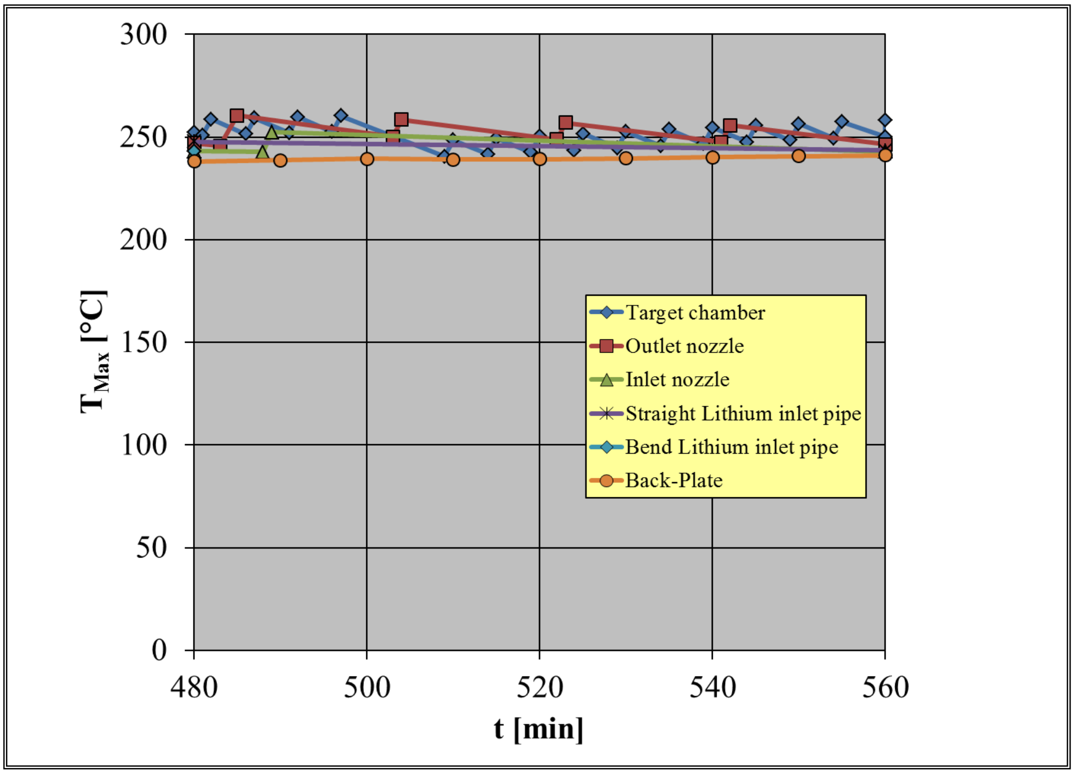

Figure 22. Configuration 2. Maximum temperature vs time. 480-560 minutes.

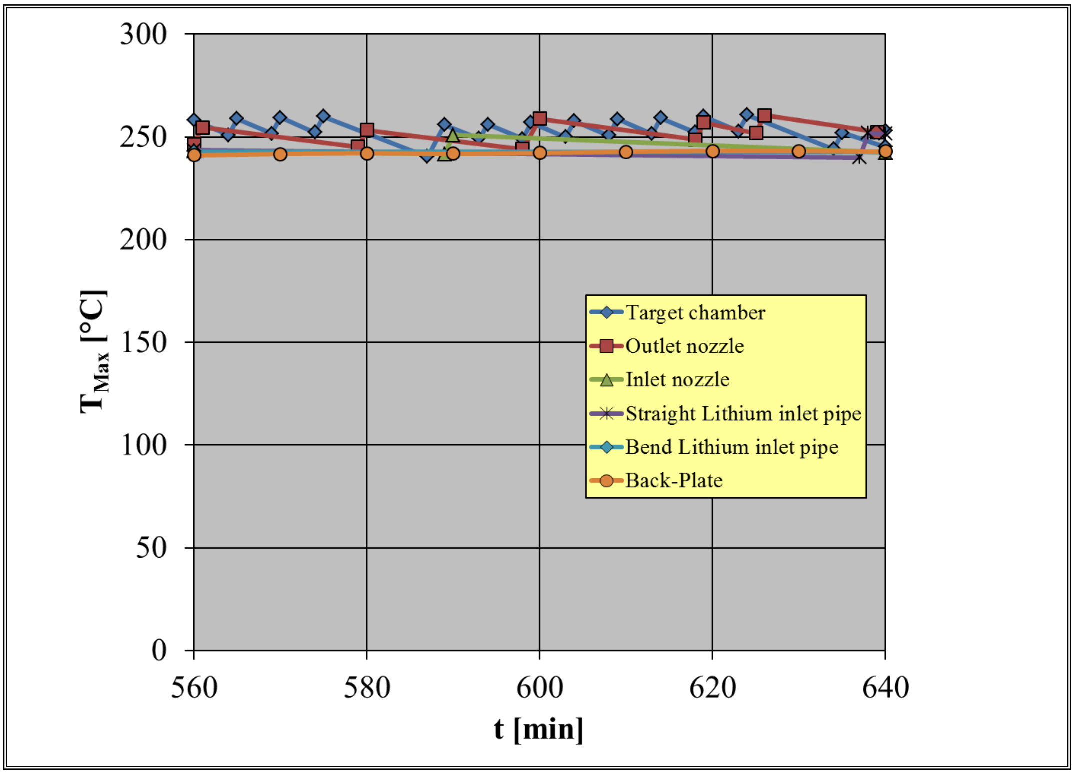

Figure 23. Configuration 2. Maximum temperature vs time. 560-640 minutes.

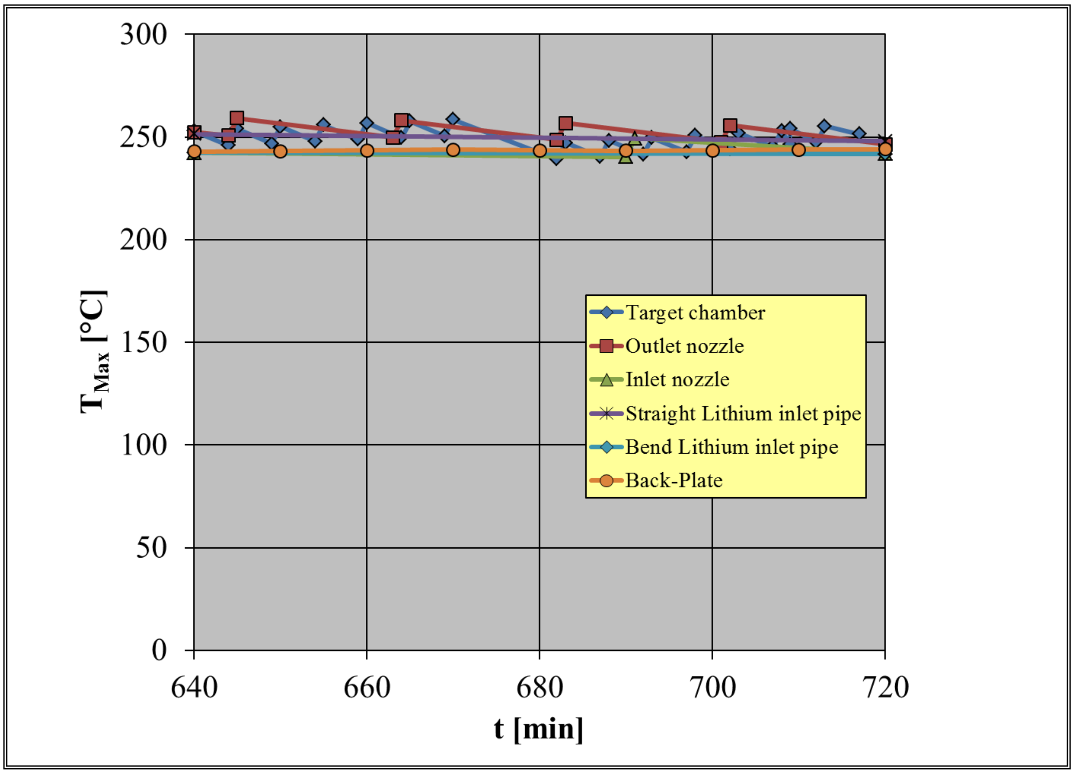

Figure 24. Configuration 2. Maximum temperature vs time. 640-720 minutes.

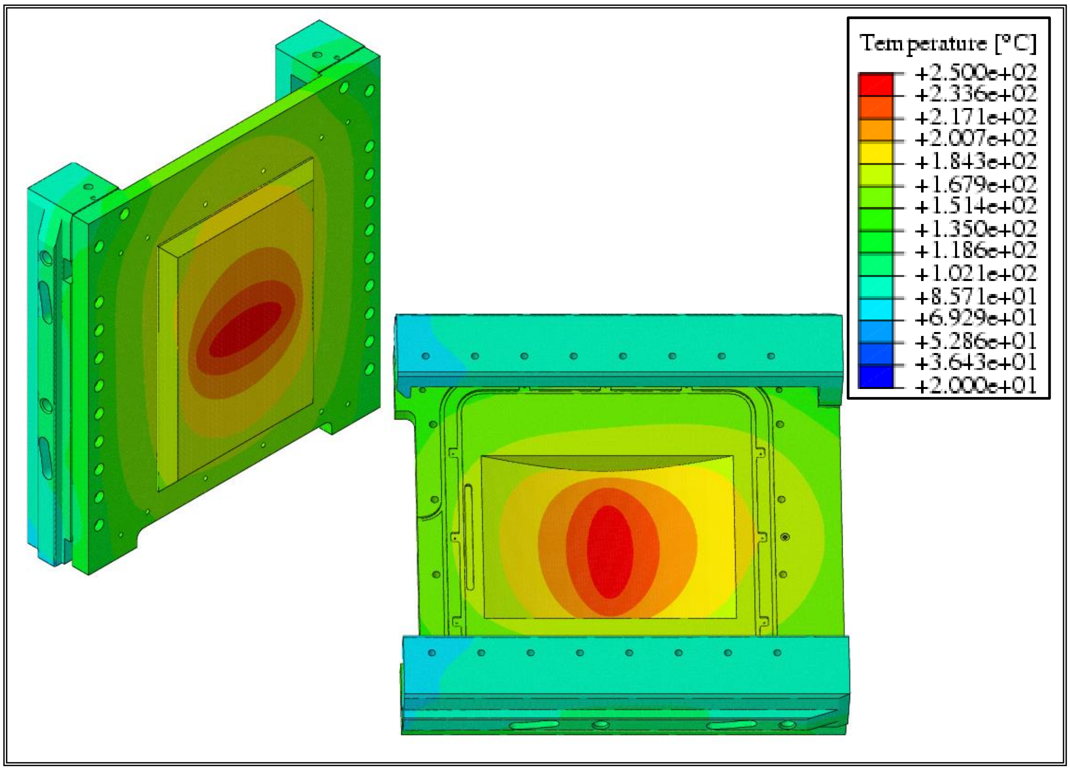

Figure 25. Configuration 2. BP thermal field - t = 720 minutes.

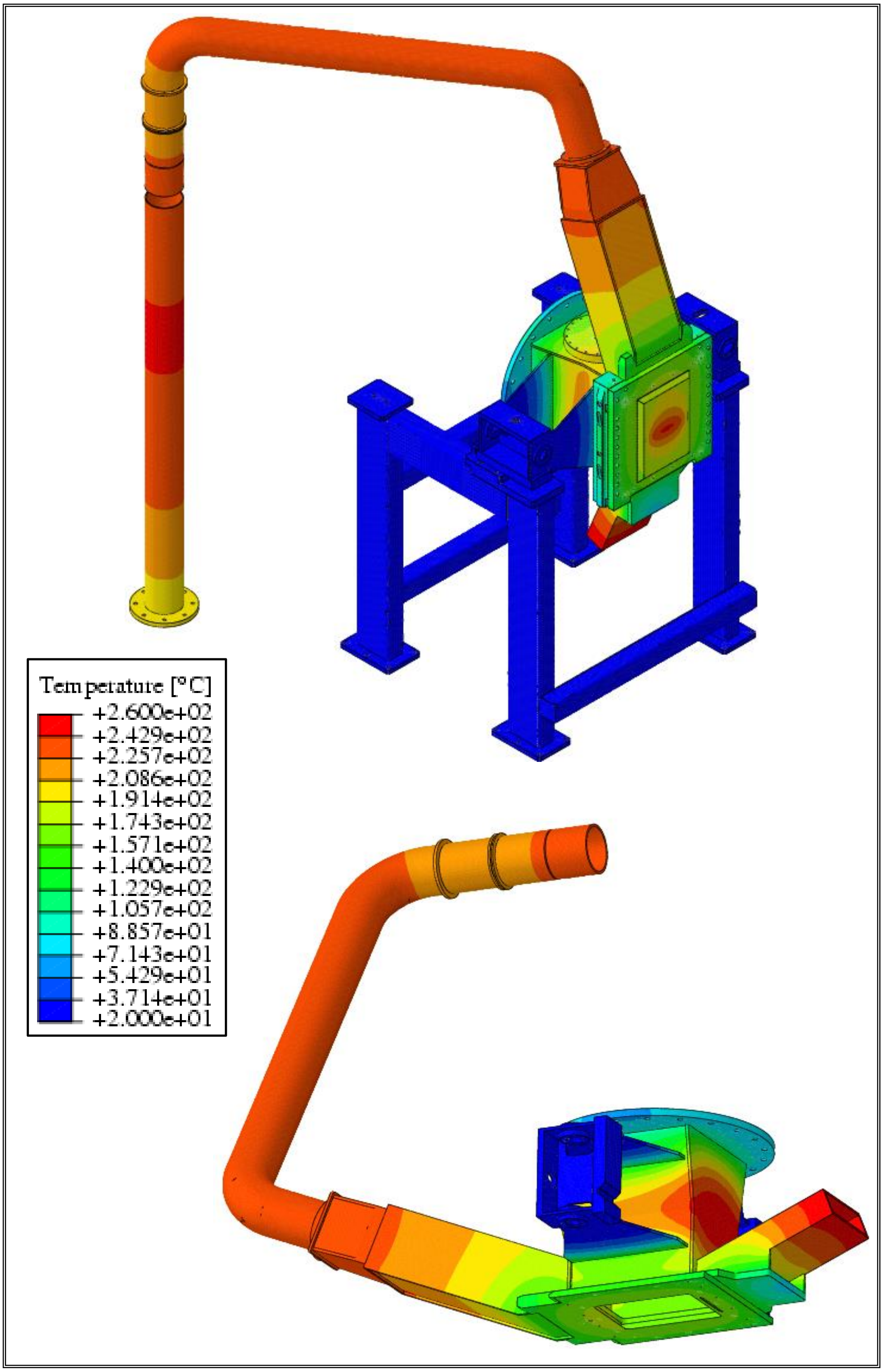

Figure 26. Configuration 2. Mock-up thermal field and particular of the TA - t = 720 minutes.

Table 3. Configuration 2. Electric heaters load profile. 0-80 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
0-1	ON	ON	ON	ON	ON	ON
1-2	ON	ON	ON	OFF	OFF	ON
2-3	OFF	ON	OFF	ON	ON	ON
3-4	OFF	ON	ON	OFF	OFF	ON
4-5	OFF	OFF	ON	ON	ON	ON
5-6	ON	ON	OFF	OFF	OFF	ON
6-7	ON	ON	ON	ON	ON	ON
7-8	OFF	ON	ON	OFF	OFF	ON
8-9	OFF	ON	OFF	ON	ON	ON
9-10	OFF	OFF	ON	OFF	OFF	ON
10-11	ON	ON	ON	ON	ON	ON
11-12	ON	ON	OFF	OFF	OFF	ON
12-13	OFF	ON	ON	ON	ON	ON
13-14	OFF	ON	ON	OFF	OFF	ON
14-15	OFF	OFF	OFF	ON	ON	ON
15-16	ON	ON	ON	OFF	OFF	ON
16-17	ON	ON	ON	ON	ON	ON
17-18	OFF	ON	OFF	OFF	OFF	ON
18-19	OFF	ON	ON	ON	ON	ON
19-20	OFF	OFF	ON	OFF	OFF	ON
20-21	ON	ON	OFF	ON	ON	ON
21-22	ON	ON	ON	OFF	OFF	ON
22-23	OFF	ON	ON	ON	ON	ON
23-24	OFF	ON	OFF	OFF	OFF	ON
24-25	OFF	OFF	ON	ON	ON	ON
25-26	ON	ON	ON	OFF	OFF	ON
26-27	ON	ON	OFF	ON	ON	ON
27-28	OFF	ON	ON	OFF	OFF	ON

28-29	OFF	ON	ON	ON	ON	ON
29-30	OFF	OFF	OFF	OFF	OFF	ON
30-31	ON	ON	ON	ON	ON	ON
31-32	ON	ON	ON	OFF	OFF	ON
32-33	OFF	ON	OFF	ON	ON	ON
33-34	OFF	ON	ON	OFF	OFF	ON
34-35	OFF	OFF	ON	ON	ON	ON
35-36	ON	ON	OFF	OFF	OFF	ON
36-37	ON	ON	ON	ON	ON	ON
37-38	OFF	ON	ON	OFF	OFF	ON
38-39	OFF	ON	OFF	OFF	OFF	ON
39-40	OFF	OFF	ON	OFF	OFF	ON
40-41	ON	ON	ON	OFF	OFF	ON
41-42	ON	ON	OFF	OFF	OFF	ON
42-43	OFF	ON	OFF	OFF	OFF	ON
43-44	OFF	ON	OFF	OFF	OFF	ON
44-45	OFF	OFF	OFF	OFF	OFF	ON
45-46	ON	OFF	OFF	OFF	OFF	ON
46-47	ON	OFF	OFF	OFF	OFF	ON
47-48	OFF	OFF	OFF	OFF	OFF	ON
48-49	OFF	OFF	OFF	OFF	OFF	ON
49-50	OFF	OFF	OFF	OFF	OFF	ON
50-51	ON	OFF	OFF	OFF	OFF	ON
51-52	ON	OFF	OFF	OFF	OFF	ON
52-53	OFF	OFF	OFF	OFF	OFF	ON
53-54	OFF	OFF	OFF	OFF	OFF	ON
54-55	OFF	OFF	OFF	OFF	OFF	ON
55-56	ON	OFF	OFF	ON	ON	ON
56-57	ON	OFF	OFF	OFF	OFF	ON
57-58	OFF	OFF	ON	OFF	OFF	ON
58-59	OFF	OFF	OFF	OFF	OFF	ON

59-60	OFF	OFF	OFF	OFF	OFF	ON
60-61	ON	OFF	OFF	OFF	OFF	ON
61-62	ON	OFF	OFF	OFF	OFF	ON
62-63	OFF	OFF	OFF	OFF	OFF	ON
63-64	OFF	OFF	OFF	OFF	OFF	ON
64-65	OFF	OFF	OFF	OFF	OFF	ON
65-66	ON	OFF	OFF	OFF	OFF	ON
66-67	ON	OFF	OFF	OFF	OFF	ON
67-68	OFF	OFF	OFF	OFF	OFF	ON
68-69	OFF	OFF	OFF	OFF	OFF	ON
69-70	OFF	OFF	OFF	OFF	OFF	ON
70-71	ON	OFF	OFF	OFF	OFF	ON
71-72	ON	OFF	OFF	OFF	OFF	ON
72-73	OFF	OFF	OFF	OFF	OFF	ON
73-74	OFF	OFF	OFF	OFF	OFF	ON
74-75	OFF	OFF	ON	OFF	OFF	ON
75-76	OFF	OFF	OFF	OFF	OFF	ON
76-77	OFF	OFF	OFF	OFF	OFF	ON
77-78	ON	ON	OFF	OFF	OFF	ON
78-79	OFF	OFF	OFF	OFF	OFF	ON
79-80	OFF	OFF	OFF	OFF	OFF	ON

Table 4. Configuration 2. Electric heaters load profile. 80-160 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
80-81	OFF	OFF	OFF	OFF	OFF	ON
81-82	OFF	OFF	OFF	OFF	OFF	ON
82-83	ON	OFF	OFF	OFF	OFF	ON
83-84	OFF	OFF	OFF	OFF	OFF	ON
84-85	OFF	OFF	OFF	OFF	OFF	ON
85-86	OFF	OFF	OFF	OFF	OFF	ON

86-87	ON	OFF	OFF	OFF	OFF	ON
87-88	OFF	OFF	OFF	OFF	OFF	ON
88-89	OFF	OFF	OFF	OFF	OFF	ON
89-90	OFF	OFF	OFF	OFF	OFF	ON
90-91	OFF	OFF	OFF	OFF	OFF	ON
91-92	ON	OFF	ON	OFF	OFF	ON
92-93	OFF	OFF	OFF	OFF	OFF	ON
93-94	OFF	OFF	OFF	OFF	OFF	ON
94-95	OFF	OFF	OFF	OFF	OFF	ON
95-96	ON	OFF	OFF	OFF	OFF	ON
96-97	OFF	ON	OFF	OFF	OFF	ON
97-98	OFF	ON	OFF	OFF	OFF	ON
98-99	OFF	OFF	OFF	OFF	OFF	ON
99-100	OFF	OFF	OFF	OFF	OFF	ON
100-101	ON	OFF	OFF	OFF	OFF	ON
101-102	OFF	OFF	OFF	OFF	OFF	ON
102-103	OFF	OFF	OFF	OFF	OFF	ON
103-104	OFF	OFF	OFF	OFF	OFF	ON
104-105	ON	OFF	OFF	OFF	OFF	ON
105-106	OFF	OFF	OFF	OFF	OFF	ON
106-107	OFF	OFF	OFF	OFF	OFF	ON
107-108	OFF	OFF	OFF	OFF	OFF	ON
108-109	OFF	OFF	OFF	OFF	OFF	ON
109-110	ON	OFF	OFF	OFF	OFF	ON
110-111	OFF	OFF	OFF	OFF	OFF	ON
111-112	OFF	OFF	OFF	OFF	OFF	ON
112-113	OFF	OFF	ON	OFF	OFF	ON
113-114	ON	OFF	OFF	OFF	OFF	ON
114-115	OFF	OFF	OFF	OFF	OFF	ON
115-116	OFF	OFF	OFF	OFF	OFF	ON
116-117	OFF	ON	OFF	OFF	OFF	ON

117-118	OFF	OFF	OFF	OFF	OFF	ON
118-119	ON	OFF	OFF	OFF	OFF	ON
119-120	OFF	OFF	OFF	OFF	OFF	ON
120-121	OFF	OFF	OFF	OFF	OFF	ON
121-122	OFF	OFF	OFF	OFF	OFF	ON
122-123	OFF	OFF	OFF	OFF	OFF	ON
123-124	ON	OFF	OFF	OFF	OFF	ON
124-125	OFF	OFF	OFF	OFF	OFF	ON
125-126	OFF	OFF	OFF	OFF	OFF	ON
126-127	OFF	OFF	OFF	OFF	OFF	ON
127-128	ON	OFF	OFF	OFF	OFF	ON
128-129	OFF	OFF	OFF	OFF	OFF	ON
129-130	OFF	OFF	OFF	OFF	OFF	ON
130-131	OFF	OFF	OFF	OFF	OFF	ON
131-132	OFF	OFF	OFF	OFF	OFF	ON
132-133	ON	OFF	OFF	OFF	OFF	ON
133-134	OFF	OFF	OFF	OFF	OFF	ON
134-135	OFF	OFF	OFF	OFF	OFF	ON
135-136	OFF	ON	OFF	OFF	OFF	ON
136-137	ON	ON	OFF	OFF	OFF	ON
137-138	OFF	OFF	OFF	OFF	OFF	ON
138-139	OFF	OFF	OFF	OFF	OFF	ON
139-140	OFF	OFF	OFF	OFF	OFF	ON
140-141	OFF	OFF	OFF	OFF	OFF	ON
141-142	ON	OFF	OFF	OFF	OFF	ON
142-143	OFF	OFF	OFF	OFF	OFF	ON
143-144	OFF	OFF	OFF	OFF	OFF	ON
144-145	OFF	OFF	OFF	OFF	OFF	ON
145-146	ON	OFF	OFF	OFF	OFF	ON
146-147	OFF	OFF	OFF	OFF	OFF	ON
147-148	OFF	OFF	OFF	OFF	OFF	ON

148-149	OFF	OFF	OFF	OFF	OFF	ON
149-150	OFF	OFF	OFF	OFF	OFF	ON
150-151	ON	OFF	OFF	OFF	OFF	ON
151-152	OFF	OFF	OFF	OFF	OFF	ON
152-153	OFF	OFF	OFF	OFF	OFF	ON
153-154	OFF	OFF	ON	OFF	OFF	ON
154-155	OFF	OFF	OFF	OFF	OFF	ON
155-156	OFF	ON	OFF	OFF	OFF	ON
156-157	OFF	OFF	OFF	OFF	OFF	ON
157-158	ON	OFF	OFF	OFF	OFF	ON
158-159	OFF	OFF	OFF	OFF	OFF	ON
159-160	OFF	OFF	OFF	OFF	OFF	ON

Table 5. Configuration 2. Electric heaters load profile. 160-240 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
160-161	OFF	OFF	OFF	OFF	OFF	ON
161-162	OFF	OFF	OFF	OFF	OFF	ON
162-163	ON	OFF	OFF	OFF	OFF	ON
163-164	OFF	OFF	OFF	OFF	OFF	ON
164-165	OFF	OFF	OFF	OFF	OFF	ON
165-166	OFF	OFF	OFF	OFF	OFF	ON
166-167	OFF	OFF	OFF	OFF	OFF	ON
167-168	ON	OFF	OFF	OFF	OFF	ON
168-169	OFF	OFF	OFF	OFF	OFF	ON
169-170	OFF	OFF	OFF	OFF	OFF	ON
170-171	OFF	OFF	OFF	OFF	OFF	ON
171-172	OFF	OFF	OFF	OFF	OFF	ON
172-173	ON	OFF	OFF	OFF	OFF	ON
173-174	OFF	OFF	OFF	OFF	OFF	ON
174-175	OFF	ON	OFF	OFF	OFF	ON

175-176	OFF	ON	OFF	OFF	OFF	ON
176-177	OFF	OFF	OFF	OFF	OFF	ON
177-178	ON	OFF	OFF	OFF	OFF	ON
178-179	OFF	OFF	OFF	OFF	OFF	ON
179-180	OFF	OFF	OFF	OFF	OFF	ON
180-181	ON	OFF	OFF	OFF	OFF	ON
181-182	OFF	OFF	OFF	OFF	OFF	ON
182-183	OFF	OFF	OFF	OFF	OFF	ON
183-184	OFF	OFF	OFF	OFF	OFF	ON
184-185	OFF	OFF	ON	OFF	OFF	ON
185-186	ON	OFF	OFF	OFF	OFF	ON
186-187	OFF	OFF	OFF	OFF	OFF	ON
187-188	OFF	OFF	OFF	OFF	OFF	ON
188-189	OFF	OFF	OFF	OFF	OFF	ON
189-190	OFF	OFF	OFF	OFF	OFF	ON
190-191	ON	OFF	OFF	OFF	OFF	ON
191-192	OFF	OFF	OFF	OFF	OFF	ON
192-193	OFF	OFF	OFF	OFF	OFF	ON
193-194	OFF	OFF	OFF	OFF	OFF	ON
194-195	OFF	ON	OFF	OFF	OFF	ON
195-196	ON	OFF	OFF	OFF	OFF	ON
196-197	OFF	OFF	OFF	OFF	OFF	ON
197-198	OFF	OFF	OFF	OFF	OFF	ON
198-199	OFF	OFF	OFF	OFF	OFF	ON
199-200	OFF	OFF	OFF	OFF	OFF	ON
200-201	ON	OFF	OFF	OFF	OFF	ON
201-202	OFF	OFF	OFF	OFF	OFF	ON
202-203	OFF	OFF	OFF	OFF	OFF	ON
203-204	OFF	OFF	OFF	OFF	OFF	ON
204-205	OFF	OFF	OFF	OFF	OFF	ON
205-206	ON	OFF	OFF	OFF	OFF	ON

206-207	OFF	OFF	OFF	OFF	OFF	ON
207-208	OFF	OFF	OFF	OFF	OFF	ON
208-209	OFF	OFF	OFF	OFF	OFF	ON
209-210	OFF	OFF	OFF	OFF	OFF	ON
210-211	ON	OFF	OFF	OFF	OFF	ON
211-212	OFF	OFF	OFF	OFF	OFF	ON
212-213	OFF	OFF	OFF	OFF	OFF	ON
213-214	OFF	ON	OFF	OFF	OFF	ON
214-215	OFF	OFF	OFF	OFF	OFF	ON
215-216	ON	OFF	ON	OFF	OFF	ON
216-217	OFF	OFF	OFF	OFF	OFF	ON
217-218	OFF	OFF	OFF	OFF	OFF	ON
218-219	OFF	OFF	OFF	OFF	OFF	ON
219-220	OFF	OFF	OFF	OFF	OFF	ON
220-221	ON	OFF	OFF	OFF	OFF	ON
221-222	OFF	OFF	OFF	OFF	OFF	ON
222-223	OFF	OFF	OFF	OFF	OFF	ON
223-224	OFF	OFF	OFF	OFF	OFF	ON
224-225	OFF	OFF	OFF	OFF	OFF	ON
225-226	ON	OFF	OFF	OFF	OFF	ON
226-227	OFF	OFF	OFF	OFF	OFF	ON
227-228	OFF	OFF	OFF	OFF	OFF	ON
228-229	OFF	OFF	OFF	OFF	OFF	ON
229-230	OFF	OFF	OFF	OFF	OFF	ON
230-231	ON	ON	OFF	OFF	OFF	ON
231-232	OFF	OFF	OFF	OFF	OFF	ON
232-233	OFF	ON	OFF	OFF	OFF	ON
233-234	OFF	OFF	OFF	OFF	OFF	ON
234-235	OFF	OFF	OFF	OFF	OFF	ON
235-236	ON	OFF	OFF	OFF	OFF	ON
236-237	OFF	OFF	OFF	OFF	OFF	ON

237-238	OFF	OFF	OFF	OFF	OFF	ON
238-239	OFF	OFF	OFF	OFF	OFF	ON
239-240	OFF	OFF	OFF	OFF	OFF	ON

Table 6. Configuration 2. Electric heaters load profile. 240-320 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
240-241	ON	OFF	OFF	OFF	OFF	ON
241-242	OFF	OFF	OFF	OFF	OFF	ON
242-243	OFF	OFF	OFF	OFF	OFF	ON
243-244	OFF	OFF	OFF	OFF	OFF	ON
244-245	OFF	OFF	OFF	OFF	OFF	ON
245-246	ON	OFF	OFF	OFF	OFF	ON
246-247	OFF	OFF	OFF	OFF	OFF	ON
247-248	OFF	OFF	OFF	OFF	OFF	ON
248-249	OFF	OFF	OFF	OFF	OFF	ON
249-250	OFF	OFF	OFF	OFF	OFF	ON
250-251	ON	OFF	OFF	OFF	OFF	ON
251-252	OFF	ON	OFF	OFF	OFF	ON
252-253	OFF	ON	OFF	OFF	OFF	ON
253-254	OFF	OFF	OFF	OFF	OFF	ON
254-255	OFF	OFF	OFF	OFF	OFF	ON
255-256	ON	OFF	OFF	OFF	OFF	ON
256-257	OFF	OFF	OFF	OFF	OFF	ON
257-258	OFF	OFF	OFF	OFF	OFF	ON
258-259	OFF	OFF	OFF	OFF	OFF	ON
259-260	OFF	OFF	OFF	OFF	OFF	ON
260-261	ON	OFF	OFF	OFF	OFF	ON
261-262	OFF	OFF	OFF	OFF	OFF	ON
262-263	OFF	OFF	OFF	OFF	OFF	ON
263-264	OFF	OFF	OFF	OFF	OFF	ON

264-265	OFF	OFF	OFF	OFF	OFF	ON
265-266	ON	OFF	OFF	OFF	OFF	ON
266-267	OFF	OFF	OFF	OFF	OFF	ON
267-268	OFF	OFF	OFF	OFF	OFF	ON
268-269	OFF	OFF	OFF	OFF	OFF	ON
269-270	OFF	OFF	OFF	OFF	OFF	ON
270-271	ON	OFF	OFF	OFF	OFF	ON
271-272	OFF	ON	OFF	OFF	OFF	ON
272-273	OFF	OFF	OFF	OFF	OFF	ON
273-274	OFF	OFF	OFF	OFF	OFF	ON
274-275	OFF	OFF	OFF	OFF	OFF	ON
275-276	ON	OFF	OFF	OFF	OFF	ON
276-277	OFF	OFF	ON	OFF	OFF	ON
277-278	OFF	OFF	OFF	OFF	OFF	ON
278-279	OFF	OFF	OFF	OFF	OFF	ON
279-280	OFF	OFF	OFF	OFF	OFF	ON
280-281	ON	OFF	OFF	OFF	OFF	ON
281-282	OFF	OFF	OFF	OFF	OFF	ON
282-283	OFF	OFF	OFF	OFF	OFF	ON
283-284	OFF	OFF	OFF	OFF	OFF	ON
284-285	OFF	OFF	OFF	OFF	OFF	ON
285-286	ON	OFF	OFF	OFF	OFF	ON
286-287	OFF	OFF	OFF	OFF	OFF	ON
287-288	OFF	OFF	OFF	OFF	OFF	ON
288-289	OFF	OFF	OFF	OFF	OFF	ON
289-290	OFF	OFF	OFF	OFF	OFF	ON
290-291	ON	ON	OFF	OFF	OFF	ON
291-292	OFF	OFF	OFF	OFF	OFF	ON
292-293	OFF	OFF	OFF	OFF	OFF	ON
293-294	OFF	OFF	OFF	OFF	OFF	ON
294-295	OFF	OFF	OFF	OFF	OFF	ON

295-296	ON	OFF	OFF	OFF	OFF	ON
296-297	OFF	OFF	OFF	OFF	OFF	ON
297-298	OFF	OFF	OFF	OFF	OFF	ON
298-299	OFF	OFF	OFF	OFF	OFF	ON
299-300	OFF	OFF	OFF	OFF	OFF	ON
300-301	ON	OFF	OFF	OFF	OFF	ON
301-302	OFF	OFF	OFF	OFF	OFF	ON
302-303	OFF	OFF	OFF	OFF	OFF	ON
303-304	OFF	OFF	OFF	OFF	OFF	ON
304-305	OFF	OFF	OFF	OFF	OFF	ON
305-306	ON	OFF	OFF	OFF	OFF	ON
306-307	OFF	OFF	OFF	OFF	OFF	ON
307-308	OFF	OFF	OFF	OFF	OFF	ON
308-309	OFF	OFF	OFF	OFF	OFF	ON
309-310	OFF	ON	OFF	OFF	OFF	ON
310-311	ON	ON	OFF	OFF	OFF	ON
311-312	OFF	OFF	OFF	OFF	OFF	ON
312-313	OFF	OFF	OFF	OFF	OFF	ON
313-314	OFF	OFF	OFF	OFF	OFF	ON
314-315	OFF	OFF	OFF	OFF	OFF	ON
315-316	ON	OFF	OFF	OFF	OFF	ON
316-317	OFF	OFF	OFF	OFF	OFF	ON
317-318	OFF	OFF	OFF	OFF	OFF	ON
318-319	OFF	OFF	OFF	OFF	OFF	ON
319-320	OFF	OFF	OFF	OFF	OFF	ON

Table 7. Configuration 2. Electric heaters load profile. 320-400 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
320-321	OFF	OFF	OFF	OFF	OFF	ON
321-322	OFF	OFF	OFF	OFF	OFF	ON
322-323	OFF	OFF	OFF	OFF	OFF	ON
323-324	OFF	OFF	OFF	OFF	OFF	ON
324-325	OFF	OFF	OFF	OFF	OFF	ON
325-326	ON	OFF	OFF	OFF	OFF	ON
326-327	OFF	OFF	OFF	OFF	OFF	ON
327-328	OFF	OFF	OFF	OFF	OFF	ON
328-329	OFF	OFF	OFF	OFF	OFF	ON
329-330	OFF	ON	OFF	OFF	OFF	ON
330-331	ON	OFF	OFF	OFF	OFF	ON
331-332	OFF	OFF	OFF	OFF	OFF	ON
332-333	OFF	OFF	OFF	OFF	OFF	ON
333-334	OFF	OFF	OFF	OFF	OFF	ON
334-335	OFF	OFF	OFF	OFF	OFF	ON
335-336	ON	OFF	OFF	OFF	OFF	ON
336-337	OFF	OFF	OFF	OFF	OFF	ON
337-338	OFF	OFF	OFF	OFF	OFF	ON
338-339	OFF	OFF	OFF	OFF	OFF	ON
339-340	OFF	OFF	OFF	OFF	OFF	ON
340-341	ON	OFF	OFF	OFF	OFF	ON
341-342	OFF	OFF	OFF	OFF	OFF	ON
342-343	OFF	OFF	OFF	OFF	OFF	ON
343-344	OFF	OFF	OFF	OFF	OFF	ON
344-345	OFF	OFF	OFF	OFF	OFF	ON
345-346	ON	OFF	OFF	OFF	OFF	ON
346-347	OFF	OFF	OFF	OFF	OFF	ON
347-348	OFF	OFF	OFF	OFF	OFF	ON

348-349	OFF	ON	OFF	OFF	OFF	ON
349-350	OFF	OFF	OFF	OFF	OFF	ON
350-351	ON	OFF	OFF	OFF	OFF	ON
351-352	OFF	OFF	OFF	OFF	OFF	ON
352-353	OFF	OFF	OFF	OFF	OFF	ON
353-354	OFF	OFF	OFF	OFF	OFF	ON
354-355	OFF	OFF	OFF	OFF	OFF	ON
355-356	ON	OFF	OFF	OFF	OFF	ON
356-357	OFF	OFF	OFF	OFF	OFF	ON
357-358	OFF	OFF	OFF	OFF	OFF	ON
358-359	OFF	OFF	OFF	OFF	OFF	ON
359-360	OFF	OFF	OFF	OFF	OFF	ON
360-361	ON	OFF	OFF	OFF	OFF	ON
361-362	OFF	OFF	OFF	OFF	OFF	ON
362-363	OFF	OFF	OFF	OFF	OFF	ON
363-364	OFF	OFF	OFF	OFF	OFF	ON
364-365	OFF	OFF	OFF	OFF	OFF	ON
365-366	ON	OFF	OFF	OFF	OFF	ON
366-367	OFF	OFF	OFF	OFF	OFF	ON
367-368	OFF	ON	OFF	OFF	OFF	ON
368-369	OFF	ON	OFF	OFF	OFF	ON
369-370	OFF	OFF	OFF	OFF	OFF	ON
370-371	ON	OFF	OFF	OFF	OFF	ON
371-372	OFF	OFF	OFF	OFF	OFF	ON
372-373	OFF	OFF	OFF	OFF	OFF	ON
373-374	OFF	OFF	OFF	OFF	OFF	ON
374-375	OFF	OFF	OFF	OFF	OFF	ON
375-376	ON	OFF	OFF	OFF	OFF	ON
376-377	OFF	OFF	OFF	OFF	OFF	ON
377-378	OFF	OFF	OFF	OFF	OFF	ON
378-379	OFF	OFF	OFF	OFF	OFF	ON

379-380	OFF	OFF	OFF	OFF	OFF	ON
380-381	ON	OFF	OFF	OFF	OFF	ON
381-382	OFF	OFF	OFF	OFF	OFF	ON
382-383	OFF	OFF	OFF	OFF	OFF	ON
383-384	OFF	OFF	OFF	OFF	OFF	ON
384-385	OFF	OFF	OFF	OFF	OFF	ON
385-386	ON	OFF	OFF	OFF	OFF	ON
386-387	OFF	OFF	OFF	OFF	OFF	ON
387-388	OFF	ON	ON	OFF	OFF	ON
388-389	OFF	OFF	OFF	OFF	OFF	ON
389-390	OFF	OFF	OFF	OFF	OFF	ON
390-391	ON	OFF	OFF	OFF	OFF	ON
391-392	OFF	OFF	OFF	OFF	OFF	ON
392-393	OFF	OFF	OFF	OFF	OFF	ON
393-394	OFF	OFF	OFF	OFF	OFF	ON
394-395	OFF	OFF	OFF	OFF	OFF	ON
395-396	ON	OFF	OFF	OFF	OFF	ON
396-397	OFF	OFF	OFF	OFF	OFF	ON
397-398	OFF	OFF	OFF	OFF	OFF	ON
398-399	OFF	OFF	OFF	OFF	OFF	ON
399-400	OFF	OFF	OFF	OFF	OFF	ON

Table 8. Configuration 2. Electric heaters load profile. 400-480 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
400-401	ON	OFF	OFF	OFF	OFF	ON
401-402	OFF	OFF	OFF	OFF	OFF	ON
402-403	OFF	OFF	OFF	OFF	OFF	ON
403-404	OFF	OFF	OFF	OFF	OFF	ON
404-405	OFF	OFF	OFF	OFF	OFF	ON

405-406	ON	OFF	OFF	OFF	OFF	ON
406-407	OFF	ON	OFF	OFF	OFF	ON
407-408	OFF	OFF	OFF	OFF	OFF	ON
408-409	OFF	OFF	OFF	OFF	OFF	ON
409-410	OFF	OFF	OFF	OFF	OFF	ON
410-411	ON	OFF	OFF	OFF	OFF	ON
411-412	OFF	OFF	OFF	OFF	OFF	ON
412-413	OFF	OFF	OFF	OFF	OFF	ON
413-414	OFF	OFF	OFF	OFF	OFF	ON
414-415	OFF	OFF	OFF	OFF	OFF	ON
415-416	ON	OFF	OFF	ON	OFF	ON
416-417	OFF	OFF	OFF	OFF	OFF	ON
417-418	OFF	OFF	OFF	OFF	OFF	ON
418-419	OFF	OFF	OFF	OFF	OFF	ON
419-420	OFF	OFF	OFF	OFF	OFF	ON
420-421	ON	OFF	OFF	OFF	OFF	ON
421-422	OFF	OFF	OFF	OFF	OFF	ON
422-423	OFF	OFF	OFF	OFF	OFF	ON
423-424	OFF	OFF	OFF	OFF	OFF	ON
424-425	OFF	OFF	OFF	OFF	OFF	ON
425-426	OFF	ON	OFF	OFF	OFF	ON
426-427	OFF	ON	OFF	OFF	OFF	ON
427-428	OFF	OFF	OFF	OFF	OFF	ON
428-429	OFF	OFF	OFF	OFF	OFF	ON
429-430	OFF	OFF	OFF	OFF	OFF	ON
430-431	OFF	OFF	OFF	OFF	OFF	ON
431-432	ON	OFF	OFF	OFF	OFF	ON
432-433	OFF	OFF	OFF	OFF	OFF	ON
433-434	OFF	OFF	OFF	OFF	OFF	ON
434-435	OFF	OFF	OFF	OFF	OFF	ON
435-436	OFF	OFF	OFF	OFF	OFF	ON

436-437	ON	OFF	OFF	OFF	OFF	ON
437-438	OFF	OFF	OFF	OFF	OFF	ON
438-439	OFF	OFF	OFF	OFF	OFF	ON
439-440	OFF	OFF	OFF	OFF	OFF	ON
440-441	OFF	OFF	OFF	OFF	OFF	ON
441-442	ON	OFF	OFF	OFF	OFF	ON
442-443	OFF	OFF	OFF	OFF	OFF	ON
443-444	OFF	OFF	OFF	OFF	OFF	ON
444-445	OFF	OFF	OFF	OFF	OFF	ON
445-446	OFF	ON	OFF	OFF	OFF	ON
446-447	ON	OFF	OFF	OFF	OFF	ON
447-448	OFF	OFF	OFF	OFF	OFF	ON
448-449	OFF	OFF	OFF	OFF	OFF	ON
449-450	OFF	OFF	OFF	OFF	OFF	ON
450-451	OFF	OFF	OFF	OFF	OFF	ON
451-452	ON	OFF	OFF	OFF	OFF	ON
452-453	OFF	OFF	OFF	OFF	OFF	ON
453-454	OFF	OFF	OFF	OFF	OFF	ON
454-455	OFF	OFF	OFF	OFF	OFF	ON
455-456	OFF	OFF	OFF	OFF	OFF	ON
456-457	ON	OFF	OFF	OFF	OFF	ON
457-458	OFF	OFF	OFF	OFF	OFF	ON
458-459	OFF	OFF	OFF	OFF	OFF	ON
459-460	OFF	OFF	OFF	OFF	OFF	ON
460-461	OFF	OFF	OFF	OFF	OFF	ON
461-462	ON	OFF	OFF	OFF	OFF	ON
462-463	OFF	OFF	OFF	OFF	OFF	ON
463-464	OFF	OFF	OFF	OFF	OFF	ON
464-465	OFF	ON	OFF	OFF	OFF	ON
465-466	OFF	OFF	OFF	OFF	OFF	ON
466-467	ON	OFF	OFF	OFF	OFF	ON

467-468	OFF	OFF	OFF	OFF	OFF	ON
468-469	OFF	OFF	OFF	OFF	OFF	ON
469-470	OFF	OFF	OFF	OFF	OFF	ON
470-471	OFF	OFF	OFF	OFF	OFF	ON
471-472	ON	OFF	OFF	OFF	OFF	ON
472-473	OFF	OFF	OFF	OFF	OFF	ON
473-474	OFF	OFF	OFF	OFF	OFF	ON
474-475	OFF	OFF	OFF	OFF	OFF	ON
475-476	OFF	OFF	OFF	OFF	OFF	ON
476-477	ON	OFF	OFF	OFF	OFF	ON
477-478	OFF	OFF	OFF	OFF	OFF	ON
478-479	OFF	OFF	OFF	OFF	OFF	ON
479-480	OFF	OFF	OFF	OFF	OFF	ON

Table 9. Configuration 2. Electric heaters load profile. 480-560 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
480-481	OFF	OFF	OFF	OFF	OFF	ON
481-482	ON	OFF	OFF	OFF	OFF	ON
482-483	OFF	OFF	OFF	OFF	OFF	ON
483-484	OFF	ON	OFF	OFF	OFF	ON
484-485	OFF	ON	OFF	OFF	OFF	ON
485-486	OFF	OFF	OFF	OFF	OFF	ON
486-487	ON	OFF	OFF	OFF	OFF	ON
487-488	OFF	OFF	OFF	OFF	OFF	ON
488-489	OFF	OFF	ON	OFF	OFF	ON
489-490	OFF	OFF	OFF	OFF	OFF	ON
490-491	OFF	OFF	OFF	OFF	OFF	ON
491-492	ON	OFF	OFF	OFF	OFF	ON
492-493	OFF	OFF	OFF	OFF	OFF	ON
493-494	OFF	OFF	OFF	OFF	OFF	ON

494-495	OFF	OFF	OFF	OFF	OFF	ON
495-496	OFF	OFF	OFF	OFF	OFF	ON
496-497	ON	OFF	OFF	OFF	OFF	ON
497-498	OFF	OFF	OFF	OFF	OFF	ON
498-499	OFF	OFF	OFF	OFF	OFF	ON
499-500	OFF	OFF	OFF	OFF	OFF	ON
500-501	OFF	OFF	OFF	OFF	OFF	ON
501-502	OFF	OFF	OFF	OFF	OFF	ON
502-503	OFF	OFF	OFF	OFF	OFF	ON
503-504	OFF	ON	OFF	OFF	OFF	ON
504-505	OFF	OFF	OFF	OFF	OFF	ON
505-506	OFF	OFF	OFF	OFF	OFF	ON
506-507	OFF	OFF	OFF	OFF	OFF	ON
507-508	OFF	OFF	OFF	OFF	OFF	ON
508-509	OFF	OFF	OFF	OFF	OFF	ON
509-510	ON	OFF	OFF	OFF	OFF	ON
510-511	OFF	OFF	OFF	OFF	OFF	ON
511-512	OFF	OFF	OFF	OFF	OFF	ON
512-513	OFF	OFF	OFF	OFF	OFF	ON
513-514	OFF	OFF	OFF	OFF	OFF	ON
514-515	ON	OFF	OFF	OFF	OFF	ON
515-516	OFF	OFF	OFF	OFF	OFF	ON
516-517	OFF	OFF	OFF	OFF	OFF	ON
517-518	OFF	OFF	OFF	OFF	OFF	ON
518-519	OFF	OFF	OFF	OFF	OFF	ON
519-520	ON	OFF	OFF	OFF	OFF	ON
520-521	OFF	OFF	OFF	OFF	OFF	ON
521-522	OFF	OFF	OFF	OFF	OFF	ON
522-523	OFF	ON	OFF	OFF	OFF	ON
523-524	OFF	OFF	OFF	OFF	OFF	ON
524-525	ON	OFF	OFF	OFF	OFF	ON

525-526	OFF	OFF	OFF	OFF	OFF	ON
526-527	OFF	OFF	OFF	OFF	OFF	ON
527-528	OFF	OFF	OFF	OFF	OFF	ON
528-529	OFF	OFF	OFF	OFF	OFF	ON
529-530	ON	OFF	OFF	OFF	OFF	ON
530-531	OFF	OFF	OFF	OFF	OFF	ON
531-532	OFF	OFF	OFF	OFF	OFF	ON
532-533	OFF	OFF	OFF	OFF	OFF	ON
533-534	OFF	OFF	OFF	OFF	OFF	ON
534-535	ON	OFF	OFF	OFF	OFF	ON
535-536	OFF	OFF	OFF	OFF	OFF	ON
536-537	OFF	OFF	OFF	OFF	OFF	ON
537-538	OFF	OFF	OFF	OFF	OFF	ON
538-539	OFF	OFF	OFF	OFF	OFF	ON
539-540	ON	OFF	OFF	OFF	OFF	ON
540-541	OFF	OFF	OFF	OFF	OFF	ON
541-542	OFF	ON	OFF	OFF	OFF	ON
542-543	OFF	OFF	OFF	OFF	OFF	ON
543-544	OFF	OFF	OFF	OFF	OFF	ON
544-545	ON	OFF	OFF	OFF	OFF	ON
545-546	OFF	OFF	OFF	OFF	OFF	ON
546-547	OFF	OFF	OFF	OFF	OFF	ON
547-548	OFF	OFF	OFF	OFF	OFF	ON
548-549	OFF	OFF	OFF	OFF	OFF	ON
549-550	ON	OFF	OFF	OFF	OFF	ON
550-551	OFF	OFF	OFF	OFF	OFF	ON
551-552	OFF	OFF	OFF	OFF	OFF	ON
552-553	OFF	OFF	OFF	OFF	OFF	ON
553-554	OFF	OFF	OFF	OFF	OFF	ON
554-555	ON	OFF	OFF	OFF	OFF	ON
555-556	OFF	OFF	OFF	OFF	OFF	ON

556-557	OFF	OFF	OFF	OFF	OFF	ON
557-558	OFF	OFF	OFF	OFF	OFF	ON
558-559	OFF	OFF	OFF	OFF	OFF	ON
559-560	ON	OFF	OFF	OFF	OFF	ON

Table 10. Configuration 2. Electric heaters load profile. 560-640 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
560-561	OFF	ON	OFF	OFF	OFF	ON
561-562	OFF	OFF	OFF	OFF	OFF	ON
562-563	OFF	OFF	OFF	OFF	OFF	ON
563-564	OFF	OFF	OFF	OFF	OFF	ON
564-565	ON	OFF	OFF	OFF	OFF	ON
565-566	OFF	OFF	OFF	OFF	OFF	ON
566-567	OFF	OFF	OFF	OFF	OFF	ON
567-568	OFF	OFF	OFF	OFF	OFF	ON
568-569	OFF	OFF	OFF	OFF	OFF	ON
569-570	ON	OFF	OFF	OFF	OFF	ON
570-571	OFF	OFF	OFF	OFF	OFF	ON
571-572	OFF	OFF	OFF	OFF	OFF	ON
572-573	OFF	OFF	OFF	OFF	OFF	ON
573-574	OFF	OFF	OFF	OFF	OFF	ON
574-575	ON	OFF	OFF	OFF	OFF	ON
575-576	OFF	OFF	OFF	OFF	OFF	ON
576-577	OFF	OFF	OFF	OFF	OFF	ON
577-578	OFF	OFF	OFF	OFF	OFF	ON
578-579	OFF	OFF	OFF	OFF	OFF	ON
579-580	OFF	ON	OFF	OFF	OFF	ON
580-581	OFF	OFF	OFF	OFF	OFF	ON
581-582	OFF	OFF	OFF	OFF	OFF	ON
582-583	OFF	OFF	OFF	OFF	OFF	ON

583-584	OFF	OFF	OFF	OFF	OFF	ON
584-585	OFF	OFF	OFF	OFF	OFF	ON
585-586	OFF	OFF	OFF	OFF	OFF	ON
586-587	OFF	OFF	OFF	OFF	OFF	ON
587-588	ON	OFF	OFF	OFF	OFF	ON
588-589	ON	OFF	OFF	OFF	OFF	ON
589-590	OFF	OFF	ON	OFF	OFF	ON
590-591	OFF	OFF	OFF	OFF	OFF	ON
591-592	OFF	OFF	OFF	OFF	OFF	ON
592-593	OFF	OFF	OFF	OFF	OFF	ON
593-594	ON	OFF	OFF	OFF	OFF	ON
594-595	OFF	OFF	OFF	OFF	OFF	ON
595-596	OFF	OFF	OFF	OFF	OFF	ON
596-597	OFF	OFF	OFF	OFF	OFF	ON
597-598	OFF	OFF	OFF	OFF	OFF	ON
598-599	ON	ON	OFF	OFF	OFF	ON
599-600	OFF	ON	OFF	OFF	OFF	ON
600-601	OFF	OFF	OFF	OFF	OFF	ON
601-602	OFF	OFF	OFF	OFF	OFF	ON
602-603	OFF	OFF	OFF	OFF	OFF	ON
603-604	ON	OFF	OFF	OFF	OFF	ON
604-605	OFF	OFF	OFF	OFF	OFF	ON
605-606	OFF	OFF	OFF	OFF	OFF	ON
606-607	OFF	OFF	OFF	OFF	OFF	ON
607-608	OFF	OFF	OFF	OFF	OFF	ON
608-609	ON	OFF	OFF	OFF	OFF	ON
609-610	OFF	OFF	OFF	OFF	OFF	ON
610-611	OFF	OFF	OFF	OFF	OFF	ON
611-612	OFF	OFF	OFF	OFF	OFF	ON
612-613	OFF	OFF	OFF	OFF	OFF	ON
613-614	ON	OFF	OFF	OFF	OFF	ON

614-615	OFF	OFF	OFF	OFF	OFF	ON
615-616	OFF	OFF	OFF	OFF	OFF	ON
616-617	OFF	OFF	OFF	OFF	OFF	ON
617-618	OFF	OFF	OFF	OFF	OFF	ON
618-619	ON	ON	OFF	OFF	OFF	ON
619-620	OFF	OFF	OFF	OFF	OFF	ON
620-621	OFF	OFF	OFF	OFF	OFF	ON
621-622	OFF	OFF	OFF	OFF	OFF	ON
622-623	OFF	OFF	OFF	OFF	OFF	ON
623-624	ON	OFF	OFF	OFF	OFF	ON
624-625	OFF	OFF	OFF	OFF	OFF	ON
625-626	OFF	ON	OFF	OFF	OFF	ON
626-627	OFF	OFF	OFF	OFF	OFF	ON
627-628	OFF	OFF	OFF	OFF	OFF	ON
628-629	OFF	OFF	OFF	OFF	OFF	ON
629-630	OFF	OFF	OFF	OFF	OFF	ON
630-631	OFF	OFF	OFF	OFF	OFF	ON
631-632	ON	OFF	OFF	OFF	OFF	ON
632-633	OFF	OFF	OFF	OFF	OFF	ON
633-634	OFF	OFF	OFF	OFF	OFF	ON
634-635	ON	OFF	OFF	OFF	OFF	ON
635-636	OFF	OFF	OFF	OFF	OFF	ON
636-637	OFF	OFF	OFF	OFF	OFF	ON
637-638	OFF	OFF	OFF	ON	OFF	ON
638-639	OFF	OFF	OFF	OFF	OFF	ON
639-640	ON	OFF	OFF	OFF	OFF	ON

Table 11. Configuration 2. Electric heaters load profile. 640-720 minutes.

Time [min]	Target chamber	Outlet nozzle	Inlet nozzle	Straight Lithium inlet pipe	Bend Lithium inlet pipe	Back-Plate
640-641	OFF	OFF	OFF	OFF	OFF	ON
641-642	OFF	OFF	OFF	OFF	OFF	ON
642-643	OFF	OFF	OFF	OFF	OFF	ON
643-644	OFF	OFF	OFF	OFF	OFF	ON
644-645	ON	ON	OFF	OFF	OFF	ON
645-646	OFF	OFF	OFF	OFF	OFF	ON
646-647	OFF	OFF	OFF	OFF	OFF	ON
647-648	OFF	OFF	OFF	OFF	OFF	ON
648-649	OFF	OFF	OFF	OFF	OFF	ON
649-650	ON	OFF	OFF	OFF	OFF	ON
650-651	OFF	OFF	OFF	OFF	OFF	ON
651-652	OFF	OFF	OFF	OFF	OFF	ON
652-653	OFF	OFF	OFF	OFF	OFF	ON
653-654	OFF	OFF	OFF	OFF	OFF	ON
654-655	ON	OFF	OFF	OFF	OFF	ON
655-656	OFF	OFF	OFF	OFF	OFF	ON
656-657	OFF	OFF	OFF	OFF	OFF	ON
657-658	OFF	OFF	OFF	OFF	OFF	ON
658-659	OFF	OFF	OFF	OFF	OFF	ON
659-660	ON	OFF	OFF	OFF	OFF	ON
660-661	OFF	OFF	OFF	OFF	OFF	ON
661-662	OFF	OFF	OFF	OFF	OFF	ON
662-663	OFF	OFF	OFF	OFF	OFF	ON
663-664	OFF	ON	OFF	OFF	OFF	ON
664-665	ON	OFF	OFF	OFF	OFF	ON
665-666	OFF	OFF	OFF	OFF	OFF	ON
666-667	OFF	OFF	OFF	OFF	OFF	ON
667-668	OFF	OFF	OFF	OFF	OFF	ON

668-669	OFF	OFF	OFF	OFF	OFF	ON
669-670	ON	OFF	OFF	OFF	OFF	ON
670-671	OFF	OFF	OFF	OFF	OFF	ON
671-672	OFF	OFF	OFF	OFF	OFF	ON
672-673	OFF	OFF	OFF	OFF	OFF	ON
673-674	OFF	OFF	OFF	OFF	OFF	ON
674-675	OFF	OFF	OFF	OFF	OFF	ON
675-676	OFF	OFF	OFF	OFF	OFF	ON
676-677	OFF	OFF	OFF	OFF	OFF	ON
677-678	OFF	OFF	OFF	OFF	OFF	ON
678-679	OFF	OFF	OFF	OFF	OFF	ON
679-680	OFF	OFF	OFF	OFF	OFF	ON
680-681	OFF	OFF	OFF	OFF	OFF	ON
681-682	OFF	OFF	OFF	OFF	OFF	ON
682-683	ON	ON	OFF	OFF	OFF	ON
683-684	OFF	OFF	OFF	OFF	OFF	ON
684-685	OFF	OFF	OFF	OFF	OFF	ON
685-686	OFF	OFF	OFF	OFF	OFF	ON
686-687	OFF	OFF	OFF	OFF	OFF	ON
687-688	ON	OFF	OFF	OFF	OFF	ON
688-689	OFF	OFF	OFF	OFF	OFF	ON
689-690	OFF	OFF	OFF	OFF	OFF	ON
690-691	OFF	OFF	ON	OFF	OFF	ON
691-692	OFF	OFF	OFF	OFF	OFF	ON
692-693	ON	OFF	OFF	OFF	OFF	ON
693-694	OFF	OFF	OFF	OFF	OFF	ON
694-695	OFF	OFF	OFF	OFF	OFF	ON
695-696	OFF	OFF	OFF	OFF	OFF	ON
696-697	OFF	OFF	OFF	OFF	OFF	ON
697-698	ON	OFF	OFF	OFF	OFF	ON
698-699	OFF	OFF	OFF	OFF	OFF	ON

699-700	OFF	OFF	OFF	OFF	OFF	ON
700-701	OFF	OFF	OFF	OFF	OFF	ON
701-702	OFF	ON	OFF	OFF	OFF	ON
702-703	ON	OFF	OFF	OFF	OFF	ON
703-704	OFF	OFF	OFF	OFF	OFF	ON
704-705	OFF	OFF	OFF	OFF	OFF	ON
705-706	OFF	OFF	OFF	OFF	OFF	ON
706-707	OFF	OFF	OFF	OFF	OFF	ON
707-708	ON	OFF	OFF	OFF	OFF	ON
708-709	OFF	OFF	OFF	OFF	OFF	ON
709-710	OFF	OFF	OFF	OFF	OFF	ON
710-711	OFF	OFF	OFF	OFF	OFF	ON
711-712	OFF	OFF	OFF	OFF	OFF	ON
712-713	ON	OFF	OFF	OFF	OFF	ON
713-714	OFF	OFF	OFF	OFF	OFF	ON
714-715	OFF	OFF	OFF	OFF	OFF	ON
715-716	OFF	OFF	OFF	OFF	OFF	ON
716-717	OFF	OFF	OFF	OFF	OFF	ON
717-718	ON	OFF	OFF	OFF	OFF	ON
718-719	OFF	OFF	OFF	OFF	OFF	ON
719-720	OFF	OFF	OFF	OFF	OFF	ON

4 Conclusions

Within the present PAR 2014 of ENEA-MSE Agreement, a research campaign has been launched in collaboration with the Department of Energy, Information Engineering and Mathematical Models (DEIM) of the University of Palermo to numerically investigate the thermal behaviour of the IFMIF target system mock-up installed at ENEA Brasimone, in order to assess the time-dependent load profile of the electric heaters devoted to reproduce the pre-heating phase of the IFMIF start-up transient operational phase.

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.

In order to properly select the electric heaters load profile which allows a maximum temperature increase within the different components as uniform as possible, an iterative approach has been followed. In particular, the electric heaters load profile has been modified, firstly, in order to ensure a uniform heating of the different components up to 250 °C and, secondly, whenever the maximum temperature achieved within each component has gone outside the temperature window 240 °C - 260 °C.

Three different thermal configurations have been assessed, and for each of them a proper electric heaters load profile has been set-up. Results obtained have shown that only in Configuration 2, where an electric heater has been foreseen onto the BP external surfaces, it has been possible to raise the BP maximum temperature near to 250 °C, achieving, after 720 minutes, the steady-state value of about 244 °C.

Nevertheless, the results obtained have shown that the heat flux provided by the electric heater placed on the BP needs to be increased as the BP cannot reach a sufficiently high temperature over large zones, particularly in the Lithium channel. Concerning the heating procedure, an optimized electric heaters time-dependent load profile which allows to increase the temperature of the TA mock-up components in a quite uniform way has been identified and proposed as the reference heaters load sequence for the experimental tests to be performed on the IFMIF TA mock-up.

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