Fission Target Design

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1. Introduction

The report describes the technical concepts and the main parameters adopted for the first design for the fission target of the multi-MW Target Station of EURISOL. Starting from the dimensions of liquid neutron converter as defined by Baseline Design, eight fission target containers were disposed around the converter and closely coupled to eight ion-sources. Two versions of design are presented[1], proposing different solutions at all levels: target geometry, heating resistance, thermal expansion compensation, supporting in the view of remote handling, type of ion source, current and high voltage powering scheme, cooling and others. At this stage of design many details are skipped, while the dimensions of different components are not yet the result of mechanical/electrical/thermal calculations.

2. Assembly description

In Fig. 1 and Fig. 2, the two versions of the design are presented. The inner cylinder represents the mercury target and the arrow shows the direction of multi-MW primary beam of 1 GeV protons having a 45 cm range in mercury. Fission material is enclosed in eight containers disposed in two rings (version 1 – Fig. 1) or one ring (version 2 – Fig. 2). After 1+ ionization inside ion-source, fission products are extracted as eight secondary beams in the reverse sense compared to the primary beam.

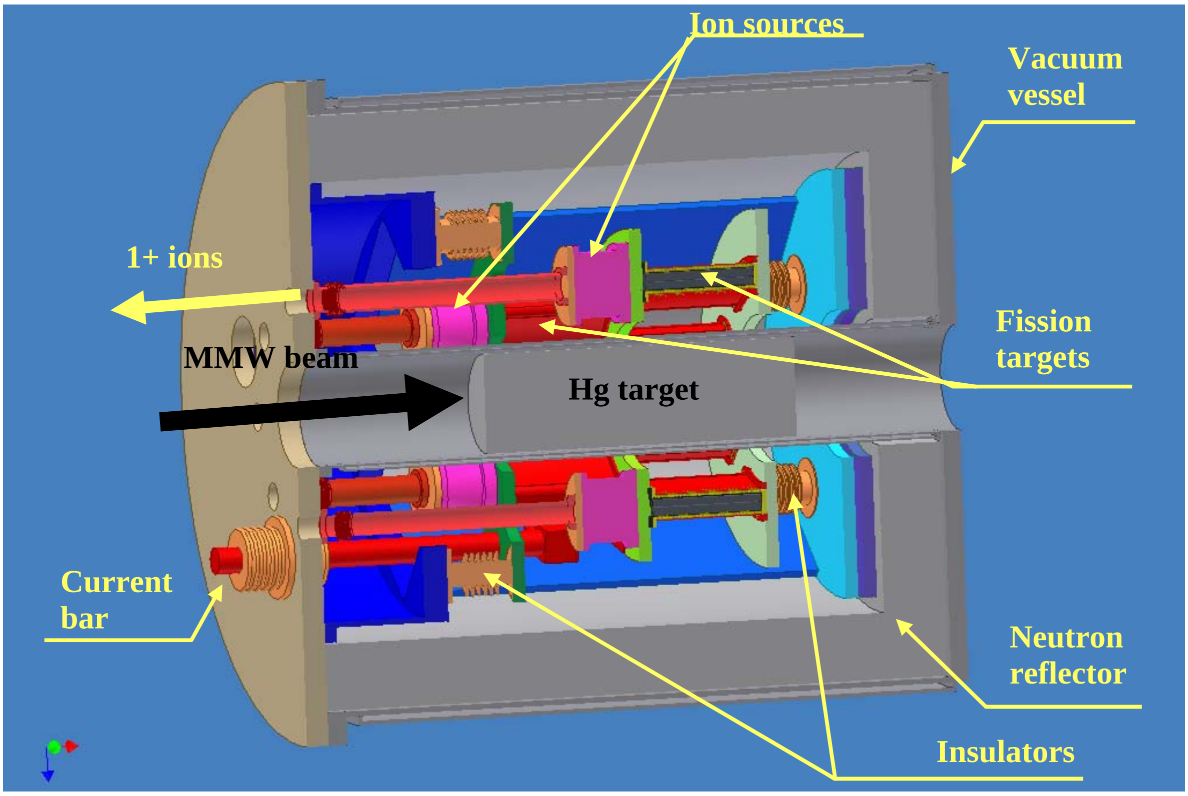

Fig. 1 First version of design.

From fast release considerations the targets are operated at high temperature and could need external

1 The third version of design, adapting for EURISOL the concepts proposed for MAFF and PIAFE projects, will be described in another report.

heating. Other components have to be cooled. The high voltage used for beam extraction is applied on ion sources, target containers and their supporting disks, and require large insulators. All the components are placed in vacuum in a large vessel connected to the ground potential. A thick graphite layer reflects the neutrons in order to increase the fission rate.

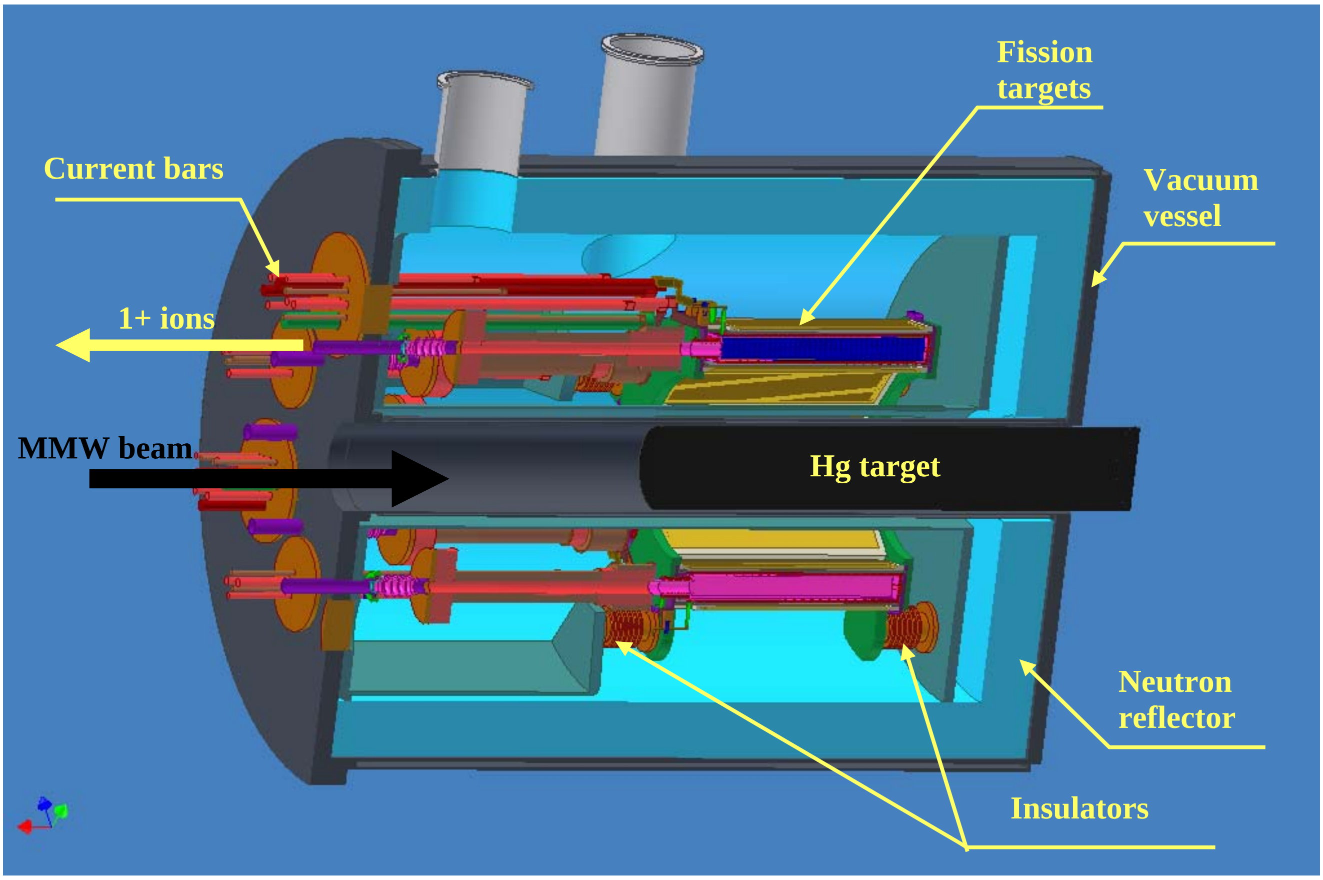

Fig. 2 Second version of design.

3. Details on components

3.1) Container of fission material

The fission material have to be placed in a container to assure a limited volume for effusion of reaction products before entering the ion source. The size of container and the length of transfer tube, that is the connection between container and ion source, impact strongly on the collection efficiency. The use of only one ion source and one cylindrical layer of fission material inside a container around the Hg target is considered to have too low efficiency. Therefore, the splitting the of fission material several containers each coupled an ion-sources have been proposed. A number of eight containers has been chosen.

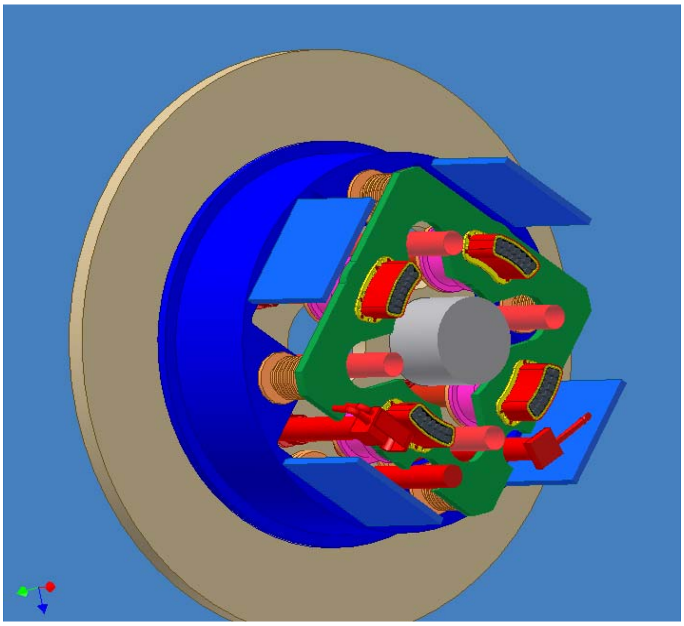

Fig.3 Transverse cut in first version of design.

In the first design (see Fig. 1 and Fig. 3) the fission material is supposed to be UCx tables with 15 mm diameter arranged in rods of about 200 mm length. The containers are disposed in two rings: one ring with 4 containers of about 1.2 liters (200x200x30 mm^3), and the second ring with 4 containers of 0.6 liters (100x200x30 mm^3). The difference in volume is impose by position and dimensions of the ion-sources. The curved shape of the container as compared to a simple parallelepiped of same dimensions (volume) assures a better coverage of neutron density distribution (higher fission rate) and smaller diameter of large vessel, but is technically more complicated. The container is made of Tungsten of 1 mm thickness and has an internal graphite cloth of 1 mm having the protective role against corrosion of W by UCx.

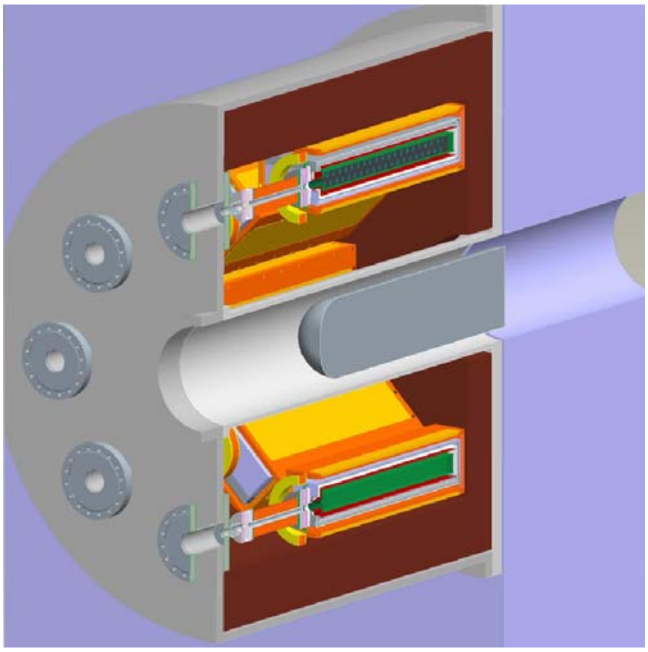

Fig. 4 Disposal of the 8 fission targets and secondary beam lines in the second version of design

The second design of the fission target assembly considers 8 targets arranged around the mercury converter (Fig. 2 and Fig. 4). Here the W containers (pink in Fig. 5) are 400 mm long and arranged in only one ring. Fission material (light gray) is in the form of limes disposed in several parallel planes crossing the exit hole of container. Their width is shorter than the width of container, leaving a drift volume for fission fragments. The graphite cloth (blue), enclosing a volume of 0.84 liters (30x 70 x 400 mm^3), has in this case the role of supporting the limes and has to allow the passage of ions from fission material into drift volume through a net of holes visible in Fig. 2. The transfer tube is supposed to be a short W cylinder with a diameter of 30 mm welded at the exit of container.

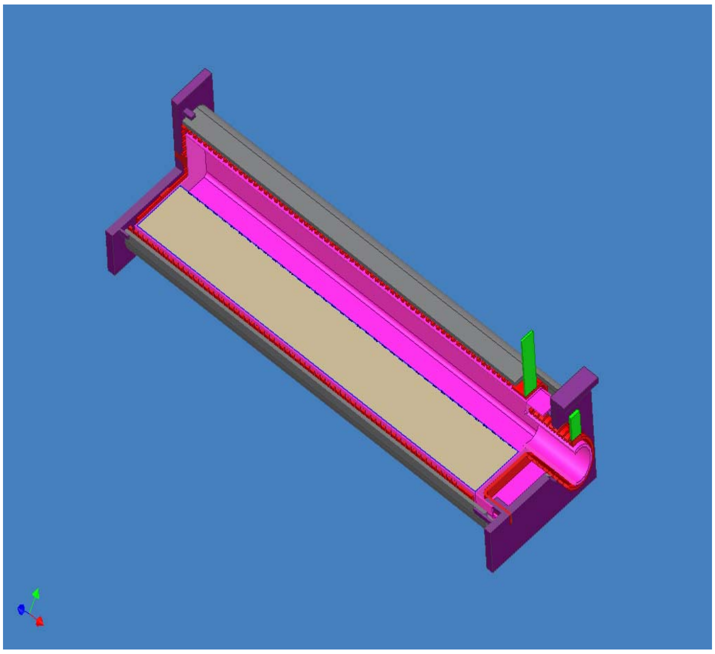

Fig. 5. One fission target in second version of design: gray-UC$_x$ limes, blue – graphite cloth, pink – target container, red – heating resistances, green – flexible electrical conectors

3.2) Heating resistance and thermal shield

Operation of fission target at temperatures up to 2100 °C is foreseen. Depending on fission material and primary beam intensity which determine the heating of the target through nuclear processes, an additional external heating estimated up to 15 kW could be required. For a current intensity of 1000 A, such an electric power corresponds to a resistance of 1.5x10^{-2} Ω , value to be compared with tantalum resistivity: 1.3x10^{-8} Ω m (at 295 K). Since the use of any insulator between the resistance and container will reduce strongly the live-time of fission target, self-supported resistances similar to that proposed for SPIRAL2 oven have been adapted in both versions of design (http://www.ganil.fr/research/developments/spiral2/files/Ch4_CTIS-edited.pd). However, solutions for feeding and thermal dilation compensation are different. These solutions will be discussed in more details below, in paragraph 3.5. As common features we mention here that single layer resistances are supposed, made of a 1-2 mm Ta sheets (red layer in figure 5) at a distance of about 1.5 mm from target container. At same distance at exterior of resistances, are installed thermal shields consisting in few very thin, of order of 100 μm, not-smooth tantalum sheets (in drawings they are represented one layer of 1 mm think – dark gray in figure 5). The transfer tube needs also heating. In second of design a cylindrical resistance concentric to the transfer tube is included to be connected to an independent current power supply.

3.3) Cooling box

Other components coming in close contact with the heating resistance have to cooled. The current bars feeding the resistance are supposed to carry in both directions the water for cooling of these components.

In case of large fission targets, at high fission rate of 10^{15} s^{-1}, cooling of fission target itself is required instead of heating. Because of that, in the second version of design, each target container together with its resistance and thermal shield are enclosed inside a double wall cooling box, drawn in yellow in Fig. 6. The cooling agent is supposed to be cold Helium, because it is more radiation hard as compared with water, and imply fewer safety problems.

3.4) Ion source and secondary beam pipe

For the goals of present design, the details on ion-sources components are not important. Only exterior dimensions, position and requirements in terms of current, high voltage or cooling are relevant. In the first version of design in Fig. 1, the ion-source is nothing but a cylinder and an insulating flange suggesting that the ion source is at high voltage while the secondary beam pipe at ground voltage. At least one current connection has to be added for the ion source, for example in the case of IRENA ion source.

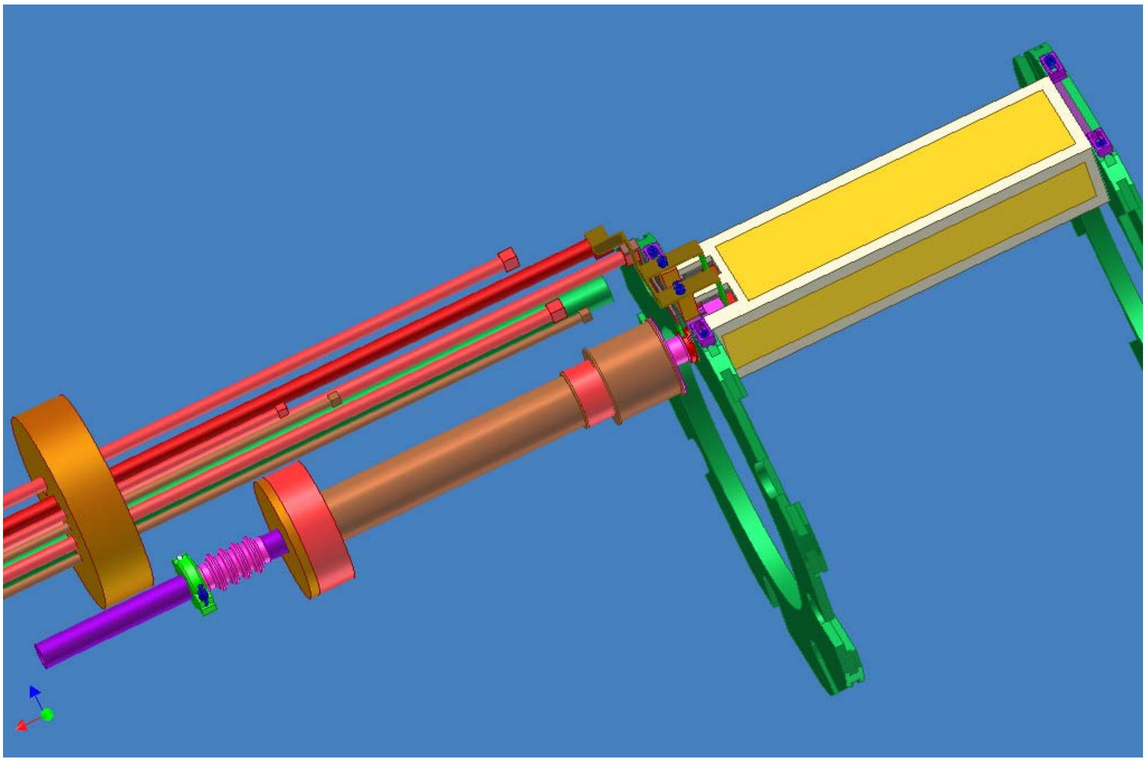

Fig. 6. A fission target and ion source unit placed on the two supporting disks (green). The eight current and HV bars powering each unit are dispose such that all units can be extracted radially.

In the second design, a rather complex electron beam ion-source is taken into consideration (see Fig. 2 and Fig. 6). At least 2 solenoids (brown in Fig. 6) and 3 electrodes inside ion source have to be powered to generate, confine and eliminate the electron beam. Again, an insulator impossible to avoid should assure mechanical contact between the body of ion source at high voltage and the secondary beam pipe at ground potential. At the other end the pipe is fixed on the large vessel flange using an elbow which allows compensation of relative movement of different components of the assembly due to thermal expansion during operation. One has to mention that the vacuum inside the ion-source and target container is assured through above pipe by pumps not shown in the figures, but supposed to be connected downstream on the secondary beam path. The vacuum inside each container is completely separated from the vacuum inside large vessel, the former being worse due to degassing from fission target, graphite cloth, etc.

3.5) Supporting disks and current bars

As discussed, extraction of secondary beams requires to rise the ion source as well as the target container to high voltage of typically 50-60 kV. A number of disks – 3 in first version of design and 2 in the second version – are employed to support the target containers and ion-sources. They are also at high voltage and fixed by 8 large insulators on grounded frame (composed of disks and longitudinal plates). The current bars feeding the heating resistances are at high voltage, too. Consequently they pass the flange of vacuum vessel through large insulators. The same is true for all current bars. Obviously, all the power supplies have to be installed on a high voltage platform shielded by thick concrete wall in order to diminish the radiation effect on electronic components. A rather long path is expected for cables at high voltage carrying the current from power supplies to the bars.

In the first version of design only a small number of bars are used. Each of the 3 disks is connected to one bar, the central disk having the role of common electric mass. Thus, the 4 heating resistances in one ring are connected in parallel (and consequently operated simultaneously). In this connection scheme, the heating resistance must be in (electrical) contact at both ends with the disks, while the container and thermal shield must be in contact with only of the two disks. Taking into account the deformation due to heating, the probability of target container or thermal shield to touch the resistance seems rather high. Moreover, the large thermal expansion coefficient of tantalum, of order of 5 mm at 2000 °C, could induce strong (compression) forces at the level of heating resistance which is fixed at both ends. To diminish the effect, the light blue disk in Fig. 1 can slide on the longitudinal dark blue plates.

In the second version of design different solution to above problems are proposed. The cooling box form Fig. 6 is closed at both ends by two plates (covers). As the box is cooled, its expansion is rather low. The container, heating resistance and thermal shield placed inside the box are at higher temperatures and expand strongly. Thus, they are fixed only at one end on the covers, while at the other end they can slide longitudinally. Expansion in transversal direction are less important, about 1 mm at maximum temperatures due to smaller dimensions. Small pieces mounted (or welded) on the covers guide the position of container and thermal shield limiting the transversal displacements to avoid their contact with heating resistance. The resistance cannot be supported in this case at both ends. It is fixed at one end on the cover considered as common electric mass together with supporting disks and cooling box. At the other end of the resistance, the connectors drawn in green in fig. 4 are made of a large number of thin (50-100 μm) tantalum sheets with total thickness of several millimeters resulting in a high current connector with good flexibility in only one direction. Connection from the feeding bar to this flexible connector can be done also by a combination of rigid and flexible connectors as shown in Fig. 6. However, an insulating support have to added to assure an enough stable position of these connectors. Such an insulator is placed on top of cooling box, that is it does not work at high temperatures and the high voltage difference is small (few tens of volts). Thus, a life-time of few month, similar to other components of fission target, seems reasonable for an insulator in such position. Concluding this paragraph, one has to say that a solution for independent feeding of heating resistances of the eight targets is proposed in the second version of design with a minimal insulating material.

The second version of design is further enriched supposing that all containers and ion-sources are operated independently: for each container were used three bars, including a separate connection to the mass and for each ion-source were used 5 bars. In total a number of 64 bars were needed, distributed on 8 multiple feedthroughs mounted on the large flange of vacuum vessel. In establishing the positions of these bars as well as other elements, a distance of minimum 50 mm has been imposed between all components having high voltage difference.

3.6) Vacuum vessel

The vacuum vessel has a diameter and length of about 1 m. It has double walls cooled by water. The required high vacuum, in the range of 10^{-6} mbar, is assured by cryogenic panels and 3 turbo-pumps to be placed behind a heavy shielding as suggested in Fig. 7. The vessel is installed on rails allowing to move it into a nearby hot-cell. For details on vacuum system see: O. Alyakrinskiy et al. “Preliminary design of vacuum system for the fission target” on www.eurisol.org.

4. Spent targets exchange and remote handling

The targets maintenance and replacement is accomplished in a hot cell located laterally to the target area. These operations are provided by a remote handling system and manipulators. In the first version of design the charge of fission targets requires not only the opening of the vacuum vessel but also displacement of supporting disks. The target container was suppose to be change independently and more often then heating resistances, thermal shield and ion source. Consequently the operations to be performed in the hot-cell were rather complex.

In second version of design, similar life-time was supposed for fission target and ion source. As seen in Fig.6 they were grouped together in one unit to be removed and replaced with minimal manipulations inside hot cell. Some details of the mechanical construction of whole assembly is reported in Figs. 7 and 8. First, the mercury converter is retracted to its position for maintenance, in a dedicated aria (not shown in Fig. 7) placed forward in the primary beam direction. A hydraulic system provide the disconnection of beam and vacuum pipes (see Figs. 8(a)-(c)). The vessel containing the fission targets, sealed by UHV metal valves, is moved into the hot cell, where the vessel will be open. The barrel supporting the 8 targets (Fig. 8(d)) can rotate by 360 degrees in order to position each target-ion-source unit in front of the manipulator that provides its removal and replacement. The spent targets are encapsulated in a container that is stored in a dedicate area.

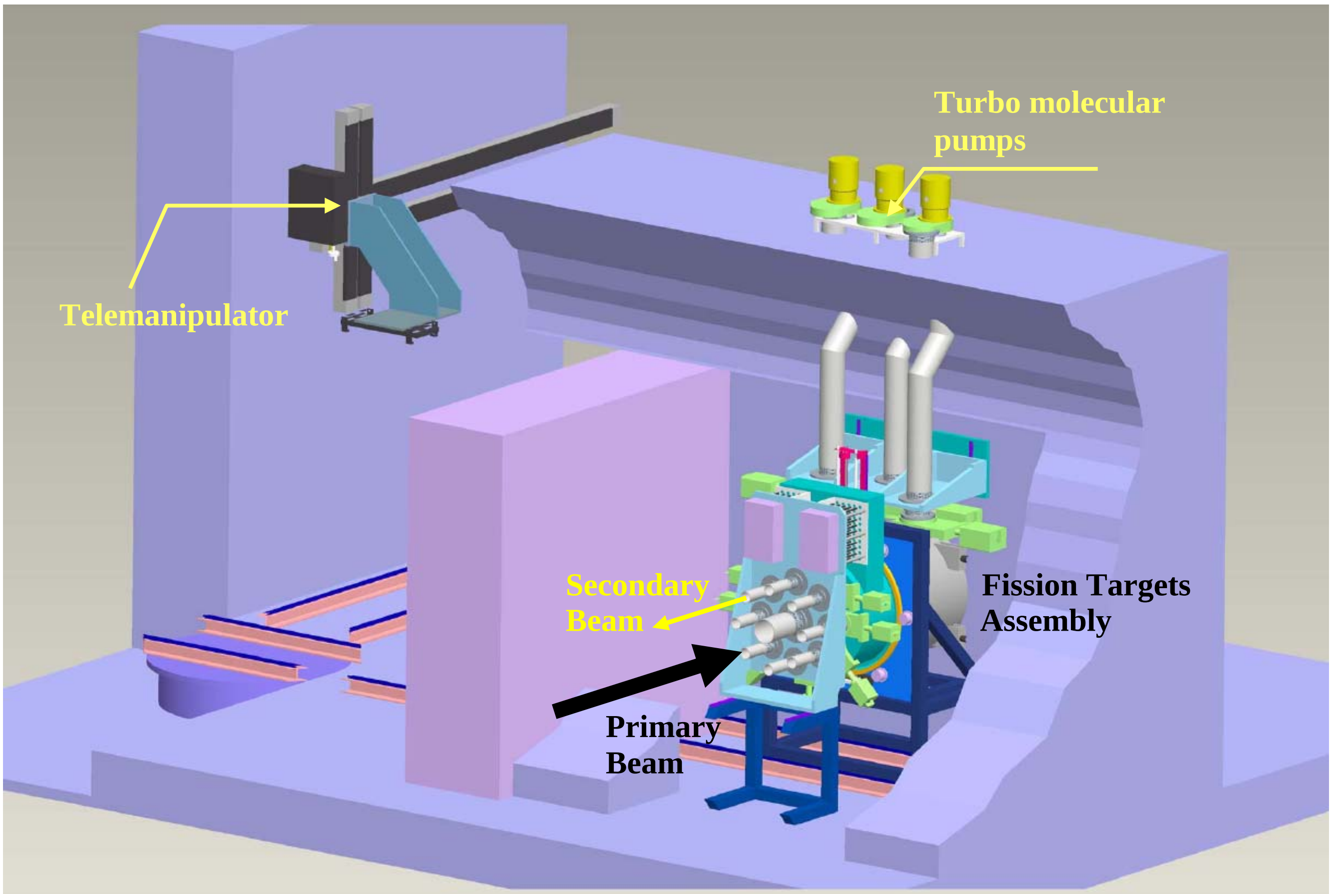

Fig. 7 Spent targets exchange concept in the second version of design

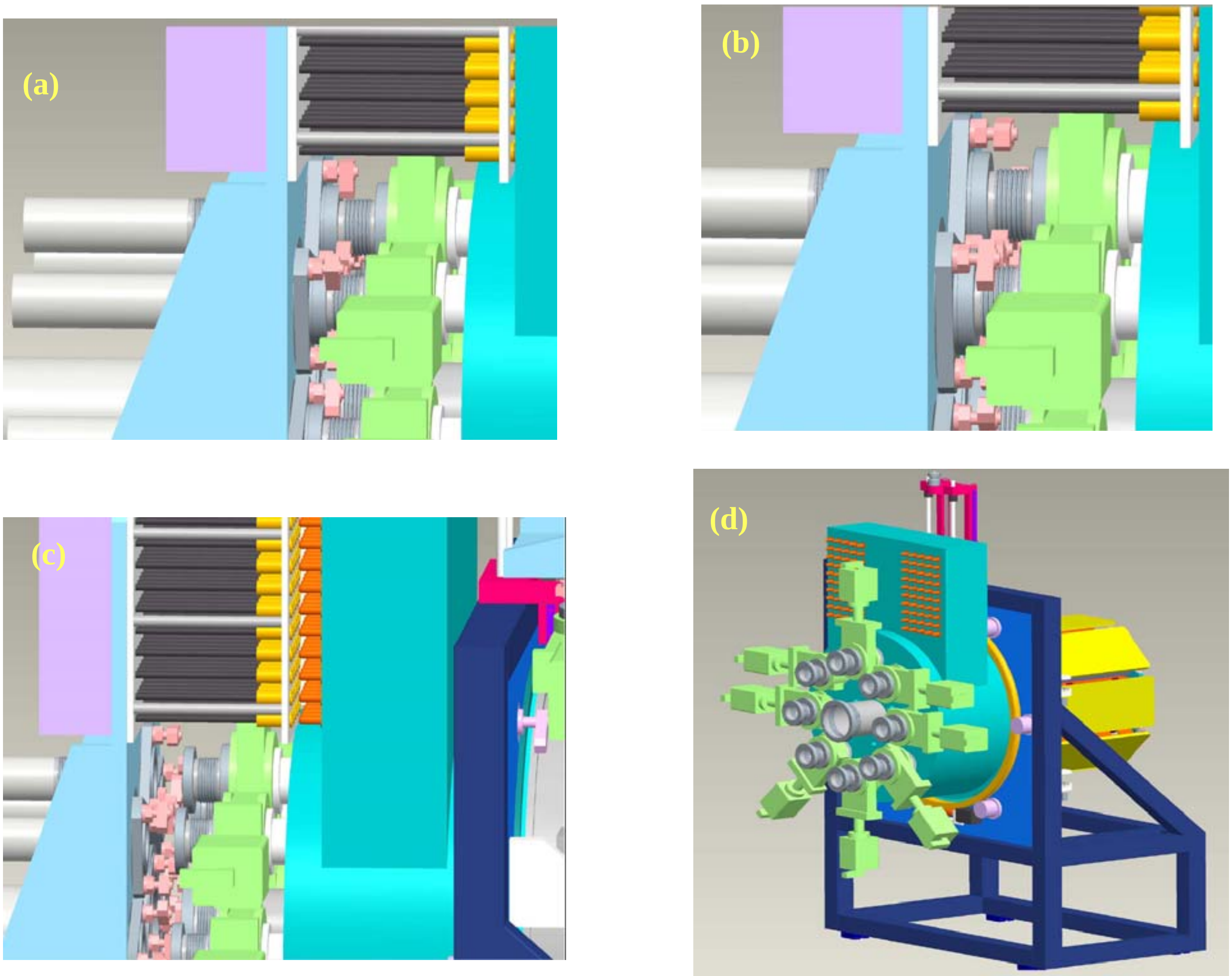

Fig. 8 Disconnection of primary and secondary beam lines: (a) starting position, (b) release of flanges, (c) longitudinal displacement. In next steps, the assembly show in (d) is moved on rails into hot-cell and vacuum vessel is opened to access the fission targets.

5. Remarks and conclusions

This represent a preliminary design of the fission target assembly integrated with the mercury neutron converter. The second solution seems the most suitable from the technological and practical point of view. Calculation results of RIBO code demonstrate that, in principle, the dimensions of the fission target does not influence to much the release efficiencies of relatively short lifetime isotopes. Even if it is preferable to deal with small quantities of UCx, the relatively big amount of uranium (several Kg) employed on those targets does not impose practical limitations. In any case, a third version of fission target assembly, based on the MAFF concept making use of small amount of ^{235}U, is under investigation. The remote handling system and the targets assembling/disassembling has been in principle well studied. To define the operations in all respects more detailed studies are required. An open question is related to the ion beams. The targets will deliver 8 independent beams, they can be of 8 different ion species or 8 beams of the same ion specie, or in other combinations. Up to now we don’t have any solution how to merge together 2 or more beams of the same ion specie.