

High Availability Remote Maintenance Approach for the European DEMO Breeder Blanket options

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Abstract. An advanced blanket maintenance concept for DEMO was developed which implies vertical multi-module blanket segments (MMS) and a small number of vertical remote handling ports. As a common feature the MMS blanket consist of in regard to electromagnetic loads and thermal stresses reasonable small blanket modules which are mounted onto a vertical back-plate that contains the coolant channels and in case of liquid metal blankets also the breeder manifolds. For all considered blanket concepts (HCPB, HCLL and DCLL) a common remote handling strategy was developed which – similar to the ITER divertor cassette maintenance – is based on the consecutive exchange of a limited number of assembled functional units. In addition to vertical insertion tools located inside the transfer casks, remote transport machines are involved that are inserted into the divertor region after the removal of the divertor cassettes to transport the MMS in toroidal direction. The transport machines are equipped with sliding carriage systems for the movement of the inboard and outboard MMS in transverse radial/poloidal direction. In the final position the MMS are either bolted onto a permanent self-supporting closed ring shield structure or are mounted onto a frame which allows for relative thermal expansion of the MMS and the vacuum vessel. While the first option seems to be possible for the HCPB and HCLL concept the later could allow for integration of a new DCLL MMS blanket option.

Introduction

The main candidate breeder blanket concepts for an European DEMO approach are currently the helium cooled ceramic breeder blanket HCPB (helium-cooled pebble bed) [1], the HCLL (helium-cooled lithium lead) concept and the dual coolant lithium lead concept (DCLL). Both, the HCPB and the HCLL breeder blankets are cooled by helium gas whilst the different breeder materials result in different Tritium extraction and circulation systems (purge gas for ceramic breeder and liquid metal for the liquid metal blanket). In the DCLL concept the breeder itself acts as a thermal transport medium which in combination with thermal insulators between the breeder and the steel structure allows for higher outlet temperatures. Some years ago the engineering activities in the view on DEMO were substantially broadened towards overall reactor engineering including the development of radial build and shielding concepts, mechanical layout and attachment systems, maintenance schemes, piping concepts and the development of the according remote handling systems as well as considerations on electrical power generation. Recently the “large module” integration concept for DEMO was presented [2], [3]. The system derived from the ITER “in vessel transporter” was adapted to the requirements of a helium-cooled DEMO reactor, where HCPB breeding blanket modules are mounted onto a modular low temperature shield and are connected to permanent helium pipes at the back of the shield modules. The blanket modules with a weight up to 10 tons are replaced utilizing an in-vessel machine, which is inserted and supported through four equatorial ports. The helium pipes have to be welded and cut with in-bore remote handling tools inside the vacuum vessel. As a result of the investigation carried out in regard to the large separate blanket module integration concept it could be stated that (i) the concept seems to be feasible in general, but (ii) due to its complexity and the large number of separate components to be replaced is likely not the optimum system in regard on reliability and maintenance time.

Demonstration fusion power plants in contrast to existing and planned experimental devices have to provide a high availability at least in the late phases of their operation to be recognized commercially interesting. In this regard the development of new advantageous blanket integration and maintenance scenarios was intensified at FZK and integrated in the European DEMO approach to come to substantially reduced remote maintenance (RM) times in comparison to the single blanket module maintenance scheme. The system presented in this contribution preserves the advantages of reasonable small blanket sub-modules in regard on fabrication, electromagnetic loads and thermal stresses while the number of handling units and in-vessel operations are dramatically reduced. The concept is based on the idea to build assemblies of blanket sub-modules and support structure including the manifolds for the distribution of the helium coolant outside the vacuum vessel and use this type of pre-assembled ‘multi-module-segments’ (MMS) as large handling units (replaced every 4 to 5 years) along with relatively simple and fast RM procedures. The new concept was developed with the aim of combining the advantages of a highly segmented blanket with the advantages of a vertical segment concept (Fig. 1).

	Separate Modules	Vertical Segments	Multi Module Segments (MMS)
Short maintenance time	-	+	+
Low forces on flex. attachment due to electromagnetic loads	+	-	+
Reasonable blanket module size for fabrication procedure	+	-	+
Reduced thermal stresses by segmentation	+	-	+
Quality Assurance	-	+	+

Fig. 1: The MMS concept was developed to combine the advantages of separate and vertical segment integration principles

Radial build and attachment concept

In regard to the integration of a ceramic breeder blanket a number of possible options for the radial build and the attachments of the MMS inside the vacuum vessel were considered. In all cases as a result of to the much higher operational temperatures the MMS can neither be bolted directly to the vacuum vessel nor to a low temperature shield. In the HCPB MMS blanket configuration it seems advantageous to attach the blanket sub-modules flexibly to the vertical MMS manifold and operate the MMS manifold at a fairly steady temperature. This can be achieved by channeling the helium return flow in thermally insulated sections and for cooling the manifold use the helium inlet flow - which in contrast to the returning flow - is almost steady-state, even in pulsed plasma regimes and for plasma-on and plasma-off conditions, respectively.

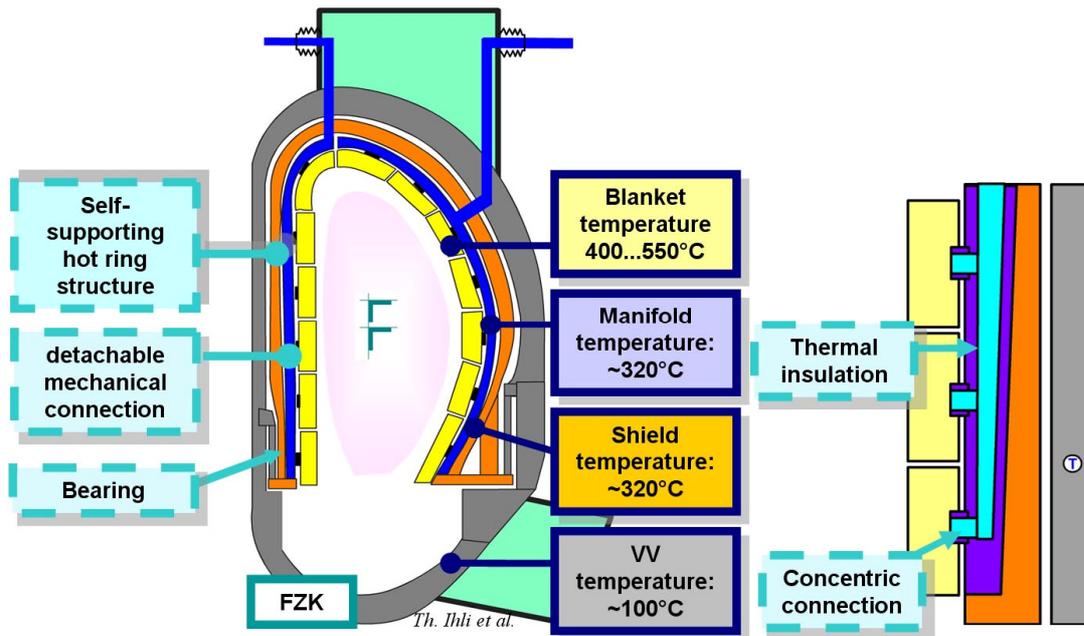


Fig. 2: Radial built attachment concept for HCPB MMS

The hydraulic connection is preferably concentric (Fig. 2, right side) with inlet Helium flowing in the annular gap between inner and outer tube and the tubes being placed in the zero point of the relative motion between blanket module and manifold. The blanket modules in front of the manifolds are acting as a thermal and neutron shield which allows operating the MMS manifold almost steady-state. The clearly defined temperature and deformation of the manifold during heat up allows connecting it rigidly to a permanent shield structure (Fig. 2). Before assembly to the vacuum vessel, the different segments of the hot ring shield are assembled outside the reactor to make sure the proper location of all drillings and sufficiently low tolerances of the structure. In the next step the hot ring shield is assembled at the reactor site along with the vacuum vessel, whereby the parts of the shield can be inserted easily through the openings in the not yet completed vacuum vessel structure. Nevertheless, to allow for replacement of shield segments in case of failures, the size of the segments of the shield are chosen in accordance to the space available in the upper remote handling ports. The sub-segments of the shield are connected by L-formed profiles at the edges. On this way enough neutron shielding can be provided and the overlapping area can be used to place removable joining elements. Fig. 3 shows a total view of the inboard, top and outboard segmentation of the hot ring shield. The design of the overlapping elements allows a local replacement of segments with simple radial movements by remote handling. The shield structure is operated at the same temperature as the MMS manifold whereby an additional cooling /pre-heating cycle for the shield structure is foreseen. The mechanical connection of the MMS manifolds and the permanent shield structure results in a strong self supporting structure. The only mechanical connection of the ring shield with the vacuum vessel is located at the bottom side where bending plates (see sketch in Fig. 2) are used to cope with the relative thermal expansions between ring shield and vacuum vessel.

The shield and the manifold structure of the MMS are connected rigidly by shear keys and bolts placed at the sides of the MMS with tool access to the bolts through the gap between the neighboring blanket modules. Also the closed shield structure can be built inside the vessel utilizing mechanical connections (e.g. bolts and shear keys). The thickness of the vacuum

vessel could eventually be reduced, as the mechanical loads during disruptions will be taken by the structure made from the shield and the manifold of the MMS.

In the DCLL MMS blanket scenario temperature changes of the MMS manifold between plasma-on and plasma-off seems to be unavoidable. Especially in a design where the blanket boxes are connected rigidly to the MMS manifold relative thermal expansions between the MMS and the shield structure can be expected. In this configuration a rigid connection of the MMS and the shield structure is likely to result in an unreliable system with large thermal stresses and undefined deformations. Therefore, the DCLL MMS should be combined with flexible attachments to mount the MMS onto a low-temperature shield or the vacuum vessel. As the access to bolts is only possible at the sides of the MMS, the permanent flexible attachments (likely bending bars or plates) are equipped with a frame that is connected to the MMS at both sides of the MMS.

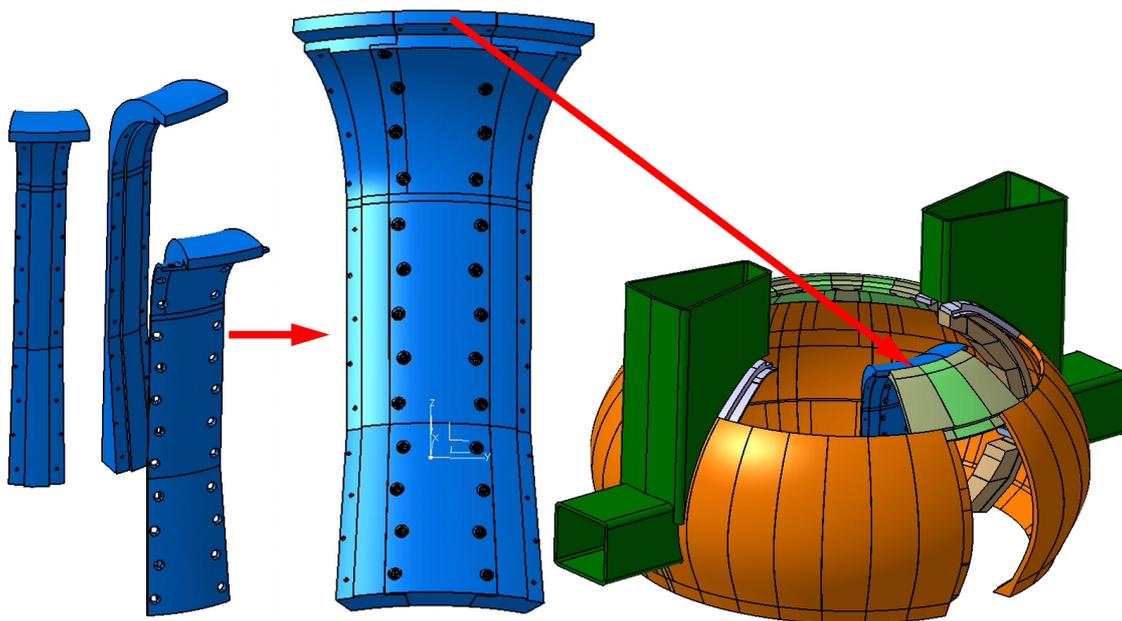


Fig. 3: Elements of the ring shield at inboard, outboard and top

Remote handling concept

Considering the vertical shape of the MMS along with the large weight it is self-evident to use vertical ports for the replacement which allows transporting and inserting the MMS with an overhead crane and winches, respectively. For the overall reactor layout and the design of the reactor building a large number of vertical ports with the need of lifting the large MMS structures out of all the vertical ports between the toroidal field coils (16 in the current DEMO approach) and the corresponding need of space above the vacuum vessel wouldn't be favorable. Especially to disassemble the shield structure below every vertical port during the blanket maintenance procedure would cause severe drawbacks. Therefore, a system was investigated that allows for reducing dramatically the number of vertical remote handling ports. In this system the replacement of the blanket is done in-time with a scheduled divertor replacement, which has to be done presumably two times per blanket life-time. The replacement of the blanket modules is done after the divertor cassettes are removed as this allows to use a relatively simple toroidal transport machine to be placed in the divertor region.

The transport machines can be inserted through the divertor ports and can move along rails in toroidal direction.

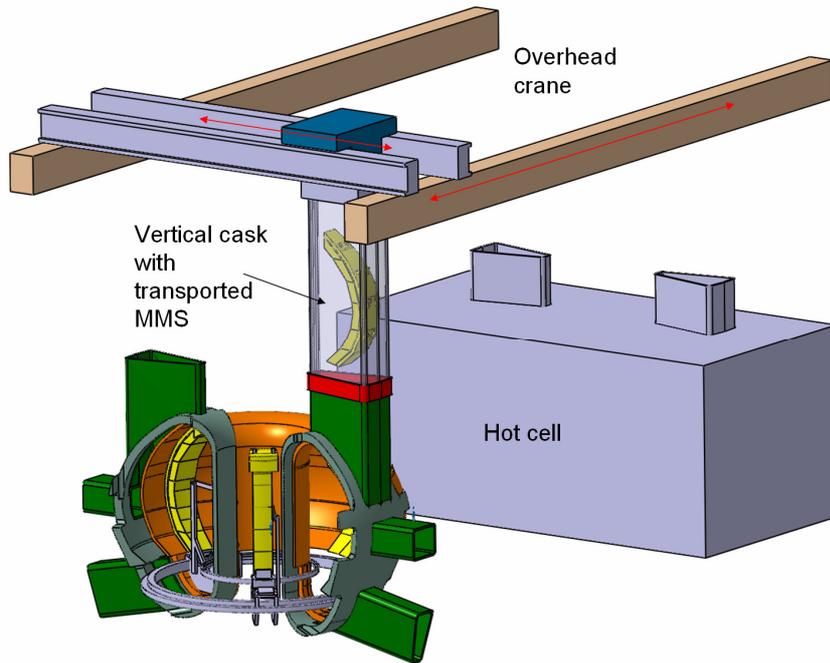


Fig. 4: MMS remote handling between reactor and hot cell with overhead crane and casks

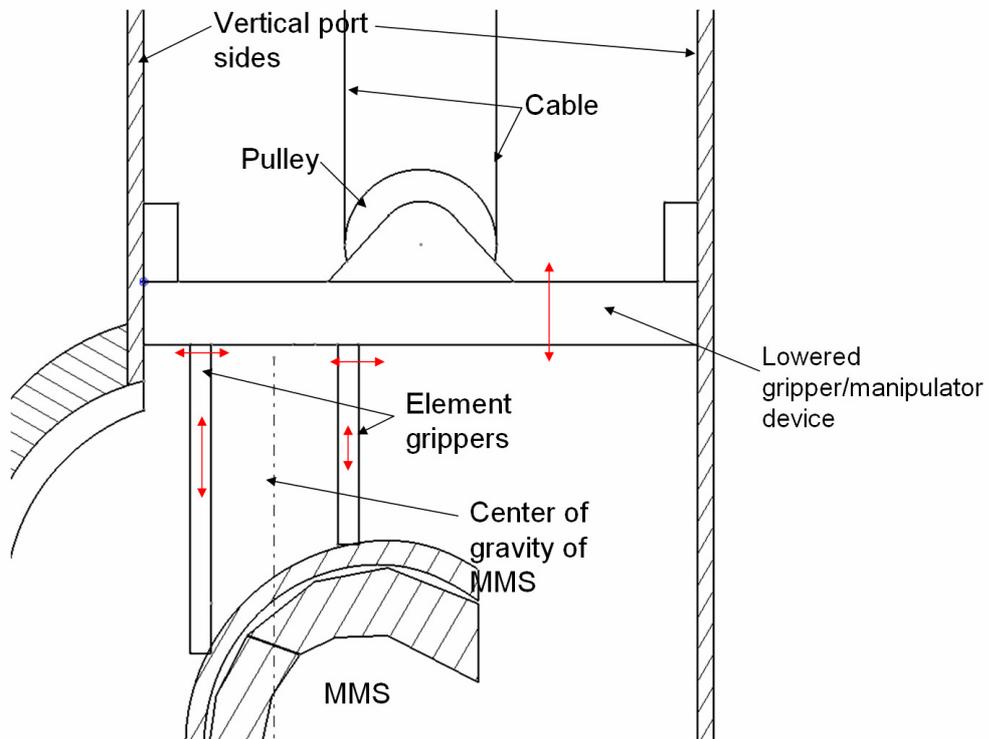
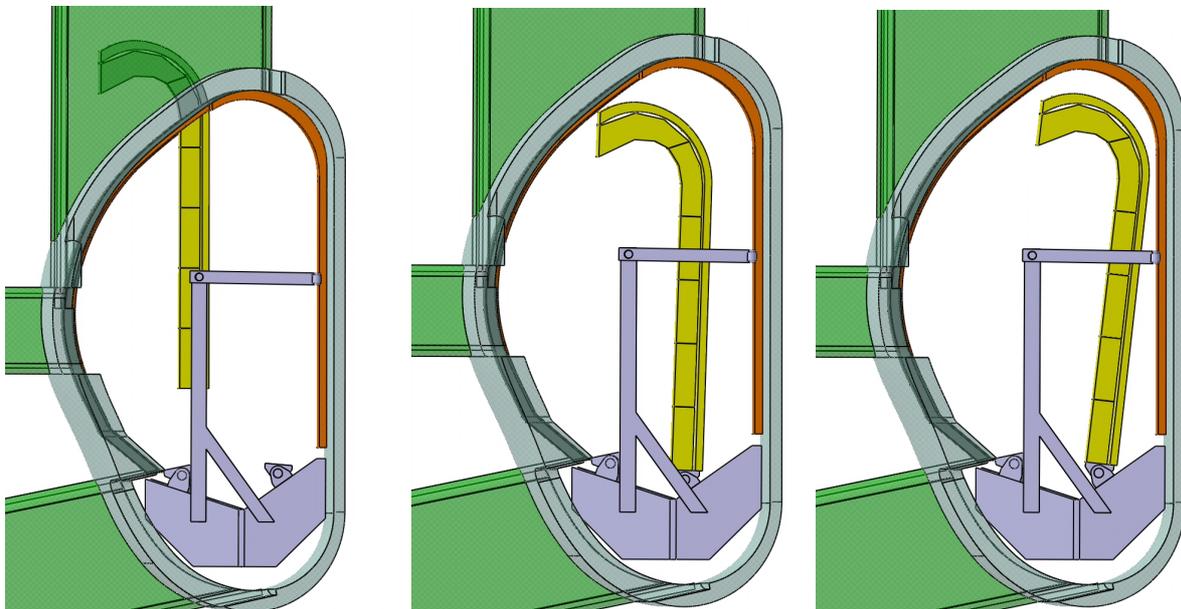


Fig. 5: Gripper/manipulator device and its operation

The basic idea for the vertical insertion machine is that a winch is used along with a gripper/manipulator device that holds the elements. The MMS elements are transported and manipulated in hanging position. They are gripped at 2-4 points at the back side of the manifold by the gripper/manipulator device (Fig. 5).

The gripper/manipulator device is used (i) to hold the MMS in hanging position inside the cask while it is being transported between hot cell and the tokamak, (ii) to perform certain adjustments in angle, horizontal and vertical position during insertion and (iii) to place the MMS onto the in-vessel manipulator. The adjustments are necessary during insertion because of the geometrical constraints of the vertical port. To perform these angular, vertical and horizontal movements the arms of the gripper/manipulator device must be capable of being adjusted in horizontal and vertical direction. During lifting/lowering the device is guided on the walls of the cask and the port.

To reduce the number of MMS to be handled the width of the MMS was chosen correspondingly to the available space in the vertical ports. The inboard region was divided into 18 degree segments (20 inboard MMS) and 11.25 degree segments (32 outboard segments), under the assumption of 16 toroidal field coils and a major radius of 8.4 m for the considered DEMO machine. The number of vertical remote handling ports for the system described here could be chosen freely but during the first approach two vertical ports were considered most reasonable.



*Fig. 6a/b/c: a) The inboard MMS is inserted through the vertical port.
b) The inboard MMS is placed on the support of the transport machine.
c) The MMS is leant against the shield and carried in toroidal direction.*

In case of the inboard the MMS is inserted through the remote handling port (Fig. 6a) until the widest section at the top of the MMS has completely passed the port. Then the gripper/manipulator drives in radial direction towards the inboard side and the winch lifts the MMS again, until the transport machine can drive under the MMS and takes over the load (Fig. 6b). The gripping/manipulation device assists during the procedure of leaning the MMS against a rail located on the ring shield wall. Alternative to the rail located on the shield wall, for the toroidal movement of the segments a roller could be inserted between MMS and shield structure (Fig. 6c). It is foreseen that four in-vessel transport machines are used in a system with two vertical ports. The first inboard and outboard MMS to be assembled is mounted in a position between the two vertical ports. The other MMS are assembled consecutively ending at the two ports. The last outboard MMS below the remote handling port is inserted at the end of the insertion procedure. This MMS will be equipped with additional shield components at

the back of the manifolds to close the permanent shield structure around the ports. The insertion and transportation procedures for the outboard MMS is similar to the procedure described for the inboard MMS.

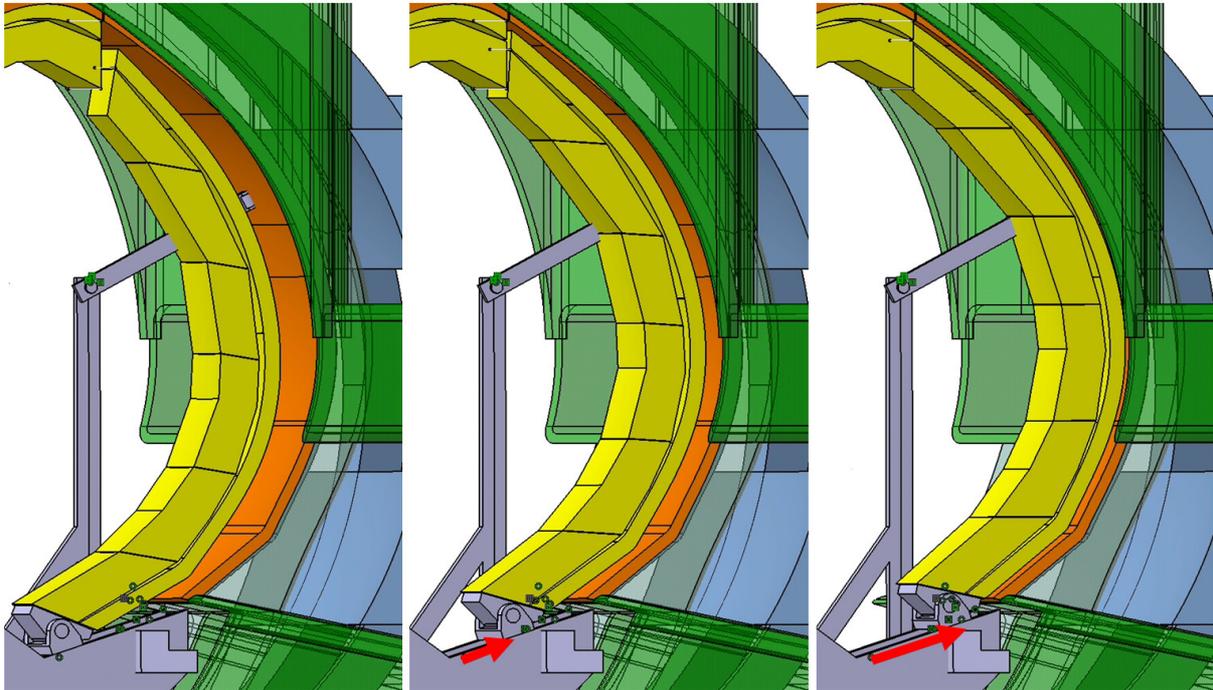


Figure 7: Outboard MMS (yellow) is moved into final position on the permanent shield (orange)

After the transport machine has reached the position where the MMS shall be mounted, a sliding carriage which supports the bottom side of the MMS moves on the machine towards the shield and brings the MMS in contact with the shield structure (Fig. 7). Guiding components between MMS and shield structure are used to allow for an exact positioning of the MMS. It is evident that the replacement of the modules will be done consecutively, with the removing of the used modules starting at the port and ending with the modules between the ports. It was ascertained that the replacement of inboard and outboard modules could be done independently in case of a failure causing the need for an unscheduled replacement of a special MMS. The worst case would be a failure of an outboard MMS between the remote handling ports which would make necessary the consecutive removal of up to 8 MMS and the divertor cassettes in the corresponding quarter of the circumference. From this a reliable system is necessary, whereby the reliability of the MMS blanket system is likely higher than in case of the large module system, as all hydraulic and mechanical connections between the blanket modules and the manifolds are done outside the reactor which allows for optimum quality assurance.

Conclusions and outlook

The new MMS reactor integration and maintenance concept involving toroidal in-vessel transport and vertical insertion through a limited number of remote handling ports offers promising features. The maintenance time could be likely reduced in comparison to a separate module maintenance scheme, the flexible attachments and hydraulic connections between the blanket modules and the manifolds could be done outside the reactor, large flexible attachment systems between vertical segments and cold components are not needed, a small number of ports have to be opened for maintenance, only relatively simple and low accuracy

remote handling steps are necessary for the large components and a small number of independent units have to be handled. A drawback of the MMS system is the increased waste volume (manifolds behind the blanket modules are likely not re-weldable due to He-production in the steel). The integration concept involves a closed ring shield that is operated at the same temperature as the manifolds of the MMS elements. The ring shield is attached to the vacuum vessel by use of bending plates. The concept will be developed and analyzed in further detail including e.g. the thermo-mechanical stress levels in the MMS and shield components especially under transient boundary conditions.

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