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The test cell configuration under IFMIF-DONES condition

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The test cell (TC) in IFMIF-DONES (International Fusion Material Irradiation Facility - Demo Oriented Neutron Source) is the meeting point of the three major systems (test systems, lithium systems, and accelerator systems) to host the irradiation test module, lithium target assembly and the end section of the accelerator line. Although the design of the TC, in a large extent, inherits that of the reference IFMIF-EVEDA (Engineering Validation and Engineering Design Activities) TC, design justifications are required to solve the existing major open issues such as cavitation of the lithium flow, activation and maintainability of key components, and etc. In this paper, these major open issues of the reference TC layout are addressed and a TC reconfiguration proposal, featuring arranging the lithium quench tank inside the TC, is introduced. The two concepts are investigated, analyzed, and compared on the aspects of lithium flow stability, tritium generation rate, key component maintenance scenarios, irradiation shielding, and in-TC components arrangement.

Keywords: IFMIF, DONES, Test Cell, Quench Tank, Lithium System

1. Introduction

As the complementary work of IFMIF-EVEDA (International Fusion Material Irradiation Facility-Engineering Validation and Engineering Design Activities) project [1], WPENS (Work Package Early Neutron Source) project in the framework of EUROFusion activities is committed to the engineering design of an IFMIF-DONES (Demo Oriented Neutron Source) facility [2, 3], which is an intensive fusion-like neutron source with the objective of qualifying structural materials that will be used in the DEMO fusion reactor. IFMIF-DONES is based on the interaction of one 40 MeV 125 mA deuteron beam and a flowing liquid lithium (Li) target to deliver high energy and high density neutron flux for fusion material irradiation experiments. IFMIF-DONES uses one accelerator as the deuteron source and intends to install one single high flux test module (HFTM), while IFMIF-EVEDA applies two accelerators and will install medium and low flux test modules besides the HFTM. The configuration of the major systems of IFMIF-DONES is expected to be very similar to the IFMIF-EVEDA design [2].

In IFMIF-DONES design, three major systems, test systems (TS), lithium systems (LS), and accelerator systems, have been identified in the IFMIF-DONES. The test cell (TC) is the meeting point of these three major systems to provide a shielded confinement to accommodate the HFTM, lithium target assembly (TA), and the end section of the accelerator beam line. As the starting point of engineering design of the IFMIF-DONES TC, the design of the IFMIF-EVEDA TC [4] has been considered as a reference. A side view of the IFMIF-DONES reference TC design is shown in Fig. 1.

During the operation of the facility, liquid Li enters the TC though an inlet Li pipe (penetration in the TC boundary), flows through the TA to receive deuteron beam to generate irradiation neutrons, and then is slowed down in a quench tank (QT). The QT, which is defined as a permanent component that is maintained or replaced in case of damage, contains a liquid Li pool to receive the hot Li from the target to avoid any boiling and thermal shock to the loop piping. The position /configuration of the QT in the IFMIF plant has a strong effect on the building design as well as on safety, maintenance and remote handling aspects due to the large size and peculiar interface properties of the QT.

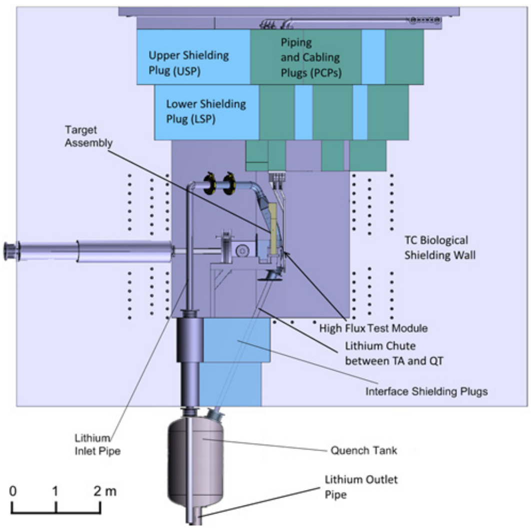

Fig. 1. Schematic side view of the IFMIF-DONES reference test cell design.

In the IFMIF-DONES TC reference design, the QT is located in the LS area and below the TC floor. A long Li chute (> 3.5 m) connects the TA and the QT and penetrates the TC floor through a removable interface shielding plug (ISP). Although there were design options on including QT inside the TC [5, 6], QT outside the TC

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configuration was selected during the IFMIF-EVEDA phase with the consideration of lower tritium generation [7], lower inventory inside the TC, possible convenient maintainability, and etc. [8]. However, open issues such as the cavitation in the Li flow inside the chute, expansion compensation of the long chute, and etc., have not been solved. Moreover, latest neutronic calculation results also question the claimed QT maintenance convenience. The QT maintenance could be, in contrary, even more complicated than the QT in-TC options.

In this paper, an optimized QT in-TC configuration is introduced to solve the open issues in the reference TC design and to simplify the QT maintenance scenario. Both concepts are investigated, analyzed, and compared from aspects of Li flow stability, QT activation, maintenance scenario, and etc. The final decision on the QT location is expected to be made in the next design phases based on more detailed analysis and integrated consideration with the IFMIF-DONES building design.

2. IFMIF-DONES Reference Configuration

As shown in Fig. 1, the reference IFMIF-DONES TC configuration features QT being arranged below the TC floor and an inclined chute connecting QT with the TA. The Li chute is shown in Fig. 2. As the extension of the TA output section, the closed chute has a rectangular shaped cross-section with an inner dimension of 260 mm (w) x 50 mm (h). Inside the chute, the Li flow occupies the lower 25 mm heights and the rest is void. Heating wires and thermal insulation materials (not shown in Fig. 1 and Fig. 2) will surround the chute to control thermal condition of the chute and surrounding areas.

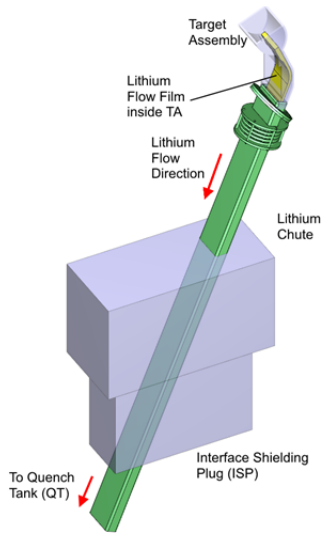

Fig. 2. Arrangement of Li chute and ISP.

In this configuration, the QT is well shielded against the neutron irradiation from inside of the TC thank to the massive shielding materials of the TC floor and the ISP. However, strong neutron streaming can still reach the QT due to the void fraction and the weak shielding function of the Li inside the chute. Although efforts have been made to reduce the void fraction inside the chute, a minimum 5 to 10 mm height void should be kept to gurantee a free surface of Li flow. Neutron streaming due to the thermal insulation materials around the chute also has to be considered as well. Latest neutronic calculations suggested up to 10^7 n/cm^2/s neutron flux on the QT [9], which means that the QT is still activated. Fig. 3 shows the activation level of the upper part of the QT after one and thirty years of irradiation [9]. This result indicates that the QT is not hands-on maintainable even after one year of irradiation and 30 days of cooling. Considering that the maintenance of the QT is only in case of damage which may happen after many years of irradiation, the higher dose accumulation on the QT will be completely close the hands-on accessibility. Under this circumstance, the QT must be replaced. A QT transportation route and corresponding equipment for massive activated component must be predefined and reserved in the LS area and other relevant systems. This maintenance scenario will strongly impact the design of the LS area as well as the IFMIF-DONES building.

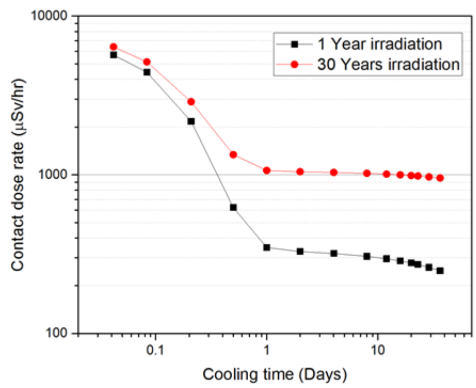

Fig. 3. Contact dose rate of QT in TC reference layout [9].

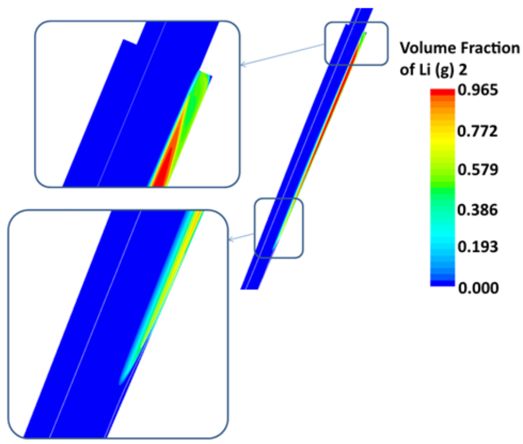

Fig. 4. Cavitation phenomenon in the Li chute

Another open issue in this configuration is the high cavitation risk of the Li flow in the chute. For the purpose of compensating the expansion of the Li chute at different temperatures, steps or gaps are often reserved inside the chute. Generation of Li gas phase in the Li flow may happen due to the flow discontinuity. This lead to high cavitation risk, and subsequently, high corrosion risk to the Li contact surfaces. Fig. 4 shows a typical cavitation phenomenon when a small step exists inside the chute. To minimize the flow cavitation an optimized design of the chute must be implemented taking into account the neutron streaming, compensation of thermal expansion, configuration of thermal insulation materials of the chute, etc.

From the point view of in-TC components, this layout provides sufficient free volume in the TC to conveniently install other in-TC components, such as the TA supporting structure.

3. Optimized QT in-TC Configuration

To solve the problem of Li flow cavitation, removing completely the chute and arranging the QT to as close as possible to the TA is the direct solution. This option installs the QT inside the TC and directly under the TA. In previous QT in-TC designs [5,6], the complete QT was inside the TC. Considering that including the complete QT in TC will dramatically increase the TC volume and bring significant impacts on the existing IFMIF-DONES building design, an optimized solution features QT being half-buried in the TC floor is introduced, as shown in Fig. 5. In this layout, the location of the TC floor is identical to that in the reference TC design. The QT connects the Li loop with a direct outlet pipe (DN 250) at the bottom.

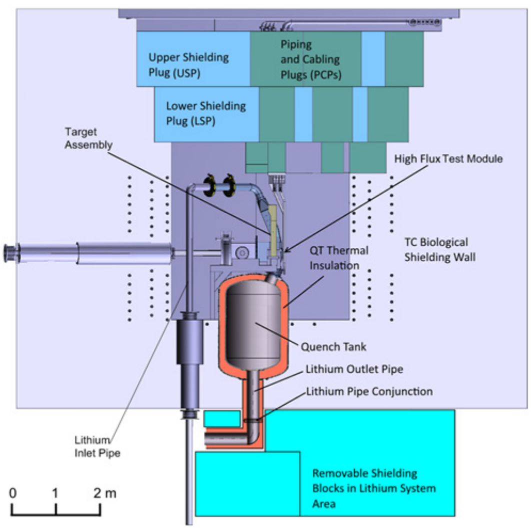

Fig. 5. Schematic configuration of QT half-buried in TC floor concept.

Because the QT is directly located below the TA, Li will directly inject into the QT without flowing through a long path. The cavitation risk that is found in the reference design is minimized. Without the long chute, thermal compensation components can be much easier to be defined and configured around the QT and Li outlet pipe.

The QT in-TC layout directly exposes the QT to the intensive neutron irradiations inside the TC and will be highly activated. Due to the big dimension of the Li outlet pipe, strong neutron steaming to the LS area is foreseen. Fig. 6 shows the strong neutron flux applied to the LS area through the Li outlet pipe: a neutron flux up to 10^8 n/cm^2/s can be observed. [9]. To effectively protect the other components in the LS area, additional removable shielding blocks in the LS area must be arranged, as shown in Fig. 5. An additional thickness of the TC floor may be applied to reduce the neutron flux but removable shielding blocks are in any way required.

Fig. 6. Neutron flux (n/cm^2/s) around the Li outlet pipe in the QT half-buried in TC floor lay out during the beam operation (10mm void fraction in the chute) [9].

It is clear that the QT will be highly activated in the TC and hands-on operation on the QT is completely impossible (contact dose rate > 1000 µSv/h at the outlet pipe flange after one year facility operation [9]). When maintenance of the QT is required, replacement is the only choice. Under this circumstance, the QT, which is already highly activated, will be removed from the TC to the access cell (AC) that is located directly above the TC [10]. Below the TC floor, a Li pipe conjunction is arranged to the Li outlet pipe so that the upper section of the Li outlet pipe can be removed together with the QT after this conjunction is disconnected. The disconnecting operation will have to be performed using remote handling equipment that is installed in the LS area.

Compared to the reference TC layout, the in-TC QT is clearly activated to a much higher level, which means a much higher inventory in the TC. However, the handling of the highly activated components claims no additional requirements to the LS area because the transportation route through the AC is already designed for transporting highly activated components, such as HFTM, TA, etc. [10].

As mentioned in the previous sections, the QT in-TC option will definitely bring more tritium generation than the reference design due to the neutron irradiation on the large amount of Li in the QT [7]. Other open issues of this configuration may include negative impact on the TA supporting structure arrangement inside the TC, and etc. Considering the limited spaces inside the TC due to the existence of the QT, design optimizations of the TA supporting structure have to be implemented. The feasibility of using a down-sized QT inside the TC is currently under investigation.

4. Comparison Overview

According to the above analysis and investigations, a preliminary comparison on the key aspects between the two configurations is summarized in Table 1.

Table 1. Overview of the comparison of the two options on the major design aspects.

	QT outside TC (Reference Design)	QT in-TC (QT half buried in TC floor)
Tritium Generation	Low (~ 15% [7])	High
Inventory in TC	Low	High
Li cavitation risk	High	Low
Potential thermal stress issue	Critical	Less Critical
QT sizing	Less Limited	Limited
QT activation	Low	High
Hands-on operation possibility	Very Low	No
Maintenance Scenario	Complex	Relative Simple
QT Transportation Route	Through LS area	Through AC

5. Summary

Major advantages and open issues of the reference IFMIF-DONES TC design have been analyzed from the point of view of the location of the QT. This layout minimizes inventory inside the TC, however, high cavitation risk has been observed in the lithium flow due to the long chute between the TA and the QT. In addition, neutronic simulation results almost negate the QT hands-on operation possibility, which was considered as one of the major motivations of QT outside TC option. Significant impacts on activated material handling in the LS area and the IFMIF-DONES building are also noticed.

An optimized QT in-TC concept is introduced considering the Li flow stability and simplification of QT maintenance scenarios. The QT is half-buried in the TC floor to reduce the volume of the TC and to reduce the impact on the IFMIF-DONES building design. The short distance between the QT and the TA can reduces Li flow cavitation risk but will increase the tritium generation in QT. Although QT is more highly activated, compared with the reference design, maintenance scenarios are less complicated and impact on other systems' designs can be minor.

It must be pointed out that the current comparison between the two concepts is very preliminary and not yet in detail. Further analysis and investigations on the concepts from the aspects of Li corrosion, activation of key components, maintenance scenarios, interfaces with other systems, impacts on IFMIF-DONES building, and etc., are foreseen and will provide important basis for the TC layout decision.

Acknowledgments

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References

[1] J. Knaster et al., The accomplishment of the Engineering Design Activities of IFMIF/EVEDA: The European–Japanese project towards a Li(d,xn) fusion relevant neutron source, Nuclear Fusion 55(8)(2015) 086003

[2] A. Ibarra et al., A stepped approach IFMIF/EVEDA towards IFMIF, Fusion Science and Technology, 66 (2014) 252–259

[3] J. Knaster et al., IFMIF, the European–Japanese efforts under the Broader Approach agreement towards a Li(d,xn) neutron source: Current status and future options, Nuclear Materials and Energy, in press,

[4] K. Tian et al., Engineering design of the IFMIF EVEDA reference test cell and key components, Fusion Engineering and Design, 89 (2014) 1694–1698

[5] IFMIF International Team, IFMIF Comprehensive Design Report (CDR), IEA Report, December 2003

[6] K. Tian et al., IFMIF target and test cell—conceptual designs, boundary condition definitions and current status of preliminary engineering design, Fusion Eng. Des., 85 (2010), 2282–2287

[7] S.P. Simakov et al., Assessment of the ^{3}H and ^{7}Be generation in the IFMIF lithium loop, Journal of Nuclear Materials 329–333 (2004) 213–217

[8] F.S. Nitti et al., The design status of the liquid lithium target facility of IFMIF at the end of the engineering design activities, Fusion Engineering and Design, 100(2015) 425-430

[9] Y. Qiu et al., Neutronics assessment of different quench tank location options in IFMIF-DONES, presented in the 28th Symposium on Fusion Technology (SOFT2016), Sept. 5-9, 2016, Prague, Czech Republic

[10] K. Tian et al., Overview of the IFMIF test facility design in IFMIF/EVEDA phase, Fusion Engineering and Design, 98-99(2015) 2085-2088