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COMMISSIONING PLAN OF THE IFMIF-DONES ACCELERATOR*

I. Podadera[†,1], A. Ibarra[1], M. Weber[1], Consorcio IFMIF-DONES España, Spain
B. Bolzon, N. Chauvin, S. Chel, A. Madur, Université Paris-Saclay, CEA, France
T. Dézsi, CER, Hungary
F. Arranz, C. de la Morena, M. García, D. Jimenez-Rey, J. Molla, C. Oliver, D. Regidor
CIEMAT, Spain
D. Bernardi, G. Micciché, F. S. Nitti, ENEA Brasimone, Italy
C. Prieto, Empresarios Agrupados, Spain
P. Cara, Daniel Duglue, Fusion for Energy, Germany
W. Królas, U. Wiacek, IFJ-PAN, Poland
L. Bellan, A. Palmieri, A. Pisent, INFN/LNL, Italy
Ll. Macià, M. Sanmarti, B. K. Singh, IREC, Spain
V. Hauer, Y. Qiu, T. Lehmann, KIT, Germany
M. J. Ferreira, C. Martins, Lund University, Sweden
J. Aguilar, S. Becerril-Jarque, M. Luque, J. Maestre, D. Sánchez-Herranz, C. Torregrosa
Universidad de Granada, Spain
J. Castellanos, Universidad de Castilla-La Mancha, Spain
[1] also at CIEMAT, Madrid

Abstract

IFMIF-DONES (International Fusion Materials Irradiation Facility- DEMO-Oriented Neutron Early Source) - a powerful neutron irradiation facility for studies and certification of materials to be used in fusion reactors - is planned as part of the European roadmap to fusion electricity. Its main goal will be to characterize and to qualify materials under irradiation in a neutron field similar to the one faced in a fusion reactor. The intense neutron source is produced by impinging deuterons, from high-power linear deuteron accelerator, on a liquid lithium curtain. The facility has accomplished the preliminary design phase and is currently in its detailed design phase. At the present stage, it is important to have a clear understanding of how the commissioning of the facility will be performed, especially the commissioning of a 5 MW CW deuteron beam, together with the lithium curtain and the beam optimization for the neutron irradiation. In this contribution, the present plans for the hardware and beam commissioning of the accelerator will be given, focusing on the most critical aspects of the tiered approach and on the integration of the procedure with the lithium and test systems.

IFMIF-DONES ACCELERATOR

The IFMIF-DONES facility [1, 2] is a fusion-like neutron source, generating a neutron flux of 5×10^{14} neutrons/cm^2/s for the assessment of materials damage in DEMO and future fusion reactors. Neutrons are generated by the interaction between the lithium curtain and the deuteron beam from a Radio Frequency LINear ACcelerator (RF LINAC) at 40 MeV and nominal Continuous Wave (CW) current of 125 mA. The facility is divided in three major group of systems: 1) the ∼100 m long Accelerator Systems (AS), grouping those systems involved in the beam production, acceleration and shaping, 2) the lithium systems (LS) which generate and control the liquid lithium target, and where the Li(d,xn) stripping reaction (with a neutron spectrum up to 50 MeV) between the deuterons and the lithium occurs, and 3) the experimental material test areas or test systems (TS), where the main component is the High Flux Test Module containing 100 cm^3 of material under test with up to 20 dpa y^{-1} to 50 dpa y^{-1}. The Accelerator Systems [3] will be formed by Fig. 1: 1) an Injector [4], composed of an ion source and a Low Energy Beam Transport (LEBT) section at 100 keV to guide the low energy ions up to the Radio Frequency Quadrupole (RFQ) and match its injection acceptance, 2) the RFQ [5] to accelerate the ions from 100 keV up to 5 MeV, 3) a Medium energy Beam Transport Line (MEBT) [6] to match the RFQ extracted beam to the injection of the Superconducting RF LINAC (SRF LINAC), 4) an SRF LINAC [7] with five cryomodules to bring the energy of the deuterons up to 40 MeV, 6) a High Energy Beam Transport (HEBT) [8] line to transport and shape the beam from SRF Linac towards the lithium target or the Beam Dump Transport Line (BDTL), in pulsed mode, 7) an RF Power System (RFPS) [9] based on solid-state technology to supply and control the RF injection into the cavities for beam acceleration and bunching, and 8) the AS Ancillaries (ASA) providing the services to the accelerator, including the vacuum generation and exhaust, the

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† ivan.podadera@ifmif-dones.es

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cryogenics, the water cooling, the electric power and the gas distribution.

The design is driven by two main goals: 1) maximize the neutron irradiation of the proper energy spectra [10, 11], 2) keep the availability of the AS above 87 % [12].

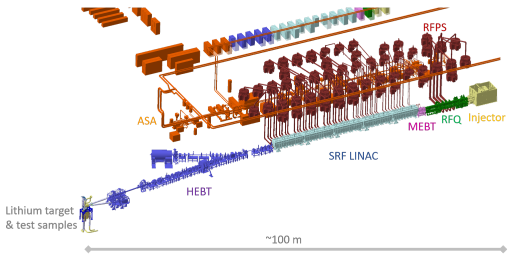

Figure 1: Integrated mockup of the IFMIF-DONES Accelerator Systems.

AS COMMISSIONING PHASES

Like in other facilities [13–19], and based on what has been performed in the prototype accelerator, the LIPAc [20], the accelerator will be commissioned in several stages. A total time of around six years has been allocated to complete the commissioning of the whole accelerator and achieve the 5 MW deuterons impinging on the lithium target. As reference point for the start of the sequence of accelerator commissioning activities, *T0* is considered as the start of the construction of the building housing the accelerator systems. It is assumed that the installation of the first systems of the accelerator could start four years later, triggering the first stage of accelerator commisioning (*T0*+4), so-called Phase 1. The scheme for the accelerator commissioning is highly coupled with the safety licensing frame, which will be pursued in several phases [21].

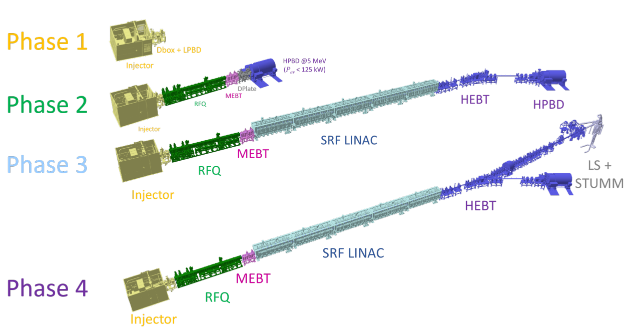

Figure 2: The accelerator during the different phases.

Phase 1

First stage will be the commissioning of the Injector system, representing the first beam operation in the facility. A slot of one year is reserved for this phase, which will be considered as fulfilled (*T0*+5) once the Injector is running reliably and the nominal beam extracted to be injected into the RFQ is characterized. For this phase, a special designed Diagnostics Box (Dbox) with a Low Power Beam Dump (LPBD), designed to stop the 140 mA at 100 keV, will be added at the end of the LEBT, in the area where the entrance to the RFQ will be located, see Fig. 2. Since many components will still not be installed, the possibility to parallelize the Injector beam commissioning with other installation activities is being assessed. During this phase, the Injector components will be installed and checked out, prior to be conditioned up to the nominal reference level of high voltage (100 kV). This phase is key to verify and optimize the integration of different systems, as it will be the first time that accelerator systems, plant systems and control systems will be working together. The operation team will use this phase to validate and tune the procedures for operating the machine, ensure the components integrity and verifying the functioning of the safety measures.

Phase 2

After the Phase 1 is completed, the commissioning will switch to Phase 2 (*T0*+5). As shown in Fig. 2, during this phase the RFQ and the MEBT will be installed, and characterized by using a specific set of beam diagnostics, the Diagnostics Plate. The beam will end in a High Power Beam Dump (HPBD). The HPBD is foreseen to be the same as that used for later stages, but placed in a temporary position. A slot of two years is reserved for Phase 2, since in addition to the installation and checkout of many components, critical tasks are expected, like the RF conditioning of the RFQ or the ramp up of the beam duty cycle. The main goal will be to characterize the beam injected into the SRF LINAC with parameters valid for the nominal beam operation. This includes the operation of the RFQ in a thermal regime where the tuning regulation using a water temperature controlled loop is necessary. For this reason, a preliminary maximum Duty Cycle (DC) of 20 % has been established, although this will be confirmed by the operation of the RFQ in LIPAc during Phase B+ [22]. The main Hardware Commissioning (HWC) tasks during Phase 2 are the RF conditioning in CW of the RFQ and MEBT re-buncher cavities. The conditioning of the RFQ is one of the main challenges faced by the accelerator, although much experience has been obtained already in LIPAc, where a field of 100 kV was recently achieved at continuous operation [22].

Phase 3

The end of Phase 2 (*T0*+7) will mean the start of the Phase 3, with the installation and commissioning of the SRF LINAC and part of the HEBT, up to the HPBD at its final location (Fig. 2). During this phase, the SRF LINAC will be installed in a single step, including the five cryomodules and the warm sections in-between, as done in other facilities. Another two years are expected for this phase. The main objectives are not only to accelerate a nominal current beam of 125 mA in pulsed mode of 1 %, but to tune the SRF LINAC to ensure lossless transmission along the cryomodules. Checkout of the beam diagnostics inside the cryomodule and along the warm sections is also important to achieve the objectives. Although the most conservative

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approach is to install and commission each of the five cryomodules one by one, it is considered that LIPAc will provide enough feedback to carry it out in one single step. Related to HWC, the main focus is placed on the commissioning of the cryogenics system, first the cryoplant and then the integration with the cryodistribution for the cryomodules. After the cryogenic temperature is stabilized, the 46 superconducting Half Wave Resonators (HWR) will be RF conditioned, to get them ready for the beam injection.

Phase 4

Finally, the last stage before moving the facility into nominal Operation, it is the Phase 4 (*T0*+9). This phase will involve the commissioning of the whole accelerator, including the last sections of the HEBT, and the integration with the other group of systems, the lithium and test systems (Fig. 2). It is therefore a pre-requisite for this phase that all those group of systems are ready by the start of this phase. In the case of the test systems, that means the STart-Up Monitoring Module (STUMM) [23] is well tested and in place, as it will serve to validate the neutronics field and align and optimize the irradiation. HWC tasks are limited to verify the procedures for remote handling of the HEBT section at the Target Interface Room (TIR), the target diagnostics and the integration with the lithium and test systems. In the case of lithium systems, this means that the whole system is in operation and the target is at stable flowing conditions. The integrated vacuum system of the accelerator and lithium systems will need to be tested and validated, including the load of lithium in the circuit, or the stability of argon injection into the target vacuum chamber. Another important point will be the alignment of the accelerator with the lithium curtain, and the STUMM. The procedure to guarantee the alignment during operation shall be reproduced and validated during this phase. One year is allocated to complete this phase.

BEAM COMMISSIONING

The main goal of the accelerator commissioning is to provide the nominal beam to the lithium target, reliably and safely. Since the beam is very sensitive to the parameters of each accelerator system, a fully understanding and characterization of each section is needed to succeed. To reach this goal, the beam properties listed in Tab. 1 for each phase are pursued. The nominal deuteron beam current is achieved for each stage, due to the strong dependence of the accelerator tuning on high space charge LINACs. Relatively low currents of about 10 mA will be anyway used for pilot beams during first steps of Beam Commissioning (BC) at each phase, and for special checkout cases. Regarding DC, 100 % will not reached for each stage, in order to speed up the commissioning process and as well to minimize activation of the accelerator components. The objectives during Phase 1 are not only to reproduce the nominal 140 mA CW beam at the output of the Injector, but to fully characterize the beam at the RFQ entrance in various beam modes. That includes operation with pilot beams, pulsed modes, and proton. This phase is expected to be speeded up by the beam tests of the complete system, and the LIPAc experience [22, 24]. During Phase 2, the BC goal is to reproduce the same beam conditions at the injection of the SRF LINAC, and fully characterize the 6D beam phase space for beam halo and activation mitigation downstream, as seen in other accelerators [25], and already done in LIPAc at low DC [26]. The maximum beam duty cycle is chosen as a tradeoff between schedule availability and machine performance. In Phase 3, the beam DC will be limited to 1 %, which is the maximum beam accepted by the HPBD at the final location for 5 MeV deuterons. Macropulses are limited up to 2 ms, which means a repetition rate of 5 Hz. A total lifetime of 2000 h is considered for the HPBD. Beam is characterized prior to entering into the multipolar magnets region of the HEBT, very sensitive to the beam. Last but not least, Phase 4 goal is to get the IFMIF-DONES nominal beam, with the beam footprint required in the lithium target, which is a rectangular shape from 10 to 20 cm in horizontal, and 5 cm in vertical. A complete set of multipole magnets [27] and beam diagnostics is devoted to safely fulfill this objective. The strategy for beam current and power ramp-up during this phase is being developed now, together with lithium and test systems. Due to the sensitivity of the whole machine to the beam current, it will probably be more sensible to start with nominal beam current, and then start ramping the DC. However, the impact of the macropulses on the liquid lithium target and the performance of the STUMM diagnostics is presently being analyzed.

Table 1: Target beam parameters for each commissioning phase. I_p is the goal of peak beam current at the beam target, T_f the final beam energy, P_p the peak beam power during a macropulse, and P_{av} the average beam power.

Phase	**1**	**2**	**3**	**4**
I_p (mA)	140	125	125	125
DC (%)	100	20	100	100
T_f (MeV)	0.1	5	40	40
P_p (MW)	0.1	0.625	5	5
P_{av} (MW)	0.1	0.125	0.05	5
Beam target	LPBD	HPBD	HPBD	LS

CONCLUSIONS AND OUTLOOK

A first version of the IFMIF-DONES accelerator commissioning plan has been presented, which follows a similar strategy to other hadron LINACs. As the project will enter soon in the construction phase, more extensive studies of the commissioning will be performed, considering co-activities during installation, checkout and hardware and beam commissioning, and including the feedback provided by the operation of the LIPAc prototype. With respect to the RF and ASA, it is under study whether, in order to speed up the commissioning, the HWC of some of them could be advanced, as a co-activity with beam commissioning.

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