Technical Note for Market Survey on LIPAc and IFMIF-DONES Injector

In preparation for Call for Tender

Contents

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IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call For Tender.

1 INTRODUCTION TO IFMIF, LIPAc, IFMIF-DONES, and FUSION FOR ENERGY

The European Joint Undertaking for ITER and the Development of Fusion Energy – in short Fusion for Energy (F4E) – is a type of European organization known as a Joint Undertaking created under the EURATOM Treaty by a decision of the Council of the European Union. F4E has three main objectives:

- Providing European contributions to the ITER international fusion energy research project being built in Cadarache, France.
- Providing European contributions to a number of joint projects with Japan that aim to accelerate the development of fusion – the "Broader Approach".
- Coordinating a programme of activities to prepare for the first demonstration fusion reactors (DEMO) that can generate electricity.

In order to test and qualify materials to be used in future fusion reactors, the International Fusion Materials Irradiation Facility (IFMIF) aims to provide an accelerator-based, deuteron-lithium neutron source to produce high-energy neutrons at sufficient intensity and irradiation volume to simulate as closely as possible the first wall neutron spectrum of future nuclear fusion reactors such as DEMO.

The accelerator system is composed of the following basic functional building blocks. The *injector system* injects a 100-keV, 140-mA, continuous-wave (CW) deuteron beam into the *Radiofrequency Quadrupole (RFQ)*, which bunches the CW beam and accelerates it further up to 5 MeV. With a transmission of at least 90%, the RFQ delivers a continuous train of bunches at a frequency of 175 MHz with an average current of 125 mA – which is the current ultimately required for the Li(d, n) nuclear stripping reaction taking place in the Lithium target. Downstream of the RFQ, a *medium-energy beam transport (MEBT)* section transports and matches the beam in both the transverse and longitudinal planes into the *superconducting RF (SRF) linac*. By means of five separate cryomodules and a particular sequence of superconducting solenoids and half-wave resonators, the SRF linac transports and accelerates the beam up to 40 MeV. After that, in the *high-energy beam transport (HEBT)* section, the bunches are transported and transversely shaped into either a *beam dump* (for machine commissioning, set-up, and fine tuning) or the Lithium target (for actual operation and high-flux neutron production).

Under the framework of the Broader Approach (BA) agreement, the Linear IFMIF Prototype Accelerator (LIPAc, see Figure 1a) is being assembled and commissioned at the Rokkasho site (Japan) with the aim to develop and validate prototypes of the building blocks for the IFMIF accelerator font end. The goal is to achieve continuous wave operation of a high current beam of 9-MeV deuterons in order to demonstrate the technological feasibility of the project.

The DEMO Oriented Neutron Source (IFMIF-DONES, see Figure 1b) facility integrates the full scale IFMIF accelerator system with the Lithium target and the test cell for actual fusion materials testing and qualification activities. As a user facility, IFMIF-DONES is expected to achieve a high inherent availability of 75% during its 30 years lifetime – which translated to the Accelerator Systems corresponds to an inherent availability of 87%. The DONES International Multilateral Agreement (MIDA) has been signed between the IFMIF-DONES España Consortium, Fusion for Energy, and Reasearch Institutes from Croatia (RBI), Japan (QST), and Italia (INFN), which establishes a comprehensive framework for decision-making, resource allocation, robust management and transparent governance of the DONES Programme. The IFMIF-DONES facility is currently under its construction phase at Escúzar site (Granada, Spain).

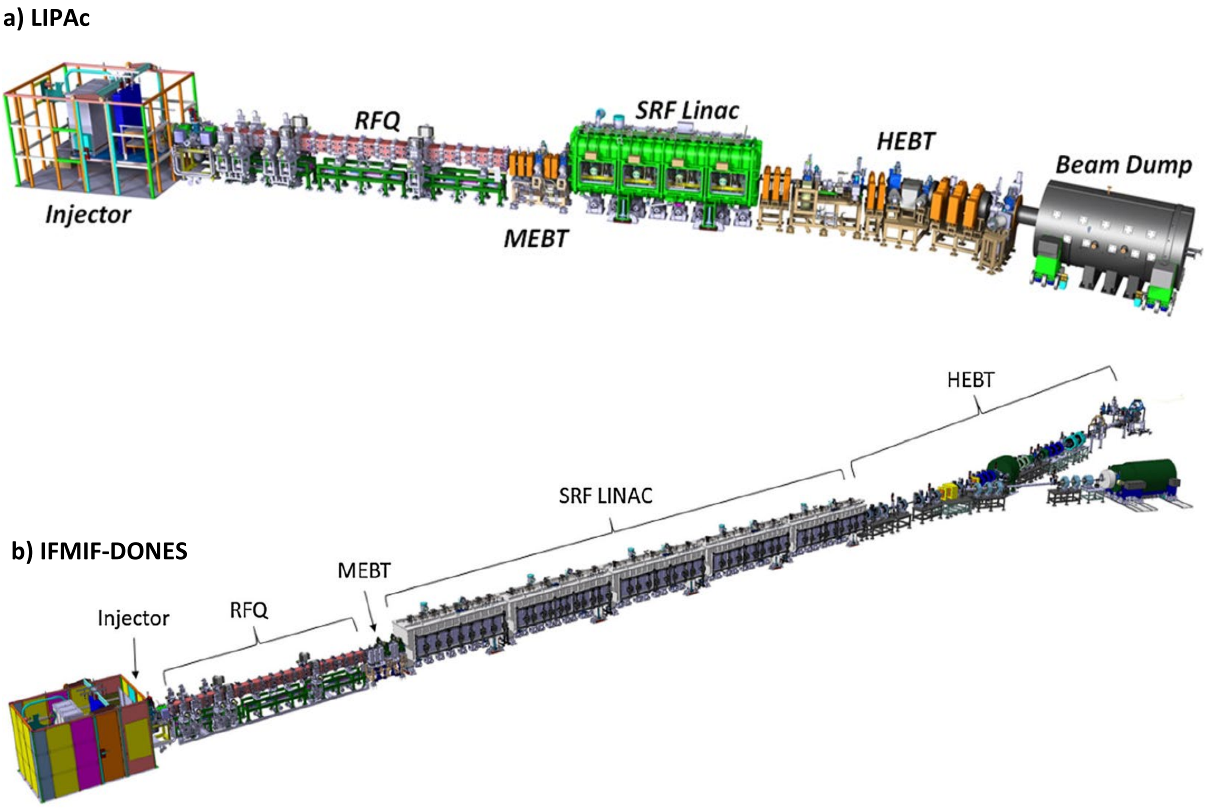

Figure 1. a) LIPAc and b) DONES accelerator subsystem layouts

The engineering and validation activities performed at LIPAc provide the most essential and up-to-date experimental information about the best technical solution of the accelerator front-end. At the present stage of the project, a number of components of both the LIPAc and the IFMIF-DONES accelerator system can be considered to share common technical requirements – which is referred to as LIPAc-DONES commonalities. Consequently, the upcoming supply of these components can be targeted simultaneously to either of the two facilities, contributing to a more efficient management of the design, manufacture, and production activities and thus granting more flexibility to the development of the project in a broader sense. The subject of the present technical note falls within the category of LIPAc-DONES commonalities and shall be integrated into either of the two facilities without the need of any major modification request.

2 DESCRIPTION OF THE IFMIF INJECTOR

2.1 TECHNICAL DESCRIPTION

As mentioned above, the IFMIF injector must deliver a D+ beam with characteristics compatible with the rest of the accelerator – i.e., a continuous-wave (CW) deuteron beam with an energy of 100 keV, a current of 140 mA, and a transverse emittance of 0.25 π.mm.mrad at the exit of the LEBT. Additionally, for machine start-up and commissioning purposes, the injector must be able to operate in pulsed mode with duty cycles as low as 0.1% and repetition rates between 1 Hz and 20 Hz, and to produce proton (H+) beams with a perveance equivalent to that of a deuteron beam – i.e., half the energy and half the current. In order to limit the power density deposited onto interceptive diagnostic devices located downstream of the accelerator front end, the shortest pulse duration produced by the injector must be of 50-100 µs.

The injector is composed of an ion source and a low-energy beam transport (LEBT) section. The source consists of an Electron Cyclotron Resonance (ECR) ion source – otherwise referred to as a Microwave Discharge Ion Source (MDIS) – operating at 2.45 GHz, owing to its intrinsic high efficiency, high availability and its ability to produce high-intensity beams with low transverse emittance and low energy spread. The ECR conditions are created in the plasma chamber into which the required gas (either H_2 or D_2) is injected. The magnetic field is created by means of magnetic coils and the RF is produced by an RF source (typically a magnetron) and transported to the plasma chamber by RF waveguides. The electrodes of the accelerator column extract, accelerate, and transport the ions into the LEBT section. All the equipment electrically connected to the source side of the accelerator column is located on a HV platform and biased up to 100 kV DC. A Faraday cage with a door controls the access to the HV elements depending on pre-defined machine conditions by means of a safety interlock.

The LEBT basically consists of two solenoids that transport the beam delivered by the source and focus it at the entrance of the RFQ for bunching and further acceleration. A heavy-gas injection is connected to the vacuum chamber to control the space-charge compensation of the beam. The LEBT contains a set of diagnostics to monitor and characterize beam parameters – such as the current, the transverse profile, the emittance and the species fraction – and to optimize and characterize the performance of the system.

The Local Control System consists of all the necessary hardware and software to control and monitor the injector system state in stand-alone mode. In order to be integrated into the accelerator control system, the injector Local Control System will have to interface with the Central Control System, the Personnel and Machine Protection Systems and the Timing System of the accelerator. In terms of safety, the injector plays a central role in the operation of the overall accelerator, since it allocates the beam shutdown safety system, allowing the fast or slow beam termination in case of malfunctioning or deviation from normal working conditions of the accelerator components.

2.2 BASIC TECHNICAL REQUIREMENTS

The main technical requirements of the injector system for nominal operation are detailed in Table 1 below:

Requirement	Target value	Acceptance criteria	Comment
Particle type	D^+	D^+	
Output energy	100 keV	(100 ± 0.1) keV	Error represents rms value.
Output D^+ current	140 mA	140 mA	Value measured at the exit of the LEBT. Assumes an RFQ transmission ≥ 90 %.
Beam current noise	1 % rms	≤ 2 % rms	At frequencies below ~1 MHz.
Species fraction D^+	99 %	≥ 95 %	At the exit of the LEBT.
Normalized rms transverse emittance	0.25 π·mm·mrad	≤ 0.30 π·mm·mrad	At the exit of the LEBT.
Duty factor	CW	CW	
Beam turn-off time	< 10 µs	≤ 20 µs	Time to zero current.
Lifetime	30	30	

Table 1: Summary of target parameters in nominal operation.

Additionally, for commissioning and start-up procedures, the injector shall also fulfil the following requirements:

Requirement	Value	Comment
Particle types	D^+ / H^+	H^+ beam production with same perveance as the D^+ beam and half its energy and current.
Operating current range	10 – 140 mA	Value measured at the exit of the LEBT. For D^+ the minimum current is 20 mA. For H^+ maximum current is 75 mA.
Pulse-duration modulation capability	1 ms – CW	Pulse duration from the source.
Minimum pulse duration with chopper operation	50 – 100 µs	Pulse duration at the exit of the LEBT by using a chopper installed between the two solenoids of the LEBT.
Repetition rate	1 – 20 Hz	To the extent possible, the injector shall be able to operate at repetition rates higher than 20 Hz in order to reduce the acquisition time of measurements.

Table 2: Extended operation parameters for commissioning and start-up procedures.

3 SCOPE OF THE FUTURE CALL FOR TENDER

The provisional scope of the contract includes the following hardware deliverables:

- Two complete injectors composed of an ion source and a low-energy beam transport (LEBT) – one for LIPAc and another one for IFMIF-DONES. The exact hardware scope is different between each of the two facilities, since: 1) power supplies need to be provided for IFMIF-DONES whereas at LIPAc the injector must be adapted to the already existing ones; 2) for LIPAc the vacuum system shall be provided by the supplier, whereas for IFMIF-DONES it is out of the scope of the contract and will be provided by IFMIF-DONES themselves. Additionally, differences for other specific components might be required to adapt to different interfaces with the two facilities (for example different positioning the accelerator vault, different connection type to cooling skid, etc.).
- Diagnostics, instrumentation, and control devices to operate the machine – for each of the two injectors.
- Local instrumentation and control system, including hardware, software, human-machine interfaces, and control cubicles – for each of the two injectors.
- Spare parts and dedicated tools and components required during the implementation of the project, covering all verification and validation tests – for each of the two injectors.
- Packaging for the shipment of the supply.

The provisional scope of the contract includes the following activities:

- Design activities to achieve a technical proposal that is compliant with the technical requirements of the system taking into account the lessons learnt from the operational data made available from the current LIPAC injector.
- Engineering analyses of equipment and systems, including an assessment of the manufacturing and assembly procedures.
- Implementation of safety analyses in line with the requirements of the target facility (i.e., LIPAC or DONES).
- Optimization of the Reliability, Availability, Maintainability, and Inspectability (RAMI) of the system and development of a Maintenance plan in line with the requirements of the target facility.
- Procurement of raw materials and components.
- Manufacturing, verification and validation of the proposed design – including any intermediate verification of subassembly components and the final Factory Acceptance Tests to validate the performance of the system in its target operational conditions. It is understood that, depending on the Supplier capabilities, FAT with D+ beam at full current and CW maybe be not feasible, and negotiations over the FAT criteria will be possible (for example performing tests with H+ beams).
- Shipment and delivery of the system to the target facility – either in Escúzar (Granada,

Spain), or Rokkasho (Aomori, Japan).
- On-site assembly, integration, check-out, individual system commissioning, and Site Acceptance Testing of the system at the target facility.
- Provision of support during the integrated commissioning and during beam operation.
- For each phase of the system lifecycle within the scope of the supply: preparation and production of detailed documentation and exhaustive data packages for review and acceptance with the participation of experts from F4E, IFMIF-DONES, QST and external experts.

The activities mentioned in the list above shall be implemented according to a strict and high-standard Project and Quality Management Plan (PQMP).

4 EXPECTED CAPABILITIES AND EXPERIENCE

The potential supplier is expected to have demonstrated experience in:

- Design, manufacturing, and operation of 2.45 GHz ECR ion sources (i.e., Microwave Discharge Ion Sources) and associated low-energy beam transfer line.
- Design, manufacturing, and operation of HV equipment and electrostatic ion optics systems.
- Design, manufacturing, and qualification of accelerator magnets.
- Design, manufacturing, and operation of ion beam diagnostics (e.g., emittance, current, beam profile, species fractions) and instrumentation (chopper).
- Design, manufacturing, and assembly of vacuum assemblies, with stringent leak tightness requirements at component level ($q < 1.10^{-11}$ mbar·l·s^{-1}).
- Beam dynamics and ion optics simulations of ion beams under strong space-charge effects.
- Design, software coding, manufacturing, and operation of control systems and EPICS-controls.
- Ideally, testing resources and capacities to perform the required Factory Acceptance Tests (FATs) of the assembled injector.
- Shipment, delivery, installation, and hardware commissioning (SAT) of the injector in its target location/facility.
- Manufacturing engineering and quality assurance and control activities required during manufacturing, assembly and testing.

5 MARKET SURVEY

To establish an optimum contract strategy, F4E needs to develop its understanding of the market with a comprehensive list of possible interested EU suppliers.

In the frame of the Market Survey, interested suppliers are invited to submit the requested information. This information will be visible to F4E only and will not be communicated to other parties, except if agreed upon by the respondent(s).

Please answer to the F4E Market Survey by clicking on this LINK.