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IFMIF accelerator facility

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Abstract

The International Fusion Materials Irradiation Facility (IFMIF) Accelerator Facility consists of two 125 mA, 40 MeV cw deuteron linacs which provide beams to the molten lithium Target Facility. The reference design for the Accelerator Facility has evolved through the several stages of the IFMIF program [IFMIF Conceptual Design Activity, Final Report, IFMIF-CDA Team (ed. by M. Martone), ENEA Frascati Report, RT/ERG/FUS/96/11, December 1996; IFMIF Conceptual Design Evaluation Report, IFMIF Team (ed. by A. Mslang), FZK report, FZKA 6199, January 1999; IFMIF KEP Report, IFMIF International Team, JAERI report, JAERI-Tech 2003–2005, March 2003]. A reference design report, with updated technical, cost and schedule information, is in preparation this year, and will be outlined in this paper.

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1. Introduction

IFMIF uses two Continuous Wave (CW) 175 MHz linear accelerators in parallel. Each provides a 125 mA, 40 MeV deuteron beam for a total of 250 mA on the target, as shown in Fig. 1. The performance requirements for the IFMIF accelerators are described in Table 1. Many aspects of the design are driven by the requirement for hands-on maintenance [1–3].

The accelerator reference design assumes utilization of conventional, room-temperature, RF linear accelerator (RF linac) technology. This technological approach is cautiously aggressive with respect to the current capabilities of RF linac technology and provides operational redundancy by allowing operation to continue at 125-mA when one or the other of the two accelerators is temporarily removed from service for repair. Each 125-mA accelerator is designed with sufficient de-rating but not with a significant upgrade capability.

Each IFMIF accelerator is a sequence of acceleration and beam transport stages. A CW140-mA deuteron beam is produced and extracted from an Electron Cyclotron Resonance (ECR) ion source at 95 keV. A Low-Energy-Beam-Transport (LEBT) section guides the deuteron beam from the source to an RFQ. The RFQ bunches the beam and accelerates 125 mA to 5 MeV. The RFQ output beam is injected through a Matching Section (MS) into a Room Temperature (RT), ramped-gradient Drift Tube Linac (DTL) of the conventional Alvarez type with post couplers, where it is accelerated to a final energy of 40 MeV. The RFQ and DTL accelerating structures are powered by an RF system

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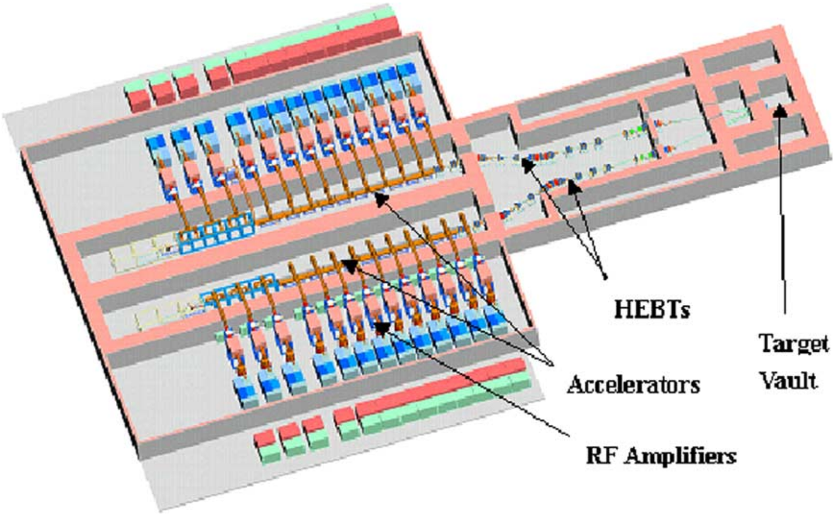

Fig. 1. Isometric view of the IFMIF accelerator facility.

Table 1
Top-level performance requirements for the IFMIF accelerator

Requirement	Specification	Detail/comment
Particle type	D^+	H_2^+ for testing (avoids activation)
Accelerator type	rf linac	175 MHz, 5 MeV RFQ followed by 5–40 MeV, 175 MHz DTL
Number of accelerators	2	Parallel operation
Output current	250 mA	125 mA per accelerator (independent operation)
Beam distribution	Rectangular flat top	20 cm horizontal × 5 cm vertical
Output energy	40 MeV	User requirement
Output energy dispersion	±0.5 MeV FWHM	Target requirement
Duty factor	CW	Pulsed tune-up and start-up
Availability	$\geqslant 88\%$	During scheduled operation
Maintainability	Hands-on	For accelerator components up to final bend in HEBT with local shielding as required; design not to preclude capability for remote maintenance
Design lifetime	30 years	

based upon use of the 175 MHz Diacrode high-power tube amplifier with a rated CW output power level of 1.0 MW. A total of 13 such amplifiers are needed for each accelerator. Operation of both the RFQ and the DTL at the same relatively low frequency is a conservative approach for delivering the high current deuteron beam with low beam loss in the accelerator. This will facilitate the achievement of hands-on maintainability without remote manipulators. The use of only one RF frequency also provides operational simplification as well as commonality of RF power components. The DTL output beam is directed to the neutron production target by a High Energy Beam Transport (HEBT). The HEBT, comprised of a series of magnetic optics elements, is required to tailor the beam to provide a flat rectangular beam profile on the flowing lithium target.

2. Status of accelerator systems

Extensive H^+ operational experience with the ECR ion source type has been obtained at CEA-Saclay (Fig. 2), with several very long runs of up to 1000 h accumulated duration, with availability of >95% achieved [4]. LANL has also achieved long-term reliable operation from a similar ECR source [5]. Operation with a pulsed D^+ beam at CEA Saclay has also been demonstrated showing that IFMIF beam performance requirements can be achieved [6].

The baseline approach for the Low Energy Beam Transport (LEBT) is a dual solenoid magnetic focus transport system with space charge compensation, small beam radius, small beam aberrations, and longitudinal space for beam diagnostics.

Fig. 2. SILHI ECR ion source at Saclay.

The RFQ for IFMIF will be ∼12.5 m, segmented into three longitudinal RF segments that are resonantly coupled through irises in intermediate end walls. This technique has been successfully proven on the LEDA RFQ and is being used for the CEA-Saclay IPHI RFQ now being constructed. As shown in Fig. 3, the RFQ is supported in a box structure that surrounds the cavity.

A short Matching Section (MS), having two single-cell buncher cavities and three quadrupole magnet sets, is provided between the RFQ and the DTL. The IFMIF DTL accelerates the beam from 5 to 40 MeV. The design is based upon conventional Alvarez technology with post couplers for field stabilization. It includes ten DTL tanks with a peak accelerating field of 1.75 MV/m. Using one RF power source per tank (the diacrode will deliver up to 1 MW out of the tube), requires 10 tanks.

The RF Power System (RFPS) uses a new kind of gridded tube called the diacrode, which overcomes the RF loss limitations of conventional tetrodes. Endurance tests with a 200 MHz TH 628 Diacrode have been performed during the IFMIF KEP, with over 1047 h at full cw power in the range of 1010–1030 kW, fully demonstrating the diacrode's capability to operate at IFMIF relevant conditions (200 MHz and 1 MW CW).

The HEBT conveys a 40 MeV, 125 mA beam some 55 m to the target and incorporates two twenty degree achromatic bends, FODO transport, a final focus and a final 9° achromatic bend followed by a 17 m drift to the target. On target, the requirement is for a beam uniformly illuminating a rectangle 20 cm in width by 5 cm in height. The beam footprint can be adjusted using different magnet settings; it should be possible, for example, to focus to a 10 × 5 cm footprint.

In developing a conceptual design for the IFMIF accelerator, the beam dynamics performance through the entire linac has been evaluated numerically. Minimizing deuterium beam loss and the resulting activation so that remote handling is not required for maintenance is a critical design requirement. Another primary goal is to meet the stringent requirements for the beam shape and current distribution on the target. Robust conceptual designs have been achieved. Techniques for simulation of the beam performance and beam loss activation modeling have been substantially refined for the IFMIF program. Error studies have been performed, indicating excellent end-to-end beam quality and achievable tolerance requirements (Fig. 4).

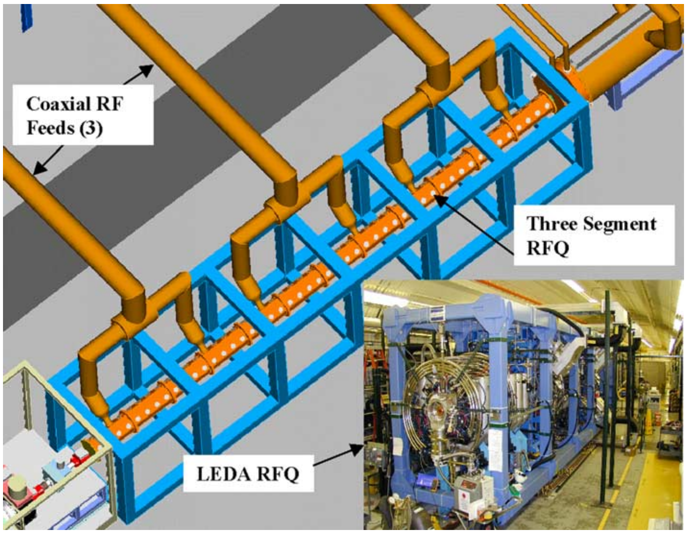

Fig. 3. Conceptual design of the IFMIF 12.5 m long RFQ compared to the LEDA RFQ.

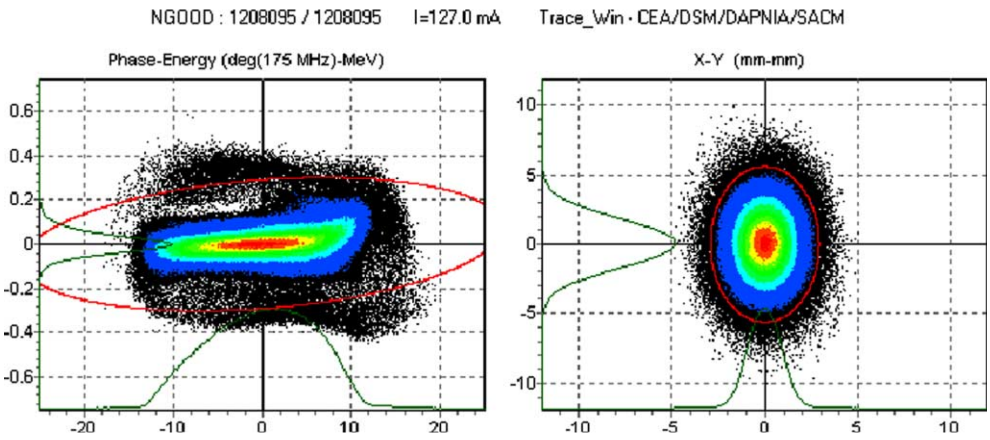

Fig. 4. Output distribution of the DTL at 40.3 MeV (with error simulation).

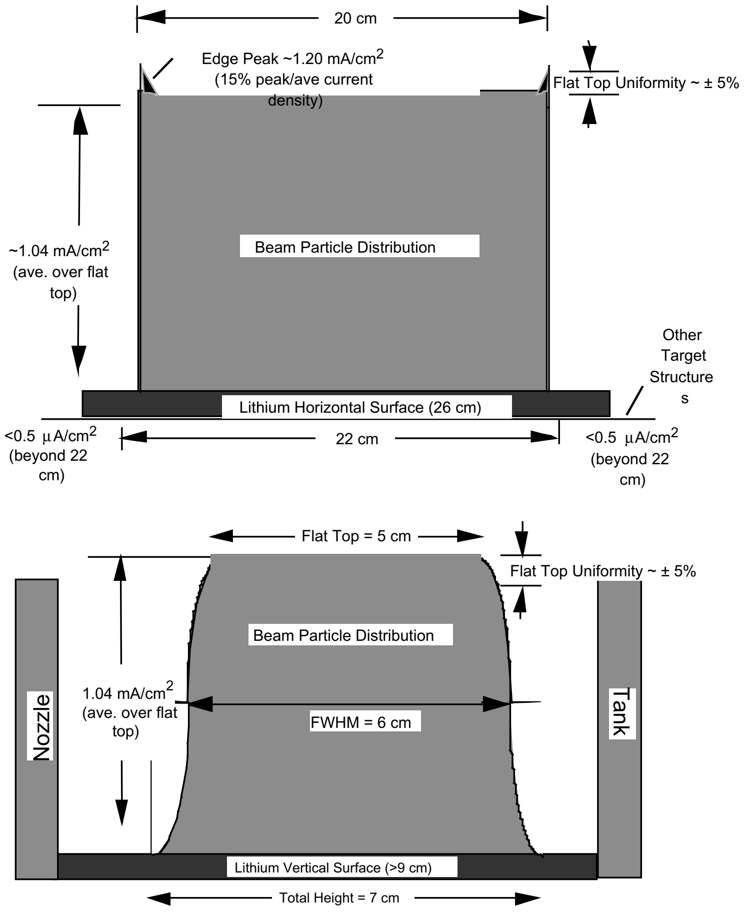

Fig. 5. Beam profile requirements; top: horizontal, bottom: vertical.

3. Interfaces and RAM

The angle at which the beam intercepts the target represents a compromise between maximizing the high flux volume in the test cell (favors smaller angle), and minimizing machine activation due to neutron back-streaming into the active beamline components (favors larger angle). A 9° beam-bending half-angle is acceptable.

In normal operation, the footprint of each of the two 125-mA beams are 5 cm by 20 cm rectangles with the long side of the rectangle oriented in the horizontal direction. On projection to the target, the two beams will be fully overlapped in the same area, thus doubling the current and flux on target. The beam footprints must be tailored in both the vertical and horizontal directions and the beam flux is required to be approximately uniform across the flat top of the beam (Fig. 5). The beam intensity in the vertical direction must be tapered over about 1 cm above and below the beam to avoid shocking the lithium flow with a sudden step increase in the beam-deposited power density.

The accelerator system and its components shall be designed to minimize the system's downtime and to assure minimum availability of 88% during normal operation of each accelerator separately. It is assumed that both accelerators are always directing the beam to the target. Failure of one of the accelerators does not constitute an unavailability event for the IFMIF facility.

4. Next steps

The IFMIF room-temperature accelerator technology reference design is at an advanced conceptual level, with proof-of-principle operation already demonstrated of the principal injector, RFQ and rf power amplifier subsystems. With an experienced team, the accelerator could proceed immediately to a construction project. In the planned Engineering Validation and Engineering Design Activity (EVEDA), preliminary design will be completed and beam validation tests with an IFMIF qualified injector, LEBT, RFQ transport cavity and diacrode rf amplifier are planned.

As accelerator technology continuing develops, new techniques may become advantageous to IFMIF before the construction project begins. Evaluation of these also helps attract young persons to the project. During the past decade, the technical and operational advantages of superconducting RF linacs have made them the technology of choice for many electron and heavy-ion beam applications. A similar set of advantages is currently being considered for the next generation of high-intensity ion linacs for tritium production, transmutation facilities and spallation neutron sources. This technology base, including prototype tests planned by various institutions during the next five years, indicate that, after extensive study and prototyping, a superconducting linac could be an alternative for 8–40 MeV portion of the IFMIF accelerator by the time it is actually built.

5. Conclusions

Refs. [1–3] report on earlier phases of the IFMIF Accelerator facility R&D and design work. The IFMIF Accelerator Facility Conceptual Reference Design is fully ready for progression into the EVEDA and construction phases of the IFMIF project.

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