International Standard

ISO 19991

First edition
2026-08

Fusion technology — Experimental magnetic confinement fusion facilities — Supersonic molecular beam injection fuelling technique for fusion devices

Technologie pour installations de fusion — Installations expérimentales de fusion par confinement magnétique — Technique d'alimentation en combustible par faisceau moléculaire supersonique pour machines de fusion

Reference number
ISO 19991:2026(en)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

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Introduction

The plasma fuelling system is integral to magnetic confinement fusion devices, including DEMO and other fusion facilities. Supersonic molecular beam injection (SMBI) is a key candidate for fuel injection, offering high efficiency with reduced wall retention of gases. SMBI has demonstrated good fuelling efficiency in many medium and small-sized devices, with higher efficiency compared to conventional methods. Although its fuelling efficiency may attenuate in large-scale equipment, long-pulse discharges in superconducting devices have shown that the good directionality of SMBI can significantly reduce wall retention[1]. This reduction in wall retention is particularly significant for the utilization of tritium in future fusion facilities.

Unlike conventional gas fuelling systems that utilize gas diffusion and are susceptible to wall retention, leading to unpredictable plasma density changes and possible facility shutdown, SMBI, with its high beam velocity, effectively mitigates such risks. Comparing to fuel pellet injection, SMBI has lower fuelling efficiency, but provides significant system stability. Currently, tritium pellet technology is not yet sufficiently mature. Therefore, as technology advances, SMBI can be considered as a complementary component of an effective fuelling system for future fusion facilities, alongside pellet injection.

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Fusion technology — Experimental magnetic confinement fusion facilities — Supersonic molecular beam injection fuelling technique for fusion devices

1 Scope

This document specifies the methods and the requirements for the supersonic molecular beam injection (SMBI) fuelling technique used in experimental magnetic confinement fusion facilities. It outlines the SMBI system components, specific requirements, and inspection procedures to ensure the effective and controlled injection of plasma fuel into fusion devices such as international thermonuclear experimental reactor and demonstration power plant.

This document applies to the formation of supersonic molecular beam (SMB) and usage of the SMBI technique on the fusion devices, including the specification of gas pressure adjustment, beam characteristics and injection rate requirements, as well as the procedures for verifying these parameters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16646, *Fusion installations — Criteria for the design and operation of confinement and ventilation systems of tritium fusion facilities and fusion fuel handling facilities*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

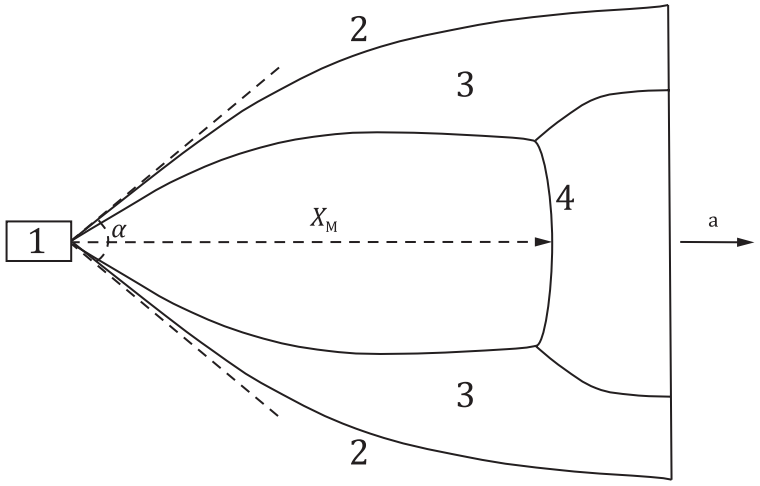
— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
supersonic molecular beam injection
SMBI
method of fuelling by generating a supersonic molecular beam through the adiabatic expansion of gas into a vacuum, maintained by a sufficient pressure differential across a Laval or Laval-like nozzle

3.1.2
beam structure
structure of the beam injected by the *SMBI* (3.1.1) system, which features a quiet zone as well as a Mach disk and other characteristics

Note 1 to entry: Figure 1 shows the beam structure.

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Key

1	injector
2	jet boundary
3	barrel shock
4	Mach disk shock
α	divergence angle
X_M	effective distance
a	Flow direction.

Figure 1 — Schematic diagram of the beam structure

3.1.3
divergence angle
α
angle at the injector outlet between the two tangents to the boundary of the beam's central cross-section

3.1.4
effective distance
X_M
length of quiet zone, expressed as the distance from the injector outlet to the Mach disk along the central axis of the beam

3.1.5
working distance
L_w
distance measured along the central axis of the beam, extending from the injector outlet to the boundary of the working chamber's inner wall

3.1.6
time-of-flight
TOF
time interval for beam particles to travel from the injector outlet to the measurement location

3.1.7
beam velocity
maximum velocity of the beam measured by the *time-of-flight* (3.1.6) method

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3.1.8
ideal beam velocity
v_m
theoretical maximum velocity that the beam can reach when, under ideal conditions, the gas's entire internal energy is completely converted into directed kinetic energy, as described by Formula (1):

$$v_m = \sqrt{\frac{2\gamma RT}{(\gamma - 1)M}} \quad (1)$$

3.1.9
standard sound speed
sound speed of a specific gas (H_2, D_2, T_2, N_2, Ne, Ar, etc.) at 288,15 K and 1,013 × 10^5 Pa

3.1.10
mean free path
λ
average distance a gas particle travels between successive collisions with other particles

3.1.11
gas source pressure
p_0
pressure of the gas supply at the injector inlet

3.1.12
background pressure
p_b
pressure of the environment surrounding the beam downstream of the injector outlet

3.1.13
maximum permissible working pressure
p_{max}
lowest value among the maximum allowable pressures of individual components in the gas circuit including valve, gas pipe and pressure vessel

3.1.14
safety gas pressure ratio
r_0
ratio of the *maximum permissible working pressure* (3.1.13) to the normal operating *gas source pressure* (3.1.11)

3.1.15
injection rate
I_{inj}
number of gas particles flowing through the injector outlet per second

3.2 Abbreviations

SMBI	supersonic molecular beam injection
TOF	time-of-flight

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