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# MULTIPURPOSE VACUUM ACCIDENT SCENARIOS (MUVACAS) PROTOTYPE FOR THE IFMIF-DONES LINEAR ACCELERATOR*

A. Sabogal†, C. Torregrosa-Martín, D. Rodríguez, Universidad de Granada, Granada, Spain
D. Jimenez-Rey, F. Martin-Fuertes, CIEMAT, Madrid, Spain
J. C. Marugán, Empresarios Agrupados, Madrid, Spain
M. Ferreira, European Spallation Source, Lund, Sweden
P. Cara, Fusion for Energy, Barcelona, Spain
I. Podadera, A. Ibarra, IFMIF-DONES, Granada, Spain
A. Delgado, U. Ruiz de Gopegui, TEKNIKER, Éibar, Spain



*Abstract*

The present study provides a technical overview of the MuVacAS setup, which has been developed with the aim of recreating vacuum-related accidental scenarios that may occur in the IFMIF-DONES facility. The ultimate goal is to evaluate the effectiveness of safety-credited components in mitigating these scenarios, which is directly related to the study of shock-wave generation and propagation in loss of vacuum accidents. The paper provides a description of the main components of the setup and outlines preliminary measurements obtained during the initial prototyping phases. The forthcoming experimental campaigns are expected to yield valuable insights into the effectiveness of the proposed mitigation measures to support the design of the safety systems of the IFMIF-DONES facility.

## INTRODUCTION

IFMIF-DONES (*International Fusion Materials Irradiation Facility-Demo Oriented NEutron Source*) is a key facility in the EUROfusion roadmap for studying and licensing materials for future fusion reactors. It will be a unique neutron fusion-like irradiation facility equipped with a linear particle accelerator impinging an intense deuteron beam (125 mA, 40 MeV) onto a liquid lithium target [1].

From a safety point of view, one of the most relevant particularities of the IFMIF-DONES LINAC is the lack of physical separation between the High Energy Beam Transport line (HEBT) and the Target Vacuum Chamber (TVC), in which the liquid Li is circulating. The reason is that in several postulated Reference Accidental Scenarios RAS [2] comprising Loss of Vacuum Accidents (LOVAs), the following events could take place: (i) The beam duct could serve as a transport line and lead to water/air contact with the liquid lithium of the target, with the risk of an eventual exothermic reaction [3]. (ii) The rupture or vaporization of part of the TVC could lead to mobilization of the activated material upstream the beam duct to the HEBT and the accelerator vault.

Several experimental studies have been found in the literature related to vacuum loss events in accelerator facilities, such as sudden air inrush [4–8] and water leaks [9, 10], and how they can be mitigated. The usual mitigation mechanism relied on Fast Isolation Valves (FIVs), as discussed in [11–14], which have closing times of tens of miliseconds. Whereas these studies provide essential insights, new experimental campaigns are necessary to be applied to IFMIF-DONES. The available results of propagation speeds are scarce, strongly depend on the initial conditions and the particular geometry of each accelerator. In addition, an assessment and characterization of the FIV trigger and actuation mechanisms are very convenient for the IFMIF-DONES licensing process.

Considering the aforementioned points, two principal objectives of the MuVacAS setup are defined: (i) To study vacuum loss events along the HEBT+TVC due to leaks or abrupt inlets of water or air, and (ii) To serve as a laboratory to test and validate relevant vacuum components that will be installed in IFMIF-DONES.

## EXPERIMENTAL SETUP

The MuVacAS setup recreates as reasonably as possible the characteristics and specifications of the vacuum chambers of the IFMIF-DONES HEBT+TVC [15], such as geometry, material, and differential pressure system. In addition, it includes three experimental modules to recreate the identified scenarios and fast acquisition systems to record and characterize their effects. The setup also includes the integration of FIVs as mitigation mechanisms and vacuum component prototypes designed for the IFMIF-DONES LIPAC.

The total length of MuVacAS is 28 m, in comparison to the 49 m of the HEBT+TVC chambers, due to space limitations. The setup is composed by two main zones (A, B) as is shown in Fig. 1. The zone A is scaled down with respect to IFMIF-DONES (24 m vs 35 m). Whereas the zone B keeps a 1:1 longitudinal and transversal scale (14 m), since the area of the TVC and last meters of the HEBT (downstream the FIV) is the one of greatest interest in the accidental scenarios.

A differential vacuum pressure system is also implemented in MuVacAS to prototype the one foreseen in IFMIF-

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† andersonsabogal@ugr.es

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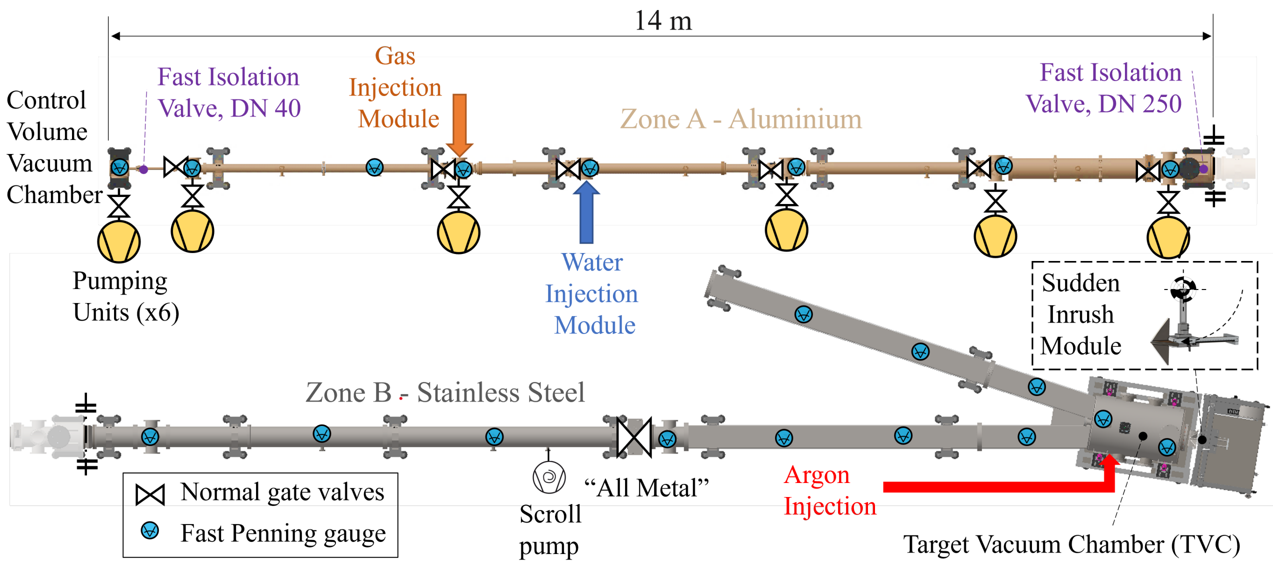


Figure 1: Longitudinal distribution of the MuVacAS setup. The total length is 28 m, divided in two zones of 14 m.

DONES to prevent Li boiling in the TVC [16]. This implies that one end requires a vacuum pressure of $10^{-8}$ mbar (to recreate the cryomodule connection), while the pressure in the TVC shall be kept within the range of $10^{-4}$ to $10^{-5}$ mbar by means of a controlled Ar injection.

### *Experimental Modules*

**Sudden Gas Inrush Module:** Its purpose is to recreate sudden gas inrushes in case of an abrupt rupture in the TVC, as well as eventual duct seizures upstream of the DN 250 FIV. The sudden gas inrush module is composed of a pendulum with a spike that is dropped and perforates an aluminium foil (0.5 mm thickness) clamped on a vacuum flange (CF 275 DN) in the TVC, which has a ∅ 600 mm diameter. This foil window and pendulum setup could be also integrated in other flange along the line.

**Gas Injection Module:** Its purpose is to recreate small leaks of different gases such as air, $N_2$, He, and Ar. The module uses an intermediate gas chamber connected to the vacuum line through a regulated leak valve and a fast solenoid electro-valve that can open and close in range of tens milliseconds. The system is able to measure the mass rate and total amount of injected gas, which can be set in the range from 0.01 g/s to 40 g/s. This flow corresponds to leaks with a hole size of 0.1 mm to 1.0 cm approximately.

**Water Injection Module:** It injects water at a point in the line, being able to recreate from a small water leak (from 0.1 ml/s to 75 ml/s) to an abrupt rupture (2 l/s) in a pipe. It represents leaks from HEBT scrapers cooling circuits.

### *Vacuum Loss Mitigation System*

The Fast Isolation Valves (FIVs) are the main vacuum loss mitigation element of the MuVacAS setup, which main objective is to validate this component. The setup will be equipped with two FIVs located in the similar positions as in the IFMIF-DONES LINAC (Fig 1). In such design, one DN 40 FIV is located downstream to the cryomodule, and at the beginning of the HEBT, and the other DN 250 FIV is located 14 m upstream the TVC. The triggering system of these valves in MuVacAS consists of "Glow Discharge" gauges type for fine vacuum ($10^{-2}$ mbar to 1 bar), and Penning gauges (IKR 070) for high vacuum ($10^{-8}$ mbar to $10^{-3}$ mbar). These gauges have a response time of 1 ms and 2 ms respectively. The FIVs, gauges, and control system are provided by the company VAT.

### *Instrumentation*

The instrumentation is equipped with two different types of acquisition systems: conventional and fast acquisition. In the first group, there are pressure gauges (cold-cathode and Pirani) and residual gas analyzer. They are used to check the general status of MuVacAS. In the second group, there are pressure gauges, triggers of the experimental modules (electric contact, encoder), accelerometers, strain gauges, and one synchronization system betweem them.

The fast acquisition instrumentation is mainly used to measure the gas front propagation and the potential change of its speed depending on the variation of diameter along the vacuum line. For this purpose, 18 pressure gauges (IKR 050 *Pffeifer*) are distributed along the line (Fig. 1), and are connected to the controller TPG 500 (*Pffeifer*). These data are acquired at 20 kHz with a National Instrument cDAQ-9220.

### *Differential Pressure System*

This system is designed to maintain a vacuum pressure gradient along the MuVacAS line. The precise control of Argon injection rates ensures that the required pressure

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conditions are maintained. The estimated flow rates ranging from $7 \times 10^{-4}$ mbar·l/s (0.04 sccm for target pressure of $10^{-5}$ mbar) to $4.5 \times 10^{-3}$ mbar·l/s (0.3 sccm for target pressure of $10^{-4}$ mbar). The argon injection control (in IFMIF-DONES) will not have pressure readings close to the TVC, therefore this proposed system will allow the evaluation of different control strategies.

## FORESEEN EXPERIMENTAL CAMPAIGNS

The main campaigns envisaged in broad terms are:

I Study of shock-wave propagation in vacuum (phenomenological point of view).

II Study of vacuum loss in the TVC in form of sudden inrushes or leaks of air (with and without mitigation).

III Study of vacuum loss in the beam duct upstream of the FIV in the form of sudden inrushes or leaks of air (with and without mitigation).

IV Study of the cooling water inlets in beam duct, in form of sudden inrushes or leaks (with and without mitigation).

V Testing the differential pressure system along the HEBT+TVC (e.g. changing the condition of injection of Argon and evaluating the final arrangements of the pressure gauges).

VI Testing of prototypes of IFMIF-DONES HEBT vacuum components (e.g. aluminum chambers, flanges, pumping and measurement system, integrating remote handling connection).

## FIRST EXPERIMENTAL AND SIMULATION RESULTS

A first setup consisting in a 3 m long vacuum pipeline of ∅ 300 mm diameter has been built to validate some aspects of the MuVacAS design, such as the fast acquisition instrumentation and the sudden air inrush mechanism. Preliminary results from these tests show that the foil window was broken correctly with the pendulum and pressure rise was captured using the fast acquisition configuration presented above. The front wave propagation speed of air inrushes in vacuum has been estimated between using the relative measurement of pressure sensors, obtaining a maximum value of 720 m/s for an initial vacuum of $2.6 \times 10^{-6}$ mbar.

### *Simulation*

A first transient simulation approach of a sudden air inrush has been carried out using Navier Stokes formulation in Computational Fluid Dynamics (CFD) to increase the understanding of wavefront propagation in vacuum. A pressure of 0.1 mbar is used to represent vacuum, due to the minimum pressure value required for fulfilling the continuous medium hypothesis in CFD. The ideal gas hypothesis is used, and the gas is considered to be inviscid. The higher-order ROE-MUSCL scheme is used for the discretization and the first-order Euler scheme is used for the transient terms.

The geometry proposed represents the dimension of a 250 mm diameter pipe (similar to the duct diameter in MuVacAS). A map of velocities at 1.0 ms after the rupture is presented in Fig.2 obtaining a maximum velocity of the order of 1200 m/s.

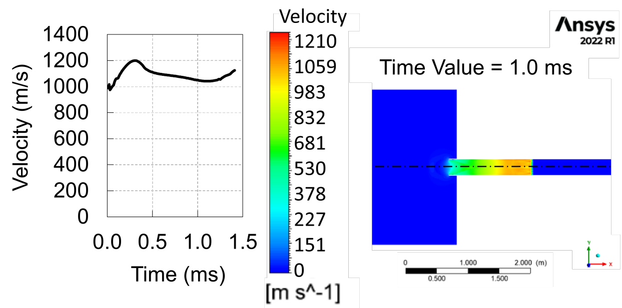


Figure 2: Maximum wave propagation velocity at the axis line over the time, and its velocity profile at 1.0 ms.

## CONCLUSION

MuVacAS will be a vacuum setup to test key technologies of IFMIF-DONES. The plan is to start experimental campaigns in Q2 of 2024. Nevertheless, some preliminary results are already available. First experimental estimations suggest inrushes propagation speeds as high as 720 m/s. CFD simulations have estimated a propagation velocity reaching values of 1200 m/s. The discrepancy is attributed to the strong assumptions of the modeling, such as instantaneous rupture and differences in the geometry, among others. These simulations will be useful for the understanding of the phenomena and interpreting results during experimental campaigns.

## ACKNOWLEDGEMENTS

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