

SSRIP ACTIVITY REPORT 2025

D. Alesini (Resp.), F. Cardelli (Laur.), S. Cantarella (Laur.), G. Catuscelli (Laur.), E. Di Pasquale (Laur.), L. Faillace (Laur.), G. Franzini (Laur.), R. Gargana (Laur.), T. Grimaldi (Laur.), G. Latini (Laur.), A. Liedl (Laur.), A. Michelotti (Laur.), P. Piersanti (Laur.), S. Pioli (Laur.), D. Quartullo (Laur.), R. Ricci (Laur.), U. Rotundo (Laur.), B. Serenellini (Laur.), A. Stecchi (Laur.), P. Tuscano (Laur.), A. Vannozi (Laur.), S. Vescovi (Laur.), G. Zachariadis (Laur.)

1 Introduction

The Scalable System for Radioisotope Production (SSRIP) is a new accelerator-based facility under development at IFIN-HH (Măgurele, Romania). The project is coordinated by INFN-LNF and hosted within the existing ELI-NP infrastructure, in accordance with Research Contract No. 4-1 dated 29.02.2024, signed by INFN and IFIN-HH. This compact linear accelerator is designed as a demonstrator system capable of producing high-brightness electron beams for radioisotope generation, capable of producing 100 pC bunches at 100 MeV and a repetition rate of 10 Hz. The SSRIP accelerator consists of five modules. The schematic layout of the modules is shown in Fig.1. The first three modules (M1–M3) incorporate the S-band photo-gun, the laser injection chamber, the emittance compensation solenoids, and the 3 m long S-band traveling-wave accelerating structures. The fourth module (M4) hosts the 1.8 m long C-band accelerating structure, together with focusing quadrupoles for matching to the experimental beamline and a dipole spectrometer for energy measurements. The fifth module (M4A) includes the final diagnostic chamber and the beam dump.

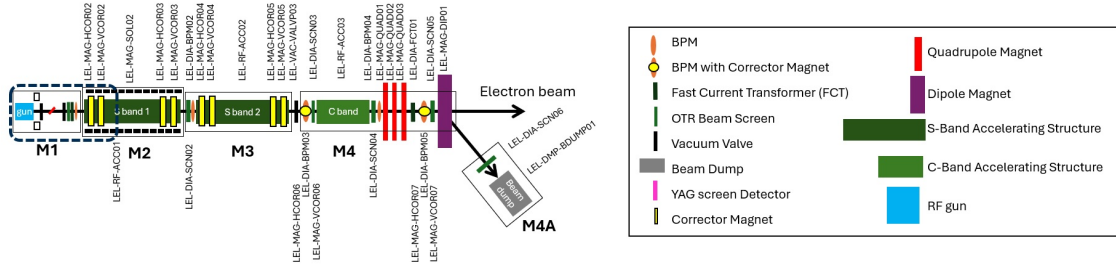


Figure 1: Schematic layout of the SSRIP LINAC.

The accelerator is equipped with six diagnostic screen chambers, each provided with pumping systems and vacuum gauges, five stripline BPMs, seven horizontal and vertical corrector magnets for beam steering, and two integrating current transformers for beam charge measurements. The RF power system is composed of four independent RF stations: three operating at 2856 MHz (S-band) and one at 5712 MHz (C-band). Each station includes a solid-state pulsed modulator and a high-power klystron amplifier. The 3D CAD model of the overall facility is given in Fig. 2. The linear accelerator is installed in the experimental area (AB1), the RF power sources are installed on the ROOF, the control room and the clean room for the photocathode are installed in the ANNEX area, while racks are installed in the CORRIDOR area and in the ROOF. The LINAC modules have been installed, connected and pre-aligned in 2024. The activities carried out in 2025

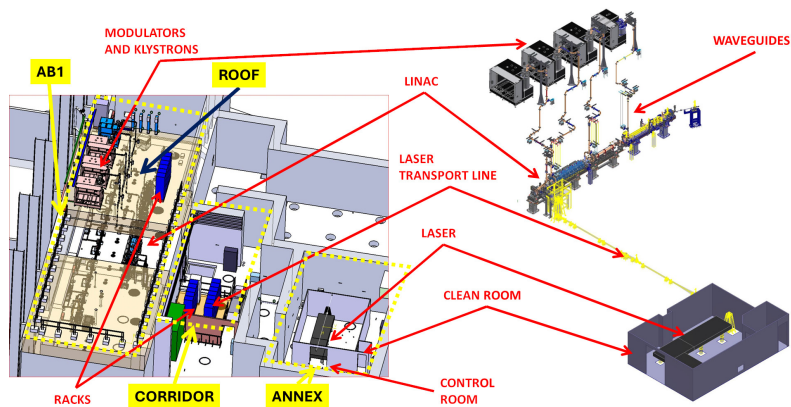


Figure 2: 3D cad model of the SSRIP project.

were mainly focused on high-power testing of the RF power sources, waveguide installation, control system integration, cabling and rack installation.

2 Installation and High-power testing of the RF power sources

As reported in the 3D layout of Fig.2, the RF power system of SSRIP is composed of four independent RF stations: three operating at 2856 MHz (S-band) and one at 5712 MHz (C-band). Each station includes a solid-state pulsed modulator and a high-power klystron amplifier. The modulators, supplied by ScandiNova, are capable of generating high-voltage pulses with precise temporal control, optimized for the drive requirements of the respective klystrons (all produced by CANON). The power and repetition rate requirements for the SSRIP project are 30 MW, 1 μ s, and 10 Hz for all S-band klystrons, and 30 MW, 0.5 μ s, and 10 Hz for the C-band klystron.

2.1 Modulator and klystron installation

The modulators were positioned in their nominal locations, and the klystrons were installed inside the modulators, connecting the output waveguides to a high-power RF load. The procedure has been quite complex and included:

1. Mechanical positioning and alignment of the modulators
2. Internal assembly verification
3. Solenoid installation
4. Insertion of the klystrons into the solenoids
5. Filling of the tanks with oil
6. Output waveguide and RF load connections
7. Cooling circuit connections
8. Klystron cathode filaments conditioning

Pictures of the klystron installation in the modulator and vacuum test of the high power RF load are given as example, in Fig.3



Figure 3: *Klystron installation in the modulator (left); vacuum test of the high power rf load installed at the klystron waveguide output (right).*

2.2 Diode Mode testing and klystron conditioning

Initial tests have been performed in diode mode (no RF drive) by progressively increasing the modulator charge voltages. High-voltage pulse signals have been monitored to verify the correct timing, flatness, and rise time as well as identify any anomalies such as breakdowns or arc events. The beam currents have been measured via oil-immersed current transformers. Voltage levels were raised gradually, with close monitoring of the vacuum and signals. Occasional breakdowns or arcs triggered interlocks, halting the test. These procedures have been repeated until full operating parameters, as defined in the klystron datasheet, have been achieved. Interlock thresholds have been also validated during this phase.

2.3 Installation of the RF Test Setup and High-Power rf test results

To carry out the high-power RF tests, the outputs of the driver amplifiers (integrated within the modulators) were connected to the inputs of the klystrons via RF coaxial cables, and a pulsed RF signal was provided at the driver inputs. The pulsed RF signal was generated using an HP E4432B signal generator, capable of producing variable-amplitude RF pulses in the milliwatt range. This signal was fed into the input of the solid-state RF amplifier serving as the klystron driver. The pulse repetition rate and pulse duration were set using a digital delay pulse generator, which also provided the TTL trigger signal for the modulator and the TTL enable signal for the driver amplifier. The high-power RF signals at the output of the klystron (forward (FWD) and reflected (RFL) signals) were made available via the probes of the directional coupler installed on the output waveguide. The output power level was gradually increased, together with the RF pulse length, until the nominal operating parameters were reached. Throughout the test, the vacuum levels inside both the klystron and the output waveguide were carefully monitored, along with the RF signals, to ensure stable and safe operation. Once nominal conditions were reached, the system was operated at nominal parameters in order to evaluate thermal behavior and overall system stability. The cooling circuits and vacuum levels were continuously monitored. Images acquired from the power meter and the oscilloscope, showing the modulator pulses (voltage and current) and the RF pulse at the klystron output are, as an example, given in Fig. 4. For all four RF stations,

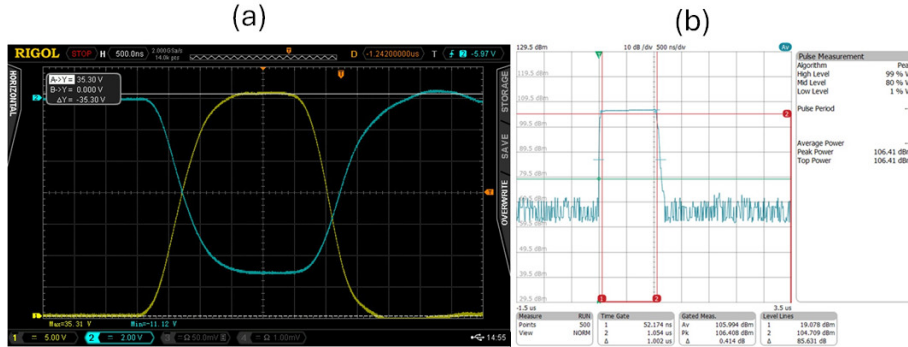


Figure 4: *S* band *n. 1*: (a) Voltage applied at the klystron cathode (cyan), klystron beam current (yellow) read with the oscilloscope during the test of the *S*-band RF Source 1; (b) RF Forward pulse read on the directional coupler with the power meter on the *S*-band.

the required SSRIP power specifications were exceeded, with each source achieving a peak output power of 40 MW with a pulse duration of 1 μ s.

3 Waveguide installation

Another fundamental activity carried out in 2025 was the installation of the waveguide network connecting the linear accelerator to the klystrons. This activity was performed both inside the experimental area AB1 and on the roof. Mobile lifting platforms were used to perform this installation. The components installed in the waveguide system include straight and curved waveguide sections, pumping units, directional couplers, ceramic RF windows and an isolator in the RF gun transmission line. The waveguides on the roof connected to the klystrons are shown in Fig. 5(b), while the linear accelerator and the waveguide system installed in AB1 are shown in Fig. 5(a). The entire waveguide network was leak-tested using a helium leak detector down to a sensitivity of 5×10^{-10} mbar L/s. After the leak test, the system was evacuated using turbomolecular pumps, followed by the activation of the ion pump system.

4 Systems Integration, cabling and rack installation

In 2025, the integration activities of several systems were completed. These included the installation of all racks, as well as the routing and termination of all cables connecting the rack-mounted equipment to the units distributed along the linear accelerator, the waveguides, and the modulators. The racks are located both in the corridor area and on the roof (see Fig.6). They house all the electronic equipment associated with the accelerator systems, including the control system, network infrastructure, LLRF system, beam diagnostics, machine protection system, vacuum system, magnet power supplies, and timing system. All installed devices and cables were tested in preparation for beam commissioning.

The control system was also successfully installed and commissioned, and control functionalities for all subsystems were implemented and validated. The system is based on an EPICS architecture, with operator interfaces implemented using Phoebus. The IOCs (Input/Output Controllers) are deployed as virtual instances orchestrated through Kubernetes.

The control room, located in the "Annex" area, was set up with six consoles with full access to the control system (see Fig.7).

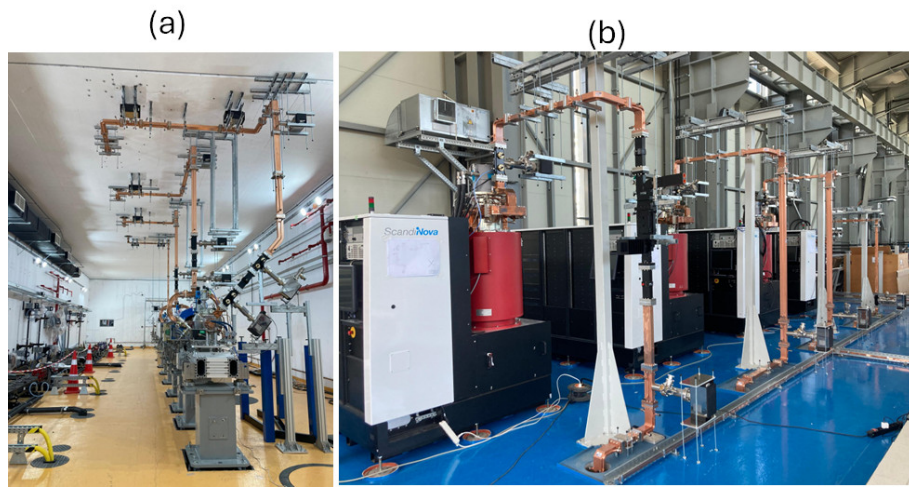


Figure 5: *S band n. 1: (a) Linear accelerator and waveguides installed in AB1; (b) Waveguides on the roof connected to the klystrons.*



Figure 6: *Racks in the "Corridor" area (left) and "roof" area (right).*

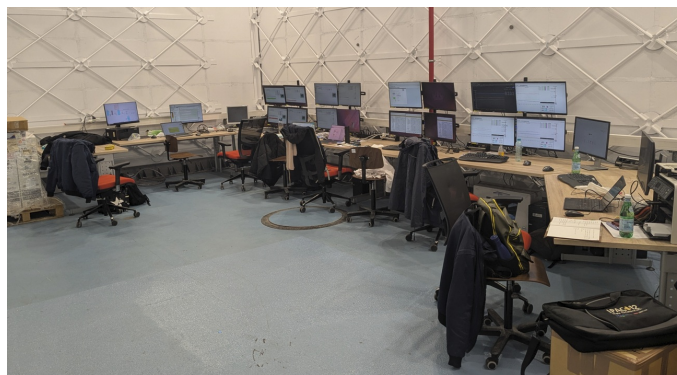


Figure 7: *Control room with six consoles in the "Annex" area .*