ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-TUP02

AN IRRADIATION TEST FACILITY AT INFN-LNS: STATUS AND PERSPECTIVES

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Abstract

In the framework of ASIF "ASI Supported Irradiation Facilities" project some beamlines available at Laboratori Nazionali del Sud - Istituto Nazionale di Fisica Nucleare (LNS-INFN) have been dedicated to irradiation tests. These beamlines have been recently upgraded in order to meet the European Space Agency specifications about radiation hardness testing of devices suitable for space applications. The Superconducting Cyclotron K800 installed at LNS can provide protons up to 80 MeV for integrated dose tests and a number of heavy ion beams for Single Event Effect studies. The beamlines are equipped with detectors that allow beam diagnostic in term of spatial uniformity, purity and energy measurements, including on-line monitoring of flux and fluence received by the device under test. Upgrades activities are now ongoing, especially to broaden up the number of available beams, both in terms of ion species and energy, to optimize the switching times from one beam to another. The paper will present an overview of the developed facility, which will take benefit of the ongoing SERSE (the superconducting ECR ion source) revamping: the new gas-box system, plasma chamber and controls system are ready to be installed within autumn 2018.

INTRODUCTION

Among the research activity carried out at at Laboratori Nazionali del Sud of the Istituto Nazionale di Fisica Nucleare (LNS - INFN) based in Catania, a part of the beam time is dedicated to irradiation tests of electronic devices and detectors as well as of cells and biological samples [1].

Irradiation activity takes advantage of a large number of ions that can be accelerated by the 15 MV Tandem Van de Graaff and by the K800 Superconducting Cyclotron (CS). In particular, this last accelerator coupled with the two high performance ECR sources operating at LNS-INFN, that is SERSE and CAESAR, can provide ion beams in a very wide range of mass, from hydrogen to lead, and energy up to 80 MeV/amu.

Two beamlines, Zero-Degree (ZD) and CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate) are equipped for irradiation tests. CATANA beamline is mainly used for hadron therapy purpose with proton beams [2,3], while the ZD beamline can be adapted to perform different kind of irradiation tests using various ion beams provided by the CS, as well as by the Tandem accelerator. Moreover, the ZD beamline is equipped for both in-air and in-vacuum radiation hardness testing.

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Recently, in the framework of ASIF "ASI Supported Irradiation Facilities" project, these beamlines and in particular the ZD one have been upgraded in order to meet the European Space Agency (ESA) ESCC No. 25100 specifications about radiation hardness testing of devices suitable for space applications.

THE IRRADIATION FACILITY

Available beams for irradiation at LNS

According to the ASIF project requirements, a list of beams and a number of diagnostic devices have been defined and developed in order to perform irradiation with protons for integrated dose tests and with heavy ion beams for Single Event Effect (SEE) studies.

In particular, for integrated dose tests proton beams are available according to the energies and the flux shown in Table 1. If necessary, energy can be reduced by means of a stack of plastic degraders.

Table 1: Proton Beams: Energies and Flux

Energy *MeV/amu*		Flux ions $cm^{-2}s^{-1}$
10 - 26	from Tandem	up to 10^7
60, 80	from CS*	

SEE tests are performed by using mainly ^{20}Ne, ^{40}Ar, ^{84}Kr, ^{129}Xe beams at 20 MeV/amu, corresponding Linear Energy Transfer (LET) and range in silicon, calculated with SRIM2008, are reported in Table 2. The selected ions provide, at the moment, the best compromise in reducing the time required for beam change (4-8 hours) and in providing a large range of LET values. In in-air irradiation, air is used to reduce beam energy, this provides several LET points up to 60 MeV/(mg/cm^2) allowing to measure the cross-section (number of events per unit of fluence) from the threshold to the saturation value.

Table 2: Ions Available For SEE Test.

Ion	Energy *MeV/amu*	LET^{SRIM} *MeV/(mg/cm^2)*	Range^{SRIM} *µm*
^{20}Ne	20	1.996	504.54
^{40}Ar	20	6.266	356.49
^{84}Kr	20	21.59	245.12
^{129}Xe	20	44.05	204.46

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Beam Diagnostic

Ion beams provided for irradiation test must be analysed in order to verify the beam energy and purity at the device under test (DUT) position, and to measure beam uniformity, flux and fluence.

In details, beam energy and purity are guaranteed by the design of the accelerators and beam transportation devices. Moreover, a two stages ΔE-E detector is available at the DUT position to provide a further check energy and purity. For proton and light ion beams (from Z=1 to Z=8) accurate energy measurement are accomplished through the measurement of the Bragg-peak in a water phantom. In particular, depth-dose measurements are obtained by using a Markus chamber (Mod 3002) inserted in the water phantom with a spatial resolution of 10 um.

Regarding spatial uniformity, magnetic elements distributed along the beam line and a set of collimators with different diameters (Fig. 1) provide a beam spot size on DUT from few mm to about 2 cm, according to the user's requests, and uniformity of ± 10% over the DUT irradiated area.

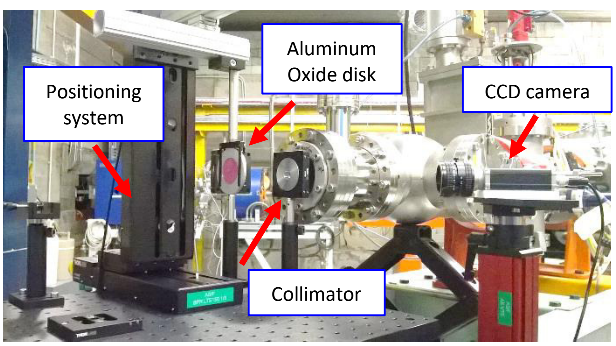

Figure 1: Experimental setup: collimator, aluminium oxide disk and CCD camera for beam profiling and positioning system for DUT placement.

Beam profile is measured acquiring, by means of a CCD camera (Fig. 1), the light emitted by an Aluminum Oxide disk (Fig. 1) when it is hit by the beam. Then, a software allows the on-line analysis of the acquired signal making possible the beam tuning in order to reach the required size and uniformity. In Fig. 2 and Fig. 3 examples of experimental transversal dose profile (with respect to the x and y axes) are shown for the proton and ^{84}Kr beams respectively. Dashed lines indicate the DUT size.

Flux and Fluence measurement are performed on-line by means of a thin plastic scintillator detector EJ-212 Scionix (50,100 μm) (Fig. 4). The thickness is selected such that the scintillator is transparent to the beam. Signal produced by scintillator are sent to a discriminator, converted in TTL standard and sent to a counter. The facility allows to measure fluxes up to 10^6 ions cm^{-2} s^{-1}. Beam is stopped when the required fluence is reached.

For proton irradiations the fluence can be measured using a Monitor Chamber, designed and built at LNS, allowing to measure up to 10^8 ions cm^{-2} s^{-1}.

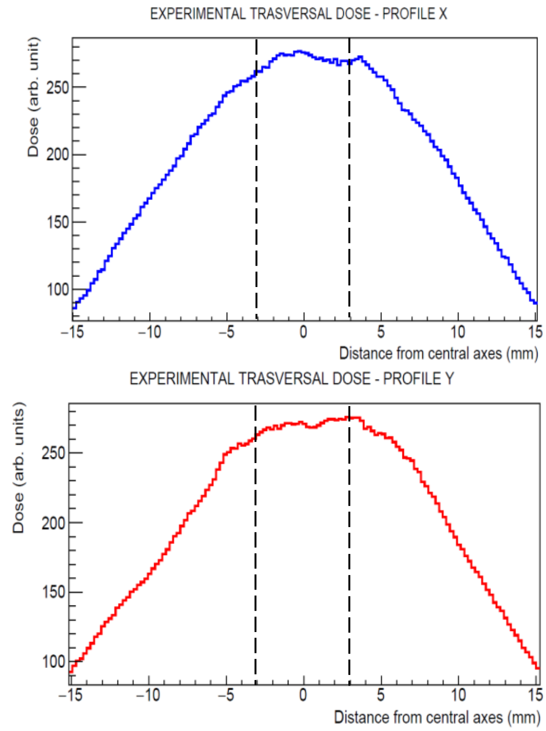

Figure 2: Experimental transversal dose profile for proton beam, with respect to the x (blue) and y (red) axes. Dashed lines delimit the DUT size where uniformity of ± 10% is reached.

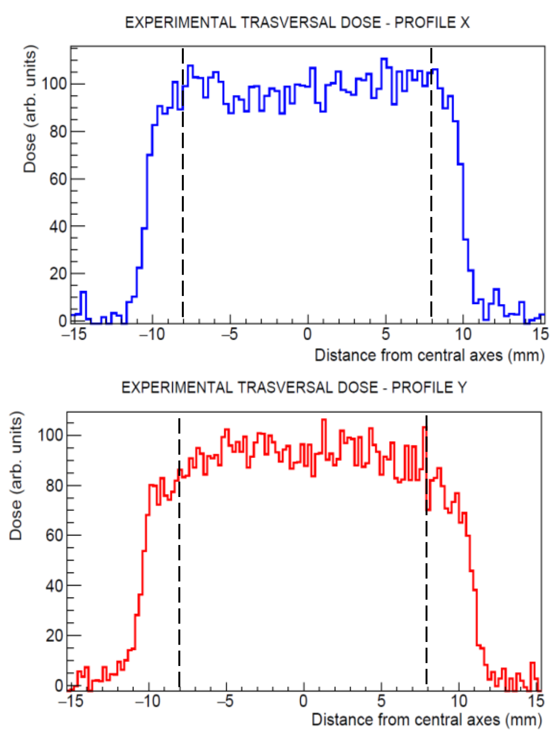

Figure 3: Experimental transversal dose profile for ^{84}Kr beam, with respect to the x (blue) and y (red) axes. Dashed lines delimit the DUT size where uniformity of ± 10% is reached.

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The output signals from all the beam diagnostic devices can be monitored from the control room during the beam setup as well as during the irradiation runs.

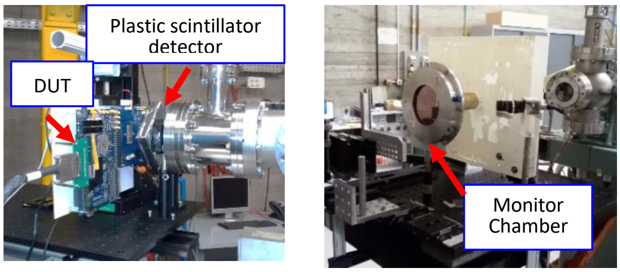

Figure 4: Experimental setup: Plastic scintillator detector and Monitor Chamber used for flux and fluence measurement for heavy ions and protons irradiation respectively. A typical board housing the DUT is also shown in the picture.

DUT Movement

The DUT can be moved along the three axes x-y-z from a remotely controlled positioning system (Fig. 1) made up of two linear motion stages allow up to 150 - 300 mm travel range, with a minimum achievable incremental movement of 0.1 µm and a bidirectional repeatability of 2 µm. Distance along z axis (corresponding to the beam axis) can also be manually changed in a wide range up to about 1.5 m. A laser distance meter allows to check the distance of the DUT from the beam exit window within an accuracy of 1 mm.

A downstream laser and a system of collimators allow the DUT alignment along the beam axis.

All the diagnostic devices are mounted on linear translation stage. In this way, according to the sequence of actions of the standard irradiation procedure, each detector can be moved and placed at the DUT position by a remote control system.

The whole remotely controlled positioning system has been design in order to provide a user-friendly system, guaranteeing high precision and repeatability in the irradiation operation.

PERFORMED IRRADIATION RUNS

From November 2017 to July 2018 five irradiation runs have been carried out at LNS. In particular, two integrated dose test have been performed using 15 MeV protons from Tandem and 60 MeV protons from CS for a total of 2 Beam Time Units (BTU). Energies have been degraded according to the user's request, and the energy values at the DUT po-sition are reported in Table 3. Average proton flux was 10^7 ions cm^{-2} s^{-1}. Three runs have been performed for SEE test using ^{40}Ar, ^{84}Kr, ^{129}Xe from CS at 20 MeV/amu, for a total of 8 BTU. Also in this case the ion energies have been re-duced (see Table 3). The average flux required during the runs was from 10^3 to 10^5 ions cm^{-2} s^{-1}.

Table 3: Ions employed at LNS for irradiation test (November 2017- July 2018). For proton beams both accelerator machines have been used (*Tandem, **CS).

Ion	Energy on DUT *MeV*	Beam Time Units (BTU)
H	10*, 30**	2
^{40}Ar	500	8
^{84}Kr	750	
^{129}Xe	612	

At LNS beam time for irradiation test will be available three times per year, 8 BTU per trimester, for totally 24 BTU (192 hours) per year.

PERSPECTIVES AND UPGRADES

In the next future irradiation facility upgrades will be focused especially in the broadening of the beam portfolio and reducing of the switch-over times. In this sense, the irradiation facility will take particular advantage of the upgrade of the SERSE ion source. In particular, a new cryo-cooling system has been already installed, making the super-conductive magnets of the ECR source independent from the Cyclotron cryostat. Moreover, a new plasma chamber and injection system will allow operations at larger extraction voltages and RF power.

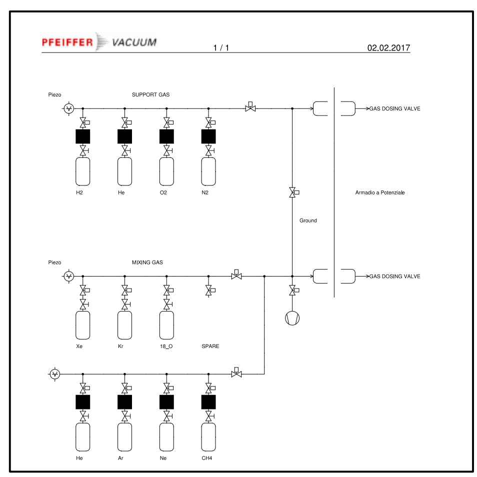

Figure 5: The new designed SERSE gas box.

A new gas box (Fig. 5) has been designed to host "on-board" of the HV platform several gaseous species or "cocktails". This last upgrade is fundamental for the irradiation facility because will guarantee a faster switch-over of the beam species during irradiation.

In addition, the availability of the SERSE ion source couple with the CESAR one will allow the possibility to provide to the users, during the same irradiation run, both gaseous and metallic ions, with a considerable broadening of the beam availability.

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