UNIVERSAL PROTON AND NEUTRON CENTRE FOR RADIATION RESISTANCE OF AVIONIC, SPACE ELECTRONICS AND OTHER APPLICATIONS AT THE 1 GEV SYNCHROCYCLOTRON IN PNPI

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Abstract

In PNPI RNC KI a universal center for testing electronic components for the needs of aviation and space and other applications is created on the synchrocyclotron SC-1000 with the proton energy of 1 GeV. The center consists of two protons and one neutron stands for test facilities developed at the PNPI in collaboration with the ROSCOSMOS Interagency Testing Center. The PNPI center is equipped with all necessary systems of diagnostics and monitoring of a beam, installation of targets on a beam. There is an opportunity to vary temperature of exemplars in the wide range. A unique conjunction of proton beams with variable energy 60-1000 MeV and atmospheric like neutron beam with broad energy range (1-1000 MeV) spectrum enable to perform complex testing of the semiconductor electronic devices at the SC-1000 within a single testing cycle.

INTRODUCTION

The proton synchrocyltrotron SC-1000 with the proton energy of 1 GeV and intensity of extracted proton beam of 1 μA [1] is one of the basic installations of the PNPI NRC "Kurchatov Institute". It was commissioned in 1970 and during exploitation it was significantly modernized. The experimental complex of the SC-1000 is used for investigations in fields of elementary particle physics, atomic nucleus structure and mechanisms of nuclear reactions, solid state physics and for the purposes of applied physics and nuclear medicine. Radiation resistances testing of electronics are conducted at the SC-1000 during more than two decades. Sharp growth of the needs in accelerated Single-Event-Effect (SEE)-testing of electronic components and systems intended for avionic/space and other applications has led to the development of new test facilities at the high-energy accelerators used as powerful sources of protons and neutrons.

In present report, a short description is presented of the proton (IS SC-1000 and IS OP-1000) and neutron (IS NP/GNEIS) test facilities developed at the PNPI in collaboration with the Branch of JSC "United Rocket and Space Corporation" - "Institute of Space Device Engineering", a Head Organization of the ROSCOSMOS Interagency Testing Center. A unique conjunction of proton beams with variable energy 60-1000 MeV and atmospheric like neutron beam with broad energy range (1-1000 MeV) spectrum enable to perform complex testing of the semiconductor electronic devices at the SC-1000 within a single testing cycle.

PROTON TEST FACILITIES

At present, 2 of 3 proton beam lines of the SC-1000 are used for radiation testing of electronics. The IS SC-1000 test facility has fixed proton energy of 1000 MeV and is located on the P2 beam line. At the IS OP-1000 facility located on the P3 beam line, proton energy can be varied from 1000 MeV down to 60 MeV by means of a system of copper degrader (absorber) of variable thickness from 73 mm (at 900 MeV) to 530 mm (at 60 MeV). A scheme of the proton beams and irradiation workstations placed in the experimental room, as well as a photo of the degrader system located in the SC-1000 main room are shown in Fig.1. The parameters of both proton test facilities are given in Table 1.

An adjustment of the proton beam profile is carried out roughly by means of quadrupole lenses whereas for final tuning a 2m-long steel collimator with 20 mm aperture is used. All irradiations are carried out at open air and room temperature. Both proton and neutron beam lines are equipped with a remotely controlled system intended for positioning the device under test (DUT) and heating in 20^{o}-125^{o}C temperature range.

Table 1: Parameters of the Proton Test Facilities

Parameter	IS SC -1000	IS OP - 1000
Irradiation conditions	Atmosphere	Atmosphere
Particle	Protons	Protons
Energy, MeV	1000	60 -1000
Flux, protons/cm^2 s	10^5 - 10^8	10^5 - 10^8
Irradiation area, mm	Ø ≥ 25	Ø ≥ 25
Uniformity, %	≤ 10	≤ 10
Status	In operation (1998)	In operation (2015)

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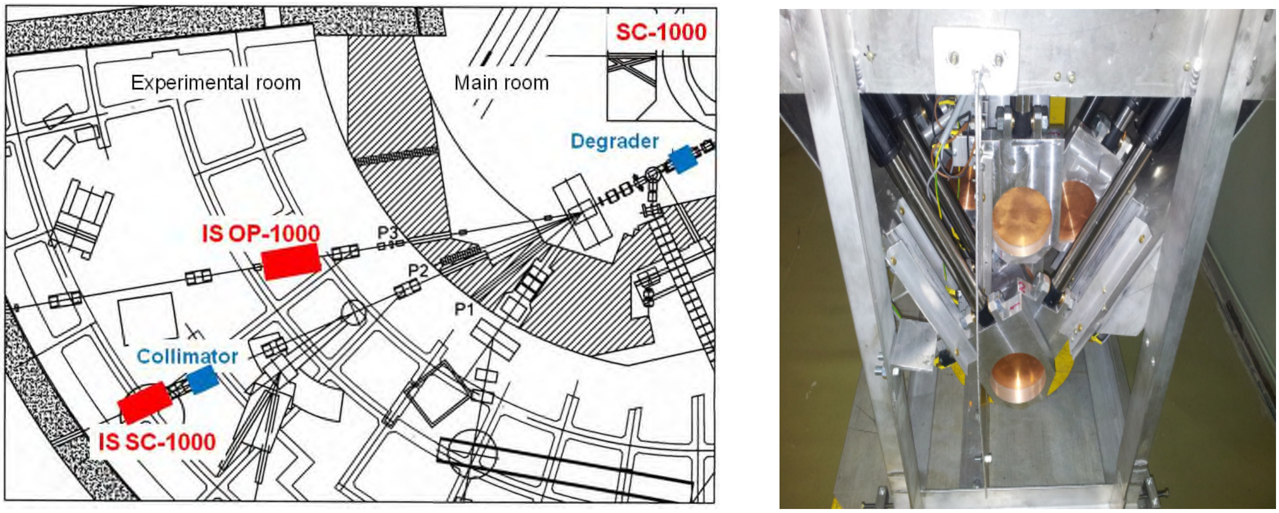

Figure 1: Left: scheme of the proton beam lines, P2 - protons with the energy of 1000 MeV, P3 – protons with variable energy of 60 – 1000 MeV. Right: device for remote variation of the absorber length and the proton energy.

Parameters of the proton beam at the outlet of copper absorber of variable thickness have been evaluated by means of the Geant-4 code calculation. Energy distribution of the initial proton beam was supposed to be of Gaussian-type with the parameters of 1000 MeV and 3.84 MeV for proton energy and standard deviation, respectively. The results of Geant-4 calculations are given in Table 2 and Figure 2. Both incoming and outcoming proton beam parameters have been verified experimentally by means of the TOF-measurements carried out using microstructure of the proton beam (~73 ns between proton micropulses).

Table 2: Parameters of the proton beam after transmission through the copper absorber (Geant-4 calculation).

Proton energy, MeV	Standard deviation, MeV	Absorber thickness, mm	Absorber transmission, %
62.1	28.20	530.5	1.6
100.09	24.63	521.2	2.3
197.93	15.77	490.8	3.4
300.21	12.12	448.7	5.4
399.12	10.24	398.0	8.4
499.24	8.92	340.9	13.5
601.03	7.89	279	22.0
699.88	7.01	213.1	35.6
800.18	6.13	144.3	56
899.85	5.13	73.11	82.1

Beam diagnostics is carried out using a set of standard tools which includes: (1) thin scintillator - screen coupled with a CCD-sensor for rapid evaluation of the beam profile image; (2) 2D-moving Se-stripe-type beam profile meter; (3) double-section ionization chamber for "on-line" control of the proton intensity (fluence); (4) Al-foil activation technique in conjunction with a high-resolution HPG-detector as absolute "off-line" monitor of proton fluency.

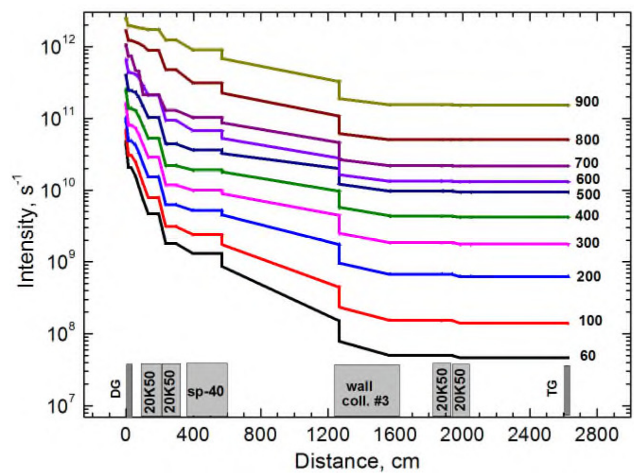

Figure 2: Dynamics of protons losses at different energies along a beam line P3: DG – absorber, 20K50 – quadrupole, SP – 40 – bending magnet, wall, coll. 3 – a wall with the collimator #3 between the main and experimental room of the accelerator, TG – target.

NEUTRON TEST FACILITY

The ISNP/GNEIS test facility is operated since 2010 at the neutron TOF-spectrometer GNEIS [2,3]. Its main feature is a spallation source with neutron spectrum resembling that of terrestrial neutrons in the energy range of 1-1000 MeV. The water-cooled lead target located inside the accelerator vacuum chamber (Fig. 3) produces short 10 ns pulses of fast neutrons with a repetition rate of 45-50 Hz and average intensity up to $3{\cdot}10^{14}$ n/s. The ISNP/GNEIS test facility is located inside the GNEIS building on the neutron beam #5, which has the following parameters:

- neutron energy range: 1-1000 MeV;
- neutron flux: $4{\cdot}10^{5}$ n/cm$^{2}{\cdot}$s (at 36 m flight path);

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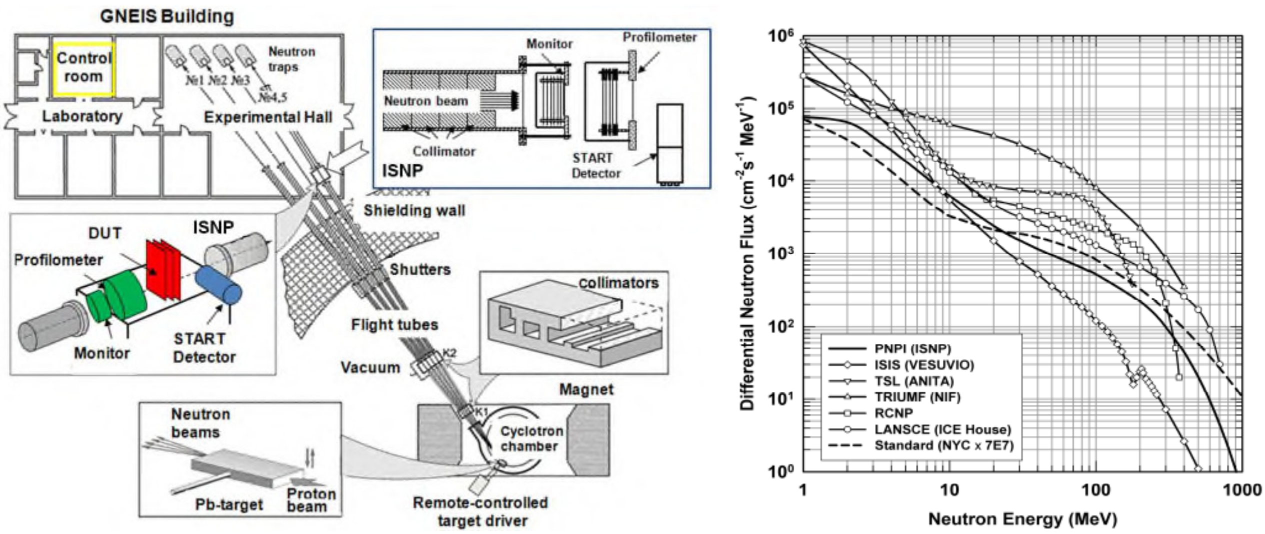

Figure 3: Left: General layout of the neutron time-of-flight spectrometer GNEIS and ISNP test facility. Right: Neutron spectrum $F_{ISNP}(E)$ of the ISNP/GNEIS facility in comparison with standard terrestrial neutron spectrum and spectra of other world-class test facilities.

- beam diameter: 50-100 mm (at 36 m flight path);
- uniformity of the beam profile plateau: ± 10%.

The neutron flux of $4 \cdot 10^5$ n/(cm^2·s) is an integral over neutron spectrum in the energy range 1-1000 MeV. It corresponds to the maximum value of 3μA of the internal average proton beam current. The neutron flux and shape of the neutron spectrum are measured using FIC (neutron monitor) and TOF-technique (Fig. 4). The FIC is a fast parallel-plate ionization chamber which contains two targets of ^{235}U and ^{238}U. The neutron fission cross sections of these nuclei are recommended standards in the energy range 1-200 MeV. The neutron beam profile is measured by means of MWPC - the 2-coordinate position sensitive multiwire proportional counter used for registration of fission fragments from the ^{235}U target deposited on the MWPC's cathode [4].

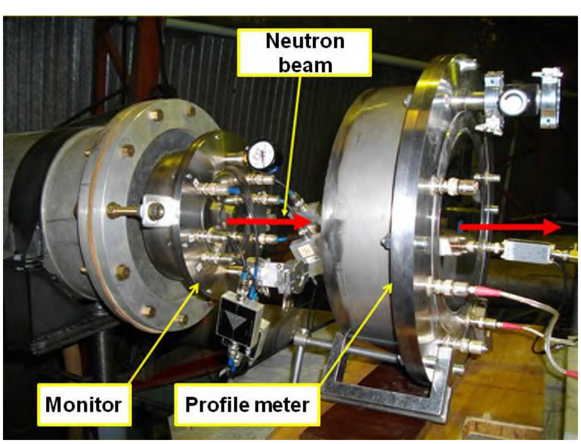

Figure 4: FIC (neutron monitor) and MWPC (profile meter).

The neutron spectrum $F_{ISNP}(E)$ is shown in Fig. 3 together with the JEDEC standard terrestrial neutron spectrum from JESD89A referenced to New York City and multiplied by scaling factor $7 \cdot 10^7$, as well as the neutron spectra of leading test facilities. Both the shape of the neutron flux and neutron intensity demonstrate that the ISNP/GNEIS is successfully competing with the other first-grade test facilities with the atmospheric - like neutron spectrum. The SC-1000 possesses a potential of the neutron intensity growth. A new irradiation station located at a distance of 5-6 m from the neutron-production target operated on the extracted proton beam enables to increase neutron flux at least 10 times at the DUT position. Simultaneously, an irradiation of the bulky equipment will be possible.

CONCLUSION

A versatile complex of test facilities has been developed at the SC-1000 accelerator of the PNPI. At present, a growing number of Russian research organizations specialized in radiation testing of the electronics conduct their research on the proton and neutron beams under direct agreements with the PNPI or with the Branch of JSC "URSC" - "ISDE".

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