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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1. Introduction

The proton synchrocyclotron SC-1000 with the proton energy of 1 GeV and intensity of the extracted proton beam of 1 μA [1] is one of the basic installations of the PNPI. It was commissioned in 1970 and was significantly modernized during its exploitation. The experimental complex of the SC-1000 is used for investigations in the fields of elementary particle physics, atomic nuclear structure and mechanisms of nuclear reactions, solid state physics, and for purposes of applied physics and nuclear medicine. Radiation resistance testing of electronics is conducted at the SC-1000 during more than two decades. A sharp growth of the needs in the accelerated single-event effect testing of electronic components and systems intended for avionic/space and other applications has led to a development of new test facilities at high-energy accelerators, which are used as powerful sources of protons and neutrons.

In the 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" (Branch of JSC "URSC"– "ISDE"), a Head Organization of the Roscosmos Interagency Testing Centre. A unique conjunction of proton beams with variable energy 60–1 000 MeV and a neutron beam with a broad energy range (1–1 000 MeV) spectrum enables to perform complex testing of semiconductor electronic devices at the SC-1000 within a single testing cycle.

2. Proton test facilities

At present, two of three proton beam lines of the SC-1000 are used for radiation testing of electronics. The IS SC-1000 test facility has a fixed proton energy of 1 000 MeV and is located in the P2 beam line. At the IS OP-1000 facility located at the P3 beam line, the proton energy can be varied from 1 000 MeV down to 60 MeV by means of a system of copper degraders (absorbers) of variable thickness from 73 mm (at 900 MeV) to 530 mm (at 60 MeV) [2]. 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 and heating it in the 20–125 °C temperature range.

Parameters of the proton beam at the outlet of the copper absorber of variable thickness were evaluated by means of the GEANT4 code calculation. The energy distribution of the initial proton beam was supposed to be of a Gaussian type with the parameters of 1 000 and 3.84 MeV for the proton energy and standard deviation, respectively. The results of GEANT4 calculations are given in Table 2 and Fig. 2. Both incoming and outcoming proton beam parameters were verified experimentally by means of ToF-measurements carried out using the microstructure of the proton beam (~ 73 ns between proton micropulses).

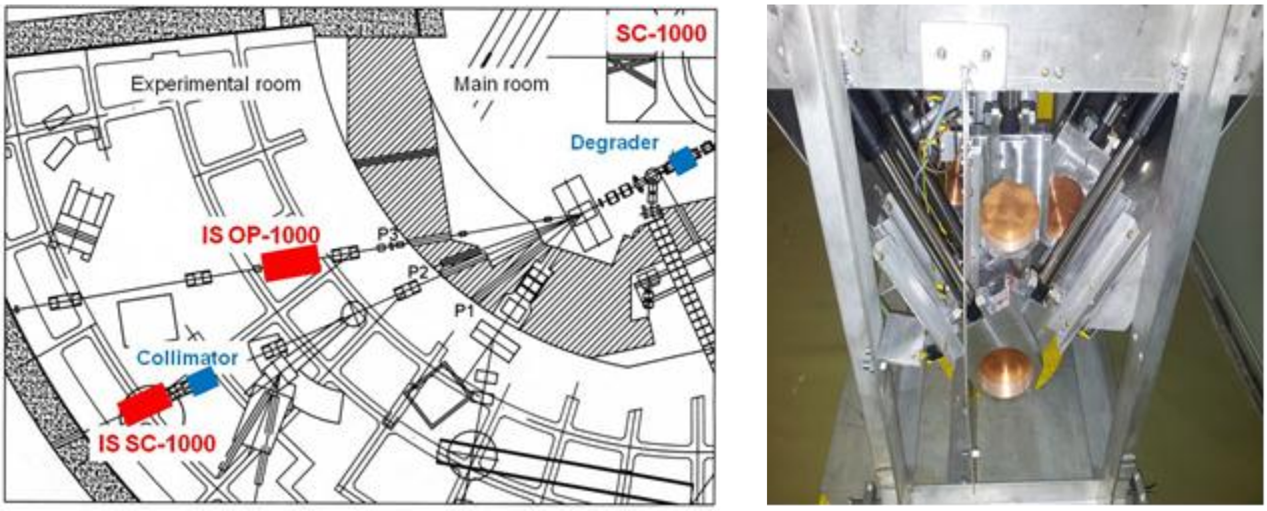

Fig. 1. Scheme of the proton beam lines: P2 – protons with the energy of 1 000 MeV; P3 – protons with the energy variable from 1 000 to 60 MeV (*left*); device for remote variation of the absorber length and of the proton energy (*right*)

Table 1

Parameters of the proton test facilities

Parameter	IS SC-1000	IS OP-1000
Irradiation conditions	Atmosphere	Atmosphere
Particle	Protons	Protons
Energy, MeV	1 000	60–1 000
Flux, $p/\text{cm}^2 \cdot \text{s}$	10^5–10^8	10^5–10^8
Irradiation area, mm	Ø ≥ 25	Ø ≥ 25
Uniformity, %	≤ 10	≤ 10
Status	In operation (since 1998)	In operation (since 2015)

Table 2

Parameters of the proton beam after transmission through the copper absorber (GEANT4 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

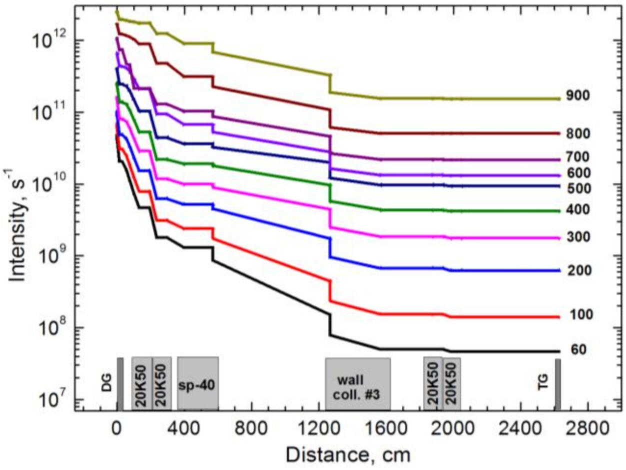

Fig. 2. Dynamics of protons losses at different energies along the beam line P3: DG – absorber; 20K50 – quadrupole; SP-40 – bending magnet; wall, coll. #3 – a wall with the collimator #3 between the main and experimental room of the accelerator; TG – target

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

3. Neutron test facility

The IS NP/GNEIS test facility is operated since 2010 at the neutron ToF-spectrometer GNEIS [3, 4]. Its main feature is a spallation source with the neutron spectrum resembling that of terrestrial neutrons in the energy range of 1–1 000 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 an average intensity up to $3 \cdot 10^{14}\ n \cdot s^{-1}$. The IS NP/GNEIS test facility is located inside the GNEIS building on the neutron beam No. 5, which has the following parameters:

- neutron energy range: 1–1 000 MeV,
- neutron flux: $4 \cdot 10^5\ cm^{-2} \cdot s^{-1}$ (at 36 m flight path),
- beam diameter: 50–100 mm (at 36 m flight path),
- uniformity of the beam profile plateau: ±10%.

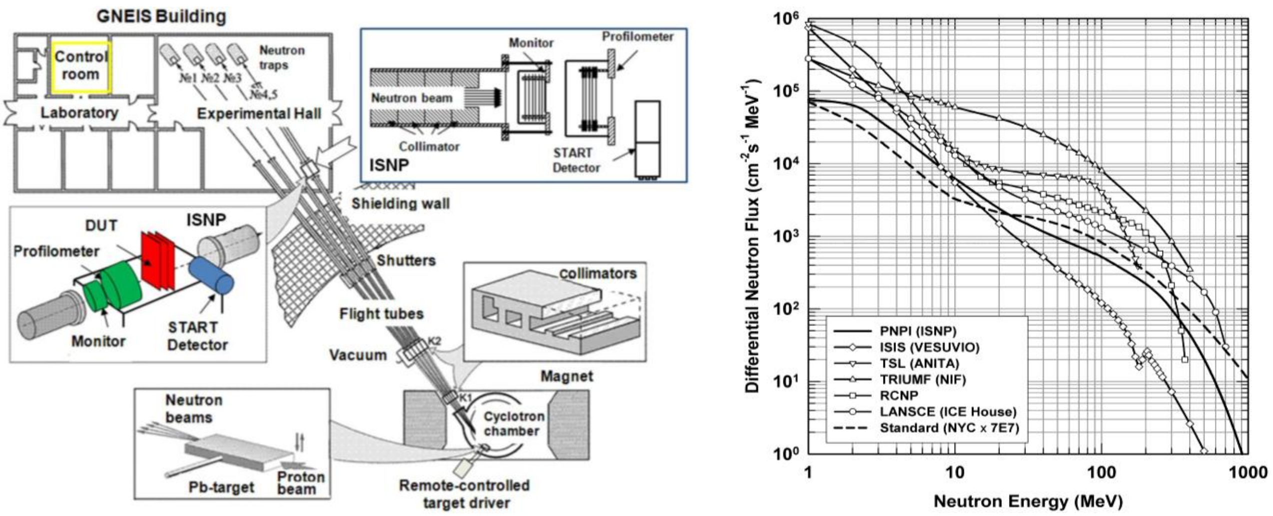

Fig. 3. General layout of the neutron time-of-flight spectrometer GNEIS and IS NP test facility (*left*); neutron spectrum $F_{IS\ NP}(E)$ of the IS NP/GNEIS facility in comparison with the standard terrestrial neutron spectrum and spectra of other world-class test facilities (*right*)

The neutron flux of $4 \cdot 10^5$ cm^{-2} · s^{-1} is an integral over the neutron spectrum in the energy range 1–1 000 MeV. It corresponds to the maximum value of 3μA of the internal average proton beam current. The neutron flux and the shape of the neutron spectrum are measured using a neutron monitor and the ToF-technique (Fig. 4). The neutron monitor 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 the recommended standards in the energy range 1–200 MeV. The neutron beam profile is measured by means of a multiwire proportional chamber (MWPC) – a two-coordinate position sensitive MWPC used for registration of fission fragments from the ^{235}U target deposited on the MWPC's cathode [5].

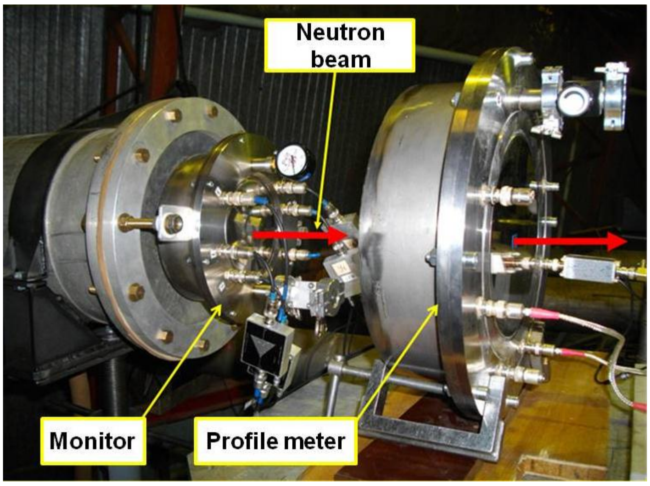

Fig. 4. Neutron monitor and a profile meter MWPC

The neutron spectrum $F_{\text{IS NP}}(E)$ is shown in Fig. 3 together with the JEDEC standard terrestrial neutron spectrum from JESD89A referenced to New York City and multiplied by a 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 demonstrates that the IS NP/GNEIS is successfully competing with other first-grade test facilities with the atmospheric-like neutron spectrum. The SC-1000 possesses a potential to increase the neutron intensity. 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 the neutron flux at least by 10 times. Simultaneously, irradiation of bulky equipment is possible.

4. 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".

Acknowledgment

The authors express their sincere gratitude to all colleagues from the PNPI who participated in the development of the radiation test facilities at the SC-1000 synchrocyclotron.

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