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Defocusing beam line design for an irradiation facility at the TAEA SANAEM Proton Accelerator Facility

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A R T I C L E I N F O

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A B S T R A C T

Electronic components must be tested to ensure reliable performance in high radiation environments such as Hi-Limu LHC and space. We propose a defocusing beam line to perform proton irradiation tests in Turkey. The Turkish Atomic Energy Authority SANAEM Proton Accelerator Facility was inaugurated in May 2012 for radioisotope production. The facility has also an R&D room for research purposes. The accelerator produces protons with 30 MeV kinetic energy and the beam current is variable between 10 μA and 1.2 mA. The beam kinetic energy is suitable for irradiation tests, however the beam current is high and therefore the flux must be lowered. We plan to build a defocusing beam line (DBL) in order to enlarge the beam size, reduce the flux to match the required specifications for the irradiation tests. Current design includes the beam transport and the final focusing magnets to blow up the beam. Scattering foils and a collimator is placed for the reduction of the beam flux. The DBL is designed to provide fluxes between 10^7 p/cm^2/s and 10^9 p/cm^2/s for performing irradiation tests in an area of 15.4 cm × 21.5 cm. The facility will be the first irradiation facility of its kind in Turkey.

1. Introduction

In high radiation environments especially space applications, high energy accelerators and nuclear reactors, performance of electronic components is critical. Electronic components must withstand the radiation for reliable performance in these environments. Radiation causes ionization and non-ionizing effects also called displacement damage [1]. Ionization effects can be classified in two categories: Single Event Effects (SEE) and Total Ionizing Dose (TID) effects. SEEs are the errors that are caused when a particle strikes the component and changes electronic component's functionality. To address the vulnerability of electronic components to such effects, tests are performed using a proton or heavy ion beam from an accelerator and checking the errors online and/or after irradiation. TID effects are the cumulative results induced by the radiation in the electronic component. For such effects, the electronic components are subjected to the γ rays from a radioactive source to provide mission equivalent radiation levels in real or accelerated dose profile. Functional tests with respect to the cumulative effect of the γ rays can be performed online or at the end of the irradiation. The non-ionizing effect where the incoming particle can change an atom's position in the crystal lattice and this effect is called displacement damage. Displacement damage tests can be performed with beams of protons, neutrons or heavy ions. Reliable performance of electronic components which is intended for use in high radiation environments must be checked by irradiation tests. Standards for space electronic components are available for these irradiation tests. The proposed beam line will enable SEE tests according to ESCC Basic Specification No. 25100 [2] in Turkey. The crucial requirements for the target area in the standard are:

- The proton beam energy should be between 20 MeV and 200 MeV.
- The flux must range from 10^5 p/cm^2/s to at least 10^8 p/cm^2/s.
- The beam size should be 15.40 cm × 21.55 cm.
- The beam must be uniform to ± 10% across the irradiation area.

A defocusing beam line is planned to be constructed at the Turkish Atomic Energy Authority (TAEA) SANAEM Proton Accelerator Facility (PAF). The facility has a proton cyclotron providing a 30 MeV continuous proton beam in order to produce radioisotopes [6]. The current is 1.2 mA and the lowest stable setting is 10 μA. The beam can be extracted towards the R&D room where the facility will be located.

The beam size and the current are tuned for radioisotope production and not for irradiation tests: the beam size is small approximately 1 cm at the R&D room [3], and the minimum beam

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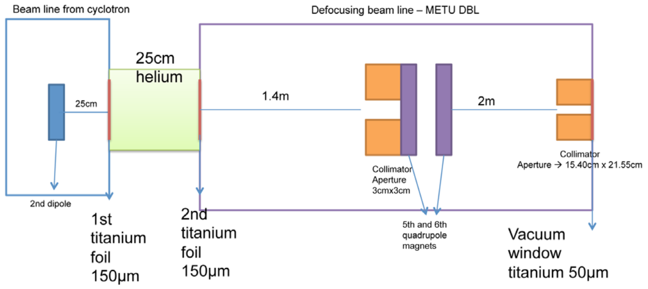

Fig. 1. Sketch showing the key components of the defocusing beam line.

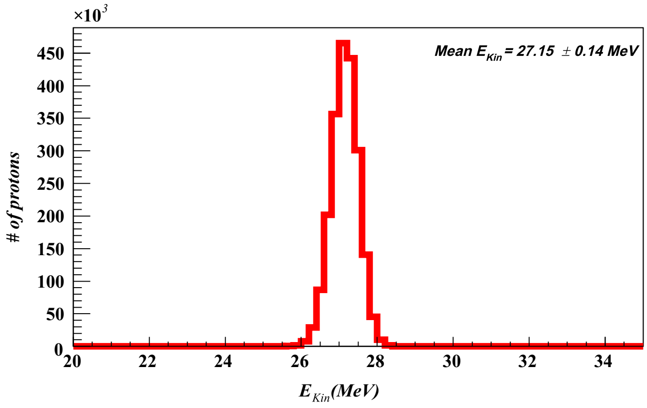

Fig. 2. Final beam energy spectrum after the vacuum window at the end of the beam line.

current corresponds to 1.9×10^{11} p/cm^2/s for the desired beam size, a flux that is too high according to the standard. Therefore a new defocusing beam line design was developed that uses a combination of quadrupole magnets and scattering foils to enlarge the beam size and reduce the flux matching the requirements of the standard. The validation of the beam line design was performed with TURTLE [4] simulations. In the next section, the final design will be presented. An earlier preliminary proposal can be found in [5].

2. TURTLE simulations

The defocusing beam line consists of quadrupole magnets, titanium scattering foils and collimators. From the cyclotron to the R&D room, the beam line has a dipole magnet and two quadrupole magnet doublets. A 5-port switching magnet will be placed to allow for several experiment to receive beam in the R&D room. The cyclotron vacuum and the defocusing beam line vacuum will be separated for operational safety. The thin titanium windows used for this vacuum isolation will also serve as scattering foils and would need to be cooled with helium. The irradiation target can be placed in air or in helium, with an additional titanium vacuum window to assure separation from the beam vacuum. Fig. 1 shows element positions in the beam line. The magnetic fields of the last two beam quadrupole magnets are 9.0 kG and −1.0 kG and their aperture 20 cm.

In the TURTLE simulation, the initial proton beam parameters as expected from the cyclotron extraction channel are given. In particular, the RMS beam sizes in x and y axes are 0.84 cm and 0.27 cm respectively, with the mean initial beam kinetic energy of 30 ± 0.6 MeV. Beam sizes, beam divergences and beam energy are calculated along the beam line. The final beam size and uniformity at the end of the beam line is that of the standard at the end of the beam line. Also, final beam distributions are uniform which is another requirement in the standard. Fig. 2 shows the final beam kinetic energy. Due to the use of the foils, the mean final beam kinetic energy is 27.15 ± 0.14 MeV, well within the range defined in the standard.

Table 1
The different aperture settings of the collimator and values and corresponding flux values.

Collimator aperture (mm)	Flux (p/cm^2/s)	Uniformity in x and y axes
1–2	3.10×10^7	±10% and ±10%
1.5–2.5	7.00×10^7	±10% and ±7%
2–3	1.20×10^8	±10% and ±9%
2.5–3.5	1.90×10^8	±6% and ±4%
3	2.50×10^8	±10% and ±10%
3–4	2.70×10^8	±5% and ±6%
3.5–4.5	3.60×10^8	±7% and ±6%
4	4.30×10^8	±8% and ±6%
4.5–5.5	5.60×10^8	±5% and ±5%
5	6.5×10^8	±8% and ±7%
5–6	6.70×10^8	±4% and ±4%
6	8.80×10^8	±6% and ±6%
7	1.10×10^9	±5% and ±4%
8	1.20×10^9	±5% and ±4%
9	1.50×10^9	±4% and ±4%
10	1.70×10^9	±4% and ±3%

In order to satisfy the beam flux requirement, another collimator is placed after the scattering foils. The collimator will be designed to enable different aperture settings. In Table 1, the aperture values and corresponding flux values are listed. The flux requirement of the standard is satisfied in all cases.

3. Conclusion

The defocusing beam line was designed with the TURTLE simulation program and will be constructed at the TAEA SANAEM Proton Accelerator Facility. The requirements in the ESA ESCC No.25100 standard for SEE tests are satisfied with the design presented here. The flux values between 10^7 p/cm^2/s and 10^9 p/cm^2/s can be obtained. The facility will serve communities with irradiation tests for working at high radiation environments. We propose this project to the Ministry of Development in Turkey and the proposal is in the final review stage. If funded, the facility will be the first of its kind in Turkey.

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