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# FIRST USER EXPERIENCE FROM THE PRETEST SETUP AND COMMISSIONING OF THE METU DEFOCUSING BEAMLINE PROJECT

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#### ABSTRACT

Spaceflight requires materials and components of satellites and spacecrafts to be tolerant to high radiation doses. Space environment consists of cosmic rays, solar particles and trapped particles, which are captured in the Earth's geomagnetic environment. Performance of electronic cards may be effected and degradation can result in complete failure of these devices by these particles. The main purpose of METU Defocusing Beam Line (DBL) is to study "Single Event Effects" by performing radiation tests of electronic components designed for space which are exposed to high doses of radiation during their duty periods. METU-DBL tests materials and devices using protons with a kinetic energy range between 15 - 30 MeV with a flux range  $10^5 - 10^{10} \text{ p/cm}^2/\text{s}$ .

## INTRODUCTION

METU-DBL construction started in the R&D Room at TAEA SANAEM PAF in 2015 and was completed in 2019. The purpose of the METU-DBL is to test sensitive electronic components which are to be used in the space environment, for "Single Event Effects" (SEE) comparable to the amount of radiation dose or equivalent flux depending on the orbit [Demirkoz, M.Bilge et al, 2017].

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Single Event Effects (SEEs) are caused by a single energetic particle. Any measurable or observable change in the state or performance of an electronic device, component, subsystem, or system (digital or analog) resulting from a single energetic-particle strike is considered of SEE. METU-DBL performed the first SEE tests in Turkey. ESA/ESCC "Single Event Effects Test Method And Guidelines" No. 25100 standard [ESA, 2014] is followed as to determine design criteria of METU-DBL. According to this standard, the requirements for the irradiation area to test materials and electronic components are shown in Table 1.

# Table 1 : ESA/ESCC No. 25100 Parameters

| Parameters   | Value  |  |  |  |
|--------------|--|--|--|--|
| Energy Range | 20 - 200 MeV   |  |  |  |
| Flux Range   | 10 <sup>5</sup> - 10 <sup>8</sup> p/cm <sup>2</sup> /s |  |  |  |
| Beam Area    | 15,40 × 21,55 cm                                       |  |  |  |
| Uniformity   | ± 10%  |  |  |  |

Also, according to this standard, at least 10<sup>11</sup> p/cm<sup>2</sup> fluence must be reached during a test. Proton tests are to be performed at 5 different energy levels within the range of 20 MeV to 200 MeV and the error rate of the tested components, called a response curve, must be obtained. The response time of the readout card of the device under test and the speed of the test hardware and software must also match the proton flux rate. The proton beam parameters at the exit of the 30 MeV proton cyclotron provided by the TAEA SANAEM PAF [TAEA, 2012] are shown in Table 2.

| Table 2 : PAF Beam Parameters |               |  |  |  |  |
|-------------------------------|---------------|--|--|--|--|
| Parameters                    | Value         |  |  |  |  |
| Energy Range                  | 20 - 30 MeV   |  |  |  |  |
| Current                       | 0,1 - 1200 µA |  |  |  |  |
| Beam Area                     | 1 cm          |  |  |  |  |

While the energy of protons in the PAF is in the range allowed for testing electronics, the lowest beam current is very high and the beam size is very small. Therefore, in addition to expanding the beam, the flux must be reduced. METU-DBL which is a 7.5 m long addition to TAEA SANAEM PAF uses quadrupole magnets to enlarge the beam and scattering foils and following collimators to reduce the flux.

In the METU-DBL, the design, integration and commissioning of the proton beamline has been carefully thought out within the scope of the space radiation test standards. The necessary cooling and vacuum subsystems in the proton beamline design are an integral part of into the system. METU-DBL has six subsystems to perform radiation tests.

- Beam Optics Subsystem, provides the desired parameters of ESA/ESCC No.25100 standard for 15 - 30 MeV protons at the target area by enlarging the beam and by reducing the flux,
- Vacuum Subsystem, keeps the proton beam under the vacuum (<10<sup>-6</sup> torr) and so that protons can not lose energy,
- Cooling Subsystem, cools the magnets which draw a high current and collimators which are under heat load from the stopping particles with a cooling capacity of 50 kW,
- Robotic Subsystem, controls the motion of electromechanical components, such as the conic collimator,
- Control Subsystem, controls and communicates with all the electronic and electromechanical subsystems,
- Test and Measurement Subsystem, measures the proton beam flux and uniformity at the target area.

One important issue for METU-DBL is shielding. Sensitive devices of subsystems must be shielded against secondary dose in the room which mainly consists of e-, X-ray and neutrons. In order to lower secondary doses, sandwich shields using aluminum, polyethylene and lead were designed to fit and surround sensitive devices. The materials used in the mechanical design, must have high mechanical strength, corrosion resistance and have minimal activation

under radiation as well as be non-ferritic to avoid introducing fringe fields into beam optics. Stainless steel 316 and aluminum 6082 were selected for most structured elements.



Figure 1 : Final Design of METU-DBL. The beam enters from the left side and after the three quadrupole magnets, the beam blows up as the beam pipe also gets wider.

The mechanical design of the METU-DBL, is based on studies of beam optics and particle tracking. For the design of METU-DBL, both MAD-X [Herr et al, 2014] and Transport [Brown et al, 2007] programs were used for the calculation of beam optics. For particle tracking simulations was performed in TURTLE [Brown et al, 2003], G4Beamline [Allison et al, 2016] as well as MCNP [Werner et al, 2018] programs. Comparison of those results of different simulation programs increases reliability and robustness of the METU-DBL design. There are three quadrupole magnets in METU-DBL system. During the installation phase, after the positioning of each magnet in the beam line, beam parameters after it were measured to compare with the results of the simulations.



Figure 2 : Beam images on an aluminum oxide beam screen taken with different current settings of the first quadrupole magnet of METU-DBL.

In Figure 2, the square of the beam size after a quadrupole magnet has a quadratic dependence for each axis on the magnetic field gradient of the quadrupole magnet. This property can be employed to determine the beam parameters before a quadrupole magnet if a scan through the quadrupoles operational current regime can be performed. This method is called the quadrupole scan and has been applied at every stage of the METU-DBL construction.

#### **METHOD**

The planning of an irradiation test performed at METU-DBL depends on several factors; such as characteristics of the device, the orbit in which it is intended to be used (LEO, MEO, GEO) the flux and duration of the irradiation, cooling requirements and special safety conditions. Tasks and responsibilities are distributed among the METU-DBL and user team. Requests from users shown in Table 3 can be performed as long as they remain within the specified limits. These parameters will verified according to the method prescribed in the list.

| Parameter                        | METU-DBL Value  | Verification Method                         |
|----------------------------------|---|---|
| Energy                           | 13.5 - 29.4 MeV   | Simulations                                 |
| Flux                             | 10 <sup>5</sup> - 10 <sup>10</sup> p/cm <sup>2</sup> /s | METU-DBL target measurement system          |
| Radiation Area                   | ≤ 15,40 x 21,55 cm                                      | METU-DBL target measurement system          |
| Homogeneity                      | ≤ ±%10  | METU-DBL target measurement system          |
| Secondary particle flux rate (%) | ≤ %10   | Simulation, Neutron and Geiger measurements |

# Table 3 : METU-DBL Parameters

Before radiation tests, the test environment and the materials to be irradiated by protons, are identified in the FLUKA [Battistoni, Giuseppe, et al, 2015] program. From the simulation results, information about the radiation doses and radioisotopes can be obtained. Additionally, SRIM [Ziegler, James F. et al, 2010] program is used to see the effects of the radiation on materials on an atomic scale. If the activation of any material is high enough that no person can approach and collect the sample in a week within a reasonable dose limit, the user is informed that the test can not be performed. Before the radiation tests, the room where the cooling tank is located and the R & D room are checked. All fittings, valves, pipes and collectors are checked for leaks and level of the resin tank which removes radioisotopes from the water, and conduction of cooling water are verified to be within limits. The flow and temperature of the cooling water are controlled and monitored from control screen in the laboratory. After checking that the vacuum of the METU-DBL pipeline is better than 10<sup>-6</sup> torr, the vacuum shutter opens but, the beam stopper remains closed. Before starting a test, the temperature of the turbomolecular pump and magnets are recorded in the checklist. The magnet power supplies are turned on and the test system is ready to measure the beam.

Radiation tests start with the operation of the PAF and the selection of the METU-DBL arm of the 5-port magnet. The beam stopper at the beginning of the METU-DBL which has a 2 seconds reaction time, can be closed to prevent the beam from reaching the target area in the case of an emergency during test. In the target area, METU-DBL has several measurement systems and as well as holders to test devices. Unless the user requests different parameters, the irradiation continues until each point of the target reaches 10<sup>11</sup> p/cm<sup>2</sup> fluence rate. Before and after the tests, the METU-DBL target measurement systems measure the flux profile and dose homogeneity of the proton beam and these parameters are shared with the user.

# **RESULTS AND DISCUSSION**

During the pretest of METU-DBL, the materials from different institutions and organizations were tested. The materials tested at different stages of installation and also different requests by users are given in Table 5.

| Material                    | Current<br>(µA) | Energy<br>(MeV) | Flux<br>(p/cm²/s)                                | Homogeneity           | Irradiation<br>Time         | Total<br>Secondary<br>Particle<br>Dose (mSv) | Calculated<br>Total Dose |
|-----------------------------|-----------------|-----------------|--|-----------------------|-----------------------------|--|--------------------------|
| Pin Diode                   | 2.0             | 30              | 1.19 x 10 <sup>11</sup>                          | ± %1                  | 30 min.<br>51 sec.          | Gamma: 3.5<br>Neutron: 5.6                   | 50 Mrad                  |
| Solar cell                  | 0.1             | 30              | 8.75 x 10 <sup>9</sup>                           | X: ± %10<br>Y: ± %27  | 19 min.<br>54 sec.          | Gamma: 0.8<br>Neutron: 6.6                   | 510 krad                 |
| Anode-Cathode of<br>battery | 0.1             | 30              | 8.75 x 10 <sup>9</sup>                           | X: ± %9.5<br>Y: ± %27 | 20 min.<br>1 sec.           | Gamma: 0.8<br>Neutron: 6.6                   | 440 krad                 |
| Solar Glasses               | 0.1             | 30              | 8.75 x 10 <sup>9</sup>                           | X: ± %1<br>Y: ± %27   | 49 min.<br>56 sec.          | Gamma: 0.8<br>Neutron: 6.6                   | *                        |
| Amplifier                   | 0.1             | 30              | 4.0 x 10 <sup>9</sup>                            | ± %1                  | (25 ± 2)<br>sec.            | Gamma: 0.2<br>Neutron: 1.3                   | 25 krad                  |
| GaNFET                      | 0.1             | 30              | 8.2 x 10 <sup>9</sup>                            | ± %1                  | SEE:12 sec.<br>TID: 30 min. | Gamma: 0.2<br>Neutron: 1.7                   | 3,4 Mrad                 |
| Metallic Glasses            | 0.1             | 30              | 3.9 x 10 <sup>9</sup> 9.8<br>x 10 <sup>9</sup>   |                       | 30 min.                     | Gamma:1.0<br>Neutron:4.2                     | *                        |
| Coating Materials           | 0.1             | 30              | 1.6 x 10 <sup>8</sup> 7.6<br>x 10 <sup>9</sup>   |                       | 55 sec.                     | Gamma:1.0<br>Neutron:4.3                     | *                        |
| Solar Cells                 | 0.1             | 30              | 8.47 x 10 <sup>9</sup><br>1.55 x10 <sup>10</sup> |                       | 9 min.<br>57 sec.           | Gamma:5.0<br>Neutron:1.0                     | *                        |
| DDA3 Photodiode             | 0.1             | 30              | 8.6 x 10 <sup>9</sup>                            |                       | 10 min.                     | Gamma:5.0<br>Neutron: 1.0                    | *                        |

 Table 5 : Radiation Test Parameters for irradiations performed during January - March 2018

 for materials and electronic components

\*The dose could not be calculated because material information was not given by users.

All pretests were performed at the highest rigidity setting of the accelerator, namely 30 MeV, which has the most stringent requirement on the beamline control. The current setting was kept low to be close to the maximum flux point ( $10^8 \text{ p/cm}^2/\text{s}$ ) of the ESA/ESCC 25100 standard

even with two quadrupoles installed. The homogeneity was better on the X-axis due to the natural beam shape delivered by the accelerators strip extraction method. There were few instances when the beam from the accelerator was lost due to RF problems during the irradiation campaign but still the longest irradiation time was about an hour. The secondary particle dose in the room was well below expectations due to strict design requirements on materials. In each irradiation, the dose required by the users were delivered without any major problems.

## CONCLUSIONS

Construction of METU-DBL has been started and pretests have been completed. For the first time "Single Event Effects" by performing radiation tests were achieved in Turkey. After the completion of these pretests, the pre-test setup was dismantled to make room for the installation of a 5-port magnet in the R&D room in May 2019, shown in Figure 3.



Figure 3 : On-going installation process of METU-DBL. Setup was completed till the end of the second quadrupole magnet.

As of the submission of this abstract, the final installation of METU-DBL was under way. The first two quadrupoles were integrated into the beamline following a vacuum shutter, a beam stopper and a stand-in section for the scattering foils and an adjustable collimator which is under production. The custom-made 3rd quadrupole magnet is now being installed. The commissioning of METU-DBL will be performed during the summer of 2019 and the first results will also be presented.

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