CYCLONE - A Multipurpose Heavy Ion, Proton and Neutron SEE Test Site.

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Abstract

In addition to the dedicated Heavy ion Irradiation Facility (HIF) for radiation SEE evaluation, the CYClotron of LOuvain la NEuve (CYCLONE) has other beam lines which can be used for radiation SEE testing : the proton radiotherapy and neutron research beam lines have both been used by the space community to assess their use for SEE testing.

This paper describes the main features of the CYCLONE accelerator, and of the various beam lines used and presents some experimental results.

I. Accelerator Facility

CYCLONE is a multiparticle, variable energy cyclotron, capable of accelerating protons (up to 75 MeV), light and heavy ions up to xenon (from 0,6 to 27,5 MeV/amu).

Heavy ions are produced with an external Electron Cyclotron Resonance source (ECR) which allows to use highly charged ions and « ion cocktails ». These are composed of ions with the same or very close mass/charge ratios produced and accelerated in the same time. Once the ions are accelerated, the different ion types are separated by either a fine tuning of the cyclotron magnetic field or by a RF frequence adjustment. This method yields very short ion switching for SEE characterization. The two cocktails used for SEE studies are detailed in table 1

Table 1.
The two cocktails and alpha beam used for SEE studies

Cocktail # 1:

M/Q = 4,94	DUT energy [MeV]	Range [µm Si]	LET [$MeV/mg/cm^2$]
$^{84}Kr^{17+}$	316	43	34

M/Q = 5	DUT energy [MeV]	Range [µm Si]	LET [$MeV/mg/cm^2$]
$^{40}Ar^{8+}$	150	42	14,1
$^{20}Ne^{4+}$	78	45	5,85
$^{15}N^{3+}$	62	64	2,97
$^{10}B^{2+}$	41	80	1.7

M/Q = 5,07	DUT energy [MeV]	Range [µm Si]	LET [$MeV/mg/cm^2$]
$^{132}Xe^{26+}$	459	43	55,9

Cocktail #2

M/Q = 4	DUT energy [MeV]	Range [µm Si]	LET [$MeV/mg/cm^2$]
$^{12}C^{3+}$	79	130	1,67
$^{16}O^{4+}$	105	104	2,9
$^{40}Ar^{10+}$	259	68	10,9

Alpha beam

Ion	DUT energy [MeV]	Range [µm Si]	LET [$MeV/mg/cm^2$]
α	9,2	63	0,4

With these cocktails LET(Si) range from 1,7 to 56 $MeV/mg/cm^2$ at normal incidence are achieved. We also developed an alpha beam for low LET needs (0,4 $MeV/mg/cm^2$).

II. Heavy Ion Irradiation Facility (HIF)

After an evaluation and assessment period, ESA has initiated the set-up of a permanent heavy ion beam line dedicated for SEE testing.

This beam line is equipped with a large test chamber (71 cm height, 54 cm width and 76 cm depth) containing the test board holder. This one is placed on a movable flange and is motor controlled in 3 directions to allow tilt, translation and alignment on the tilt axis. This chamber is also equipped with a variable aperture iris, light and a camera for device positioning.

The different beam characteristics are controlled and monitored by a set of different detectors placed in a specially designed dosimetry box and in the test chamber.
The detection system consists of the following devices :

- A Passivated Implanted Planar Silicon (PIPS) detector is used to measure the transverse (X and Y) beam profiles. In order to reach a spatial resolution, the detector is equipped with a small collimator (∅ = 2,5 mm). During the scan, a flux measurement is done every 2,5 mm during 2 seconds. When an axis is completed, the profile is displayed on the user interface and the ± 10 % width is calculated. The required homogeneity is ± 10 % over an area of 25 mm in diameter.

- A second PIPS detector is used to determine the ion flux and to calculate the counting ratios for the different detectors.
- Four plastic scintillators, placed at 90 degrees to each other, are used to monitor the beam uniformity during irradiation.
- A Parallel Plate Avalanche Counter (PPAC) is used to monitor the beam flux. Its counting rate is integrated to provide the total fluence on the user's Device Under Test (DUT). This detector can also be used to switch off the beam when a preset fluence is reached.

All line information and dosimetry data are sent to a PC either in direct (dosimetry data) or via a Programmable Logic Controller (PLC) (line status).

Each installation feature can be accessed through the PC. A complete user interface interface in C/C++ in a Windows environment has been designed to help the user during the different shift phases (positioning, selection, run, ...). Several tools have been added for data analysis (SEU plot, dose calculation, ...) [1]. The users have access to all the beam flux control, dosimetry features, device positioning, vacuum controls and cross section versus LET via 3 screens and 10 icon tool bars. A fourth screen is reserved for CYCLONE staff. In addition, several warnings are provided to the users in case the uniformity or flux change during irradiation. Screens are divided by function :

- BOARD-POSITION
- DATA-BEAM
- BEAM LINE
- OPERATOR.

Figure 1 represents the DATA-BEAM page. This one is the most used while in run. It includes information about the ion species, the selected device, shows beam characteristics and displays run results.

Following the official opening of the HIF in November 1996, several test campaigns have been carried out. The facility has been used by DASA, IMS2, TEMIC, HIREX and ESA on devices ranging from FFT chip to DSP's and from 1 Mbit SRAM's to 16 Mbit DRAM's. Results from these test will be published by the individual test house but we can mention that most users were very satisfied with this new set-up.

However, results from the ESA correlation program, carried out on 128Kx8 SRAM's from Toshiba are presented here. The irradiation was carried out using the M/Q = 5 cocktail and the devices tilted at 0°, 45° and 60° in order to have a wide LET range. The SEU results are presented graphically on figure 2. This graph contains the BNL (ref. ■) and CYCLONE (ref. Δ) data.

By comparison of the threshold LET, the saturation cross section and the general shape of the curve, we can conclude to a good correlation between the two sets of results.

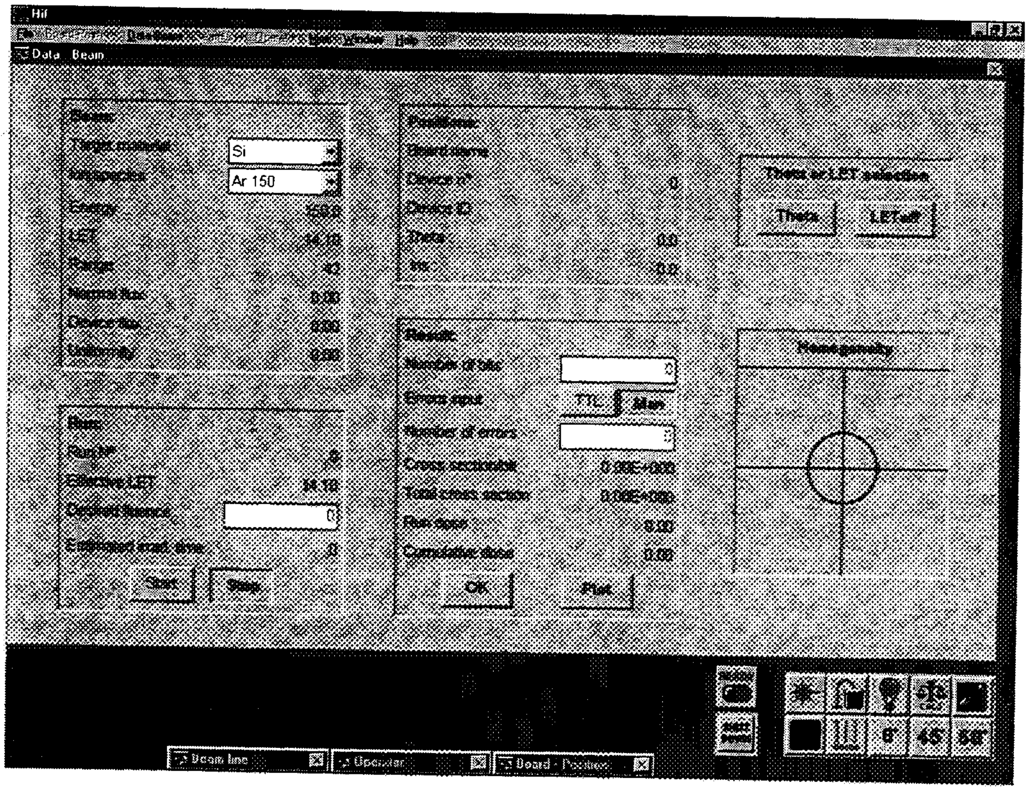

Figure 1 : DATA - BEAM screen

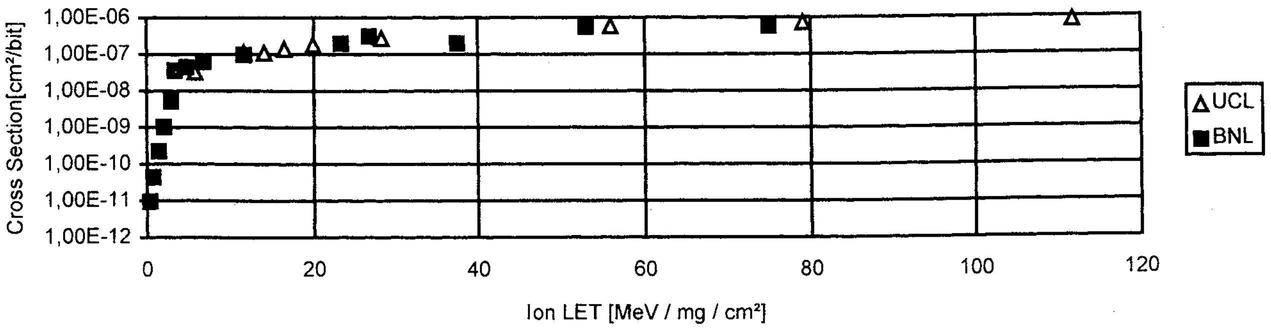

Figure 2 : SEU test results for Toshiba 128 Kx8 SRAM

III. Proton Beam Line

One of CYCLONE proton beam line, originally equipped for proton radiotherapy, has been modified for SEE testing.

The beam spreading and homogenization is achieved with a 250 µm thick lead foil placed 7 meters in front of the device position. In the way, a ± 10 % homogeneity is reached over an area of 10 cm in diameter. Beam profiles are measured with a movable diode in a water phantom.

The beam monitoring is performed by a transmission ionization chamber connected to a specially dedicated dosimetry system. This detector is calibrated with a faraday cup for flux measurements.

The proton energy on the target can be modified between 10 and 75 MeV either by cyclotron adjustment or by using plastic energy degrader placed just in front of the device. The energy is determined with the Janni range table, this method has been controlled by measuring the Bragg peak position with the diode in the water phantom.

Neutron contamination in the proton beam has been measured using the activation technique. Both nickel (for fast neutrons) and gold (for thermal neutrons) foils have been used during a 60 MeV proton beam run. The ratio of fast neutrons (3 - 12 MeV) fluence to proton fluence is 5.3 10^{-4}, the thermal one is 1.4 10^{-4} [2].

The dosimetry procedure has been controlled by ESA with nylon dosimeters. A 10 MeV proton beam was used to irradiate the dosimeters to a dose level of 30 kGy. After dosimeter analysis, the administered dose was within a few percent of the desired dose.

During the HIF test campaign in November 1996, Matra MMS/ESA also assessed the proton beam line. These tests shown the usability of our low energy protons (e.g. 20, 40 and 60 MeV) for high density memory characterization (low energy threshold) [4].

As proton SEU testing with energies of 20, 40 and 60 MeV appear rather low, one example of obtained results is given in figure 3.

As can be seen, the 20 MeV results already point toward a threshold value so a more complete curve would need even lower energy testing. The second visible effect is the bias variation, passing from 5 to 3,3 V increase drastically the cross section.

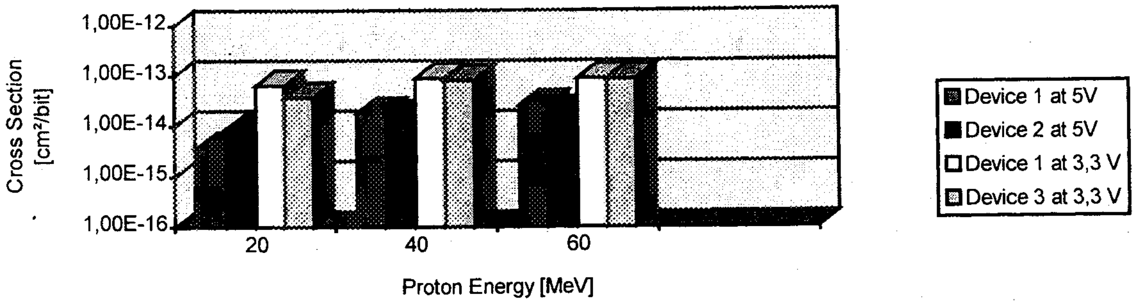

Figure 3 : Proton irradiation of 128Kx8 SRAM from Sony

IV. Monoenergetic Neutron Beam

These last years, analysis of component behavior under neutron flux has gained considerable interest.
A collimated neutron beam in the energy range of 25 to 70 MeV can be produced using the CYCLONE proton beam.

The ^{7}Li(p,n)^{7}Be$_{gs}$ and ^{7}Li(p,n)^{7}Be* reactions (Q values are -1.6 and 0.4 MeV respectively) produce a quasi monoenergetic neutron beam. The layout of the neutron beam line is shown in figure 4.

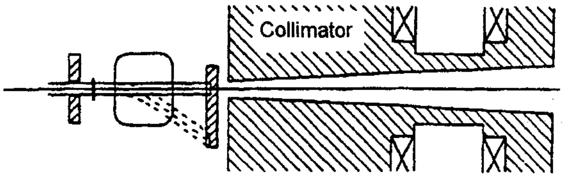

Figure 4 : Neutron beam line

The proton beam irradiates a thin lithium target and the magnetically deflected on a graphite beam stop. A second magnet, placed behind, is used to sweep out the charged particle contamination from the neutron beam. The whole set-up is surrounded by a concrete and iron shielding. The neutron beam is collimated by several brass cylinders of increasing internal diamerter [3].

The figure 5. shows neutron spectra for three different proton energies (36, 48 and 63 MeV). On these graphs, we see that about 50 % of the neutrons are at a well defined energy (E $_{neutron} \approx$ E $_{proton}$ - 2MeV, fwhm = 2MeV). The remaining 50 % are in a broad, rather uniform, low energy tail [5].

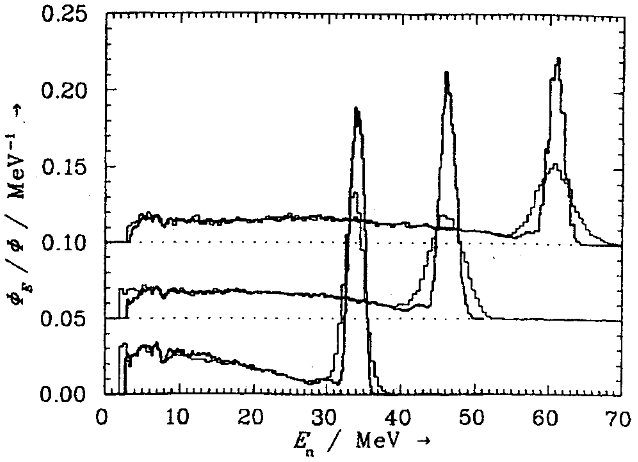

Figure 5 : Neutron energy spectra

At 3 meters from the production target, the peak neutron flux observed for a 10 µA proton beam on the 3 mm thick target is about 1E6 neutron/s over an area of 40 mm in diameter. This value is reached for a proton energy above 30 MeV, where the reaction cross section saturates around 35 mBarn. A higher flux is reachable using target thickness of up to 10 mm. During irradiation, the flux is monitored by the proton beam dump current reading.

Both ESA and Dassault have assessed this beam line for SEE works.

SEU results for proton and neutron irradiation of Hitachi are shown in Figure 6 [6]. Proton data were taken using the PIF facility from Paul Scherrer Institut (Villigen, Switzerland). These results show that the 63 MeV neutron cross section lies between the 50 and 100 MeV proton results and that passing from 38 to 68 MeV neutron doubles the neutron cross section (9,2 10^{-14} and 1,9 10^{-13} respectively for 38 and 63 MeV).

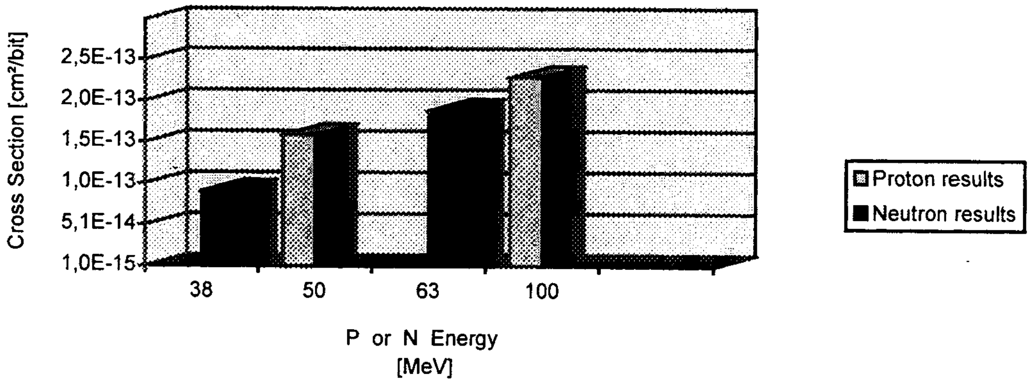

Figure 6 : Proton and neutron irradiation results for Hitachi 512Kx8 SRAM (HM628512P-7 9235)

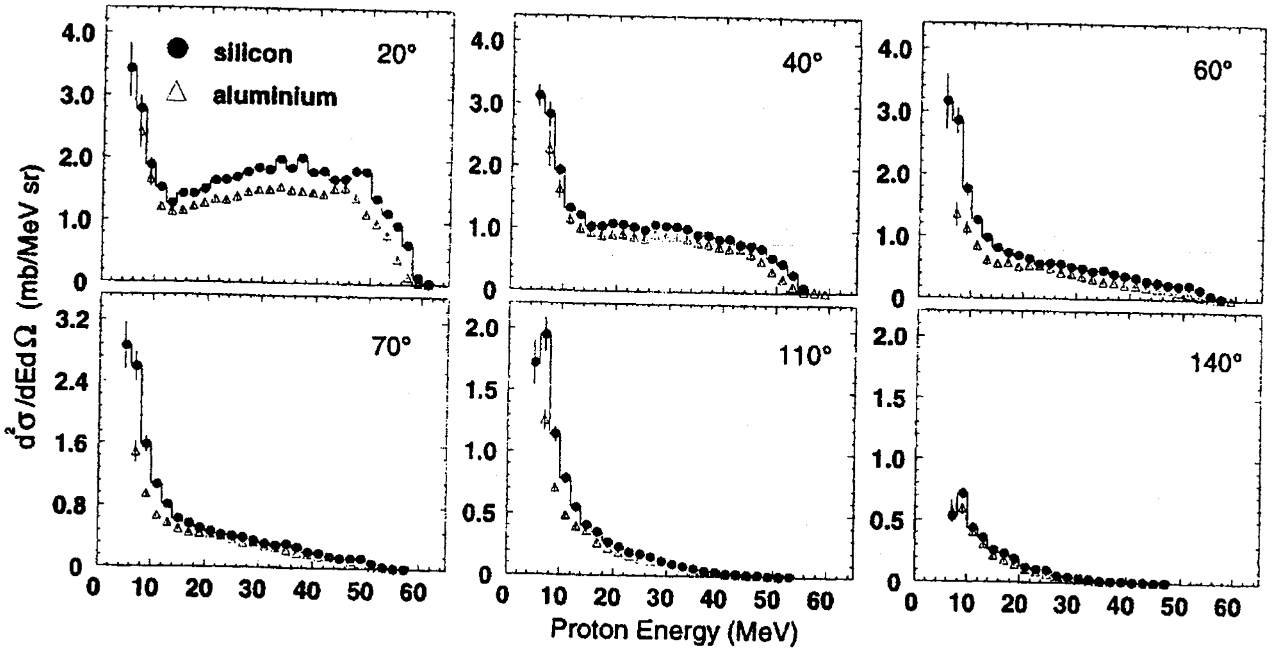

Figure 7 : Proton energy spectra for Si and Al for six laboratory angles

Some measurement of double-differential cross sections for light charged particle production from (n,px), (n,dx), (n,tx) and (n,αx) reaction on aluminum and silicon have also been carried out on this beam line [7,8]. These measurement are of great interest for the high altitude avionic community. Once these cross sections and reaction multiplicities are known, they can be used in different simulation tools. Preliminary results are presented on figure 7. The protons energy spectra for six laboratory angles is shown for aluminium and silicon. These results were taken using 5 X 5 cm², 1 mm thick slabs irradiated by 63 MeV neutrons. The analysis of the data indicates a good agreement between aluminum and silicon values for the four ejectiles.

Upgrade of this beam line are foreseen in a near future. This one will include a device positioning system and a user interface in the line of HIF.

V. Conclusion

Having both proton and neutron beam lines next to the HIF places CYCLONE at a very attractive place when considering SEE work. The HIF on its own represents quit a unique set-up and it is hoped it become the European version of BNL. A Web page has been designed to give the latest information on this line, additional technical data (electric connections, mechanical set-up, ...) and the beam schedule (http ://www. sc.ucl.ac.be/CYC/hif/esa.html). As low energy proton and neutron testing are of interest to the space (avionics) community, improvement in line of HIF are considered. Device positioning systems, automatic controls, additional dosimetry set-up and user interface are foreseen, but as shown already today testing can be carried out.

VI. References

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