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Novel Applications of a 235 MeV Proton Therapy Medical Cyclotron in Space Radiation Research

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Introduction

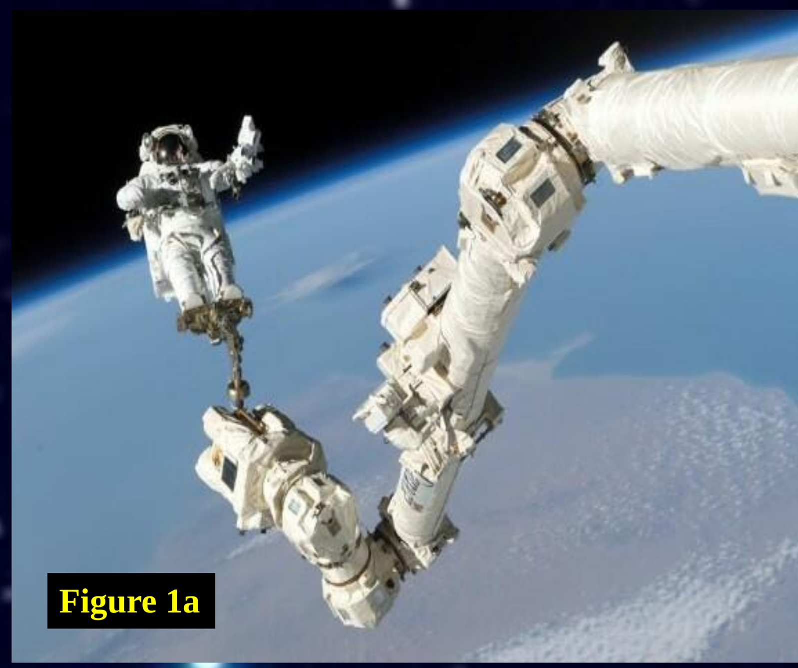
During extravehicular activity (EVA) astronauts are exposed to intense, life-threatening sporadic radiation from solar flares made of protons with a wide energy distribution (**Figure 1**). Consequently, the design of the space suits and their radiation shielding ability are vital to safety of the astronauts and ultimate success of the mission concerned.

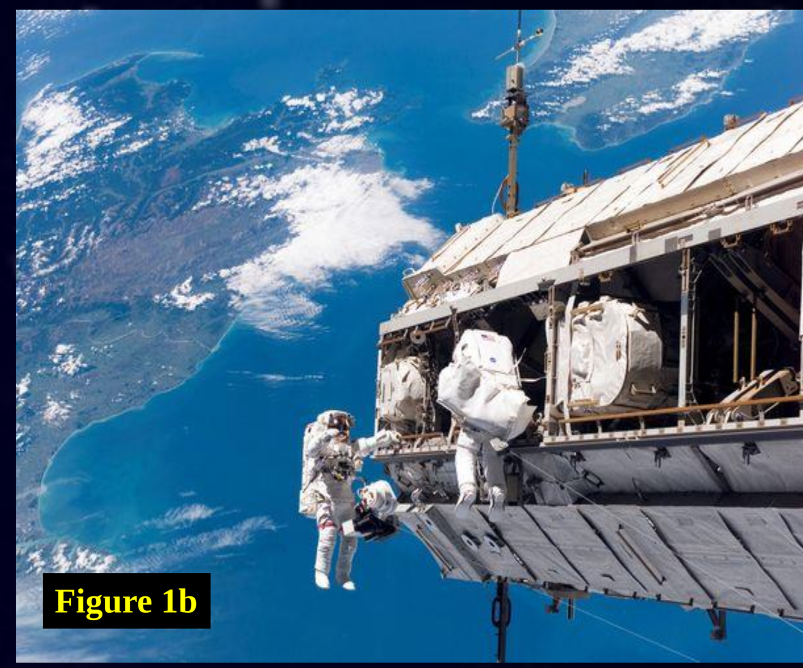
We have simulated the solar flares by reprogramming the treatment planning system (TPS) of the 230 MeV medical proton therapy cyclotron operated by WPE and developed a novel method for the testing of space suit components.

We have parameterised the historical solar flare data (proton energy versus proton flux) collected from previous mission logs and altered the conventional proton treatment planning system to replicate the solar flare spectra.

In this report we highlight the feasibility of the above irradiation set up and shielding calculation results for the Extravehicular Visor Assembly EVVA used by astronauts of US Space shuttle as well as International space station (ISS).

Furthermore, from the derived LET distribution of the transmitted protons, shown in our presentation in this conference, we will present the results of retrospectively calculated radiation doses in the eyes of the astronauts received in the previous space missions.





Figures 1 The International Space Station (ISS) astronauts during routine EVA. The astronaut (left) is harnessed to a flexible robot arm linked to hull of the ISS. During a solar flare the astronauts are exposed to a very high instantaneous proton dose.

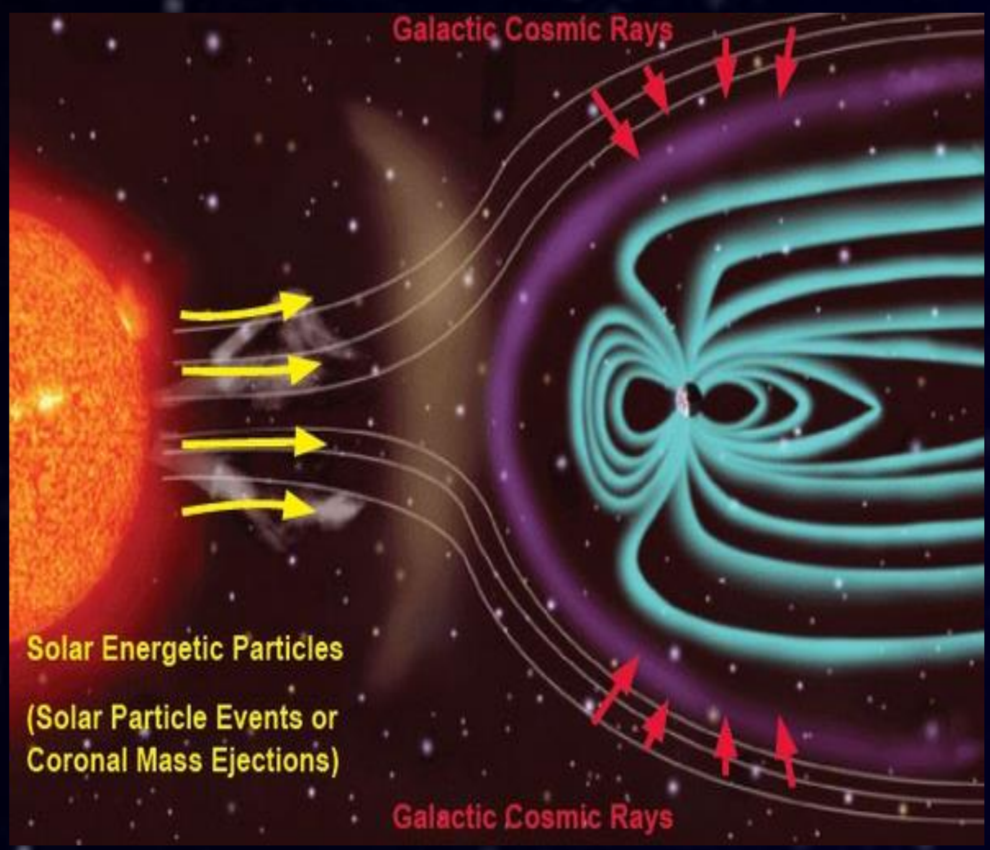


Figure 2 The superimposed (conceptual) picture of the Sun implicating the coronal activity engulfing our earth. The geomagnetic field (Van Allen Belt) enclosing the earth and directions of Galactic Cosmic Rays are also indicated.

Main Goal

Simulation of typical SFE using the 230 MeV proton therapy cyclotron at WPE (**Figure 3**) and set up a testing rig for the materials to be used to construct space suit components in particular, EVVA (**Figure 4**). Furthermore, this set up will also be used to calibrate radiation dosimeters for astronauts and radiation hardness testing of electronic components dedicated to space applications.
The eye, in particular the lens is a very radiosensitive human organ. A sudden burst of solar flare protons could result in a complete blindness to the astronaut undertaking an EVA. Hence, the efficacy, including the radiation shielding property of the visor assembly plays an important role in the human space endeavour.

Characteristics of Solar Flares

Solar flare events (SFE) are sporadic, and it is difficult to predict the duration and intensity of the radiation. The frequency of SFE varies from several events per day when the Sun is particularly "active" to less than one event every week when the Sun is "quiet", following the 11-year solar cycle (**Figure 2**)

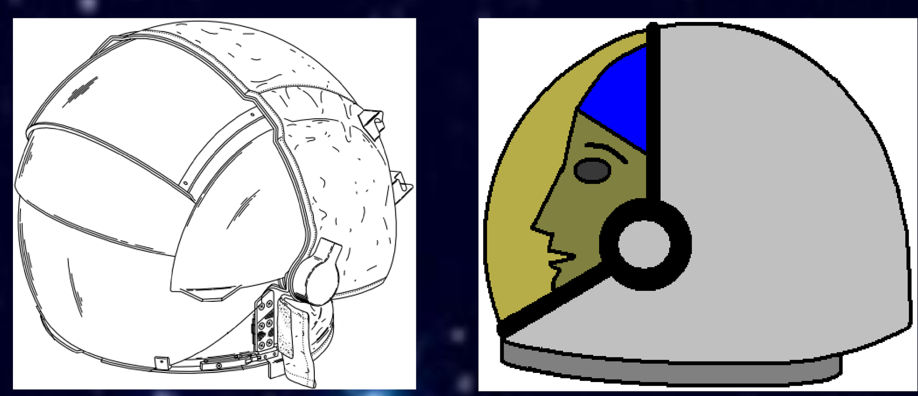


Figure 4 The EVVA considered in our work. The space suit helmet used by NASA space shuttle as well as ISS astronauts is shown in left. The figure on the right implicates the basic structure of the helmet we used in our calculations.

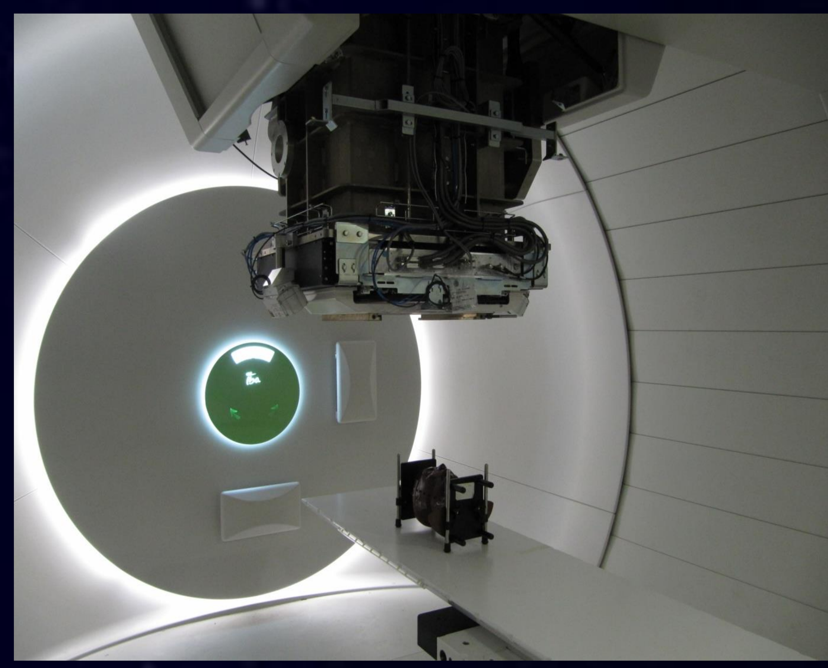


Figure 3 The proton irradiation set up at the pencil beam gantry of the WPE medical cyclotron showing an anthropomorphic head phantom for holding the Extravehicular Visor Assembly (EVVA).

Principle

As protons travel through a medium such as tissue or water, they continually loose energy and after they have travelled a set distance they deposit the rest of their kinetic energy and come to a stop.

When a single energy proton beam is incident on water, or other material, there is an almost constant flux of protons with a decreasing energy, from the initial energy at the surface to zero just past the protons range.

To simulate the proton energy spectrum from the three previous solar flare event spectra shown in **Figure 5a** the spectra were converted to the proton fluence versus the protons range in water. Using the proton therapy planning system a treatment plan was set up with layers placed at depths corresponding to each range point in **Figure 5b**, the relative weight of each layer was set to the corresponding fluence at each point on the graph. In **Figure 5c** the exposure time of the 5 x 5 cm² proton beam at 1 nA is shown as functions of proton energy.

By changing the relative weights of each of the proton energy layers any solar flare spectrum up to 230 MeV can be simulated.

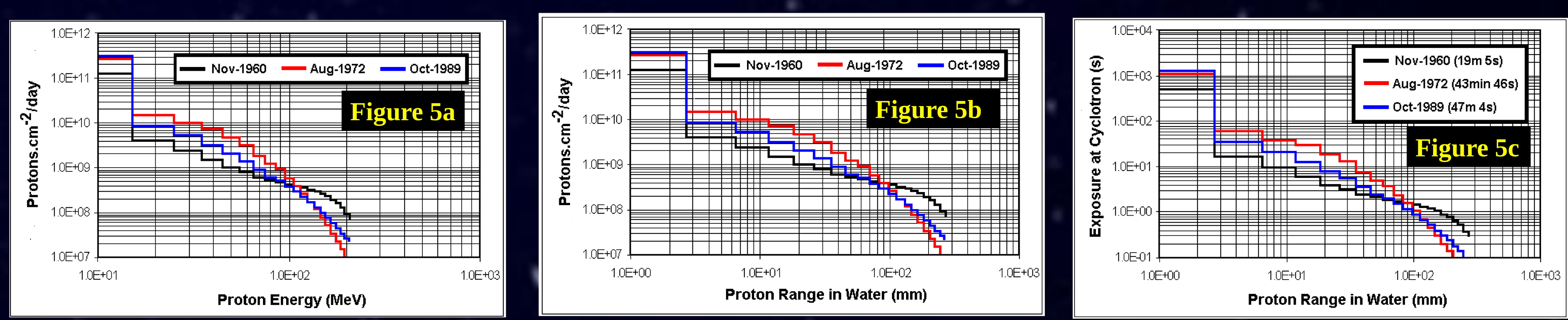


Figure 5 The proton energy spectra of three previous solar flare events. **(a)** The spectra as taken from the records in proton fluence vs. energy. **(b)** the spectra converted to fluence vs. proton range in water. **(c)** the spectra input into the treatment planning system in irradiation time vs. proton range.

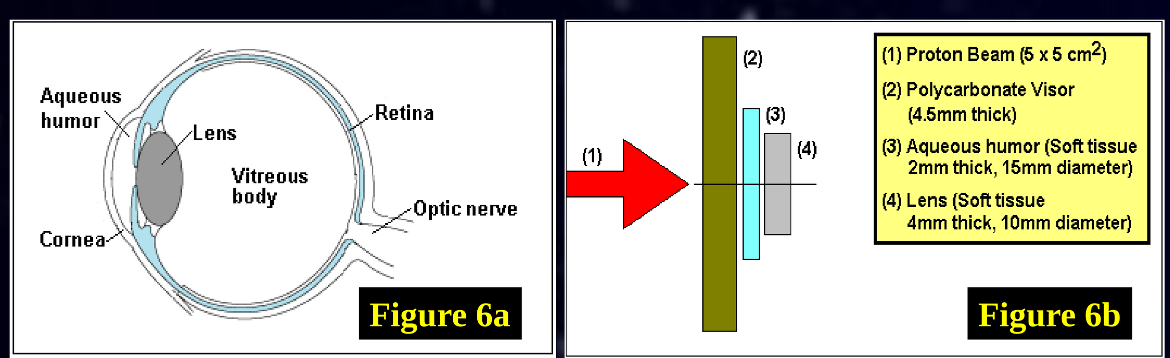


Figure 6 (a) A schematic diagram of a human eye **(b)** the model of the lens used in the calculation.

Proton Dose and LET calculation

The anatomy of human eye showing the essential parts is depicted in **Figure 6a** and the physical model of human eye used in dosimetry calculations is shown in **Figure 6b**. The proton dose (D_p) and dose averaged LET (LET_{av}) in the lens were calculated using equations 1 and 2 respectively: (**Figure 6b**).

$$D_p = \frac{1.602 \times 10^{-13} a_l \sum_{i=0}^{n} \Delta E_i \varphi_i}{m_l} \quad \text{Gy)} \qquad (1)$$

$$LET_{av} = \frac{\sum_{i=0}^{n} \Delta E_i \varphi_i}{t_l \sum_{i=0}^{n} \varphi_i} \times 10^{-3} \quad (\text{keV}/\mu\text{m}) \qquad (2)$$

where a_l, m_l and t_l represent the cross section area (0.79 cm²), mass (314 mg) and thickness (4 mm) of the lens respectively. ΔE_i and ϕ_i stand for energy loss of the protons of ith bin in the lens and corresponding proton fluence.

The calculated proton dose rate and energy averaged LET in the lens of astronaut's eyes corresponding to the three solar flare events are shown in **Figure 7**.

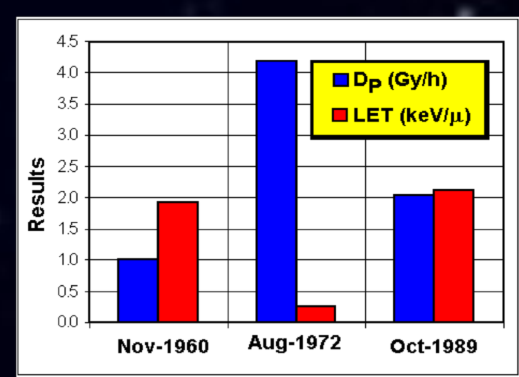


Figure 7 The calculated dose and average LET to astronaut`s eye lens.

Summary and Conclusion

We have demonstrated the feasibility of using a proton therapy cyclotron like the IBA Proteus 230 at WPE, with a maximum energy of 230 MeV, to simulate the solar flare protons.

The energy of solar flare protons peaks at 20 MeV and rapidly drops to about four orders of magnitude at 200 MeV, typical energy of a proton therapy cyclotron, the intensity of the high-energy tail is considered to be negligible. The biological dose delivered to critical organs of astronauts is predominantly due to protons of energy below 100 MeV.

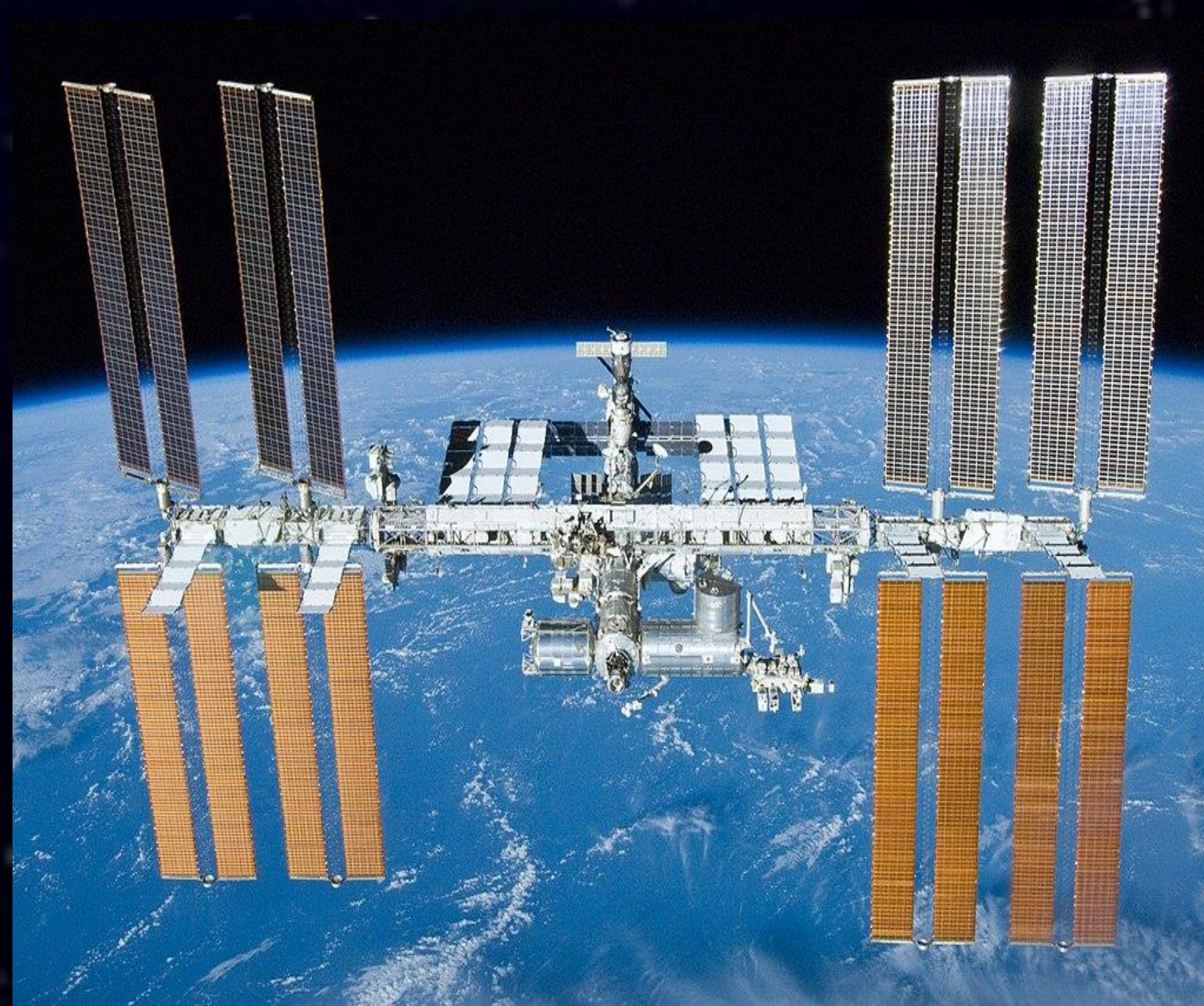
The ambient (background) dose in space during EVA is caused by galactic cosmic rays as well as trapped particles which can be well predicted. On the other hand, the occurrence of solar flares is unpredictable and the magnitude of delivered biological dose could be many times higher than the background dose.

The eye (lens) of the astronaut is a vulnerable organ during EVA, which is protected against radiation by merely a few millimetre thick polycarbonate visor. This motivated us to develop this irradiation set up to validate the shielding efficacy and structural integrity EVVA, in particular the polycarbonate visor.

The operation of the WPE Space Radiation Testing Rig is fully integrated to the standard treatment planning system dedicated to routine cancer radiotherapy with an irradiation area of up to 30x40 cm² .

In our present calculations we have ignored the production of secondary particles, predominantly fast neutrons. A detail Monte-Carlo simulation is under way to simulate the characteristics of secondary neutrons.

The rig could also be used for radiation hardness testing of electronic components to be used space radiation environment.



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