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 235 MeV proton medical 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 missions 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 Vehicle (EVA) 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 realistic size of retrospective calculated radiation doses in the eyes of the astronauts received in the previous space missions.

Main Goal
Simulation of typical SFE using the 235 MeV proton therapy cyclotron at WPE (Figure 3) and set up a testing regime for the materials to be used to construct space suit components in particular, EVA (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 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 endeavor.

Characteristics of Solar Flares
Solar flare events (SFE) are sporadic and it is difficult to predict the duration and intensity of the event. 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).

Proton Dose and LET calculation
The anatomy of human eye showing the external part is depicted in Figure 6a and the physical model of human eye used for dosimetric calculations is shown in Figure 6b. The proton dose (Dp) and energy averaged LET (LETav) in the lens were calculated using equations 1 and 2 respectively (Figure 6b).

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D_p = \frac{N \cdot \Sigma E \cdot \rho \cdot \frac{\sigma_{\text{p}}}{m_{\text{p}}}}{0.632 \times 10^{-5} \Sigma E \cdot \rho \cdot \frac{\sigma_{\text{p}}}{m_{\text{p}}}}
\]

\[
LET_{av} = \frac{\Sigma E \cdot \rho \cdot \frac{\sigma_{\text{p}}}{m_{\text{p}}}}{0.632 \times 10^{-5} \Sigma E \cdot \rho \cdot \frac{\sigma_{\text{p}}}{m_{\text{p}}}}
\]

where \(N\) is the number of protons in the beam, \(E\) is the energy of the protons, \(\rho\) is the mass energy absorption coefficient for protons, \(\sigma_{\text{p}}\) is the mass stopping power of protons, \(m_{\text{p}}\) is the mass of the proton, \(\Sigma E\) is the total energy, and \(\rho\) is the mass energy absorption coefficient for protons.

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

Summary and Conclusion
We have demonstrated the feasibility of using a proton therapy cyclotron like the IBA Proton 235 at WPE, with a maximum energy of 235 MeV to simulate the solar flare protons.

The energy of solar flare protons can be as high as several hundred MeV, therefore energy of proton therapy cyclotron, all necessary in the high energy end is considered to be negligible. The biological dose delivered to critical organs of astronauts is predominantly due to penetration of energetic MeV protons.

The solar background dose in space during CME 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 a sporadic event of short duration but of high dose. Solar proton events could be many times higher than the background dose.

The design of the visor is a valuable organ during EVA, which is protected against radiation by basically a few millimeters thick polycarbonate visor. It is motivated to develop this irradiation set up to study the shielding efficacy and structural integrity EVA, in particular the polycarbonate visor.

The purpose of the WPE Space Radiation Testing Rig is to faithfully simulate the standard irradiation planning system dedicated to cancer radiotherapy with an irradiation time of up to 30-60 min.

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

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

References
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