A new low energy irradiation facility at BNL

P. Thieberger

Collider Accelerator Department, Brookhaven National Laboratory

The purpose of this article is to introduce a new low energy ion irradiation facility for radiobiology being implemented at Brookhaven National Laboratory's Tandem van de Graaff accelerator facility. Laboratory testing of radiation effects is an important tool to enable a better understanding of damage mechanisms and for the development of countermeasures and risk assessments. This applies both to biological effects as well as to effects on computer components. In both cases there are two complementary approaches. On the one hand, it is critical to replicate exposures to the high energies and large variety of ions present in the galactic cosmic ray spectra and in solar particle events. On the other hand, it may be useful to study the effects of a single ion species across a wide range of energy to detail specific effects under controlled conditions.

Low energies may be of particular interest for the second approach since the high energy ions lose energy when traversing spacecraft materials and produce the maximum damage just before coming to rest in the astronauts' bodies. Thus, energies lower than most present in the primary cosmic ray spectrum are appropriate to cover the range of maximum LET (the Bragg peak) but, due to their short ranges, they are only useful to perform studies with thin samples such as cell cultures. Figure 1 illustrates the very large range of LET values and penetration depths in water (or tissue) for iron beams from 10 keV per nucleon to 1 GeV per nucleon.

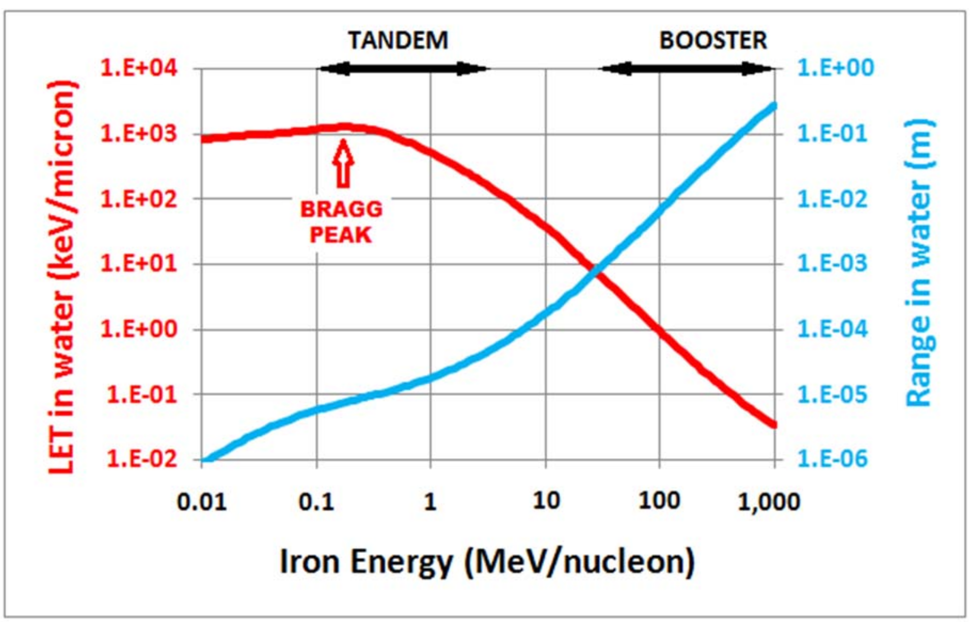

Figure 1: LET values and ranges of iron ions in water for energies from 10 keV per nucleon to 1 GeV per nucleon [1]. The energies available from the BNL Booster and Tandem accelerators are indicated.

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There are currently two ion irradiation facilities at Brookhaven National Laboratory (BNL) where radiation effects studies are conducted. One is the NASA Space Radiation Laboratory (NSRL) [2)] which began operations in 2003. It uses ion beams from a synchrotron accelerator called the AGS Booster[3)] that provides the entire range of ion species from protons to uranium at kinetic energies from 50 MeV to 1 GeV per nucleon. Radiobiology research with moderate to high energy beams is conducted here, but radiation effects on space electronics are also evaluated at this facility, and some physics and detector experiments are also performed.

The other BNL accelerator conducting space radiation effect studies is the Tandem van de Graaff facility. To date only electronic devices, optical devices, photoelectric cells, ion detectors and solar sail materials have been exposed to these low energy beams. Most of the studies are conducted in a large well-instrumented vacuum chamber, the Single Event Upset Test Facility (SEUTF) [4)] developed in 1987 through a collaboration with NASA, the National Security Agency (NSA), the Naval Research Laboratory (NRL), and the US Army Space and Strategic Defense Command (USASSDC). As an important part of this facility a high precision dosimetry chamber was designed and installed. This system is still actively used and improvements have been implemented over the years. The new radiobiology facility we describe here, designed to irradiate samples in air, is installed just behind the SEUTF chamber and will take full advantage of the existing sophisticated dosimetry system.

Figure 2: The BNL Tandem van de Graaff Facility building located .5 mile from the Medical and Biology Departments and 1.1 miles from the NSRL facility.

The BNL Tandem Facility[5)] (see Figs. 2 and 3) consists of two upgraded model MP Tandem van de Graaff accelerators. These two accelerators operate independently and have been used until now to provide the heavy ion beams to the Relativistic Heavy Ion Collider (RHIC) accelerator complex, including the NSRL facility. Beams from these accelerators are also used for the applied research mentioned above and for the irradiation of plastic films for the fabrication of ultra-fine-pore track-etched filter materials. Over the last several years, about 30% of the beam time has been used for these non-nuclear physics applications. More time will now become available as the RHIC complex (including NSRL) transitions to a new source of heavy ions; the Electron Beam Ion Source (EBIS) [6].

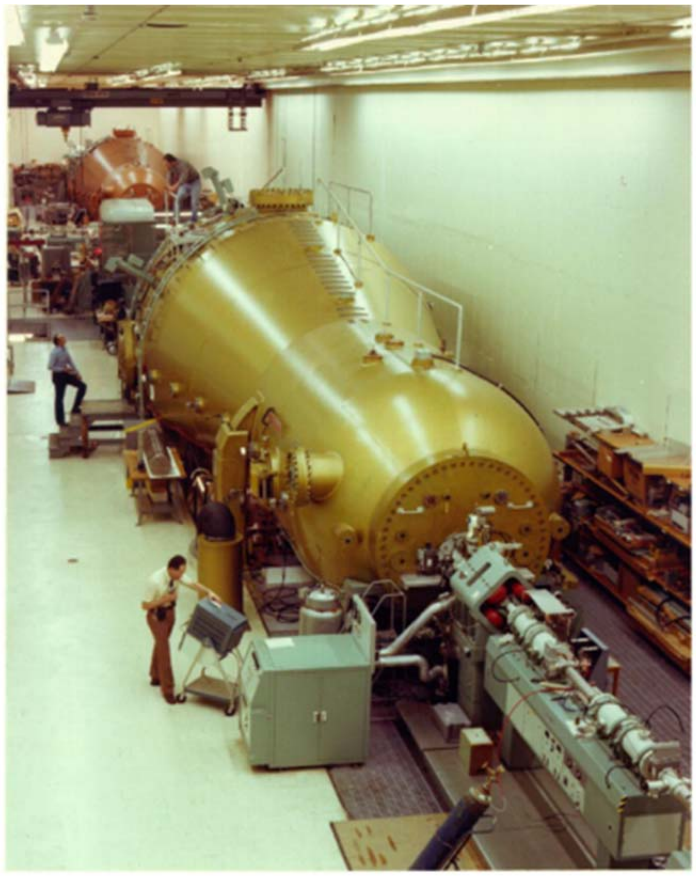

Figure 3: The BNL Tandem van de Graaff facility's two model upgraded MP accelerators. Negative ions are injected and accelerated through an evacuated acceleration tube to a potential as high as 15 MV at the center of the pressure vessel containing the insulating gas (SF_6 and N_2 at ~10 atmospheres). After a number of electrons are removed as the beam traverses a thin carbon foil, the now positive ions are accelerated back to ground potential and transported to the irradiation areas.

The location of the new irradiation enclosure is outside of the vacuum and just downstream of the SEU test chamber as shown in Figs. 4 and 5. The dosimetry system is common to both applications. Appropriate beam divergence corrections are calculated and applied in each case. A specially designed very thin window installed just downstream of the SEU chamber allows the ions to emerge from the vacuum. The window must be very thin to avoid excessive energy loss of these low energy ions. The successful design of this special window described below was the main challenge that had to be overcome to make these ions available for radiobiology experiments.

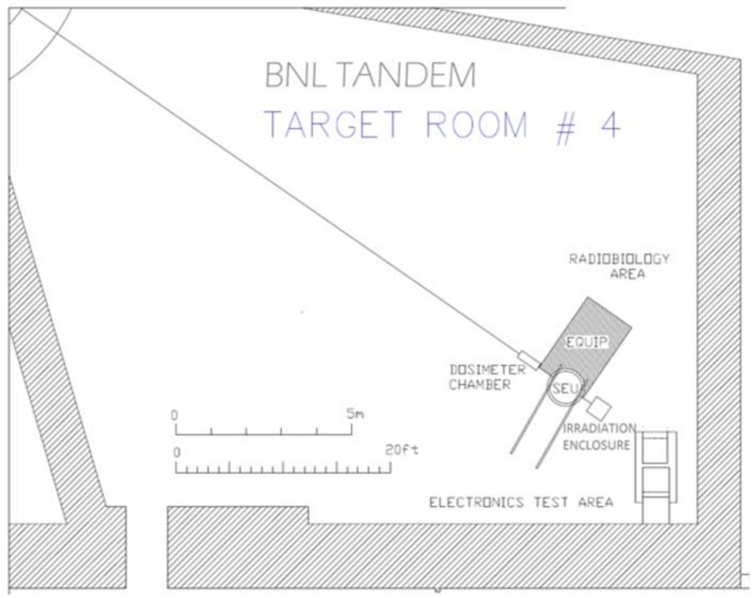

Figure 4: Location of the new radiobiology irradiation enclosure shown in a plan view of the target room. The long beam line allows the beam to spread resulting in good uniformity across the central portion that is used for the irradiations.

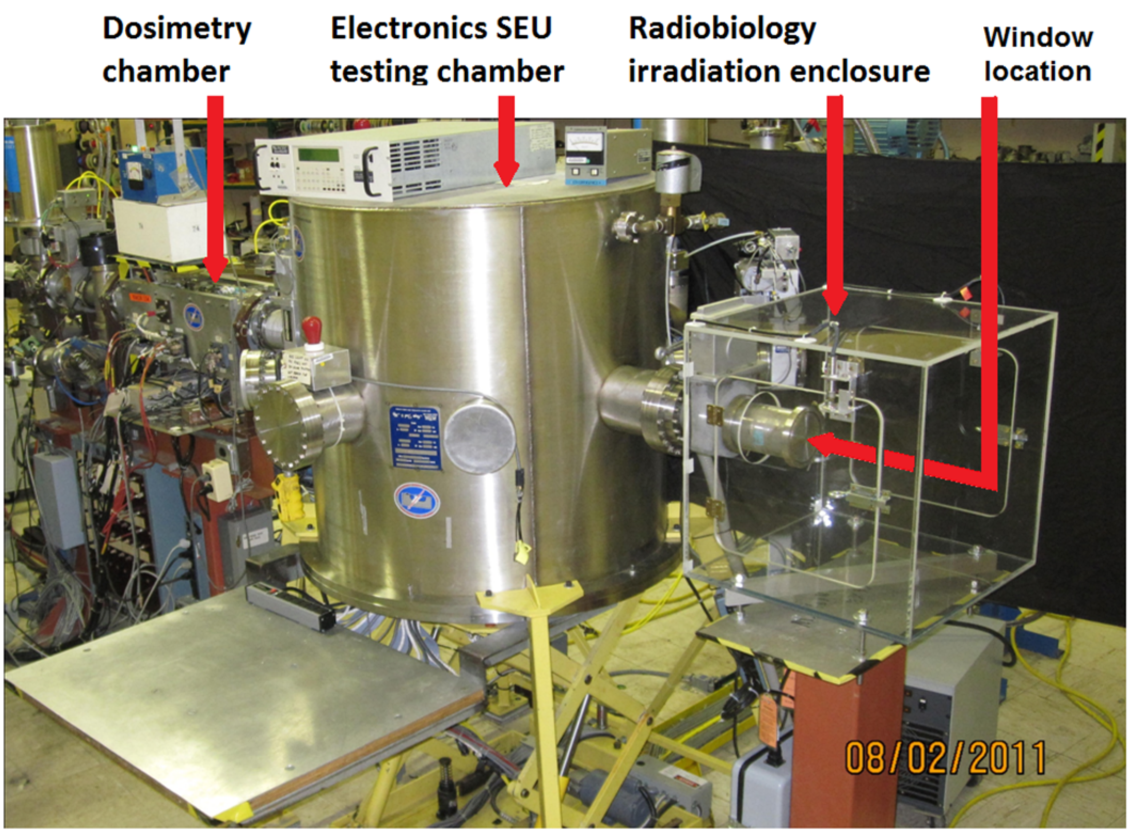

Figure 5: The new radiobiology irradiation enclosure is shown at the right of the picture, the Single Event Upset Test Facility (SEUTF) chamber in the middle and the dosimetry chamber used for both at the left.

In Figure 5, the large SEUTF chamber is in the middle of the photograph, flanked by the dosimetry chamber on the left and the new radiobiology irradiation enclosure on the right. The ion beams will go through the SEUTF chamber before entering the irradiation enclosure. A very thin but strong vacuum window is necessary to allow the ions to exit the vacuum without losing too much energy. The material chosen is a Co, Cr, Ni and Fe based alloy called HAVAR that is available[7)] in thicknesses down to 100 micro inches or 2.54 μm. Calculations indicated that the specified strength of this material should allow fabrication of an 11-mm diameter circular window capable of sustaining the pressure difference with a safety factor of ~2. Such a window was fabricated and tested.

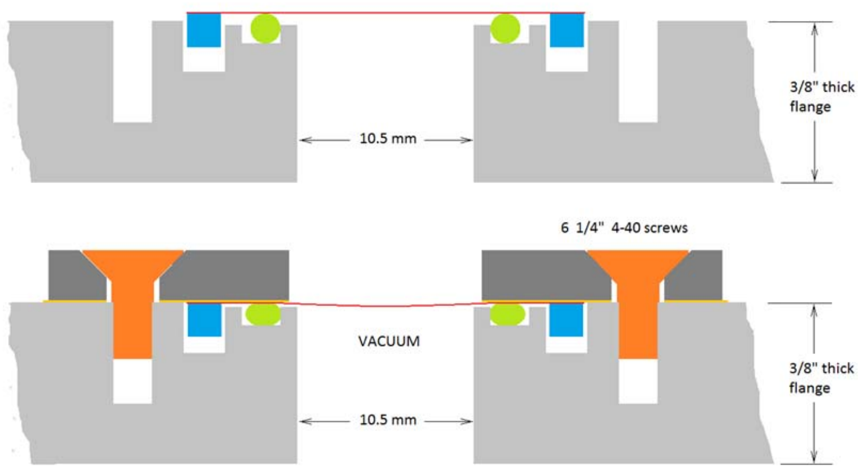

Figure 6: Schematic cross section of the Havar window arrangement. At the top, the window (red) glued to its stainless steel ring (blue) rests on the o-ring (green) on top of the aperture machined into a standard stainless steel 3/8" thick vacuum flange (gray). At the bottom, the o-ring has been compressed by the top flange (dark gray) and six screws (orange). Between the top flange and the Havar film there is a thin lubricated Teflon washer (yellow).

The unusual aspect of the vacuum window design [8)] shown in Fig. 6 is the separation of the mechanical support function and the vacuum sealing function. The mechanical support is achieved by gluing the film to stainless steel rings while the vacuum seal is achieved by clamping the foil between a lubricated Teflon disc and the vacuum sealing o-ring. Friction is thus minimized and contact with rough surfaces is avoided. Bursting of these windows was tested by using nitrogen at slowly increasing pressures. It was determined that the expected safety factor of 2 has been achieved. Accelerator protection against window ruptures is nevertheless provided through the use of an interlocked fast acting valve. A schematic of the window design is shown in Fig. 6.

Ion beam transmission tests through one of these widows were performed using a 4.3 MeV per nucleon iron beam, and the results are shown in Fig. 7. The energy losses in the window and in air were measured and found to be exactly as expected.

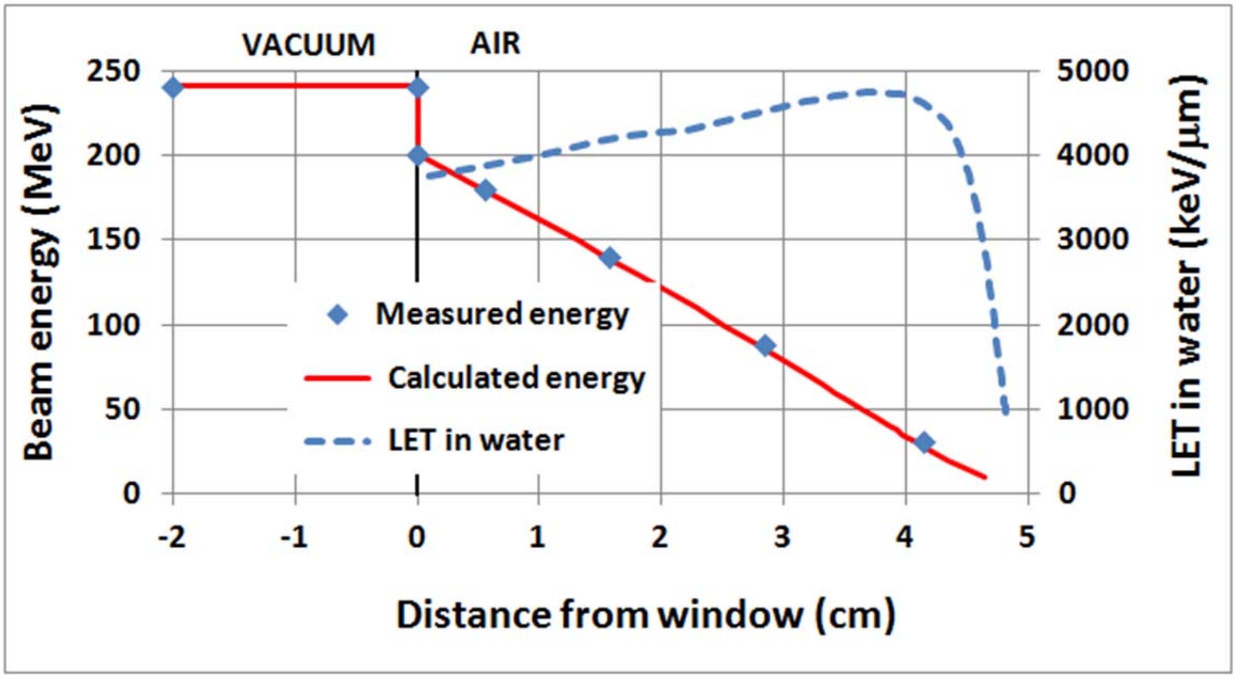

Figure 7: Energies of an iron beam, first in vacuum with and without interposing the 95-microinch thick HAVAR window and then in air as function of the distance from the window. The errors are smaller than the points. The initial energy was 241 MeV (or 4.3 MeV/nucleon) and the energy loss values in HAVAR and in air are well reproduced by the red curve calculated by using results from the SRIM code [1)] The dotted line shows LET values in water, which vary as the beam loses energy.

Examples of ion species and maximum energies that will be available for radiobiology research are listed in Table 1. These values take into account the energy lost in the window and in 5 mm of air. The available energy ranges for some of these ions and the corresponding LET values are shown in Fig. 8.

Table 1: Maximum energies and corresponding LET values and ranges in water for some of the heavy ions that will be available for radiobiological studies at the BNL Tandem. Lower energies may also be selected.

Ion	Z	Energy from accelerator (MeV/u)	Energy at sample (MeV/u)	LET in water (KeV/µm)	Range in water (µm)	(mm)
p	1	28.8	28.8	2	8050	8.05
Li	3	9.6	9.6	50	657	0.66
B	5	7.9	7.8	147	348	0.35
C	6	8.3	8.2	208	282	0.28
O	8	7.1	6.9	400	179	0.18
Si	14	5.8	5.3	1210	91	0.09
Fe	26	4.6	3.6	3730	55	0.06
Ge	32	3.7	2.6	5400	44	0.04
Ag	47	2.9	1.7	8250	35	0.04
Au	79	1.7	0.8	11400	30	0.03

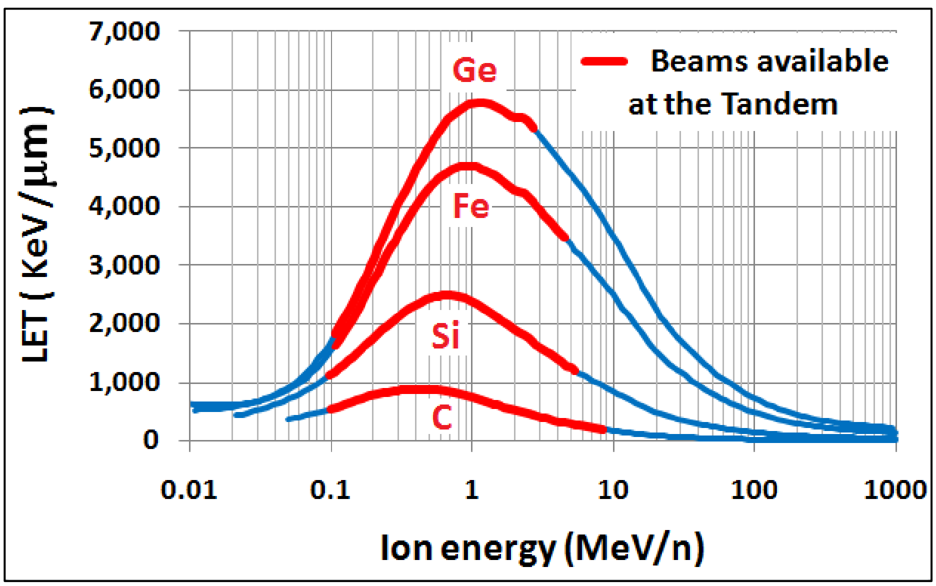

Figure 8: LET values in water as function of energy [1)] for four of the ion beams available at the BNL Tandem. The available energies are indicated in red.

As the ions penetrate into a target they gradually lose energy and their LET values change. This variation of LET and energy as function of penetration depth into a water (or tissue) target is illustrated in Figs. 9 and 10 for six of the beams available at the BNL Tandem.

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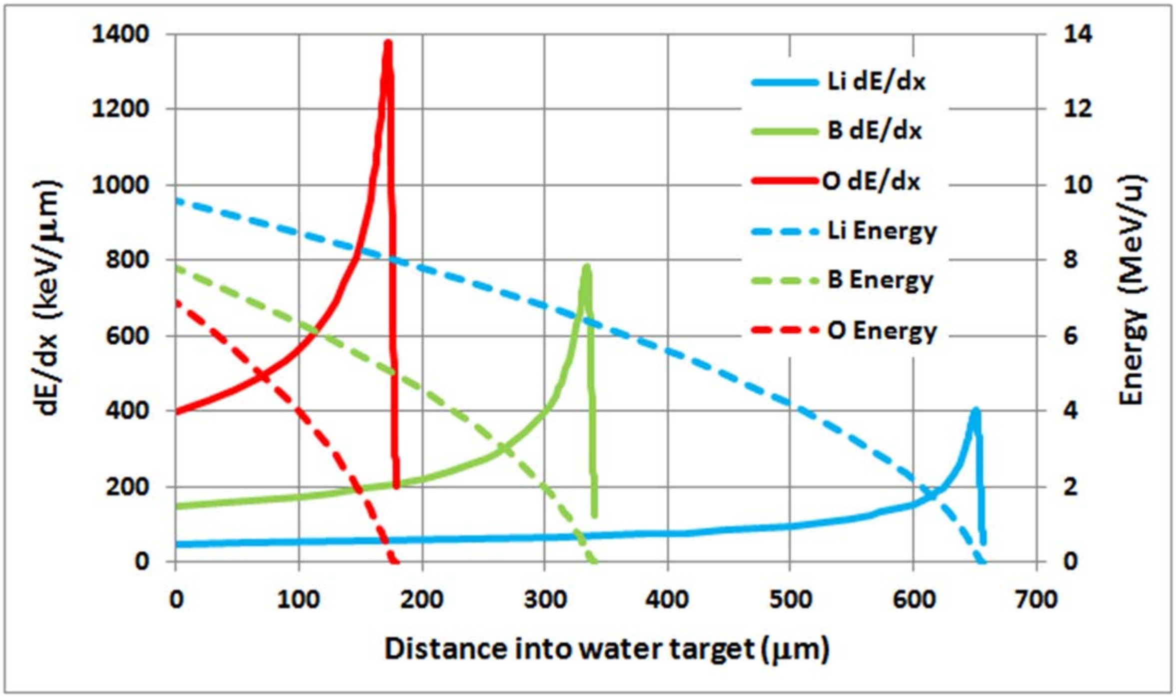

Figure 9: Energy and LET values in water (or tissue) as function depth for three beams available at the BNL Tandem accelerator facility calculated using results from the SRIM code [1)] .

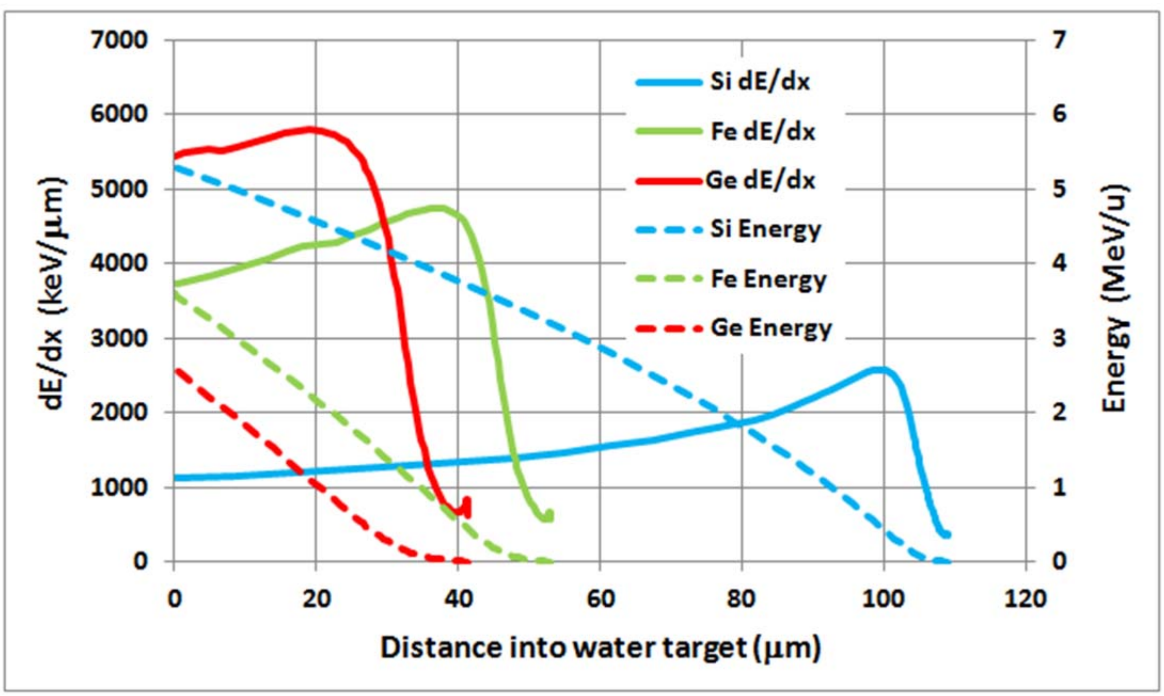

Figure 10: Energy and LET values in water (or tissue) as function depth for three beams available at the BNL Tandem accelerator facility calculated using results from the SRIM code [1)] .

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The new radiobiology research facility at the Tandem extends the ion energy range available for radiobiology experiments at BNL. Full advantage will be taken of the existing infrastructure including excellent dosimetry, the established user program, and the support functions developed by the Medical and Biology Departments for NSRL. The very short penetration ranges of these low energy ions close to the Bragg peak will require the development of experimental techniques somewhat different from the ones used at higher energies. For example, it may be of interest to considering the use of ultra-thin and strong sample substrates or covers made of graphene films. The close proximity of the new facility to the NSRL and to the BNL Biology and Medical Departments may prove convenient for many researchers.

References:

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