A VERY THIN HAVAR FILM VACUUM WINDOW FOR HEAVY IONS TO PERFORM RADIOBIOLOGY STUDIES AT THE BNL TANDEM*

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Abstract

Heavy ion beams from the BNL Tandem Van de Graaff accelerators will be made available for radiobiology studies on cell cultures. Beam energy losses need to be minimized both in the vacuum window and in the air in order to achieve the ranges required for the cells to be studied. This is particularly challenging for ions heavier than iron. The design is presented of a 0.4” diameter Havar film window that will satisfy these requirements. Films as thin as 80 microinches were successfully pressure tested. We discuss design considerations and present pressure and vacuum test results as well as tests with heavy ion beams

INTRODUCTION

The use of energetic heavy ions for radiobiological studies requires the ion beam to exit the accelerator vacuum through a thin window so that the biological specimens can be irradiated in air. This is not problematic for ions of many hundreds of MeV per nucleon as used for example at the NASA Space Radiation Laboratory (NSRL) at BNL [1] since the windows can be fairly thick without significant energy losses. This is not true at lower energies of up to ~ten MeV per nucleon as available for example at the BNL Tandem Facility [2], where such energy losses become very significant, often limiting severely the energy remaining for irradiation. The problem is of course much less severe for light ions, and there are a number of low energy facilities where such studies are being conducted mostly with protons and alpha particles. In the US the prime example is the RARAF facility [3] and a list of European facilities is provided in reference 4.

The purpose of the present work is to extend as much as possible the mass range of ions useful for radiobiology that can be delivered by the BNL Tandem Van de Graaff accelerators. We investigated the possible compromises between aperture size on the one hand and window thickness and corresponding energy losses on the other. We then designed, fabricated and successfully tested a thin 1.1 cm diameter window capable of transmitting for example 200 MeV (3.6 MeV/n) iron ions with an initial accelerator energy of 240 MeV. In the following sections we describe these developments and tests.

CHOICE OF WINDOW DIAMETER

Due to the significant energy losses when traversing the window there is a tradeoff between the ion energy that can be delivered and the maximum possible window diameter since the larger the diameter the thicker the film needs to be. The material of choice is a very strong alloy of Co, Cr, Ni, and Fe named Havar that has been used before for vacuum window applications [see e.g. reference 5]. As shown in Fig. 1, we used their bursting pressure test results to estimate energies (expressed as ranges in water) for four heavy ion beams of interest to the biologists. Before energy loss, these beams are 99 MeV C, 187 MeV Si, 255 MeV Fe and 268 MeV Ge.

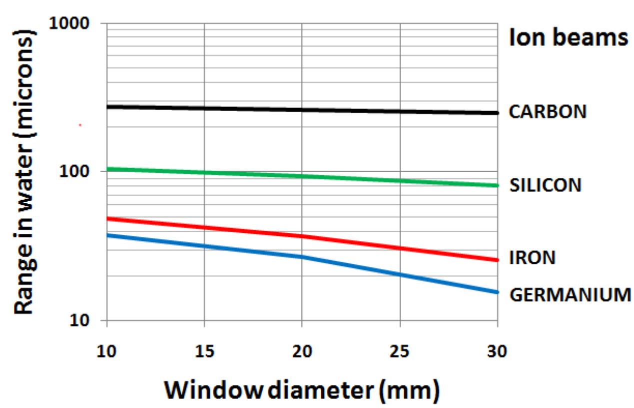

Figure 1: Initial estimates for possible Havar window diameters based on scaling from an experiment [5] where a 100 microinch thick window, 4.7 mm in diameter was shown to burst at 133 psia. A safety factor of 2 was used here.

Since the heaviest ions are of greatest interest and a minimum range in water of ~40 microns is required [6], it was decided to chose a diameter close to 10 mm corresponding to a required Havar film thickness of about 100 microinches which is close to the thinnest material available [7]

WINDOW DESIGN

To approach a bursting pressure close to the theoretical limit given by the ultimate strength of the film it is necessary to minimize friction at the periphery and to

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avoid contact of the film with sharp or rough edges. Figure 2 shows a cross-sectional view of the design. The film is glued with an epoxy adhesive to a 2 cm ID ring, and o-ring sealed by compression through a lubricated Teflon washer. Separating the functions of vacuum sealing and of radial support is a practical solution that optimises performance. The axial force on the film due to the pressure differential is entirely supported by the lubricated o-ring thus minimizing friction.

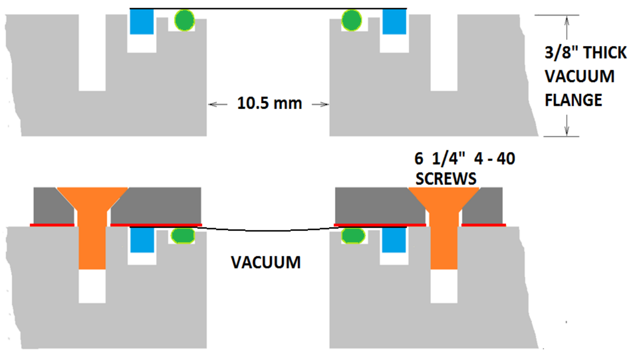

Figure 2: Schematic cross section of the Havar window arrangement. At the top, the window (black) glued to its stainless steel ring (blue) rests on the o-ring (green) on top of the aperture machined into a standard stainless steel 3/8" thick vacuum flange (gray). At the bottom, the o-ring has been compressed 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 (red).

PRESSURE AND VACUUM TESTING

Before installing the window on the vacuum chamber, rupture tests were conducted with compressed nitrogen gradually pressurizing the air-side of the window and recording the pressure value at which the window failed. This was repeated several times. Table 1 shows the results for the 95 microinch thick window. Vacuum leak rates were determined with a helium leak detector. Similar tests were conducted with 80 microinch thick material. While the bursting pressures were only slightly lower, the leak rates were substantially higher.

Table 1: Pressure and Vacuum Test Results

Havar thickness	Window	Vacuum leak rate	Bursting Pressure	
	#	(Atm. cc/s)	(PSIG)	(Atm.)
95 microinches	1	1.25E-5	30.5	2.08
	2	1.15E-5	36.5	2.48
	3	1.15E-5	36.0	2.45
	4	1.2E-5	26.0	1.77
	5	1.06E-5	47.0	3.20

The observed leak rates may be due to pinholes in the film or more likely to helium diffusion through the thin material. In any event the values measured are quite compatible with the large pumping speed installed on the vacuum chamber where the window will be mounted.

The measured bursting pressures provide a safety factor of about 2 which is adequate in view of the additional accelerator protection afforded by a fast vacuum valve system installed in the beam line.

The measured bursting pressure can be compared to a calculated value of 35 psi obtained using formulas for pressure loads on membranes given in reference 8. For these calculations an ultimate strength of 2.7 E5 psi for cold rolled Havar was assumed.

These measurements and calculations show that we have successfully developed a window that extends the available range of heavy ions in air that are of interest for radiobiological studies.

TESTING WITH A HEAVY ION BEAM

The ion beam chosen for these tests was a 241 MeV (4.3 MeV/n) iron beam. A silicon surface barrier detector was used with its preamplifier and its amplifier connected to a pulse height analyzer to first measure the ion energy loss caused by just the window material with vacuum on both sides. For this purpose the detector was installed in the Brookhaven Tandem Single Event Upset Test Facility's [2] vacuum chamber and the window could be inserted in the path of the ions with an externally controlled actuator. Two energy spectra were recorded; one with and the other without the window inserted. Also two pulse generator calibration peaks were recorded to measure a possible ADC zero offset.

Then the window was installed on the chamber, the chamber was again evacuated and the detector was mounted in air, next to the window, in such a way that its distance to the window could be adjusted.

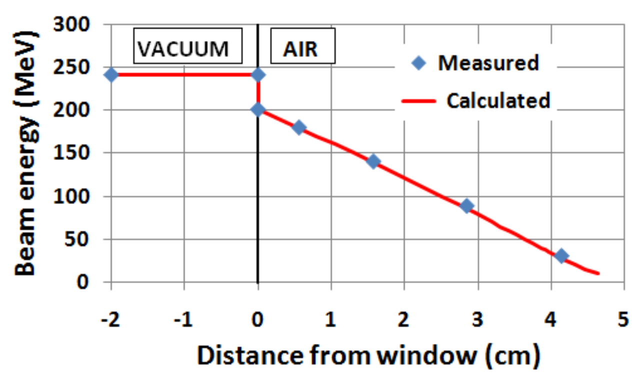

Figure 3: Energies of an iron beam, first in vacuum with and without interposing the 95 microinch thick HAVAR window and then in air as function of the distance from the window. The initial energy was 241 MeV and the energy loss values in HAVAR and in air are well reproduced by the red curve calculated by using results from the SRIM code [9].

The result of these energy measurements and the predicted energy loss profile calculated using the code SRIM [9] are shown in Fig.3. The known energy of the beam was used to determine the pulse height-to-energy conversion factor. We can conclude that the window thickness is as advertised (which was also confirmed by weighing) and that, not surprisingly, the absorption in air is as expected. We see that it takes about 1 cm in air to lose as much energy as is lost in the window.

HEAVY ION BEAMS THAT WILL BE AVAILABLE FOR RADIOBIOLOGY STUDIES AT THE BNL TANDEM

Based on the tests described above we now know the energies of the heavy ions we will be able to deliver for radiobiology research. Examples of such beams are listed in Table 2. The values given correspond to beams that traversed a 95 microinch thick Havar window and 0.2" (0.51 cm) of air which is close to the minimum possible as determined by the geometry of the window. Also listed are the linear energy transfer (LET) values at the entrance of the sample and the ranges in water.

Table 2: 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.

Ion	Z	Energy from accelerator	Energy at sample	LET at sample	Range in water
		(MeV/n)	(MeV/n)	(KeV/μm)	(μm)
p	1	28.8	28.8	2.02	8050
C	6	8.3	8.2	208	282
Si	14	5.8	5.3	1.13E3	110
Fe	26	4.6	3.6	3.73E3	55
Ge	32	3.7	2.6	5.40E3	44
Ag	47	2.9	1.7	8.25E3	35
Au	79	1.7	0.8	1.14E4	30

Before actual radiobiology studies can be conducted, the experimental area will need to be prepared to adhere to all the hygiene and safety requirements in a way that is compatible with the activities ongoing in this area.

In figure 4 we show how the LET values of C, Si, Fe and Ge ions vary as function of their energy [9], and we indicate the energy ranges of these ions that will become available for radiobiology studies at the BNL Tandem. While these energies could also be reached starting with higher energy ions (e.g. from at the NSRL facility) by using absorbers, such degraded beams would be less monochromatic, less pure and more expensive to deliver.

The galactic cosmic ray flux of these ions peaks at around 1000 MeV/amu, but the lower energies are reached through absorption in spacecraft materials and in human tissues. For example, the range of 1000 MeV/n iron ions in water is 27.5 cm [9]

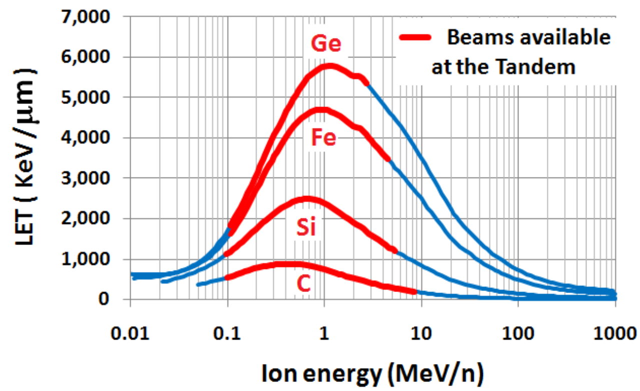

Figure 4: LET values in water as function of energy [9] for four of the ion beams available at the BNL Tandem. The available energies are indicated in red.

CONCLUSIONS

The tests described in the previous sections were conducted behind the large vacuum chamber used by the Single Event Upset Test Facility (SEUTF) [2]. The uniform beams and precise dosimetry system developed and perfected over many years for the SEUTF will be used for this application as well.

By developing and testing a thin Havar beam window we have demonstrated the capability of delivering a range of heavy ions from the BNL Tandem that are of interest for radiobiological studies. The large LET values of some of these beams exceed by far the LET values available without absorbers at the other facilities used for studying the radiobiological effects of energetic heavy ions.

We are grateful for very helpful advice received from Dr. Peter Guida.

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