Ground-based Testing of Bubble Detectors

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Introduction

- The CSA and IBMP has been using bubble detectors for neutron dosimetry in space for many years.
- Despite this fact, major issues remain unresolved regarding the use of bubble detectors in the space radiation environment
- Principle among these issues is the sensitivity of bubble detectors to primary energetic protons and HZE particles.
  - What is the mechanism by which radiation—protons, HZE particles, in addition to neutrons—produces bubbles in the sensitive volume of a bubble detector?
  - If bubble detectors are only sensitive to neutrons, again, what is the mechanism of bubble formation?

Preliminary Ground-based Testing

- Using bubble detectors and a bubble detector reader of the same type as that aboard the ISS (on loan from the CSA), we have carried out several preliminary experiments to quantify the sensitivity of bubble detectors to energetic protons.
- Irradiations were made to protons of energies ranging from 80 to 230 MeV at the ProCure Proton Therapy Center in Oklahoma City, OK USA.
- This energy range is similar to that of trapped protons encountered when the ISS traverses the SAA and during larger SPEs.

Proton Beam Parameters

Energy (MeV/amu)	β (*v*/*c*)	$LET_\infty H_2O$ (keV/μm)	Range (cm in H_2O)
78	0.384	0.88	5.0
162	0.522	0.52	18.33
226	0.592	0.42	32.37

Experimental Results

First Configuration: **Along the proton beam**

- The bubble detector has been irradiated with 3 different energies
- The proton sensitivity has been calculated
- Results of the experiments are listed in Table 1

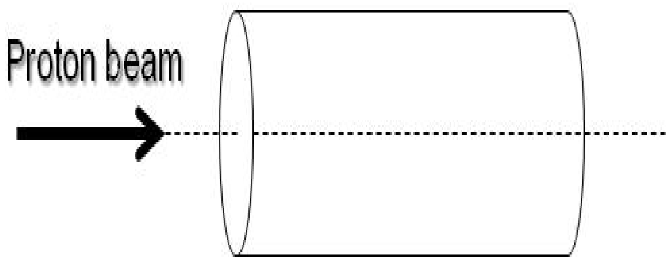


Table 1: Results of the experiments along beam

Ep, MeV	BD number	Proton fluence, p.cm-2	# of bubbles	Proton sensitivity, bubbles/(p.cm-2)
78.2	9020	(2.363±0.236).107	243±16	(10.290±1.222).10-6
162	8116	(10.369±1.036).107	432±21	(4.166± 0.462).10-6
226	8721	(15.089±1.508).107	502±22	(3.327± 0.364).10-6

Experimental Results

Second configuration: Perpendicular to the proton beam

- In this configuration, the bubble detector has been irradiated with 3 different energies

- Results of the obtained sensitivity are listed in table 2

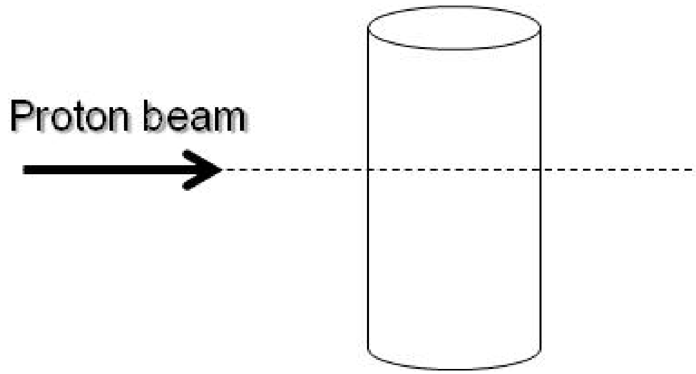


Table 2: Results of the experiments along beam

Ep, MeV	BD number	Proton fluence, p.cm-2	# of bubbles	Proton sensitivity, bubbles/(p.cm-2)
78.2	8721	(2.138±0.214).107	182±13	(8.515± 1.060).10-6
162	8522	(10.720±1.072).107	509±23	(4.748±0.519).10-6
226	9114	(13.561±1.356).107	419±20	(3.089± 0.344).10-6

Experimental Results_ continued

Third configuration: under 45 degree to the proton beam

- In this configuration, the bubble detector has been also irradiated with 3 different energies.

- Results of the obtained sensitivity are listed in table 3.

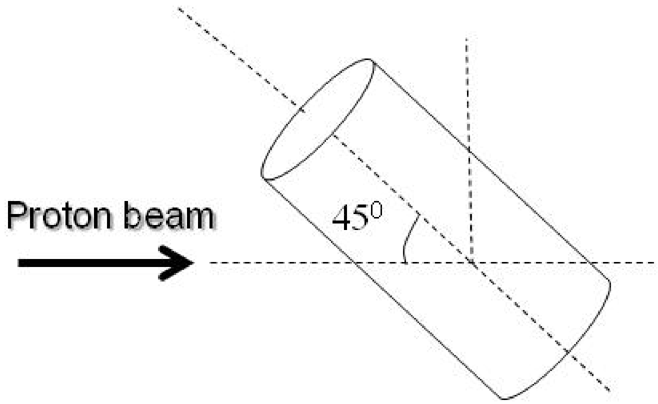
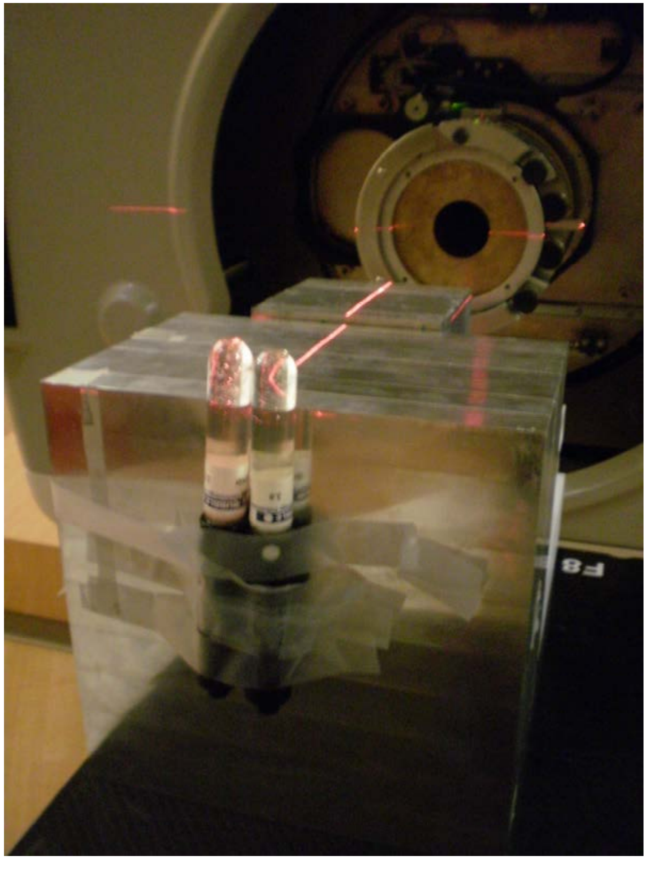


Table 3: Results of the experiments along beam

Ep, MeV	BD number	Proton fluence, p.cm-2	# of bubbles	Proton sensitivity, bubbles/(p.cm-2)
78.2	8721	(2.363±0.236).107	228±16	(9.651± 1.158).10-6
162	9020	(7.382±0.738).107	387±20	(5.242±0.588).10-6
226	8623	(9.741±0.974).107	479±22	(4.917±0.540).10-6

Partially Covered Exposures

- Two Bubble Detectors positioned so that half of active volume fully in beam and other half covered by 22 cm of Aluminum.
- 22 cm Aluminum is sufficient to stop 230 MeV protons
- Irradiations carried out to 226, 162 and 78 MeV protons
- Region in beam dominated by protons, region behind shielding dominated by neutrons



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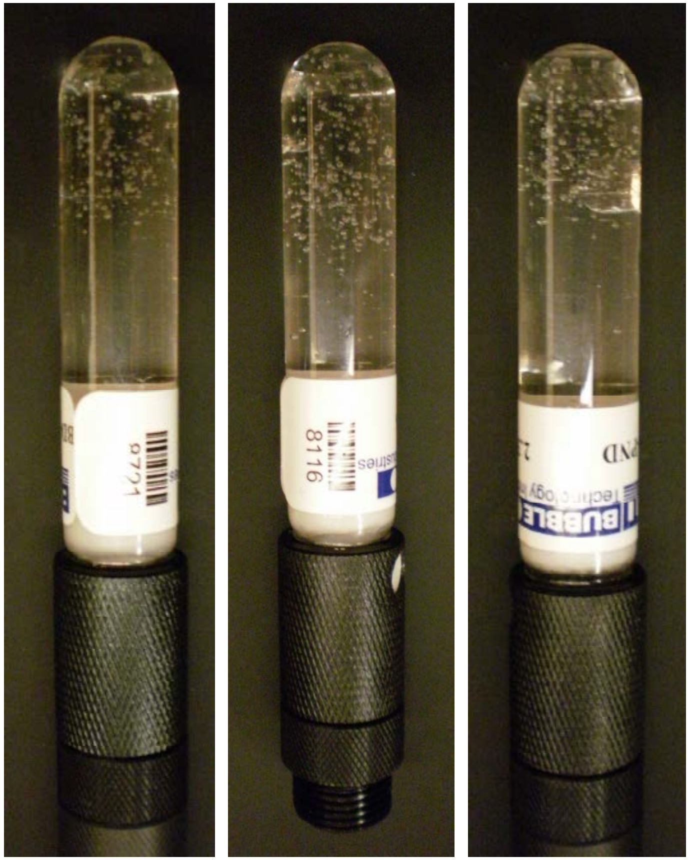
Partially Covered BD Results

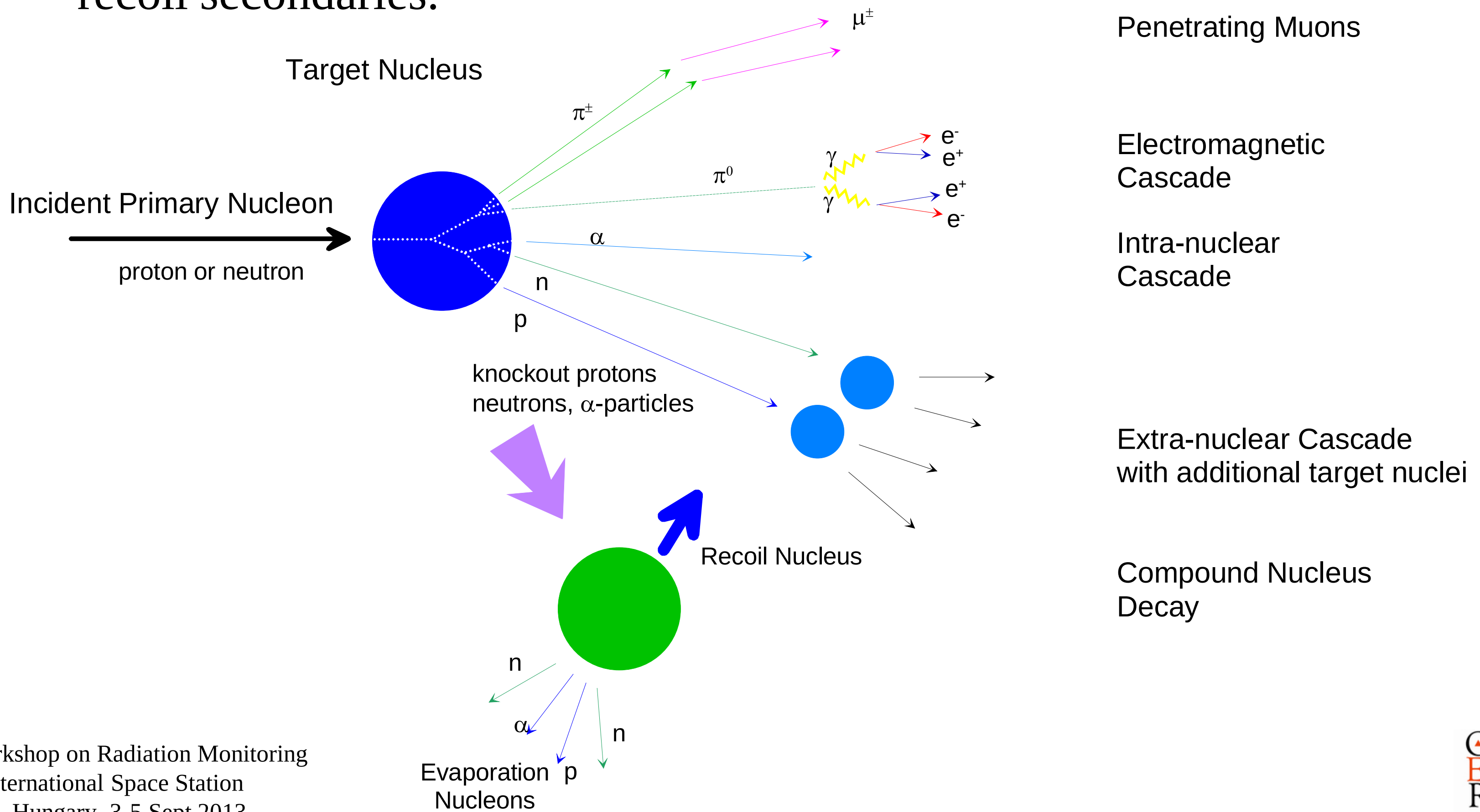


Proton Energy (MeV)	BD Number	Proton Fluence (cm^{-2})	No. of Bubbles	
			uncovered volume	covered volume
78	8721	$5.06 \pm 0.51 \times 10^7$	168 ± 13	2 ± 1
	8220	$5.06 \pm 0.51 \times 10^7$	111 ± 11	5 ± 2
162	8116	$8.26 \pm 0.83 \times 10^7$	212 ± 15	29 ± 5
	8917	$8.26 \pm 0.83 \times 10^7$	170 ± 13	15 ± 4
226	9114	$9.36 \pm 0.94 \times 10^7$	164 ± 13	8 ± 3
	8623	$9.36 \pm 0.94 \times 10^7$	162 ± 13	5 ± 2

clearly see bubbles from protons in the beam...and a few neutrons behind the stopped beam.

Target Fragmentation

- High energy protons (and correspondingly lower-energy neutrons) undergo non-elastic target fragmentation interactions with heavy nuclei in the detector.
- Produces heavy, high-LET (hundreds of keV/μm), short-range (μm) recoil secondaries.



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Bubble Detector as a high-LET charged particle detector

- Characterize Bubble Detectors using heavy ion beams of known LET at HIMAC or NSRL
- Determine the low-LET threshold of Bubble Detectors
- Characterize Bubble Detectors in ground-based high energy neutron environment similar to that encountered in during spaceflight –LANSCE
- Based on environment models, previous measurements, determine the "average" LET of particles above the low-LET threshold of Bubble Detector.
- Use high-LET modeling results + low-LET threshold to determine conversion coefficients to covert number of bubbles into high-LET dose and dose equivalent.

Conclusions

- When used in the mixed field aboard Spacecraft, Bubble Detectors are actually High-LET (including neutrons) particle detectors, not just neutron detectors.
- Bubble Detectors could be used in conjunction with TLD or OSLD as low resolution total dosimeter.
- In principle, existing Bubble Detector system on ISS could be used in conjunction with existing Pille TLD system on ISS as low resolution total dosimeter: both readout capabilities are already present.
- However, first we need to do extensive ground-based calibration to fully characterize the response of Bubble Detectors to both high-LET charged particles, high energy neutrons and high energy protons.