Multi Wall Carbon Nano Tubes as Material for a Space Elevator on the Moon. J. A. Carmona Reyes[1], S. Peters[1,2], G. Herdrich[1,2], R. Srama[1,2,3], J. Schmoke[1], M. Cook[1], L. Matthews[1], R. Laufer[1,2], T. W. Hyde[1], [1]CASPER (Center for Astrophysics, Space Physics and Engineering Research), One Bear Place 97310, Baylor University, Waco, TX 76798 [2]Institute of Space Systems (IRS), Universitaet Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany [3]Dust Accelerator Laboratory, Max-Planck-Institute, Heidelberg, Germany (Truell_Hyde@baylor.edu)

Introduction: The space elevator has long been a dream of mankind. The primary challenge to this dream has been finding a material able to support its own weight over the distances involved. Although the possibility of forming carbon tubes was discovered as early as the 1950s [1], only recently (1991) has the community become aware of their ability in this arena [2]. The advantage of having an operating space elevator on the moon is readily apparent. However, the material employed to construct such a device would need to not only be able to provide the load capabilities required but also remain resistant to the solar wind. In an attempt to conduct an initial examination of the effects that plasma has on Carbon Nano Tubes (CNTs), a gaseous electronics conference reference cell (GEC reference cell) was employed to investigate how they react under varying plasma environments.

Carbon Nano Tubes: Carbon nano tubes are multi wall nano tubes having a density of 1.74 ± 0.16 g/cm^3 [3], an outer diameter of 13 to 40 nm and a breaking length of several thousand kilometers (i.e, tensile strengths of several gigapascal) [4]. CNTs are one of the lightest and strongest materials in existence. Unfortunately to date, tubes longer than 18.5 cm have not yet been produced [5].

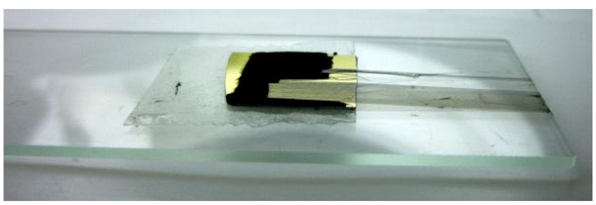


Figure 1. CNT-forest.

The samples used for this experiment were pulled from a CNT-forest having tubes 400 µm tall, with threads maintained by Van der Walls forces. CNT layers were stacked atop one another (up to 60 layers) and then exposed to differing plasma conditions produced within a rf capacitively coupled argon plasma. CNT holders were created so that each tube was isolated from all surfaces which might contaminate the results. Samples were introduced into the GEC reference cell and initially prepped using a cryogenic system which brought the entire vessel to a pressure of 9×10^{-7} torr. After each experiment, the samples were removed and photographed using an E-Zoom 6 microscope. System electronic data was collected via GPIB and images were collected using a CCD monochromatic camera at 60fps for each run.

Experimental Operating Conditions: The reference cell employed produced an argon plasma at user defined power and pressure conditions. On the moon's surface, an atmosphere of 1×10^4 particles per cm^3 during lunar day and 2×10^5 particles per cm^3 during lunar night was measured by the Apollo missions. This atmosphere consisted mainly of neon, hydrogen, helium and argon where the first two are derived from the solar wind with only 10% of the Helium believed to be of lunar origin. Argon appears as ^{40}Ar and ^{36}Ar, where the latter is assumed to be of solar wind origin and again represents not more than 10% [6]. Although the parameters employed here (as determined by Langmuir probe and listed in Table 1) do not properly represent the lunar environment, they do perhaps give some idea of how CNTs might degrade under lunar conditions.

	conditions	T_e [eV]	N_e [cm^{-3}]	N_i [cm^{-3}]
high	5 W, 600 mT	9.3	$1.4*10^9$	$1.6*10^9$
low	2 W, 57 mT	9.6	$0.8*10^9$	$1.2*10^9$

Table 1 Experimental plasma conditions used. All probe data was taken without samples inside the cell.

Data and Analysis: Samples of 10, 20 and 40 CNT layers were exposed to the plasma as described above. Degradation of 10 CNT layers occurred very rapidly, with intial samples dissolving before experiment end. The timing therefore was lowered to15 min exposures.

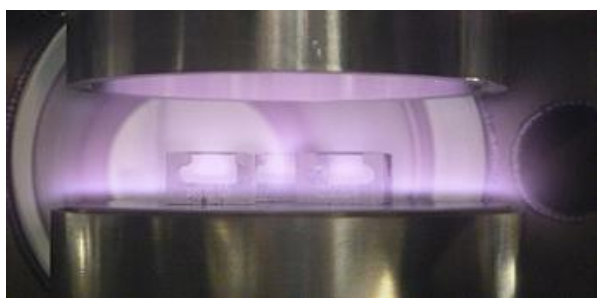


Figure 2. GEC Reference Cell used in this study. Three samples employing different layers were exposed to an argon plasma. High pressure/ high power conditions (as described in Table 1) were employed for a maximum of 15 min.

The pictures shown in table 2 were collected before and after the CNTs were exposed to the plasma. Magnification and exposure are the same for each figure. The average horizontal intensity is given in Fig 3. The results show a 15 to 20 percent degradation under both plasma conditions.

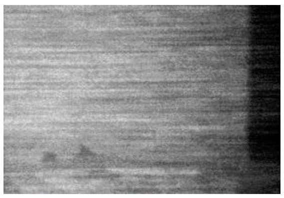
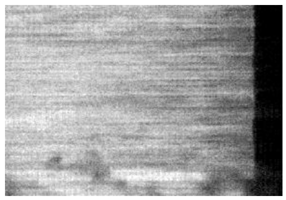
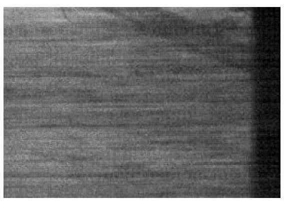
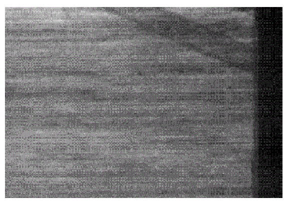
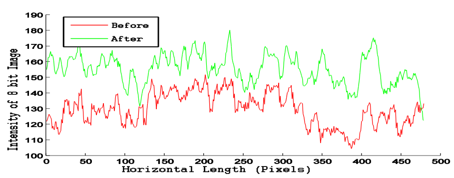
Unexposed CNTs	Exposed CNTs
High Power / High Pressure Conditions	
	
Low Power / Low Pressure Conditions	
	

Table 2: 20 layer CNTs exposed to the plasma conditions presented in table 1. After 15 min, degradation is recognizable under both conditions.

Intensity Profile

High Power / High Pressure Conditions



Low Power / Low Pressure Conditions

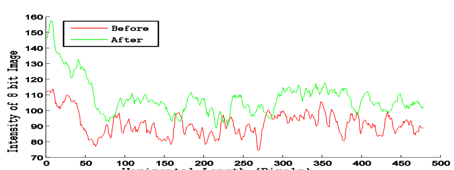


Figure 3: Analysis of the CNT to argon plasma. Pressure conditions resulted in a degradation change of less than 15%.

To further understand the degradation rate, an array of pictures for three different samples (5, 10 and 20 layers) were collected over a 50 minute exposure to a 2.0 Watt, 50 mTorr plasma (Figure 4) and then analyzed using spatial FFT. The results are shown in Figure 5 and again predict a slower degradation rate for 20 layer CNTs and a faster degradation rate for 5 layer CNTs.

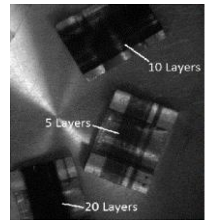


Figure 4: CNT samples inside the GEC reference cell.

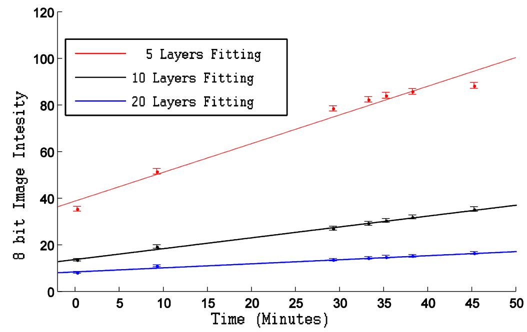


Figure 5. Degradation rates for 20, 10 and 5 layer samples were approximately 9%, 25% and 80% per hour respectively assuming the 120 intensity level as the point where the CNTs had disintegrated completely.

Conclusion and Future Research: Degradation of Carbon Nano Tubes (CNTs) was investigated under varying plasma conditions. These intial results show that plasma degradation may well be a problem for such material located in a lunar environment. Future research will involve exposing CNTs to environments closer to representative lunar plasma and impact conditions, using CASPER's light gas gun (LGG) and Inductively Plasma Generator (IPG). This will allow examination of plasmas and debris parameters (plasma gas mixtures, densities and temperatures) closer to lunar norms under laboratory conditions.

References: [1] Radushkevich, L. V. and V. M. Lukyanovich, V. M. (1952) *JPC, 26*, 88-95. [2] Monthioux, Marc and Kuznetsov, V. (2006) *Carbon, 44*. 1621–1623 [3] S.H. Kim, G.W. Mulholland and M.R. Zachariah (2009) *Carbon*, 1297-1302. [4] Min-Feng Yu et al. (2000) *Science, 287*, 637-640. [5] X. Wang et al. (2009) *Nano Letters. Vol. 9(9)* 3138-3141. [6] Heiken, G., Vaniman, D. and French, B. M. (1991) *Lunar Sourcebook*, Cambridge University Press. [7] Shirley, j. H. and Fairbride, R. W. (1997) *Encyclopedia of Planetary Science*, Kluwer Academic Publisher