XPS measurements of organic molecule degradation after exposure to MeV ion irradiation

Noel A. Guardala[1], John D. Demaree[2], Jerimy C. Polf[3]

[1]Dept. Of Physics, George Washington University, Washington DC 20052
[2]DEVCOM Army Research Lab, Aberdeen Proving Ground MD 21005
[3]Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore MD 21201

Purpose: To understand radiation-induced material degradation in polymers and some ceramics, as well as health effects in biological systems, it is important to assess all of the possible mechanisms by which radiation interacts with them. Although many aspects of ionization damage are considered well-understood, the complex nature of the interactions between radiation fields and particular nuclei could add complexity to the actual damage done in realistic environments (nuclear waste storage, human space missions, nuclear reactor operations). In particular, interactions of energetic charged particles with carbon nuclei can produce a number of nuclear reactions, with localized damage to the irradiated material. We have assessed bond breakage and molecular rearrangement after exposure to MeV ion beams of hydrogen to simulate both recoil protons or fast neutrons and helium to simulate both alpha emitters and ejected He nuclei by high energy particles. Samples were also exposed to lower energy carbon and oxygen ions simulating the effect of primary recoiling atoms in light ion or neutron fields.

Methods: Powders of glucose, coupons of PMMA, and films of bovine DNA (dissolved in water, then dried on a silicon wafer) were exposed to various ion beams using a National Electrostatics 5SDH-2 ion accelerator. Energies were chosen to bracket particular nuclear reactions (e.g., p,alpha reaction in ^{19}F, or resonant elastic scattering of protons on ^{12}C). X-ray photoelectron spectroscopy (XPS) was used to measure changes in the irradiated materials, using a PHI Versaprobe II spectrometer.

Results: XPS proved to be a sensitive tool to assess compositional changes from irradiation-induced loss of volatile species (particularly O, F, and N-containing fragments) during vacuum irradiation. Additionally, high resolution XPS of the photo-peaks allowed us to discern changes in chemical bonding after irradiation and correlate them to suspected mechanisms of material degradation.

Conclusions: While material degradation in the studied systems broadly correlated with the total amount of ionization energy absorbed, some differences were noted which may be ascribed to additional effects of resonant nuclear reactions. These effects could be either positive or negative, depending on the application, and will be further assessed for a complete understanding of radiation damage in these materials.

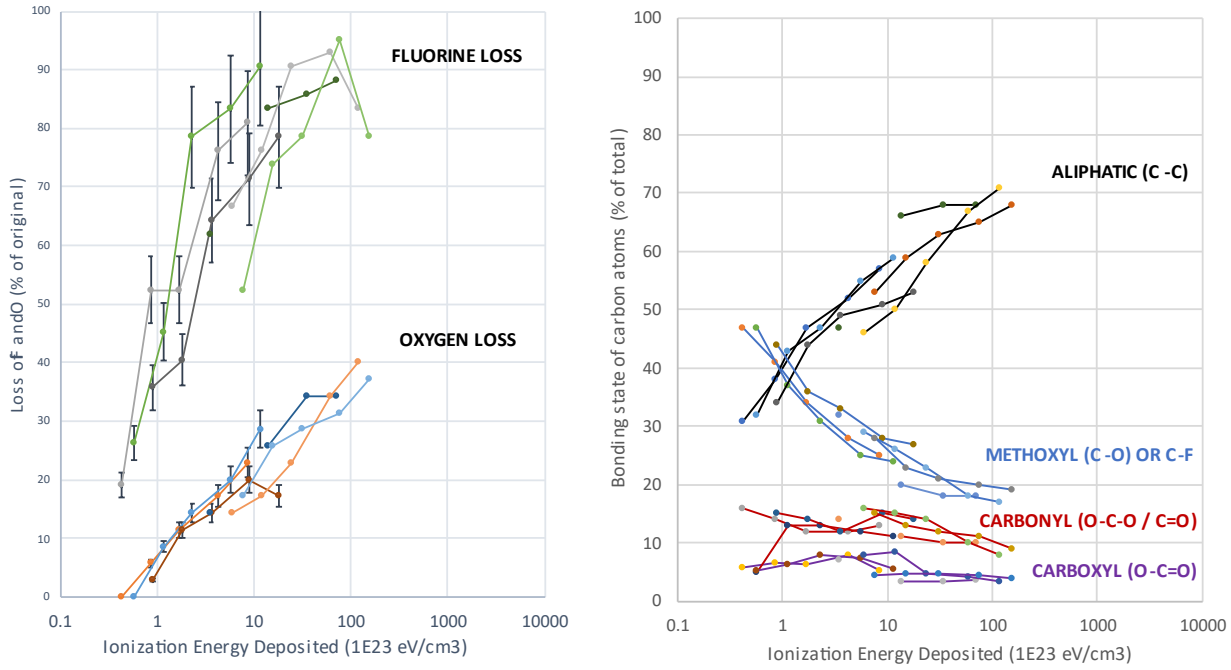

Figure 1. Ionization-induced composition and bonding changes in fluorodeoxyglucose after exposure to ion beams of hydrogen and helium, showing preferential degradation of C-O and C-F bonds.

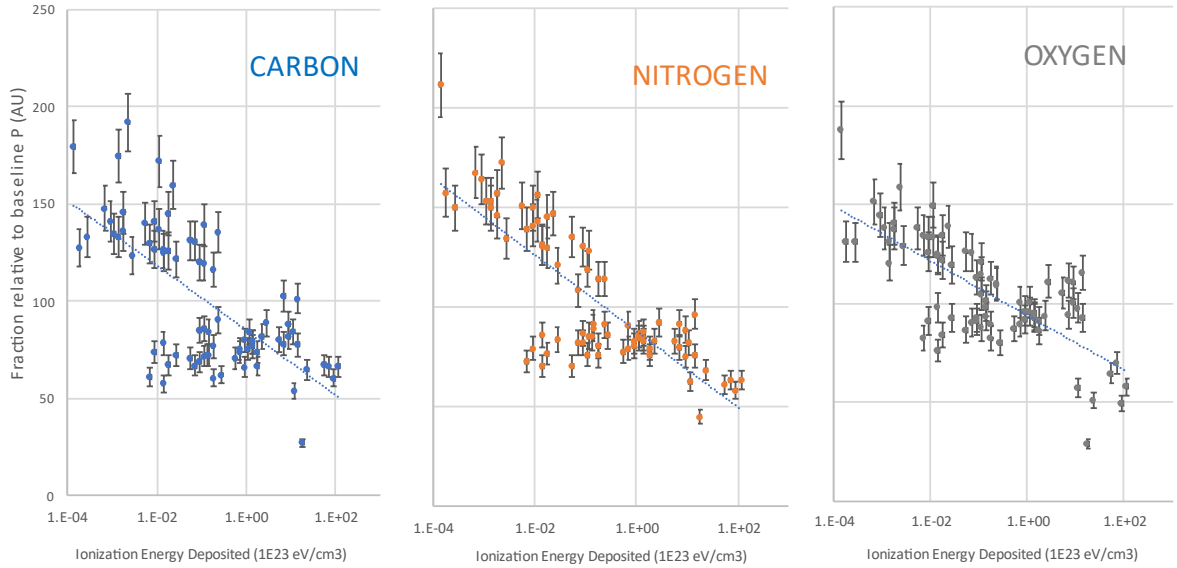

Figure 2. Ionization-induced composition changes in dried films of bovine DNA after exposure to ion beams of hydrogen and helium, showing loss of C, N, and O (relative to P) with increasing dose.