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

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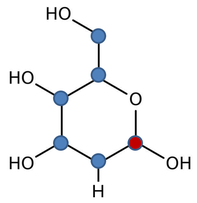
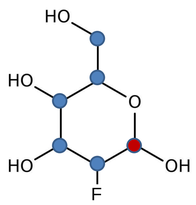
**Purpose:** To understand radiation-induced material degradation in polymers and some ceramics, as well as health effects in biological systems, it is important to assess all of the possible mechanisms by which radiation interacts with them. Although many aspects of ionization damage are considered 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 this study, we have used X-ray photoelectron spectroscopy (XPS) to assess 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).

**Degradation of glucose / enhancement via nuclear reaction:** Powders of deoxyglucose (DG) and fluorinated deoxyglucose (FDG) were exposed to various ion beams using a National Electrostatics 5SDH-2 ion accelerator. Energies were chosen to bracket threshold of (p,$\alpha$) reaction in $^{19}$F.

DG




FDG

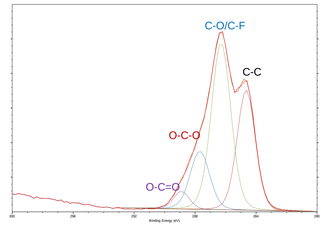



**NEC Pelletron accelerator**

H+ (1, 2, 3 MeV)
He+ (1, 2 MeV)
He++ (4.5 MeV)

Current 10-100 nA, 2 mm diameter
Fluences 2.5E14 – 5E15 ions/cm2

**PHI Versaprobe II**, monochromated Al x-rays, data analysis via CasaXPS, composition & carbon 1s bonding state



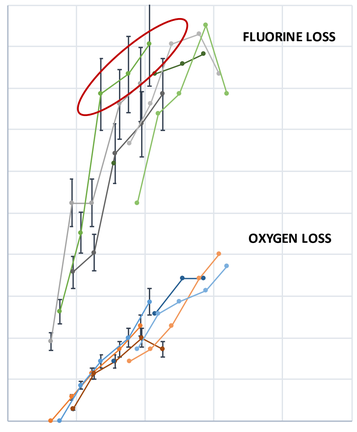

DG degradation
(loss of O, bond reduction from C-O to C-C)

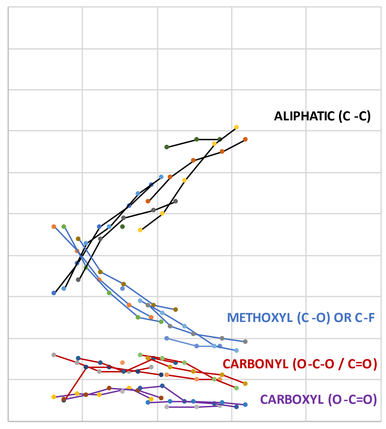






FDG degradation
(loss of O & F, bond reduction from C-O/C-F to C-C)

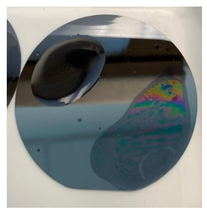


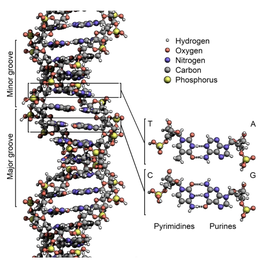



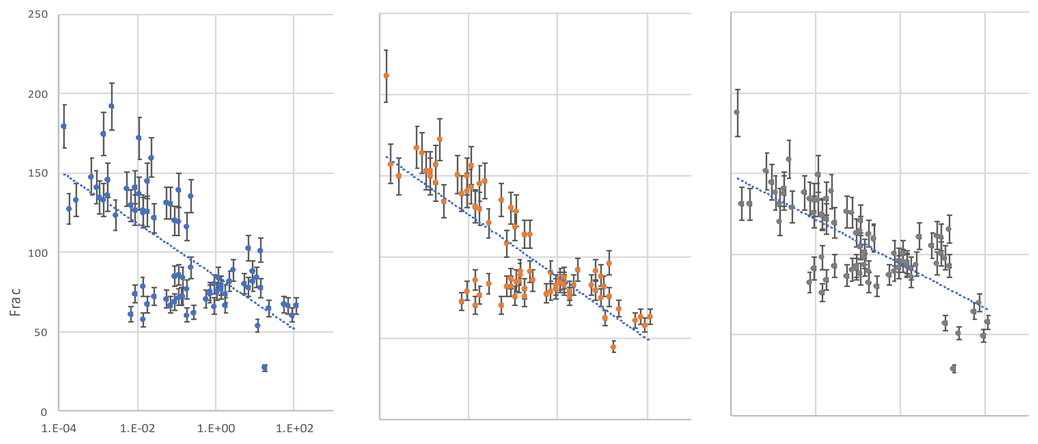

DG and FDG undergo similar degradation under irradiation, which scales with total ionization energy delivered to sample. O and F lost relative to carbon, C-O and C-F bonds preferentially attacked.

Higher chemical and physical stability of FDG complicates measurement (FDG is more stable than DG, and does **not** degrade significantly more than DG solely due to alpha reaction). However, there is a hint of enhanced F loss with proton irradiation at 2 MeV, where (p,$\alpha$) reaction rate is highest.

**Degradation of bovine DNA:** Calf thymus DNA was dissolved in water, spread across a clean silicon wafer, and allowed to dry. H and He ion currents were <100 nA over 2mm diameter areas, and fluences varied from 1E13 – 5E15 ions/cm2. XPS was used to evaluate compositional change at the surface after irradiation, normalizing to the amount of phosphorus present, since fragments containing C, N, and O leave the system during vacuum irradiation.






In agreement with published *in situ* x-ray studies, degradation of dry DNA scales with total energy deposited (dose), regardless of the ion used, across many orders of magnitude. Nitrogen is most easily liberated, indicating preferential damage to DNA base pairs, although loss of oxygen (associated with both base pairs and phosphate backbone) is nearly as significant. Further studies of bonding changes, as well as low-dose exposure of dry and hydrated DNA, are underway.