BACKGROUND

In fall 2015, we (Dick Kiefer and Bob Orwoll) jointly have three research grants from NASA. Two of these are in collaboration with a small business, International Scientific Technologies, in Radford, Virginia. Our current research is focused in three areas: the development of new lightweight materials for shielding astronauts and electronic devices from hazardous radiation on long-term missions in space; exposing polymeric materials to the space environment on the International Space Station; and formulating building materials from simulated Martian topsoil. This continues a research program that we have been conducting for a number of years with NASA support.

Radiation protection is a critical technological challenge that must be met before manned scientific stations can be established on the moon and humans can travel to Mars. The different kinds of radiation for which protection is necessary are briefly described below.

• X-rays and gamma rays. High energy photons (i.e., short wavelength radiation) are easily capable of breaking chemical bonds—think DNA, for example.
• Galactic cosmic rays. This radiation is made up of the bare nuclei of atoms from hydrogen through iron. Some of these ions travel with such enormous velocities so that when they strike an object they leave behind a long path of broken chemical bonds and ionized particles. Thus, these ions are very hazardous to living cells and electronic components
• Neutrons. Neutrons are not naturally found in space because, outside the nucleus, they have a brief 10-minute half-life. However they are present inside a space craft (and inside high flying aircraft). They are formed when a high-speed nucleus in the galactic cosmic radiation interacts with a nucleus in the space craft. Nuclear fission occurs resulting in the fragmentation of the two nuclei and the generation of a cascade of nuclear particles including neutrons.

Shielding against these radiations requires different elements depending on the radiation. These are described below.

• High atomic-number elements can be effective for shielding against X-rays and gamma rays because the high-energy photons are absorbed as they knock out the tightly-bound inner shell electrons in the high atomic-number atoms
• On a unit mass basis, the element that is most effective at absorbing the energy of galactic cosmic radiation (GCR) is, surprisingly, hydrogen. A bare nucleus in GCR with great kinetic energy loses most of its energy by Coulombic interactions with the nuclei and electrons in the shielding material. Elements, other than hydrogen, in the shielding have neutrons in their nuclei. These neutrons increase an atom’s mass—and therefore
the mass of the shield--without affecting its charge. So, per gram, hydrogen is the most effective shielding element.

- Some isotopes such as $^{10}$B are very effective at absorbing neutrons. Neutrons are more efficiently absorbed if they are slowed down and hydrogen atoms are particularly effective at slowing neutrons.

For use in space, strong, thermally stable and lightweight polymers are needed. Polymers which have aromatic units (e.g., phenylene rings) in the backbone tend to be stronger and more thermally stable than aliphatic polymers. Examples of commercially available high-strength polymers include Kevlar, Ultem, and Kapton. All of them have aromatic backbones. Of course, a great advantage of such polymers over metals is their light weight. In our laboratory, we synthesize strong, thermally stable polymers with a high hydrogen content so they can also serve as shielding against radiation.

**CURRENT RESEARCH**

**Making Martian bricks** - Human exploration of Mars will require structures for living and working. One approach under consideration by NASA is to build such structures with bricks made from the granular and powdered material found on the Martian surface, the so-called Martian regolith. A polymeric adhesive such as an epoxy would serve as a binder to cement the regolith particles together. We have obtained material that closely resembles Martian regolith; it is found in lava fields on the Hawaiian Islands. We are investigating this brick-making technology using different designs and binders.

**Development of novel polymers as lightweight shielding materials** - As described above, lightweight shielding to protect astronauts against galactic cosmic radiation can be made from high hydrogen-content polymers. Polyethylene is a good example. However, we are trying to develop polymers that, in addition to providing radiation shielding, can be used for other purposes—in structural components, in plumbing, as insulation, etc. Unfortunately, hydrogen-rich (i.e., aliphatic) polymers such as polyethylene that would be good for shields lack the thermal and mechanical properties that might be needed in structures or insulation. Good strength and thermal stability are obtained by incorporating aromatic repeat units into the macromolecule, such as in Kevlar. But such high-performance polymers have much less hydrogen per gram owing to the aromaticity.

In designing a system that combines aromatic and aliphatic units, one might imagine simply mixing a hydrogen-rich aliphatic polymer with a high-performance aromatic polymer to obtain a “compromise” system. Unfortunately, such simple blending of two polymers almost always yields structurally weak materials because, with rare exception, pairs of polymers are immiscible. Attempts to mix two polymers lead to weakly interconnected micro-phases and a material with fragile integrity.

We are investigating a way to get around this demixing. In our method, an aliphatic polymer is dissolved together with an aromatic polymer in a solvent. Each polymer is then independently and simultaneously crosslinked so that the aliphatic and aromatic...
chains become irreversibly entangled as interpenetrating polymer networks (IPNs). We will test the method with (1) solubility studies (polymer networks swell in a good solvent but cannot completely dissolve), (2) glass-transition temperature measurements, and (3) elemental analysis of the product.

**Exposure of polymers to the space environment** - Polymer samples in the form of thin films are being prepared for exposure to the space environment at the International Space Station in 2016 or 2017. A majority of the polymers to be studied have been synthesized by students in our group. The samples will include high performance polymers that have aliphatic substituents—that is, have an enhanced hydrogen content. Some contain additives in the form of nanoparticles of high atomic-number elements whose purpose is to absorb X-rays and gamma rays. Others contain nanoparticles of boron or gadolinium, elements with large neutron-capture cross sections. Some of the samples will have additives to protect against erosion of organics by atomic oxygen, an extremely reactive species present in low earth orbits, such as at Space Station altitudes.