absorbed non-productively, these neutrons can be slowed down, reflected back into the fuel, and used to carry on the chain reaction. The efficient sustaining of the fission process requires the maintaining of a delicate balance between neutrons produced and lost, with as few neutrons lost as possible.

Unfortunately, for the early designers of nuclear reactors, the preferred structural material for withstanding the corrosive and high temperature environment inside a reactor was stainless steel, which has a high propensity for absorbing neutrons. This was a particularly unacceptable situation in the metal jackets, called cladding, used to contain the small, compressed pellets of uranium fuel.

In a typical sequence of reactions, a fast moving neutron is produced by fissioning fuel. It travels out of the fuel, passing through the cladding. It enters the surrounding water, where it is slowed down or moderated by a series of collisions with hydrogen nuclei in the water molecules. It then randomly drifts or diffuses back into the fuel, passing a second time through the cladding.

In sustained operations, nearly every neutron makes two, or more typically, numerous passes through the cladding before causing another fission. Given this, it was clear that a new cladding material, one that had a very low propensity for absorbing neutrons, needed to be developed. Like clear glass is transparent to light, suitable metals, with high strength, ductility, durability, and resistance to corrosion in high temperature environments, needed to be, as well, transparent to neutrons.

Basic Energy Sciences researchers were aware of one metal, zirconium, which seemed to have most of the desired properties. In certain elaborately prepared experiments, these researchers confirmed that zirconium in rare and purified form absorbed very few neutrons.

Moreover, when zirconium was combined with tin, an alloy named *zircalloy* was formed. This material was found to be not only highly transparent to neutrons, but also capable of performing well at even higher temperatures than the stainless steels of the day.

Only one major barrier stood in the way. In all natural ores where zirconium was found, it was intricately mixed with another metal, hafnium. Unfortunately, hafnium exhibits just the opposite neutronic properties.

Hafnium's propensity for absorbing neutrons is 600 times larger than that of zirconium. The presence of even a minute amount of hafnium would have an overwhelmingly defeating effect on reactor performance by drastically reducing neutron population. The separation of hafnium from zirconium was essential, but the two metals were chemically very similar.

Before interest developed in using zirconium as a cladding material in nuclear reactors, several tedious and expensive hafnium separation processes were developed, but none had been used to make more than a few ounces of purified zirconium and its compounds. When the usefulness of purified zirconium was first confirmed, Basic Energy Sciences researchers at several laboratories, most notably Ames and Oak Ridge National Laboratories, began to look for more efficient and practical separation methods suitable for large scale operations.

The first major advance came with the discovery at Ames Laboratory that an absorbent material, called silica gel, selectively removed hafnium from a solution of the tetrachlorides of zirconium and hafnium in methyl alcohol. The purification process also removed several other undesirable elements, yielding a zirconium oxide product well suited for further processing. Although this was a "batch" process, which was not readily adaptable to large scale operations, the finding produced valuable technical insights.

Building upon these insights, Basic Energy Sciences researchers at Oak Ridge National Laboratory modified an existing process, called the Fischer thiocyanate process, and applied it to the zirconium separation task. As in other ore refining processes, it used continuous flows of extracting liquids, which were better suited to large scale operations.

This modified process, known generically as a solvent extraction process, was similar to another method used by other Oak Ridge researchers to extract uranium from plutonium. This other effort happened to be undergoing development and refinement at the same time, and a useful collaboration ensued.

In its simplest form, the process worked by gravitational mixing of chemicals in a long (greater