than 50 feet), narrow (4-inch diameter), vertical tube filled with a column of liquid. An aqueous (water based) solution containing dissolved zirconium ore salts, along with its hafnium contaminants, was fed slowly into the middle of the filled tube. A suitable solvent—one having an affinity for both hafnium and zirconium, but with a slight preference for hafnium—was fed in at the bottom. Such solvents, like liquid ether, are lighter than water and float towards the top. At the same time, an acid—one having the ability to strip both hafnium and zirconium from the solvent, but with a slight preference for zirconium—was fed in at the top. Concentrated acids are slightly heavier than water and sink towards the bottom.

In this way a system was created where there were two slowly moving, counterflowing, and partially mixing currents of liquids. The solvent tended to carry the zirconium and hafnium elements up the column, with increasing concentrations of hafnium. As the liquids passed through each other, the downward flowing acid solution tended to strip the zirconium and hafnium elements from the solvent, with increasing concentrations of zirconium.

The net result was an increased concentration of hafnium in the solvent, which was drawn off at the top, and an increased concentration of zirconium in the acid, which was drawn off at the bottom. The zirconium-enriched output stream could be further refined simply by adding more length to the tube. Using pumps and a series of connected tube lengths, Basic Energy Sciences researchers achieved their highest purities with 120- and 150-foot lengths.

The commercialization of this process depended on two unrelated areas of basic research. First, the researchers had to find a good solvent. Guided by years of fundamental research on separations technology, this turned out to be a chemical known as methylisobutyl ketone. The acid was a common one used in such cases, namely, hydrochloric acid (HCl).

Second, they had to experiment with the system and determine the optimum conditions under which the process would work. The key variables concerned the concentrations of the salts, acid and solvent, and their respective flow rates, and the diameter, length, and possible internal configurations of the tube. The successful accomplishment of this tedious second step was significantly accelerated by an innovative approach employing radioactive tracers to tag and elucidate the behavior of all the key process constituents.

This process was then scaled up to a pilot plant, and eventually to a commercial production facility, capable of producing about 1 million pounds of purified zirconium per year at the Northwest Electrodevelopment Laboratory. The technology was subsequently transferred to Teledyne Wah Chang and Western Zirconium.

Today, the two firms together produce about 2,500 tons of purified zirconium and 50 tons of hafnium per year. About 50 percent of the United States' total metallic zirconium production is used as cladding material for new or replacement fuel rods in nuclear power reactors. The remainder, with hafnium left in, is used as a constituent of magnesium alloys and superconducting magnet wire.

The hafnium separated from the zirconium also has important applications. The very quality that makes hafnium a poor material for cladding—its high propensity to absorb neutrons—is ideal for use in control rods inserted into a reactor to slow down the chain reaction.

Other desirable characteristics of hafnium include good ductility, machinability, and hot water corrosion resistance. Most of the U.S. hafnium production is used for control rods in naval reactors for nuclear powered ships and submarines. Other uses for hafnium include additives in high-strength materials, corrosion-resistant steels, cutting tool alloys, and optical glass.

Three decades have elapsed since Basic Energy Sciences advances first made zircalloy production practical on a large scale. In the intervening years, no better material has been found for the key applications, such as cladding inside reactors, and the special benefits of zircalloy continue to accrue.

If stainless steel had been used instead of zircalloy, the task of maintaining that delicate balance between neutrons produced and lost would have been accomplished much less efficiently. The level of uranium enrichment in reactor fuel would have had to be raised significantly. It is estimated that, due to the increased enrichment requirement, the nuclear power produced in the United States, without zircalloy, would have cost $800 million more in 1987 alone. These savings continue to accumulate with each passing year and are likely to