Introduction to Nuclear Reaction Products

As noted in the Preface, there are four classes of measurements that have been made to show that it is possible to trigger nuclear reactions with chemical energies. They involve the detection of heat, nuclear reaction products, energetic particles and low-energy (infrared or sound) phenomena. That is, there are measurements that deal with energy (heat or particle kinetic energy or low-energy emissions) or with matter (slow reaction products or fast particles). The production of heat at levels which simply cannot be explained by known chemical reactions was addressed in the last section. Now we consider the measurement of reaction products that are left behind after the occurrence of LENR. Energetic particle measurements are the subject of the next section.

Before dealing directly with reaction products, we should pause to note the wide variety of nuclear reactions. They are not as numerous as chemical reactions, but still run to the thousands of possibilities. In principle, any exothermic nuclear reaction can be a source of energy. The problem is that to stimulate most nuclear reactions, the amount of total energy that is needed exceeds the energy from the reactions. That is, most nuclear reactions are not viable energy sources. Note that a similar situation, overcoming “energy barriers,” is the focus of the search for catalysts in chemistry. Catalyzing nuclear reactions is a phrase sometimes associated with LENR.

It happens that elements near both extremes of the periodic table are either actual or candidate energy sources. Heavy isotopes of U and Pu, impacted by neutrons, fission to produce the power currently extracted from over 400 reactors around the world. Fission reactors have the drawback requiring radioactive fuels, producing dangerous radiations during operation, and generating significant amounts of radioactive waste after operation. At the low mass end of the periodic table are isotopes of hydrogen (notably deuterium and tritium), plus a few other isotopes, which can produce energy by fusion, if they collide with sufficient energy. Such energies can be attained for large numbers of reactant particles by heating them in plasmas that have temperatures in the range of 100 million K. The fusion reaction products are generally not dangerous, but the fast neutrons that result from many fusion reactions are dangerous and they activate radioactivity in nearby materials, and create a waste problem.

Many people, Martin Fleischmann included, think it was a mistake to term nuclear reactions stimulated by low energy phenomenon as “cold fusion.” Aside from the relative nature of the term “cold,” it was, and is even more so now, unclear that fusion is the only, or even dominant LENR. There is a great deal of experimental evidence, and some theoretical concepts, regarding the possibility of nuclear reactions involving elements across the periodic table. This is not to say that all LENR are something other than fusion reactions. It is, rather, an assertion that many other nuclear reactions fall under the heading of “LENR.”

When atoms of one element are changed into atoms of another, the process is called transmutation. There is a long history of interest in such processes. It includes alchemy, the many efforts by some well-intentioned experimenters and numerous charlatans to turn various substances into gold. When particle accelerators with enough energy to induce nuclear reactions became available early in the last century, transmutation reactions became possible

and even routine in physics laboratories. However, the amounts of new materials produced in beam experiments are small and not economical.

Global interest in valuable materials, such as gold and silver, dates to antiquity. But, after the filling of most of the slots in the periodic table and since the industrial revolution, many other elements came to be valuable. Uses range from alloying metals to increase their useful properties to doping of semiconductors for microelectronics. For decades after WW II, the US had a strategic stockpile of elements. Arranged by atomic number, they included He, Be, diamonds, Cr, In, Co, Ge and Mo. This stockpile has been sold off. However, the vagaries of geology and politics might lead again to the hoarding of some technologically valuable elements. The point is that, if transmutations of one element to another by LENR were both controllable and greatly scaled up in rates, it is conceivable that needed elements could be produced on demand.

There is one particular isotope of hydrogen, namely tritium, which is a basic material for nuclear weapons. It boosts the performance of fission bombs, either as separate weapons (A Bombs), or as the primaries in fusion devices (H bombs). But, it has a half life of only 12.3 years. Hence, its production is of interest to countries with nuclear weapon stockpiles. The US last produced tritium for weapons in 1988 when a reactor production facility in South Carolina was closed. Since then, the need for tritium to top off weapons has been satisfied by using tritium from decommissioned devices. In 1998, it was decided to employ two light water reactors in Tennessee for tritium production. The question of whether or not LENR could be used to provide tritium for nuclear weapons arose early in the field. Production rates demonstrated to date are dramatically lower than what is needed. However, that does not rule out this possibility in the future. Tritium also finds uses in self-powered lighting for watches and firearm night sights, controlled nuclear fusion, analytical chemistry and tracing of oceanic currents.

Most of the attention to transmutations in LENR experiments has involved heavier elements. The reports that it is possible to produce nuclear reactions involving heavy elements startled even researchers already studying LENR. Some people in the field reacted with incredulity to reports of transmutations as did most scientists in 1989 after the Fleischmann-Pons announcement. There are two reasons for this amazement. One was the fact that the original name “cold fusion” was taken quite literally by many people, and transmutations were entirely outside of that vision. The second was that the coulomb barrier, already high for fusion of light atoms, is immense for nuclear reactions in atoms with heavier nuclei. That is, according to normal two-body picture of nuclear collisions and reactions, much greater kinetic energies are required to overcome the mutual repulsion of two positively-charged heavy nuclei.

The critical fact is that, despite skepticism, many laboratories reported the appearance of new elements in LENR experiments. In 2003, George Miley compiled a list of 15 laboratories in six countries, which had reported transmutations. He summarized the appearance of elements across the periodic table in LENR experiments. His data on the increase in the amounts of elements showed peaks as a function of atomic mass. Mizuno also took such data, which showed peaks in elemental production close to those found by Miley and his colleagues. The data in both cases are quite scattered. However, the fact that two independent and different

experiments lead to the same picture of elemental production is one of the more enticing facts in the field.

Widom and Larsen later computed nuclear reaction probabilities as a function of atomic mass, that is, nuclear size. They found that peaks occurred at each nuclear size for which one more wavelength for neutrons in nuclear matter fit into the nucleus. The positions of their peaks agreed reasonably with Miley's data, and hence with Mizuno's results. This is one of very few direct comparisons (over plots) of experiment and theoretical computations in the entire field.

The conduct of transmutation experiments is very challenging. If elements are observed with some instrument after an experiment, it does not guarantee that they were not there prior to the run. Before an experiment, the element of interest might have been widely distributed and below the detection threshold for the instruments being used. If the experiment served to concentrate the element at some locations on a cathode, moving it above the minimum detectable limit of an analytical instrument, it would be measurable without any increase of the number of atoms of interest in the entire experiment. In several electrochemical experiments, the authors argue that some of the newly observed elements could not have been deposited electrochemically at the sites where they were found. This is a useful argument, although it does not preclude some concentration mechanism.

Logically, an experiment that purports to show increase in the amount of any element during a run should have analyses for that element done in all the phases and materials that went into the experiment. This is doubly challenging. First, there is a sampling problem. That is, materials are not homogeneous at the nanogram level and it is not possible to consume all of the experimental material for analysis before it is run! Second, even if a defendable procedure for adequate sampling without unduly changing the experiment is possible and accomplished, the analyses that are needed to quantify low-levels of the elements of interest are costly and time consuming. Analyzing for parts per million, billion, or trillion levels of impurities is challenging. The analyses would generally have to be done by analytical specialists with the needed and usually expensive equipment and considerable expertise. There are dozens of analytical methods for specific elements, so the selection of which technique to use for each of the elements of interest is not easy. In experiments like Miley's and Mizuno's, where a few dozen elements are germane, there is the added difficulty of making an analytical choice many times. In general, many of the LENR experiments reporting transmutations have not included adequate chemical analyses.

One of our goals in ICCF-14 was to focus attention on how LENR transmutation experiments should be conducted from the perspective of scientists who specialize in trace element analyses. David Kidwell was invited to present a paper on trace analysis of elements in a Pd matrix. His expertise is in inductively-coupled plasma mass spectroscopy (ICP-MS). The message is not that you can find evidence of changes in the measured isotopic content of a sample, but rather how does one establish what was the source of the changed content.

There were two new and related reports of transmutation research at the conference. Both followed the earlier reports of Iwamura *et al* in which deuterium permeation of multi-layered Pd foils resulted in the transmutation of Cs to Pr and Sr to Mo. The two new works involved

the second of these reactions. The first was by Yamaguchi and his colleagues. Four beam analytical methods were employed, including Proton Induced X-ray Emission, Elastic Recoil Detection Analysis, Nuclear Reaction Analysis and Rutherford Backscattering. An increase in the amount of Mo was observed in 25% of the runs. The authors now seek to improve both the sample uniformity and the deuterium permeation rate.

The second permeation and transmutation paper was by Hioki and his collaborators. The Sr was implanted into the Pd and multi-layered foils. The analyses for Mo were performed with Time-of-Flight Mass Spectroscopy and X-Ray Photoelectron Spectroscopy. Mo was clearly seen with the XPS technique. However, the mass spectroscopy data was not yet conclusive. Work is continuing.

Interest in transmutations in the LENR field is appropriately high for both scientific and practical reasons. Hence, a workshop on transmutations was organized immediately after the conference by George Miley. About fifty people attended the half-day workshop, another measure of the interest in transmutations. A summary of that workshop by Miley is also included in this section.