LENR-Induced Transmutation of Nuclear Waste

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Abstract —

Quantum Rabbit (QR) research on the low-energy fusion and fission (low-energy nuclear reactions, or LENR) of various elements indicates possible pathways for applying that process to reducing nuclear materials. In a New Energy Foundation (NEF)-funded test conducted at Quantum Rabbit lab in Owls Head, Maine, QR researchers initiated a possible low-energy fission reaction in which ^{204}Pb fissioned into ^{7}Li and ^{197}Au (^{204}Pb → ^{7}Li + ^{197}Au).[1] This reaction may have been triggered by a low-energy fusion reaction in which ^{7}Li fused with ^{32}S to form ^{39}K (^{7}Li + ^{32}S → ^{19}K). These results confirmed earlier findings showing apparent low-energy fusion and fission reactions.[2] Moreover, subsequent research with boron indicates apparent low-energy fusion reactions in which boron fuses with oxygen to form aluminum and with sulfur to form scandium.[3] At the same time, the QR group has achieved what appear to be low-energy transmutations of carbon using carbon-arc under vacuum and in open air.[4] The research group at QR believes these processes can be adapted to accelerate the natural decay cycle of uranium-235, plutonium-239, radium-226 and the fission products cesium-137, iodine-129, technetium-99 and strontium-90 with the long-term potential of reducing the threat posed by radioactive isotopes to human health and the environment.

Uranium-235

In addition to the uranium stored at nuclear reactors (the U.S. inventory is shown in Figure 1), there are about 2,000 tons of highly enriched uranium in the world, produced mostly for nuclear weapons, naval propulsion and smaller quantities for research reactors. The half-life of uranium-235 is more than 700 million years. The first step in this process—the alpha decay of uranium-235 into thorium-231—consumes the bulk of this enormous span of time. The half-lives of the isotopes that follow thorium-231 total approximately 33,000 years with the stable isotope lead-207 as the conclusion of the process.

QR research indicates it may be possible to intervene in the decay cycle of uranium in order to reduce the amount of time needed to achieve its transmutation into lead. The most obvious window for intervention is at the beginning of the cycle, by inducing uranium-235 to fission into one of the lighter isotopes in the radioactive decay chain. We propose using lithium, the catalyst element in the studies cited above, as the catalyst for the following low-energy fission reaction:

$$^{235}\text{U} \rightarrow {}^{7}\text{Li} + {}^{228}\text{Ac}$$
uranium-235 → lithium-7 + actinium-228

According to this hypothesis, the low-energy fusion of lithium with sulfur, resulting in potassium, triggers the low-energy fission of uranium into lithium and actinium. The low-energy fusion reaction can be written as follows:

$$^{7}\text{Li} + {}^{32}\text{S} \rightarrow {}^{39}\text{K}$$
lithium-7 + sulfur-32 → ^{39}K

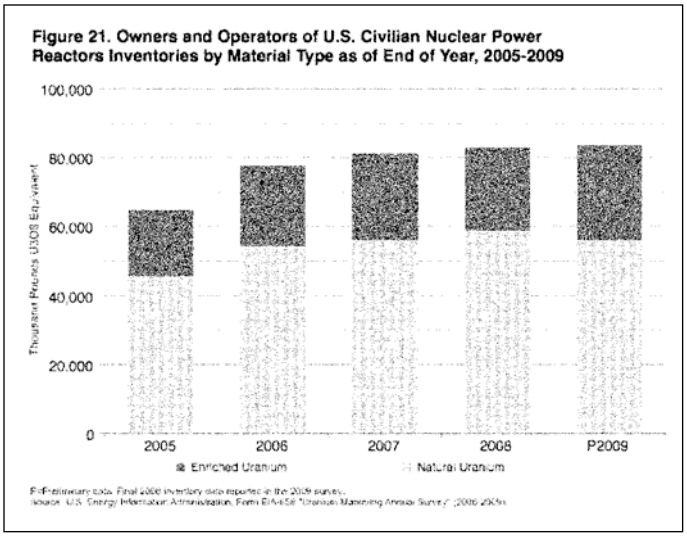

Figure 1. Inventory of natural and enriched uranium in U.S. nuclear reactors.

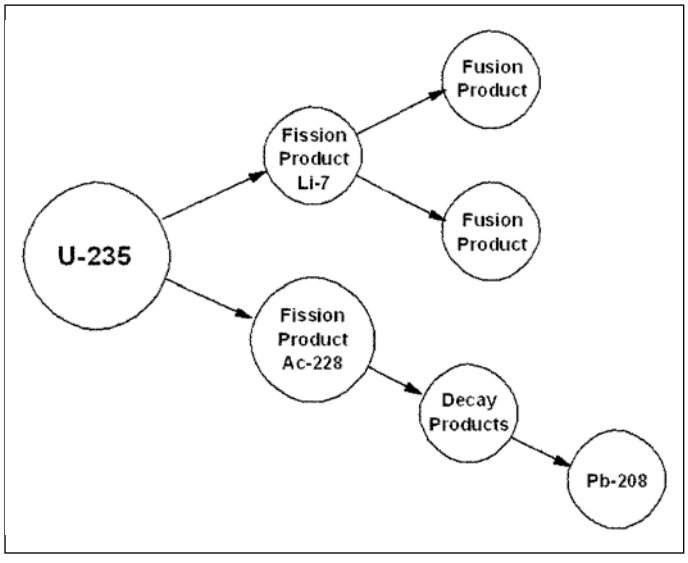

Figure 2. LENR-induced transmutation of uranium-235.

These reactions are summarized in Figure 2. If achieved, they set in motion the natural decay cycle beginning with actinium-228 and ending with lead-208 shown in Figure 3. Note that the low-energy nuclear reaction (LENR) that causes the uranium-235 to fission into actinium-228 results in U-235 being cycled downstream into the natural decay chain of thorium-232.[5]

If actinium-228 is produced as predicted, and the natural decay-cycle indicated in Figure 3 set in motion, the half-life of uranium-235 is compressed from over 700 million years to slightly over 1.9 years. The process is summarized in the formula:

$$^{235}U \rightarrow {}^{7}Li + {}^{228}Ac \rightarrow {}^{208}Pb$$
uranium-235 → lithium-7 + actinium-228
(thorium-232 decay cycle) → lead-208

Plutonium-239

There is a significant amount of plutonium-239 in spent nuclear fuel (see Table 1). It may also be possible to use LENR to compress the decay cycle of plutonium-239. Plutonium-239 has a half-life of 24,000 years. As mentioned in the Abstract, the QR research group achieved promising results with the low-energy fusion of boron. A series of experiments for the possible reduction of plutonium-239 similar to the QR boron experiments can be designed using boron as the catalyst element. The low-energy fission reaction we propose testing is as follows:

$$^{239}Pu \rightarrow {}^{11}B + {}^{228}Ac$$
plutonium-239 → boron-11 + actinium-228

This low-energy fission reaction is theoretically triggered by several low-energy fusion reactions[3]:

$$^{11}B + {}^{16}O \rightarrow {}^{27}Al$$
boron-11 + oxygen-16 → aluminum-27

$$^{11}B + {}^{34}S \rightarrow {}^{45}Sc$$
boron-11 + sulfur-34 → scandium-45

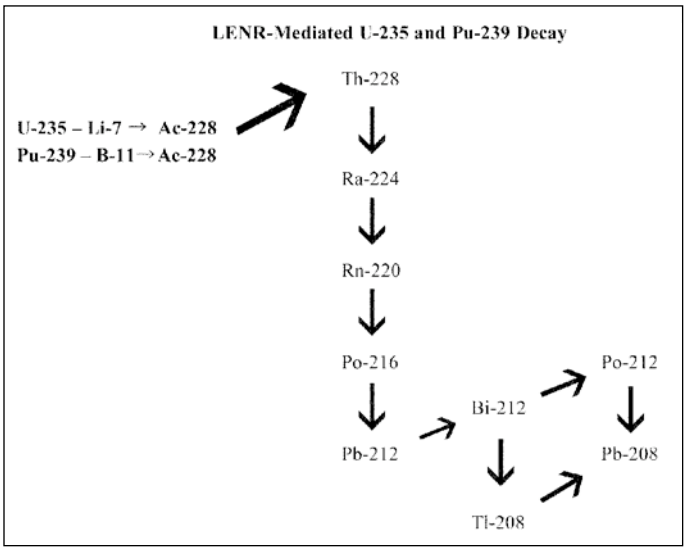

Figure 3. Accelerated decay series: U-235 and Pu-239. Downward arrows represent alpha decay; upward arrows represent beta decay.

Once again, if these LENR are successful in producing actinium-228, like U-235 in the formula described above, Pu-239 would be cycled downstream into the thorium-232 decay chain with the end product being the stable isotope lead-208 (Figure 3). This process can be summarized as follows:

$$^{239}Pu \rightarrow {}^{11}B + {}^{228}Ac \rightarrow {}^{208}Pb$$
plutionium-239 → boron-11 + actinium-228
(thorium-232 decay cycle) → lead-208

Radium-226

Contamination by radium-226 continues to be a problem at U.S. military installations and other sites around the world. Radium-226 is part of the U-238 decay chain with a half-life of 1,600 years. With LENR, it may be possible to compress this time frame considerably by achieving the low-energy fission of Ra-226.

Earlier QR research on carbon-arc may offer a method for achieving this possibility. Numerous LENR have been reported, both in open air and under vacuum.[7] These low-energy fusion reactions could possibly be used to prompt the low-energy fission of radium-226, compressing the half-life of radium and accelerating the natural decay cycle from more than 1,600 years to approximately 22 years. (See Figure 4.)

The low-energy fission reaction we propose testing is:

$$^{226}Ra \rightarrow {}^{12}C + {}^{214}Pb$$
radium-226 → carbon-12 + lead-214

This low-energy fission reaction could possibly be triggered by low-energy fusion reactions including those between carbon and oxygen noted in QR carbon-arc research:

$$^{12}C + {}^{12}C \rightarrow {}^{24}Mg$$
carbon-12 + carbon-12 → magnesium-24

$$^{12}C + {}^{16}O \rightarrow {}^{28}Si$$
carbon-12 + oxygen-16 → silicon-28

$$^{12}C + 2(^{16}O) \rightarrow {}^{44}Ti$$
carbon-12 + 2(oxygen-16) → titanium-44

$$^{12}C + {}^{32}S \rightarrow {}^{44}Ti$$
carbon-12 + sulfur-32 → titanium-44

$$2(^{12}C + {}^{16}O) \rightarrow {}^{56}Fe \text{ (+2 protons)}$$
2(carbon-12 + oxygen-16) → iron-56 + two protons

Cesium-137

Cesium-137, a product of nuclear fission is a major radionuclide in spent nuclear fuel. It is of major concern for

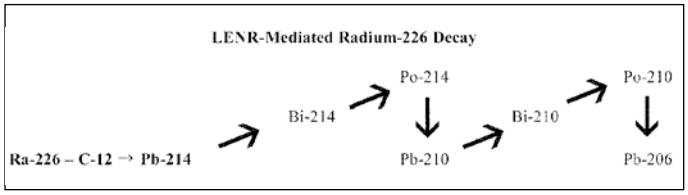

Figure 4. Accelerated decay series: Ra-226. Downward arrows represent alpha decay; upward arrows represent beta decay.

Department of Energy environmental management sites and has a half-life of 30 years. It decays by emitting a beta particle. Its decay product, barium-137m (the "m" is for metastable) stabilizes by emitting an energetic gamma ray with a half-life of approximately 2.6 minutes. It is this decay product that qualifies cesium-137 as a radiation hazard.

The environmental dangers posed by cesium-137 were highlighted by the crisis at Fukushima Daiichi reactor in Japan. Writing in the *Proceedings of the National Academy of Sciences*,[6] an international team of scientists described the threat posed by cesium-137:

> The largest concern on the cesium-137 (^{137}Cs) deposition and its soil contamination due to the emission from the Fukushima Daiichi Nuclear Power Plant (NPP) showed up after a massive quake on March 11, 2011. Cesium-137 (^{137}Cs) with a half-life of 30.1 y causes the largest concerns because of its deleterious effect on agriculture and stock farming, and, thus, human life for decades. Removal of ^{137}Cs contaminated soils or land use limitations in areas where removal is not possible is, therefore, an urgent issue.

Contamination by cesium-137 was a major problem following the Chernobyl disaster. As John Emsley states[7]:

> Uranium fuel rods in nuclear power stations produce cesium-137. The half-life of cesium-137 is 30 years, which means that it takes over 200 years to reduce it to 1% of its former level. For this reason, an accident at a nuclear power plant can contaminate the environment around for generations, which is why the Chernobyl accident in the Ukraine in 1986 was such an environmental disaster. It released a large amount of radioactive cesium-137 which drifted all over Western Europe, affecting sheep farms as far west as Scotland, Ireland and Wales, over 1,500 miles from the accident. There it was washed to earth by heavy rain and taken up by the roots of plants, thus becoming part of the vegetation that sheep ate.

Using LENR, it may be possible to convert cesium-137 to tellurium-130, a stable non-radioactive isotope, thus redirecting and compressing the cesium-137 decay cycle (Figure 5). The LENR-induced fission formula is as follows:

$$^{137}\text{Cs} \rightarrow {}^{7}\text{Li} + {}^{130}\text{Te}$$
cesium-137 → lithium-7 + tellurium-130

In theory, the low-energy fission reaction would be triggered by the low-energy fusion of lithium and sulfur:

$$^{7}\text{Li} + {}^{32}\text{S} \rightarrow {}^{39}\text{K}$$
lithium-7 + sulfur-32 → potassium-39

In a separate experiment, cesium-137 may also transmute into neodymium-148 through a low-energy fusion reaction:

$$^{137}\text{Cs} + {}^{11}\text{B} \rightarrow {}^{148}\text{Nd}$$
cesium-137 + boron-11 → neodymium-148

If the fusion reaction can be proven and scaled to production levels, it would then be possible to convert dangerous radioactive waste into a valuable rare earth metal widely utilized today in the magnets in hybrid vehicles.

Iodine-129

Iodine-129 is a long-lived isotope of iodine created primarily from the fission of uranium and plutonium in nuclear reactors. It decays with a half-life of 15.7 million years. Significant amounts were released into the atmosphere following nuclear weapons tests in the 1950s and 1960s. Iodine-129 is long-lived and mobile in the environment and is thus of special importance in disposal and management of spent nuclear fuel.

It may be possible to compress the natural decay cycle of this radioisotope through the process of low-energy fission. The LENR-induced fission reaction is as follows:

$$^{129}\text{I} \rightarrow {}^{7}\text{Li} + {}^{122}\text{Sn}$$
iodine-129 → lithium-7 + tin-122

Once again, according to theory, low-energy fusion of lithium and sulfur would serve as the catalyst for the reaction:

$$^{7}\text{Li} + {}^{32}\text{S} \rightarrow {}^{39}\text{K}$$
lithium-7 + sulfur-32 → potassium-39

Table 1. Composition of spent nuclear fuel. [Source: James Laidler, Development of Separations Technologies Under the Advanced Fuel Cycle Initiative. Report to the ANTT Subcommittee, December 2002.]

Detailed Composition of 1 Metric Ton of Spent Nuclear Fuel	
	Fission Products
955.4 kg U	10.1 kg lanthanides
8.5 kg Pu (5.1 kg ^{239}Pu)	1.5 kg ^{137}Cs
0.5 kg ^{237}Np	0.7 kg ^{90}Sr
1.6 kg Am	0.2 kg ^{129}I
0.02 kg Cm	0.8 kg ^{99}Te
38.4 kg fission products	0.006 kg ^{79}Se
	0.3 kg ^{135}Cs
	3.4 kg Mo isotopes
	2.2 kg Ru isotopes
	0.4 kg Rh isotopes
	1.4 kg Pd isotopes

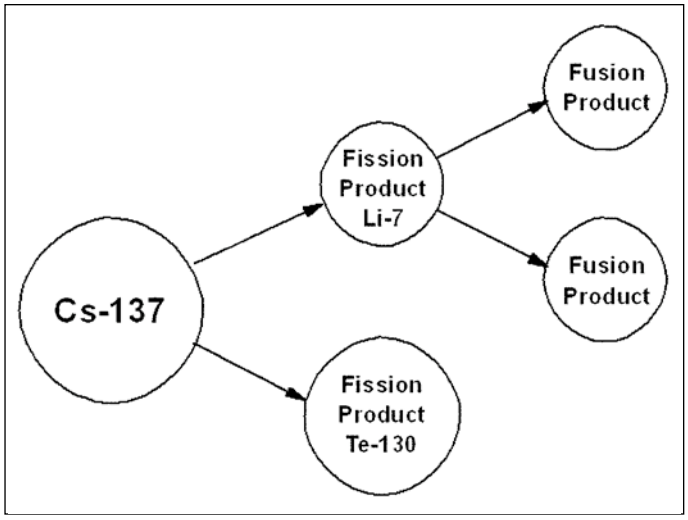

Figure 5. LENR-induced transmutation of cesium-137.

During the experiment, iodine-129 may also transmute into barium-146 through a simultaneous fusion reaction:

$$^{129}I + {}^{7}Li \rightarrow {}^{136}Ba$$
iodine-129 + lithium-7 → barium-136

Technetium-99

Technetium-99 is a radioisotope of technetium that decays with a half-life of 211,000 years to stable ruthenium-99. It is the most significant long-lived fission product of uranium-235. Its high fission yield, relatively long half-life and mobility in the environment make technetium-99 one of the more problematic components of nuclear waste. There have been releases into the environment from atmospheric nuclear tests, nuclear reactors and in the late 1990s from the Sellafield plant, which released nearly 1,000 kg into the Irish Sea.

It may be possible to accelerate the half-life of Tc-99 by inducing the following low-energy fission reaction:

$$^{99}Tc \rightarrow {}^{7}Li + {}^{92}Zr$$
technetium → lithium-7 + zirconium-92

Once again, in theory, the reaction would be triggered by the low-energy fusion of lithium and sulfur:

$$^{7}Li + {}^{32}S \rightarrow {}^{39}K$$
lithium-7 + sulfur-32 → potassium-39

During the experiment, Tc-99 may also transmute into Pd-106 through the following fusion reaction:

$$^{99}Tc + {}^{7}Li \rightarrow {}^{106}Pd$$
technetium-99 + lithium-7 → palladium-106

If successful, this process would facilitate the transmutation of a radioactive waste product into a precious metal used in LENR research.

Strontium-90

Together with cesium-137, strontium-90 is a component of spent nuclear fuel. It is a radioisotope that has an intermediate half-life of about 30 years, the worst range for half-lives of radioactive waste products. Not only are they highly radioactive, but also they have long enough half-lives to last for hundreds of years. Strontium-90 acts like calcium and is taken up by plants and animals and deposited in bones. John Emsley describes strontium-90 as follows[8]:

> Strontium-90 caused a major worldwide pollution concern in the mid-twentieth century, being produced by above-ground nuclear explosions which contaminated the whole planet with it. These tests took place between 1945 and 1963. Strontium-90 is a serious threat because it is one of the most powerful emitters of ionizing radiation and therefore capable of causing serious damage to dividing cells. Its presence was detected in the milk teeth of infants in the 1950s, showing how prevalent it had become, having been washed out the atmosphere on to grassland, to be eaten by cows, and so end up in milk and other dairy products.

It may be possible to remediate strontium-90 through a simple low-energy fusion process. The formula is as follows:

$$^{90}Sr + {}^{12}C \rightarrow {}^{102}Ru$$
strontium-90 + carbon-12 → ruthenium-102

Guidelines for Methodology

The experiments on low-energy transmutation cited in the Abstract can serve as a starting point for designing experiments to test the nuclear reduction hypothesis presented in this paper.[9] A vacuum tube similar to that used in the QR low-energy transmutation tests and shown in Figure 6 can be considered for the nuclear reduction tests. Because silver is a strong conductor of electricity and a neutron absorber, we propose using it as the anode and cathode material, with other test materials adjusted for each experiment as indicated below. Moreover, silver may react independently with lithium to form tin ($^{109}Ag + {}^{7}Li \rightarrow {}^{116}Sn$). This reaction was noted in a previous QR test.[10] Keep in mind that these sug-

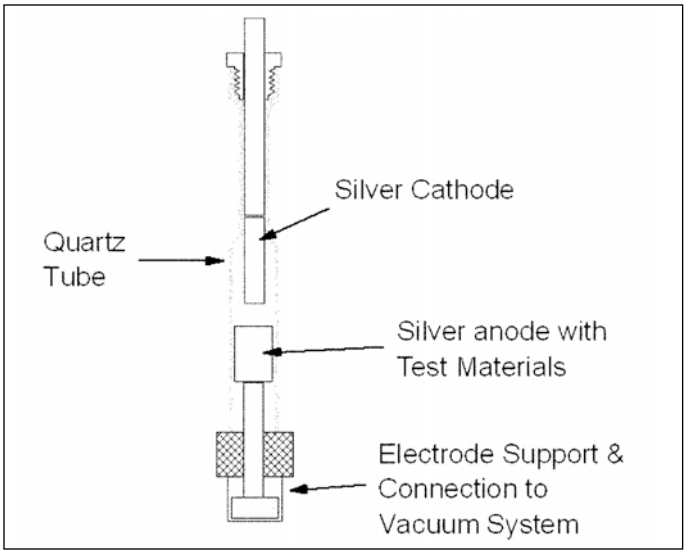

Figure 6. Tube and electrode configuration.

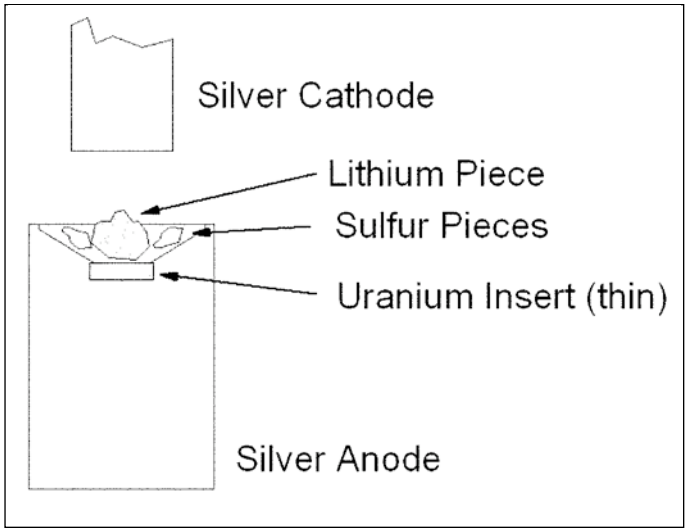

Figure 7. Electrodes and test material suggested for the U-235 → Li-7 + Ac-228 experiment.

gestions are guidelines only, based on previous low-energy fusion and fission experiments. They will need to be adjusted in real time based upon further study and experience.

Uraninum-235

$^{235}U \rightarrow {}^{7}Li + {}^{228}Ac \rightarrow {}^{208}Pb$

Electrodes made of Ag

Test Materials:
1. Uranium insert (thin wafer or foil) in anode
2. Lithium test material
3. Sulfur test material
4. Pure neon/oxygen backfill

Plutonium-239

$^{239}Pu \rightarrow {}^{11}B + {}^{228}Ac \rightarrow {}^{208}Pb$

Electrodes made of Ag

Test Materials:
1. Plutonium insert (thin wafer or foil) in anode
2. Boron test material
3. Sulfur test material (optional)
4. Pure neon/oxygen backfill

Radium-226

$^{226}Ra \rightarrow {}^{12}C + {}^{206}Pb$

Electrodes made of Ag

Test Materials:
1. Radium insert (thin wafer or foil) in anode
2. Carbon (graphite) test material
3. Sulfur test material
4. Pure nitrogen/oxygen backfill (Note: Adding nitrogen allows the process to take advantage of potential carbon-nitrogen reactions such as those noted in QR research.[11])

Cesium-137

$^{137}Cs \rightarrow {}^{7}Li + {}^{130}Te$

Electrodes made of Ag

Test Materials:
1. Cesium insert (thin wafer or foil) in anode
2. Lithium test material
3. Sulfur test material
4. Pure neon/oxygen backfill

$^{137}Cs + {}^{11}B \rightarrow {}^{148}Nd$

Electrodes made of Ag

Test Materials:
1. Cesium insert (thin wafer or foil) in anode
2. Boron test material
3. Sulfur test material
4. Pure neon/oxygen backfill

Iodine-129

$^{129}I \rightarrow {}^{7}Li + {}^{122}Sn$
$^{129}I + {}^{7}Li \rightarrow {}^{136}Ba$

Electrodes made of Ag

Test Materials:
1. Iodine inserted in or on anode
2. Lithium test material
3. Sulfur test material
4. Pure neon/oxygen backfill

Technetium-99

$^{99}Tc \rightarrow {}^{7}Li + {}^{92}Zr$
$^{99}Tc + {}^{7}Li \rightarrow {}^{106}Pd$

Electrodes made of Ag

Test Materials:
1. Technetium insert (thin wafer or foil) in anode
2. Lithium test material
3. Sulfur test material
4. Pure neon/oxygen backfill

Strontium-90

$^{90}Sr + {}^{12}C \rightarrow {}^{102}Ru$

Electrodes made of Ag

Test Materials:
1. Strontium insert (thin wafer or foil) in anode
2. Carbon (graphite) test material
3. Sulfur test material
4. Pure neon/oxygen backfill

Procedure for the Above Experiments:
1. Insert is placed on or into the anode.
2. Measured quantity of test materials are placed in anode recess.
3. Glass/quartz tube is placed over the anode assembly.
4. Cathode is inserted into the tube and secured at the desired separation from the anode.
5. Fill with neon (or nitrogen for Ra-226) to 2 torr.
6. Strike plasma using direct current (D.C.)
7. Admit oxygen fill to 6 torr. Continue until reaction noticeably slows or tube is in danger of breaking (approximately 10-20 minutes).
8. Disconnect power and allow sample to cool.

Conclusion

As of this writing, the problem of nuclear waste disposal remains unsolved. In an op-ed published in the *Santa Monica Daily Press*,[12] Dr. Jeffrey Patterson, former head of Physicians for Social Responsibility (PSR), stated:

> 2011 was a scary year for nuclear reactor sites. The summer floods threatened to encroach on reactors in Nebraska and Iowa, an earthquake and a hurricane happened in quick succession to rattle and flood the East Coast, and the continuing events of the Fukushima-Daiichi reactor accident provided harrowing examples of the threats posed to spent fuel at reactor sites. The fate of spent fuel there kept the world on edge for days. It's worth noting that the amount of fuel in vulnerable storage pools in Japan was far less than what is crowded into pools at many U.S. reactors. As we all learned, a loss of coolant could produce a fuel melt and large radiation release.

> It wasn't supposed to be this way. Used reactor fuel was to be permanently stored in deep underground repositories, away from floods and other natural hazards. But the solution to the nation's nuclear waste problem has been elusive for decades. Meanwhile, 65,000 metric tons of spent reactor fuel is still looking for a home.

The Blue Ribbon Commission on America's Nuclear Future proposes transferring spent nuclear fuel, now scattered at 70 locations around the U.S., to temporary storage areas, pending selection of more permanent deep geologic repositories. This proposal is not without controversy. As Dr. Patterson[12] states:

> Moving spent fuel around the country is not a risk worth taking. Rather than addressing the problem, an "interim" facility would only relocate it. So what is the best option? Hardened on-site storage of spent fuel. It's safe, cost-effective—and readily available. PSR and over 170 public interest organizations from all 50 states are calling for adoption of this approach. Storing reactor fuel at reactor sites in hardened buildings that can resist severe attacks, such as a direct hit by high-powered explosives or a large aircraft, as is done in Germany, offers the safest and most sensible option until a permanent repository can be found.

These proposals offer opportunities for research on LENR-induced transmutation. Research laboratories could be set up at future on-site hardened facilities or even now at current waste storage sites, as well as at future interim facilities. These laboratories can begin first-round investigation of LENR-induced transmutation. If successful, scale-up can proceed to levels required to reduce the on-site, regional and global inventory of nuclear waste.

Moreover, LENR-induced transmutation may offer an efficient, low-cost alternative to accelerator transmutation of waste (ATW). In 1999, the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management submitted a report to Congress entitled "A Roadmap for Developing Accelerator Transmutation of Waste (ATW) Technology." Sekazi K. Mtingwa of MIT describes this approach as follows[13]:

> Transmutation means the transformation of one atom into another by changing its nuclear structure. In the present context this means bombarding a highly radioactive atom with neutrons, preferably fast neutrons, from either a fast nuclear reactor or spallation neutrons created by bombarding protons from a high-energy accelerator on a suitable target.

Oak Ridge National Laboratory (ORNL) is currently investigating methods for ATW. An article in the *ORNL Review* states[14]:

> Conceived by scientists at Los Alamos National Laboratory, ATW uses a linear accelerator system to produce neutrons for transmutation of excess weapons plutonium and other radioactive DOE wastes, such as technetium-99 and iodine-129.
>
> Ultimately, the potential of partitioning and transmutation to waste management is this: If a radioactive waste stream no longer exists, then it poses no radiological hazard. More than anything else, this simple fact has spurred the recent resurgence of interest in partitioning-transmutation technology.

Meanwhile, in the Euro zone, the European nuclear establishment is pressing ahead with a $1.2 billion R&D project to look into high-energy neutron-induced transmutation. The first stage of the project, the setup of a demonstration system known as "Guinevere" that combines a particle accelerator and a nuclear reactor, took place in January 2012 at the Belgian Nuclear Research Center at Mol. A larger version of the reactor system, known as Myrrha (Multipurpose Hybrid Research Reactor for High-tech Applications), is scheduled to become operational in 2023. A press release from the World Nuclear Association explains the thinking behind the project[15]:

> Myrrha will be able to produce radioisotopes and doped silicon, but its research functions would be particularly well suited to investigating transmutation. This is when certain radioactive isotopes with long half-lives are made to "catch" a neutron and thereby change into a different isotope that will decay more quickly to a stable form with no radioactivity. If achievable on an industrial scale, transmutation could greatly simplify the permanent geologic disposal of radioactive waste.

The Quantum Rabbit group estimates that research on LENR-induced transmutation could begin at a fraction of the estimated $1.2 billion startup cost of the Myrrha project. (QR estimates $1.2 million for feasibility study and $12 million to develop a prototype system, amounts that are respectively 0.1% and 1% the cost of Myrrha.) Rather than a highly centralized billion-dollar processing system, LENR-induced transmutation technology could be distributed to nuclear power stations around the globe (Figure 8) at an affordable cost. The task of nuclear remediation would become the responsibility of the individual power station and thus remain local instead of becoming highly centralized. Also, the amount of power needed to conduct LENR-induced transmutation would be miniscule compared to the power required to operate a particle accelerator and nuclear reactor. At the very least, research on LENR-induced trans-

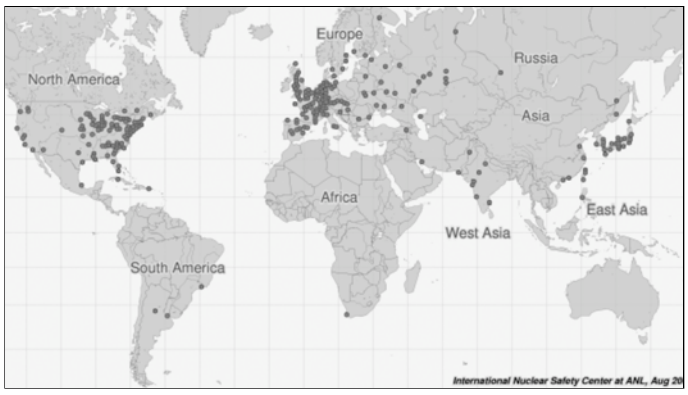

Figure 8. Nuclear power stations around the world.

mutation should proceed on a parallel track to the high-energy neutron-induced transmutation projects currently underway or under consideration in order to determine which approach yields the most promising results.

Acknowledgement

The author wishes to thank Charles Entenmann for suggesting research on the modification of the radioactive decay chain utilizing low temperature, pressure and energy.

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About the Author

Edward Esko is founder and president of Quantum Rabbit LLC. He designed the Quantum Rabbit® vacuum tubes used in the above research, plus the formulas and protocols utilized in QR studies. Esko is co-author, with Alex Jack, of *Cool Fusion: A Quantum Approach to Peak Minerals, Nuclear Waste and Future Metals Shock* (Amber Waves, 2011), which features a compilation of his articles from *Infinite Energy* describing the Quantum Rabbit research.

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