II. Science and Technology

INTERVIEW: *Steven B. Krivit*

The Promise of Low Energy Nuclear Reactions

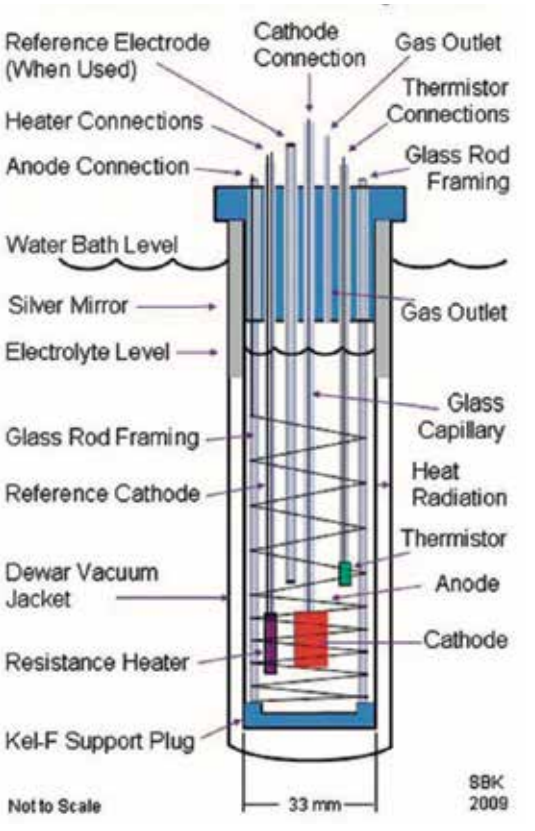
This is an edited transcription of a written interview with Steven B. Krivit, conducted for EIR *by Charles Notley, August 23, 2022. Mr. Krivit is an author, editor, publisher, and international speaker who has specialized in Low Energy Nuclear Reactions (LENR) research since 2000. His full biography is available here; follow him at* New Energy Times.

What Is LENR?

Charles Notley: Like most Americans, most *EIR* readers are completely unfamiliar with the phenomena known as LENRs (Low Energy Nuclear Reactions). Would you please introduce us to LENRs? What is it? Is it real? How to induce it? What does it do?

Steven Krivit: LENRs are a relatively new set of physical scientific phenomena that teach us of the existence of a previously unrecognized category of nuclear reactions. As such, there is great variance in opinion about this developing field. Some of the opinions are driven by what some scientists observe in the experiments, and for some, what they *want to believe* is happening. Some of the opinions are driven by the interests of commercial and investment *promoters* in the field. My opinions are driven by 23 years as an independent author, writer, and reviewer of the subject. Although I have collaborated with scientists, from time to time writing peer-reviewed journal articles, I have never had any business relationship with any scientist, investor, or company that is involved in the field.

In my opinion, LENRs are neither fission nor fusion, but fundamentally a weak-interaction-mediated



Steven B. Krivit

Fleischmann-Pons 1989 Electrolytic Cell Schematic

A schematic of electrolytic cell used by Fleischmann and Pons in their 1989 isoperibolic calorimetry experiments. The platinum anode wire was wound in a helical configuration around the glass support rods, surrounding, with a fairly even distribution, the palladium cathode in the center.

The experiments conducted by Fleischmann, et al. showed that accurate values of the rates of enthalpy (the thermodynamic quantity equivalent to the total heat content of the system) generation in the electrolysis of light and heavy water can be obtained from measurements in a simple, single-compartment Dewar type calorimeter cell, as shown here. The electrolysis of heavy water at the palladium electrodes showed a positive excess rate of enthalpy generation; this rate increased markedly with current density, reaching values of approximately 100W/cm^3 at approximately 1A/cm^2. It also showed that prolonged polarization of palladium cathodes in heavy water led to bursts in the rate of enthalpy generation; the thermal output of the cells exceeded the enthalpy (total energy input) to the cells by factors in excess of 40 during these bursts. The total specific energy output during the bursts as well as the total specific energy output of fully charged electrodes subjected to prolonged polarization (5-50 MJ/cm^3) was 10^2–10^3 times greater than the enthalpy of reaction in chemical processes.

Courtesy of Steven B. Krivit

Steven B. Krivit

process initiated by ultra-low momentum neutrons. The primary fuel component appears to require a form of the chemical element hydrogen, either normal hydrogen or its heavy isotope called deuterium, either in gas or a liquid form. The secondary fuel component appears to require a type of metal that, like a sponge, readily absorbs lots of hydrogen. Such metals include palladium, nickel, and titanium. The experimental results demonstrate the production of thermal energy at *scientifically*—but not *technologically*—significant levels. Despite the low absolute levels of thermal output observed so far, the scale, relative to the volume of mass of the reactants, is far beyond that of any known chemical reaction.

The results demonstrate a wide variety of *direct nuclear phenomena* such as isotopic shifts, elemental changes, charged particles, helium, tritium, and *indirect nuclear phenomena* such as melting and vaporization of metals where the reactions take place.

How to induce it is the $10 trillion question. There are at least 20 major experimental configurations, most of them can be triggered in a variety of ways, some more reliably than others.

Krivit: When the phenomena was reported in 1989 by electrochemists Martin Fleischmann and Stanley Pons, they and people who took their work seriously immediately recognized that the experiments showed thermal energy production—*at nuclear scale*. Yet the most amazing and perplexing aspect of the discovery was that, despite the nuclear-scale rates of energy production, the reactions did not produce commensurate high rates of biologically hazardous radiation.

Fleischmann and Pons, to their own later regret, assumed and claimed that they had achieved a new, simpler, and cheaper route to nuclear fusion. As their announcement came at a time when traditional nuclear fusion research was suffering from continued budget cutbacks, they could not have made themselves greater political targets. Equally problematic was the fact that their proposition that nuclear reactions at high rates, with only low-energy stimuli, contradicted—not *laws of physics*—but 100 years of scientific *opinion*. That's the fundamental reason why LENRs are heretical.

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Electrochemists Martin Fleischmann (right) and Stanley Pons in 1989. They created a stir in the scientific community with their claim of achieving fusion reactions at room temperature in a tabletop experiment.

Anyone with some basic understanding of the experiments, however, who spends a few hours objectively looking at the best examples of the published research, will recognize that Fleischmann and Pons, however unintentionally, stumbled on a *new scientific phenomenon that indicates a potential new source of*

A New Scientific Phenomenon

Notley: What do you see as the promise that LENR holds for mankind? Do you see the mastery of LENR as making revolutionary changes in the way we will do things in the future on Earth and in Space, as electricity has done for us, and fusion will do, or is it a lesser, technical innovation?

energy. Science authorities of the day branded them frauds, calling them incompetent and delusional. These representatives of the scientific community were emotional, incredulous, and angry.

A few months after Fleischmann and Pons made their public announcement in March 1989, they realized that fusion was not the most accurate way to describe what they had found. Many of their followers were less willing to shift their thinking about the fusion explanation that Fleischmann and Pons had initially proposed.

I've had direct contact with the scientists involved in the conflict and have examined their role in this history in my book *Fusion Fiasco* (2016). For the most part, their initial reactions were unscientific, although, to a large extent, understandable: Again, the results presented by Fleischmann and Pons conflicted—not with any *laws* of science—but they conflicted, dramatically, with what scientists had *believed* for 100 years: that nuclear reactions that might produce significant energetic output could be initiated with only high-energy input. Low-energy nuclear reactions show otherwise, and reveal a vast new area of science waiting to be explored—one that has every indicator of a possible future source of clean, abundant, energy.

Marie and Pierre Curie in their laboratory.

LENRs suggest that we may, in the future, have the ability to relatively easily create elements across the Periodic Table. Creation of new elements is routinely done, but to date only with complex high-energy devices. To do such things with tabletop devices? Well, that sounds much too close to the alchemy of previous centuries that was directly associated with charlatans.

Everything we do know about LENRs indicates that if it scales up from lab experiments to viable technology, it would produce no greenhouse gases, no radioactive waste, and require only common raw materials to operate.

The hard part is to appreciate this immense *potential* in the current context. I think it's helpful to remember what it was like a long time ago when the French physicist Pierre Curie (1859–1906) noticed that radium melted an amount of ice in a given time faster than could be explained by any known scientific theory. Curie knew that a novel, unexplained source of energy was producing the heat. That, in a similar way, is what Fleischmann and Pons observed in their experiments. The Curie discovery shows, with just a little imagination, how today's LENR scientific curiosity could grow into tomorrow's practical source of power. The problem, as I mentioned, is *context.* We tend to look for validation from the broader science community. That validation, for the most part, does not exist in LENRs right now, but it has been slowly growing.

Interest in LENR

Notley: Over the past year-and-a-half, there has been a renewed interest in LENR on behalf of our government. Can you say what sector is driving that interest? Military? Space? A combo? Other? How about the general public? Perhaps harder to assess.

Krivit: Any technology can be used for good or evil, and LENRs will be no exception. That's why so many intelligence and defense agencies began paying serious attention to it.

In the last year and a half, the funding from ARPA-E (the Advanced Research Projects Agency—Energy, a U.S. government agency, modeled after the Defense Advanced Research Projects Agency, tasked with promoting and funding research and development of advanced energy technologies)[1] is the latest and most

1. For more on LENR, and the role of ARPA-E in funding LENR research, see its Sept. 13, 2022 "Exploratory Topics Announcement," Appendix A, "Low Energy Nuclear Reactions," pp. 58–59.

visible Federal activity in LENRs. It's also the first time the Department of Energy has successfully funded LENR research. In 2004, several scientists who were advocates of the "cold fusion" concept asked the Department of Energy to take a second look at "cold fusion." Those scientists were very selective and limited in the data they presented to the DOE. Worse, as I discovered in 2010, the key evidence that they presented for "cold fusion" was fabricated. Needless to say, their efforts did not pan out well for them or for the field.

In 2005, Allen Widom and Lewis G. Larsen published a groundbreaking theory that offered an explanation for LENRs that did not require any physics "miracles" or "magic." Their theory, which did not assert the claim of "cold fusion," was based on standard physics. Larsen and Widom had pieced together a wide variety of disparate scientific phenomena, intersecting several areas of physics, that no one had previously figured out. Larsen then began an outreach campaign to the mainstream science community and the U.S. government, resulting in several years of mostly behind-the-scenes activity.

By 2009, even detractors of the theory acknowledged the progress the theory had caused in bringing increasing acceptance of the field. For example, Pat McDaniel (University of New Mexico, retired from Sandia National Laboratory) wrote in 2009 that the "Widom-Larsen theory is considered by many [people] in the government bureaucracy to explain LENR." Another detractor of the theory was their competitor Peter Hagelstein who wrote in 2013:

> Widom and Larsen have put forth a model to describe excess heat and transmutation in LENR experiments. This model is the single most successful theoretical model that the field has seen since it started; it has served as the theoretical justification for a program at NASA; and it has accumulated an enormous number of supporters both within and outside of the condensed matter nuclear science community.

Neither Widom nor Larsen have ever given a lecture on their theory at the International Conference on Condensed Matter Nuclear Science. I will be the first to do so on Aug. 31.

Beyond Chemical

Notley: Many scientists and lay persons have a bad feeling about the results and reportage of the 1989 Pons-Fleischmann Experiment attempting to create room-temperature fusion (so-called "cold fusion"). But LENR is not "room temperature fusion." You characterize it as somewhere "in between" conventional chemical reactions and nuclear reactions. Explain the reason those boundaries exist.

Krivit: As I mentioned earlier, for the foreseeable future, there will remain a contingent of people who refuse to accept the new science of LENR research, regardless of how we identify it. Some of these people are just stuck in their thinking. Some of them have spent a good part of their lives publicly opposing the research, based on their expertise in science. No one likes to eat their hat, admit they were wrong, or lose a bet. When I began writing about the field in 2000, everybody called it "cold fusion," and so did I. But I was starting from zero knowledge. I was also not dissuaded from looking at it just because some science experts said it was theoretically impossible. If someone tells you that something is scientifically impossible, they are not being scientific.

By 2008, after studying the field full-time for five years, it became clear to me that the products of the experiments, although nuclear, were inconsistent with the products expected from deuterium-deuterium nuclear fusion. Moreover, there was an inconsistency with the reactants. Plenty of experiments were showing results using ordinary hydrogen, and they contradict the "cold fusion" hypothesis. On Aug. 20, 2008, at the American Chemical Society national meeting, I identified eight experimental facts that conflicted with the hypothesis of "cold fusion." I publicly declared that LENRs did not look like "cold fusion." It wasn't what most people in the field wanted to hear. I unintentionally became a heretic within a field of heretics. Move the clock 15 years forward, and experiments with normal hydrogen are now very popular. Lots of people in the field still call it "cold fusion," however, because that's their habit, preference, or belief.

Power Produced

Notley: In LENR, it is reported that the "microscopic levels of heat released on metallic surfaces is beyond any chemical reaction." Can you say just how

LENRs vs. Chemical Energy Sources

Source of Energy	Approx. Energy Density (Watt-hours/kilogram)
Alkaline Battery	**164**
Lithium Battery	**329**
Zinc-AirBattery	**460**
Direct Methanol Fuel Cell (35% efficient)	**1,680**
Gas Burning Microgenerator (20% efficient)	**2,300**
100% Efficient Combustion of Pure Methanol	**5,930**
100% Efficient Combustion of Pure Gasoline	**11,500**
LENRs (based on an assumption of 0.5 MeV per nuclear reaction in a LENR system	**57,500,000** (maximum theoretical energy density—only a fraction would be achievable in practice)

Reproduced from a slide from a presentation by Lewis Larsen in September 27, 2011, showing approximate comparative energy densities of various energy sources. Larsen's theoretical calculations assume an idealized system of perfect efficiency and establish a theoretical upper bound on a potential energy release from a deuterium-based LENR device with a working surface area of 1 cm^2. To estimate the potential of power density for LENR, Larsen used a value of 0.5 MeV per nuclear reaction. Assuming a rate of approximately 10^{14} reactions/cm^2/s, each releasing 26.9 MeV of heat above and beyond the energy to create the neutrons, that gave a theoretical upper bound on total heat production 34 times the input power. Thus, he calculated the energy density for the LENR reactions at approximately 57,500,000 Watt-hours/kg.

Comparing that to pure gasoline at 100% combustion efficiency with approximate energy density of approximately 11,500 Watt-hours/kg, LENR is 5,000 times as energy dense. Larsen wrote that this is the maximum theoretical energy density and that, in practice, only a fraction of this would be achievable.

Larsen calculated the surface area power density of a theoretical 1cm^2 LENR-based device to be 428 W/cm^2. Scaling up from that to 1m^2—a 10,000-fold increase—would provide a 4.28 MW power source. Compared to the maximum amount of solar power reaching the Earth's surface, about 0.001 MW/ m^2, the area density of LENR thermal power output is 4,000 times greater. The area thermal power densities potentially achievable with LENR technology are thus vastly larger than any power generation technology based on capture and conversion of energy from incident solar photons of various wavelengths.

How long a given LENR fuel will produce power directly, factors into its effective energy density and is yet to be determined.

far beyond? In other words, just how powerful is it? Enough for a significant power source? A military weapon? Interstellar propulsion?

Krivit: It's good to remember that the unexplained heating effect initially observed by Pierre and Marie Curie, years later [was] found to be from nuclear fission, becoming later still, one of the world's most significant energy sources. I think it's generally safe to say that the rate of heat release observed in LENRs is at least 1,000 times greater than any known chemical reaction.

Another related question is *volumetric energy density*; that is, how much potential energy might exist in a gram of water if used in a LENR experiment? These are difficult calculations to make and require lots of assumptions, including assumptions about reactants and theory. In my book *Hacking the Atom* (2016), I quoted a rough calculation from Lewis Larsen of a one-square-meter LENR panel. He speculated it would produce power at a rate of 4.28 megawatts of electricity; about 4,000 times the rate of power generated by an ideal solar panel of the same size. The most exciting experiments are those which have continued to produce heat, long after the input power has been turned off.

In terms of a military weapon, based on the energy release, I don't see any concern. That's the beautiful part of the reaction. Explosive devices require *fast* reactions. LENR experiments consistently show *gradual* energy releases. However, if LENRs can be used to make elements across the Periodic Table, they could theoretically be used to produce traditional nuclear weapons.

International Research

Notley: Can you say something about the intensity in which governments and science labs in other countries are approaching LENR? Is there a LENR "race" going on? Or, are the scientists engaged in cooperative, mutually-supportive research and reportage?

Krivit: We are 34 years into the field and there is still an overwhelming stigma, based on its heretical nature. This stigma runs counter to the scientific evidence and the technological possibilities for LENRs. At

25th International Conference on Condensed Matter Nuclear Science

The 25th International Conference on Condensed Matter Nuclear Science (ICCF25) convened Aug. 27–31, 2023 in Szezecin, Poland. Attendance was about 150 in person and 38 online, making it the largest such gathering of scientists focused on LENR research. According to the ICCF website:

> The aim of ICCF25 is to increase cross-disciplinary discussions and exploration in the field of low-energy nuclear reactions, to provide an opportunity to enhance international collaboration in solid-state fusion research by presenting new scientific results, developments and applications that are needed to make clean energy production an everyday reality.

The main topics discussed were "heat production, transmutation of elements, electrochemical experiments, engineering applications, hot gas experiments, plasma experiments, instrumentation, beam experiments, material studies, and theoretical and computational studies."

Speaking on Day 4, Steven Krivit delivered his paper, "A Basic Introduction to the Widom-Larsen Theory." According to a report by *Infinite Energy*, the international technical magazine for cold fusion and new energy technologies,

> This is the first time at an ICCF conference that someone has provided a basic introduction to the main concepts of the theory.

In his paper, says *Infinite Energy*, Krivit highlighted the four basic steps of the theory: creation of heavy electrons; creation of ultra-low-momentum (ULM) neutrons; capture of ULM neutrons; creation of new elements. Details of the Widom-Larsen Theory are described in *New Energy Times* Article 13. At the conference, Krivit announced that he will host an LENR session at the June 2024 American Nuclear Society national meeting in Las Vegas, and is looking for contributors.

Concerning the conference, Krivit himself reports:

> Most interesting is that there is a strong new interest in performing experiments with normal hydrogen. This means a) these researchers are no longer locked into the old way of thinking about DD [deuterium-deuterium] "cold fusion" and they are giving more accurate consideration to what the data say—and if the data say the experiments can work with normal hydrogen instead of heavy hydrogen (deuterium), and if they can work with nickel instead of expensive palladium, this is huge progress because many more experiments can be performed with the same amount of money, and any potential future commercial application will be more practical.

When Krivit reported (see *New Energy Times* Article 12) that "Deuterium and Palladium [Are] Not Required" 15 years ago, his report was not warmly received and appreciated by most of the LENR research community.

some point—it may come gradually or suddenly—the science will win and the stigma fade away. As nations go, Japan seems to be the most progressive and open-minded for the research. Toyota, Nissan, and Mitsubishi are involved in the research and there is a new, large research program at Tohoku University that spans five Japanese universities. The experimental scientists are often engaged in cooperative, mutually supportive research and reporting. However, any time someone develops something of potential commercial value they keep quiet, until after they file for patent protection. The theoretical scientists are almost always engaged in competitive behavior; that's just the way things are.

Conferences

Notley: On August 27–31, you will be attending the 25th International Conference on Condensed Matter Nuclear Science (ICCF-25) in Szczecin, Poland. Please tell our readers something about the history of these conferences and about what's

expected to occur at this particular one.

Krivit: Throughout the history of the field there have been regular series of domestic LENR conferences, in Russia, Japan, and Italy. The Italian conference typically had an international presence, probably because people liked going to Italy! The ICCF-series, starting in 1990, has been the major regular international conference and it is very hospitable to scientists who believe in the cold fusion hypothesis. According to the schedule, 38 papers will be presented live, 15 virtually. Additionally, there will be 32 posters displayed.

The Widom-Larsen Theory

Notley: I understand that you will be presenting a paper at ICCF-25, "A Basic Introduction to Widom-Larsen Theory." Congratulations! I hope your participation is fruitful for you and the other attendees! Without diving into the super-technical, please tell us a little bit about the Widom-Larsen Theory, and your relationship to Lewis G. Larsen, who died in 2019.

Krivit: The key parts of the theory that are exciting to me are that (a) the concept is explainable in plain English, (b) it is supported by rigorous mathematical equations, (c) no Coulomb barrier explanation needed, and (d) it can explain experimental results achieved with hydrogen as well as deuterium fuel.

I personally ignored the Widom-Larsen Theory for a year after its initial preprint publication in 2005. I had zero interest in any theory. Finally, in a lecture roughly similar to the one I'm going to give next week, someone explained the basic concepts of the theory to me. And they did so without a single mathematical equation! If you've ever sat through a LENR theory presentation, you've invariably been exposed to page after page of voluminous calculations. If you can't follow the math, you can't follow the theory. Around 2006, I started reaching out to Widom and Larsen to learn more. Widom did not respond to any of my requests. Larsen, slowly, began responding. As he learned that I was sincere, and also not attached to the belief of "cold fusion," he spent more time teaching me about the theory. I later made contact with Widom.

The Best Way Forward

Notley: What do you see as the best way forward to advance LENR, without making unfulfillable promises? What roles do you see for government, the private sector, the scientific community, academia, and the general public?

Krivit: The best way forward is for LENR scientists to accurately and objectively report what they see experimentally. If they don't see evidence of "fusion," it would be counterproductive to keep calling it that. The second most important thing, is for more mainstream journal editors to find more courage. Some papers do get published, but there is still a major fear of the subject. Scientists who are early adopters of new, radical ideas often become targets of ridicule and hostility from their more conservative peers, so the science advances at a snail's pace, and researchers often give up trying to publish in mainstream journals. I have a joint paper in peer review right now. The first four journal editors I submitted it to refused to even send it out for peer review.

Why Understand Science?

Notley: If I have omitted a LENR-related topic you believe should be addressed, now is the time to introduce it and say something about it.

Krivit: Nothing comes to mind. You have asked great questions.

Notley: Maybe then you have some closing remarks for our readers. Perhaps some general words of encouragement to pursue progress in science, either as a scientist or as someone informed on science matters, to the purpose of qualifying themselves to exercise good judgment as citizens of an advancing industrial republic. That's the way I look at it anyway.

Krivit: I think understanding science is a fundamental skill we would all benefit to have. I might go so far as to say it's fundamentally intrinsic to any democracy. You don't have to be a scientist to understand science. I'm a perfect example. My formal education is in business administration and information technology, but I've always had a passion and capacity for learning about science. You learn one step at a time. That's all it takes.

Notley: Thank you very much!