Time for a game-changing nuclear technology

David Kramer raises issues vital to world energy policy in his report "As its renaissance recedes, US nuclear industry looks abroad" (PHYSICS TODAY, November 2012, page 24). If the world continues with its current rate of development and population growth, global energy consumption is projected to expand by 350% by 2100. Few credible options are available to meet that need, so we'd better find some sustainable solutions.

The relatively new abundance of shale gas is creating price competition in US energy markets, but the low price of natural gas is not the only factor driving the competition. Natural-gas power plants have achieved remarkable efficiencies of more than 60%, and their low capital cost and relatively short build time make them attractive investments in energy generation. Those characteristics create significant challenges for the nuclear industry.

The principal barriers preventing nuclear power from competing in today's mix of energy technologies are relatively low efficiency and large scale. Current light water reactor technology tops out at about 34% efficiency, and typical advanced LWR plants cost on the order of $10 billion, which means that few utility companies in the US can afford them. And even small modular LWRs (SMLWRs) are not that small. For one such design, the reactor with its steam generator is more than 25 meters tall, not including the relatively large building for the turbine required to turn steam into electric power. The complexity of such a large structure makes its build time relatively long and its cost potentially high.

Going back to basic principles can provide opportunities to overcome those barriers. Thermodynamic efficiency can be dramatically improved—to more than 50%—by running reactors at higher temperatures and by better harnessing the reaction energy through a high-heat-capacity medium and state-of-the-art turbine generators. Reactor temperatures around 950 °C, more than three times that of current advanced LWRs, have been demonstrated over sustained periods in Japan. However, higher temperature alone cannot dramatically change the economics of nuclear power. Reducing reactor size while maintaining high thermal output is the key to better economics.

Fortunately, high-efficiency reactor designs are now being pursued. One of these, the Energy Multiplier Module, is being developed by General Atomics. The EM^2 is a compact fast reactor about 12 meters high, with 265 megawatts electric (MWe) output. The immediate challenge for the reactor is proving out the fuel element, which consists of novel ceramic cladding and fuel that enable the reactor to operate at high temperatures and high power densities. The company is also developing and testing a compact high-speed turbine generator that can achieve efficiencies of more than 50%.

The Washington-based TerraPower, backed by Bill Gates, also is pursuing a fast reactor based on sodium as a coolant, with an innovative fuel-handling system and core design that can output 500 MWe. The conceptual design of its traveling wave reactor has been completed with the objective of finishing construction and startup by 2020.

The new designs could also

- Produce reactor cores that have 30-year lifespans.
- Burn various forms of nuclear fuel while creating dramatically less waste.
- Reduce proliferation risk.
- Provide cost-competitive electricity through new, lower-cost fabrication and construction of nuclear power plants.

The typical arguments against more advanced designs are that they will take too long and that the technical risks of fuel and power conversion are high. But what does "too long" mean? Photoelectric materials were discovered in the 1800s, yet we are still working on them. Windmills go back much further in history. Yet neither of those technologies is currently game changing. There are countless other examples. Moreover, due to market conditions, it is unlikely that many LWRs or SMLWRs will be built in the next 10–20 years. So this would be a great time to come up with truly game-changing approaches.

Risk must be considered in the context of assessing the ultimate reward. If the energy content from known uranium reserves could be efficiently extracted, it would be 60 times that of known world oil reserves, 50 times the known gas reserves, 20 times the known coal reserves, 260 times the energy from using only LWR technology, or the equivalent of about 90 trillion barrels of oil—400 times the oil reserves of Saudi Arabia. Assuming an oil equivalent of $80 per barrel, the value of known uranium reserves would be $7.3 quadrillion. That's a pretty attractive reward.

Truly new approaches to nuclear energy have not been developed because the nuclear industry has good reasons to be extremely risk averse, and government policies discourage the innovation and science-based discovery that could advance nuclear power.

It may be time for physicists, the professionals who led the creation of nuclear reactors, to take a hard look at the science of new materials and research on new processes to help continue the development of radically new technologies like those indicated above to provide energy for many centuries. The nuclear industry needs a major paradigm shift toward better economics, improved safety, proliferation reduction, and reduction of nuclear waste. At the very least, we need to inspire our youth to explore the possibilities. Engaging those who only know one approach to nuclear power will not change anything. Basic logic and Albert Einstein's famous quote dictate that you cannot solve a problem with the same reasoning that was used to create it in the first place. However, changing the constraints can change the solution.

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Identifying Herschel misidentification

We read and appreciated the brief note about the opening of the Herschel archives (PHYSICS TODAY, April 2012, page 30), but noticed that the credit for the illustration was misidentified. We write to correct the identification. From our past study of the Herschel drawings by William, Caroline, and John and from research for our book,[1] we learned that the white-on-black comet drawings such as the panel

of four that included the Halley's Comet drawings (more than "sketches") shown in the PHYSICS TODAY piece, which had been credited to Caroline Herschel, were instead by John Herschel, her nephew. Previously we had corresponded with the Harry Ransom Center at the University of Texas at Austin about these misattributions and those of several similar drawings. We were pleased to see, during the January 2012 meeting of the historical astronomy division of the American Astronomical Society when we had the pleasure of visiting the archives, that personnel there had already made the changes and now list the drawings as being by John Herschel.

Caroline Herschel, born on 16 March 1750, was at least 85 years old when Halley's Comet visited in 1835–36, and she was 95 when similar drawings of a comet from 1845 were made.[2] Although she lived to nearly 98 years of age, in her later years she was no longer drawing astronomical phenomena. John, age 43 in 1845, was flourishing and using complex media to draw in his atmospheric style. The drawing in PHYSICS TODAY matches the style of the engravings he published in his 1847 book *Results of Astronomical Observations Made During the Years 1834, 5, 6, 7, 8, at the Cape of Good Hope*.

References

1. R. J. M. Olson, J. M. Pasachoff, *Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science*, Cambridge U. Press, New York (1998).
2. R. J. M. Olson, J. M. Pasachoff, http://arxiv.org/abs/1212.0809.

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Notes on the hippies who saved physics

During some heavy cleaning, I happened to notice Sam Schweber's review of David Kaiser's book *How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival* (PHYSICS TODAY, September 2011, page 59).

I was a graduate student at Brandeis University in 1960–62, but I quit to work in the defense industry. I did so mainly because Schweber and others discouraged my claim that the Einstein-Podolsky-Rosen effect implied a faster-than-light information transfer. That was years before Bell's theorem. I had gotten the idea from reading David Bohm's *Quantum Theory* (Prentice-Hall, 1951) in my senior year at Cornell University and David Inglis's 1961 paper in *Reviews of Modern Physics* about the tau–theta puzzle. Schweber and the others basically told me to "shut up and calculate." I finished my PhD at the University of California, Riverside, in August 1969 after a master's at UC San Diego in 1967.

Schweber's review gives the false impression in the first paragraph that Elizabeth Rauscher's Fundamental Fysiks Group was merely "a small group of graduate students." That is a gross misrepresentation of Kaiser's clear text to the contrary. Most of the members, including department head Geoffrey Chew, Henry Stapp, John Clauser, Nick Herbert, and me, already had PhDs. In addition, Herbert was not a "peripheral member" of the group but a core member from the beginning. And finally, Schweber's claim that Bell's theorem was not obscure prior to 1975 is falsified by the statistics that Kaiser presents very clearly in his book.

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Data's sound debut

The article "Shhhh. Listen to the data" in the May 2012 issue of PHYSICS TODAY (page 20) was very enjoyable. I was disappointed, however, that no mention was made of the original work of Fiorella Terenzi in sonification of data, which she refers to as "acoustic astronomy." In 1987 Terenzi, now here at Florida International University, converted radio observations from radio galaxy UGC 6697 into sound for her PhD thesis at the Computer Audio Research Laboratory at the University of California, San Diego.

Her reasons for doing the conversions were the same as mentioned in the PHYSICS TODAY story, but Terenzi did it in a sound studio where no one had ever before used the equipment for that purpose. She went on to describe the B-flat intonation of such audification and how sound could reflect the chemical, physical, and dynamical properties of the celestial object being studied. In addition to her PhD, Terenzi obtained a record contract with Island Records and produced an internationally successful CD entitled *Music from the Galaxies*.

Terenzi's groundbreaking work should not be forgotten among the new generation of scientists who now buy audio processing software and sonify any data stream with ease.

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