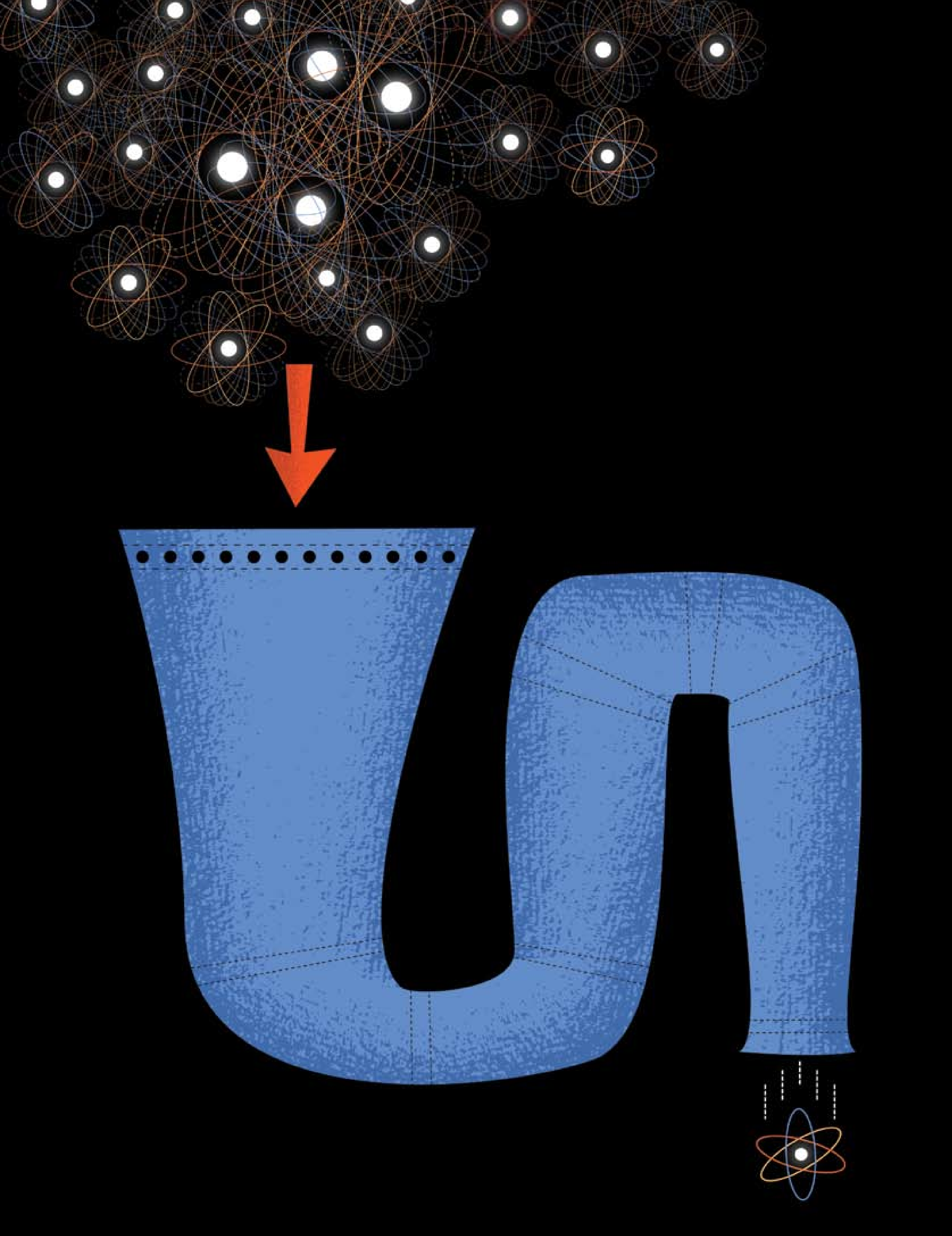

The new concept involves fast-neutron reactors, which can recycle their own waste. They can also efficiently denature excess military plutonium to make it unattractive for weapons use, and they can harvest the vast amount of energy that current reactors leave in their used fuel. Unlike the plutonium-recycling method used for thermal reactors in some countries, the new process does not produce plutonium that is pure enough for nuclear weapons.

> *The technology of fast reactors is well advanced.*

Development and demonstration of this recycling process in the United States was terminated in 1994, just as it was approaching completion. Today's industry and utilities have evolved and are showing that fast reactors can do the recycling economically. The work must resume. In addition, the government must complete development of a technology to recover the useful materials from current types of spent fuel.

Several technologies have developed since the early days of nuclear power, when analysts thought uranium was scarce, and planners expected that used fuel would have to be recycled if nuclear power were to make a lasting contribution to the world's energy needs. During that period, facilities in a number of countries were specifically designed to extract weapons plutonium from used reactor fuel. It was thought that this same technology, called PUREX, would be used to eventually extract enough plutonium from used fuel to permit the construction of "breeder" reactors. Those reactors would produce even more plutonium, making the resource base effectively unlimited.

The major problem with PUREX for commercial reactors, other than cost, is that it involves massive commerce in plutonium that can also be used to make crude nuclear explosive devices. This led Presidents Ford and Carter to ban the processing of used nuclear fuel for other-than-weapons purposes, as part of a diplomatic attempt to stop all such processing by other countries. That didn't work. PUREX is being used for commercial fuel in France, England, Russia, and elsewhere. It is now clear that there is little if any connection between the restraint of the United States and the proliferation of nuclear weapons.

In the 1980s, work began in earnest to find recycling technologies that involved only materials that cannot be readily diverted for weapons. Two major breakthroughs were made. The first was a way to extract usable materials from used nuclear fuels electrochemically—a form of electroplating called "pyroprocessing." The second, complementary breakthrough was an adaptation of the fast-neutron reactor to use the pyroprocessed product.

Pyroprocessing is inherently inefficient in separating nuclear materials. That's fortunate. Although the process can be tuned to recover essentially all of the plutonium and other materials usable as nuclear fuel, it does not produce clean plutonium. The pyroprocessed material can be used in fast reactors, but it is otherwise of no value without further processing, and it is very difficult to handle.

The technology of fast reactors is well advanced. Much of it stems from earlier work on breeder reactors that were built in the United States, France, Germany, Japan, and Russia. But the type of fuel used here is quite different. This and other advances have rendered the design almost invulnerable to safety concerns that beset the early breeder reactors.

There has been some experience with operating the new reactors with recycled fuel, but a demonstration facility would be necessary before major commercial deployment. Also, while the feasibility of recycling the fuel from such reactors has been demonstrated, practical large-scale production facilities have not yet been designed.

Additional optimization and demonstration is necessary to further develop the technology for extracting the useful components of the spent fuel from the current generation of reactors. Completing the development of this technology, along with testing and demonstration, is possible for a small fraction of the cost of developing and demonstrating the acceptability of a second repository comparable to Yucca Mountain.

General Electric has developed a rather comprehensive outline of a fast-reactor recycle system, called Super-PRISM or S-PRISM, which it would presumably be willing to build as a demonstration plant if funding was available.

ROLE OF THE NRC

The U.S. Nuclear Regulatory Commission has reviewed reactors similar to those proposed, and has concluded that they could be licensed under existing regulations. Fast reactors of earlier design are already licensed and operated in several countries worldwide. The fast reactors would have distinct, demonstrated safety advantages over the earlier ones, so no licensing difficulties are expected, other than those typical of first-of-a-kind facilities.

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URANIUM SHORTAGE

A shortage of uranium for nuclear plants looms, as U.S. utilities compete with China and India for the fuel, according to an analyst.

A shortage peaking in a decade could boost uranium prices to $500 a pound or higher, according to Kevin Bambrough, with Sprott Asset Management. "You have to go to mines that are not even there yet in order to try and contract supply," he told *StockInterview*.com, according to *Primezone*.

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> **Sooner or later, efficient recycling to preserve resources will be required.**

While there has been no formal licensing review of the new recycle technologies, effective safety and safeguard measures, such as those now associated with handling power-plant fuel, will be required.

Industry studies suggest that fast reactors with recycling could be economically competitive with the current thermal-neutron power plants, except for first of a kind costs. Cost estimates for treating the thermal-reactor fuel are far less developed. Clearly, however, there will be substantial reductions in the cost of waste handling, storage, packaging, and disposal.

There is enough experience with this class of reactors to establish that operation and maintenance cost would be about the same as with current plants. While capital and operation and maintenance costs dominate the economics of nuclear power, fuel cost could become significant. The price of uranium could increase dramatically as countries such as China put their massive nuclear power programs in place. Some analysts conclude that uranium at current cost may be exhausted in a few decades. In the longer term, however, fast reactors will make the cost of uranium irrelevant.

When spent fuel is processed for recycling, the waste problem is simplified by separating the output into three distinct streams:

- THE PRODUCT STREAM, DESTINED FOR NEAR-TERM RECYCLING, CONTAINS THE PLUTONIUM AND A SIGNIFICANT FRACTION OF THE FISSION PRODUCTS. IF IT IS TO BE FUEL FOR FAST REACTORS, IT ALSO CONTAINS THE OTHER LONG-LIVED HEAVY ELEMENTS AND AN APPRECIABLE AMOUNT OF UNBURNED URANIUM, A MIXTURE THAT IS IDEAL FOR THE PURPOSE.
- THE REMAINDER OF THE UNUSED URANIUM CONTAINS MORE THAN 90 PERCENT OF THE ENERGY IN THE ORIGINAL FUEL, AND CAN BE SAFELY AND EASILY STORED FOR EVENTUAL USE AS FAST REACTOR FUEL
- THE BULK OF THE FISSION PRODUCTS IS THE REAL WASTE, AND ITS RADIOACTIVITY IS LARGELY GONE AFTER A FEW HUNDRED YEARS. IN CONTRAST, THE TRADITIONAL UNTREATED USED REACTOR FUEL IS REQUIRED BY REGULATION TO BE ISOLATED FOR A GUARANTEED 10,000 YEARS OR MORE.

With the waste streams separated, specifically designed waste-storage strategies are feasible. The small residue of very long-lived waste products that could not be economically recovered would be only mildly radioactive, making it manageable. A facility such as Yucca Mountain would be adequate for the few centuries it would take for the toxicity of the waste to fall below that of the original ore.

ADDRESSING CONCERNS

In the earlier approach to recycling, the most useful component of the used fuel—plutonium—was to be extracted using PUREX, a technology that was explicitly designed for producing weapons materials. While the plutonium extracted from commercial fuel using this technology is not ideal for weapons use, it could be used to make a clumsy, unreliable nuclear device that would have a low yield by nuclear-weapons standards, but still could make a devastating explosion. The new recycling methods make such material much less accessible and far less attractive for diversion.

Related to the nuclear waste problem is the challenge of securing excess weapons materials in the United States, Russia, and elsewhere. The only effective alternative to physical protection—guards and intrusion barriers—is to make the material unattractive by using it in a reactor. The fast reactor can do this much more quickly, and with fewer complications than current types of reactors. Excess weapons materials constitute an ideal startup fuel for fast reactors, pending the availability of their own recycled fuel.

Thermal reactors, the type currently employed around the world, use their uranium fuel inefficiently. They discard as much as 99 percent of the energy content of the ore as "waste," in one form or another. The early worry that uranium would soon run out changed around 1980, when discovery of very large deposits of high-grade ore in Australia assured that there would be enough uranium to fuel current types of reactors for several decades. The magnitude of the discoveries, combined with a downturn in the economy caused by increased oil prices, discouraged further exploration.

Now the outlook has changed again. Massive nuclear plant construction programs are proceeding around the world, although not yet in the United States. While renewed exploration will undoubtedly find more uranium deposits, most experts expect that the price will rise as cheap supplies dwindle. Sooner or later, efficient recycling to preserve resources will be required. Timing will

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WASTE TRANSPORT

Nuclear waste can be shipped safely, according to a report by the National Academy of Sciences.

The federal government hopes to store 70,000 tons of nuclear waste in Yucca Mountain, in Nevada. That waste, currently located in 39 states, would require 4,300 shipments over 24 years by rail and highway, according to the *Associated Press*.

"The radiological risks ... are well understood and are generally low," the report by a 16-member committee said. However, accidents involving intense, prolonged fires could release radioactivity. The report did not review the threat of possible terrorist attacks on the shipments.

depend on factors currently unpredictable—such as the importance assigned to reducing carbon dioxide emissions in hopes of slowing global warming. But the need to manage the accumulating nuclear waste effectively is a critical reason to resume the development now.

Russia has had a development program similar to the one in the United States for several decades and it has had considerable success. It appears likely that they will take their technology to the demonstration phase before long.

Several other countries, including Japan, India and China, have programs to develop fast reactor recycle technologies. They feel that they can leap frog to the new technology, conserving their limited uranium supplies, avoiding spent fuel issues, and bypassing concerns over diversion of materials for weapons use.

THE ROLE OF UTILITIES

Construction of first- and second-generation nuclear power plants proceeded aggressively in the United States until regulatory, political, and intervenor pressures made them uneconomical. Utilities have always been willing to undertake new technologies that are practical and not subject to unreasonable interference. Deployment and innovation will resume when profitability returns. Historically, industry has met the energy demand, even when the challenges were thought to be immense.

What is the incentive for a utility to look to this new type of system, when they can build perfectly good nuclear plants of the conventional variety? Today, the driver to deploy this type of system is the current nuclear waste problem. Left unsolved, there will be continued public opposition to nuclear power. The Yucca Mountain repository has limited capacity. A successful recycling program would reduce the volume and hazard of materials that require deep geological disposal by a factor large enough to extend the repository's useful lifetime indefinitely.

While pursuit of the next generation of nuclear power must not be allowed to derail current efforts to add to our existing fleet of nuclear power plants, we urgently need to demonstrate a safe and effective recycle technology and start deploying it as soon as possible.

William H. Hannum, Gerald E. Marsh, and George S. Stanford are physicists who worked on fast reactor development before retiring from the U.S. Department of Energy's Argonne National Laboratory.

::COUNTERPOINT

Concerns About Fast-Neutron Reactors

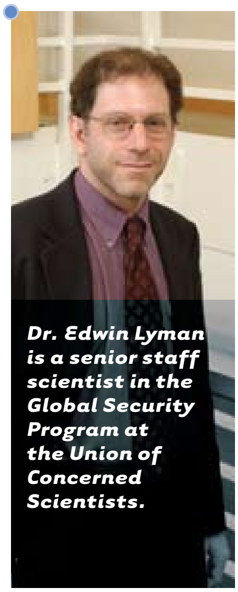
By Dr. Edwin Lyman

Fast-neutron reactor proponents oversimplify the technical and engineering difficulties, enormous expense, and safety, security and proliferation concerns associated with the technology. It is easy to draw up plans on paper for a nuclear fuel cycle that looks great—but the challenge is always in the engineering.

In this case, the authors rely on unproven technology that has had no success in the past. Fast neutron reactors have uniformly been extremely expensive to build, challenging to operate, and marred by serious safety problems. The Superphénix fast reactor in France operated with a capacity factor of only 15 percent, for example. The Monju reactor in Japan experienced a serious sodium fire in 1995 and has not yet resumed operation.

And the "pyroprocessing" technology promoted in the *Scientific American* article has been a failure. A program at Argonne National Laboratories to use this technology to process a small amount of spent fuel from a defunct experimental breeder reactor in Idaho has performed so poorly that the Energy Department is actively seeking cheaper, safer alternatives. Argonne has already had ample opportunity to prove the technology; it has been under development since the 1960s. It's time to put it to rest.

Even if the fast reactors and pyroprocessing plants worked as advertised, extracting plutonium and other actinides and fissioning them with a



Dr. Edwin Lyman is a senior staff scientist in the Global Security Program at the Union of Concerned Scientists.