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LETTERS SCIENCE & SOCIETY POLICY FORUM BOOKS *ET AL.* PERSPECTIVES REVIEWS

A Late Triassic Trove of Fossil Plants

ALTHOUGH IT COULD BE ASSUMED FROM Erik Stokstad's News Focus article "Utah's fossil trove beckons, and tests, researchers" (5 Oct., p. 41) that the only fossils found in the Grand Staircase–Escalante National Monument in southern Utah are the remains of dinosaurs, mammals, and other tetrapods, nothing is farther from the truth.

Limited research has already shown that the Mesozoic strata exposed there (~65 to 250 million years old) also contains abundant fossilized remains of invertebrates (*1*) and land plants (*2*) and that the potential for significant discoveries is large (*3*). For example, personal experience indicates that plant fossils from the early part of the Age of Dinosaurs are widely distributed in the terrestrial Chinle Formation of Late Triassic age in the monument (*4*). Such fossils have been known in the area of the monument since the early 1900s (*5*) and include petrified wood, leaf compressions, and palynomorphs.

In more recent years, some of these fossils have been discussed briefly (*6*), and it is clear from these few accounts that the new monument contains important deposits of Late Triassic plant fossils. In fact, it contains the remains of the second largest Late Triassic petrified forest in the world (*7*), known informally as the Wolverine Petrified Forest, which is just now being studied for the first time. A comprehensive study of the Chinle Formation flora will provide new knowledge about the land flora that grew near the west coast of Pangea during the Late Triassic and formed the base of the terrestrial food pyramid in that region. Also, it has the potential of providing new data on the paleoclimate of the region. Preliminary study of the wood structure in the logs in the above-mentioned petrified forest indicates that the logs do not have annual rings, which is unexpected because the area appears to have been under the influence of a strong megamonsoon during the Late Triassic (*8*).

A large trunk of the extinct Late Triassic conifer *Araucarioxylon arizonicum* exposed in the Wolverine Petrified Forest in the Grand Staircase–Escalante National Monument, Utah.

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letter2science.org), or regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

The Pros and Cons of Nuclear Fuel Recycling

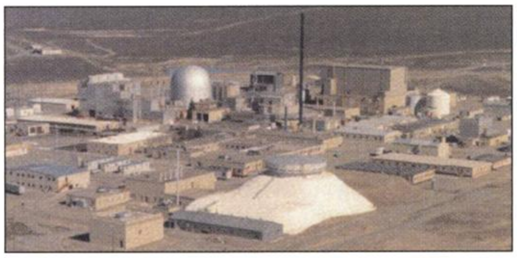
IN "PLUTONIUM AND THE REPROCESSING OF spent nuclear fuel" (Policy Forum, *Science*'s Compass, 28 Sept., p. 2397), Frank N. von Hippel reiterates the standard arguments against reprocessing in response to the National Energy Policy Development Group report that advocates a reexamination of U.S. policies on reprocessing R&D. The report also states that "the United States will continue to discourage the accumulation of separated plutonium worldwide" (*1*). Most of us who advocate a resumption of U.S. R&D in advanced reprocessing and remote fuel fabrication methods that avoid plutonium separation agree.

All fuel cycles must use enrichment or reprocessing, and both technologies provide routes to proliferation. There currently exists a 30% global excess of enrichment capacity, and any nation acquiring enrichment facilities today appears suspicious on economic grounds. This situation will reverse in the next two decades as U.S. gaseous diffusion enrichment plants retire and as current excess military and civilian enriched uranium supplies are consumed.

The natural trajectory for enrichment technology is toward methods that are more efficient and therefore easier to conceal; for reprocessing, it is toward methods that make the waste stream as clean as possible and the fuel quite dirty and therefore hard to steal. Thus, the emergence of a global market for new enrichment technologies and services deserves concern, particularly at the scale implied by the use of seawater uranium for the expansion of once-through reactor systems.

These concerns also relate to storage issues. Only a few long-term methods can be envisioned for managing nuclear waste. The strategy of highly dispersed and protracted surface storage may continue indefinitely. Conversely, a small number of geologic repositories might be sited to take this waste. I doubt we will site a "mega-repository" capable of holding centuries of global spent fuel, such as the proposed Pangea site in Australia, or that tens or hundreds of repositories will ever be sited worldwide. Thus, for sustainable fission energy production, the scarce resource will not be uranium, but will almost certainly be repository capacity.

Decay heat creates the fundamental limitation on repository capacity. For spent fuel, the fission products—^{137}Cs and ^{90}Sr with half-lives of 30 years—generate roughly half of the total repository heat load. The actinides—principally the heavy elements ^{241}Am (458 years) and ^{238}Pu (86 years)—provide the other half. We can actively manage the fission product heat. For example, in unsaturated media like Yucca Mountain, the simple ventilation of the drift tunnels would recover ~50% of the repository thermal capacity every 30 years. But we cannot actively manage the actinide heat, which is deposited over too long a time. This is why, in the longer term, it will likely make economic sense to recycle actinides back into reactors, and why it is correct and appropriate for the United States to develop new technologies for this purpose.



Reactor and pyroprocessing research facilities at Argonne-West in Idaho.

The broad adoption of the Nuclear Nonproliferation Treaty can be credited in large part to the commercial potential seen in nuclear energy. Our development of new fission-energy systems that better manage their waste streams could create new incentives for broad adoption of even more rigorous international norms: in particular, comprehensive International Atomic Energy Agency (IAEA) Safeguards Agreements that include an Additional Protocol, which, when adopted by a nation, allows IAEA inspections anywhere within that country to confirm the absence of undeclared nuclear activities (*2*). This creates a worthy goal for future nuclear energy R&D.

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2. Additional Protocols are now in force in 22 nations: http://www.iaea.or.at/worldatom/Programmes/Safeguards/sg_protocol.shtml

Response

PETERSON'S NIGHTMARE IS DIFFERENT FROM MY own. Mine is that the Bush Administration is undercutting the more than two-decade-old campaign to end civilian commerce in weapon-usable plutonium just when that campaign is on the verge of success. Britain, France, Russia, Japan, and India are still separating annually more than 20,000 kg of pure plutonium from spent fuel—enough for at least 2500 nuclear explosives—but, in fact, deregulated utilities are becoming more resistant to subsidizing these uneconomic programs.

Peterson worries about the challenge of siting "tens or hundreds" of deep underground respositories for spent fuel in the United States. But it would take hundreds of years for any such problem to develop. The proposed Yucca Mountain repository would hold about as much spent fuel as will be discharged over the lifetimes of the ~100 nuclear power plants in the United States. Because of a lack of utility interest, there has not been a construction permit for a new nuclear power reactor issued in the United States since 1979 (*1*). Worldwide nuclear capacity is ~3.5 times that of the United States' and is projected to stay about constant for the next 20 years as a result of a combination of modest growth in the developing world and decline in the industrialized world (*2*).

Peterson is right about the danger of the proliferation of small-scale uranium enrichment technology. Pakistan produced its weapon-grade uranium using technology acquired by A. Q. Khan while he worked in the Urenco commercial centrifuge enrichment plant in the Netherlands (*3*). Khan returned to Pakistan and built an enrichment plant reportedly based on Urenco designs (*4*). However, the fuel used in most of the world's nuclear-power reactors is low-enriched and not weapons useable. In contrast, commercial spent-fuel reprocessing technology produces pure plutonium directly useable for the production of nuclear weapons.

In short, my objections to the proposal to launch a new U.S. reprocessing R&D initiative are: (i) reprocessing is not needed within this century, and (ii) the Bush Administration proposal is being greeted by foreign reprocessing establishments as a rollback of U.S. opposition to commerce in plutonium.

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Carbon Sinks and Conserving Biodiversity

ALTHOUGH CARBON SEQUESTRATION through better management of forests and farmland does not provide a long-term alternative to reducing greenhouse gas emissions, it might provide limited and short-term benefits for the climate. The Kyoto Protocol of the United Nations Framework Convention on Climate Change allows Land Use, Land Use Change and Forestry (LULUCF) projects under certain constraints. These projects include a planned set of activities designed to enhance carbon sequestration in terrestrial ecosystems. Concerns have been raised about the potential effect of such projects on biodiversity; for example, that old growth, biodiversity-rich forests could be replaced by plantations of fast-growing trees. However, under a number of circumstances, win-win situations could be created between climate change mitigation and biodiversity conservation, and these were the topic of discussion at the international conference "Carbon Sinks and Biodiversity" held in Liège, Belgium, in October.

For example, in developed countries and countries whose economies are in transition, ecosystem restoration through revegetation of a fraction of noncultivated agricultural and marginal lands offers a potential for climate change mitigation. This requires taking all greenhouse gas fluxes into account. Such revegetation can be achieved in a number of ways, including by encouraging the use of biofuels and chemicals derived from biomass. Peatlands could be protected and former peatlands converted back to either their original state or some other managed state with higher water tables. Afforestation of peatlands should generally be avoided, as it would endanger biodiversity and the greenhouse gas balance of such ecosystems.

In developing countries, measures to avoid deforestation and to restore native forests strike a good balance between climate change mitigation and conservation of biological diversity. Policies for the conservation and sustainable use of existing forests should be aimed at increasing rural incomes, empowering local users of forests, and promoting good governance of natural resources. Because measures to avoid deforestation would be difficult to translate into verifiable greenhouse gas emission credits in the Kyoto Protocol, they should be promoted through other policies. Sustainable agroforestry systems should be promoted as a form of land management for mitigating climate change and for biological diversity conservation, because these provide numerous socioeconomic and environmental benefits.

Whereas the potential of carbon sequestration measures in a given terrestrial ecosys-

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