MATERIALS SCIENCE

Panel Hopes Compromise Will Bail Out Neutron Source

The Advanced Neutron Source (ANS), a planned $3-billion nuclear reactor, promises to generate powerful beams of neutrons that, like x-rays, would open a new window into the structure of matter. But before it can do so, the project must first generate enough political support to overcome two hurdles. One is a price tag that may already be beyond the reach of the Department of Energy's (DOE's) falling budget. The other is its use of weapons-grade uranium as fuel, a practice that flies in the face of the Clinton Administration's policy to stem the proliferation of nuclear weapons.

Administration officials have been trying to keep ANS alive (*Science*, 11 November, p. 963), but they concede that the criticism could eventually prove lethal. "There's an erosive effect when you have opposition like that," says a senior nonproliferation official at the White House, who requested anonymity. To shore up support, DOE is considering redesigning the project, at the risk of degrading the science and raising the price.

A recent study by Brookhaven National Laboratory laid out the dilemma facing DOE, which plans to build ANS at its Oak Ridge (Tennessee) National Laboratory. The reactor can't live up to its scientific promise unless it runs on the type of highly-enriched uranium (93% uranium-235) that terrorists covet for building nuclear weapons. But dilute the fuel enough to meet the current U.S. nonproliferation policies—(20% ^{235}U)—and you destroy the project's scientific value.

Last month, in an attempt to find a way out of this bind, a DOE advisory panel suggested a new design for the ANS that would run on fuel with 35% enrichment. While scientists say they could live with the resulting reduction in capability, critics say the compromise would raise ANS's cost by at least $400 million. In addition, the fuel still wouldn't meet the standards set by the United States and other countries to guard against the proliferation of nuclear weapons. "There are only two classes of uranium under U.S. law and international custom," says Alan Kuperman, a consultant at the Nuclear Control Institute in Washington. "And 35% fuel qualifies as highly-enriched uranium."

Playing percentages. Enrichment refers to the amount of ^{235}U—the explosive form of the element—in the fuel. Natural uranium isn't dangerous because it's mostly nonexplosive ^{238}U with a tiny fraction of ^{235}U mixed in. To make the first atomic bombs, researchers on the Manhattan Project learned how to increase the amount of ^{235}U. The more ^{235}U, the less total material you need to start a nuclear explosion. With standard weapons-grade fuel, enriched to 93% ^{235}U, it would take just 50 kilograms. With an enrichment of 20% ^{235}U, it would take an impossibly large 6 tons.

Fuel that is 20% ^{235}U qualifies under the definition in the Energy Policy Act of 1992, which calls for the phaseout of weapons-grade uranium, and under the Reduced Enrichment for Research and Test Reactors (RERTR) program, a program created in the 1970s and recently restarted that is designed to discourage worldwide use of weapons materials for civilian research. Under this program, the U.S. and Europe are now cooperating to convert more than 300 research reactors from weapons-grade to low-enrichment uranium.

Seven reactors that can't perform their intended function without weapons-grade fuel have received exemptions under the program—three facilities in the United States, two in France, one in Belgium, and one in Holland. But the policy encourages countries to design future research reactors in a way that doesn't require highly enriched uranium.

If the Clinton Administration builds the ANS as planned, say nonproliferation activists, it would lose control over the use of nuclear materials in Europe. U.S. officials would be on shaky ground in trying to persuade Germany to scrap plans to use weapons-grade uranium in a new reactor, called FRM-II, that is also a source of neutron beams (though a less powerful one than ANS would be). The German project has already won government approval and is scheduled to start running around 2000. While the U.S. weapons material is carefully guarded, the standards in Europe are considerably more lax, argues Kuperman.

All these political considerations argue strongly against using enriched uranium. On the other hand, the scientific considerations all point the other way. The worth of the project depends on the machine's total flow or "flux" of neutrons: the higher the flux, the better the science. "The best way to get that high flux is to use highly enriched uranium," says Robert Bari of Brookhaven. "Once you start to de-enrich it—start poisoning the fuel with ^{238}U—you start to detract from the performance of the reactor." With 20% enriched fuel, the reactor would emit less than a third of the hoped-for neutron flux.

In fact, at that level, the project would not be worth doing, says DOE's Basic Energy Sciences Advisory Committee (BESAC), which discussed the recent DOE report, drawn up by a group headed by Bari, at a meeting last month. The panel believes the scientific community won't get its money's worth from the reactor unless ANS reaches a neutron flux at least five times that achieved at the world's leading source—a reactor in Grenoble, France. The original design, it noted, would have met this requirement.

A middle ground. Last month, BESAC took Bari's report and used it as the basis for a proposed compromise design. This new design would use a larger core composed of three cylinder-shaped "elements," instead of the previously planned two, to allow the project to run on fuel with 35% enrichment. Those expensive changes would mean a degraded performance, although Bari says the project "might just barely skim by."

DOE is considering whether to endorse this option, says Iran Thomas, acting assistant director for basic energy sciences, and expects to reach a decision by February. An official at the State Department, which has been involved in the discussions and would have to approve any changes, refused to comment on the BESAC recommendations.

At Oak Ridge, however, ANS Director William Appleton says he's willing to embrace the 35% solution as a fair compromise. "I think this addresses the proliferation concern. ... The fanatics want us to go down to 20%," he says, but that won't meet the performance goals.

But even if the DOE manages to reach some kind of compro-

OPTIONS FOR ADVANCED NEUTRON SOURCE

Criteria	Original	Compromise	Low Option	Activists*
Fuel Enrichment (% uranium-235)	93	35	20	20
Core Volume (liters)	67.6	82.6	82.6	108
Fuel Density Required (g/cc)	1.7	3.0	3.5	4.2**
Performance (neutron flux***)	100%	80%	30%	65%
Cost (billions)	**$3**	**$3.4**	**$3.07**	**$3.07******

* Recommendation of Nuclear Control Institute
** Not yet developed
*** 7.3 x 10^{19} neutrons/square meter/second
**** Plus unknown R&D costs
SOURCE: ROBERT BARI/BROOKHAVEN NATIONAL LABORATORY

mise, the proliferation concerns won't disappear. The Germans say FRM-II cannot be redesigned to run without weapons-grade uranium. FRM-II is meant to run with very low power and use a very small core, yet still get a flux of neutrons comparable to the reactor in France. The small core requires highly enriched fuel, explains Wolfgang Böning of the Technische Universität in Munich. "This is not as ambitious as ANS. A redesign [to use less enriched fuel] would kill the project."

Nonproliferation activists are particularly worried about the German project because the fuel—imported from other countries, including Russia, and stored at the Bavarian lab—might be vulnerable to terrorist theft. And they accuse U.S. officials of soft-pedaling the potential risks because of a desire to build the ANS. "I think the U.S. government has not gone to the mat on this, and the main reason is ANS," says Kuperman. "We can't say it's wrong to build reactors with enriched uranium and then go ahead and do it ourselves."

Kuperman's organization is joining with the Natural Resources Defense Council and the Union of Concerned Scientists to oppose ANS unless it uses fuel with less than 20% enrichment. He says it's possible to do this if the project leaders build a much larger core—nearly twice the size of the original. Bari says the trouble with that option is that it would require an extremely dense fuel—denser than anything that now exists.

The White House official says the Clinton Administration may have trouble swallowing the 35% solution because of the signal it might send to other nations concerned about possible diversion of the enriched fuel for nuclear weapons. "The thinking is we shouldn't impose a new standard." But he says the overwhelming worry with ANS right now is its cost. So far, Congress has appropriated only small amounts of money each year to cover research and development, and has balked at spending the first dollar for construction. The political support must be found to reverse that trend, he says.

"[ANS supporters] don't need the opposition of the nonproliferation community and the people trying to save money," says the official. The fear is that, together, the two forces may be strong enough to push ANS off the Administration's agenda.

–**Faye Flam**

PALEONTOLOGY

Ninety Ways to Be a Mammal

Mammalian evolution after the death of the dinosaurs is a long-running performance—65 million years and counting. Naturally, in a run that long, the cast has changed many times. But a new paleontological analysis suggests that, at least in North America, the number of players on stage at any given time has always returned to the same level.

According to a massive database compiled by postdoc John Alroy at the University of Arizona, the magic number of mammalian genera—groups of closely related species—is about 90. His analysis, the first to document an equilibrium in mammals with hard statistics, joins a growing number of studies showing that such steady states can persist for long stretches of time. "It's amazing—a system that not only approaches a steady state, but a relatively stable steady state for more than tens of millions of years," says diversity expert Michael Rosenzweig of the University of Arizona.

And Alroy's database, adds Rosenzweig, provides a solid basis for theoretical work on evolutionary rates, speciation, and extinction: "This level of sophistication in the data will allow us to get at the root causes of diversity patterns."

Paleontologists have praised the work too, because it proves what some have long suspected: That the pattern of increasing mammalian diversity through time, which appeared in some older analyses, was an artifact. "He's done exactly what was needed," says Philip Gingerich of the University of Michigan. "Some people tend to think that everything builds up and up to the present. And it's not so."

Alroy bases his conclusions on an analysis of the terrestrial mammalian fossil record in North America, excluding only airborne bats and marine mammals. His data were presented last month at meetings of the Society of Vertebrate Paleontologists and the Geological Society of America in Seattle and earlier at a meeting of the Ecological Society of America in Knoxville, Tennessee. They show that, after the Cretaceous-Tertiary extinctions 65 million years ago, the number of mammalian genera shot up to a high of about 130 genera 55 million years ago. Thereafter, the number of genera waxed and waned, sinking to as low as 60 and rising up to 120, presumably in response to climate change and immigration. These fluctuations lasted millions of years, but diversity always converged on an equilibrium of about 90 genera, says Alroy, who successfully tested the equilibrium hypothesis against a statistical model of random change.


SMITHSONIAN MUSEUM OF NATURAL HISTORY

Different faces, similar numbers. Mammal species have changed over the past 65 million years, but the number of genera has always returned to 90.

Paleontologists have previously explored the history of mammalian diversity, and some, such as Richard Stucky of the Denver Museum of Natural History and Jason Lillegraven of the University of Wyoming, have also suggested a steady state. But these analyses used a rougher time scale and older taxonomic data, and Lillegraven is still "pessimistic" about overcoming the sampling problems inherent in the fossil record: "I'm not sure the data are good enough to make such sweeping conclusions at this point."

Others think Alroy's labors have created a strong case. Alroy, who began this project as a junior in college, pored over more than 1500 papers and devised a new quantitative method to improve the time resolution in his analysis; the technique makes using statistics feasible. Alroy's work follows the path laid down by Jack Sepkoski of the University of Chicago, who charted the extinctions and radiations of marine invertebrates. "But he did it 10 times better than me," says Sepkoski.

Assuming that the equilibrium exists, what maintains it? To some, the long-term equilibrium suggests an ecological carrying capacity for the continent; Stucky speculates that energy availability—what's around to eat—may be enforcing the limit. Rosenzweig suggests species fare better when diversity is low, in part because they face less competition from other species; as diversity increases, however, speciation declines and extinction rates go up. The result is continual turnover at a constant number.

The true test of that idea is whether origination and extinction rates vary with diversity. Alroy's preliminary analysis suggests that damped speciation rates alone are keeping diversity in check, while Stucky's work points at extinction rates. There's still a long way to go before scientists understand what maintains diversity, but Alroy has given both ecologists and paleontologists a number of issues—and the number 90—to think about.

–**Elizabeth Culotta**