strated, the RBMKs have a design flaw that comes into play at certain power levels if water in the tubes evaporates and the control rods are not inserted. The nuclear reaction speeds up—instead of slowing down, as it would in a U.S. reactor. No one has come up with a failsafe solution yet, though the Russians have tried to make it less likely to occur by installing faster control rod mechanisms, adding neutron absorbers, replacing old tubes with stronger ones, and training operators better. In addition, some of the older RBMKs are being run at 70% power until they are "retubed."

But graphite reactors aren't the only ones causing headaches. The other threat comes from a younger system known as the VVER 440-model 230, the first generation of technology styled on the U.S. pressurized water reactor. Ten of these reactors are now in operation. The fuel is located in a small core inside a heavy steel pressure vessel. Water flows around it, serving as a moderator, a coolant, and a means of transferring heat to the turbines. The VVER 440-230s are safer than RBMKs, and are reputed to be among the stablest reactors in the world—as long as they remain within normal pressure and temperature limits. But they, too, were designed with efficiency, not safety, in mind.

Also built without the heavy concrete containment structure that surrounds Western reactors, the VVER 440-230s again have no barrier to stop radiation leaks if other systems fail. And they lack redundant cooling systems, standby control cables, and adequate fire prevention systems. For efficiency, the Soviets often located as many as four in a single, thin-walled building. The consequence is that a serious accident could threaten all at once. Says Gallucci: "We believe these reactors cannot really be made safe in terms of what 'safe' means to us in the West."

That puts the U.S. government in a "terrible ethical position," says Gallucci. Doing nothing would be "like sticking your head in the sand," but providing technical fixes may prolong the use of reactors that ought to be abandoned. By improving them, says Gallucci, "you become complicitous" in their operation.

The right thing to do, safety experts testified at a hearing before the Senate Energy and Natural Resources Committee on 16 June, would be to shut down these systems. "There is a growing international consensus that the remaining 15 RBMKs and 10 VVER 440-230s should not be operated any longer than absolutely necessary," said Ivan Selin, an electrical engineer and chairman of the U.S. Nuclear Regulatory Commission. Indeed, the IAEA, in an unusual, radical decision, in 1991 urged that Bulgaria's four VVER-230 reactors at the Kozloduy plant near the Danube River be closed. These reactors are among the oldest of their type and because they are situated on one of Europe's main waterways, they pose a greater potential threat than Chernobyl. After Soviet technicians departed, Bulgaria invited the IAEA in to take a look. Western experts found that the plant had fallen into a bad state of disrepair and lax management. Bulgaria agreed to shut down two of the reactors for technical fixes and operator retraining last year, but both are scheduled to come back on line later this year, to Europeans' dismay. The remaining two reactors have continued to run without significant changes, according to the IAEA's Rosen.

Bulgaria's problems are typical of the rest of eastern Europe. Bulgaria's citizens now depend on cheap electricity provided by the Kozloduy plants, Rosen told the Senate. The country has precious few other energy sources—or cash to exploit them. Bulgaria gets 40% of its electricity from Kozloduy; to make the repairs now under way, it has been forced to ration electricity. "For some time to come, I believe we are obliged to accept that all the plants at Kozloduy will be needed," said Lord Marshall of Goring, Britain's former nuclear power chief, now head of the World Association of Nuclear Operators, who has been to Kozloduy.

Russian officials also are saying they cannot afford to close down older plants—not even the RBMKs. They have suggested, however, that it might be possible to phase them out by replacing them with the latest model Soviet reactor, called the VVER 1000. This is a modern pressurized water machine, comparable to the best in the United States and Europe. About 11 of them were under construction at the time the Chernobyl accident occurred. Work on them came to a halt, but now the Russian nuclear ministry would like to resume building them, with Western financial help.

This proposition—to rebuild the entire Russian nuclear industry—is what sends cost estimates into the billions of dollars, according to Gallucci. And he doubts that "that kind of money" will be available as foreign aid. Instead, if the Russians and other eastern European countries want money for new reactors, they will probably have to obtain commercial financing. And, to do that, they will have to prove that they can repay loans. That means restructuring economies to reduce energy subsidies.

In the meantime, says Lord Marshall, "we have no alternative but to make the existing reactors as good as possible," even if it is distasteful to share responsibility for them. Marshall is more optimistic than other Western experts that the Soviet reactors can be run safely. The majority view, as expressed by Rosen, is that "we have put a lot of bandaids on" a dangerous situation, and that it will take a much stronger effort to reduce the risks of an accident—an effort that the Western leaders failed to agree on earlier this month.

–Eliot Marshall

ENVIRONMENTAL RESEARCH

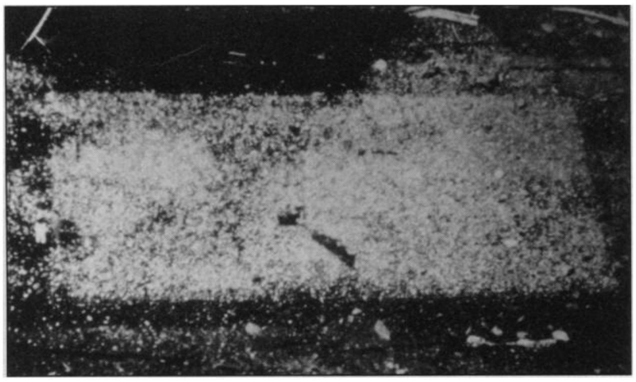
Oil-Cleanup Method Questioned

The workers cleaning up after the 1989 Exxon Valdez oil spill in Prince William Sound dubbed it the "magic rectangle": a swathe of oil-drenched beach, roughly the size of an Olympic swimming pool. The "magic" was that within days of undergoing an experimental oil-removal treatment back in 1989, the rectangle had been transformed into a much cleaner field of sand and cobblestones. The press loved it, seizing on this success story as dramatic proof of the power of the new technique, called "bioremediation," because it aimed at cleansing Alaska's oiled beaches by using fertilizer solutions that stimulate the appetites of the state's native oil-munching microbes. Indeed, the magic rectangle helped persuade officials of the Environmental Protection Agency (EPA) and the state of Alaska to give Exxon the go-ahead to use bioremediation in its efforts to clean up the spill.

Some 3 years later, however, some scientists and oil cleanup workers are challenging not only the early enthusiasm but the claims that Exxon's larger scale bioremediation efforts have been generally effective. Two weeks ago, for example, the Science Advisory Board of the Environmental Protection Agency, which has been evaluating bioremediation experiments conducted by the EPA in Prince William Sound during 1989 and 1990, released an "unapproved working draft" of its review that concludes that the treatment's efficacy wasn't all it was cracked up to be. While the board's draft report calls the bioremediation study "a significant accomplishment," it states that "only in some of the field studies was convincing evidence of bioremediation obtained."

Publicly, most of the board members who performed the review have refused to comment until it's presented in final form to EPA administrator William Reilly. One particularly skeptical reviewer told *Science*, however: "You have to make a leap of faith [to say] we achieved anything. I think they may have overreached the data."

That's just what several scientists familiar with the results of both the EPA experiments and Exxon's wider efforts to use bioremediation feel. "What I've feared all along," says Ernie Piper, who was the on-site coordinator of the Oil Spill Response Division of Alaska's Department of Environmental Conservation (ADEC) during the cleanup, "is that people are going to come out of this experience in Alaska thinking that we've got the silver bul-



The magic rectangle. Its appearance boosted bioremediation's reputation for efficacy.

let here—and by no means have we got that." Indeed, Piper claims that the physical force exerted by the high-pressure wands used to spray the fertilizer solution on the beaches actually accounted for much of the cleansing attributed to enhanced microbial activity.

Scientists at EPA and at Exxon dispute such criticism. Roger Prince, senior staff biochemist at the Exxon Research and Engineering Co. in Annandale, New Jersey, and one of the lead scientists on Exxon's bioremediation project, says that the company has the data to prove that the fertilizers it applied to the oiled beaches—a total of 100,000 pounds of nitrogen during the summers of 1989 and 1990, plus 7000 pounds in the summer of 1991—increased the rate of oil biodegradation 3- to 5-fold. Not only that, they're getting ready to publish the data, he says, as a "brochure" for the public before submitting it to a peer-reviewed journal. In addition, says Prince, Exxon presented a summary of their data to scientists on the EPA advisory board.

But until Exxon publishes its bioremediation data somewhere, most environmental scientists have to depend on the results of the EPA field studies to assess the technique's overall effectiveness. EPA began those studies in May of 1989, 3 months after the Exxon Valdez dumped its 11 million gallons of oil into Prince William Sound. Agency scientists tested the bioremediation techniques at two sites on Knight Island, which were treated in 1989, and one each on Elrington and Disk Islands, which were treated the following year. The measure of success was the speed of improvement compared to that achieved by other cleanup methods or by natural oil degradation.

According to ADEC officials, traditional cleanup tools such as rock-washing machines, which actually dig up the beaches in order to cleanse the rocks, would have taken years to clean the roughly 1200 miles of beach contaminated by the spill. And they would also disturb biological communities, damage shoreline profiles, and present a thorny problem of disposing of tons of beach materials. So even a small success with bioremediation would be better than nothing, says former ADEC microbiologist Jon Lindstrom, who has since moved to the University of Alaska in Fairbanks. "The data didn't indicate that [bioremediation] was such a great idea, but we didn't think it would do a lot of harm either," he says.

But before trying to determine how quickly bioremediation worked, EPA scientists needed to determine which fertilizers best stimulate the microbes' appetites for oil, measured against each other and against various cocktails of diverse fertilizers. They also needed to define what was the best method of applying the fertilizers—by spraying them on or as slow-release briquettes—and how often to apply them. After workers blasted the beaches with steaming hot water, which spread the oil in a thin layer, they applied several different fertilizer combinations. One of the most successful was Inipol EAP 22, which contains mostly urea and oleic acid. According to the EPA advisory board's draft review, this preparation "conclusively" enhanced oil disappearance at Passage Cove—one of the two sites on Knight Island.

Inipol also significantly sped up oil clearance at the Elrington Island site. At those two sites, the fertilizer treatments sped up oil degradation by about two summers compared to the time it would have taken to disperse the oil on the beach mechanically and let the microbes degrade it at natural rates, estimates Hap Pritchard, a microbial ecologist at the EPA's Gulf Breeze laboratory who headed up the agency's bioremediation experiments. He concedes, however, that the cleanup times proved difficult to assess accurately. The EPA's advisory board concurs: "The specific estimates of cleanup time given in this report have considerable statistical uncertainty."

One problem with the measurements, says Pritchard, is that the bugs' appetite for oil was healthy even before the fertilizers were applied, giving researchers a high baseline from which to start. Prince agrees, and points to another confounding factor: Different components of oil break down at various rates. "It's complicated to find an overall rate of biodegradation," he says. "That's why it's taken us a while" to get Exxon's own data out, he says.

And while the EPA experiments indicated that Inipol was the method of choice for cleaning the beaches, there was a problem: Neither it nor the other fertilizers had an effect on Disk Island, according to EPA's draft report on the Alaskan bioremediation. So if bioremediation really works, why would it cleanse one strand but come up dry when tested on another?

EPA researchers don't have the answer to that question. But Pritchard speculates that a number of geological factors on Disk Island might have interfered with the fertilizer's ability to enhance biodegradation. For one, he says, the island's beaches are fairly protected from the wind, so there was less wave action to stir up oxygen for the microbes. Second, Disk Island hosts larger amounts of "biomass" than do other islands, particularly algae that might compete for fertilizer nutrients. But Pritchard points out that the successfully treated beaches mirrored the types of beaches and the conditions under which Exxon used bioremediation. "If you want to get a flavor for how successful bioremediation was, that's the data to look at," he says.

If there's anything that scientists involved with the Alaskan bioremediation efforts can agree on it's that the technique needs a lot more refining before it becomes a standard cleanup tool for marine oil spills. "It was clear that [in Alaska] we were in the embryonic stage of a new science," says Alex Viteri, an environmental engineer at ADEC who worked on a state bioremediation committee during the cleanup. "And there's still a lot of work to be done to get out of the embryo stage," he says.

On the beach. Cleanup worker sprays Inipol on a polluted Alaskan beach in 1989.

EPA is committed to doing this work: In 1992 it's spending $8 million on bioremediation research, part of a larger program that's devoted to high-tech approaches to getting rid of hazardous wastes in the environment. In addition, EPA has a program to test the effectiveness and safety of new oil spill bioremediation products.

But what's really needed to understand bioremediation of oil spills better is a controlled spill and cleanup, Viteri says. He and ADEC have been trying to launch such a study in Alaska, but they've been held back by public opposition to the plan. Viteri envisions a more scientific pursuit, in contrast to the frenetic atmosphere of cleanup workers sopping up the remains of an environmental disaster. After the spill happened, Viteri says, "science went in upside down. Now we have to go in with science standing up."

–Richard Stone