

Technical and political hurdles have slowed Russia's efforts to dismantle dozens of decommissioned submarines before they fall apart or their nuclear fuel is stolen

Haunted by Red October

SEVERODVINSK, RUSSIA—A giant crane hoists the sheet-metal cowlings off the rusty bowels of a Cold War dinosaur: a 40-year-old nuclear submarine. Buffeted by driving rain off the White Sea, workers with acetylene torches clamber through the corroded remains of the Victor class sub's conning tower and quickly pick their way down several meters into the dim hole. Beneath their feet is a compartment holding the ship's nuclear reactor, filled with 246 tubes of enriched uranium fuel and highly radioactive daughter isotopes that had accu-

time bombs," says Frolov. "We've waited far too long already to get rid of them."

That view is echoed in governments across the Western world. When the Soviet Union crumbled in 1991, nearly 200 decommissioned nuclear submarines were tied up at shipyards across Russia, from the Kola Peninsula in the northwest to Vladivostok in the Far East. More than a decade later, and thanks partly to hundreds of millions of dollars in Western assistance, Russia has dismantled more than half the Soviet-era sub-

Less likely but just as grave, the ships pose a proliferation threat. In principle, experts say, a terrorist group could mount a sophisticated operation to snatch the enriched uranium fuel.

Last month's tragedy on the Barents Sea highlights the precarious nature of these Cold War leftovers. On 30 August, nine Russian sailors lost their lives when a 40-year-old decommissioned submarine, the K-159, sank in a storm while being towed to nearby Polyarny for dismantlement. Fortunately, its reactor appears to be intact. Russian officials say they plan to raise the K-159 next year and remove the nuclear fuel.

Even before the accident, Western governments considered Russia's nuclear fleet to be one of the highest nonproliferation priorities in the former Soviet Union. At a G8 summit in Canada last year, governments pledged hundreds of millions of dollars over the next decade for sub dismantlement. And in early July, the European Commission and seven other governments allotted a further €160 million toward the effort.

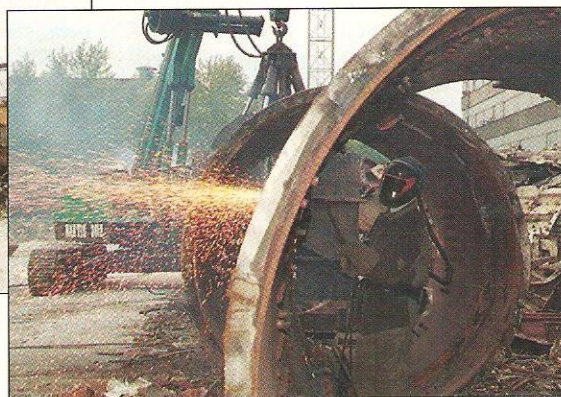


Iron grip. Decommissioned nuclear submarines are brought to this dry dock (above) for dismantlement at the Zvezdochka shipyard; carving up a haul (right).

mulated during the reactor's lifetime.

"We're on a tight schedule," says Oleg Frolov, chief engineer here at the Zvezdochka shipyard, which granted a reporter from *Science* rare access to the once-secret facility. Norway has paid millions of euros to have two of these dilapidated attack subs dismantled by 15 November. But it's not only the need to meet milestones on a contract that has the Zvezdochka crew working overtime: There's an imminent danger that the deteriorating ballast tanks will give out, sending the subs and their nuclear remains to the bottom of Dvina Bay. "These things are ecological

marines, removing their spent fuel and radioactive compartments and chopping up their hulls for scrap. But dozens of reactors from these ships, *Science* has learned, are afloat in bizarre buoys near the shipyards; Russia says it simply doesn't have the cash to haul them in and store the radioactive remains. Moreover, more than 100 subs still await dismantlement, according to Russia's Ministry of Atomic Energy (Minatom). These corroding hulks, Frolov and others say, are disasters waiting to happen, because the subs could sink and perhaps disgorge their spent fuel.



But Russia's pas de deux with the West has been awkward and filled with missteps. Although the government has avidly sought Western expertise and funding, it has often been reluctant to divulge information—technical data on nuclear reactor design, spent fuel, and radioactive waste—that's crucial to the task. "It's hard to even know what the scientific and technical issues are," says Vince Novak, manager of the European Bank for Reconstruction and Development's Northern Dimension Environmental Partnership.



Radioactivity coast to coast. Russia's decommissioned nuclear subs await their fate at military facilities along the Kola Peninsula and near Arkhangelsk in the northwest and off Vladivostok and the Kamchatka Peninsula in the Far East.

Another challenge is gaining access to the military docks where subs are berthed to ensure that Russian methods are sound.

But there are encouraging signs that Russia is becoming less secretive, which could unfetter Western assistance and, observers hope, get the remaining submarines dismantled before the next disaster strikes.

Sittin' on the dock of the bay

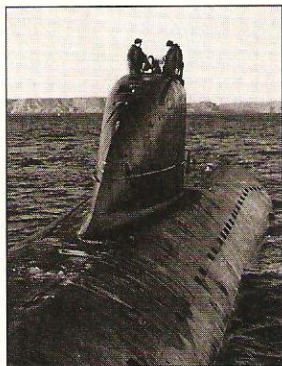
Taking apart subs is a big business at Zvezdochka, which employs 10,000 workers in a sprawling complex built to service the Northern Fleet. Many of the fleet's submarines, once the pride of the Soviet navy, were launched from a shipyard on the opposite bank of the Dvina River. Zvezdochka has dismantled 19 subs since 1996, and its facilities are first-rate. A pair of gigantic shears from the U.S. Department of Defense is used to carve up 40-ton sections of hull removed from the subs in a dry-dock cradle. The United States also paid for a \$60 million Russian-designed facility in which fuel assemblies are hoisted from the subs and put in transport casks for rail transfer to the Mayak reprocessing center in the Ural Mountains. There the spent fuel will be processed for use in civilian power stations.

Dismantling most types of nuclear submarines, if the ships are undamaged, is "not technologically challenging," says Bill Youngstrom, who directs the U.S.

Defense Threat Reduction Agency's dismantlement efforts in Russia. Since 1996 the agency has managed a \$461 million initiative, part of the multibillion-dollar U.S. Cooperative Threat Reduction (CTR) program, to improve the facilities at Zvezdochka, the Nerpa shipyard in Snezhnogorsk, the Vilyuchinsk shipyard in Kamchatka, and the Zvezda shipyard in Bolshoi Kamen, on the Sea of Japan (see map). Overall, CTR funds have paid for the dismantlement of 25 intercontinental missile-capable submarines, with 16 more planned by 2007 and a further seven by 2012.

Getting the fuel off one type of submarine in particular—Alpha class attack subs with liquid metal-cooled reactors, of which seven were built—may be far more difficult. "The Russians never planned good ways to defuel these boats," Youngstrom says. Viktor Akhunov, head of Minatom's nuclear decommissioning department, agrees: "We don't know whether to extract the fuel or simply extract the whole radioactive area from these ships for storage and eventual natural decontamination."

Another formidable task lies



Cold War Relics

	Strategic subs	Multipurpose subs	Service vessels
Decommissioned	52	140	44
Dismantled	45	44	5*
Waiting for dismantlement	7	96	39
Defueled	3	23	
Waiting for defueling	4	73	

* In process of dismantlement.

off Russia's eastern coast: three damaged subs of the Pacific Fleet that are riddled with radioactive contamination from Cold War accidents. Akhunov says that cutting up these subs would expose workers to severe radiation risks. "The best option," he says, is to insert these small ships into much larger Shark class submarines. The makeshift sarcophagi, Akhunov says, "can be placed on shore and left for ages to decontaminate."

Minatom is also struggling to cope with a dilapidated fuel facility at Andreeva Bay, near the border with Norway, that stores 21,000 fuel assemblies extracted during the 1970s. These were submerged in a cooling pond that had hemorrhaged radionuclides into the groundwater and the bay until steps were taken in 1999 to stanch the flow. The assemblies were moved to concrete silos that are already corroding. "This is our most

dangerous site," says Akhunov. "We have to get the fuel out now." The plan is to ship it to Mayak if Minatom can find the funds for the transfer. Once the fuel is removed, huge amounts of contaminated water, concrete, and metal scrap will have to be dealt with.

Even with the fuel removed, the reactors themselves present a challenge. Many of the reactors removed so far have been simply left floating in their original compartments—huge circular buoys weighing up to 1600 tons. According to a report last January from the International Atomic Energy Agency, there are 89 such bobbing radioactive blocks, including 57 in Sayda Bay near Murmansk. Akhunov says that Minatom hopes to raise money to cut up the reactors offshore and store the remains onshore. Because the reactors are contaminated with primarily short-lived radionuclides, Minatom expects much of the radioactivity to decay over the next 70 years. In the meantime the ministry has scrapped plans to build a waste repository for reactors and spent fuel rods on Novaya Zemlya island above the Arctic Circle, citing concerns that global warming could make the permanently frozen ground there unstable.

It has instead settled on a facility on the Kola Peninsula. "We want to store the waste as close to the submarine bases as we can," says Akhunov.

Another overarching technical issue is what to do with liquid radioactive waste from submarine cooling systems, fuel-handling facilities, and

spills. Japanese experts have been at the forefront of efforts to tackle this problem. In 2000, the Japanese government commissioned the floating "Landysh" ("Lily of the Valley") facility in Bolshoi Kamen Bay, near Vladivostok, to dispose of such waste.

Military secrets revealed

Russia's reluctance to divulge data hampered the Landysh project early on. "Getting technical information was always a problem, because everything is considered secret," says Jim Stephens, an engineer at Crown Agents, a U.K. firm contracted by the Japanese government to manage its Russian sub programs. The information was coughed up eventually. "Although they knew they needed us, there was huge distrust," he says.

The key question now is whether Western experts will win more access to sensitive sites. Russian officials have long opposed visits by foreigners to military facilities, contending that it has sufficient expertise to carry out dismantlement on its own. But Western governments that are paying substantial sums for these programs have long pushed for more accountability. Russia's own contributions are paltry by comparison. Minatom has budgeted \$204 million in 2003 to stabilize thousands of sites across the country that pose potential proliferation threats. Only \$70 million of that is earmarked for dismantlement—a mere down payment on a "huge job" that could end up costing close to \$4 billion, says Akhunov.

Disputes over access and liability, for example, have impeded Japan's decade-long, \$170 million assistance program at the Zvezda shipyard near Vladivostok, where 41 general-purpose subs await dismantlement. For many years, "the Russian side did not admit access to the location at all," which also serves as the base for the Landysh project, says Toshiyuki Kawakami of the Japan-Russia Committee for Co-operation on Reducing Nuclear Weapons. In a high-profile snub last November, Yoshitaka Sindo, Japan's parliamentary secretary for foreign affairs, was refused entry to Zvezda. However, Kawakami says, "after controversial negotiations" the Russians relented, enabling Japan to reaffirm its commitment to submarine cleanup in a June agreement to speed up stalled programs.

A similar thaw is taking place in the northwest. "The Russians are much more willing to open up access to us now," says Torbjorn Norendal, special adviser on nuclear safety at the Norwegian Ministry of Foreign Affairs. He points to a recent Minatom decision to allow Norwegian inspectors into Andreeva Bay, where Norway had funded projects to help create safer environments for cleanup workers. "We told them more money would follow once access was granted," Norendal says. Since Novem-

ber, a Norwegian contractor has had monthly access. One big hurdle was overcome last May, when Russia and several partner countries and organizations signed the Multilateral Nuclear Environmental Program for Russia, which clarifies tax and liability issues surrounding nonproliferation activities. With donors now writing checks, the accord provides legal assurances for €1.8 billion worth of proposed projects.

"Working with Minatom is getting easier," says Eduard Avdonin, deputy director of Minatom's International Center for Environmental Safety. He points to recent successes such as improved Western access at Andreeva, an international conference in Vladivostok last fall on the ecological threats posed by mothballed nuclear submarines, and joint re-

search on the ecological impacts of ocean-dumping radioactive materials.

Nowhere is the recent glasnost more evident than at Zvezdochka. "Back in 1993 when American advisers first came here, we realized that we had a vast amount in common. Now other countries are getting involved too," says Frolov. When the shipyard finishes these two Victor class submarines, it hopes to turn its shears to three more, if it wins a contract for the job from Canada and Italy. "As soon as the funding is secure, we'll get them out of the water and the world will be that much safer," Frolov says. But scores more decommissioned and deteriorating nuclear subs would still be waiting in line.

—PAUL WEBSTER

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Physics

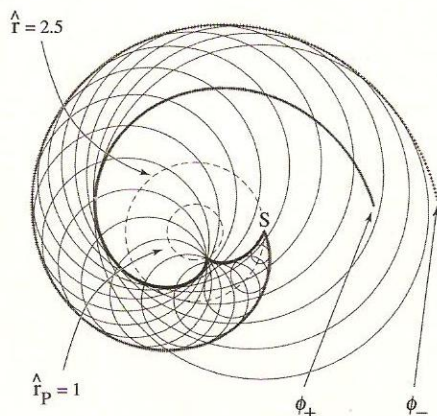
Money Spinner or Loopy Idea?

A tabletop synchrotron claimed to generate unusual radiation could transform communications and radar systems. But critics say it is based on flawed science

BRISTOL, U.K.—After the Turweston Aerodrome in Northampton shuts down for the night, three physicists wheel onto the runway a 2-meter-long device and jack it up on a scissor lift. They flip a switch and the machine emits radio waves that they pick up with an antenna down the runway. They rotate and tilt the device at a variety of angles, noting the radiation intensity, then move the antenna farther away and repeat the experiment. The trio—John Singleton of Los Alamos National Laboratory in New Mexico, Houshang Ardavan of the University of Cambridge, and Arzhang Ardavan of the University of Oxford—leave before dawn and return in the evening. Odd nocturnal activity, perhaps, but the researchers are chasing a dream: to cir-

cumvent the hallowed inverse square law, which holds that radiation intensity falls off in proportion to the square of the distance.

Others say they're chasing a phantom. If the team's machine—called a polarization synchrotron because it rotates a polarization pattern much like a conventional synchrotron rotates charged particles—does indeed emit radiation that defies the inverse square law, it would shake the physics community and possibly spur radical design alterations for all sorts of devices that generate electromagnetic radiation. "This machine opens up a new way of emitting radio waves," Singleton claims. Antennas powered by miniature polarization synchrotrons would require less power or transmit farther—perhaps, for ex-



To dizzying effect. According to their model of how the polarization synchrotron emits radiation, the Los Alamos-Oxford team claims that spherical wavefronts spiral away from the machine (point source S, left).

