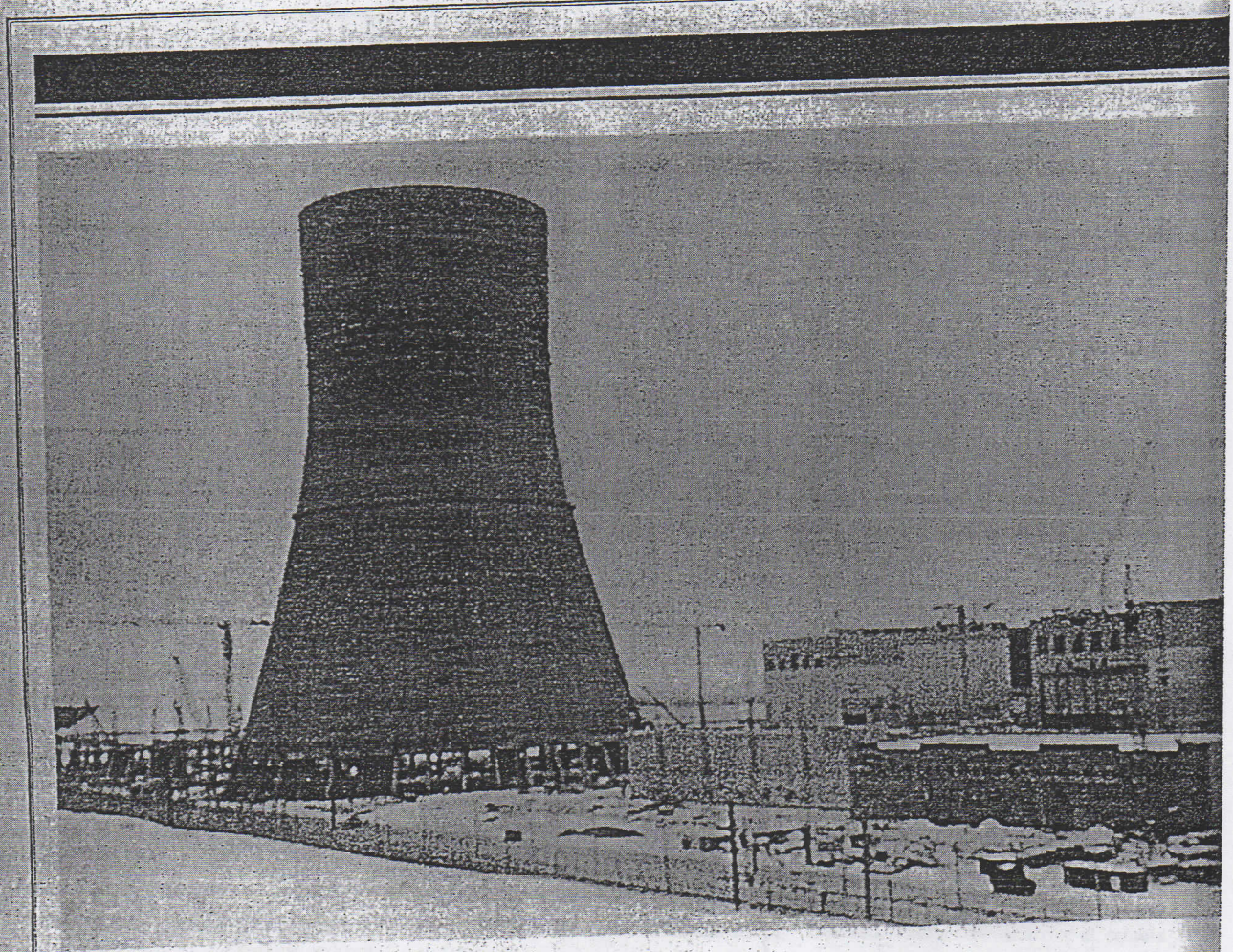
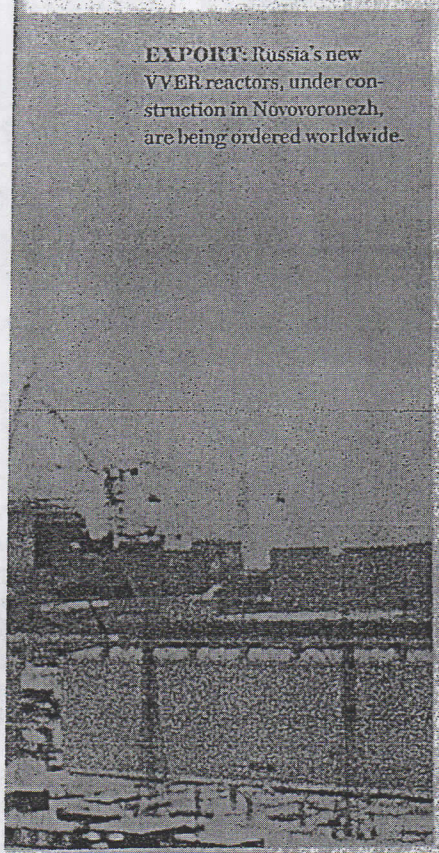


ENERGY

RUSSIA'S NEW EMPIRE: Nuclear Po

The federation is aggressively selling reactors all over the world, raisi

By Eve Conant



EXPORT: Russia's new VVER reactors, under construction in Novovoronezh, are being ordered worldwide.

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FOR ANY COUNTRY THAT MAY be considering acquiring its first nuclear reactor, Russia's annual ATOM-EXPO offers a seemingly simple solution. At a recent event, thousands of people from around the world flocked to a giant, czarist-era exhibition hall. A visitor could hear vendors such as Rolls-Royce talk about steam generators, watch reporters interview experts for a Russian nuclear-themed television program or pick up a "Miss Atom" calendar featuring the year's prettiest Russian nuclear workers.

The real action, though, was at a multilevel booth for Rosatom, Russia's state-owned nuclear company, which exuded a Steve Jobs vibe of pure whiteness and know-how. That was where "newcomers," as the Russians fondly call them, from nations that do not have nuclear power plants heard about options and signed cooperation agreements for Rosatom to build or even operate reactors for them. At one point, photographers snapped shots of Nigerian nuclear officials as they clinked champagne flutes with Rosatom chief Sergey Kirienko, celebrating their baby steps toward joining Russia's growing roster of clients, including Turkey and Vietnam. Rosatom has already finished reactors in China and India. In July, Finland chose the company over French and Japanese competitors for its next reactor.

The big show was all part of a Kremlin-backed $55-billion plan to make Russia a leading global supplier of nuclear power. Already the country intends to build roughly 40 new reactors at home, and it expects as many as 80 orders from other countries by 2030. Included are facilities that would generate power and desalinate water, of particular interest in the Middle East. The expansion comes as Germany is abandoning nuclear power, the U.S. industry is struggling and Japan is in the midst of soul-searching about its post-Fukushima intentions. President Vladimir Putin has called the build-out "a rebirth, a renaissance" of Russia's nuclear technology.

Rosatom is eyeing British and American markets, too—it owns uranium mines in Wyoming and supplies about half of the fuel used in U.S. reactors, according to the World Nuclear Association. But for now it is primarily targeting developing nations and countries that had close ties to the former Soviet Union. For some of these newcomers, Rosatom has a unique offer: it can be a one-stop nuclear shop. It will provide fuel and will permanently take back the spent fuel from its reactors—eliminating the need for some countries to build geologic waste repositories. That service, offered by no other country, "is a tremendous marketing advantage for the Russians," says Alan Hanson, who recently joined the Massachusetts Institute of Technology after 27 years as an executive at Areva, Rosatom's French competitor.

Russia is sweetening the deal by providing scholarships to young men

IN BRIEF

Russia is preparing to sell unconventional reactors to developing countries that have little nuclear power experience. The models include breeder reactors that make plutonium, mini reactors meant to float on the ocean and pressurized-water reactors equipped with passive safety features intended to stop a reactor meltdown without human intervention. Western experts say some of the models may not be as safe as Russian officials maintain and could increase the chance that weapons-grade material would spread worldwide.

and women from client nations to study in Russia and obtain degrees in "nuclear power plants and facilities." And because an average reactor costs at least $3 billion, Russia is offering the first ever rent-a-reactor program in which Rosatom builds and runs reactors on foreign soil.

Many of the world's nuclear experts are concerned that Russia is galloping ahead too fast. They worry that Rosatom is willing to do business with any nation, which could lead to the proliferation of nuclear material or know-how. Rosatom has had discussions with countries that the West considers dictatorships, such as Myanmar (Burma) and Belarus. And just this past July the president of Iran—a country mired in fresh U.S. sanctions over its nuclear ambitions—visited the Kremlin to ask Putin for more reactors beyond the one Russia already built.

Russian officials balk at the criticism and are enthusiastically casting a wide net. Kirill Komarov, a Rosatom executive tasked with overseas expansion, told reporters at a press conference in June 2012, "There is no country in which we will not be interested to build a plant."

Experts also worry that Russia's nuclear leaders do not place a top priority on safety. Although safety features are prominent in new designs, "the government owns and funds both the designer and the independent safety review. It was this arrangement in Japan that has been recently flagged as contributing to issues in the Fukushima accident," says Susan Voss, president of the Santa Fe consulting firm Global Nuclear Network Analysis and formerly a scientist working on reactor design at Los Alamos National Laboratory.

Rosatom spokesman Sergey Novikov insists that the federal supervisor, Rostechnadzor, "is absolutely independent." Russia says that all the reactor technologies Rosatom is promoting have the most modern safety features. But some Western experts remain dubious about how protective those features truly are.

FAST AND FURIOUS

RUSSIA IS ALREADY the world leader in developing one controversial option: fast-breeder reactors. More typical reactors in use worldwide consume enriched uranium fuel and generate waste that remains highly radioactive for thousands of years. Breeder reactors essentially recycle fuel. As the enriched uranium burns in the core, it generates neutrons, which collide with low-grade uranium (that cannot function as a fuel) in a blanket around that core, turning the uranium into, or "breeding," plutonium. The reactor can later consume that plutonium (it still generates highly radioactive waste). Breeder reactors can produce 10 to 100 times more energy from a set amount of uranium than the more standard varieties—boiling-water and pressurized-water reactors—can.

The U.S. built experimental breeder technology in the 1970s and 1980s but abandoned it—in part because abundant uranium supplies were cheap but also because the design heightens the chance for proliferation of weapons-grade uranium and plutonium. It "can provide cover for a weapons program," says Frank N. von Hippel, a physicist at Princeton University and former assistant director for national security at the White House Office of Science and Technology Policy. Voss adds that fast reactors give a country "a direct source of weapons-usable plutonium."

What is more, accidents can be very difficult to handle because the core is immersed in liquid-sodium coolant, in contrast to the water used to keep more standard reactors from overheating. Workers cannot just pop the lid to get to troubled areas because "sodium catches fire if exposed to air or water. And we live in a world of air and water," von Hippel explains. The Russians struggled through several fires to learn how to better control the technology, but von Hippel says another safety issue looms: a meltdown could lead to a small explosion that could "blow the top off a reactor" and widely disperse radioactive products such as plutonium, uranium, cesium and iodine.

Today the Russian BN-600, housed near Yekaterinburg, is the world's only commercially operating breeder reactor. Its workers are immensely proud that it has been operating for 30 years, 10 years longer than expected.

A Rosatom subsidiary, OKBM Afrikantov, has designed a BN-800 facility, now being built, and a BN-1200; the numbers in the reactor names give the power capacity, in megawatts (1,000 MW is a large reactor). The BN-800 can be modified to run on plutonium from retired nuclear weapons. A U.S.-Russia nonproliferation agreement stipulates that the BN-800 will be used to consume some of the stockpiles of Russia's weapons-grade plutonium. The BN-1200, however, is designed to produce plutonium for fuel, according to Leonid Bolshov, director of the Nuclear Safety Institute at the Russian Academy of Sciences.

Despite international hand-wringing, Rosatom has a long-term Advanced Nuclear Technologies Federal Program that envisions shifting a significant portion of its resources to breeder reactors by about 2050. The goal is a nuclear industry where all fuel is reprocessed, not dumped in unpopular storage sites. "We will have a closed fuel cycle; we have to," says Vladimir Galushkin, a passionate international coordinator at OKBM Afrikantov. "There is no other path."

FLOATING NUKES

THE SECOND controversial technology Russia is pursuing is the small modular reactor. It is a scaled-down version of the classic pressurized-water reactor. The small Russian models include spin-offs from old Soviet nuclear-powered submarines and icebreakers. They are much cheaper than the typical mammoth reactor, and they can be prefabricated to arrive at remote locations that might lack strong construction standards or a trained workforce. The drawbacks: they produce only 300 to 500 MW, and critics contend that mass production would scatter reactor risks more widely. Still, one Russian specialist, Dmitri Statzura, told me at a wind-whipped nuclear construction site in southern Russia that "mass production is a real possibility." He was particularly excited about the VBER, a 300-MW model that will first be built for remote areas of Kazakhstan.

At the same time, Russia is trying to shoehorn its breeder-reactor technology into a mini reactor called BREST. The de-

Eve Conant, a freelance writer based in Washington, D.C., and a former staff writer and Moscow correspondent for *Newsweek*, traveled to Russia on a grant from the Pulitzer Center on Crisis Reporting.

PHOTOGRAPH BY SRIRAMA JASTI, AP Photo

sign uses molten lead as the coolant, which is much less reactive to air and water than sodium is. Of course, lead is a known toxic substance, "but most industries know how to deal with it," says Kevan Weaver, director of technology development at TerraPower in Bellevue, Wash., which is developing its own fast mini reactors. "The Russians do have the most experience," Weaver explains. They have used their reactors in at least seven submarines and have built two onshore prototypes. TerraPower tests its prototypes in a Russian facility in Dimitrovgrad.

The potential spread of many fast small reactors worries groups such as Bellona, an international environmental organization in Oslo that tracks the Russian nuclear industry. Russia has arrested and jailed nuclear whistle-blowers, including one of Bellona's contributors, a Russian ex-navy officer accused of treason. Bellona has detailed nuclear accidents on Soviet submarines and says that four subs are lying dead on the ocean floor, their reactors still presenting a hazard.

What concerns Bellona environmental researcher Igor Kudrik lately, however, is Russia's desire to mass-produce mini reactors that can float. The country's first floating plant, the *Akademik Lomonosov,* is partially built and is scheduled to begin operating in 2016. The idea is to have easily maneuverable 35-MW reactors that could be towed to difficult-to-access regions or energy-intensive ventures such as desalination plants, with cables running to land to distribute power.

The U.S. toyed with the idea in the 1970s but considered it too dangerous, with a high potential for contaminating entire marine food chains. "I also can't imagine that floating nuclear reactors don't pose particular security risks when it comes to terrorists," says Sharon Squassoni, director of the Proliferation Prevention Program at the Center for Strategic and International Studies in Washington, D.C. Kudrik adds that remote locations would not have the people or gear needed to handle an accident or an incoming tsunami: "This is not a diesel generator that you can fix on your knee and restart." Nevertheless, China, Algeria, Indonesia, Namibia and others have expressed interest.

Bolshov downplays the concerns. He notes that the plants would be placed at the shoreline. "I do not see any difference between an at-shore and onshore plant" from a security standpoint. Bolshov says. In addition to boosting exports, the floating reactors could help Russia dominate the exploitation of the Arctic's offshore petroleum reserves as climate change makes more regions accessible for drilling.

A SAFER OPTION

ALTHOUGH RUSSIA is promoting its exotic breeders and floating mini nukes, it is most aggressively hawking its latest generation of pressurized-water reactors, known as VVERs. The infamous reactors that melted down in Chernobyl in 1986 also relied on pressurized water to make steam, which turns a turbine to create electricity. But VVERs have a fundamentally different design and are housed in a containment building; the Soviet Union did not build such structures around the Chernobyl reactors because they were huge.

Whether Russian training of foreign nuclear workers raises concerns or not, it is vital to preventing reactor accidents.

VVERs differ from those old models and from Western designs in several ways. For instance, they have horizontal steam generators, which Western experts agree are more accessible for maintenance. Russian fuel pellets also have holes in their centers, which provide better cooling for safety, according to Vladimir Artisyuk, vice rector for science and foreign affairs at the Central Institute for Continuing Education and Training in Obninsk. The biggest advances are passive safety features—systems intended to shut a reactor down without human intervention, even if the plant loses backup electricity from the outside power grid. Among the features are water tanks that can flood the core using just gravity. The reactor can also be cooled with air. "In Fukushima, this one system would have saved them," chief engineer Viktor Vagner claims proudly at the site of two reactors under construction near Russia's southern border.

Rosatom's passive safety systems have already been built into India's Kudankulam reactors, and they are making the VVER a popular choice. Rosatom is building, or has signed contracts for, 19 VVERs outside of Russia. New Western designs, such as Westinghouse's AP1000 pressurized-water reactor, include similar features, and most experts interviewed for this story say they do not see any significant differences in safety between the Western and Russian models. One American consultant, who helps Eastern European countries assess Russian options and does not want his name used, says, "The Russians are definitely up to snuff, and it's nice to be able to say that."

Good design does not preclude the possibility of bad construction, however. "There are still lingering concerns over the quality of their manufacturing of parts and components, construction quality and vendor support in the longer term once the reactor is up and running," the consultant says. Bolshov counters that Rosatom is watching those issues carefully: "Rosatom has made serious investments to have competition among manufacturers for better quality and price."

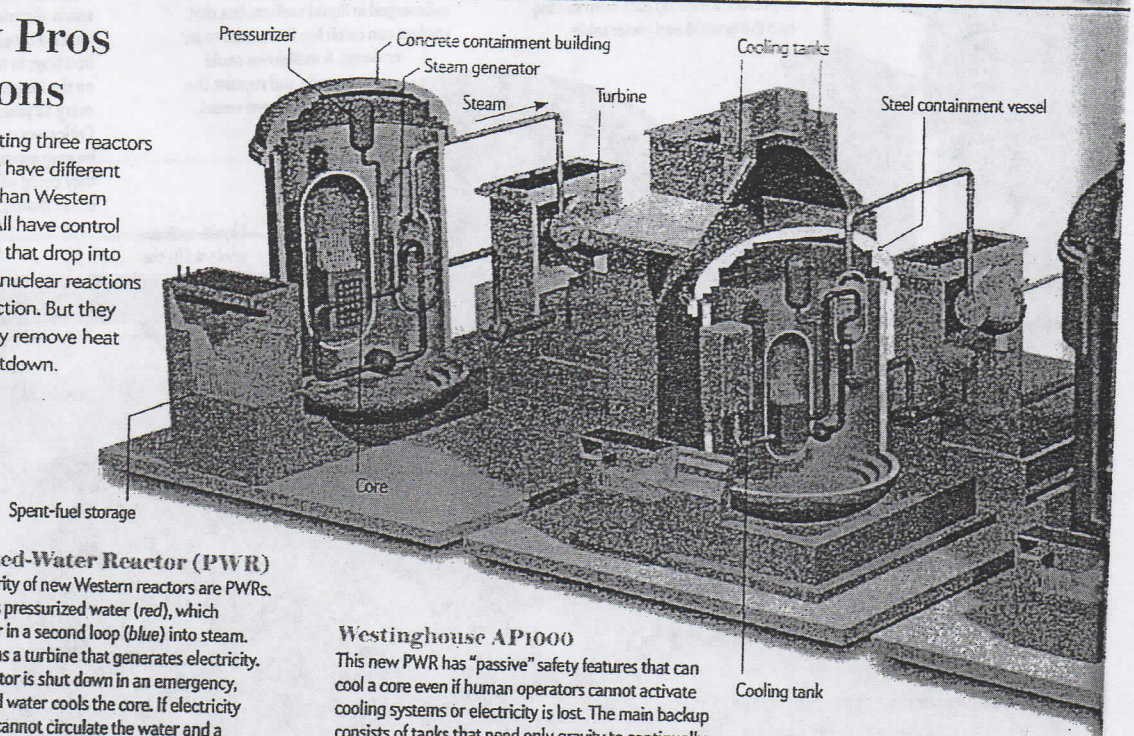
Another reason the VVERs are considered safe is a feature meant to prevent a Chernobyl-style accident. In the days after Chernobyl exploded, the Soviet Union tasked Bolshov, then a working physicist, with somehow figuring out how to contain Chernobyl's melting reactor core. He devised a makeshift platform of snakelike pipes cooled with water, covered with a thin graphite layer and stuffed between two one-meter-thick concrete layers. "It was done as a sandwich," Bolshov says. Heroic coal miners dug underneath the fuming reactor and inserted the platform to "catch" the molten core before it sunk into the earth and hit the water table.

In the end, Bolshov's creation did not have to fight the sinking core, which solidified just two meters short of the sandwich. Yet the close call paved the road for Russia's modern "core catchers": bowl-shaped vessels cooled by water and made

REACTOR DESIGNS

Safety Pros and Cons

Russia is promoting three reactors (*red names*) that have different safety features than Western designs (*blue*). All have control rods (*not shown*) that drop into the core to stop nuclear reactions during a malfunction. But they differ in how they remove heat to prevent a meltdown.



Pressurized-Water Reactor (PWR)
The vast majority of new Western reactors are PWRs. The core heats pressurized water (*red*), which converts water in a second loop (*blue*) into steam. The steam spins a turbine that generates electricity. When the reactor is shut down in an emergency, the pressurized water cools the core. If electricity is lost, pumps cannot circulate the water and a meltdown could occur, so backup power is essential.

Westinghouse AP1000
This new PWR has "passive" safety features that can cool a core even if human operators cannot activate cooling systems or electricity is lost. The main backup consists of tanks that need only gravity to continually flood the core with cooling water for several days.

of steel, iron and aluminum oxides, built directly under all of Russia's new pressurized-water reactors. Core catchers are already buried 4.5 meters below the two VVER-1200s going up in southern Russia.

Russia views the core catcher as vital. France's Areva design also includes one. Some experts have argued that core catchers would not have made a difference at Fukushima. But several of the plant's reactor cores "slumped" into the concrete underneath, as von Hippel describes it, prompting him to conclude: "A core catcher is a good idea."

M.I.T.'s Hanson and others argue, though, that the larger goal of safety engineers should be minimizing possible damage so much that core catchers are superfluous. "The public and the reactor owners will never buy the argument that a reactor is safe because it has a core catcher. Once the core is destroyed, the reactor is a total waste, and controlling the molten material after the fact does not eliminate off-site doses" of radiation, Hanson says. Westinghouse has adopted that approach; spokesperson Scott Shaw says the company's new AP1000 does not need a core catcher. If the core were to begin melting, an operator could flood the space around the reactor vessel with water held in tanks, for up to 72 hours.

PROLIFERATION OF WORRY

ROSATOM'S VVER PLANTS come with another innovation, one related to cash. The company will build Turkey's first reactors—four VVER-1200s—under a unique "build-own-operate" deal akin to a 60-year rental. It is the first time the arrangement has been used for a nuclear plant anywhere in the world, but Rosatom hopes the arrangement will catch on. "This is very attractive for newcomers," Rosatom's Novikov says.

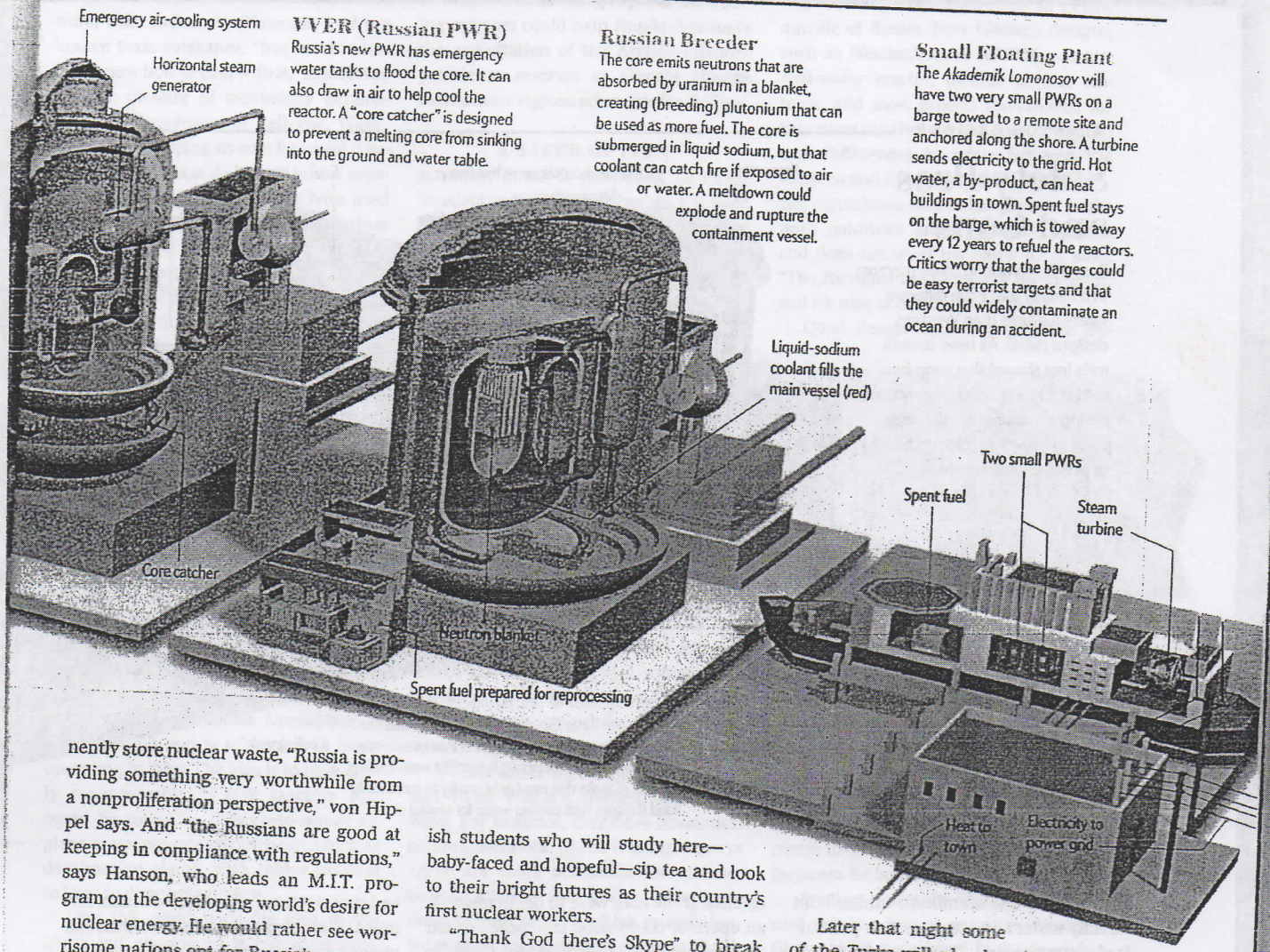
This rental plan, yet another part of Russia's effort to widen access to nuclear technology, worries proliferation watchers, particularly when it comes to the Middle East. Russia has completed Iran's only reactor, a VVER-1000, and has trained Iranian technicians in nuclear energy. The West fears that Iran is using its knowledge to develop clandestine weapons.

"It's hard not to look at the interest in civilian nuclear reactors in Turkey and other countries in the region as part of a hedging strategy," says Eric Edelman, former U.S. ambassador to Turkey. Although nuclear reactors are a far cry from nuclear weapons, expertise in nuclear technology and access to the nuclear fuel cycle, he says, "still opens the door for a more proliferated Middle East." Henry Sokolski, executive director of the Washington, D.C.–based Nonproliferation Policy Education Center, agrees that training could potentially be used for nefarious purposes. "I don't care how proliferation-proof the hardware is—the training isn't."

Some naysayers also claim that reactors could be run to generate plutonium. Yet "plutonium from a pressurized-water reactor is isotopically wrong for bombs," says Robert Kelley, a former program manager for nuclear intelligence at Los Alamos National Laboratory and a former International Atomic Energy Agency inspector. "It doesn't bother me in the slightest that Russia is selling pressurized-water reactors." The real problem, he says, would be with enriching or reprocessing nuclear fuel, ramping it up to weapons-grade material.

By agreeing to take back and perma-

Illustration by Don Foley



VVER (Russian PWR)
Russia's new PWR has emergency water tanks to flood the core. It can also draw in air to help cool the reactor. A "core catcher" is designed to prevent a melting core from sinking into the ground and water table.

Russian Breeder
The core emits neutrons that are absorbed by uranium in a blanket, creating (breeding) plutonium that can be used as more fuel. The core is submerged in liquid sodium, but that coolant can catch fire if exposed to air or water. A meltdown could explode and rupture the containment vessel.

Small Floating Plant
The *Akademik Lomonosov* will have two very small PWRs on a barge towed to a remote site and anchored along the shore. A turbine sends electricity to the grid. Hot water, a by-product, can heat buildings in town. Spent fuel stays on the barge, which is towed away every 12 years to refuel the reactors. Critics worry that the barges could be easy terrorist targets and that they could widely contaminate an ocean during an accident.

nently store nuclear waste, "Russia is providing something very worthwhile from a nonproliferation perspective," von Hippel says. And "the Russians are good at keeping in compliance with regulations," says Hanson, who leads an M.I.T. program on the developing world's desire for nuclear energy. He would rather see worrisome nations opt for Russia's one-stop-shopping approach to nuclear development than conduct nuclear projects on their own.

THE NEXT GENERATION ... OF PEOPLE

WHETHER RUSSIAN TRAINING of foreign nuclear workers raises concern or not, it is vital to preventing reactor accidents, many of which are caused in whole or in part by human-operator error. "Even small reactors require training people up in a big, big way," Sokolski says.

Russia has been training newcomers in Obninsk, a two-hour drive from Moscow. New dorms and classrooms are being added here to old ones to handle a flood of foreigners expected in the coming years. Far from home, the first of some 600 Turkish students who will study here—baby-faced and hopeful—sip tea and look to their bright futures as their country's first nuclear workers.

"Thank God there's Skype" to break the tedium, 21-year-old Gökçehan Tosun says in a coffee shop near her dorm. Next to her is Olgun Köse, practicing his English, a relief after months of grueling Russian lessons. "We've seen much cold, we've seen minus 35 degrees," he says, his eyes widening at the memory of his first Russian winter. Yet with guaranteed careers and good salaries ahead, they are the envy of their friends.

Later that night some of the Turks will play in a band, Rockkuyu, after Turkey's Akkuyu nuclear project. Köse talks of how oil is "finished," how solar is too expensive, and how nuclear energy is green, "fast and beautiful." The students believe the new reactors will give Turkey, and themselves, entrée into a scientifically advanced and sustainable future. "Turkey will grow up," Köse says.

And Russia will be right there to help them.

MORE TO EXPLORE

Tracking Nuclear Proliferation within a Commercial Power Program. Susan Voss. Nonproliferation Policy Education Center. August 2012. http://bit.ly/144h1HI

Russia's Nuclear Renaissance. Eve Conant. Pulitzer Center on Crisis Reporting, 2012–2013. http://bit.ly/SmCOEu

Rosatom's English-language Web site: www.rosatom.ru/en

World Nuclear Association's Russia Web page: http://bit.ly/1bNtbxH

SCIENTIFIC AMERICAN ONLINE

To download apps that track Russia's reactors, go to ScientificAmerican.com/oct2013/conant