

Power Surge

New nuclear technologies meet needs for electricity and safety

BY LEE SHERMAN | PHOTOS BY KARL MAASDAM

Last winter, the cavernous vault housing OSU's nuclear test facility was base camp for a team of elite scientists from Shanghai and Beijing. For six months, the Chinese engineers studied every bolt, tube and plastic elbow in the scale-model reactor. They ran accident simulations and analyzed the data. They posited every scenario under the sun, from a punctured pipe to "loss of coolant" to a complete loss of offsite power known as a "station blackout." Each time, the reactor shut down safely without a hitch.



Nuclear scientists YuQuang Li (left) from China's State Nuclear Power Technology Company and Professor HanYang Gu of Shanghai Jiaotong University calibrate instruments for a test of OSU's scale-model reactor.

In the spring, these top-gun scientists took their OSU training home to China. They're overseeing construction of the world's first Westinghouse AP1000 plant, which broke ground in Zhejiang Province in March. Three more of the Westinghouse plants will go up in short order. Cost to the Chinese government: \$8 billion, including \$500,000 for safety analysis test training at OSU as part of the Westinghouse tech-transfer program. By 2030, China hopes to have more than 100 reactors up and running.

"China has a very aggressive nuclear power plant plan," says OSU Professor Qiao Wu, who trained the Chinese team under contract to Westinghouse.

The Chinese team was in Corvallis to benefit from OSU's national leadership in developing advanced light-water nuclear energy technologies, making them safer, more efficient, more economical, more portable and more flexible. Groups who tour the Radiation Center — a '60s-vintage building on the west edge of campus — must sign in and clip on a visitor's badge before

"It is unlikely that we can meet our aggressive climate goals if we eliminate nuclear power as an option." – President Obama, *New Energy for America*

entering. The olive-drab corridors with their low ceilings and chocolate-brown linoleum seem unlikely passages into a world-class research facility. But up and down those modest hallways, ordinary wood-veneer doors open into some of the world's most advanced nuclear-science laboratories.

There, faculty and students are researching the next generation of nuclear power: high-temperature gas-cooled reactors, modular reactors that minimize operator error, new ways to reprocess and recycle spent fuel, uber-sophisticated computer simulations, remote radiation detection and other forward-looking technologies.

As environmental, economic and humanitarian threats loom across the globe, researchers point to nuclear's

huge potential for cheap, clean electricity. Princeton University's Carbon Mitigation Initiative estimates that doubling global production of electricity by nuclear fission (now 16 percent or 370 gigawatts) could prevent 1 billion tons of annual carbon emissions by 2055.

Last fall, President Obama expressed support for continuing to explore nuclear technologies. "It is unlikely that we can meet our aggressive climate goals if we eliminate nuclear power as an option," the Obama New Energy for America plan states.

Aggressive for Passive

It's more than a little ironic that China is adopting this new-era technology ahead of the United States.



Last winter, OSU nuclear engineer Qiao Wu trained Chinese engineers in the operation of the Westinghouse AP1000 plant. Behind him are DongJian Zhao (left) of the Shanghai Nuclear Energy Research and Development Institute and Professor Hanyang Gu of Shanghai Jiaotong University.

After all, the AP1000 — a 1,000-mega-watt light-water reactor that uses “passive” shutdown technologies to minimize operator error — was extensively tested in Corvallis at the university’s Radiation Center, earning licensure from the U.S. Nuclear Regulatory Commission (NRC) in 2005. But as this and other innovative nuclear technologies were advancing in labs at OSU and other American universities such as MIT and the University of California, Berkeley, plant construction in the U.S. was stalled. Concern about proliferation (radioactive materials getting into the hands of terrorists or rogue nations) led to a ban on fuel reprocessing in 1976. The leak at Three Mile Island and the meltdown at Chernobyl hardened fears. Meanwhile, other nations moved ahead. Today, France gets 80 percent of its power from nuclear. Japan is at 30 percent. The U.S. is at 20 percent, a proportion that China, now at 2 percent, aspires to attain within 20 years.

In China, where cities are bursting at the seams and infrastructure is

racing to catch up, the urgent need for power simply outstrips worries about nuclear accidents, explains Wu, a native of China. And then there’s the environment. China’s heavy reliance on coal is choking crowded urban areas.

Nuclear energy is being revisited as an important clean, green alternative, along with wind and solar.

“The pollution is devastating,” says Wu.

Indeed, pollution — more precisely, carbon dioxide and other fossil-fuel emissions — is at the heart of the nuclear-energy renaissance gathering momentum here and abroad. Greenhouse gases pose

a threat to Planet Earth that dwarfs the danger of nuclear power, many scientists and environmentalists have concluded. In that context, nuclear energy is being revisited as an important clean, green alternative, along with wind and solar, because it can produce great quantities of energy and emit relatively little carbon dioxide.

“Global warming is the new touchstone for the nuclear debate,” says OSU nuclear engineering Professor Todd Palmer. “A lot of former anti-nukes are now rallying around it. They’ve realized the value of the technology.”

As the Earth warms, rising seas, failing crops, dwindling water supplies and slumping economies will hit the poorest peoples soonest and hardest, experts agree. Nuclear power could boost living standards in developing nations — thereby easing their adaptation to changing conditions — without adding to the problem by spewing harmful gases into the atmosphere, advocates argue.

“It is abundantly clear that countries with affordable electricity

have citizens who live longer,” says Palmer. “In study after study, quality of life is directly tied to cheap, abundant power. I tell my students that anything we can do to make nuclear technology more readily available to everybody is a humanitarian effort.”

Nuclear Niche

OSU is in the vanguard of the rebirth. Its Department of Nuclear Engineering and Radiation Health Physics, whose enrollment has doubled since 2004, came in eighth (behind Michigan, MIT, Wisconsin, Texas A&M, Penn State, Berkeley and North Carolina State) in last year’s *U.S. News and World Report’s* college rankings. However, its research niche — safety — has earned it an international reputation that transcends the national ranking (which department Chair José Reyes points out is weighted heavily on statistical criteria such as numbers of students and faculty). In 2004, Reyes led a 14-nation United Nations research program in Vienna to lay out a worldwide vision for nuclear reactors that are “passively safe.” His year with this nuclear brain trust inspired and energized him.

“It really gave me a global perspective,” says Reyes. “There’s a tremendous need for power in developing nations.”

By using standardized designs that are pre-licensed and replicable (versus designing a unique plant for each site), emerging technologies can dramatically cut construction costs. While old-era plants went up at a snail’s pace (seven to 10 years), new designs can be built in half the time. Utility companies can begin recouping their investments years earlier. Eyeing the quicker turnaround, U.S. companies have ordered at least half a dozen AP1000s for projects over the next decade.

Like older plants such as Oregon’s Trojan (connected to the grid in 1975, decommissioned in 1993, demolished in 2006), the AP1000 is a pressurized light-water reactor. That is, it uses ordinary H₂O to cool the core, where pellets of uranium dioxide are stacked. The difference is that those old plants employed manmade mechanisms

VIRTUAL REACTION

Simulations let researchers “see” at subatomic scales

The new generation of nuclear technology benefits from a transformative technological advance: supercomputing. The conversion from pencils and slide rules to keyboards and computer clusters gives engineers potent tools to tighten safety margins and trim costs, tools that were unimaginable in decades gone by.

Next to safety, cost is the biggest hurdle for the nuclear industry. By helping to eliminate waste and minimize errors, computing can make nuclear energy more competitive with coal, hydropower and natural gas. And the best way to do that is through simulation.

“Simulation lets us predict much more accurately how a system will behave,” explains OSU researcher Todd Palmer, who specializes in fundamental physics. “In the nuclear industry, it has been very, very valuable in terms of ‘squeezing the margin’ out of a system” — that is, eliminating extraneous costs by making more precise projections in advance.

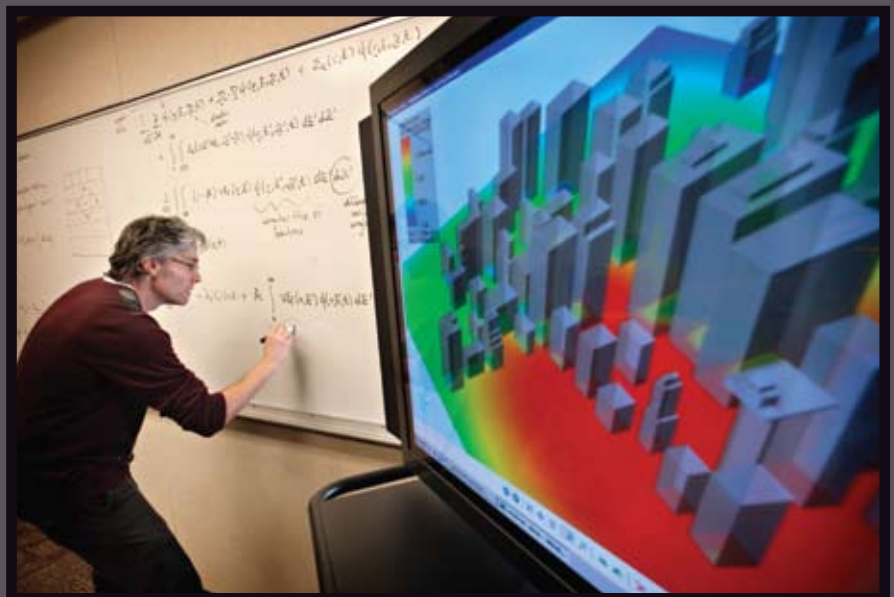
Simulation, he says, is the “third branch,” behind theory and experimentation, of 21st-century science. “It’s a sophisticated tool for interpolating amongst the data sets that you gather

from experiments,” he says. “You can coax details out of these problems you could never measure in an experiment.”

Working at the nexus of physics, mathematics and computer science, Palmer creates digital enactments of nuclear reactions occurring on a subatomic scale. Although the reaction can’t be seen visually, it can be pictured theoretically. Using thorny computations and computer code, Palmer can simulate the invisible chain reaction set off by uranium 235 isotopes inside nuclear fuel.

“It’s intensely mathematical,” says Palmer. “These problems are so hard, we call them ‘trans-computable.’ They can overwhelm any computer.”

Computer-aided design is also nurturing the nuclear renaissance. “In the old days — 20, 30 years ago — all the drawings were done by hand,” Assistant Professor Brian Woods notes. “You’d have electrical drawings, mechanical drawings, civil engineering drawings. Now, with computer-aided design and manufacturing (CAD/CAM), you can design the entire plant in three dimensions before you even pour any concrete.”



Simulating nuclear reactions, says OSU nuclear physicist Todd Palmer, reveals details that are difficult to measure through experiment.

THE WASTE QUESTION

Recycle through reprocessing

When José Reyes shows folks around the Radiation Center, he likes to hold up a small, black cylinder about the size of a pencil eraser. “This,” he says, “is a replica of a uranium fuel pellet. A pellet like this holds as much energy potential as three barrels of oil, one ton of coal, and 17,000 cubic feet of natural gas.”

As compelling as those comparisons are, they don't address the long-term disposal of spent fuel. At OSU, these back-end issues, too, are getting attention. Alena Paulenova, a radiochemist from the former Czechoslovakia, is investigating ways to reprocess spent fuel. Reprocessing promises not only to squeeze more energy out of the fuel, but also to shrink the volume and slash the radioactivity of the remaining waste. About 97 percent of the spent fuel can be recycled, leaving only 3 percent as toxic waste.

One of three women on the eight-professor faculty (a female-to-male ratio that Todd Palmer lauds as “off the charts” in a male-dominated field), Paulenova is studying the chemical properties of actinides (radioactive elements such as uranium, plutonium, neptunium and americium) for the Advanced Fuel Cycle Initiative (AFCI). Current U.S. Department of Energy (DOE) plans for the ultimate disposal of solidified wastes in a deep, stable geological repository call for lower toxicity and, ultimately, novel reprocessing protocols. This is where Paulenova's research, funded by the DOE's Nuclear Energy University Program, fits in.

Unlike countries that recycle nuclear fuel (such as France and the United

Kingdom), the U.S. employs the “open fuel cycle,” which generates thousands of tons of long-lived radioactive waste. The processes being developed by Paulenova and other APCI researchers — chemical separation of long-lived from shorter-lived elements — will lead toward a “closed fuel cycle” offering a dual benefit: reducing radioactivity as well as proliferation risks.

“Reprocessing spent fuel to recover uranium and plutonium avoids wastage of a valuable resource,” says Paulenova. “They both can be recycled as fresh fuel, saving up to 30 percent of the natural uranium that would otherwise be needed. Recyclable materials currently locked up in storage could conceivably run the U.S. reactor fleet of about 100 gigawatts for almost 30 years without any new uranium input.”

The waste that ends up in nuclear disposal sites will have a much more abbreviated half-life (the time it takes to lose half of its radioactivity), thus decaying to a relatively harmless state in several hundred years — compared with 100,000 years for waste stored without reprocessing.

“After chemical reprocessing, the waste will decay to an acceptable level of radiation in as little as 300 years,” says Paulenova. “An ‘acceptable radiation dose,’ as defined by the NRC, means a level similar to natural uranium ore.”

Another area of investigation seeks to bind plutonium to inert elements, rendering it un-useable for nuclear weapons production. The risk of proliferation would plummet, notes Paulenova.

(valves and pumps), while the new design relies on natural forces (gravity, convection, evaporation and condensation) to shut down and cool the reactor during an accident. For 72 hours, no human action is needed. The flawed-operator nightmare (a doughnut-sated Homer Simpson snoozing at the controls of the fictional Springfield Nuclear Power Plant) is thus vanquished.

“The human element is often the weak link in reactor safety,” notes Palmer.

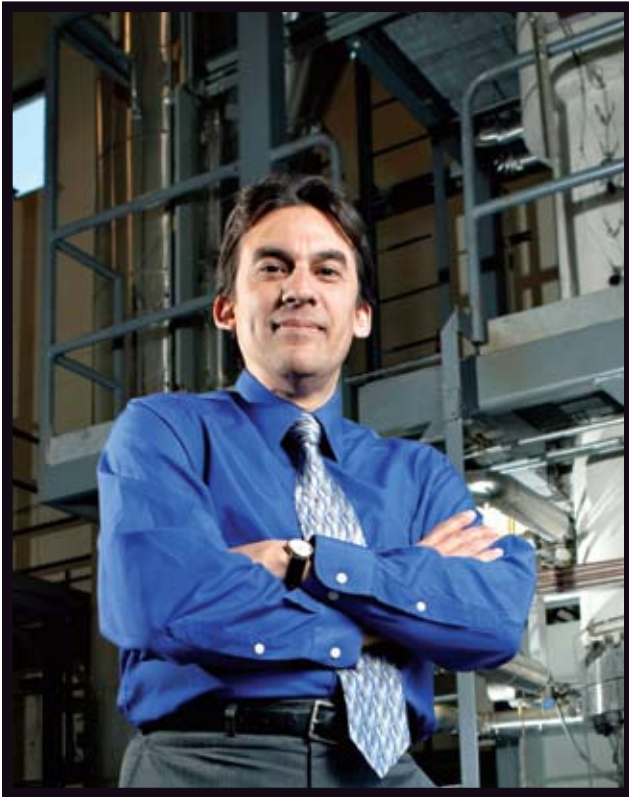
Another study could lead to better monitoring through remote sensing with an “antineutrino detector.” Alex Misner of Beaverton, Oregon, one of Palmer's graduate students, is collaborating with researchers at Lawrence Livermore and Sandia National Laboratories to distinguish normal operations from the abnormal use of a reactor for weapons material production. Down the road, the finding could lead to closer monitoring of nuclear activity in friendly — or unfriendly — nations.

Small Is Beautiful

The future of nuclear also comes down to a question of scale, and on that issue, pending certification, OSU technology is already moving into the international marketplace via NuScale Power. This OSU spinoff company, headquartered in downtown Corvallis, is developing compact, portable reactors that can be manufactured in the Henry Ford tradition, on an assembly line, then placed right where they're needed, singly or in clusters. About the size of a single-wide mobile home, the 300-ton units can be hauled by truck, barge or train. As local demand grows, communities can add new units. For developing nations, when the fuel is spent, the module is replaced, tightly monitored by the International Atomic Energy Agency. With current technology, the fuel will last for two years. This “distributed energy” model — ideal for remote locales (the Alaska bush, for instance) and small communities (especially in developing countries) — obviates the need for stringing power lines to a central grid.



Dramatic reductions in nuclear waste are possible, says Alena Paulenova, through spent-fuel reprocessing.



José Reyes is taking OSU's small-scale, passively safe technologies global through the Corvallis-based spinoff company, NuScale Power.

Reyes, chief technology officer for NuScale, and CEO Paul Lorenzini, former president of PacificCorp (owner of Pacific Power) with an OSU Ph.D. in nuclear engineering, are scouting U.S. manufacturers and seeking customers across the globe. "It's exciting," says Reyes. "You lay out a map of the country and they say, 'This is where we need power.'"

The 12-module design, developed and tested in Reyes' lab, is now in the pre-application phase of the complex certification gauntlet. NuScale principals meet quarterly with the NRC, the agency that confers what Reyes calls the international "gold standard" of official approval. Data show a steep spike in safety for compact, passive reactors compared with conventional reactors. "Our risk study showed that the probability of an accident is more than extremely low; it's remarkably low," says Reyes.

Shrinking a passive design into moveable modules, encasing them in dual steel chambers and submerging them in a pool 65 feet beneath the earth pushes the chance of an accident almost off the charts, according to Reyes. "It's really a very, very robust design," he says. "I would

describe it as a reactor inside a thermos bottle underwater, underground. On top of that you have a big, concrete lid. All of those serve as barriers to releasing radiation."

Comfort Zone

With nuclear technology surging forward, some of the old fears are fading. "For a long time, the biggest challenge we've had is public acceptance of the technology," says Palmer. "But younger generations are so much more comfortable with technology and so much more reliant on electricity for everything they use, from cell phones to PDAs to Xboxes. They're also so much more environmentally conscious. Those two things are coming together to really help people understand the value of nuclear technology."

Adds OSU nuclear engineer Brian Woods: "Tom Brokaw always talks about the World War II generation as the 'greatest generation.' Well, I believe the current generation of students will be the greatest generation because they'll be the ones to solve the world's energy crisis — and maybe even save the planet." **terra**

HIGH HEAT

From nuclear to hydrogen

Farther out on the drawing board is another promising design: the high-temperature, gas-cooled reactor. The fuel, sand-like granules of uranium coated with silicon carbide, is cooled by helium instead of water. Not only is helium the universe's second most abundant element, it's also extremely stable and lighter than air (ideal for party balloons). If helium escapes into the atmosphere, it vanishes benignly into the heavens.

These reactors run at 1,000 degrees Celsius, three times hotter than light-water reactors, a level that significantly boosts efficiency. Even more intriguing to scientists is the possibility of producing hydrogen via a process called "thermochemical water-splitting." At very high temperatures, chemical catalysts can be used to "crack" H₂O molecules, thus freeing the hydrogen, a clean-burning alternative to petroleum. If, as many experts predict, future vehicles are fueled by hydrogen, gas-cooled reactors could power our cars at the same time they light up our homes, says OSU researcher Brian Woods.

Woods is focusing on the safety of two types of gas-cooled systems: "pebble bed" (the fuel is encased in tennis ball-sized "pebbles" of graphite tough enough to withstand mega-temperatures) and "prismatic block" (the fuel is contained in a cubic or hexagonal graphite lattice). With \$6 million from the NRC, he and Todd Palmer are collaborating with the University of Michigan and Texas A&M to build a one-quarter-scale gas reactor test facility — unique in the nation — to test how the systems perform in even the worst-case scenario.

"It's our job," Woods says, "to make sure that no matter which design is used, it meets a rigorous standard, that you can say with absolute confidence that it will be safe in any and all accident conditions."



A new generation of high-temperature reactors cooled by helium is the subject of Brian Woods' research.