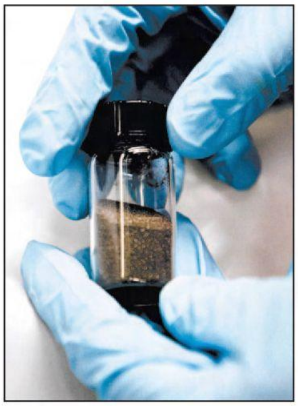


Tribune photo by Zbigniew Bzdak

Argonne scientists use uranium powder in their quest for a reactor fuel that would be useless to terrorists.

A TRIBUNE INVESTIGATION

U.S. races to defuse peril from uranium

Scientists aim to solve riddle, retrieve bomb fuel

International Atomic Energy Agency photo

Inspectors from the International Atomic Energy Agency take samples last year at a shuttered reactor in Serbia. The U.S. removed highly enriched uranium from the facility in 2002—but only after an American non-profit group helped pay for the mission.

After the Sept. 11 attacks, nuclear terrorism suddenly seemed plausible—the new worst-case scenario. Americans wondered whether Osama bin Laden could get his hands on the bomb and whether the U.S. was doing enough to stop him. Suitcase bombs, yellowcake and WMD entered the nation's lexicon.

Quietly, though, the U.S. government was trying to defuse a ticking threat of its own making.

At Argonne National Laboratory, scientists worked feverishly to eliminate terrorists' easiest route to a nuclear device: the highly enriched uranium used in dozens of research reactors that the U.S. and Soviet Union had scattered around the world during the Cold War.

A small team of scientists, working out of aging labs near Lemont, hoped to invent a new fuel that could be used in reactors but be useless for bombs.

If they succeeded, the U.S. might finally be able to secure tons of weapons-grade material.

If they failed, it would set back by many years the heart of U.S. efforts to deny terrorists access to such material—keeping the nation, and the world, vulnerable to a nuclear nightmare.

STORY BY TRIBUNE STAFF REPORTER SAM ROE BEGINS ON PAGE 10

TRIBUNE INVESTIGATION

The search for a magic fuel

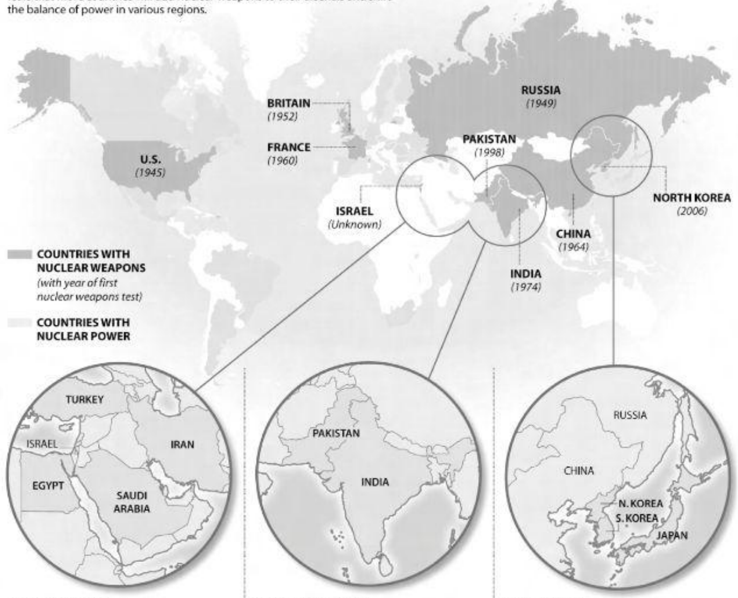
Argonne, Russia confront a scientific hurdle in their bid to replace bomb material in the world's reactors

Second of two parts

By Sam Roe
Tribune staff reporter

Dawn of a second nuclear age?

Experts worry that the world is entering a new phase of the nuclear era, with fears that more countries will add nuclear weapons to their arsenals and shift the balance of power in various regions.



THE MIDDLE EAST

Iran is believed to be building nuclear weapons to match Israel, which is widely thought to have had them for decades, although officially, it neither confirms nor denies this. If Iran joins the nuclear club, other regional powers could try to follow suit. The Shiite nation's potential Sunni rivals include **Saudi Arabia,** which helped finance Pakistan's nuclear program, **Turkey** and **Egypt**, which already has a nuclear energy program.

THE SUBCONTINENT

Long-standing tensions between **India** and **Pakistan** reached a new level when both countries conducted nuclear tests within weeks of each other in 1998. Since then relations between the two nations have improved, but differences over the disputed Kashmir region continue to be a stumbling block. Even amid peace talks, both countries test-fired nuclear-capable missiles in November in what amounts to their own version of a Cold War.

THE FAR EAST

North Korea's first nuclear weapons test, in October, put the region on notice that the nation could soon join China and Russia as a nuclear power. There are concerns that the impoverished nation could try to sell nuclear materials and technology to other countries or to terrorist groups. **Japan** traditionally has been strongly anti-nuclear and the U.S. has promised to defend it. But with an unpredictable potential nuclear power not far from its shores, Japan could be tempted to develop its own nukes as a deterrent. The same goes for **South Korea,** which had a nuclear weapons program in the 1970s.

Note: All nations with nuclear weapons also have nuclear power except Israel.

Sources: International Atomic Energy Agency, Bulletin of the Atomic Scientists, news reports and Tribune archives

Chicago Tribune / Adam Zoll and Steve Layton

After 25 years, tens of millions of dollars and dozens of classified missions, America's quest to retrieve the world's most potent nuclear fuel had come down to this: a secret meeting in the heart of Moscow.

At one end of a conference room sat Russia's top nuclear scientists and bureaucrats. At the other were the Americans, led by Argonne National Laboratory's Armando Travelli, who had traveled to the Russian capital in the winter of 2003 to hear the results of a scientific test with grave implications for U.S. national security.

The unlikely research partnership of former Cold War rivals hoped to create a nuclear fuel that would persuade nations with highly enriched uranium to trade it in for something better and safer.

If the test was a success, Travelli might finally retrieve tons of the bomb-grade material that America and Russia had provided over decades. If the test failed, it would set back U.S. non-proliferation efforts for years.

The Russians told Travelli's team that there were some minor problems but nothing to worry about. They would do additional work and get back to the Americans.

"May I see the pictures of the test?" Travelli asked.

"I'm sorry," the head of the Russian team replied. "There are no pictures available."

The Russian, Travelli recalled, then abruptly stood up and walked out, followed by his colleagues.

Travelli approached the last Russian packing his belongings, a low-level scientist who had been quiet at the meeting.

"I'd like to see the pictures," Travelli said. "When might there be pictures?"

The man leaned down and pulled three 8-by-10, black-and-white photographs from his briefcase, then put them on the table.

Travelli picked them up. One by one, he studied them, knowing that America's future—and his own—was at stake.

A top nuclear physicist, Travelli had spent the last quarter-century trying to bring home weapons-grade uranium America had supplied to dozens of nations in an ill-conceived program launched by President Dwight Eisenhower called Atoms for Peace.

Toiling in the twilight zone where hard science and clandestine missions intersect, Travelli had weathered congressional indifference to his project, research budgets set at zero and, by some accounts, his own missteps.

A persuasive scientist-diplomat, he had even managed to patch together a promising solution with the scant resources at his disposal. The question was whether it would work.

Or was he banking too much on unproven science and his own ability to charm the Russians, other foreigners—even his own bosses?

Turning to science for a solution

Nuclear research reactors are like sports cars: They run faster with a high-octane fuel—in this case, highly enriched uranium.

A powerfully fueled reactor can conduct an experiment in a week; a poorly fueled one could take a month. For private reactor operators producing and selling radioisotopes for medical uses, such as cancer radiation, that gap can mean the difference between profit and loss.

The challenge facing Travelli and his team of Argonne scientists was to invent a fuel strong enough to satisfy reactor operators, but weak enough to be useless to terrorists trying to build a nuclear weapon.

By the early 1990s, Travelli's team had solved this riddle for many reactors around the globe. He carefully noted each success story by replacing a green triangular magnet with a red one on a large metallic world map in his office.

But dozens of other reactors still would not operate on anything but bomb-grade fuel. And because none of these reactors were precisely the same, the Argonne scientists faced the overwhelming task of inventing a special fuel for each one.

Plus, dozens of reactors worldwide used bomb-grade fuel supplied by Russia, and no one was addressing those.

So in 1993 Travelli traveled to Moscow and eventually helped cut a groundbreaking deal: U.S. and Russian scientists would team together to craft a single, all-purpose fuel that would work in all the reactors, regardless of make, model or country of origin.

To do that, they had to make a fuel with a low percentage of uranium-235, the potent isotope behind the atomic chain reaction that causes nuclear explosions.

U-235 is unsteady, so the trick was to find some way to stabilize it while packing it densely enough to give the fuel the necessary power. Travelli's team knew that adding certain elements could calm the uranium; his team tested more than 30 before deciding to stake their work on molybdenum, a hard, gray metal used to strengthen steel.

Officially, this exotic, experimental mixture was called "uranium-molybdenum dispersion fuel." For the cause of disarming the threat of nuclear terrorism, Travelli's team hoped it would be the magic fuel.

Unlike race cars, reactors run on solid fuels; that meant Argonne scientists were using metals, powders and plates. They knew the tiniest mistake in making a nuclear fuel invited failure. "It's not a blacksmith's job, that's for sure," said Jim Snelgrove, a fuel specialist at Argonne.

Work began in earnest. Argonne scientists melted together chunks of uranium and molybdenum, machined the mixture into powder, added aluminum, then pressed and rolled the metal into thin, shiny plates the size of credit cards. These miniature fuel plates were placed in a research reactor in Idaho for a full year of testing. The radioactive plates then returned to Argonne in special casks inside a hazmat truck.

Workers wearing protective bodysuits and using mechanical arms cut the plates with fine instruments and photographed the pieces under an electron microscope. The early results were encouraging: no evidence of cracks, swelling or bubbling.

Tribune photo by Zbigniew Bzdak

Armando Travelli of Argonne National Laboratory had staked his future on developing a single fuel that could replace the highly enriched uranium at research reactors around the world.

But the same couldn't be said of the U.S.-Russian partnership.

It quickly began splintering. The Russian scientists, still suspicious from the recent Soviet past, were hesitant to share information, turning in lab reports that offered scant detail. Later, they accused Travelli's team of trying to steal their technology.

Further complicating matters, the U.S. in 1999 placed economic sanctions on Travelli's partner in Russia, a nuclear contractor called NIKIET, for allegedly providing "sensitive missile or nuclear assistance" to Iran.

Travelli struggled to find a new lab, at one point appealing to his influential friend in the Russian nuclear bureaucracy, Nikolay Arkhangelsky. But Arkhangelsky demurred, upset like his colleagues at the U.S. sanctions.

After nearly two years and three more trips to Moscow, Travelli finally found a new laboratory. Work on the magic fuel picked up dramatically.

One night, after reviewing the Russians' progress at a Moscow lab, Travelli was walking down the hallway of his hotel when Gerard Hofman, a fuel development specialist at Argonne, called him into his room.

"I think you'd better see this," he said.

Travelli's eyes locked on the TV as the World Trade Center towers crashed to the ground.

U.S. misses wake-up call

In the tense weeks that followed Sept. 11, many wondered whether terrorists could obtain an atomic weapon, whether a bomb could fit into a suitcase, whether the U.S. was doing enough to prevent a nuclear catastrophe.

But the American government didn't intensify efforts to retrieve uranium.

U.S. officials didn't call emergency meetings. Congress didn't hold hearings on the issue. President Bush and Capitol Hill didn't even provide more money for the effort.

The program's budget stayed flat at $5.6 million.

The lack of action exasperated those who knew that the highly enriched uranium scattered around the globe was the quickest way for Al Qaeda or other terrorists to build a crude nuclear device.

Jack Edlow, whose company, Edlow International, ships nuclear fuel back to the U.S., was in his Washington office on Sept. 11. He looked out his back window and saw smoke rising from the Pentagon.

"I thought they would get themselves a couple of hundred million dollars, and we would get the whole thing cleaned up in a couple of years," Edlow recalled. "I thought everybody would say, 'Let's go get this stuff before it comes back to haunt us.' "

Eleven months after the terrorist attacks, the U.S. did manage to remove two nuclear bomb's worth of uranium from Serbia and ship it back to Russia. But to pay for the mission, the State Department asked the Nuclear Threat Initiative, a non-profit group founded by Ted Turner and former Georgia Sen. Sam Nunn, to donate $5 million; that was more money than the government contributed to the mission.

Even after Sept. 11, America was relying on funding from a non-profit for critical national security work.

"It was embarrassing," recalled Allan Krass, a State Department official involved in the operation. But officials, he said, had no choice: "We needed the money."

IN THE WEB EDITION

■ Retrace Travelli's quest, testing your knowledge of his struggle to retrieve bomb-grade uranium at **chicagotribune.com/atoms**

Cracks begin to surface

After the terrorist attacks, Travelli felt more pressure than ever to succeed. That feeling intensified when he learned a competing team of French scientists was trying to invent a nearly identical magic fuel.

Throughout 2002, the French and the U.S.-Russian teams both reported great progress with their fuels, predicting the material would be ready for reactors in three years. They were so confident they began planning training seminars so other nations could learn about the fuel and place orders.

At an international conference in Aix-en-Provence, France, in 2003, Travelli's team and the French scientists told colleagues and the trade press that their separate fuel programs were right on track.

But privately, the French were telling a far different story, Travelli recalled.

They pulled Travelli's team aside at the convention center and laid out pictures of their latest tests. The often-unstable uranium particles looked fine. But there were bizarre, meandering cracks—like the hairline fractures of a bone—in the aluminum portion of the fuel in which the uranium particles were embedded. Travelli had never seen anything like it.

The French fuel was failing.

Alarmed, Travelli and his team flew back to Chicago and immediately began sifting through dozens of photos of their own tests. Was it possible their fuel had the same problems, but they had somehow missed it?

Sure enough, they began to recognize tiny little bubbles—almost imperceptible—inside the fuel plates. They were aligned in such a way that if the Americans were to jump ahead with advanced testing as the French had, the tiny bubbles would likely multiply and connect, forming the same cracks seen in France.

Travelli's Russian partners hadn't run any tests yet. But his former partners had.

NIKIET, the Russian nuclear contractor still under U.S. sanctions, was quietly developing its own reactor fuel. Travelli had heard NIKIET was experiencing similar failures as seen in France.

Aware of the dire implications, Travelli's team flew to Moscow in December 2003 to see if it could learn of NIKIET's results.

The crucial meeting was held at the Bochvar Institute, the lab working with Travelli. His Russian allies from the lab and the government were on hand. NIKIET, barred from contact with the Americans, was represented at the meeting by subcontractors.

After the Russians assured Travelli that there were only minor problems with the NIKIET fuel, they walked out of the meeting. But the last one to leave pulled out detailed pictures of the tests from his briefcase and gave them to Travelli.

He studied each of the three photographs carefully. He could see the small meandering lines in the aluminum portion of the fuel, just as he had seen in France.

The evidence now was overwhelming: The magic fuel was a bust.

Feeling as though his life's work had collapsed, Travelli returned to his hotel. A few minutes later, the phone rang. It was a State Department official. He wanted an update.

Back in America, a bitter fallout

After his dream fuel failed, everything changed for Travelli.

In the summer of 2004, Energy Department officials began taking firmer control of America's effort to retrieve bomb fuel. They wanted it run out of Washington, not Chicago. They wanted the fuel work managed out of a federal lab in Idaho, not Argonne. They wanted new scientists involved, not the same group that had been leading it the last 26 years.

And three years after the Sept. 11 attacks, they finally asked to double the budget.

Travelli heard about these changes piecemeal. Then one day, an Argonne administrator, Phillip Finck, called him into his office. Finck told the longtime scientist that energy officials wanted him out. He could stay on as a scientific adviser, but an Argonne colleague would replace him.

Moreover, energy officials wanted Travelli to make this announcement that weekend at a conference in Vienna—one that Travelli himself had organized.

Travelli was stunned. He had fought to keep the effort alive for nearly three decades, often in the face of little support. Now that Sept. 11 had finally moved his work to the top of the national security agenda, he was supposed to step down?

Travelli balked.

But Finck, Travelli recalled, told him he didn't really have a choice; funding from the Energy Department was at stake.

Five days later in Vienna, at a jammed conference with dozens of familiar faces, Travelli an-

TRIBUNE INVESTIGATION

nounced the leadership changes. Later, an energy official read a proclamation in his honor. When she finished, the crowd gave Travelli a standing ovation. People chanted for him to speak. But he declined, afraid of what he might say.

Many experts were surprised that such an eminent scientist would be removed during America's war on terror.

"I had never come across anyone in public service who had accomplished so much for national security with so few resources provided by the government," said Alan Kuperman, a non-proliferation expert and professor at the University of Texas at Austin.

But Edlow, the owner of the nuclear shipping firm, thought Travelli had it coming. "He was looking for the perfect fuel," Edlow recalled, "and always looking and always looking and always looking."

Krass, the retired State Department official, offered a pragmatic assessment. In his view, Travelli was treated unfairly. "But," he said, "somebody has got to walk the plank."

Energy officials deny that the magic-fuel bust prompted Travelli's removal. They said they simply wanted the program run out of Washington, where it could get the attention it deserved.

After Travelli was removed, he stayed at Argonne for eight months as an adviser, earning the same $172,000 salary.

At one point, an energy official overseeing the effort to retrieve bomb fuel sent Travelli an e-mail demanding that he address a pressing financial mess. An arm of the State Department had withdrawn $500,000 related to work on the magic fuel in Russia—the first time it had ever asked for money back.

It had not gotten regular reports, and the program had stretched far beyond the original plan. Feeling as though he was being unduly blamed for the failure of the magic fuel—a failure that occurred independently in three countries—Travelli submitted his resignation, effective July 2005.

The man who had been charged with retrieving America's scattered uranium, partly because of his diplomatic skills, submitted a blunt, angry letter.

"Fear of being fired has replaced the pursuit of excellence as a motivator for our work," he wrote in resigning, "and the main concern today is to satisfy every wish of frequently incompetent and unpredictable bureaucrats in Washington."

Threats left unchecked

In the last year, energy officials say they have made great progress. Six more reactors have given up using weapons-grade fuel—a far faster success rate, the officials said, than Travelli had accomplished.

And in December, the U.S. helped relocate nearly 600 pounds of uranium from a former East German lab to a specially secured Russian facility. The U.S. also has spent tens of millions to bolster security at some overseas reactors, providing fences, cameras, heavy-duty doors and vaults.

But there are other signs that efforts actually have gone backward. For instance, in the most difficult cases of securing bomb fuel—particularly in Russia, where officials are reluctant to cooperate—the U.S. has simply quit trying.

Travelli has not given up. He was hired by Ted Turner's nonprofit group to work as a consultant on addressing the fuel issue in Russia. Last spring, Travelli traveled to Moscow, once again teaming up with Arkhangelsky, the once-mysterious Russian who served by turns as his rival and partner over Travelli's quarter-century quest.

But Turner's group has struggled to raise enough money to keep the effort alive.

So the 72-year-old Travelli spends most of his time visiting with his three grown sons and puttering around his suburban Hinsdale home, a three-bedroom split-level with a large back-yard garden.

Over 26 years, Travelli and his team helped 22 nations stop using bomb-grade fuel in 33 reactors, eliminating the use of 3.3 tons and ridding the world of 120 potential nuclear weapons. But more than 100 reactors still use the dangerous fuel, with an estimated 40 tons out of U.S. control.

Travelli also spent eight years trying to develop a magic fuel. In the end, it failed. His successors continue that mission, but they are at least several years away from a solution.

The metallic world map Travelli had used to carefully chart his work still hangs on the wall of a small, rarely used office on Argonne's campus.

No one tends to the map anymore.

Science as a tool against terror

Keeping bombmaking material from falling into the wrong hands is not just a military or diplomatic challenge, it is a scientific one. Argonne National Laboratory researchers were asked to invent a fuel potent enough to power nuclear research reactors but weak enough to be useless to terrorists. What resulted was a three-decade hunt for a magic fuel that has so far proved elusive.

The challenge

Researchers wanted to create a low-enriched uranium (LEU) fuel that would behave like highly enriched uranium (HEU) fuel. HEU is defined as consisting of 20 percent or more of U-235, a fissionable form of the element whose nucleus can be split to release energy. The remaining amount is U-238, a non-fissionable form.

The idea

Research reactors are powered by fuel plates, aluminum slabs with a uranium compound at the center. By keeping the same amount of U-235 in the fuel plate but adding more U-238, scientists hoped to dilute the concentration of fissionable uranium while maintaining its power.

EXAMPLES OF URANIUM MIXES IN FUEL PLATES

Diagrams below are representational. Actual fuel plate particles contain a mixture of both forms of uranium.

HEU: About 90% U-235 *(Concentration used by many research reactors)*

LEU: Less than 20% U-235 *(Concentration scientists needed to achieve)*

Anatomy of a reactor's fuel plate

PLATE ASSEMBLY

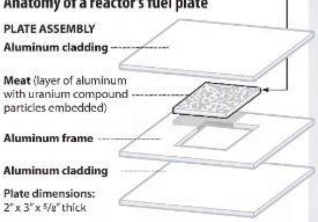
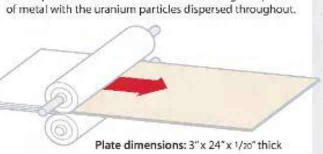
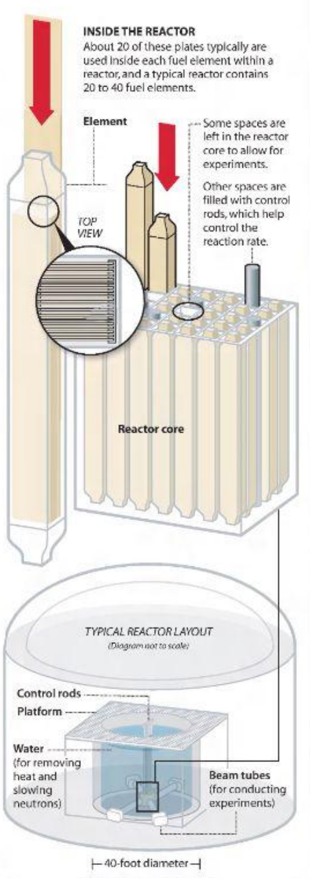


PLATE COMPRESSION

Once the plate is assembled, it is compacted using rollers to compress its contents. The result is an elongated piece of metal with the uranium particles dispersed throughout.





Early attempts

1978 The U.S. Department of Energy asks Argonne National Laboratory to develop alternative fuels for research reactors to replace highly enriched uranium.

1979-85 A research team led by Armando Travelli tests dozens of materials to find one that will work best with uranium to create the desired ratio of U-235 to U-238. The winner: a uranium-silicon compound, which proves effective in many reactors.

1988 Energy Department budget cuts leave Argonne with no money to invent fuels needed for other reactors.

1990-91 The uranium-silicon fuel begins to fall out of favor. The reason: The U.S. stops accepting spent fuel from foreign research reactors for reprocessing (separating leftover uranium for reuse). With fewer options for reprocessing, the fuel becomes less practical to use.

A magic fuel solution?

1993 New funding from the State Department allows Argonne researchers to team up with their Russian counterparts to develop alternatives to the HEU fuels used in U.S.- and Soviet-supplied research reactors.

1995 The Department of Energy resumes funding Argonne's research. Travelli's team begins searching for a single LEU fuel that will work in all HEU reactors.

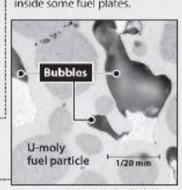
1996 Testing of a uranium-molybdenum (U-moly) compound begins. It is denser than the silicon compound and more easily reprocessed.

1999 The U.S. places trade sanctions on the Russian lab working with Travelli's team for allegedly providing nuclear technology to Iran.

2000 Argonne selects another Russian lab with which to work. That lab starts testing U-moly.

2002 French researchers announce that they, too, are working on a U-moly fuel to replace HEU.

March 2003 Travelli learns from the French that their U-moly fuel is not working. Travelli and his team recheck photos of their own tests of the fuel and find that small bubbles have formed inside some fuel plates.



Argonne National Laboratory

Failed Argonne fuel plate viewed under a microscope.

December 2003 Travelli's team learns that Russian tests of the U-moly fuel also have failed, setting the program back several years.

July-November 2004 Energy officials replace Travelli and move management of fuel research from Argonne to a federal lab in Idaho.

2004-present Argonne tries fixing the problem by adding small amounts of silicon to the aluminum in the fuel cell's meat layer. As of January 2007, early test results are promising, but three to four more years of tests are needed, including exams to see if the fuel can be reprocessed—a roadblock when silicon was used previously.

Sources: Armando Travelli; Argonne National Laboratory

Chicago Tribune / Adam Zoll and Steve Layton

WHERE GAPS REMAIN

America faces bigger risk than agency claims

Energy officials ignore bomb-grade uranium in some reactors—and in other instances simply quit trying

By Sam Roe
Tribune staff reporter

The U.S. Energy Department is exaggerating its progress in securing tons of nuclear-weapons fuel spread across the globe, a Tribune investigation has found.

Among the ways the government overstates its success is through a numbers game that ignores the highly enriched uranium in many reactors around the world.

Officials also have allowed huge amounts of nuclear fuel to sit around for so long in other nations that material once posing little risk now represents an extremely dangerous one.

And, some experts say, America does not even know how many facilities worldwide use highly enriched uranium fuel, the easiest pathway to an atomic bomb for rogue nations and terrorists.

Republican and Democratic administrations alike have fallen short in the three-decade effort to retrieve bomb-grade fuel that the U.S. and Soviet Union supplied to civilian research facilities in dozens of countries during the Cold War.

Energy officials say they have made significant strides since 2004, when the agency restructured its program to retrieve bomb fuel and doubled the effort's budget. They point out that six research reactors, including two in Libya, have given up their bomb fuel in the last 12 months—a far faster rate than in previous years.

"Overall, I think we are doing very well," said Andrew Bieniawski, who oversees the program for the National Nuclear Security Administration, an arm of the Energy Department.

Many facilities are not being targeted. One near Moscow has enough uranium to make more than 300 atomic bombs.

But documents and interviews show that one of the first things energy officials did after the restructuring was to make their job easier: They quit trying to remove bomb fuel from eight reactors that proved to be difficult cases, including one in Russia using four nuclear bombs' worth of fuel a year.

Other potentially dangerous facilities never have been targeted. One in Obninsk, near Moscow, has nearly nine tons of highly enriched uranium fuel—enough for more than 300 atomic bombs. It alone represents one-fifth of all the bomb-grade uranium out of U.S. control.

And even with increased funding, energy officials still rely on private donations. The Nuclear Threat Initiative, a nonprofit foundation started by Ted Turner and former Georgia Sen. Sam Nunn, is raising money to address gaps in America's effort to secure bomb fuel in Russia.

The U.S., which has been slow to stop using bomb fuel in its own reactors, wants Russia to abandon use of the material. But Moscow has no such plans.

"Why? What for?" asked Boris Onykiy, head of the Moscow Engineering Physics Institute, where a research reactor using weapons-grade fuel is housed in an aging concrete building.

When a technician was asked why a laboratory adjacent to the reactor was so cold—about 45 degrees—he chuckled and waved his hand at 20 broken glass-block windows.

Onykiy called U.S. efforts to convince his institute to give up the bomb fuel a "useless task" because the material is critical for research. Besides, he insisted, there is no security risk.

"Even if somebody steals something, he won't be able to run away," Onykiy said. "We will punish him."

President Bush has been unwilling to push Russia on the issue. At a summit in Slovakia in 2005, Bush and Russian President Vladimir Putin agreed to continue working together to remove bomb fuel from civilian reactors "in third countries"—but not necessarily in their own.

In all, the Bush administration is trying to remove weapons-grade fuel from 60 research reactors worldwide, often speaking of this list as if it were complete. But there are at least 41 more reactors using highly enriched uranium fuel that the U.S. is not addressing.

Many of these reactors are called "critical facilities," which often use large amounts of bomb fuel for dry runs of key experiments. "They represent an unnecessary hazard," said Frank von Hippel, an arms control expert at Princeton University who has visited such reactors in Russia.

If the Bush administration were to count all of the reactors that use highly enriched uranium, its progress would be much less than claimed.

The Energy Department says it is considering targeting more reactors. "This program is evolving," Bieniawski said.

Energy officials said the main reason the agency removed eight reactors from its target list was because scientists have been unable to invent fuels to replace the weapons-grade material powering the facilities. In other words, these reactors were taken off the list because the government failed to find a solution, not because it retrieved the material.

The agency also added nine reactors to the list. Those facilities are small and use tiny amounts of weapons-grade fuel.

Laura Holgate, a former manager of non-proliferation programs for the Energy Department and the Pentagon, believes a more basic problem plagues the entire effort: The U.S. still does not know all the locations and quantities of the world's highly enriched uranium.

"You cannot accurately judge your progress if you don't have a clear sense of the totality" of the problem, said Holgate, who now works at the Nuclear Threat Initiative.

Bieniawski, the energy official, disputes that assessment. He said the agency recently helped compile a classified report that is "the most comprehensive, complete inventory done to date" on enriched uranium worldwide. He said there is likely only "very little" bomb-grade material that is unaccounted for.

But Armando Travelli, a former Argonne National Laboratory physicist who once led America's effort to retrieve bomb fuel, said his team occasionally would stumble upon previously unknown reactors using bomb-grade uranium. "I think there are several spots in the world where there is still highly enriched uranium that hasn't been discovered. Hopefully it's not much."

Likewise, experts say no one knows for sure how much used, or "spent," bomb-grade fuel remains at reactors worldwide. This spent fuel remains highly enriched and usable in nuclear weapons.

For years, U.S. officials didn't bother retrieving spent fuel because it was so radioactive from being burned in reactors that thieves could not touch it without causing themselves serious harm or death.

But the U.S. has ignored spent fuel for so long—in many cases allowing it to sit in storage at reactors for 30 years—that some of the material is no longer highly radioactive. This means terrorists could spirit it away without immediate physical risk.

Only 7 percent of the known quantities of U.S.-supplied spent fuel has been shipped back to America. Eighteen tons remain spread worldwide. Much of that fuel is in Europe and other parts of the developed world, but experts say the material is a potential threat no matter where it is.

Last week provided a fresh reminder. Georgian authorities disclosed they caught a man trying to sell highly enriched uranium he had hidden in plastic bags inside his pocket.

He came from the nation with the largest supply of vulnerable bomb fuel: Russia.

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