



research reactors remains unsecured, a possible target for theft. The foreign political, economic, and technical support for nuclear science and nuclear energy programs helped create powerful nuclear complexes that have distorted the development of both science and energy policy in developing countries. Rather than a blessing, the nuclear age became in many ways a costly burden.

ATOMS FOR PEACE FOUND ITS FIRST AND most public venue at the August 1955 U.N.-sponsored International Conference on the Peaceful Uses of Atomic Energy held in Geneva. The U.S. delegation, by far the largest, included almost 200 scientists and was accompanied by a swimming-pool type nuclear research reactor that was installed and ran at the conference site. Tens of thousands of people visited the reactor. Some were even allowed to operate it. As historian of science John Krige has noted “[T]he presentation of the U.S. reactor in Geneva was a masterpiece of marketing. It was intended to demystify nuclear power and to show that anyone and any nation could exploit it safely and to social advantage.”

Between 1956 and 1962, the United States awarded Atoms for Peace program grants to 26 countries for the purchase of research reactors. The recipients of these grants included Argentina, Brazil, South Korea, Iran, Israel, Pakistan, Sweden, and Taiwan, all of whom went on to develop nuclear weapons programs. Most of these programs were eventually abandoned, but some succeeded. The example of research reactors is important because it shows the imbalance between the short time it takes to establish nuclear technology, the longevity of such technology, and the tedious and costly effort to replace it once it is recognized as having been a mistake.

From the beginning, most domestic U.S. and Russian research reactors were fueled with weapon-grade highly enriched uranium (HEU), enriched to 90 percent or more of the isotope uranium 235, which was skimmed from military production in both countries. In contrast, the early U.S. research reactors supplied to foreign countries, such as the one

exhibited at Geneva, used low-enriched uranium (LEU) fuel, enriched to just below 20 percent, which was and still is the enrichment level considered of least proliferation concern. By 1958, however, the United States began to export HEU for use in research and other reactors.

Atoms for Peace and similar programs created problems for the countries that supplied nuclear know-how and technology as well as those who were being encouraged to pursue it, fueled regional rivalries, and became the bane of the international community.

This helped the United States to avoid the problems associated with having different sets of reactor designs and fuels for use at home and abroad, and took advantage of its rapidly growing stockpile of HEU that began to accumulate after 1956, following a massive four-year expansion of its fissile material complex.

From that point forward, weapon-grade HEU became the default fuel for research reactors worldwide, despite the fact that the atomic bomb dropped on Hiroshima had been made from 60 kilograms of HEU with an average enrichment of only 80 percent and that the simple gun-type design of the weapon was considered so reliable that it was used without testing. The drive to use HEU even led some operational research reactors to be converted from LEU to HEU. In total, supplier states (all of whom had nuclear weapons) provided nearly 50 countries with HEU to fuel hundreds of civilian research reactors that were built up until the mid-1970s. The United States alone exported almost 26,000 kilograms of HEU to fuel research and other prototype reactors. Today, nearly 100 metric tons of civilian HEU (both in fresh and spent fuel) remain worldwide, far less than the 1,600-metric-ton global military HEU stockpile, but enough for thousands of nuclear weapons or explosive devices.<sup>1</sup>

China's 1964 nuclear test fueled superpower fears of the further spread of nuclear weapons to regions where they might want to intervene and led the United States and the Soviet Union to propose the 1968 Nuclear Non-Proliferation Treaty (NPT). India's 1974 nuclear test,

which used plutonium from a reactor supplied by Canada for peaceful purposes, spurred further concern about nuclear proliferation in developing countries. The United States launched a series of initiatives in response. Among these was the Nuclear Suppliers Group (NSG), which established agreed rules for the international sale of nuclear technology for peaceful purposes. The United States also initiated the Reduced Enrichment for Research and Test Reactor (RERTR) Program in 1978, aimed at converting research reactors using HEU to LEU fuel and targets. In an irony of history, the United States and other suppliers are now offering recipients financial assistance to return the HEU fuel that was once given as a gift.

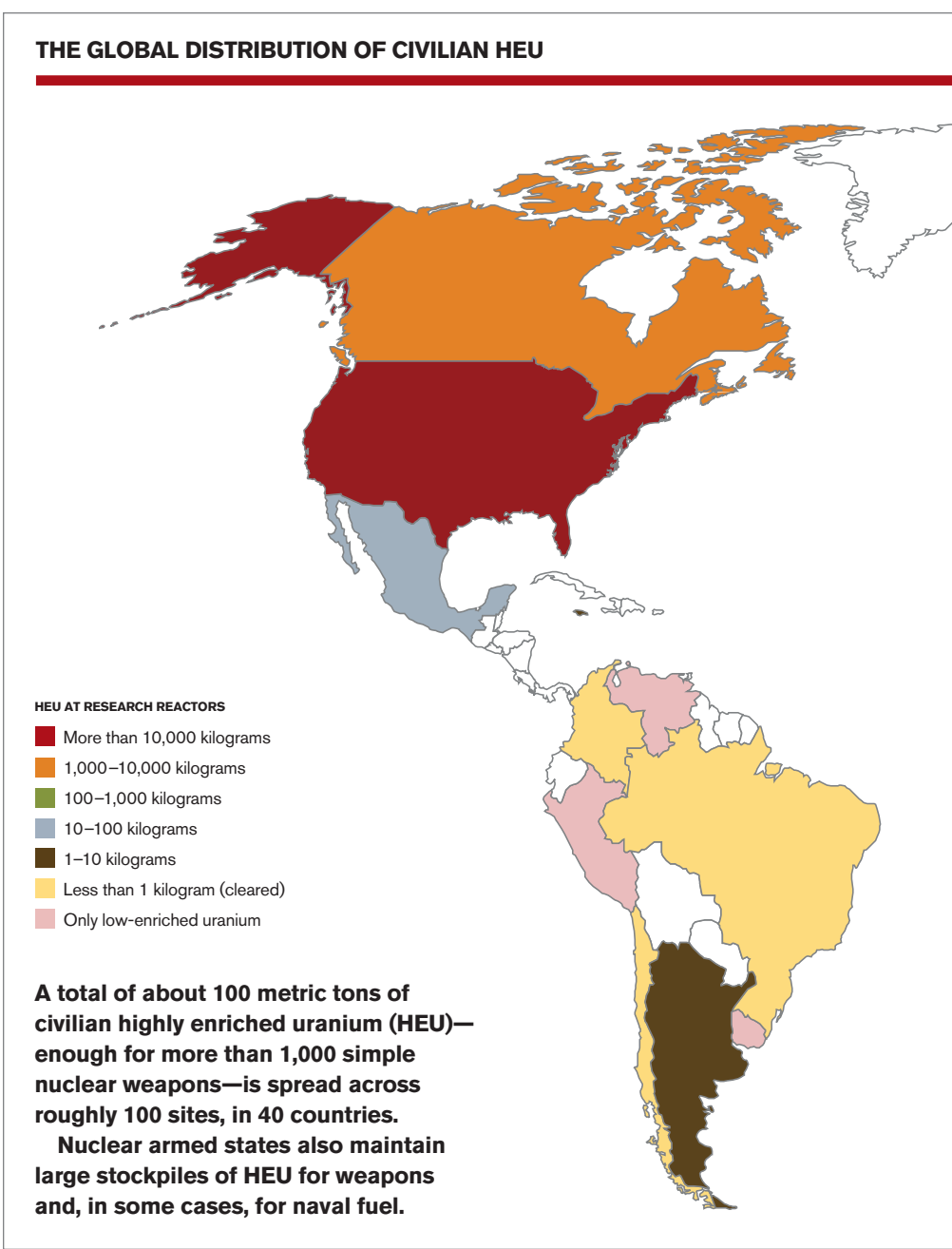
As of 2008, after three decades of U.S. and international efforts to eliminate the use of HEU in the civilian nuclear fuel cycle, only 14 countries have been cleaned out of the material (see “The Global Distribution of Civilian HEU,” p. 44). If not for recent concerns about nuclear terrorism, progress would be even less significant. Under the most optimistic assumptions, it will take at least 10–20 years to consolidate and dispose of the fresh and spent fuel recovered from these facilities. Most facilities may simply be shut down rather than converted.

ANOTHER MAJOR FOCUS OF ATOMS FOR Peace was training foreign students in nuclear science and engineering. The overlap between the knowledge and skills needed for research, development, and management for nuclear power and those needed for nuclear weapons didn't discourage the U.S. program.

U.S. government laboratories played a particularly important training role. Between 1955 and 1977, the U.S. Atomic Energy Commission (AEC) and its successor, the Energy Research and Development Administration, hosted more than 13,000 researchers from nearly every country in the world—from Afghanistan to Zambia. A 1979 investigation by the General Accounting Office (GAO) found that some of these researchers “participated in unclassified research projects which could, at least indirectly, provide skills useful to a nuclear weapons program.”<sup>22</sup>

In addition to these research opportunities, there were also training programs. The Argonne International School of Nuclear Science and Engineering ran from 1955 to 1960 and trained 413 students from 44 countries. Another Argonne program ran from 1960 to 1965 and trained 256 students from 29 countries. The Oak Ridge School of Reactor Technology hosted 115 students from 26 countries between 1959 and 1965. These training programs were aimed at fostering the nuclear knowledge base in client countries, but this turned out to include the know-how necessary to build nuclear weapons. The GAO concluded, “While some of the training related directly to such key technologies as uranium enrichment and reprocessing, other aspects, in our opinion, could also have enhanced, at least indirectly, a nation's nuclear weapons capability.”<sup>23</sup>

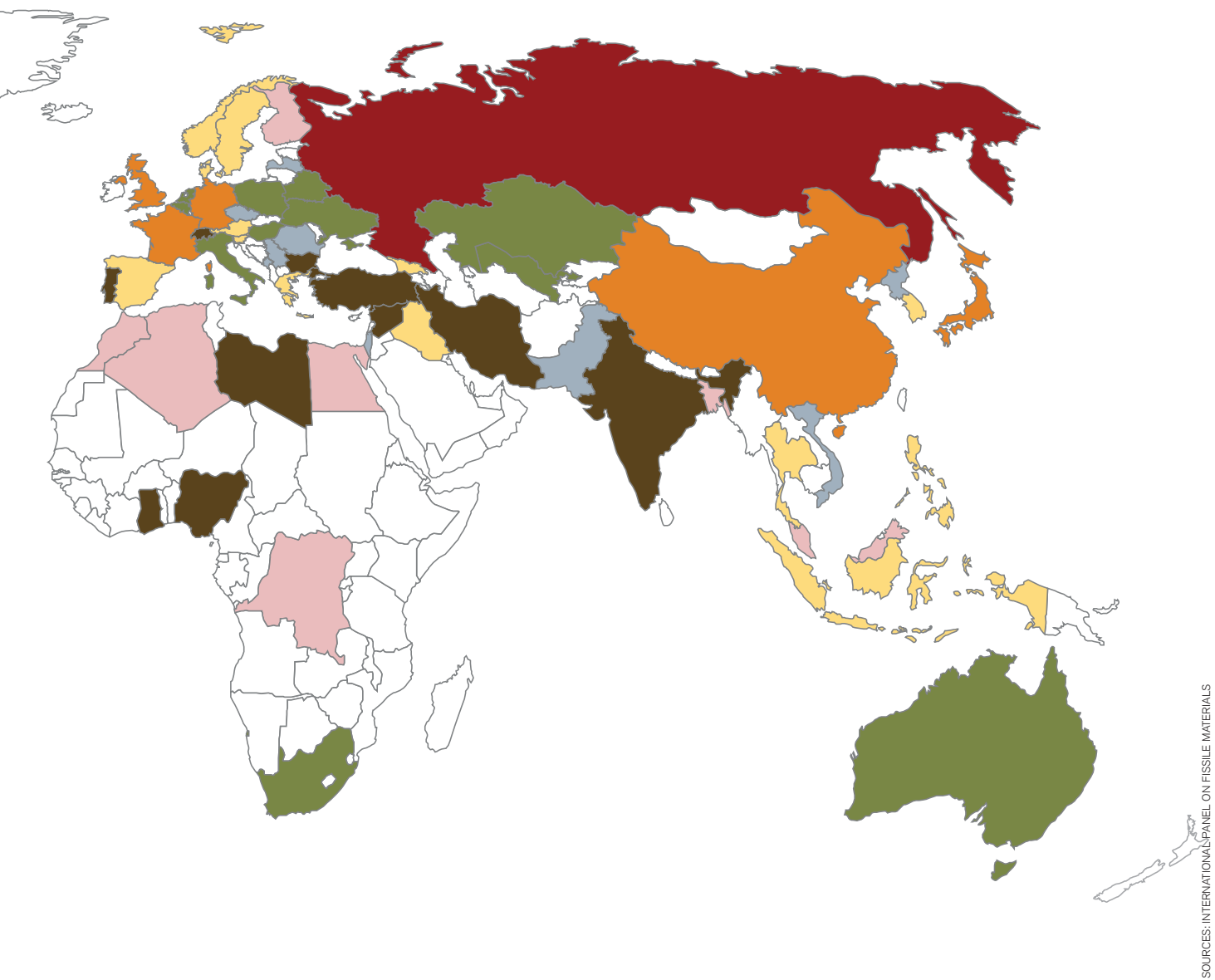
The programs were seen as prestigious and made a big impact on nuclear science in recipient countries, creating a privileged group of scientists and administrators. An AEC study found that “[m]any of those who have completed various types of training in the United States now hold positions of leadership in nuclear energy programs, universities, and industries and research centers in their home countries.”<sup>24</sup> Alumni included



scientists who went on to become senior officials in nuclear programs in apartheid South Africa, South Korea, Spain, Egypt, Taiwan, and Yugoslavia.

One prominent graduate of U.S. training was Pakistan's Munir Ahmed Khan, who studied at Argonne. He went on to work at the International Atomic Energy Agency, becoming head of the Nuclear Power and Reactor Division. In 1972, Pakistani leader Zulfikar Ali Bhutto made Khan head of the Pakistan Atomic Energy Commission (PAEC) at the same time that Pakistan decided to launch a nuclear weapons

program. Khan presided over PAEC until 1991, and was both architect and manager of the nuclear weapons program. He oversaw the establishment of the uranium enrichment program at Kahuta (made famous by A. Q. Khan), the design and start of construction of the Khushab plutonium production reactor, the design and cold-testing of nuclear weapons, and the setting up of the nuclear test site. He also had ambitious plans for Pakistan's civil nuclear power program, including many power reactors, the reprocessing of spent fuel, and even plutonium-fueled breeder reactors.



The U.S. laboratory training programs largely ended in the mid-1960s not because of concerns about their proliferation risk, but because similar courses had become available at U.S. colleges and universities. University degree programs and programs offered by businesses involved in the nuclear industry trained thousands of foreign students and technicians. While these programs made nuclear training more common place, they also created new dilemmas for the United States.

In the early 1970s, the shah of Iran proposed a very ambitious nuclear

power program aimed at building more than 20 reactors. The United States encouraged and supported this vision by what was then a key strategic ally in the Middle East. Iran was also very wealthy after the increase in oil prices that followed the 1973 Arab-Israeli war and offered a lucrative market for many U.S. goods and services. In 1975, Secretary of State Henry Kissinger signed a National Security Decision Memorandum, "U.S.-Iran Nuclear Cooperation," that laid the basis for the planned sale of nuclear reactors to Iran at an estimated cost of

more than \$6 billion. Thirty years later, with Iran accused of having a nascent nuclear weapons program, Kissinger explained the U.S. rationale: "They were an allied country, and this was a commercial transaction. We didn't address the question of them one day moving toward nuclear weapons."<sup>5</sup>

As part of its nuclear plans, Iran offered to pay MIT to admit 50 students to the master's of science program in nuclear engineering. Since this would almost double the number of students in the program, Iran offered to pay





## A CAUTIONARY TALE FROM THE CONGO

The story of the first African reactor is among the more vivid examples of the untoward legacies of Atoms for Peace.

Since the 1940s, the Belgian Congo had attracted international attention for its large reserves of uranium, and became a key source of raw material for the Manhattan Project. To receive a nuclear reactor as a quid pro quo was the idea of Monseigneur Luc Gillon, a Belgian priest and later president of the Catholic-Jesuit University of Lovanium in Leopoldville, now the University of Kinshasa. According to Michela Wrong's *In the Footsteps of Mr. Kurtz*, "like a colonial administrator who uses his years in the tropics as a chance to build up his butterfly collection, Mgr. Gillon seized the opportunity to indulge in his hobby: nuclear research." Despite resistance from within the Belgian government, he managed to acquire and transfer to Africa the research reactor that had been erected and operated at the Second Atoms for Peace conference, held in Geneva in 1958. But history has its own tempo. Barely 18 months after the reactor went critical, colonial rule ended in the Belgian Congo.

The United States in 1970 replaced the first Congo reactor with a higher power TRIGA (Mark II) reactor (above). Gen. Mobutu Sese Seko, who had seized power in 1960, was a U.S. ally and saw the reactor as a symbol of power and prestige and good relations with Washington. The TRIGA II reactor never used highly enriched uranium, but two of the reactor's fresh fuel assemblies did go missing from the site some time in the 1970s. One of the assemblies resurfaced in a 1998 sting operation in Rome, where it was for sale on the black market. Nothing is known about the whereabouts of the second fuel assembly.

The reactor is still listed as operational. It continues to stand as an object lesson that one cannot parachute a nuclear reactor into a developing country and expect it to be an automatic source of progress and development. ■ ZIA MIAN & ALEXANDER GLASER

MIT more than \$500,000 for additional professors, classrooms, and support facilities, in addition to the tuition costs for the students.

The then-head of MIT's nuclear engineering department later explained, "The attitude then was much different than it is today about the potential dangers of somebody diverting plutonium and making weapons. . . . I taught a course in enrichment, reprocessing, fuel manufacture, and the like. We were teaching [the Iranian students] how to do it, as we were teaching people from all over the world."<sup>6</sup>

TODAY, SOME ARGUE THAT A GLOBAL expansion of nuclear energy is necessary to help reduce the greenhouse gas emissions that drive climate change and to meet growing demand for electricity, especially in rapidly urbanizing and industrializing countries. The World Nuclear Association, an industry lobby group, reported in July 2008 that nuclear energy was under "serious consideration" in more than 30 countries that do not currently have reactors.<sup>7</sup> Other analysts have identified nearly 20 countries that have no nuclear power plants and in many cases few nuclear scientists and engineers, yet since 2006 have announced plans to build one or more reactors by 2020. They include Algeria, Australia, Bangladesh, Egypt, Indonesia, Israel, Jordan, Libya, Morocco, Nigeria, Qatar, Saudi Arabia, Syria, Turkey, the United Arab Emirates, Vietnam, and Yemen.

With cost estimates in excess of \$4 billion for a typical 1,000-megawatt plant, suppliers of nuclear technology have been lining up to make deals in what is akin to a nuclear gold rush. As part of its Global Nuclear Energy Partnership, the United States signed up 21 countries, including Ghana, Senegal, Jordan, and many former Soviet states, as well as former Soviet-client states in Eastern Europe. France has created a new government body, the France Nuclear International, to help countries create the structures required to establish and operate nuclear programs. The French nuclear industry giant AREVA has signed contracts across Africa, including with Algeria, Libya, Morocco, and South Africa,

to train nuclear engineers and share nuclear expertise. These training efforts, AREVA hopes, will lead to the sale of power reactors. The United States, France, and the United Kingdom have all signed nuclear cooperation agreements with the United Arab Emirates. Russia's nuclear industry is also seeking to expand. It has offered to sell reactors and provide training to Egypt, and wants to build additional reactors in India. China hopes to build more reactors in Pakistan.

The United States, Russia, France, and Britain have all signed nuclear deals with India, even though it has refused to sign the NPT, has a growing nuclear arsenal, and is currently banned from the international nuclear marketplace by the rules of the NSG. But as part of what has been dubbed the U.S.-India nuclear deal, the United States has been leading the charge to exempt India from these rules. Even before the U.S.-India nuclear deal has been fully realized, it is having troubling consequences. Pakistan and Israel, which are also denied access to the nuclear technology marketplace for the same reasons as India, have sought similar exemptions and so far been refused. The India deal is also feeding the South Asian arms race.<sup>8</sup> Pakistan's National Command Authority, which has responsibility for its nuclear weapons program, declared in August 2007, "The U.S.-India nuclear agreement would have implications on strategic stability as it would enable India to produce significant quantities of fissile material and nuclear weapons from un-safeguarded nuclear reactors." The authority "expressed firm resolve to meet the requirements of future credible minimum deterrence." Recent satellite imagery shows that Pakistan is building two new plutonium production reactors, and it may have accelerated its HEU production by using more of the powerful centrifuges that it was recently reported to have developed.

Today's proponents of a nuclear-powered future argue that the proliferation risks are small from the light water power reactors (LWRs) that are now being offered for sale and would be even smaller if limits were imposed on countries having their own uranium

enrichment and plutonium separation (reprocessing) plants. A 2004 report by Victor Gilinsky, Marvin Miller, and Harmon Hubbard, however, pointed out the need "to revise the conventional wisdom that LWRs are a safe proposition for sitting in just about any country so long as

Expanding nuclear power around the world will inevitably lead to a further increase in the stocks and flows of uranium and plutonium, materials that are fundamental parts of the nuclear fuel cycle and could be used to make nuclear weapons.

there are no accompanying commercial uranium enrichment facilities or reprocessing facilities." The report highlighted that "contrary to conventional wisdom LWRs can be copious sources of near-weapon-grade plutonium that can be used to make powerful nuclear weapons" and that "small, clandestine reprocessing plants could provide the reactor's owners with militarily significant quantities of nuclear explosives."<sup>9</sup>

However one judges the risks of particular technologies, some things are clear. Expanding nuclear power around the world will inevitably lead to a further increase in the stocks and flows of uranium and plutonium, materials that are fundamental parts of the nuclear fuel cycle and could be used to make nuclear weapons. It will also be accompanied by more nuclear research to improve existing technologies, to develop new ones, and to acquire basic expertise by countries that have little or no capability so far. Together these constitute a critical dilemma for nuclear power: a nuclear program that is small by commercial standards, perhaps no more than a research capability, is still generally large enough to support a substantial nuclear weapons program.

This is not a new conclusion. Rather it confirms a fundamental insight of

the 1946 Acheson-Lilienthal Report, authored largely by J. Robert Oppenheimer, which concluded: "So long as intrinsically dangerous activities may be carried on by nations, rivalries are inevitable and fears are engendered that place so great a pressure upon a system

of international enforcement by police methods that no degree of ingenuity or technical competence could possibly hope to cope with them."<sup>10</sup>

Given the current international political and economic system, the globalization of prevailing nuclear energy technologies is likely to trouble the world for decades to come. As with the legacies of Atoms for Peace, it will matter little whether the efforts to promote nuclear energy as a way to ward off climate change and to power economic growth are well-intentioned or a return to the use of nuclear technology as a source of profit and influence.

The only effective way to reduce the risks may be to confront and resolve the sources of the "rivalries" and "fears" that drive decision makers' sense of insecurity. Prudence, to say nothing of other reasons, suggests that the international community should consider how to establish a credible, equitable, and just nuclear nonproliferation and disarmament regime before taking seriously the vision of a nuclear-powered world. ■

FOR NOTES, PLEASE SEE P. 57.

*Zia Mian is a research scientist and Alexander Glaser is a member of the research staff in the Program on Science and Global Security at Princeton University. Glaser is a member of the Bulletin's Science and Security Board.*

## A frightening nuclear legacy

### CONTINUED FROM P. 47

1. "Global Fissile Material Report 2008," International Panel on Fissile Materials, Princeton, NJ, forthcoming, available at [www.fissilematerials.org](http://www.fissilematerials.org).

2. "Difficulties in Determining if Nuclear Training of Foreigners Contributes to Weapons Proliferation," General Accounting Office, April 23, 1979.

3. Ibid.

4. Ibid.

5. Dafna Linzer, "Past Arguments Don't Square With Current Iran Policy," *Washington Post*, March 27, 2005.

6. Farah Stockman, "Iran's Nuclear Vision First Glimpsed at MIT," *Boston Globe*, March 12, 2007.

7. World Nuclear Association, "Emerging Nuclear Energy Countries," July 2008, [www.world-nuclear.org/info/inf102.html](http://www.world-nuclear.org/info/inf102.html). It lists them by region. In Europe: Italy, Albania, Portugal, Norway, Poland, Belarus, Estonia, Latvia, Ireland, Turkey; in the Middle East and North Africa: Iran, Gulf states, Yemen, Israel, Syria, Jordan, Egypt, Tunisia, Libya, Algeria, Morocco; in Central and Southern Africa: Nigeria, Ghana, Namibia; in South America: Chile, Venezuela; in Central and Southern Asia: Azerbaijan, Georgia, Kazakhstan, Mongolia, Bangladesh; and in Southeast Asia: Indonesia, Philippines, Vietnam, Thailand, Malaysia, Australia, New Zealand.

8. Zia Mian, A. H. Nayyar, R. Rajaraman, and M. V. Ramana, "Fissile Materials in South Asia and the Implications of the U.S.-India Nuclear Deal," Research Report No. 1, International Panel on Fissile Materials, September 2006.

9. Victor Gilinsky, Marvin Miller, and Harmon Hubbard, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors," Nonproliferation Policy Education Center, Washington, D.C., October 2004, [www.npec-web.org](http://www.npec-web.org).

10. Full text available at [www.ipfmlibrary.org/ach46.pdf](http://www.ipfmlibrary.org/ach46.pdf).

## French nuclear forces, 2008

### CONTINUED FROM P. 54

1. Nicolas Sarkozy, president of the French Republic, speech given at the presentation of *Le Terrible*, Cherbourg, March 21, 2008.

2. We are grateful for valuable editorial comments provided by Bruno Tertrais at the *Fondation pour la Recherche Stratégique*.

3. Nicolas Sarkozy, speech on defense and national security, Porte de Versailles, June 17, 2008. The white paper is available at [www.defense.gouv.fr/livre\\_blanc](http://www.defense.gouv.fr/livre_blanc).

4. Sarkozy also declared that France "has no other weapons beside those in its operational stockpile," a statement that excludes the existence

of a reserve of warheads like the United States and Russia. We estimate, however, that France has a small inventory of spare warheads.

5. Sarkozy, speech given at the presentation of *Le Terrible*, Cherbourg, March 21, 2008.

6. On January 19, 2006, on the occasion of his visit to the Strategic Forces, former French president Jacques Chirac stated: "As I emphasized immediately after the attacks of 11 September 2001, nuclear deterrence is not intended to deter fanatical terrorists. Yet, the leaders of states who would use terrorist means against us, as well as those who would consider using, in one way or another, weapons of mass destruction, must understand that they would lay themselves open to a firm and adapted response on our part. This response could be a conventional one. It could also be of a different kind." Although the language used by President Sarkozy does not mention terrorists, the phrase "whatever form it may take" could be interpreted as including a state using terrorist means as well.

7. French government, "Fighting Proliferation, Promoting Arms Control and Disarmament: France's Contribution," 2005, p. 64.

8. Jacques Chirac, speech given during his visit to the Strategic Forces, January 19, 2006.

9. Bruno Barrillot, *France and Nuclear Proliferation* (Lyon: CDRPC, 2001), p. 16.

10. *Air Actualités*, No. 579 (March 2005), p. 6; *Air Actualités*, No. 611 (May 2008), p. 61. To learn more about *Air Actualités*, see [www.defense.gouv.fr/sites/air](http://www.defense.gouv.fr/sites/air).