torate was decimated. We have to have the right people. We have to attract the best proposals. That takes time."

The education budget accounts for only 7½% of NSF's entire $1.5 billion appropriation this year. The orthodox centerpiece of the science and mathematics education program is graduate fellowships. Moreover, Congress specified that $5 million of its total appropriation be spent for instructional research instrumentation predominantly at four-year colleges. Shakhashiri figures that about 50% of the directorate's budget will go to precollege science and math education.

Catalysts. To advance this program, NSF will expand its customary mode of operation from being responsive to proposals to taking more aggressive action. "We are not going to be just onlookers in this program," says Shakhashiri. "We expect to have some ideas from our advisers, staff and other concerned parties to do some innovative things. We see ourselves as catalysts. What we do here should help prevent the country from experiencing the awful cycle of science-education crises."

Some approaches are already in place. One is the Presidential Awards for Excellence in Science and Mathematics Teaching, a program introduced in 1983 and repeated last October to recognize two top teachers from each of the 50 states, the District of Columbia and Puerto Rico. The directorate also funds summer institutes, museum exhibits, and has supported such television series as "Nova," "The Brain" and "3–2–1 Contact." In the past few months it has funded several proposals. Examples: David Goodstein at Caltech was awarded $641 000 for a two-year program to assemble a dozen talented high-school physics teachers who would produce videotapes and print materials for the use of students watching a new television series, "The Mechanical Universe"; Thomas Post at the University of Minnesota received $718 000 for a two-year investigation of ways to teach number concepts and develop proportional reasoning skills to junior–high students; Paul Horwitz at Bolt, Beranek and Newman got $367 000 for a two-year project to create interactive computer games to help junior-high students understand physics concepts.

Shakhashiri wants to foster partnerships with commercial corporations to promote better science and math education and reward bright students and talented teachers. Some corporate programs already exist, such as the Westinghouse Talent Search, Phillips Petroleum's "Search for Solutions," and Amoco's $12-million contribution to the University of Chicago to develop new precollege science materials.

NSF has tradition going for it. After Sputnik, it stimulated several creative new high-school science education programs—notably, the Physical Sciences Study Committee, led by Jerrold Zacharias of MIT; Harvard Project Physics, headed by Gerald Holton of Harvard; ChemStudy, with Glenn T. Seaborg and George Pimentel of Berkeley; and Engineering Concepts Curriculum Project, under the leadership of Edward David, then at Bell Labs, and John Truxal, then at Polytechnic Institute of New York.

"NSF will have to come up with some splashy programs like those to have a real effect," says a Congressional staffer who observed the Foundation's zeal for innovation during the 1960s. "The agency has a lot of good will out there to get the job done." —IG

New reports warn of mounting nuclear proliferation threat

Of all the issues that divide the US and Soviet Union, nuclear nonproliferation is not among them. It is in the mutual interests of both superpowers to limit the spread of nuclear arms. "We and the Soviets are of a common mind on that," says Richard T. Kennedy, a US ambassador-at-large who advises Secretary George P. Shultz on nonproliferation policy. On 28–30 November, Kennedy met in Moscow with Andronik M. Petrosyants, chairman of the USSR atomic energy committee, in the fourth round of a series of wide-ranging talks that began in Washington in 1982 to strengthen the Nuclear Nonproliferation Treaty.

The importance of the meeting was heightened for two reasons: It enabled the Reagan administration to disclose what took place at a secret meeting last summer in Luxembourg with representatives of 11 industrial nations that are actual or potential exporters of nuclear material and technology. The US had tried to convince the supplier countries to refrain from major new commitments or to require full safeguards for any nuclear deals. By several accounts, the US proposal was defeated. The results of the meeting take on increased significance with the release of two reports in November cautioning that international safeguards and political persuasion are unlikely to prevent a few nations from gatecrashing the nuclear "club" by the end of the decade—thereby joining the US, Soviet Union, Britain, France and China as full-fledged nuclear weapons states. The US–USSR meeting in Moscow, furthermore, is a prelude to the Nonproliferation Treaty Review Conference of 125 nations that signed the treaty, taking place in Geneva next August to review the progress and problems of nuclear arms control.

The second reason is related in part to the first. The nonproliferation treaty requires the US, Soviet Union, and other club members to take steps to end the nuclear arms race "at an early date." The Kennedy–Petrosyants exchange, in the event, became a curtain-raiser for the resumption of arms-control talks between Shultz and Foreign Minister Andrei A. Gromyko in Geneva on 7–8 January.

Nonproliferation ethic. In a speech to the United Nations Association of the US on 1 November, Shultz characterized the nations represented at the Luxembourg meeting as the world's main nuclear suppliers—besides the US, of course, Australia, Belgium, Britain, Canada, France, Italy, Japan, the Netherlands, Sweden, Switzerland, and West Germany. In addition to these countries, says one of the new reports, *Nuclear Proliferation Today*, by Leonard S. Spector, senior associate at the Carnegie Endowment for International Peace, the suppliers include Argentina, China, and South Africa. "As we pursue our dialog with emerging suppliers," Shultz said in his speech, "we will work to assure that they, too, come to understand and adopt the nonproliferation ethic that traditional suppliers have developed over the past quarter century."

When the US held a monopoly on nuclear technology in the early years of the atomic era, such authorities on the subject as Dean Acheson, David Lilienthal and Bernard Baruch considered the proliferation of nuclear power plants and supporting fuel-cycle facilities to be unthinkable. They advocated international ownership and oversight of nuclear facilities with weapons potential. The official US position changed as nuclear power turned commercial in the 1950s. In 1953 President Eisenhower launched the Atoms for Peace program. Forseeing the risks involved, Eisenhower proposed creating the International Atomic Energy Agency to provide a system of safeguards against diverting nuclear material to bombs while, at the same time, to promote peaceful uses of nuclear energy. Organized in 1957, the agency now inspects nuclear installations in 50 nations and accounts for the amount of enriched uranium and plutonium to make sure that the material is not

diverted to make nuclear weapons.

The *N*th-country problem that worried Western physicists and other scientists in the 1960s became a reality in 1964 when China exploded its first nuclear bomb. Soon afterward, largely through US diplomacy, efforts began to negotiate an international nonproliferation treaty—a prodigious matter as it turned out. In 1968 the Nuclear Nonproliferation Treaty was signed; it was placed in force in 1970. In adhering to it, non-nuclear nations agree not to acquire "nukes" in their arsenals and to accept IAEA inspections of their nuclear facilities.

'Greek tragedy.' Even so, there were few illusions about keeping the nuclear club exclusive. At the time President Kennedy signed the Limited Test Ban Treaty with the Soviet Union in 1963, defense policy experts such as Albert Wohlstetter of the University of Chicago agreed that by the mid 1980s as many as 15 or 20 nations would possess nuclear weapons. It was accepted wisdom, recalled Shultz in his address to the UN Association, "that the spread of nuclear weapons was inexorable, advancing like a Greek tragedy to some preordained disaster."

Accordingly, once China entered the club, it seemed predestined that India would follow. India consistently opposed IAEA as an invention of the superpowers to prevent developing countries from obtaining nuclear energy. Homi Bhabha, the first head of India's Atomic Energy Commision, spoke of the "inalienable rights of states to produce and hold the fissionable material required for their peaceful power program." On 18 May 1974, India detonated a nuclear device of about 15 kilotons (in the range of the Hiroshima bomb) at the Pokharan Range in the western Rajasthan Desert. India characterized its test as a peaceful explosion intended for studying the cratering and cracking effects on rocks—a purpose that it claimed would not violate its assurances to Canada and the US that plutonium-239 produced at its 40–MW CIRUS reactor would not be used for weapons.

London Group. India's test came shortly after the US Central Intelligence Agency circulated reports that Israel made a few nuclear weapons from Pu^{239} separated in its reprocessing facility from spent fuel in a 24-MW reactor at Dimona in the northern Negev Desert. With reactor hardware, nuclear fuel and heavy water supplied by many countries, including the US, Canada, West Germany and France, both India and Israel, possessing ample talent and technology of their own, seemed at the threshold of the nuclear club by 1974—and beyond control by the IAEA, because neither had signed the Nonproliferation Treaty. To make matters worse, fuel-cycle facilities for producing fissile uranium-233 had been supplied to Brazil by West Germany and to Pakistan and South Korea by France. Alarmed by the situation in 1974, the US and 14 other nations, including Canada, Japan, Western European countries and the Soviet Union, Czechoslovakia, East Germany and Poland, convened in London to tighten the policies and procedures for exporting nuclear supplies, components and technology. By 1976, the London Suppliers Group, as the nations came to be called, agreed on a "trigger list" of technologies that could be transferred to other countries only if the customers agreed to IAEA controls over imports.

Another group, known as the Zangger Committee, after its chairman, Claude M. Zangger, a Swiss physicist and government official, consists of 21 nations that have established similar lists of nuclear-weapons technologies. At the urging of the US State Department, the Zangger Committee recently enlarged its lists to include components of ultra-high-speed gas centrifuges.

Despite the international apparatus to curtail the traffic in nuclear material and knowhow, the number of nations considered technologically capable and politically motivated continues to increase. Spector names eight emerging nuclear-weapons countries—India, Pakistan, Israel, Libya, Iraq, Argentina, Brazil and South Africa (see box). A report sent to members of Congress on 24 September by Warren H. Donnelly of the Congressional Research Service lists 23 nonnuclear-weapons states with the potential, based on the capacity of their nuclear industry, to produce plutonium or highly enriched uranium. Donnelly also examines political pressures to acquire nuclear weapons and countervailing restraints that could reduce incentives to join the club.

Donnelly's report states that a reasonably industralized state with sufficient determination and financial resources, and without interference by other nations. could produce some nuclear weapons within perhaps three to five years. Among the countries with the greatest nuclear capability—meaning the installed nuclear facilities and scientific and technical talent—Donnelly lists Israel, India, Italy, Argentina, West Germany, Japan and South Africa. Those countries with the greatest pressure to joint the club, according to Donnelly, are Israel, Pakistan, Cuba, India, Iran, Iraq and South Africa. "Just as many non-nuclear weapons states may feel pressure pushing them toward nuclear weapons," writes Donnelly, "so too these states may be subject to . . . constraints." Thus, a nation that believes itself threatened by a neighbor's developing nuclear capacity may be tempted to follow Israel's example when it destroyed Iraq's Osirak reactor in an air raid on 7 June 1981. Iran had failed to demolish Osirak on 30 September 1980, eight days after the Iran–Iraq War started. Without technicians and technology of its own, Iraq relied upon France for the construction and operation of Osirak. It bought a fabrication facility from Italy and uranium ore or "yellowcake" from Brazil and Portugal.

The countries most likely to join the club next, Donnelly concludes, are Argentina, Israel, India, Pakistan and South Africa, in that order. Though Japan, West Germany, Belgium, Italy and the Netherlands possess nuclear capability, writes Donnelly, these countries are constrained by culture and politics from developing nuclear arms.

Scientific imperative. In his recent book, *Weapons and Hope*, Freeman Dyson argues that in the case of each member nation of the club, scientists rather than generals took the initiative in getting nuclear-weapons programs started. "In each case of which we have knowledge, scientists were motivated to build weapons by feelings of professional pride as well as of patriotic duty. The construction of a bomb was a technical challenge which aroused their fiercest competitive instincts. . . . The nuclear arms race from 1940 to 1960 was powerfully reinforced by the professional ambitions of scientists who saw nuclear weapons technology as a grand arena for the exercise of their talents. The walls of official secrecy which surrounded these exercises made professional rivalries more intense and gave a false glamour to the new technology," Dyson writes.

"But now no more," claims Dyson. "Since 1964, anybody who wanted to know the general principles of fission weapon design could find them explained by Robert Serber in the declassified *Los Alamos Primer*. Since 1979, anybody who wanted to know how hydrogen bombs work could refer to Howard Morland's article in the November 1979 issue of *The Progressive*. Nuclear weapons design has been stripped of its mysteries, and there is no longer any scientific glory attached to it. . . . From now on there will be no more first-rate scientists driving the nuclear arms race with their rivalries. Even in scientifically backward countries, young people of talent now know that nuclear weapons have ceased to be a scientific challenge."

Political factors. Dyson's idea of scientific imperative appears to gain support from an observation by J. Robert Oppenheimer on the US decision to develop the hydrogen bomb. Oppenheimer was quoted as saying the design was "technically so sweet" that development of the bomb was inevitable. By contrast, a recent analysis of the fac-

tors determining whether countries acquire or forgo nuclear weapons, presented in *The Dynamics of Nuclear Proliferation* by Stephen M. Meyer of MIT, contradicts the primacy of the scientific or technological imperatives. Meyer argues that political and military factors dominate—that the will is more important than the way in the decision to join the club.

Secretary of State Shultz appears to agree with Meyer's theory. In seeking to prevent new entrants to the club, he told the UN Association last November, "we have employed a range of political, economic and security measures." These, along with IAEA safeguards and efforts by the London Suppliers Group, have not decreased the risk of proliferation, however. According to Spector, the Nuclear Nonproliferation Act signed by President Carter in 1978 has been violated by the US itself. While the act is intended to make suppliers more sensitive to curtailing nuclear exports, it did not prevent two American brokers, Edlow International and SWUCO Inc, from arranging the sale of uranium fuel processed in Belgium and France to South Africa through a consortium of Swiss utilities. During 1982 hearings on exports to South Africa before a committee of the House of Representatives, it was revealed that the State Department had been advised of the deal before it was completed but had taken no steps to discourage Edlow and SWUCO from proceeding.

According to Shultz, the Reagan administration's approach is to consult and cooperate with other nations to thwart the destabilizing effects of proliferation. In keeping with this policy, the US has been discussing with Japan and the European Atomic Energy Community (EURATOM) long-term arrangements on reprocessing nuclear fuels and using plutonium. Although President Reagan initialed an agreement on nuclear energy with China last April, formal cooperation has foundered, because China has yet to provide assurances it will not help other nations build nuclear arms. Washington is concerned about China's nuclear exports to Pakistan and South Africa.

Such actions and the black-market traffic in nuclear material and technology, warn State Department officials and Ambassador Kennedy, cause the specter of more nuclear weapons states to haunt the world. "Pakistan and India may be poised on the brink of a major arms race," writes Spector in his report for the Carnegie Endowment. Moreover, Argentina, with the most advanced nuclear program in Latin America, could produce a deliverable weapon in "several years"—a situation that causes Brazil to accelerate its program. —IG

Will the nuclear club be enlarged?

Here is a list of eight countries that "took important steps" toward nuclear-arms capability in the past year, according to a report by Leonard S. Spector of the Carnegie Endowment for International Peace. Details are based on the report.

▶ Argentina, with the most advanced nuclear program in Latin America, disclosed after five years of secrecy it had a gaseous-diffusion enrichment plant capable of producing weapons-grade U^{235} soon. The inauguration in December 1983 of Raul Alfonsin, marked the end of the military junta and raised hopes of change in the nation's nuclear program. Still, Argentina refuses to sign the Nonproliferation Treaty or to ratify the Treaty of Tlateloco, which would make all Latin America a nuclear-free zone.

▶ Brazil, though considerably behind Argentina in nuclear programs, possesses the scientific and industrial underpinnings necessary to design and fabricate nuclear weapons. Currently, Brazil lacks a source of plutonium or highly enriched uranium, but during the early 1980s it began to accelerate a series of nuclear programs without safeguards and outside the ambit of its projects with West Germany. Among these is a plant at the Instituto des Pesquisas Energeticas e Nucleares (IPEN) at the University of Sao Paulo to develop a centrifuge enrichment capability for weapons-grade material by 1990.

▶ India exploded a nuclear "device" in 1974 with Pu^{239} produced at unsafeguarded facilities at the CIRUS reactor and a reprocessing plant at the Bhabha Atomic Research Center (formerly called Trombay). A new reprocessing plant at Tarapur has a maximum output of 135 to 150 kg of plutonium per year, three times larger than the Trombay plant. It can process uranium oxide fuel from all of India's nuclear power plants, which now consist of Tarapur I and II, Rajasthan I and II and the unsafeguarded Madras I. India is not believed to have deliverable nuclear arms, but has the talent and is expanding its facilities.

▶ Iraq may have aimed to develop nuclear weapons by the mid-1990s, but its program has been essentially dormant since Israel destroyed the French-supplied Osirak reactor in June 1981. France has agreed in principle to rebuild the reactor under stringent specifications calling for low-enriched fuel and French technicians to operate it as a regional research center. Still, no significant reconstruction work has started. Meanwhile, since the Israeli raid, Iraq has adopted a clandestine strategy to obtain weapons-grade plutonium through black-market sources in Europe

▶ Israel has the technology, materials and talent to produce nuclear weapons quickly—though US intelligence officials have claimed for the past decade that it probably already has an arsenal of 10 to 20 Hiroshima-sized bombs. A recent report by Georgetown University Center for Strategic and International Studies concludes that Israel will produce enough nuclear material in its Dimona reactor to make 100 warheads by the end of the century. Other possible sources of bomb-grade material, according to the CIA, are France, credited with providing 14 kg of plutonium in 1967—enough for one or two weapons—and a clandestine cache of about 100 kg of highly enriched uranium supplied by the US Atomic Energy Commission to the Nuclear Materials and Equipment Corporation in Apollo, Pennsylvania, for processing and subsequently "lost." Despite investigations, the uranium has not been located.

▶ Libya has attempted to buy nuclear technology from China, Pakistan, Argentina, the Soviet Union, Belgium and elsewhere, according to reports. In 1974, Libya sought assistance for a nuclear program from General Atomics Corporation, but the State Department and Congress opposed this. In 1977, Libya signed an accord with the Soviet Union for a 440-MW nuclear power reactor, but construction is hung up in protracted negotiations between the countries. Libya is considered to be decades away from having the technology to build a bomb.

▶ Pakistan may be able to produce weapons-grade uranium at its enrichment facility near Kahuta, "thereby surmounting the final obstacle on its 12-year quest for nuclear arms," writes Spector. Its plan to build a 900-MW nuclear power plant at Chashma has met a total boycott by all nuclear supplier nations—an important milestone in US efforts to establish a common front in curbing the spread of nuclear arms. In the recent past China has reportedly provided Pakistan with material and information for nuclear weapons.

▶ South Africa has the capability to produce highly enriched uranium at its secret enrichment plant at Valindaba, which it claims uses a process that is "an invention of our own." The plant can yield enough for two or three nuclear weapons per year. Therefore, South Africa may have an many as 15 to 25 Hiroshima-sized bombs. If reports that it imported substantial quantities of low-enriched uranium from China in 1981 are true, South Africa could rapidly enrich this material to weapons grade, substantially increasing its stockpile of nuclear explosive material. Under a 1957 agreement, the US has trained South Africans in nuclear science and engineering and supplied two small research reactors in the 1960s. In August 1977 the Soviet Union notified the US that one of its surveillance satellites had spotted what appeared to be a nuclear test site in South Africa's Kalahari Desert. After US experts confirmed the finding, the two superpowers, in a rare display of unity, warned Pretoria against exploding a nuclear device. In 1979 a US satellite detected a distinctive two-pulse flash over the South Atlantic near a South African naval exercise. South Africa denied it had detonated a nuclear device, and no corroborating evidence of fallout has been obtained. Rumors persist that South Africa and Israel cooperate in nuclear weapons development. —IG