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Atoms for Peace after 50 Years:
The New Challenges and Opportunities

December 2003

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About This Report

This report has drawn on a series of workshops held on the general subjects of Defense, Deterrence, and Nonproliferation (April in Livermore, California); Civilian Applications (May in Gotemba, Japan); and the Cross-Cutting Issues of Materials, Governance, and Public confidence (July in Saclay, France). The chairs of the workshops in order were William Schneider (Vice-Chairs Leonard Weiss and Chris Williams), John Taylor (Vice-Chairs Alan Waltar and Mortimer Mendelsohn), and Michael May (Vice-Chairs Siegfried Hecker and Charles Curtis). Appendices A through C document these workshops.

Established in 1996, the Center for Global Security Research (CGSR) brings together diverse expert communities to address common challenges with significant policy implications for key decision-makers. Our aim is to expand the knowledge of the technology–policy interface by studying ways in which science and technology can enhance national security. This report comes from the participants in the workshops, with an emphasis on providing clarity on issues rather than forcing consensus. Our method is to pose specific questions that help define what we know and what we do not, what we can and cannot agree on, and what is needed to resolve unknowns.

The organizers and workshop chairs are especially grateful to Jor-shan Choi, Tom Isaacs, Neil Joeck, Carl Poppe, Craig Smith, Eileen Vergino, Leonard Weiss, and Michael Wheeler. Many workshop participants—too numerous to mention by name—contributed their ideas and criticisms, all of which have been considered, but the responsibility for this report rests solely with the organizers. Special thanks go to John Ahearne, V.S. Arunachalam, Harold Bengelsdorf, Jacques Bouchard, Tom Cochran, Garry George, Jack Gibbons, Victor Gilinsky, Caroline Jorant, Pief Panofsky, Bruno Pellaud, and Atsuyuki Suzuki for many insightful comments and suggestions. The workshops were held under the direction of Ronald F. Lehman II, Director of the CGSR. Robert N. Schock, Senior Fellow at the CGSR, was the project director.

Center for Global Security Research Lawrence Livermore National Laboratory

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" … the United States pledges before you—and therefore before the whole world—its determination to help solve the fearful atomic dilemma—to devote its entire heart and mind to find a way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life."

Executive Summary

This report draws on a series of international workshops held to mark the fiftieth anniversary of President Dwight D. Eisenhower's Atoms for Peace address before the United Nations General Assembly. A half-century after President Eisenhower's landmark speech, the world is vastly different, but mankind still faces the challenge he identified—gaining the benefits of nuclear technology in a way that limits the risks to security. Fifty years after Eisenhower declared that the people of the world should be "armed with the significant facts of today's existence," the consequences of his bold vision should be evaluated to provide a foundation upon which to shape the next fifty years.

Policy and technology communities cannot escape the legacy of a half-century of nuclear technology expansion. At the same time, citizens need to consider the future role of military and civilian nuclear technology in a global strategy to meet the challenges of the twenty-first century. The new century brought with it a set of contradictions regarding nuclear technology. Nuclear knowledge, technology, materials, and facilities have spread around the world, but control and management of the nuclear genie have not kept pace.

The Cold War is over, but not the threat from weapons of mass destruction, including the prospect that nuclear, chemical, or biological weapons may get into the hands of terrorists. Nevertheless, mankind continues to explore the frontiers of technology, including nuclear technology. Public concern about nuclear safety and security—exacerbated by accidents, nuclear weapon proliferation, and terrorism—confronts major growth in applications of nuclear technology in nuclear power, medicine, agriculture, and industry. While some developed countries have essentially stopped civilian nuclear-power expansion, mainly for economic reasons, several developing states—notably China and India—plan increases in the nuclear generation of electricity. Ironically, while governments still seek answers to long-term, nuclear-waste disposal, other concerns about the environmental health of the planet such as climate change, regional air pollution, and possible rising natural gas prices have also renewed interest in nuclear power, even in countries that once sought to terminate their own nuclear programs.

Many of these contradictions can and will be resolved—for better or worse. A wide range of forces—economic, political, and technical—will determine the impact of nuclear technology in the future, and no consensus exists on the outcome. The significance of nuclear technology for civilian or military purposes may expand, contract, or remain the same. This suggests a matrix of basic possibilities from which we focus on five alternative futures: (1) More civilian/Less military significance, (2) Less civilian/Less military significance, (3) Less civilian/More military significance, and (4) More civilian/More military significance. Of course, changed circumstances could also result in (5) the significance of both civilian and military nuclear technologies remaining about the same as today. Experts offer compelling logic why each of these alternatives is more likely or desirable. For each of these futures or their modifications, a more comprehensive vision can be presented and specific measures recommended. Some call for a new nuclear "compact" or "bargain" to share benefits and reduce risks. No matter which alternative future emerges, however, dealing with the legacy of existing civilian and military nuclear materials and infrastructure will keep important nuclear issues active for the next half-century.

Recommendations

Participants in the workshops support different visions and preferences for the future, but nearly all urge action in five areas, each of which emphasizes international or domestic security considerations:

- Any robust nuclear future requires that broad international security concerns be addressed, including the foundations of international order, the architecture of security institutions, the sources of global and regional conflict, and reactions to threats emerging from even small nation-states, nonstate actors (such as transnational terrorists), and substate hybrids (such as rogue officials acting outside formal government policy). This requires addressing the security calculations of nations outside the Nuclear Non-Proliferation Treaty (NPT) as well as those inside the NPT that may consider acquiring nuclear weapons. Transforming military capability, both advanced conventional and nuclear, must take place in the context of a better understanding of what assures, dissuades, deters, defends, and defeats. Both forces in place and the infrastructure and personnel that provide responsive hedges in the future must be designed to enhance security for friends and allies and to shape less hostile behavior by potential adversaries. In short, although many of the ideas discussed below involve the so-called "supply side" of nonproliferation, powerful forces must be addressed on the "demand side." Indeed, addressing the violence of subnational and transnational groups must accompany reforming the behavior of nation-states.

- The nuclear nonproliferation framework built around the NPT and the International Atomic Energy Agency (IAEA) has been essential and needs to be strengthened. However, growing latent capabilities and offshore networking among governments, industries, and nonstate actors of nuclear-proliferation potential—combined with just-in-time breakout capabilities—pose severe challenges to enforcement. Reliable mechanisms for decisive enforcement action beyond the existing practices must be developed. Some believe an entirely new framework may be necessary, but even among who those who hold this view, opinions are polarized over whether the emphasis should be on supply or demand—that is, controlling the technology through arms control and export controls, for example, or changing the nature and circumstances of the states that will have access to the technology. Prevention remains the goal, but may fail, requiring more effective approaches to counter proliferation. Whatever the framework, the current weakness in international treaty enforcement of the NPT must be addressed.

- The near-term nuclear technology future requires that control and security of weapon-usable materials—in particular, plutonium, and highly enriched uranium—have the highest priority. Over the long term, minimizing the amount of weapon-usable material and its accessibility must be a common goal. Obtaining greater international confidence in materials protection, control, and accountability will entail greater multilateral transparency, cooperation, oversight of management and control, and some believe ownership. Opinions are scattered on which activities are best handled by national governments and which might benefit from a greater mandate for multilateral arrangements or international organizations. Control of nuclear weapon-usable material remains the keystone of nonproliferation and the centerpiece of preventing nuclear terrorism, but the widespread latency of nuclear capability requires that assessments and safeguards go far beyond just confirming the immediate status of declared materials. More attention must be placed on the security context in which the materials exist and the prospects for breakout or theft.

- Clearly identifiable, non-nuclear issues involving resources, the environment, and security will soon compel a new, great debate over nuclear power. Market economics and finance will dominate decisions about future civilian nuclear applications, but those externalities considered in the political arena together with others, such as safety, security, and the environment, will weigh heavily in these decisions. Thus, a better understanding of the wider implications of technology options and alternative risks and benefits from different approaches broadly calculated is needed for policy-makers and the public considering further nuclear development. International and domestic security must be explicit in these assessments.

- The importance of U.S. leadership and international cooperation to reduce the risk and to maximize the benefits of nuclear technology is widely understood around the globe. That said, broader U.S. leadership has been weakened over the years because the United States has lacked a well-focused vision of the nuclear future. Concurrently, American technological innovation has declined in a number of civilian nuclear fields, further reducing American influence on some decisions with important international security implications such as fuel-cycle futures. To reverse this trend, a bold vision for the role of nuclear technology in the twenty-first century should be articulated soon with sufficient clarity to create a policy imperative sustained over time by a mandate for action from the U.S. President and the Congress.

In short, all the participants in these workshops—whether pessimists or optimists about the civilian nuclear enterprise and whatever their differences on international security strategy—believe that security issues must come first no matter what civilian nuclear future is advocated or emerges. In fact, the civilian nuclear enterprise will be severely hampered without attention to the security issues. Furthermore, whether the civilian nuclear enterprise expands or contracts and whether nuclear weapon concerns increase or decrease, managing the security legacy of the last fifty years will engage us for decades to come and must be accomplished with the most up-to date technology available.

As President Eisenhower foresaw, nuclear technology will continue to evolve, not only in power generation and defense, but also in medicine, agriculture, and industry. Each possible nuclear technology path addresses different expectations, and each brings its own difficulties. A problem-free nuclear future is not an option. Thus, action must be taken to ensure that security comes first and that the nuclear future is what we choose, not the result of drift and inattention. Bold but different proposals are made for enhanced or new frameworks addressing supply or demand or both. Some of these proposals revisit the trade-offs between the benefits of peaceful nuclear technology and nonproliferation obligations. Others focus more on security or disarmament. Still others look to enhance restraint by those nations not party to the NPT. Central to the debate over management of the nuclear future is the question of which principles or rules should be applied universally and which should be tailored to specific countries, circumstances, or timeframes. How NPT parties should relate to nonparties remains an issue, involving what benefits come from being a party and what responsibilities for restraint accrue from not being a party. Strengthening the existing framework for managing nuclear matters is essential, whether or not a new "bargain" or "compact" is required. In either case, a concrete, step-by-step process with meaningful options enlightened by an articulation of a clear vision of our objectives for the future is needed if nuclear technology is, in Eisenhower's words, "to serve the hopes rather than the fears of mankind."

Overview

Challenges of the Nuclear Era

Over the last century, the world has experienced unprecedented political and technological change, much of it accelerated by the discovery and exploitation of atomic power. In many ways, the twentieth century was the atomic century. Just over a hundred years ago, radioactivity was discovered. More than four decades later, the first controlled nuclear reaction was achieved. This was followed within three years by the first nuclear-weapon detonations at the end of World War II. By 1953, the ideas that would shape the next 50 years of nuclear progress had emerged. These ideas transformed the last half of the twentieth century. As we enter a new century being transformed by globalization and revolutions in biotechnology, information technology, and other innovative applied sciences, nuclear technology continues to help us shape the world.

In the formative stage of the nuclear era, no world leader better captured the issues and options that would drive the next 50 years than President Dwight David Eisenhower in the Atoms for Peace speech. Recently returned from the Bermuda Summit with the United Kingdom and France, Eisenhower spoke on December 8, 1953, to the United Nations General Assembly. As the Cold War entered the bipolar thermonuclear age, the President offered a bold proposal to address the nuclear technology challenges facing the world. He stated that "if the fearful trend of atomic military buildup can be reversed, this greatest of destructive forces can be developed … to serve the peaceful pursuits of mankind." In particular, he proposed to help non-nuclear weapon states develop the civilian benefits of nuclear technology, including electric power, medicine, and agriculture. In support of that objective, Eisenhower proposed an "international atomic energy agency" as a bank for fissionable and other materials.

Despite the hope contained in the Atoms for Peace speech, over the last 50 years, both nuclear policy and technology fell short of Eisenhower's vision in many ways. Despite the apparent success of nuclear deterrence and eventually arms reductions, the development of massive nuclear arsenals by the United States and the Soviet Union and the steady spread of nuclear weapon technology around the globe inspired great fear that continues. India, Israel, and Pakistan, and initially France and China, refused to sign the Nuclear Non-Proliferation Treaty (NPT). All acquired nuclear weapons. More recently, North Korea withdrew from the NPT and signaled that it has nuclear weapons. This year, the International Atomic Energy Agency (IAEA) found evidence of undeclared highly enriched uranium in Iran, despite that government's assertion that its program is only for civilian purposes. Accidents at Three Mile Island, Chernobyl, and Tokai-mura undermined public support for nuclear power. The slow progress in dealing with the waste from nuclear operations has contributed to this lack of confidence and support. Even debate about irradiated food illustrates underlying pubic concern about nuclear technology.

Fifty years after Eisenhower's speech, the world is vastly different and his ultimate goals remain elusive. The United States–Soviet Union rivalry is over, but concerns about nuclear proliferation and terrorists using weapons of mass destruction (WMD) are spreading. The extraordinary economic growth in the industrialized world was matched by a handful of developing countries, but it is in sharp contrast to numerous failing economies and failed states. Technical advances in transportation, communication, and human health are offset by concerns about climate change, drug-resistant disease, resource depletion, an economic divide between North and South, and environmental degradation. Doubts exist about the globe's ability to sustain its heavy dependence on fossil energy.

Future Nuclear Scenarios

As we begin the second 50 years following Eisenhower's Atoms for Peace initiative, it is not obvious whether nuclear technology for either military or civilian applications will have more, less, or the same significance. An examination of the changing circumstances and future alternatives in the context of the challenges highlighted by President Eisenhower is therefore warranted. Alternative nuclear scenarios can be viewed in terms of combinations based upon the significance of military and civilian applications. Five basic directions might apply with more, the same, or less significance for military and/or civilian applications **(Figure 1)**. Each of these can characterize the world, a region, or a nation, today or in the future.

- **Nuclear Enterprise**—maintaining a modern, intensive nuclear power and technology sector while avoiding the pursuit of military applications. An example might be today's Japan.
- **Nuclear Synergism**—moving to obtain or increase both nuclear weapons and nuclear power and technology. Iran, India, China, and perhaps Pakistan, might be examples.
- **Nuclear Security**—building a military nuclear capability to address security concerns, but with civilian technology clearly minor or a secondary goal; in some cases, it may be a cover. Examples might be Pakistan and North Korea. In the same category, but following a different logic, are those opposing nuclear power because of the security threat it might pose while focusing on nuclear deterrence, nuclear threat reduction, and countermeasures. This is a view held by some in the United States and elsewhere.
- **Nuclear Free**—strong opposition to most nuclear technology applications. An example might be New Zealand.
- **Nuclear Legacy**—not greatly changing nuclear force levels or the amount of nuclear materials and embedded nuclear power and technology. The United Kingdom is perhaps an example, but nearly all nations with nuclear enterprises will have accumulated nuclear material and legacy facilities to deal with for many decades.

Driving Forces

A range of economic, political, and technological factors will determine which of the five outcomes is most likely. These factors point in different directions. and each brings unintended consequences. In some cases, dominant trends may generate a backlash that

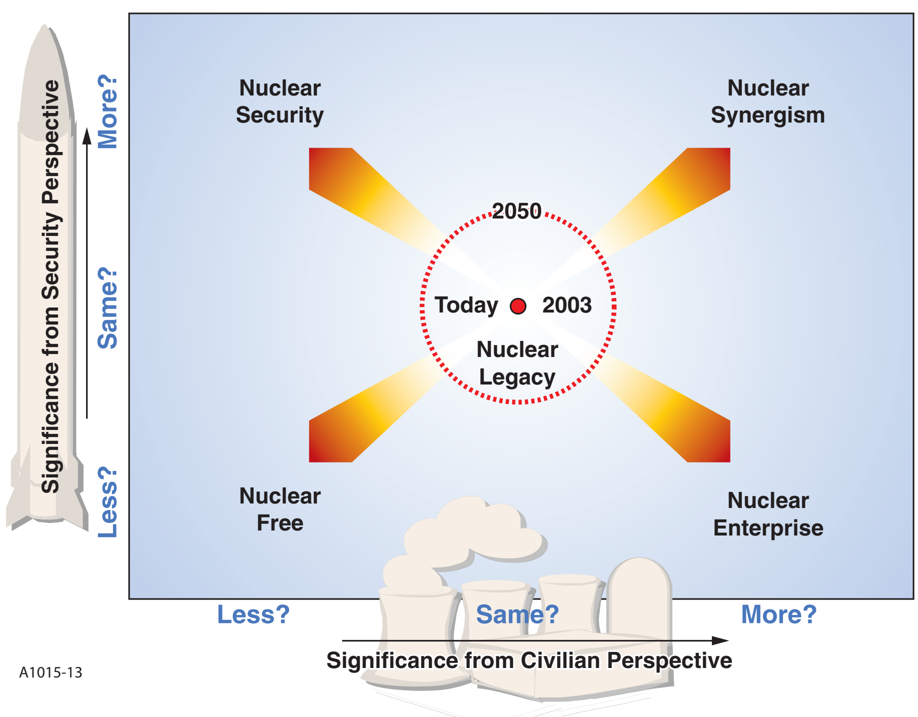

Figure 1. Alternative nuclear technology futures.

is itself important. For example, export controls on nuclear component sales in the open market may encourage difficult-to-monitor black market networks or even less transparent technical self-sufficiency. Participants in the workshops identified a number of forces, some of which are listed below.

Primarily Civilian Factors

- Increased interest in nuclear generation of electricity in some developing nations.
- Institutionalized opposition to existing nuclear power (even in some states already heavily invested in nuclear power).
- Increased support for nuclear power to address climate change as a nonpolluting alternative to fossil fuels with high carbon emissions.
- Desire to prevent or reduce pollution in the face of global population and economic growth.
- Growing enthusiasm for nuclear applications in medicine, agriculture, industry, and food production.
- Public sensitivity, and in some cases suspicion, about nuclear safety and security.
- Recent public support for nuclear power in some countries (e.g., Switzerland).
- Concern over rising natural gas prices.
- Depletion or loss of access to fossil fuels from troubled regions by force or embargo.
- Sunk costs of commercial nuclear power.
- Advances in technology and its global dissemination, including nuclear technology.
- Advances in alternative power generation technologies (e.g., renewables).
- High financial and opportunity costs associated with nuclear construction.
- Accumulating stocks of civilian nuclear materials and waste for which future use, storage, and disposition remain undecided or undemonstrated.
- Complex regulatory requirements for nuclear power versus more deregulation of natural-gas power generation.
- Uncertainty about nuclear risk versus benefit methodologies and priorities.

Primarily Security Factors

- Safety, security, and disposition of nuclear weapon materials and delivery systems left over from the Cold War.
- Regional violence, terrorism, and the adequacy of the international security architecture.
- Difficulty achieving timely and consensual decision-making to enforce nonproliferation commitments.
- The development of advanced conventional weapons.
- The growing interest in nuclear weapons among states in troubled regions.
- Lack of confidence that the current nonproliferation regime can meet the challenges of the spread of knowledge, technology, facilities, covert networks, agile manufacturing, sophisticated concealment and deception, third-country acquisition, and just-in-time production.
- Credibility of security guarantees from the nuclear weapon states.
- Rate of U.S.–Russia nuclear-weapon reductions.
- Responses to new proliferation.

At the same time, the participants recognize that unforeseeable catalytic or transforming events are almost certain to play roles as well. Another nuclear accident, a catastrophic terrorist attack, actual use of nuclear weapons, global economic depression, a dramatic scientific breakthrough, or a climate change or other environmental crisis are just a partial list of events that can significantly affect the future of civilian and military use of nuclear technology, positively or negatively.

Recommendations

When President Eisenhower spoke in 1953, he sought to enhance international security, but at the same time he wished to expand opportunities for civilian applications of nuclear technology. Key Eisenhower goals were met arguably with the end of the Cold War, the fall of the Berlin Wall, the reduction of the great powers' nuclear arms, the near-universal membership in the NPT, and the spread of nuclear reactors and science to nearly all sizeable countries.

Still, not all participants underscore the positive aspects of Atoms for Peace. Many workshop participants believe that Atoms for Peace accelerated the spread of nuclear weapon capabilities, in part by distorting energy economics and scientific investment. Some view the speech as an attempt to maintain the advantage of the nuclear near-monopoly held by the United States by substituting a step-by-step approach for immediate disarmament, while others express the view that the Atoms for Peace initiative and the IAEA and NPT regimes altered the basic outcomes only at the margin.

In any case, all participants seem to agree that the legacy of the past keeps nuclear technology issues significant in the years ahead. Many think that the application of nuclear technology will increase. Some believe that security concerns are manageable, but others remain pessimistic. Despite many different approaches, however, widespread agreement exists on much that needs to be done in the near term to understand and shape a better future.

Five general, overlapping recommendations attract broad support. Each involves complex interactions between technology and policy. All five place a premium on security to meet the new dangers of the twenty-first century and to reap potential benefits of electrical power, industrial, medical, agricultural, and research options. Although the link between each beneficial nuclear technology and military threat, proliferation, or terrorism varies, few are without some risk, requiring greater diligence (e.g., the physical protection of radiological sources for nuclear medicine).

Address the Fundamentals of International Security

So long as nations and nonstate actors such as terrorists remain motivated to acquire and use nuclear weapons, maintaining the military, diplomatic, and financial capabilities to counter these threats and to work toward eliminating the circumstances that feed the motivations are necessary. The United States and other key nations must contribute to and cooperate in a security system that protects nations that forgo nuclear weapons and reduces the threats from regimes or terrorists that seek them. Some of this will involve U.S. military and civilian nuclear technology, but much of the broader security context for dealing with nuclear futures will be shaped by security, political, and economic factors determined by non-nuclear considerations such as regional conventional balances and the nature of the regimes in power. Few participants see comprehensive nuclear disarmament as a practical near-term tool for addressing the risks, but many are interested in sustaining international arms restraint or developing new, perhaps more cooperative approaches. A central theme is uncertainty that the United Nations Security Council can act decisively to address crises or evolving threats to international security. At the same time, concern is expressed over the costs and dynamics resulting when nations act in smaller coalitions or even unilaterally.

Transforming military capability, both advanced conventional and nuclear, must take place in the context of a better understanding of what assures, dissuades, deters, defends, and defeats. Both forces in place and the infrastructure and personnel that provide responsive hedges in the future must be designed to enhance security for friends and allies and to shape less hostile behavior by potential adversaries. Given that prevention may fail, better approaches to counter proliferation are needed. Although many of the ideas discussed below involve the so-called "supply side" of nonproliferation, powerful forces must be addressed on the "demand side." Indeed, addressing the violence of subnational and transnational groups must accompany reforming the behavior of nation-states.

Strengthen the Effectiveness and Enforcement of the Nonproliferation Regime

The threat that nuclear proliferation poses to international security must be recognized and given high priority. Nearly all participants agree that the NPT is a necessary but insufficient framework for addressing proliferation. If the NPT unravels or is perceived as ineffective, many participants feel that the immediate loss of security could not be reversed. As a consequence, a number of suggestions to strengthen the effectiveness of the overall NPT regime receive considerable support: (a) wider adherence to the Additional Protocol on inspections, (b) smarter export controls and assessments employing modern technology, and (c) permitting exports only to states adhering to the Additional Protocol. In addition to strengthened collective security arrangements, participants see reliable enforcement of current NPT commitments as key to the success of nonproliferation. With North Korea announcing its withdrawal and Iran having threatened withdrawal, participants note that allowing states caught in violation of the NPT to escape the consequences of their violations by withdrawal seriously undermines both nonproliferation and international law.

In addition to the supply-side approach to nonproliferation, some participants also argue that more must be done to address the demand side. It may be possible to negotiate new security arrangements to avoid proliferation by additional states. It may also be possible to build on the Proliferation Security Initiative or the Iraq model to prevent states from acquiring nuclear weapons.

Secure Facilities and Materials

The breakup of the Soviet Union, along with the emergence of a number of failed or failing states, has made the control of nuclear materials in all countries extremely urgent, especially those with readily usable weapon materials. Highly enriched uranium anywhere, including in research reactors, is an especially dangerous weapon-usable material—and efforts to remove these materials from as many locations as possible should be redoubled. Strengthening the Convention on Physical Protection of Nuclear Materials (CPPNM) can help ensure that civilian weapon-usable materials are better controlled. An enhanced regime of safeguards and security should be established to deal with the diversion of nuclear materials for illicit purposes. This may require the IAEA to move beyond its basic role of monitoring and verification into more active oversight of management and control of civilian materials and facilities. Some participants advocate incremental increases in multilateral or international ownership of material and facilities. In any case, new technology and a significant commitment of funds by the member states are needed to improve materials protection, control, and accountability and enhance international transparency and therefore confidence.

Given the magnitude of the task and the impossibility that all radiological sources can be secured at once and guaranteed secure for all time, a systems approach is needed along with criteria for setting priorities and establishing metrics for evaluating progress. Likewise, given insider threats, the international community must not substitute its initiatives for ownership of the problem by responsible national governments. Programs must be designed to avoid perpetuating an "entitlement" mentality with respect to funding for security. Worse, perverse incentives should not be created to tolerate security flaws in order to attract international funding.

Exploit Civilian Nuclear Opportunities While Enhancing Security

Nearly all participants saw a need to ensure that civilian opportunities to utilize nuclear technology are assessed in terms of the risks and the benefits to society. Benefits from nuclear power, medicine (diagnostics and therapy), agriculture, industry, and research must be balanced against security, safety, public concerns, and environmental risks. In addition, the proper cooperative roles of industry, governments, and public stakeholders must be defined to move forward. Governments must lead in improving confidence and credibility in civilian applications. Development of a shared understanding of the risks as well as the benefits is essential, but is insufficient without greater confidence that both the nuclear industry and government regulators have set clear priorities.

Reassert U.S. Policy and Technical Leadership

Much of the world looks to the United States for leadership on nuclear technology and policy. But the capacity for U.S. leadership is influenced significantly by the presence or absence of American participation in key fields of nuclear technology. In addition, the United States must speak clearly on the issues of collective security, enforcement of agreements, and civilian applications. In both technology and policy, American leadership must encourage cooperation while being guided by sound principles. Whatever policy outcomes the United States may choose to promote, they would benefit from a strong technological posture and a systematic vision such as President Eisenhower's Atoms for Peace speech, but updated to reflect the concerns and needs of today's world and that anticipated in the coming years.

Discussion

Essentially all participants in these workshops—whether optimists or pessimists about the civilian nuclear enterprise and whatever their differences on international security strategy—believe that the security issues must come first no matter what civilian nuclear future emerges from technology and the marketplace. There is no consensus on the details of these five themes, but a number of ideas are widely shared.

Address International Security Fundamentals

In many ways, the end of the Cold War is the fulfillment of Eisenhower's dream, but the reality of today falls short of his vision. Operationally deployed nuclear weapons of the superpowers and overall nuclear-weapon stockpiles are a fraction of what they once were and are unlikely to return to Cold War levels. On the other hand, latent nuclear-weapon capability worldwide is growing as dual-use technology, access to information, high-speed computation, and agile manufacturing spread to more and more countries. The NPT—and the nonproliferation regime more broadly—have slowed the spread of nuclear weapons over the past 50 years. That said, three key threats to international security operate at the edge of the current nonproliferation regime: terrorist acquisition of nuclear weapons, rogue-state cooperative proliferation, and regional competition in South Asia, the Middle East, and Northeast Asia.

Deterrence and Defense

The United States has adopted a "capabilities-based" approach to military planning with a "New Triad" that grants nuclear weapons a significantly reduced, yet still vital role to "Assure, Dissuade, Deter, Defend/Defeat." Specifically, the New Triad includes nuclear and non-nuclear (e.g., advanced conventional weapons [ACWs], etc.) strategic strike forces, passive and active defenses, and a responsive infrastructure capable of producing new offensive strike and defensive capabilities (and associated C^4ISR [Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance]) in a timely fashion. The shift to capabilities-based planning reflects the environment of the twenty-first century in which it is more difficult to forecast future security challenges or adversaries reliably or to optimize military forces for a specific threat. Continued advances in high-precision conventional munitions and other advanced C^4ISR capabilities, together with novel approaches to the conduct of joint military operations (as demonstrated during Operations Enduring Freedom and Iraqi Freedom), provide the United States with significant new non-nuclear military options and new means of reassuring friends and allies of U.S. security commitments, dissuading potential adversaries from engaging in arms competition with the United States, deterring would-be aggressors, and swiftly defeating a potential adversary.

The development of these new non-nuclear capabilities lead some to question whether nuclear weapons should remain a vital element of U.S. national security strategy and defense planning. Incremental reductions are underway toward levels far below the height of the Cold War, but some suggest reduction to lower levels soon, say a few hundred weapons, and legal prohibitions on first use. Such steps could be cited in diplomatic bodies to help generate greater support for global nonproliferation efforts among those for whom disarmament has been a central concern. Some who challenge the wisdom of further "no first use" constraints or very low numbers in the near term counter that a smaller nuclear arsenal is possible only by encompassing a new set of capabilities focused on a much narrower set of targets and contingencies than during the Cold War. Virtually all participants agree, however, that the residual U.S. nuclear arsenal, with its Cold War legacy of large numbers of relatively high-yield, low-accuracy warheads and MIRV'ed delivery systems seems inappropriate for the evolving international security environment. Numerous participants express the view that, whether employing capabilities-based or threat-based planning, the numbers and kinds of nuclear weapons in the U.S. arsenal should be matched to the evolving security environment.

At the heart of the debate over the role of nuclear weapons and appropriate capabilities for the future is the long-standing question of whether it is the destructiveness of nuclear weapons or the credibility of their use that deters. Proponents of developing new nuclear capabilities argue that for reassurance, dissuasion, and deterrence to be credible, U.S. nuclear forces must be seen, not as weapons of retribution, but as rational, potentially usable "weapons of last resort." Others disagree and tend to emphasize the perceived dangers of "lowering the nuclear threshold" and heightened arms competition. As of this writing, the debate over U.S. nuclear policy is still in flux. The administration of President George W. Bush completed its Nuclear Posture Review (NPR) in December 2001 and proposed funding to research new nuclear-weapon capabilities. The Congress is debating these proposed programs, as well as the policy and other implications of the NPR.

America's relations with key foreign governments can also have a significant impact on the future direction of U.S. nuclear policy. United States–Russia relations have improved considerably since the end of the Cold War, while economic expansion in China may exert pressure to draw Beijing closer to the West. With the continued decay in Russian conventional forces, Russia's political and military leaders have publicly placed increased doctrinal emphasis on nuclear weapons, and the nuclear establishment in Russia continues to receive considerable resources. Also, despite retaining a large stockpile—including an extensive arsenal of tactical nuclear weapons—Russia reportedly is also developing new tactical nuclear weapons. For its part, China is also augmenting and modernizing its nuclear stockpile.

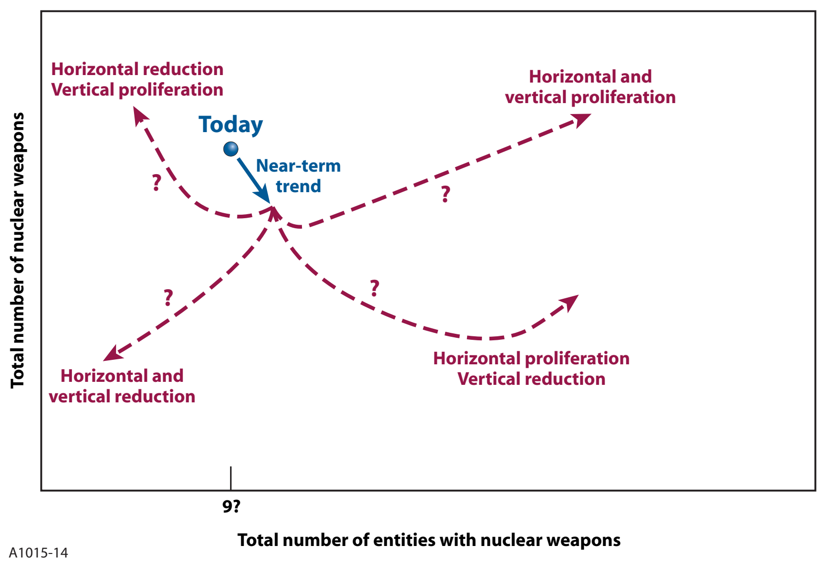

Figure 2. Horizontal and vertical proliferation change.

Additionally, there is continuing concern that more states or subnational entities will seek nuclear weapons. As a result, the number and distribution of nuclear weapons in the future will be different from what it was during the Cold War, but the world will not necessarily be safer. Although reductions by the United States and Russia will likely considerably reduce the total number of stockpiled weapons, nuclear weapons and nuclear capability may be more widely distributed geographically. The outcome of the present situations in North Korea and Iran will likely have a telling effect on future weapon distribution, not only among potentially hostile states, but also conceivably among friendly states such as Japan and South Korea.

Nuclear Proliferation

The relationship between strategic deterrence and regional nuclear proliferation is not clear given the post-Cold War shift away from bipolarity and the complexity of regional rivalries and domestic politics **(Figure 2)**. The apparent near-term trend seems to be toward more entities possessing nuclear weapons (more horizontal proliferation), but at the same time fewer total nuclear weapons in the world (less vertical proliferation).

A number of factors may motivate further nuclear proliferation over the next several decades. The end of the Cold War ended the U.S.–U.S.S.R. strategic rivalry, but also weakened some security assurances and bipolar crisis management in several violence-prone regions. This may have the undesirable consequence of increasing regional insecurities and regional arms competition. Additionally, nuclear weapons are seen in the domestic politics of a number of states as enhancing international political status; thus, their political appeal may continue well into the future. Some states may exploit fear of nuclear weapon programs to gain financial or other assistance from the international community. As a consequence, these states ultimately may complete their acquisition of nuclear weapons. This may be the case with North Korea. Strengthened conventional forces may offer some states a military alternative to WMD, but fear of the conventional forces of others may be as great a motivator of nuclear proliferation as fear of WMD. The wars in Iraq and Afghanistan demonstrated the overwhelming superiority of U.S. ACWs, C^4ISR, joint warfare flexibility, and rapid response.

Advanced conventional weapons will likely reduce the reliance on nuclear weapon options for U.S. planning, but may generate alternative reactions among potential proliferators. Some nations may forgo nuclear weapons in the face of such force, especially if ACWs of their own or from allies enhance their security. Others, however, may seek nuclear weapons as an "asymmetric response" to the advanced conventional weaponry of the United States or conventional military superiority of neighbors. Fear of preventive or preemptive action against WMD proliferation may discourage some proliferation, but for nations determined to acquire nuclear weapons, that prospect places a premium on timely, clandestine acquisition before the United Nations Security Council, coalitions, or neighbors can take such action.

The different approaches taken toward Iraq and North Korea may be taken as an object lesson for new proliferators. Iraq was not believed to have nuclear weapons and military force was used, while North Korea, which many believe has nuclear weapons, has benefited from a lengthy diplomatic process. This may be interpreted by some proliferators as demonstrating the value of avoiding international confrontation over NPT compliance until nuclear weapons are in hand or are feared to be in existence. The increased availability of nuclear technology in the hands of second-tier exporters such as Pakistan, Iran, and North Korea or "loose nukes" out of Russia, North Korea, Pakistan, or elsewhere may create a new generation of instant proliferators. Several countries in the Middle East or North Africa might be candidates for such a strategy of nuclear proliferation.

In general, the role technology plays in proliferation is diverse and uncertain, given that primary drivers of proliferation are international or regional security concerns, the inability of many regimes to field effective non-nuclear forces, national pride, and the nature of ruling regimes. There are disagreements on whether the existence of the P-5's nuclear forces motivate proliferation, are a pretext for proliferation, or discourage proliferation. Many nations benefit from the existence of a nuclear umbrella or strong security guarantees such as those provided by a formal alliance. Whether the absence of such guarantees, especially a nuclear umbrella, is a primary driver of proliferation in specific cases remains contentious, especially because of uncertainties about when and how to provide security guarantees to countries already trying to acquire nuclear weapons. Also, some uncertainty exists about the reliability of extended deterrence in a future WMD-armed environment.

Among the specific actions involving nuclear matters put forward by a number of participants to shape or respond to the fundamentals of international security are—

- Addressing the domestic and international motivations for acquiring WMD and strengthening global and regional security frameworks. This requires that explicit attention be paid to the demand side of the nuclear proliferation equation.

- Improving our understanding of what actually assures, dissuades, deters, or defends/defeats potential adversaries, including nonstate actors.

- Seeking alternatives to nuclear weapons where possible and transforming the nuclear weapon stockpile and infrastructure to meet future needs to assure, dissuade, deter, or defend/defeat at the lowest prudent levels.

- Reevaluating existing nuclear and conventional weapon programs with respect to damage limitation and reduced collateral damage.

- Providing enhanced national security and more effective sharing of the benefits of civilian nuclear technology for those nations that forgo WMD.

- Creating conditions that discourage reliance upon nuclear weapons or their use.

Strengthen Nonproliferation Effectiveness and Enforcement

The NPT Regime

President Eisenhower's Atoms for Peace speech laid the basis for the NPT as well as for much declassification of and assistance with civilian nuclear knowledge and technologies. This dual set of consequences made some participants question whether too much knowledge was given away in return for too little international control. However, most of what was given away was discovered anyway, while the control regime that emerged provided tools for helping manage the spread of nuclear technology.

Since Eisenhower's speech, nuclear knowledge, nuclear technologies, nuclear infrastructure, nuclear materials, and nuclear weapons have proliferated. Still, most nations of the world have forsworn weapon development. Nearly all have signed the NPT (188/194) with the notable exceptions of India, Pakistan, and Israel. Some that had programs or even weapons have terminated their programs (Brazil, Argentina) or eliminated the weapons (South Africa, Ukraine, Belarus, and Kazakhstan). Iraq's illegal nuclear weapon program was blocked by military action and international inspections.

Although the NPT defines the major elements of the nonproliferation regime and is honored by the great majority of nations, a number of separate bilateral and multilateral agreements contribute to the strength of the overall regime. The Nuclear Suppliers Group agreements, export controls, along with national intelligence operations have limited, but not halted, the spread of sensitive technology.

The IAEA makes an important contribution to the nonproliferation regime. It routinely conducts successful inspections and safeguards throughout the world. Iraq and North Korea, however, failed to fully cooperate with the IAEA to meet their NPT obligations. In such cases, the IAEA is obligated to refer the matter to the United Nations Security Council. Even taking these cases into account, there has been no known diversion of weapon-usable nuclear material from IAEA-safeguarded civilian facilities since the inception of the IAEA. That said, some nations have employed nominally civilian nuclear programs as a pretext to acquire technologies for military programs, or they have acquired materials, equipment, technology, or technical personnel from the civilian sector for their nuclear weapon programs. For this and other reasons, the IAEA's role has been expanded and augmented by intelligence to provide better information and ensure that (a) legitimate civilian sector facilities are not masking nuclear weapon programs and (b) covert activities are not underway even as declared operations continue under IAEA safeguards.

After both the Indian test of a nuclear device in 1974 and the discovery of a covert Iraqi nuclear weapon program in 1991, the international community strengthened the IAEA. Today, many believe there is a clear need for new initiatives to bolster the reach and effectiveness of the IAEA. The IAEA's Information Circular (INFCIRC) 540, calling for an additional safeguards protocol for example, allows the IAEA to receive much more comprehensive declarations from cooperating countries regarding activities and facilities of interest and expands the opportunity for the IAEA to follow up on possibilities of covert facilities. Furthermore, the CPPNM presents guidance to countries on what constitutes appropriate levels of protection to materials and facilities of concern. While it is clear that universal adoption of either or both of these measures are necessary steps, it is not clear to the workshop participants that this will be sufficient protection from the diversion of materials.

IAEA safeguards have long operated on the principle that timely detection deters countries from diverting materials or misusing facilities. These principles remain the core of IAEA safeguards, although these safeguards have not always been fully funded and implemented. Recent events show, however, that the presumption of timely discovery may not be warranted and that simply focusing on declared facilities may be an inadequate defense. Some NPT nations appear to be violating the spirit and perhaps the letter of their obligations. Other countries are troubling because they have not joined the NPT and therefore have programs outside international safeguards and they may—in the case of Pakistan—have clandestinely assisted an NPT state, Iran. Numerous participants offer the possibility of encouraging among the three significant nonparties (India, Israel, and Pakistan) a greater emphasis on physical protection and restraint in a manner that will enhance international confidence. Some believe that such a regime of restraint can be built around an agreement or treaty to cut off unsafeguarded production of fissile material. And the rise of fundamentalist terrorism raises the stakes enormously should terrorists access nuclear weapons or even dangerous materials that can be used as radiological dispersal devices. Although physical protection is essentially a national responsibility, interest in global security and the need to integrate it with safeguards make this an issue for multinational discussion. The new IAEA provisions are a first response to these threats. However, a safeguards regime without additional protocols cannot provide effective early warning. Moreover, without a defined, agreed-upon enforcement mechanism, an enhanced safeguards system is insufficient.

Enforcement

The capacity of the leadership of the nations of the world to address collective international nuclear security threats has been challenged by the post-1998 response to Iraq, which exposed deep-seated divisions within the P-5 over NPT enforcement and regional security assessments. Significant differences have emerged among nations on how to deal with compliance issues involving North Korea and Iran. The NPT and the IAEA are instruments of the member states, but the member states must provide enforcement, especially the P-5 in concert with the United Nations Security Council.

Enhanced safeguards and security using twenty-first century technology may be the most rapid and effective solutions to dealing with the diversion of nuclear material from IAEA-safeguarded facilities. The use of cutting-edge technology should also be explored with respect to the more difficult problems of detection of covert activities and potential breakout from the NPT. Examples of advanced technologies include tagging of materials, environmental sensors, real-time communication of safeguards and relevant surveillance data, satellite surveillance, and modern, secure software and communications all along the information chain.

Despite having declared at the Head of State Summit in 1992 that further proliferation would be a threat to international security, the United Nations Security Council subsequently has had difficulty acting decisively (especially in the case of North Korea) to meet this high standard. Alternative, ineffective approaches have been taken because of the inability to reach meaningful agreement within the Security Council. Disputes reflect different political interests, but common ground might be expanded if there were greater clarity in advance on obligations and responses to violations or threats, whether involving the NPT or not. Nevertheless, the nature of twenty-first century proliferation can no longer be effectively addressed by relying solely on a twentieth century agreement that did not anticipate today's conditions. The NPT may therefore need to be supplemented with new approaches to prevent nations or nonstate actors from acquiring nuclear weapons.

Even among those who favor additional or enhanced measures within the existing framework, few believe this is sufficient to deal with the more extensive latency in nuclear weapon potential possible in the future. Most believe that more attention needs to be paid to the causes of proliferation (i.e., the demand side or motivations). Some believe that significant progress can only be made in reducing risks by addressing this area. A large, but diverse group of participants favor new bargains or frameworks, and some specific proposals were put forward. Some believe that a new, somewhat separate nonproliferation regime is needed to deal with nonsignatories to the NPT, while others believe that a more comprehensive regime is needed for everyone. Still others express concern that negotiating a new NPT might destroy the old one. In their view, if the NPT is allowed to unravel, the immediate decrease in security for all nations may not be reversed.

Questions regarding a clear definition of what constitutes an NPT violation recur. Predictable, effective, and rapid enforcement of the NPT even when the legal issue is clear has also been problematic. Ideally, IAEA action would be sufficient to keep nations compliant, but North Korea, Iran, and Iraq demonstrate that high-level political or even military intervention is needed where a nation has strong inclinations to acquire nuclear weapons. If a country of concern has a protective advocate on the Security Council, the United Nations or relevant coalitions will have a difficult enforcement task, and nearly every country of concern has at least one sympathetic P-5 member on the Security Council with a veto. A significant concern frequently expressed is that the regime must find a rapid and effective way to deal with states that benefit from adherence to the NPT only to subsequently withdraw to take advantage of the acquired capabilities in possible weapon programs. The centrality of these issues deserves special consideration given concerns about the viability of the NPT regime in the face of the spread of latent nuclear weapon capability. A predetermined response to such actions that allows for a rapid and firm reaction would be difficult to negotiate and might still not work in the Security

Council. Some participants advocate that any state withdrawing from the NPT be required to return technology and materials transferred under the NPT. Some advocate international control or ownership of facilities and materials being used by countries that have been in violation of the NPT or where there are circumstances that pose a threat to international security. Indeed, the Director General of the IAEA suggested in October 2003 that a new framework be negotiated from which withdrawal is prohibited. This is also very controversial.

There is debate over whether NPT obligations not to acquire nuclear weapons are clearly stated and agreed, but at the same time there is concern that attempts to clarify the definition will result in a weaker overall regime. This could result from watering down interpretations of obligations from what some parties now assert is required or from loosening restraints in one area in order to negotiate agreements in other areas, such as cooperation and peaceful benefits of nuclear technology. The question arises whether the NPT regime can be strengthened without wider adherence to the Additional Protocol on Inspections and indeed whether the Additional Protocol is sufficient. Limiting exports of all nuclear materials and goods to those states complying with INFCIRC 540 can increase collective security, but it may result in treaty withdrawals or weakening of the regime in other ways. Of particular concern is the possible acquisition by terrorists of weapon-usable material. This lends a particular urgency to the need for stricter controls and more assured enforcement mechanisms.

Export controls have been insufficient to prevent proliferation of weapon-related materials and equipment and have of necessity been modified and supplemented. The challenges to export control may be even greater today because of transnational technology-trading networks. The IAEA has exposed the increased magnitude of this problem from rogue states and terrorists, and its Director General has called for consideration of a more expansive approach. Nevertheless, important steps have already begun. The IAEA General Conference adopted a resolution (GC (44)/RES/20) in November 2000, forwarded to the United Nations Secretary-General, covering its activities on "Measures against illicit trafficking in nuclear materials and other radioactive sources." These activities include establishing an illicit trafficking database and assessment program and defining a "Design Basis Threat" as a basis for establishing physical protection to prevent the theft of nuclear materials. Yet the IAEA makes it clear that the primary responsibility for establishing export controls and protections systems lies with the individual states: "State systems of accounting for and control of nuclear material (SSAC) are fundamental to States' ability to fulfill their international obligations, be it in safeguards agreements with the agency, in the Convention on the Physical Protection of Nuclear Material (CPPNM), in bilateral supply and co-operative agreements or in export control arrangements or to implement INFCIRC/225/Rev 4 (Corr.)." This message is seemingly not being heeded as indicated by the paucity of signatories to the Additional Protocol and even the CPPNM, which only 45 of the 86 nations involved have signed as of November 2003.

More proliferation-resistant, fuel-cycle facilities have been advocated to prevent diversion of fuel from facilities properly inspected, monitored, and controlled by the IAEA, but some argue that current rules and procedures are sufficient to secure existing facilities as long as the IAEA is allowed access. Proliferation-resistant technology, however, may not greatly reduce problems of withdrawal and breakout, covert facilities, or "nth" country supply without stronger enforcement.

Specific actions that many participants believe clarify regime issues and shape a more secure future are—

- Strengthening the NPT fissile material regime with (1) wider adherence to the Additional Protocol on Inspections, (2) export controls and assessments utilizing modern accounting and location technology, and (3) permitting exports only to states adhering to INFCIRC 540.
- In addition to strengthening collective security arrangements and addressing other demand-side motivations, enforcing current NPT commitments is seen as key to the success of nonproliferation.
- Assisting countries of greatest concern with safety and security measures. The extension of the concept of international peer reviews of effectiveness developed for the Nuclear Safety Convention to nonproliferation could well enhance physical security as well.

- The United Nations Security Council clarifying that under international law a state cannot escape its obligations or the consequences of a treaty violation by invoking a withdrawal clause after the fact. Permitting states caught in violation of the NPT to escape the consequences of their violations by withdrawing undermines both nonproliferation and international law.

- Better defining obligations and privileges under the NPT, exploring indicators of potential violations and steps to be taken if these indicators appear, including special inspections.

- Expanding the IAEA's mandate to include oversight of management and control of civilian materials and facilities.

- Imposing international control of facilities and materials in the event of a material breech threatening international security.

- Better separating the role of promoting nuclear energy from the role of securing and safeguarding materials and facilities.

- Providing funds to exploit new technologies for safeguards and security.

- Elevating the commitments of United Nations member states to more rigorous definition and enforcement of the international export control systems by specific international agreements or protocols, such as the Proliferation Security Initiative.

Secure and Minimize Fissile and Radiological Material

One of the most critical dimensions of national security and international stability is ensuring that the essential ingredients of nuclear weapons—in particular, weapon-usable materials—do not fall into the hands of terrorists. Effective control is also an essential element for continued arms reduction efforts. On the civilian side, ensuring environmental protection and protecting public health represent critical added dimensions. While it is true that nuclear materials provide positive public benefit (e.g., carbon-free electrical power, medical diagnostics and treatments, agricultural and industrial applications, research tools), avoiding their illicit use is a major challenge.

In the near term, already separated weapon-usable materials pose the major danger, mainly from excess nuclear weapon stocks. The United States and Russia have over 90 percent of the weapon-usable materials in the world, in weapons and outside them. Rightly or wrongly, the United States feels confident about the security of its material. There have been more questions about the security of Soviet material. Since 1991, the Nunn–Lugar program has spent about a billion dollars a year to stabilize, transform, and downsize the Russian nuclear-weapon complex; secure Russian nuclear material, warheads, and technologies; limit production of fissile material; dispose of excess fissile material; and establish transparency in the nuclear-weapon reduction process. Of the Russian weapon-usable material, it is currently estimated that 100 metric tonnes are under comprehensive upgrades of physical security, 122 metric tonnes are under interim security upgrades, and 378 metric tonnes remain to be upgraded. The future of this program is unclear at the date of this writing. The G-8 agreed to contribute $20 billion over 10 years through nonproliferation projects mainly in Russia in order to prevent terrorists from obtaining WMD. Since the 2002 G-8 summit, approximately $16 billion of the initial $20 billion has been pledged.

Weapon-usable materials from the civilian nuclear fuel cycle come next as a concern. Nuclear power currently accounts for approximately 16 percent of global electricity consumption. The global population, currently at about 6 billion, is forecast to grow to 8–12 billion over the next century. Energy demand is forecast to expand, moving about 400 exajoules per year today to more than 1,500 exajoules per year by 2100. This is to accommodate the burgeoning population as well as the consequent increase in the Gross Domestic Product worldwide. Nuclear technology, whether for power or for medical and industrial applications, will grow to meet the growing demands. How much growth depends on the demand for the goods and services provided.

Nuclear power provides significant amounts of electricity that may increase in response to concerns about global warming and pollution from fossil fuels. To date, nuclear power reactors have not been a source of material for nuclear weapons. Unless we take a global view of increased energy demand, uncontrolled growth in the demand for power can produce a number of chaotic outcomes: (a) spread of spent-fuel reprocessing; (b) spread of uranium enrichment; (c) significantly increased quantities of weapon-usable nuclear materials in spent fuel, much of it in non-nuclear weapon states; (d) gradual lessening of the "self-protection" of the discharged spent fuel containing large quantities of plutonium; and (e) an ever-increasing burden of waste to be stored, transported, and then disposed of, in spite of the continuing difficulties of opening even a small number of repositories.

A large global inventory of separated weapon-usable nuclear material (mainly plutonium and highly enriched uranium) exists and will continue to grow due to an imbalance of its production and utilization. Given the spread of relevant information regarding the design of nuclear weapons over the past decades, preventing access to such materials is the strongest barrier to preventing such proliferation. In contrast, the great majority of nuclear materials of concern in civilian fuel cycles remains under effective IAEA safeguards. The reporting requirements, inspections, and material protection, control and accountability features serve in these cases to preserve the confidence that these facilities and activities are being used as intended and that the materials have not been diverted to unauthorized uses. A very large portion of the plutonium, for example, resides in spent fuel that is largely self-protecting and under careful and effective monitoring by the IAEA. Diversion by a country or subnational group without detection would be most difficult. This framework continues to provide a foundation of confidence that almost all countries of the world with nuclear activities are conducting themselves in accord with international norms and expectations.

Nevertheless, more needs to be done to reach a safeguards regime and international nuclear regime that effectively counters the emerging threats and trends. Prospects for shared regional or international control of nuclear materials, facilities, and activities and the application of cutting-edge science and technology in sensors, information technology, data transmission, and instant communication may be among the ways to complement and even transform the security landscape. The world cannot deal with a twenty-first century problem with twentieth century technology. With some exceptions, state-of-the-art, twenty-first century technologies are not being applied to the problems of security, verification of agreements, management and control of materials, and enforcement of agreements and regulations. Control of weapon-usable material remains the keystone of nonproliferation and the centerpiece of preventing nuclear terrorism, but the widespread latency of nuclear capability requires that assessments and safeguards go far beyond just confirming the immediate status of declared materials. More attention must be placed upon the security context in which the materials exist and the prospects for breakout or theft.

To better secure weapon-usable nuclear materials and civilian facilities and nuclear materials, most participants endorsed the following actions as an appropriate response:

- Accelerate the removal of highly enriched uranium from civilian facilities.
- Reinforce worldwide nuclear-weapon materials control, protection, and accounting (MPC&A), and diversion-alerting practices. Focus national intelligence on MPC&A and facilitate exchange of information, especially on separated nuclear-weapon materials.
- Tighten security worldwide in existing facilities that contain nuclear weapon materials.
- Adopt the CPPNM and assist the IAEA in working out the details of its implementation. The extension of the concept of international peer reviews of effectiveness developed for the Nuclear Safety Convention to nonproliferation could enhance physical security.
- Determine what additional control measures are technologically feasible and what measures of merit could be used to assess their desirability.
- Adopt INFICIRC 540, and, in collaboration with representatives from the major nuclear suppliers and users, make nuclear-related exports conditional upon such adoption by the recipient country, whether or not that country is party to the NPT.
- Develop an approach under which custody of fuel provided under the NPT is returned to the suppliers or placed under international control, when countries are in material breech or withdraw.
- Develop more accurate definitions of items subject to export control, promulgate higher standards of implementation, and cooperate in ensuring that best practices are followed.

Exploit the Benefits of Nuclear Technology While Enhancing Security

Nuclear Power

If uncertainty plagues the international security dimension of nuclear technology, it haunts civilian applications, in particular nuclear power. The degree to which nuclear power can actually satisfy the growing needs of the developed as well as the developing world is also under debate. High-population countries like China and India will likely dominate the future of nuclear power worldwide given their planned economic growth **(Figure 3)**. After a period of global growth through the 1970s and into the 1980s, there has been a hiatus in new plant orders in the United States and a general slowdown globally. No new nuclear plants have been ordered in the United States since 1978 and none ordered after 1973 have been built. Worldwide public acceptance of nuclear power is mixed, and there is little or no agreement on how to integrate risks and benefits. A viable alternative to nuclear power as a replacement for burning carbon-producing fossil fuel has not yet emerged. How and if nuclear power might expand seems tightly linked to international security concerns.

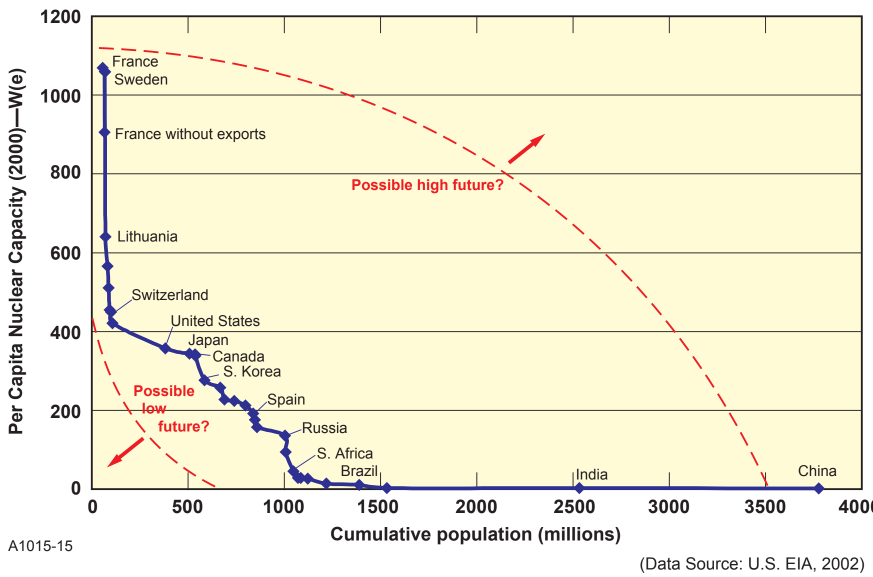

Figure 3. Nuclear power capacity on a per capita basis versus cumulative population on a country-by-country basis, with indicated future uncertainties.

Some participants feel that despite Article IV of the NPT, limitations must be placed on the spread of civilian applications, especially in light of any expansion of nuclear power. They believe that it makes no sense for certain countries to ever have weapon-usable material in civilian form, material that can be used as a screen for a covert nuclear-weapon program. Others believe that Article IV of the NPT requires full dissemination of civilian applications and expertise, albeit with full-scope safeguards. Some would like to see a new distinction made between states that have access to full fuel-cycle capabilities and others that should only have proliferation-resistant reactors. Others think that this dichotomy will never be acceptable to the "have-nots," especially without disarmament by the nuclear weapon states under Article VI of the NPT.

Proponents of once-through and recycle make similar arguments about the contributions of their technology to international objectives in terms of energy, cost, the environment, global warming, and waste management. Both believe that their approach provides the most proliferation-resistant future. However, both involve processes that could produce weapon material. With the exception of CANDU reactors, once-through requires enrichment. Recycle results in a plutonium economy. The seriousness of the threat from nuclear power-related activities, particularly in comparison with other more direct routes to weapons is uncertain. Also, is the recycle of spent fuel or the spread of enrichment technology the greater risk? How close to a weapon capability can a state come before we care about abrogation or covert programs?

The general slowdown of nuclear power expansion worldwide has been caused by a variety of factors, including the substantial reduction in the growth of demand for electricity over earlier estimates, higher capital costs for new plants, and an abundance of natural gas at historically low prices that has made gas-fired plants more economical than the traditional base-load plants, particularly nuclear ones. Another significant factor is the public and political resistance to nuclear technology. The latter is evidenced by political measures to impose moratoria on nuclear power in countries such as

Sweden and Germany. Heavy reliance on nuclear power in Japan, even though to reduce dependence on offshore sources of fossil fuel, has recently been called into question. Until recently, research-and-development (R&D) budgets for civilian power have been steadily declining in most of the industrialized countries since the mid-1980s, with the exception of Japan and France. Most recently, the Swiss rejected by almost 70 percent a ballot measure to close all nuclear power plants.

Several initiatives in the United States and elsewhere, however, indicate renewed interest in nuclear power. In the United States, there is support in the National Energy Policy for expansion of nuclear power capacity. A new Department of Energy (DOE) program, the Nuclear Power 2010 Initiative, has been started to enable the deployment of new nuclear power plants in the United States over the next decade. In addition, an advanced DOE nuclear energy R&D program, the "Generation IV" initiative, is being planned with both a U.S. and an international component that aims to develop and demonstrate one or more new advanced nuclear-energy systems for longer-term future deployment. A parallel effort with similar goals, the International Project on Innovative Nuclear Reactors and Fuel Cycles, is being pursued through the IAEA.

The nuclear industry may be unable to overcome economic, security, and regulatory barriers for new market entry in a timely way without significant government intervention (i.e., research, development, and demonstration; liability limitations; regulatory reform) and possible market distortion. There is a wide range of views on questions about the economics of nuclear power compared with the competition, especially advanced gas combined-cycle plants.

Waste Management

Today, there are no operating repositories for the permanent disposal of spent nuclear reactor fuel and other high-level radioactive wastes. Furthermore, there is a mixed record of progress, as countries with advanced nuclear programs (e.g., Canada, Germany, the United Kingdom, and France) have suffered major setbacks in their attempts to site such a repository. Others, notably Finland and Sweden continue to make progress, while the U.S. program faces opposition from interested and affected groups.

After more than a decade and the expenditure of about $10 billion (paid by electricity consumers), authorization has been given by Congress for DOE to proceed with the application for the licensing of a U.S. repository for spent fuel at Yucca Mountain in Nevada. A Waste Isolation Pilot Project facility for the disposition of plutonium-containing, low-level radioactive waste has been placed into operation at Carlsbad, New Mexico, following active involvement with the public in the decision-making process.

Other countries' progress in radioactive-waste management varies ahead and behind that of the United States. Sweden has an efficient repository of adequate capacity for its nuclear plant wastes and the design and is proceeding with the licensing of an intermediate-level waste repository. Finland has adequate storage capacity for its nuclear plant wastes and a spent-fuel repository is moving ahead through the design and licensing phase. France has confirmed that work should proceed on two underground laboratories to study high-level waste disposition. Most other countries are at an earlier stage. At present, all store their spent fuel at the nuclear plant sites. The availability of low-level-waste disposal capacity in the United States is limited, and the cost per unit volume has increased sharply, compensated by substantial reductions in the generation of waste.

Nonpower, Civilian Nuclear Technologies

The economic impact of nonpower, civilian nuclear technologies, on the other hand, is very robust, more than three times nuclear power in terms of sales. Perhaps the most significant success story over the past half-century in harnessing radiation to serve modern humanity is in the field of medicine. Diagnostics and therapy, as well as sterilization of drugs and diagnosing drug testing on live patients, lead the applications. Nuclear technology is also used in agriculture for higher crop production, the development of new species, improved animal health, and the eradication of pests. Nuclear technology has allowed the food-processing industry to significantly reduce the cases of food-borne disease. In industry, process control, plant operations diagnostics, materials development, testing and inspection, and exploration for new energy resources all utilize nuclear technology. Power for space vehicles completes the list. Not to be overlooked however, is the use of neutrons and gamma rays in a wide range of diagnostic research to probe samples and processes, both organic and inorganic.

Public Perceptions and Trust

After an initial period of enthusiasm through the 1960s, public acceptance of nuclear power diminished due to a variety of factors, including the general fear of radiation, the specter of nuclear warfare, and the occurrence of accidents involving the release of radioactivity. A "not in my backyard (NIMBY)" attitude has spread beyond the developed to the developing world. Still, some feel that the principal reason that no new plants have been ordered is that they simply cost too much to build. Capital costs are high, and any accident puts a tremendous amount of capital at risk and drives insurance costs up. This view is prevalent in the commercial capital sector. Others point to the high cost of meeting safety and environmental concerns as impediments to growth.

Most participants feel there has been too little communication between the governments and other institutions charged with managing the nuclear enterprise and the various public constituencies they serve. The future of civilian applications rides primarily on public confidence that the benefits of nuclear technology substantially outweigh the risks and that the government regulators have public safety as their top priority. This issue is crucial to the ultimate goal of providing the benefits of nuclear technology. Without good, interactive communication, the confidence needed to pursue these benefits is lacking and the nuclear enterprise, which is now centered mainly in the democracies of the world, will fail. Since the relationship of civilian nuclear technology and weapons is deeply inscribed in the public mind, effective communication must address the relationship between security and civilian applications in a reliable and persuasive way and be followed by action, particularly at a time when terrorist threats loom large in the public mind. Much of the communication effort must also address the disparities in understanding both the benefits and the risks that exists within government circles, even though governments nominally respond to the public in most countries.

New technologies that enhance public health and fight disease have inspired greater public confidence in nuclear medicine than in nuclear power. It should be noted that the medical community goes out of its way to avoid using the words "nuclear" and "radiation." Nuclear technology is a very important contributor to agriculture, again largely unnoticed by the public. Nuclear engineering has made important advances that have been neglected in the United States for some years. These fields of endeavor should be assessed in light of today's needs. Because of public policy concerns such as security, safety, and the environment, governments must engage but with a clear recognition of the important role that market economics play.

Specific actions to maximize the civilian benefits of nuclear technology while placing the highest priority on security (in addition to certain steps regarding the IAEA) include—

- Define, in collaboration with representatives from the major nuclear suppliers and users and the countries where nuclear power programs may rapidly expand, a nuclear fuel-cycle program that both meets the various users' needs as they see them and eliminates or at least minimizes the amount of accessible, unused, or separated fissile materials and the number of locations where it is stored.

- Nearly all participants see a need to ensure that civilian opportunities to utilize nuclear technology are assessed in terms of the risks and the benefits to society. A comprehensive assessment of the benefits from nuclear power, medicine (diagnostics and therapy), agriculture, industry, and research, balanced against security, safety, and environmental risks, must be carried out. Concerns over proliferation and terrorism require more explicit assessments. In addition, the cooperative roles of industry and governments must be defined in order to move forward.

- Some efforts to "inform" the public have increased the fear of nuclear technology. More and better dialogue and engagement with the public on nuclear technologies and on security and civilian benefits and risks—including radiological terrorism—will help clarify the actual versus perceived risks and the trade-offs, but much of the problem will not be resolved until the public has greater trust that nuclear industry and government regulatory procedures are giving safety and security greater weight in decisions.

Provide U.S. Policy and Technology Leadership

American technological strength, both for international security and civilian applications, has been singular and remarkable but the United States has lost influence in some areas of nuclear technology. Little has been done to invest in the future of nuclear technology; the United States needs to make a serious investment in the next generation of nuclear scientists and engineers. Divisions among the world's democracies over the proper roles for nuclear power and nuclear deterrence continue because legitimate policy disagreements and technological disparities exist. Whatever policies and technologies the United States pursues in international security and civilian applications, they should follow from a systematic vision such as that contained in President Eisenhower's Atoms for Peace speech, reflecting the needs not just of today's world but also of the next 50 years.

Participants feel that it is important that the United States speak clearly on issues of international security, enforcement of agreements, and civilian benefits. To this end, the following actions are advocated to present a vision of the future and how to shape it:

- Devote a Presidential speech to a comprehensive vision of the nuclear future, addressing the opportunities and challenges of our age, perhaps in the context of the fiftieth anniversary of President Eisenhower's speech.

- Charge a senior official to report to the President and the nation periodically on implementation of initiatives associated with a comprehensive integrated nuclear policy that deals with security and civilian opportunities.

A Final Word

Nuclear technology is mature and widespread, already providing mankind with benefits in defense, energy, medicine, agriculture, and other applications. With the benefits come risks, however, primarily related to security and safety. We confront a legacy of large nuclear-weapon stockpiles, huge civilian and military fissile-material inventories, and large quantities of nuclear waste, even as nuclear technology advances and diffuses. The marketplace primarily will determine the extent of civilian applications, and governments primarily will determine the future applications for defense purposes. In neither case, however, does a single group control decision-making, which will be driven by increasingly complex factors.

The rising specter of WMD terrorism accompanies a growing interest in nuclear power to protect the environment and provide more geo-politically secure sources of energy. Concern over terrorism even permeates consideration of the growing field of nuclear medicine with its improved treatments for cancer and other diseases. Potential nuclear proliferation through violations of the NPT or through the withdrawal by law-abiding states that wish to join with the nuclear weapon states and the three nuclear weapon-possessing states outside the NPT may significantly reshape the international security environment.

Not everyone believes that further proliferation is inevitable or that it will bring disaster. Some believe that it will bring more restraint, but all agree it will complicate interactions and may become dangerous. Dealing with the fundamental security and political motivations for proliferation needs more explicit attention of the sort we have given to supply-side restraints. Particular emphasis is placed on providing improved security conditions and guarantees. Support for the NPT is strong among participants, but they remain divided about the treaty regime's ability to address the emerging challenges of spreading technology.

Bold but different proposals are made for enhanced or new security frameworks, addressing supply or demand or both. Some of these proposals revisit the trade-off between the benefits of peaceful nuclear technology and nonproliferation obligations. Others focus more on security or disarmament. Still others look to enhance restraint by those nations not party to the NPT. Some focus on prevention; others would invest more in response. Central to the debate over management of the nuclear future is the question of which principles or rules should be applied universally and which should be tailored to specific circumstances or timeframes. How NPT parties should relate to nonparties remains an issue, involving what benefits come from being a party and what responsibilities for restraint accrue from not being a party. Whether the advance and spread of nuclear technology works more for the advancement or to the detriment of mankind may depend on decisions made or not made over the next few years.

Disclaimer

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Appendix A: International Security

Defense and Deterrence

As we look 20 to 25 years into the future, the Cold War image is no longer relevant, the international geo–political situation continues to be highly uncertain, and the world has to be prepared for surprises. The continued proliferation of nuclear, chemical, and biological weapons and ballistic-missile delivery systems is a distinct possibility. Threats from weapons of mass destruction (WMD) may come not only from states but also from sub-national groups. The current U.S. strategy of assurance, dissuasion, deterrence, and defeat has to be tailored to new situations.

To respond to an uncertain future, the United States has adopted the concept of a capabilities-based force, including its nuclear forces. This concept implies a synergy of nuclear and non-nuclear forces and of offensive and defensive capabilities. As a result, nuclear weapons will continue to be a part of the U.S. defense strategy in the future. Although advances in high-precision conventional munitions and other war-fighting capabilities will provide the United States with significant military options, nuclear weapons may be chosen for certain areas.

A new relationship with Russia is proceeding down a more fruitful course, and a new relationship with China is evolving. Russia may continue to draw closer to the West and economic expansion in China may exert pressure in that direction as well. This offers hope that the West will continue to reduce its nuclear arms, and that the United States and Russia will continue to implement agreements to reduce their nuclear weapon stockpiles, including non-strategic nuclear weapons. Although a U.S. missile defense will likely expand, it will not be robust enough to affect the calculus of reductions over the next 20 years or so.

Nevertheless, some believe that despite their improved relations, the United States and Russia have nuclear weapon stockpiles exceeding those necessary for mutual deterrence. It is argued that reductions deeper than those called for in the Moscow Treaty[1] should be implemented relatively quickly. Moreover, the current rationale for the size of the stockpile is not mutual deterrence, but the lack of capability to manufacture new or replacement warheads. What must be kept in mind is that other nations—China in particular—are augmenting and modernizing their nuclear stockpiles. There is continued concern that additional states or sub-national entities will seek to join the nuclear club. As a result, the number and distribution of nuclear weapons in the future could be very different from that during the height of the Cold War. Although reductions by the United States and Russia may considerably reduce the total number of stockpiled weapons, nuclear weapons and nuclear capability may be more widely distributed geographically. The resolution of the present situation in North Korea will likely have a telling effect on this future.

Given this backdrop, we may ask what the U.S. nuclear stockpile will look like over the next 20–25 years. If the United States is unable to modernize its nuclear warheads in the absence of nuclear testing, the weapons in the stockpile will not change but uncertainties in the level of confidence in their performance may increase. Nevertheless, there may be ways to incorporate some new capabilities without nuclear testing.[2] The B61-Mod 11 is such an example. Delivery

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[1] The Treaty Between the United States of America and the Russian Federation on Strategic Offensive Reductions, signed at Moscow on May 24, 2002 (the "Moscow Treaty").

[2] The Defense Science Board 2003 Summer Study on the *Future of Strategic Strike* has posed an alternative approach to the Stockpile Stewardship Program that suggests exploiting the large inventory of previously tested and proven devices as a source of physics packages to be evolved to meet future needs. This approach does not rule out nuclear

platforms may become obsolete, unless decisions to implement follow-on systems are made and executed in a timely fashion. Furthermore, unless there have been significant changes, the U.S. nuclear-weapon infrastructure will continue to deteriorate, with a very limited capability to manufacture new warheads. The United States will not be producing plutonium for nuclear weapons and may not be producing tritium. Dismantled weapons will be the source of nuclear materials for any remanufacturing requirements.

However, this situation—an aging stockpile and an eroded infrastructure—could change, as the United States assesses the role and value of its nuclear weapons. Surprise can never be ruled out and nuclear weapon capabilities may need to be re-assessed in the future. Potential issues that could affect such reassessments include—

- Use of a nuclear weapon or a radiological dispersal device (RDD) somewhere in the world, greatly escalating tensions and invoking the threat of nuclear retaliation.
- Emerging threats or situations may exert pressure to develop new, special-purpose nuclear weapons, requiring the resumption of nuclear testing.
- Problems arising in existing nuclear arsenals that cannot be solved through the Stockpile Stewardship Program. This may necessitate modernization of the stockpile, requiring the reinvigoration of production capabilities. This may also include the resumption of nuclear testing.
- Use of nuclear weapons in a regional conflict, e.g., South Asia.
- The evolution of global terrorism, coupled with conflict in the Middle East, could expand to nuclear use.
- Breakout in regions of concern and in particular development of nuclear weapon programs in nuclear-capable countries, e.g., Taiwan and Japan.

Clearly, all these issues need careful discussion and analysis before any potential impact on a future nuclear-weapon policy can be assessed. Non-nuclear options to deal with these potentialities should be explored as well, and the potential benefits of ratification and implementation of the Comprehensive Test Ban Treaty (CTBT) need to be revisited.

On the other hand, steps can be taken to improve the situation so that nuclear weapons become less of a factor in the future. Some key developments would be—

- The extension of security assurances by the major powers to their allies in regions of instability.
- The strengthening and improved enforcement of international norms against the acquisition and use of nuclear weapons.
- Improved relations between the existing major nuclear powers: France, the United Kingdom, China, Russia, and the United States.
- The ability of an expanded NATO to provide security arrangements that mitigate against states' seeking to acquire nuclear weapons.
- Deployment of an effective missile defense and the sharing of this technology or partnering with other states.
- Enhanced security cooperation via arms sales, missile-defense sharing, intelligence sharing or military education and training.

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testing. However, if coupled with modern manufacturing technology, it could permit a much smaller stockpile, more closely coupled to strategic needs.

- Strengthened norms with effective enforcement mechanisms.
- Multilateral or unilateral military action or defense agreements.
- Positive and negative security assurances.

In any case, it seems highly likely that nuclear weapons will continue to play a significant role in U.S. strategic thinking about deterrence and defense over the next several decades. The hard question to answer will be whether the international security environment will be more or less dangerous as a consequence.

The Major Nuclear Powers

As we look at the growth or decline in the total number of nuclear weapons over the next 25–50 years, the factor that can have the greatest impact is the anticipated decreased need to deter Russia. Consequently, Russia and the United States account for most of the change in this area. Neither country views the other as an adversary. Both recognize that the massive stockpiles accumulated during the Cold War are no longer required and have codified reductions through the INF, START, and Moscow treaties. At present, the United States and Russia have agreed to field not more than 1,700–2,200 operationally deployed strategic nuclear weapons by 2012, but each side retains the capability to reconstitute to higher levels should there be a serious reversal in the geo–political situation.

Clearly then, whether nuclear weapon stockpiles continue to go down depends on the evolving relationship between the United States and Russia. It appears that only a resumption of Cold War-like belligerence could cause such a turnaround. Russia's drive to improve its economy and the well-being of its people will stimulate continued integration with the West. It appears then as this relationship matures, other opportunities for nuclear arms reductions may be possible as the role of nuclear weapons in United States–Russia relations diminishes. However, this assertion raises two significant issues: (1) how low can the United States and Russia go, and (2) although the numbers may go down, the United States (and others) may seek new kinds of nuclear weapons to deal with emerging requirements that cannot be met by the weapons designed for Cold War-era deterrence.

The Other Nuclear Powers

China continues to see nuclear weapons playing an important role in its security and contributes about 400 strategic and tactical nuclear weapons to the global stockpile. China has been undergoing a sustained program of modernizing its nuclear forces. Factors that could influence China's future nuclear policy are—

- The role, both actual and perceived, that ballistic missile defense might have on the efficacy of its own forces, particularly if deployed in Asia.
- The need to deter the United States should China make a military move against Taiwan or others in Asia.
- As a means of influencing a Japanese decision to go nuclear.
- Developments on the Korean peninsula.
- Concerns about U.S conventional superiority and force projection.
- Continued economic and potential development, and integration with the West.

Although these factors may make China's stockpile increase or stay the same, it is difficult to foresee reductions in China's nuclear arsenal. However, actions to limit increases in China's arsenal need to be seriously considered, especially by the United States.

The United Kingdom has completed decommissioning of its WE 177 (lay-down bomb) and Chevaline (Polaris) warhead. The future of its deterrent program (both strategic and sub-strategic) will reside solely in its Trident Ballistic Missile Submarine (SSBN) system. In the 1998 Strategic Defense Review (SDR), the Labor government announced that the United Kingdom will maintain fewer than 200 operationally available warheads, and public estimates[3] place the future stockpile for the Nuclear-powered SSBN fleet at about 185, including spares. The United Kingdom also made clear in the SDR that its arms control position is to enter into nuclear-warhead arms control only on a multilateral basis. The United Kingdom is at a "minimum deterrent" level and its number of nuclear weapons is unlikely to change much in the future, if at all.

In 1996, President Chirac announced several dramatic reforms of France's armed forces, including a cancellation of programs announced in the 1980s that would have increased the size of the French nuclear stockpile. A significant step was to retire the S3D intermediate-range missile from service, without replacement. This followed the withdrawal from service of France's nuclear gravity bomb and the reduction from five squadrons of Mirage 2000Ns to three committed to nuclear missions. Nevertheless, France has committed to modernizing its nuclear forces remaining in service. France's current stockpile is estimated[4] to be about 450 warheads, down from a peak of 550 during 1991–1992. Whether it would entertain additional reductions is uncertain, but increases seem unlikely at this time.

Israel's policy is neither to confirm nor deny that it possesses nuclear weapons, although it is generally accepted that it has been a nuclear state for decades.[5] One public source quotes estimates[6] of the Israeli nuclear arsenal to range from 75–200 weapons, comprising bombs, missile warheads, and possible non-strategic weapons. During the last few years, Israel has been modernizing its navy to make it nuclear-capable. It is generally argued that Israel acquired nuclear weapons to counteract the potential conventional superiority of its neighbors. The threat of Israel conducting nuclear attacks presumably would either prevent Israel's neighbors from trying to eliminate it as a state or punish them for doing so. Barring any fundamental shift in this threat perception, its nuclear force is likely to remain stable for some time to come. A significant increase is unlikely unless a neighboring state acquires nuclear weapons or lasting peace is found in the Middle East.

In 1998, India and Pakistan conducted nuclear tests and by now probably possess a few to several dozen nuclear weapons. The primary reason for their weapons appears to be for deterrence, primarily to avoid escalation of the conflict over Kashmir. Another important reason for India's interest in nuclear weapons is its long-range concern about China. The potential for leakage or transfer from Pakistan to other states or terrorist organizations also poses a serious problem. The India–Pakistan rivalry is quite dangerous. Military doctrine, use control, and crisis stability are not well defined; the risk of miscalculation is high in an environment of continued hostility and low-level conflict. Furthermore, arguments have been made, especially in New Delhi, that nuclear weapons will not prevent India from engaging in limited war—in effect, that nuclear weapons do not deter all forms of conflict even between two nuclear-armed states. This argument makes even the relatively small number of nuclear weapons in this region

[3] www.thebulletin.org.

[4] www.thebulletin.org.

[5] See, for example, Avner Cohen, *Israel and the Bomb* (Columbia University Press, October 1998).

[6] www.thebulletin.org.

a serious concern. Expansion of their stockpiles is likely to be governed by further steps both sides take regarding missile and nuclear testing, as well as defensive measures. Economic reasons have not restricted arms growth in the past and are unlikely to do so in the future. In spite of the relatively small numbers of nuclear weapons, both sides must maintain a costly development and production infrastructure to sustain these stockpiles. Supporting these infrastructures could be a stimulus for horizontal proliferation as export markets may be sought for the critical technologies and materials.

Limits to Nuclear Growth

In terms of the sheer quantity of nuclear weapons, it appears that the current trend toward smaller numbers could continue for the foreseeable future. The major driver would be continued integration of Russia with the West and the decreased utility of the arsenals of the United States, Russia, the United Kingdom, and France for great-power deterrence. China remains a wild card and caution must be exercised to minimize the conditions that would motivate China to increase its arsenal and to move away from a minimum deterrence posture. Nevertheless, there seem to be more opportunities in the future for collaborative rather than confrontational relations between the major nuclear weapon states. Israel, India, and Pakistan will likely have little impact on the overall numbers in the immediate future, but that does not minimize the danger, especially regarding Kashmir.

So, how low could we expect these numbers to go under favorable circumstances? Assuming that Russia and the West continue to move closer together, China stays at about the same level, and problems do not worsen in the Middle East and South Asia, the numbers will continue to be dominated by the actions of the United States and Russia. If both powers reach a stage in their relations such that their security interests no longer require an arsenal at the Strategic Offensive Reductions Treaty (SORT) level, then perhaps both can go below 1,700–2,000 operationally deployed strategic nuclear warheads. In addition, tactical nuclear weapons, which are not covered by the START and SORT treaties, need to be addressed. Other factors then come into play. Economics and modernization play a large role in Russia, whereas infrastructure and production capability are issues in the United States. For example, even at the 1,700–2,000 levels, the United States is planning a substantial "responsive force," primarily because of the inability of its current weapons complex to manufacture new warheads[7] in case of a system failure or a sudden, dramatic change in relations with another major power.

In addition, some believe that a move to lower numbers for U.S. and Russian stockpiles requires a major change in strategic posture, such as moving away from the deployment of a full triad or drastically reducing the target set. Without such a change, it is argued a reduction to levels where multilateral engagement can occur is unlikely. Assuming these concerns are dealt with, it is doubtful that the United States will reduce its nuclear weapon stockpile to a level comparable to China or any other regional nuclear weapon state. In addition, the U.S. nuclear umbrella has helped convince other nations, such as Japan, not to develop their own nuclear forces. Japan is already threatened because of North Korea's claim of its own nuclear weapons. The United States dropping to a low level might exacerbate the situation and provide another reason for Japan to decide to join the nuclear club. With its latent nuclear capability, Japan could achieve a nuclear weapon capability relatively quickly.

With China having several hundred nuclear weapons, it is difficult to see how the United States would be motivated to reduce its stockpile to the range of hundreds. More likely, the

[7] The National Nuclear Security Administration (NNSA) is restoring the capability to manufacture plutonium pits at Los Alamos as an interim capability (about 50 per year). There are plans for a more robust capability (about 500 pits per year), perhaps at the Savannah River complex, sometime in the future.

United States will maintain a total stockpile (deployed plus reserves) in the thousands. Even with the assumption of continued good relations with Russia, it is difficult to see Russia going much lower than the United States. There is always the concern of reciprocity between the United States and Russia, be it formal or informal. In addition, Russia may have similar concerns about China.

If all these factors are overcome and the nuclear weapon states reduce their warheads to very low numbers—on the order of tens to the low hundreds—the possession of just a few weapons by any one entity becomes a much bigger factor in the strategic calculations of all states. A high premium would be placed on knowing with much greater confidence the exact number of weapons, both deployed and reserve, of all parties. If an agreement to disclose these numbers were implemented, it would have to be accompanied by an intense and intrusive verification regime to provide the needed confidence.

At this time, such a verification regime appears to be technically challenging.[8] There are approaches, however, such as the New Court (NC) framework,[9,10] which bear looking into. In this multilateral approach, all sites associated with nuclear warheads (production, storage, and deployment) would be registered and their external perimeter sealed using International Atomic Energy Agency (IAEA)-like technologies supplemented with National Technical Means (NTM). Movements of items between registered NC sites would be done under a tags and seals regime, with no monitoring. Movements to a non-NC site would be monitored. Greatly increased transparency in declarations of nuclear-warhead related sites would be required.

In attempting to understand the long-term factors driving the number of nuclear weapons that may exist 50 years from now, it is important to consider what future uses countries might envision for such weapons. While we cannot speak for all states that currently possess nuclear weapons, we can get a glimpse from the current policies of the United States. In the past, the U.S. strategic nuclear triad was designed and implemented around deterrence of a large-scale nuclear attack on the United States or its allies by the Soviet Union. The picture is very different today and the role for nuclear weapons has contracted. Nevertheless, in an unclassified briefing[11] on the recently concluded U.S. Nuclear Posture Review (NPR), it was pointed out that, although the United States and Russia have a new relationship heading down a much more positive course, the United States continues to see a role for nuclear weapons. This role has been expanded from the Cold War to *assure* allies and friends, to *dissuade* competitors, to *deter* aggressors, and to *defeat* enemies. In addition, the United States may face multiple, potential opponents in the future. Because we cannot predict in advance who these opponents may be, the NPR has adopted the concept of a capabilities-based force, underscoring the need for greater flexibility for a range of contingencies. In addition to reduced nuclear forces, these capabilities include active and passive defenses, non-nuclear capabilities, and a responsive infrastructure, designed to address a spectrum of contingencies.

The NPR views an operationally deployed nuclear force for immediate and unexpected contingencies, where force size is not driven by an immediate contingency involving Russia.

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[8] Such a regime would necessarily involve verifying the presence of actual warheads, rather than the strategy adopted under the START treaty of verifying delivery vehicles for which an agreed number of warheads has been attributed.

[9] Robert L. Rinne, *An Alternative Framework for the Control of Nuclear Materials* (see www.ciaonet.org/wps/rir01/RinneAlternative99.pdf).

[10] U.K. Atomic Weapons Establishment, *Confidence Security and Verification: The Challenge of Global Nuclear Weapons Arms Control* (see www.awe.co.uk/main_site/scientific_and_technical_publications/pdf_reports/awe_study_report.pdf).

[11] J.D. Crouch, http://usinfo.state.gov/topical/pol/arms/stories/review.htm.

Contingencies envisioned may include rogue states possessing WMD. This is underscored by the recent National Strategy on Weapons of Mass Destruction[12] that states "The United States will continue to make clear that it reserves the right to respond with overwhelming force—*including through resort to all of our option*s [emphasis added]—to the use of WMD against the United States, our forces abroad, and friends and allies."

The NPR's goal is to reduce operationally deployed strategic nuclear warheads to 1,700–2,200 by the year 2012. However, the NPR states a need to maintain a responsive force for potential contingencies—an ability to augment the operationally deployed force over time to respond to unexpected adverse changes in the security environment. Hence, the NPR sees a role for nuclear weapons into the future not driven by an adversarial relationship with Russia. The United States may even seek to develop[13] new kinds of nuclear warheads that have unique effects-based characteristics, rather than area destruction. Reduction of collateral damage is one goal; another is a weapon designed for hardened and deeply buried targets.[14] As long as countries like the United States see a security role for nuclear weapons that goes beyond great-power deterrence, there will be a barrier to how low the United States is willing to go in its number of nuclear weapons. Nevertheless, how low the United States can go is driven less by concepts of deterrence than by the inability of the nuclear weapon industrial complex to respond to operational needs in a timely fashion.

As we look toward the future, another factor affecting decisions about nuclear stockpiles is modernization of both the warheads themselves and their delivery platforms. Twenty years or so from now, the weapons in the U.S. stockpile and their delivery systems will be the ones we have right now. A major decision is required and major financial costs could be incurred to modernize. Currently unforeseen changes over the next 20 to 25 years could also affect the British and French views of their long-term nuclear requirements.[15]

Nonproliferation

As with defense and deterrence, uncertainty and surprise also mark nonproliferation in the world 15–20 years out. Recent events in Iraq, Iran, and North Korea remind us how quickly things can change. As a result, the problem of nuclear proliferation and the global response to it have evolved over the past 50 years and we expect continued evolution over the next 20 to 50 years. As noted in Appendix D, Atoms for Peace succeeded the failed Acheson–Lilienthal and Baruch proposals for the multilateral control of the spread of nuclear technology and nuclear weapons. It thus represents only the first of many evolutionary changes in nonproliferation policy.

Atoms for Peace enjoyed some success, notably the institutionalization of the IAEA, but by itself it could not anticipate all future contingencies, and in some cases, some argue, accelerated the process of proliferation. In just over the decade following President Eisenhower's speech, France and China detonated nuclear weapons and joined the United States, Soviet Union, and

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[12] *National Strategy to Combat Weapons of Mass Destruction*, December 2002, available at www.whitehouse.gov/news/releases/2002/12/WMDStrategy.pdf.

[13] Whether or not a new kind of warhead can be placed in the stockpile without having to resort to nuclear testing is uncertain. Most weapon designers believe that a really new warhead design has to be tested.

[14] The Bush Administration has tasked the weapon laboratories to begin designing a Robust Nuclear Earth Penetrator (RNEP) to hold at risk hardened and deeply buried facilities, such as command and control bunkers, WMD storage sites, or missile bases that cannot now be defeated by using the weapons currently in the U.S. nuclear inventory. The RNEP would be based on repackaging an existing warhead.

[15] For the U.K., the 1998 Strategic Defence Review and the post-9/11 "New Chapter" debate (see the U.K. Ministry of Defence website) present the United Kingdom's current position with respect to nuclear deterrence and arms control.

United Kingdom as nuclear weapon states. China's development of nuclear weapons in the context of the Cultural Revolution was particularly alarming, given the fanatical rhetoric associated with that movement. At the same time, with significant French assistance, Israel clandestinely developed its own nuclear weapons. France gave Israel a production reactor, a reprocessing plant, and some highly enriched uranium (HEU) as well. Furthermore, the French made at least some of their nuclear test results available to the Israelis and may have allowed Israelis at some of their nuclear tests. China also provided various levels of help to other countries and French president Valery D'Estaing's memoirs credit the United States with assisting France in miniaturizing its nuclear weapons. India and Pakistan later developed their own nuclear programs using outside assistance when available under the Atoms for Peace philosophy.

The Nuclear Non-Proliferation Treaty

In response to the threat of nuclear proliferation, the Nuclear Non-proliferation Treaty (NPT) was negotiated in the 1960s. The world acknowledged that nuclear technology and nuclear weapons had spread to a dangerous extent. In an effort to limit the number of states acquiring nuclear weapons—and avoid the question of whether or not Israel possessed nuclear weapons—the NPT defined a nuclear weapon state as one that had detonated a nuclear device before January 1st, 1967. The NPT was an admission that loose international monitoring in exchange for access to "peaceful" nuclear technology—the Atoms for Peace bargain— had not prevented some states from acquiring nuclear weapons or weapon technology, nor had it prevented those already with weapons from helping other states.

A stronger commitment was required, so the NPT raised the bar. Under the terms of the NPT, before a state gained access to nuclear technology (Article IV), it not only accepted IAEA monitoring (Article III) but it also formally renounced its right to acquire nuclear weapons (Article II). The treaty was unequal, as it recognized the right of the five nuclear weapon states (NWSs) to retain their weapons but denied that right to all other parties to the NPT. To balance this inequality, an arms control bargain was tacked on to the nonproliferation deal—the five "legal" NWSs were allowed to retain their weapons, but agreed to negotiate in good faith to end the nuclear arms race and proceed with other nations to general and complete disarmament (Article VI).

A large number of states rapidly confirmed their commitment to nonproliferation by adhering to the treaty. By now, almost all countries of the world have joined the NPT, making it the international treaty with the broadest coverage. A number of threshold countries—such as Sweden and Switzerland—joined the NPT to benefit the common good and in spite of their traditional independence in national defense. France finally joined in the early 1990s, thereby legally confirming its commitment not to export sensitive technology without the NPT conditions. China also joined in the 1990s. Several large countries abandoned their nuclear ambitions for the sake of better relations with their neighbors (e.g., Argentina and Brazil). South Africa destroyed its seven nuclear devices, seeing no more need for them. Several states of the former Soviet Union decided not to keep the nuclear weapons left in their territory.

India refused to sign, claiming that the treaty established a hypocritical regime legalizing the possession of nuclear weapons by some—including China, who had defeated India in a war only a few years before the NPT was signed—and denying them to others. It conducted a nuclear test in 1974 using equipment and materials imported under conditions of peaceful use. Because the test came after January 1967, India could not become a legal NWS. For decades following the 1974 test, India did not conduct additional tests, making its status all the more confusing. Linking its decision to India, Pakistan also refused to join. The nonproliferation cause was further challenged in 1979 when a U.S. Vela satellite detected what may well have been a nuclear test in the South Indian Ocean, which went unclaimed, but has since been attributed to Israel or South Africa. Despite these absentees, the world sought to maintain the position that there were only five NWSs, and that the other NPT parties would fulfill their promise not to develop weapons.

At the beginning of the 1990s, the safeguards system put in place by the IAEA met new challenges that forced it to sharpen its skills and to question the very basis of the system. The technical experience gained in the dismantling of the weapon programs of South Africa, Argentina, and Brazil made even more glaring the weaknesses of the system as revealed by Iraq. The inspectorate saw the need to strengthen its verification procedures and the Board of Governors of the IAEA had to reconsider in a political context the underlying verification assumption of dealing only with "declared facilities."

In Iraq, IAEA inspections and intelligence services failed to identify an ongoing nuclear-weapon program. It took the 1991 war to reveal that Baghdad was in non-compliance with its NPT commitments. The United Nations Security Council resolutions mandated the IAEA to fully assess the Iraqi nuclear program and to physically eliminate its infrastructure. This task resulted in the destruction of all known elements of the Iraqi nuclear program, at least until December 1998 when the inspectors were forced to withdraw. The lessons of Iraq were loud and clear: the narrow mandate of the IAEA—focused on "activities declared by the State"—had reached its limits. The vista had to be opened to any site, with an unrestricted right of access. Soon after the Gulf War, the IAEA engaged in a major overhaul of its verification system. First, mandatory measures were adopted in 1995 (e.g., environmental sampling); they are currently very valuable in the verification of the Iranian nuclear program in a series of "special inspections" by the IAEA inspectorate. Other even more intrusive measures were embedded in an "Additional Protocol" adopted by the Board of Governors in 1997, a legal document that requires—unfortunately—formal acceptance by the State.

The IAEA was more effective in North Korea. International safeguards had succeeded at the outset in exposing non-compliance. In 1992, at the beginning of its verification work immediately after entry into force of the safeguards agreement, the IAEA was denied access to a waste site. Using other means, the IAEA sampled material at the declared facilities and found the results of isotopic analysis to be inconsistent with the government's declaration of its past nuclear activities. The Board of Governors was informed. Subsequently, North Korea threatened to leave the NPT, changing its mind only after signing the 1994 Agreed Framework with the United States. This agreement sidestepped North Korea's NPT violations, restricted the IAEA's inspection rights, but succeeded in stopping fuel reprocessing. Yet, it failed to prevent North Korea from clandestinely pursuing alternate nuclear activities and from restarting reprocessing activity.

For more than a decade, Iran has been pursuing more or less clandestine activities with assistance from NPT member states. Export controls were clearly insufficient to prevent Iran's undeclared undertakings. These activities include the purchase of almost two metric tonnes of uranium oxide and fluorides, their conversion to metallic form, and the assembling and tuning of hundreds of centrifuges. While the construction of light-water power reactors is of lesser concern, the IAEA must by all means monitor very closely the Iranian nuclear program. As firmly requested by the IAEA's Board of Governors and the European Union, Iran appears ready to cooperate with stringent IAEA monitoring and verification, but it remains to be seen whether Tehran will honor its latest promises.

In a nutshell, the 1991 war with Iraq brought about a sea change in the inspection rights and inspection tools available to the IAEA. The central issue now is to make sure that the IAEA uses these tools in monitoring nuclear activities around the world. Decisiveness in implementation must more than ever have priority over the bureaucratic developments of criteria and inspection guidelines. Today, the major weakness of the IAEA verification system is the voluntary nature of the Additional Protocol. Thus, instead of focusing on the essential proliferation concerns, the IAEA may well waste time and resources dealing with countries willing to adopt the Additional Protocol but who pose no proliferation risk. Until rogue NPT member states sign the Additional Protocol, the strengthening of IAEA safeguards will remain of limited interest for the near future

Potential Proliferators

September 11, 2001 made evident the need to rethink how to deal with the evolving nonproliferation problem. The possibility that terrorists might acquire nuclear weapons—or any other WMD—cannot be ignored. The international community was forced to look at two relevant dimensions: on the one hand, the absolute priority to be given to nuclear material security in both NWSs and non-nuclear weapon states (NNWSs) to prevent theft and diversion; and on the other hand, the continuing importance of safeguards verification by the IAEA to detect and deter clandestine weapon programs in a country, either at the hands of the government, or at the hands of a sub-national group taking refuge in the country. The U.S. National Security Strategy[16] characterizes the former as states "*determined to acquire weapons of mass destruction, along with other advanced military technology, to be used as threats or offensively to achieve the aggressive designs of these regimes*." The latter refers to groups such as al-Qai'da that desire to destroy their adversaries with little regard for the global consequences. The more damage they can inflict, the better.

The acquisition of a single nuclear weapon by a rogue state or a terrorist organization represents a greater threat to global peace and security than does the expansion of an existing nuclear weapon states' stockpile by tens of weapons. Whether a rogue state is deterred from using such a weapon is problematic. For example, a rogue state might use a nuclear weapon to gain a significant advantage against a neighbor that had no nuclear weapons of its own or was not allied with a nuclear-armed power, such as the United States. Another possibility is that a rogue state might detonate such a weapon anonymously, seeking to have the blame fall elsewhere, perhaps to catalyze a war. Even without the actual use of a nuclear weapon, a rogue could use its possession to threaten and bully its neighbors or competitors.

Although it is highly unlikely that terrorist organizations can design and manufacture a usable nuclear weapon from scratch without the complicity of host countries, there are a number of possibilities: (1) they can acquire one from another state; (2) they can acquire nuclear materials or weapon components on the black market for a crude but deadly device; (3) they can steal one; or, (4) they can acquire radioactive materials to create an explosive RDD. The first three have the potential for great harm and disruption; the fourth would not cause significant casualties, but could spread chaos and widespread economic disruption. Because it is highly unlikely that such groups would be deterred from using a nuclear device or weapon once they had one, tremendous effort needs to be expended to prevent their acquiring one. To this end, the United States has recently emphasized in its National Security Strategy the use of preemptive actions to counter such threats.

Proliferation: Driving Forces

A number of factors may motivate further nuclear proliferation over the next several decades. The end of the Cold War to some extent ended superpower rivalry at the regional

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[16] The National Security Strategy of the United States of America, September 2002, is available at www.whitehouse.gov/nsc/nss.pdf.

level, which may result in regional insecurities and regional arms competition. Regional insecurity may be manifested by further nuclear proliferation. Furthermore, proliferation may occur in response to the conventional weapon superiority made evident in the recent war against Iraq. The war demonstrated the overwhelming superiority of U.S. advanced conventional weapons (ACWs), C^4ISR,[17] war-fighting capability, and flexibility and rapid response in executing the war plan. On the one hand, the capability of ACWs will likely erode the need for nuclear weapons. On the other hand, it may appear to many nations that they have no capability, outside of nuclear weapons, to deter the United States from using its conventional superiority against them.

The U.S. doctrine of taking preventive or preemptive action to stop proliferation may or may not encourage horizontal proliferation. On the one hand, the different approaches that the United States has taken toward Iraq and North Korea may be interpreted as a reluctance to take military action against a state that has—or claims to have—even a very small nuclear arsenal. This may put a premium on the acquisition of a nuclear capability to thwart U.S. intervention. In addition, U.S. preemption could encourage a "use or lose" posture on the part of adversary states acquiring nuclear weapons. On the other hand, preemptive operations can put at risk transfer of nuclear technology by second-tier exporters such as Pakistan, Iran, and North Korea to potential proliferators.

Nuclear proliferation may also occur as a response to defenses. The United States is implementing a global missile defense system to protect itself against limited ballistic missile strikes. Although it appears that the United States is at least many years, away from an effective, deployed system, the potential for the United States or other nations to develop missile defense may, at some point, enter into another nation's proliferation calculation. However, a more likely development is that countries faced with an enemy armed with missile defense may choose to enhance their ballistic or cruise missile systems by using Multiple Independently Targetable Reentry Vehicles (MIRVs), or by incorporating penetration aids and other countermeasures as the United Kingdom did in response to Soviet defensive measures in the 1960s and 1970s.

China, for example, may see its minimum deterrent undercut by the U.S. missile defense and decide that it needs to increase its arsenal to offset the advantage gained by such a defense. Alternately, it could develop Multiple Reentry Vehicle (MRVed) or MIRVed systems, and perhaps use penetration aids to maximize stress on a missile defense system. On the other hand, China could conclude that expanding offensive capabilities would be too costly and that it would be more beneficial to invest the same resources elsewhere, for example in economic development. Furthermore, a new proliferator may seek nuclear weapons to balance U.S. military preeminence. In addition to developing nuclear weapons, it might try to develop cruise missiles or unconventional delivery means as a way around U.S. missile defenses. How this will play out in the future may depend on how the United States sizes its global defenses and whether it remains at a "limited strike" level or seeks a more robust defensive system.

Connected with the fear of preemption, nuclear proliferation may also occur as a response to perceptions about the value the United States places on its own nuclear weapons. Although the United States is reducing its stockpile and lessening its reliance on nuclear weapons, the U.S. NPR and National Security Strategy discuss a synergy between nuclear and conventional weapons that may appear to threaten other countries' own security. They may perceive this to be a move toward making nuclear weapons more usable, perhaps even to prevent proliferation. In addition, U.S. consideration of new nuclear weapons (e.g., bunker busters) and renewed

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[17] C^4ISR stands for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance.

nuclear testing (regardless of the fact that such thinking remains highly speculative) amplify this perception. These perceptions, whether true or not, may stimulate proliferation.

An opposing view is that the U.S. ability to marry the separate capabilities associated with preemption, missile defense, and nuclear strike places proliferators in a position where they can accomplish very little in the way of delivering an effective threat against the United States or its allies. This is a competing hypothesis that U.S. actions dissuade or deter proliferation. However, it must be pointed out that unconventional delivery would counter missile defense and, absent truly effective intelligence, clandestine or hardened deployment might counteract preemption.

Nuclear proliferation may also occur if nuclear security guarantees come to be seen as ineffective or incredible. North Korea presents a case in point, as its acquisition of nuclear weapons threatens South Korea and Japan. The U.S. nuclear umbrella has protected the latter two against Russian and Chinese threats, but may not have the same effect against North Korea. If Japan, for example, were to perceive the U.S. nuclear deterrent to be irrelevant to the North Korean threat, whether because of U.S. reductions in the number of nuclear forces or because of a perceived reduction in the U.S. willingness to use these capabilities to defend it, then Japan may feel compelled to develop its own nuclear force.

States such as North Korea or Pakistan, which have an infrastructure to produce nuclear materials and weapons, may export this technology to offset costs or for strategic reasons. In fact, a network of suppliers could arise, each member providing a critical part of the technology. For example, materials might come from one party, fabrication technology from another, and test data from a third. This has already happened with ballistic missile technology and there is a strong possibility that it could happen with nuclear materials and components.

Regardless of any need to support a nuclear weapon infrastructure, another possibility is the potential for countries that have no shared strategic interests to collaborate in order to acquire nuclear weapons and delivery means. In addition, the possibility exists that states with shared strategic interests, such as hostility to the United States, may combine their efforts. If this scenario evolves, for example among Islamic states, and several become nuclear-equipped, then a real threat to international security can emerge with an entirely new set of dynamics. It may be difficult to keep such development secret.

In addition to changes based on strategic calculations, a number of unpredictable events could shock the world and initiate rapid change. These would include—

- Nuclear weapon use;
- Effective use of biological weapons or chemical weapons;
- Use by a state without an adversarial relationship to the United States;
- A major nuclear weapon accident;
- A major loss of nuclear material (for example, from Russia to a third party).

In the previous sections, it was suggested that overall numbers of nuclear weapons are likely to decline. From the point of view of fewer weapons and a reduced alert status, we might argue that the danger is being reduced. However, a number of new and not very-well-understood factors may place significant pressure on new states and non-state actors to acquire nuclear weapons.

Given this uncertainty, the policies adopted and the problems they are intended to address must be reevaluated. The NPT, for example, was extremely important in reassuring large numbers of states that their security was not in danger and that they could forgo nuclear weapons. Key security agreements with Taiwan, South Korea, and Japan provided reassurance against the Soviet Union and China in the East, while NATO reinforced security against the Soviet Union in the West. Security challenges have significantly changed, however, and what worked before may not work in the future. The Nuclear Suppliers Group (NSG), the Missile Technology Control Regime, the Australia Group, and other multilateral agreements have achieved mixed results in stemming the proliferation of WMD.

The war against Iraq is one manifestation of the latest evolution of U.S. nonproliferation policy. Previously, only Israel had used a military strike to stop WMD proliferation. The United Nations' inability to come to an agreement on how to deal with the Iraqi proliferation threat may well be repeated in other cases, specifically North Korea. However, U.S. action in Iraq may be impossible to repeat in North Korea, without significant international cooperation. At the same time, Iraq and North Korea's defiance of their international obligations may inspire others to follow suit. This could take the form of latent nuclear states deciding that if their security is no longer assured by international agreements, they must take independent measures. On the other hand, the successful disarmament of Iraq may dissuade other states from developing weapons unless they can do so relatively quickly. Regardless of the outcome in Iraq and North Korea, these cases bring up the need for greater attention to counterproliferation measures in cases where supply-side efforts fail to prevent proliferation. Supply-side measures should be reinforced where possible, but they may not eliminate demand for nuclear weapons in certain key states. Nuclear weapons have an enduring appeal and policy must adapt accordingly. States may proliferate in novel ways in the future, relying more on the Internet and electronic mail than on boats and planes to transfer technology. Novel policy responses must be considered beyond the supply-side measures that enjoyed limited success in the past but may be inadequate in the future.

For many in the world, nonproliferation and disarmament have by now become inextricably linked. From this perspective, the key element in nonproliferation is Article VI of the NPT. Yet—as discussed earlier in this appendix—nuclear weapons will almost certainly continue to play a key role in deterrence and defense for the foreseeable future. Many of the NPT signatories will seek at the 2005 NPT Review Conference to hold the five NWSs to their commitments and it may be difficult to convince them to continue adhering to their Article II commitments in view of the NWSs' continued reliance on nuclear weapons. "Squaring the circle" of deterrence and disarmament poses yet another challenge for policy-makers as they are asked to honor a policy that may have made sense in 1968 (the year the treaty was opened for signature) but may appear to some as unrealistic 35 years later.

Many questions need to be addressed over the next few years:

1. On a bilateral basis, is strategic engagement and Cooperative Threat Reduction (CTR) a sufficient response to the threat of leakage of nuclear material, expertise, and technology from Russia? Because Russia continues to produce weapon-usable materials in its civilian and military nuclear programs, is there a need for a fissile material cutoff agreement that includes civilian materials? If not, is the CTR program in the unenviable position of having to run fast just to stay in place, and thus remain a useful but highly limited approach to the protection of weapon materials in Russia?
2. Is a CTR program with other nuclear weapon states possible or desirable? Other states with nuclear weapons face the same problems as Russia, albeit on a smaller scale. The international community's goal of keeping weapon materials out of the hands of terrorists suggests support for expanding the CTR program to such other countries, provided the program does not end up indirectly promoting the production of more weapons.

3. Is intervention to prevent proliferation, as against Iraq, applicable elsewhere and sustainable domestically? Much is also likely to depend on the public's perception of what is happening on the ground in post-war Iraq. If the post-war government is seen as in turmoil, with the prospect of an anti-U.S. democratic government emerging over the longer term (that might conceivably want nuclear weapons), domestic support for regime change for nonproliferation reasons may not be sustainable.

4. Are the security agreements that removed the motives for key states to develop nuclear weapons still robust? The end of the Cold War (and with it, attendant rivalries that in the past could be contained because of superpower rivalry over larger issues) may have eroded the ability to prevent proliferation through security agreements. Such erosion may be a continuing feature of world politics over the next two decades. Are new, tailored security arrangements required to prevent such erosion?

5. Are new security arrangements necessary to prevent certain states from developing nuclear weapons? Security arrangements are "patches" sometimes needed to prevent a nuclear arms race from occurring among countries in a region at high risk for conflict. They are imperfect instruments that bring their own problems in the execution. Other diplomatic efforts to produce trust and reduce tensions in an area should have higher priority, but can be extremely difficult to carry out effectively for political reasons. Each case is unique and must be approached as such.

6. Will the NPT implode over Article VI and the *de facto* policy to tolerate proliferation in some states while fighting it (sometimes literally) in others? A U.S. decision to resume nuclear testing would further strain the NPT, considering the debate over Article VI and testing that took place during the NPT Review Conference that produced the Treaty's indefinite extension. In addition, support for sanctions against proliferators has been inconsistent over the years, and is perceived as depending more on national security interests than on principles.

7. Are the legal limitations under the U.S. Atomic Energy Act and the NPT—especially with respect to providing nuclear safety assistance—preventing us from ensuring against terrorist seizure of nuclear weapons from new nuclear states? Would providing such assistance promote easier deployment of nuclear weapons and raise the risk of nuclear war? This question raises similar issues to those raised earlier in connection with the notion of expanding the CTR program to other countries. There is a tradeoff that must be examined carefully in each case. Prudence might dictate that we should require considerable transparency of the nuclear arsenal of the country we would be assisting.

8. How will North Korea's decision to withdraw from the NPT and declare that it possesses nuclear weapons affect the NPT? These situations are highly complicated. North Korea's nuclear mendacity has tarnished the constructive engagement and made negotiations highly problematic. The U.S. decision to launch the Proliferation Security Initiative, with plans to interdict the transfer of proliferation-relevant technology on the high seas, may have an important impact on negotiations with North Korea and on technology transfer in general. Depending on its resolution, the North Korea challenge to the nonproliferation regime may loosen the commitments of Japan, South Korea, and Taiwan *not* to make their own nuclear weapons. Should they decide to make such weapons, the NPT would effectively die. Conversely, any resolution of this situation that leaves North Korea with nuclear weapons and not under any sanctions underscores the weaknesses of the Treaty, which has no provisions for enforcement except via the United Nations Security Council in which a veto of sanctions might be exercised by China, among others. Another possible outcome from the current negotiations is a larger but more forceful bargain that might include major revisions:

    - Modular fossil-fueled plants instead of nuclear facilities.

- A short timeframe for completion of the first module.
- The simultaneous removal of all spent fuel in North Korea.
- A verifiable shutdown of all nuclear activities including enrichment.
- Verifiable elimination of all nuclear weapons in North Korea.
- A verifiable pledge of no transfers by North Korea of nuclear technology (leaving missile sales for another round).

9. Does the NPT–IAEA safeguards system have to be improved to provide timely warning of proliferation? Post-1991 intrusive inspections based on good intelligence uncovered serious nuclear weapon-related activities; such inspections can prevent proliferation. But the charter of UNMOVIC[18] allows significantly more intrusive inspections than those by the IAEA. To have more confidence in the agency's inspections, the charter of the IAEA has to move in the direction of more intrusive, surprise inspections. This presents not only logistical difficulties, but also the need for a change in cultural attitudes at the IAEA, focusing on outcomes and not on process.
10. Does the NSG need to be made more effective in regulating international nuclear commerce? Stopping the spread of technology may be impossible over the long term, but we must continue to try to stop the transfer of weapon materials and equipment for producing them. While recognizing that tertiary nuclear transfers are occurring among countries not part of the current official group of suppliers, it is still the case that certain technologies and components are the exclusive domain of the NSG. It is apparent that the list of prohibited items should be expanded if proliferators and sub-national groups are to be kept from acquiring them.
11. Do we need to revise the NPT to strike a new "grand nonproliferation bargain"? It is apparent that NPT-allowed processing of weapon-usable materials (plutonium and HEU) by non-weapon states, along with assistance in such production by NPT members, has created a new class of NPT member states. These are states stockpiling weapon-usable materials that can be quickly transformed into weapons. The NPT should not be an instrument for latent proliferation. Accordingly, a new nonproliferation bargain might prohibit assistance for such production by both weapon and non-weapon states, and possibly incorporate a total ban on production by non-nuclear weapon states in exchange for a guarantee by the nuclear weapon states of reprocessing services. In addition, a new bargain might involve an arrangement whereby current non-NPT members possessing nuclear weapons are offered a prescribed role in the regime as long as this can be done without unraveling the current system, i.e., loosening the taboo on new weapon states. Such changes might be accompanied by measures compelling more restraint by those parties.
12. Would developments in U.S. offensive and defensive technology—and a resumption of nuclear testing—make multilateral agreements to prevent proliferation impossible? The increasing gap between U.S. conventional military capabilities and the rest of the world suggests that other states may see nuclear weapons as a *deterrent needed against* the United States. The policies of the United States should be formulated with the awareness of this risk. The testing issue, as indicated earlier, butts up against U.S. commitments in the NPT Review Process, which in turn relates to the nurturing of a nonproliferation ethic that has grown up since the establishment of the NPT. Horizontal proliferation is a function of many factors, but in some cases at least, may be encouraged by vertical proliferation.

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[18] UNMOVIC is the United Nations Monitoring, Verification, and Inspection Commission.

13. Should the United States share with our NPT allies the technology and intelligence that allows us to detect proliferation? There have been numerous instances when intelligence relating to proliferation activities has come to the U.S. via foreign sources and allied intelligence agencies. We may want to share our own technologies for detection with those who can help us and who may have other sources to exercise beyond our own. But, this should be limited to those allies who share our nonproliferation philosophy as indicated by their commitment to the current nonproliferation regime.
14. What will be the long-term relationship on nuclear issues between the United States and Russia? Will it be along the lines of the United States–United Kingdom or United States–France? Will new cooperative programs or agreements be needed? Will cooperation extend from civilian applications and nonproliferation activities to defense? This will have significant impact on the level of technology and information exchanged, both for security and civilian applications.

Conclusions

Figure A-1 illustrates the interaction between defense and deterrence and nuclear proliferation. The horizontal axis represents horizontal proliferation. It currently stands at eight,[19] but the recent admission by North Korea[20] may boost the number to nine. The vertical axis represents the total number of nuclear weapons possessed by these entities. Because the United States and Russia largely dominate any significant changes in this number—at least over the next decade—the vertical axis represents at least numerically the role of nuclear weapons in defense and deterrence strategies worldwide. Currently, the total number of nuclear weapons in the world, although not precisely known, is on the order of tens of thousands. It is important to remember that different dynamics drive changes on the two axes.

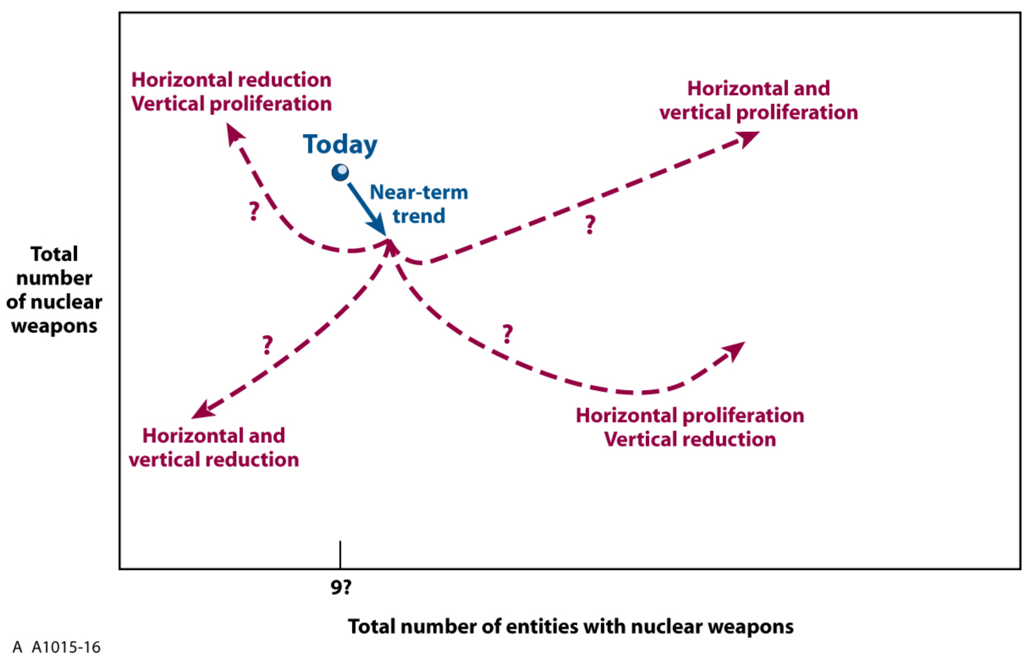

Figure A-1.

[19] The generally recognized states with nuclear weapons are the United States, Russia, China, the United Kingdom, France, Israel, India, and Pakistan.

[20] On April 24, 2003, North Korean officials told U.S. Assistant Secretary of State James Kelly that their country possessed nuclear weapons, something that had been suspected for some years.

As Figure A-1 illustrates, the apparent near-term trend seems to be toward more entities possessing nuclear weapons, but fewer total weapons. Clearly, North Korea's assertion moves the arrow to the right (increased horizontal proliferation), as would nuclear ambitions in Iran. However, the arrow is also moving down (vertical reduction), primarily because of actions to be taken by the United States and Russia under the Moscow Treaty.

More importantly, Figure A-1 illustrates that in spite of the near-term trend, there are other possibilities for the future. Four general cases are shown: (1) more nuclear weapons in the hands of all actors in the world and additional proliferation to new entities; (2) horizontal proliferation, but continued reductions in the overall number of nuclear weapons, i.e., continuing the present trend; (3) reductions in both the numbers of weapons and in the number of entities; and, (4) more nuclear weapons overall, but a reduction in the number of entities. Clearly, in-between cases are possible, but the illustration provides a framework in which to examine the interplay between defense/deterrence and proliferation.

Figure A-2 shows how the space might be restricted in the vertical dimension to reflect the view of resistance in the United States and Russia to moving to very low levels of nuclear weapons. The gray band near the bottom of the figure represents a notional barrier that might be anticipated in the foreseeable future. The reason for the positive slope of the barrier (i.e., it increases as one moves to the right on the horizontal axis) captures the thought that the United States (and Russia, too) will probably stay at higher limits if the number of proliferators rose considerably.

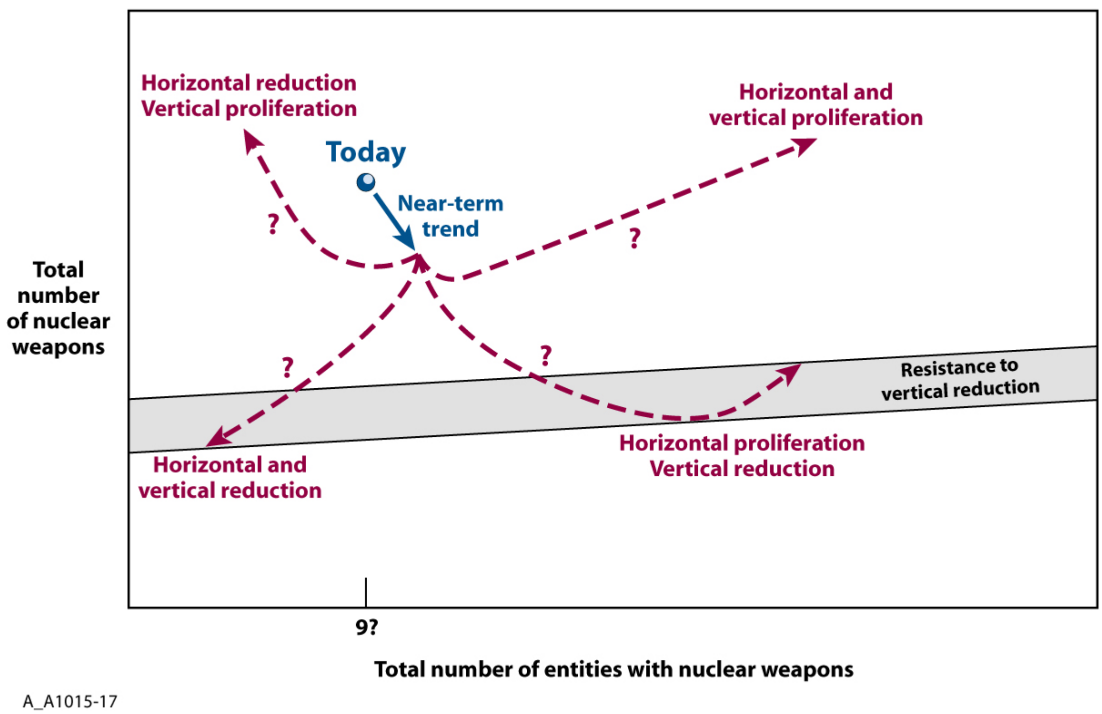

Figure A-2.

One concept not captured simply by looking at the number of weapons in the vertical dimension is the fact that all weapons are not equal in their potential for use. This fact becomes especially important as we look ahead at the horizontal dimension. At the present, perhaps most of the extant nuclear weapons are viewed as "weapons of last resort," whose purpose is fulfilled if they are never used. But as the horizontal trend is toward more players, the idea that some, e.g., terrorists, may view nuclear weapons as a weapon of first choice becomes more relevant. Based on the previous discussion, **Figure A-3** illustrates what may be the best possible scenario for the future—reductions in both dimensions, but with real barriers that preclude the complete abolition of nuclear weapons. However, many factors could prevent us from realizing the best scenario.

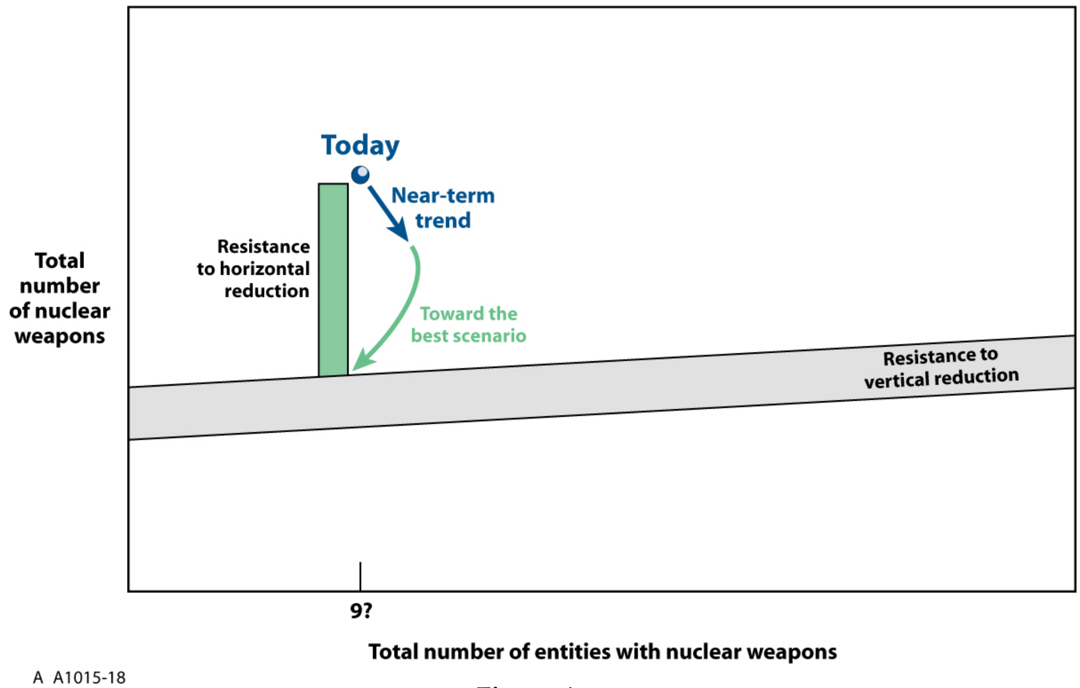

Figure A-3.

The potential for the proliferation of nuclear weapons to states or non-state actors is a major concern of the 21st century. Even failed, unstable states can now produce nuclear weapons, and the acquisition by terrorists of such weapons is a fearful possibility. It is clear that we can no longer deal with these 21st century problems with 20th century solutions. The NPT does not address the new challenges of terrorists, rogue states, and regional competition. The current nonproliferation regime needs reassessment and new tools need to be developed. We need to upgrade the NPT and the IAEA to a new generation of technology, inspections, and monitoring using advanced sensors, tags and seals, and information technology. New concepts that stress facilities, management and control of materials, and regional concerns should be developed. Effective means to enforce the NPT and deal with violations must be implemented.

Appendix B: Civilian Applications

Introduction

In the 50 years since Eisenhower's Atoms for Peace speech, notable advances have been made in providing the benefits of peaceful uses of nuclear technology to people throughout the world, although more so in the developed world than in the developing and undeveloped world. Nuclear power has contributed significantly to the production of electricity worldwide. Impressive advances have been made in medical, industrial, food processing, and agricultural applications of nuclear technology. These benefits have been achieved while making some progress toward the goal of reducing the motivation of states to develop nuclear weapons.

While partially realized in that the number of nuclear weapons states has only increased from 5 to perhaps as many as 10, Eisenhower's vision has not been fully achieved because of clandestine violations of the Nuclear Non-proliferation Treaty (NPT) and the emergence of international terrorist groups that might obtain weapon-usable material from excess weapons stockpiles or from the civil applications sector. Yet, there has been no known diversion of weapon-usable nuclear material from safeguarded civilian facilities since the inception of the International Atomic Energy Agency (IAEA). These issues are discussed fully in Appendices A and C.

After an initial period of enthusiasm through the 1970s, public acceptance of nuclear energy was quelled due to a variety of factors, including a general fear of radiation, the specter of nuclear warfare, and the occurrence of accidents involving the release of radioactivity (Chernobyl, a nuclear power plant in the U.S.S.R. and Tokai-mura, a nuclear-fuel reprocessing plant in Japan). Although the accident at the Three Mile Island nuclear plant in the United States did not cause any radiation-related health effects, it contributed to a loss in public confidence. Incidents resulting from the loss of control of radioactive sources from medical and industrial applications, e.g., Goianna, the site of a release from an abandoned medical radioactive source in Brazil, have also raised safety concerns. In spite of these concerns, nuclear technology, both in the production of energy and in non-energy applications, has continued to expand globally because of the evident benefits it provides.

The enormous and beneficial impact of peaceful nuclear technologies on the civilian sector has been much less on the disadvantaged sector of the world's population, and this leaves an unattended international security issue. **Figure B-1** is a projection of global population, divided into the developed (OECD) states, the Soviet Union and its former client states (REFs), and the so-called developing countries (DCs).[1] Regardless of the eventual total world population, it is immediately obvious that the bulk of any population growth will be in the developing world, where two billion people now live without access to energy services including electricity and whose standards of living (life expectancy, infant mortality, environmental conditions, and economies) are far below even the least developed country. Without access to electricity, related energy services, and more modern technologies, these conditions cannot be improved. Because there will likely be four to five times as many people in the developing as in the developed world, an unchanged situation in these countries will present an international security issue (at the very least uncontrolled migration, and at the worst international terrorism and potential regional or global conflict).

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[1] *Global Energy Perspectives*, A Joint IIASA–WEC Study, International Institute for Applied Systems Analyses (IIASA), Laxenburg, Austria, 1996.

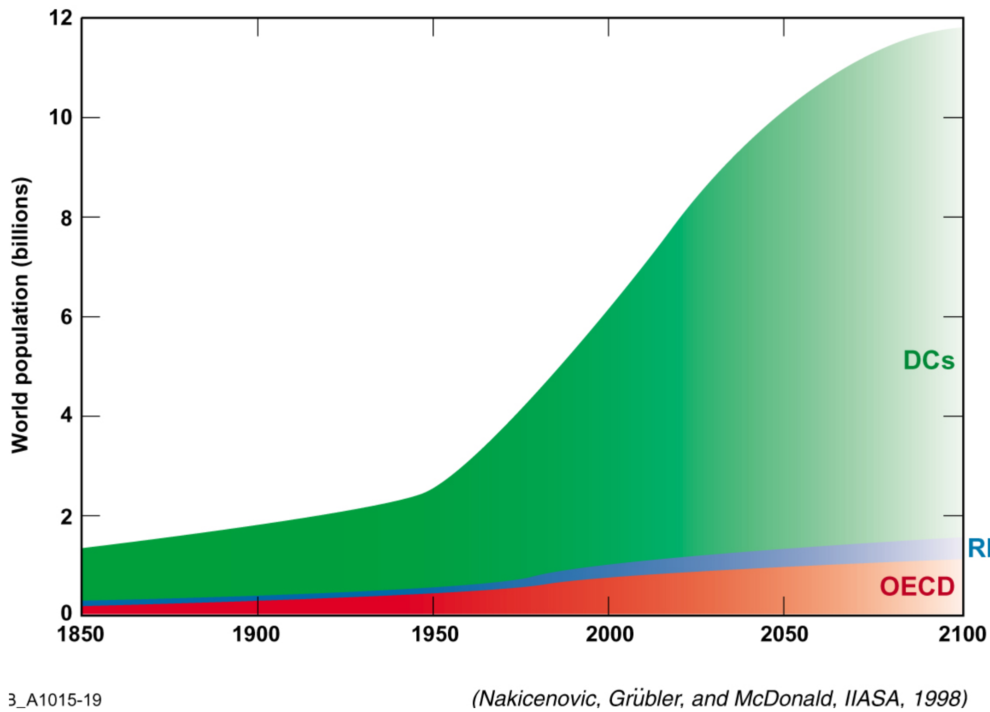

Figure B-1. World Bank and United Nations' projections of world population (Source: *Global Energy Perspectives, IIASA/WEC,* 1998).

Where this energy, including electricity, will come from is open to debate, but most careful analyses have concluded that a robust mix of energy sources (fossil, renewable, and nuclear) is necessary to at least provide the necessary options to accomplish this goal. Similarly, it is necessary to transfer appropriate technologies, including nuclear technologies in medicine, food, agriculture, environmental protection, and safety.

The challenges to the international nonproliferation regime must be addressed to enable continued effective implementation of increased peaceful uses of nuclear energy and nuclear technology. While efforts are underway to develop new advanced reactor concepts for the long term, major technological advances are unlikely to be seen in the marketplace for at least a few decades because it typically takes that long to deploy new technologies on a significant scale. Expanding nuclear power in the near term will depend on deploying improved economically competitive plants of proven technology, such as the Advanced Light Water Reactor (ALWR).

Non-power applications of nuclear technology, including those in medicine, agriculture, security, public health, space exploration, and industry, can be expected to advance more rapidly due in part to the much shorter deployment time. In addition, the ventures they are associated with (human health and space exploration) generally enjoy greater public support.

A key challenge is to provide widespread access to the benefits of nuclear technologies in ways that are safe, secure against misuse, have minimum impact on the environment, and at costs to make them accessible to the consumers.

A summary follows of the present status and future prospects of the civilian applications of nuclear technology. The text that describes the current status of nuclear power is much shorter than that describing the non-power applications status because of the great variety of the non-power applications. In contrast, the length of text devoted to future prospects is much longer for nuclear power because of the greater number of uncertainties in its future prospects as compared with non-power applications.

Nuclear Power

The Current Situation

As of January 1, 2003, 441 nuclear power plants are in operation worldwide with a total net installed capacity of 359 gigawatts-electric [GW(e)]. Thirty-two nuclear power plants are under construction worldwide, with much of the new construction in India and China, reflecting expanded use of nuclear power capacity in the developing countries. Nuclear power plants provided some 16% of the world's electricity production in 2002, generating 2,574 terawatts-hour (TWh).[2] These plants are operating safely and on average with high reliability and competitive costs.

Today, many countries depend critically on nuclear power, which generates 39% or more of the electricity in 10 countries. Western Europe relies on nuclear energy for ~37% of electricity with France generating 77%, Spain 28%, the United Kingdom 25%, and Germany 30%. In Asia, Japan produces 30% of its electricity via nuclear power and Korea produces 37%. The former Soviet Union countries rely significantly on nuclear electricity with Russia at 15%, Ukraine and Armenia at 45%, and Lithuania at 77%, the highest in the world. Twenty percent of U.S. electricity is from nuclear power and five of its States derive 50% or more of their electricity from nuclear power.

This rapid expansion of nuclear energy production between the 1960s and 1990s was accompanied by problems of unreliability and two serious accidents [Three Mile Island, a light-water reactor (LWR) system, and Chernobyl, an RBMK system]. In light of these accidents, improvements were made to the safety systems of all U.S. plants as well as to the LWR plants of many other countries. Greatly increased emphasis was also placed on operations and operational training. The Institute for Nuclear Power Operations (INPO) was formed to provide industry oversight of operational proficiency. Improvements were also made in the RBMK-type reactors operating in the Soviet Union, with aid from the IAEA and its members. The nuclear industry extended the INPO concept worldwide by forming the World Association of Nuclear Operators (WANO), to which all nuclear power countries belong.

These changes led to major improvements in the safety and reliability of U.S. nuclear plants over the past two decades. As shown in **Figure B-2**, U.S. average capacity factors increased from 58% to 88% between 1984 and 1999, reaching a record of over 90% in 2002.[3] The safety and reliability records in other countries are comparable, although some of them did not experience the earlier difficulties of the United States. WANO performance data for 2002 shows that capacity factors have reached 87.3% worldwide, steadily improving from a level of 77.2% in 1990.

[2] Power Reactor Information System, IAEA, Vienna, http://www.iaea.org/programmes/a2/index.html.

[3] Nuclear Energy Institute, "Resources and Nuclear Data," http://www.nei.org/index.asp.

As the movement toward deregulation of electricity rates gained momentum in the United States, major reductions occurred in embedded nuclear plant assets. These assets were particularly high for the last group of plants constructed during the oil supply crises and double-digit inflation of the 1970s, some of whose capital costs reached to the $5,000–6,000/kilowatt-electric [kW(e)] range and took upward of 10 years to complete. The reductions in assets were affected in part by the sale of plants at low prices, with major write-offs of the embedded capital by the sellers. Capital write-offs authorized by regulators also reduced assets to help effect the transition to a competitive electric market. In addition, the plant purchases resulted in a consolidation of ownership of nuclear plant capacity, permitting major reductions in overhead costs. The amortization costs and overhead costs thus dropped, and combined with the increase in plant capacity factors, nuclear plants became economically competitive and profitable in the 1990s.

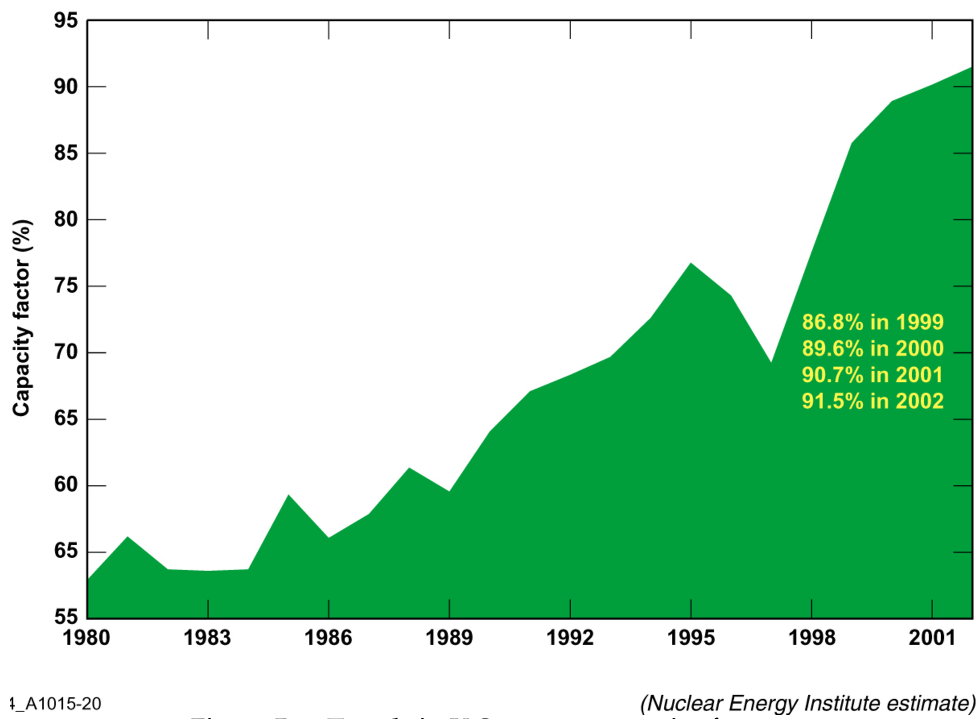

Figure B-2. Trends in U.S. average capacity factors.

Figure B-3 shows electricity production costs for U.S. nuclear plants in the past decade. In 2002, the 103 U.S. nuclear power plants generated electricity competitively, at a median cost of 1.71 cents/kW(e)-hour with a retail value of nearly $50 billion. In 2001, a record low in production costs was set at 1.68 cents/kW(e)-hour. Stable fuel costs and high capacity factors are the most significant contributors to nuclear-power-plant low production costs. Fuel costs were 0.45 cents/kW(e)-hour compared with 1.36 for coal and 3.44 for natural gas. As seen in Figure B-3, capacity factors for 2002 reached a record high for the fifth year in a row at 91.5%. The increased capacity has added 26,000 megawatts-electric [MW(e)] to the electric grid, the equivalent of about 26 new 1,000-MW(e) nuclear plants, since 1990. Only hydropower presently has lower production costs than nuclear power in the United States. Comparable costs for coal in 2002 were 1.85 cents/kW(e)-hour and for natural gas and oil, 4.06 and 4.41 cents/kW(e)-hour, respectively.[4]

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[4] FERC Form 1, DOE/Energy Information Agency Form 412, Estimates by Nuclear Energy Institute based on two-thirds of U.S. plants' filings of FERC Form I or EIA Form 412.

Further improvements are being made to increase the value of the investments in operating plants. The power ratings of many U.S. operating plants are being upgraded, and 20-year extensions to their licenses are being obtained, so as to continue their supply of electricity through the mid-century. The combination of higher reliability, lower production costs, and upgrades over the past decade has provided increased power output equivalent to 20 new 1,000-MW electric plants. Similar records have been achieved in other countries.

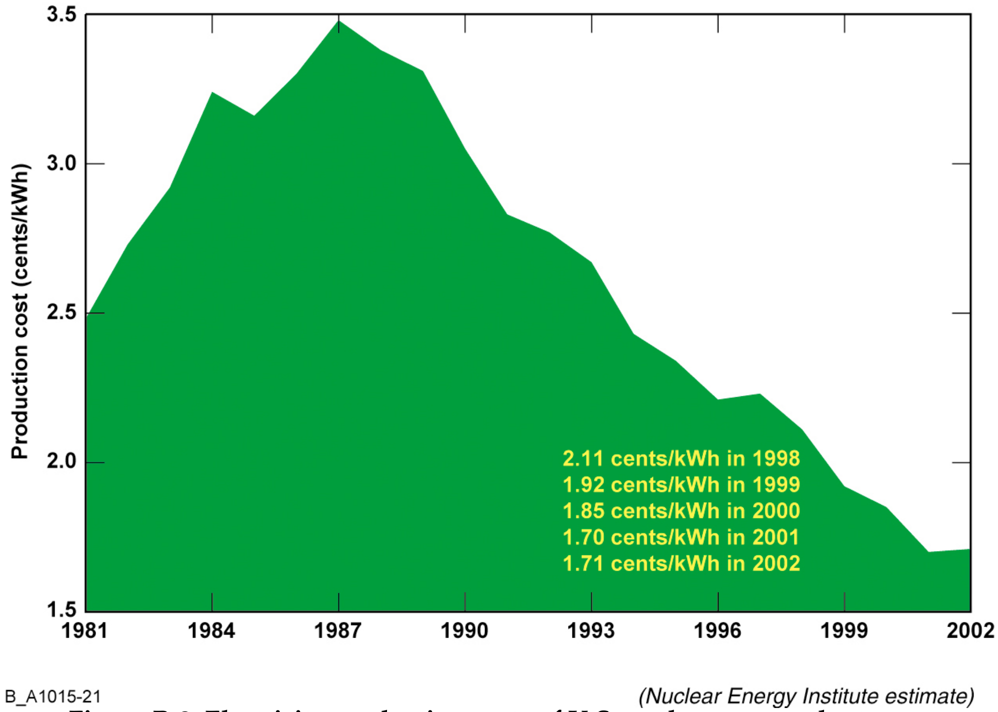

Figure B-3. Electricity production costs of U.S. nuclear power plants.

Nuclear power plants are also being used to address a present serious proliferation concern: the potential for the diversion of weapon-grade highly enriched uranium (HEU) and plutonium from the stockpiles of nuclear weapons declared excess through the START II agreements and stored in the United States and Russia. In a joint U.S.–Russia program, HEU is being blended down to low enrichments and used as fuel in nuclear power plants, greatly increasing its proliferation resistance.

Some nations have employed nominally civilian nuclear programs as a pretext to acquire technologies for military programs, or they have acquired materials, equipment, or technical personnel from the civilian sector for their nuclear weapons programs. Indeed, there has been no known diversion of weapon-usable nuclear material from safeguarded civilian facilities since the inception of the IAEA. That said, nuclear power development has been used as a cover for weapon development by certain countries. Although concern was expressed by some in the 1950s that many nations might acquire nuclear weapons in 10 to 20 years, only seven nations beyond the U.S. and U.S.S.R. did. Four of these—the United Kingdom, France, Israel, and China—used military technology, acquiring weapons prior to the completion of the NPT and technology development and became nuclear weapon states under the NPT. The other three—India, South Africa, and Pakistan—acquired their weapons clandestinely under the cover of civil nuclear-power development. South Africa dismantled and disabled its nuclear weapons in 1990, an act subsequently verified by the IAEA. The ramifications of these actions, including the recent problems in North Korea and Iran, are discussed in Appendices A and C.

The utilization of nuclear power is presently at a pivotal point. After a period of global growth through the 1970s and into the 1980s, there has been a hiatus in new plant orders in the United States and a general slowdown globally. The abrupt reduction in electricity demand growth initiated by the OPEC embargo caused the cancellation of many nuclear and fossil base-load power plants orders. No new nuclear plants have been ordered in the United States since 1978. The general slowdown of nuclear power expansion worldwide has been caused by a variety of factors, including the substantial reduction in the growth of demand for electricity over earlier estimates, an abundance of natural gas at historically low prices that has made gas-fired plants more economical for capacity expansion than new traditional base-load plants, particularly nuclear ones, and public and political resistance to nuclear technology. The latter is evidenced by political measures to impose moratoria on nuclear power in countries such as Sweden and Germany. Heavy reliance on nuclear power in Japan, even though to reduce dependence on offshore sources of fossil fuel, has recently been called into question. Until recently, R&D budgets for civilian power have been steadily declining in most of the industrialized countries since the mid-1980s, with the exception of Japan and France.

On the other hand, several recent new initiatives in the United States and internationally indicate growing interest in the revitalization of the nuclear energy option.[5] A new program, the Nuclear Power 2010 Initiative, based on the Department of Energy's (DOE) Near-Term Deployment Roadmap,[6] has been funded to enable the deployment of new nuclear power plants of proven technology in the United States in the next decade. In addition, an advanced nuclear energy R&D program, the "Generation IV" initiative, is being planned and coordinated with other countries with the aim to develop and demonstrate advanced nuclear-energy systems for longer-term future deployment. A parallel effort with similar goals is being pursued through the IAEA. The directors of six major national nuclear laboratories involved in nuclear energy have urged that the U.S. government re-vitalize its support of nuclear power to achieve a vision of "sustainable, peace, prosperity, and environmental quality, enabled through immediate U.S. leadership in the global expansion of nuclear energy systems." Some more positive events have also occurred in Europe. A proposal for a moratorium on nuclear plants in Switzerland was rejected by a 70% majority of the voters. Finland issued requests for bids to build a new nuclear plant and has selected the Areva/Siemans 1,600-MW(e) LWR (EPR) for contract negotiations.

There is general international agreement that deep underground disposal is the ultimate option for high-level radioactive waste and that it is technically feasible, requiring specialized technical resources It is also agreed that surface storage of high-level radioactive waste can be managed safely and securely if the financial resources and the political commitment are in place to see it through. Because there is lack of confidence that institutions can be counted on to execute such a commitment over many millennia, the consensus is that sooner or later, the wastes must be disposed of deep underground.

Authorization has been given by Congress for DOE to proceed with the licensing of a U.S. permanent repository for spent fuel, the Yucca Mountain Repository in Nevada. This authorization was based on extensive R&D and engineering studies. About $22 billion is available from the nuclear utilities' electricity consumers. A Waste Isolation Pilot Project repository for the disposition of transuranic radioactive waste has been placed into

[5] U.S. National Energy Policy Report, "Reliable, Affordable, and Environmentally Sound Energy for America's Future," http://www.pppl.gov/common_pages.

[6] *A Roadmap to Deploy New Nuclear Power Plants in the U.S. by 2010*, DOE–NE and its Nuclear Energy Research Advisory Committee.

operation at Carlsbad, New Mexico, following active involvement with the public in the decision-making process.

Other countries' progress in radioactive-waste management varies ahead and behind that of the United States. Sweden has put into operation an efficient repository of adequate capacity for its nuclear plant wastes and the design and licensing of an intermediate-level waste repository is proceeding. Finland has adequate storage capacity for its low-level wastes and a spent-fuel repository is moving ahead through the design and licensing phase. France has confirmed that work should proceed on two underground laboratories for spent-fuel disposition research, one in clay and one in granite. Most other countries are at an earlier stage. At present, most spent fuel is stored at the nuclear plant sites.

The availability of low-level-waste disposal capacity in the United States is limited, and the cost per unit volume has increased sharply in recent years, compensated by substantial reductions in the generation of waste. In 1980, more than 3.7 million cubic feet of low-level waste were disposed of commercially. In 1999, the volume of low-level waste production declined to 272,262 cubic feet, a 93% reduction.[7] Yet, in 23 years not a single new fully licensed disposal facility has been built, raising concerns that nuclear plants will not have the ability to dispose of low- and intermediate-level radioactive waste in the future.

Prospects for Continued Utilization of Nuclear Power

The demonstrated benefits of electric power to date (increases in standards of living and decreased infant mortality for example, when electricity is readily available) provide a strong basis for projecting the continued usage and expansion of nuclear power in size and scope of application. Two key future benefits center on its intrinsic ability to produce combustion-free energy that eliminates greenhouse-gas and air-pollution emissions and on the long-term sustainability of its fuel. But the actualization of such projections depends critically on meeting a series of technological and institutional challenges.

Utilizing the projections of IIASA–WEC,[8] a major growth in primary energy production will be needed to serve a global population estimated to reach the range of 9 to 10 billion by 2100. An increasing portion of this primary energy will be in the form of "grids" (electricity, hydrogen, gas, and district heat) as compared with "liquids" (oil products, methanol, ethanol) or solids (coal and biomass). Grids will grow from a combined 30% of primary energy today to 60% by 2100. In this context, electricity production needs will grow by 480% in a high economic growth scenario, 440% for moderate economic growth, and up to 140% in an ecologically driven scenario governed by conservation and by greenhouse-gas emissions reductions (by 2100 to one-third of the global emissions in 1990), and assuming major deployment of renewables and nuclear power. This is clearly an enormous industrial challenge that requires contributions from all energy sources. Because none of these scenarios includes nuclear energy applications other than electricity production, success in R&D to expand the applications (e.g., to provide industrial heat or to produce hydrogen as an energy source for transportation) would accordingly increase the potential level of nuclear power usage.

The uncertainty in the degree to which commercial nuclear power can satisfy this need suggests a range of scenarios for nuclear power growth:

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7 Nuclear Energy Institute, "Resources and Nuclear Data," http://www.nei.org/index.asp.

8 *Global Energy Perspectives*, a joint IIASA–WEC Study, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1996.

- Slow reduction in the dependence on nuclear energy, perhaps leading to its demise over the 40- to 50-year time frame;
- Sustained use at or near current levels (20% U.S. electricity; 16% worldwide), implying modest growth as total levels of electricity production continue to grow;
- Increased dependence on nuclear generation, ranging to large-scale growth with significant displacement of fossil fuels.

Indications are that the first scenario is not likely. The 32 new nuclear plants now under construction represent a 9% increment to the currently worldwide operating fleet of 423 reactors during a period of relatively slow growth in electricity demand. The rapid loss of the electricity-generating capacity represented by reduction or elimination of the nuclear fleet would present a major disruption to world economies. The third scenario, involving a major increase from current levels, can be envisioned under certain conditions (and is projected by many experts), but is presently constrained by the present high cost of nuclear power plants. Thus, the second scenario, in which nuclear power capacity is sustained, appears to be more likely. There is, of course, no single global scenario but a collection of regional and state scenarios. It may well end up that, on a global average, the second scenario will emerge.

Major factors will determine how much nuclear energy will contribute to this global energy demand and which of the nuclear-power growth scenarios is most likely. They are cost, the stability of fuel supply, environmental considerations (global climate change, regional air pollution, waste disposition), proliferation concerns, and the future growth rate of energy and technology needs. Maintenance of an excellent safety record is essential to assuring public safety and public confidence as well as protecting plant investment.

Cost competitiveness is a key factor influencing the near-term deployment of conventional new plants. Because of the relatively high capital cost, such new plants do not presently compete with fossil power economically. Substantial development work continues to further reduce the capital cost of these plants.

Yet, either of two changes could make new nuclear plants economically competitive even without further reductions in capital costs: a significant increase in gas price or internalization of fossil-plant environmental costs as is already applied to nuclear plants. **Figure B-4** illustrates the dramatic sensitivity of gas price to the competitive position of a combined cycle gas-fired turbine (CCGT) power plant, the type most favored for new construction by electric utilities today. It also illustrates the economic advantage of presently operating nuclear plants.

The present overnight capital cost of General Electric's Advanced Boiling Water Reactor, which has been built and operated successfully in Japan, is in the range of 1,400 to 1,600 $/kW(e), making it competitive with the CCGT at gas prices in the range of 5.5 to 6.5 $/MMBTU. The Westinghouse AP-1000, presently under review by the Nuclear Regulatory Commission (NRC) for design certification, is estimated at 1,000 to 1,400 $/kW(e) overnight capital cost, but, although of proven technology and fully tested, has not yet been built and operated and will initially require substantial expenditures for first-of-a-kind engineering. Capital cost estimates for modular direct-cycle, high-temperature gas-cooled reactors are in the same range. The above cost estimates have been provided by the respective reactor suppliers.[9] All are based on construction being completed in a 4- to 5-year timeframe,

[9] *The Future of Nuclear Power*, An Interdisciplinary Study, Massachusetts Institute of Technology, July 2003.

consistent with overseas experience and doable in the United States with a combined construction and operating license (COL).

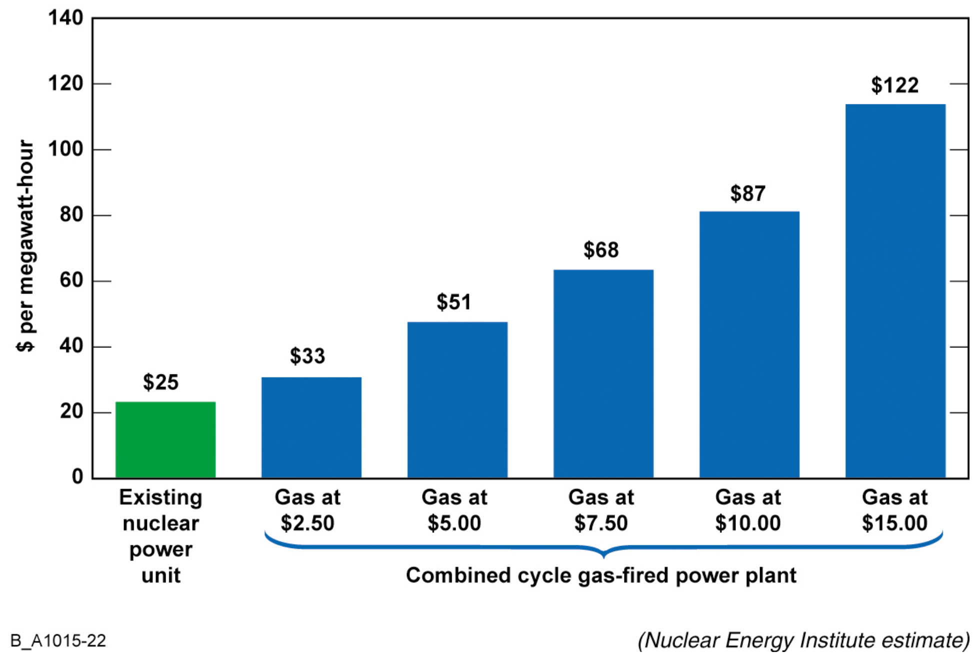

Figure B-4. Gas price impact on the electricity cost of gas-fired plants.

Table B-1 shows equivalent electricity costs between the CCGT and a new conventional nuclear power plant over a range of ALWR nuclear plant, EPC capital costs, and CCGT gas prices. These capital costs lead to estimated levelized electricity costs in the range of 4.2 to 5.9 cents/kW(e)-hour.

Table B-1. Approximate equivalence of ALWR EPC capital cost and natural gas price to CCGT plant.

ALWR capital cost, $/KW(e)	Electricity generation cost, $/MW-hr	Natural gas price to CCGT, $/MMBTU
1,000	41.5	3.8
1,100	44.5	4.2
1,200	47.5	4.8
1,300	50.5	5.1
1,400	53.5	5.5
1,500	55.5	5.8
1,600	58.5	6.2

An MIT study, partially sponsored by the Sloan Foundation,[10] gives a preliminary levelized electricity cost estimate from ALWRs at 6.7 cents/kW(e)-hour, indicating that with continued development, it should be possible to achieve a cost of 4.4 cents/kW(e)-hour. All of the above nuclear-plant cost estimates include the cost of radioactive waste management and plant decommissioning, and 0.1 cent/kW(e)-hour to cover the cost of spent fuel disposition.

[10] *The Future of Nuclear Power*, An Interdisciplinary Study, Massachusetts Institute of Technology, July 2003.

The MIT study cites combined cycle gas turbine generation ranging from 3.8 to 5.6 cents/kW(e)-hour, similar to that in Figure B-5, and pulverized coal-fired generation at 4.2 cents/kW(e)-hour. Even partial internalization of greenhouse-gas emission costs, perhaps through a form of emissions credit trading, would substantially close, if not eliminate, the gap in cost between new nuclear and coal plants. With a few exceptions, gas prices over the past decade have been in the range of $3/MMBTU. Prices have been edging up recently however and are approaching the $6/MMBTU range.

The cost comparisons above focus on nuclear electricity generation versus natural gas because, in the present market, gas is the primary preference for new capacity additions. Of course, coal-fired plants have been the traditional competitors to nuclear power, both of which are base-load generators. The present gap in electricity cost between nuclear and coal-fired power is smaller than that for gas-fired power. The ability of nuclear power to achieve economic competitiveness will be easier if the utilities turn away from their present preference for gas-fired plants as base-load units, putting coal versus nuclear back into competition.

Investors in nuclear plants will look for significant electricity cost advantages for nuclear plants and not just parity against alternative choices because rate deregulation removes the regulator's assurance of return on investment. Further, the time required to obtain the return is much greater than for a CCGT with low capital investment.

Licensing uncertainties have posed major financial risks for nuclear plant investors in the past. Changes in licensing requirements after construction had started and delays in getting the operating permit after the plant was finished greatly increase the total construction time. To cope with this problem in the future, regulatory processes have been improved by the NRC in two respects. First, a licensing standardization policy has been adopted that provides the opportunity for a reactor manufacturer to seek a site-independent design certification and the prospective plant owner-operator to obtain a separate early site permit. With a certified design and an early site permit, a nuclear-power plant operator can then apply for a combined COL before making a major investment in plant equipment and construction. Second, a risk-informed, performance-based framework is under development to substitute a subjective oversight of plant safety performance with objective performance criteria governing such oversight. When fully defined, these improvements can provide a more effective and stable regulatory process.

The Nuclear Power 2010 Initiative has been framed as a phased program to address these uncertainties. The first phase, presently underway, has the goal of demonstrating the effectiveness of the design certification, early site permit, and COL processes. The goals of the second phase is to complete the detailed design and construction and construction plans in order to provide a sound cost and schedule that would permit a prudent decision to make the investment. The third phase would then entail the construction and operation of the plant(s). The first and second phases are being cost-shared by industry and DOE, while the third phase will be funded solely by industry with the help of tax incentives similar to those provided to alternative power generators. Lack of success in this effort, with the resultant further weakening of the supporting physical and human infrastructure, will substantially increase the barrier to future development of advanced nuclear plants.

Other factors apply more critically to the potential market for small developing and underdeveloped countries: the economics of nuclear plants with small unit power output and the infrastructure needed for safety, nonproliferation, and radioactive waste management. Present nuclear plants are very large, ranging from 600 to 1,500 MW(e) to achieve cost-competitiveness through economy of scale. But the grid capacity of many of the developing countries is too small to justify such a large single block of power. This mismatch presently reduces the attractiveness of nuclear power in some parts of the world, but can be remedied either by developing economically competitive small nuclear plants or by utilizing regional electric grids. Countries with small electric grids have limited infrastructure with which to manage spent fuel, radioactive waste storage and disposition, and to assure safety and nonproliferation. Here, regional, integrated fuel and radioactive materials management would greatly reduce the infrastructure needs. It is the prospect of success in such developments that is behind the IIASA–WEC "ecologically driven" scenario that envisions a high nuclear-power component of that scenario.

In addition to the cost and infrastructure issues, it is essential that the present excellent safety and reliability of operating nuclear plants worldwide be sustained as the plants continue to age. Failure to do so would not only cause a regression in public opinion but would defeat the aim to achieve cost competitiveness. New challenges to safety, reliability, cost, and public acceptance have arisen with the attack on the New York World Trade Center in 2001, namely, concern as to the vulnerability of nuclear power plants to a terrorist attack. The security of nuclear facilities against attack has been urgently addressed ever since 9/11. Initial evaluations have indicated that nuclear power plants, fuel storage facilities, and transport casks are relatively robust against such attack compared with many other elements of the U.S. industrial infrastructure. Nevertheless, plant security has been substantially increased. The NRC has expanded safety regulation to include the possibility of attacks on nuclear plants, by both increasing security requirements and upgrading the "design basis threat" definition on the basis of which every nuclear plant must be evaluated. Similar evaluations have been taken by other nations with nuclear energy facilities. These protective actions that have their counterparts across the entire industrial infrastructure are prudent and necessary, but it is evident that they are not sufficient. The other primary response must be to subdue the terrorists. Such actions are already underway and require unprecedented international cooperation to expect to successfully achieve this preventative response.

Improving Intrinsic Proliferation Resistance

Given these prospects for continued utilization of nuclear power and nuclear technologies, the changes that have occurred to the international nonproliferation regime over the past 50 years, and in particular in the last 10 years, must be addressed. The success of four states, and perhaps six, in clandestinely acquiring nuclear weapons accentuates the need to strengthen NPT control and compliance measures, especially materials protection, control, and accountability systems, export controls, monitoring and inspection for compliance, and enforcement capabilities. The specific institutional ways in which the nonproliferation regime should be strengthened involve both military and civilian activities and are outlined in Appendix C.

Although these institutional measures to improve proliferation resistance deserve high priority, there is merit in systematic analytical assessment of the proliferation resistance of specific designs of nuclear power systems. A major development effort is needed before such an analytical methodology can be validated and confidently applied. But, if successfully developed, it could identify weaknesses leading to improved intrinsic proliferation resistance, such as in design, materials content and accessibility, diversion detection, security against diversion, and chemical, physical, and radiation barriers against diversion. Further, it could help determine the proper balance between the intrinsic features and the institutional control processes. An outline of the overall assessment process, the R&D necessary to develop it, and potential intrinsic proliferation-resistant features is given in DOE's Report Technological Opportunities to Increase the Proliferation Resistance of

Global Civilian Nuclear Power Systems (TOPS) Report prepared by an international task force.[11]

The practicality of pursuing these various increased proliferation-control measures has been questioned and a substitute approach suggested of prohibiting the less proliferation-resistant technologies, such as fuel recycle. Admitting that effective control of proliferation through an international regime is a very difficult task, this alternative suggestion raises serious practicality questions of its own, starting with the historical pattern that technology has not been stopped although it has been controlled. This was the underlying premise of Atoms for Peace once it was realized that secrecy would not be effective in stopping the march of nuclear weapon technology.

An extreme version of this alternative is that nuclear power technology be prohibited. But how would such a prohibition affect nonproliferation efforts? Uranium enrichment and plutonium separation could still be used to produce weapon materials. Large quantities of weapon-usable materials would still have to be protected from diversion. The primary means of disposing of HEU and plutonium from excess weapons would be curtailed. The human infrastructure with the expertise to address proliferation issues would be reduced. The R&D necessary to develop adequate proliferation resistance in the fuel cycle would be stopped.

The Potential Role of International or Regional Fuel Services

Regional Spent Fuel and High-Level Waste Storage and Disposition

From an international perspective, changes are needed in the management of spent fuel and high-level waste. Presently, individual nations carry the responsibilities in this area. International standards provided by the IAEA are used at the discretion of each country. But the high cost and political difficulties of developing geological repositories combined with long-term environmental uncertainties and proliferation concerns suggest that cooperative regional repositories will become appropriate, likely after the initial operations of a small number of national programs. Gaining a global public consensus on the importance of regional repositories is needed.

Several proposals have been made recently to provide such regional facilities. Spent-fuel storage facilities for international users, built and operated in Russia through private sponsorship but under stringent international standards, has been proposed by T. Cochran, National Resources Defense Council.[12] An Internationally Monitored Retrievable Storage System (IMRSS) as an interim commercial warehousing method for managing the worldwide spent-fuel stream has been proposed by W. Haefle & C. Starr.[13] An International Repository Project Pangea, had also been proposed by C. McCombie, et al.,[14] as a commercially sponsored, deep, natural geological repository for spent fuel and high-level waste, located in central Australia, and to be available for all countries. The effort on that project has ended. Garwin and Charpak also propose regional repositories, emphasizing that it is preferable that they be commercial enterprises under strict regulation.[15] Each of

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[11] Technology Opportunities to Increase the Proliferation Resistance of Civilian Nuclear Power Systems (TOPS), Report by the TOPS Task Force of the DOE Nuclear Energy Advisory Committee, January 2001.

[12] Regional Spent Fuel Storage in Russia, NPT, Inc., 1999.

[13] Haefle & Starr, IMRSS, East Asia Seminar, Lawrence Livermore National Laboratory, Las Vegas, Nevada, March 2000.

[14] C. McCombie, et al., Pangea Resources Australia Pty Ltd, 2001.

[15] Richard L. Garwin and Georges Charpak, *Megawatts and Megatons, A Turning Point in the Nuclear Age?*, Knopf, 2001.

these proposals identifies the IAEA as the responsible authority for verifying adherence to stringent safeguards requirements and assuring universal transparency and accountability of all related activities.

Enrichment and Nuclear Fuel Recycle Services

Eisenhower's proposal for an international bank of fissionable material never materialized, but the idea has potential merit as an economic means of handling those portions of the nuclear fuel cycle of concern from a proliferation standpoint. Experience shows that nuclear power plants fueled with low-enrichment uranium (LEU) and operated in the once-through fuel cycle are highly proliferation-resistant because the initial fuel is not weapon-usable and becomes highly radioactive once used for power production. It is in fuel servicing, however, that the potential exists for diversion to weapon development through the clandestine use of enrichment facilities and fuel-recycle activities.

International or regional fuel services can provide LEU and reprocessed mixed oxide (MOX) fuel assemblies to countries utilizing nuclear power. Not only will greater proliferation resistance be achieved but also substantial improvements in economy. Enriching and reprocessing facilities are capital-intensive. To gain economy of scale, large output volumes are needed, making one facility capable of serving the fueling needs of many power plants. Just as in spent fuel and high-level waste management, it is questionable economically for each nation to provide its own fuel services. The global nuclear industry today is in fact following this course, driven by economic necessity. The few exceptions to this raise the question as to their real intentions. Contractual arrangements for these services could provide assurances of fuel supply.

Such services can be provided by government or private organizations under strict regulations. Transparency and unconstrained access for compliance monitoring is required. Accreditation of the fuel-service providers requires demonstrated ability to adhere to NPT compliance standards. Countries interested in developing nuclear power capability will not need to invest in fuel-service capabilities and thus will not have available these means of diverting weapon-usable materials from their commercial nuclear-power facilities.

Conceptual approaches of this sort were a focus of attention during the International Fuel Cycle Evaluation carried out in the 1970s. Related concepts have been proposed in the form of a global network of facilities that would provide all fuel services, including waste disposal.[16]

Fuel Supply Sustainability

The availability and the costs of producing natural uranium play an important role in deciding on nuclear-fuel-cycle options. Future shortages in uranium supply are cited by some as a reason for the pursuit of fuel-recycling and fast-breeder-reactor technologies. Yet, others believe there are plenty of natural uranium resources to sustain a "once-through (direct-disposal)" nuclear fuel cycle for a long time. In the addendum to this appendix, the availability of uranium supplying a modest growth in once-through nuclear power capacity to 2050 is estimated, and the production costs of uranium likely to support the on-set of economically competitive advanced fuel cycle technologies are examined.

Adequate uranium supplies are needed to support an expanded long-term (beyond mid-century) reliance on nuclear power operating on a once-through fuel cycle. Assuming a

[16] *Toward a New Nuclear Regime*, ICAAP 2003, Cordoba, Spain, May 2003.

nominal growth rate for nuclear power of 2% per year to 2050, the nuclear capacity could grow from today's 359 GW(e) to ~1,000 GW(e) at 2050. Correspondingly, the annual uranium requirement would grow from 61,000 tonnes to approximately 18,000 tonnes, with a cumulative uranium requirements from now to 2050 of over 5 million tonnes.

The IAEA and OECD estimate that approximately 4 million tonnes of known uranium resources could be available at production costs up to $130/kilogram-u (or $50/pound of yellow cake). [17] This indicates a deficit between projected requirements and known resources of about 1 million tonnes of natural uranium by 2050. Additional sources of natural uranium exist beyond known resources, but they are expected to occur in deposits on basis of indirect evidence, or they are very low-grade resources not now economically recoverable. If these less-probable or speculative resources can be developed in a timely fashion, the natural uranium fuel supply will be extended significantly. The addendum provides an evaluation of the IAEA–OECD data leading to the conclusions above.

There are two ways that a long-term, abundant supply of uranium can be provided: (1) by recycling spent fuel from power reactors so as to utilize its plutonium and residual uranium, and (2) by extracting uranium from seawater. Nuclear fuel recycle has been developed and is in commercial operation in Europe with their LWRs (thermal spectrum reactors). But the abundant fuel supply needed for sustainability entails recycling spent fuel from fast-spectrum reactors. Extensive R&D and demonstration has been carried on fast-reactor recycling showing that it is feasible, but the systems the systems developed to date are much too high in cost and proliferation concerns have not been fully satisfied. Uranium extraction from seawater is also feasible but is also faced with serious cost hurdles because the uranium concentration in seawater is only about 4 parts per billion. Innovative R&D programs on each of these approaches are needed to address the cost and proliferation issues.

There is substantial disagreement on the importance and role of a closed fuel cycle in future deployment of nuclear power. These differences have been recently highlighted by the MIT Interdisciplinary Study of the Future of Nuclear Power and the critique of that study by the French Commissariat á l'Énergie Atomique (CEA).[18]

The MIT study's overall conclusions are that the best choice to provide for a large expansion of nuclear power is through conventional reactor plants operating in the open, once-through fuel cycle, although present designs need to be reduced in capital cost to gain market acceptance. Adequate uranium resources are available at reasonable cost to support this choice. Public acceptance is critical to a successful expansion.

The CEA critique agrees with the MIT study that nuclear power is an important option with which to meet the future needs of global electric power generation and the mitigation of deleterious climate change as well as for near-term deployment, now through 2040, of conventional once-through reactors, primarily LWRs. But CEA states that new LWR plants are competitive now with natural gas-fired (CCGT) and coal-fired generators in Europe and uranium resources, based on OECD–IAEA data; CEA's critique questions that the uranium supply needed to fuel the MIT study's deployment scenario at an economically attractive price will be sufficient. CEA further states that "the reprocessing and MOX recycling option using current industrial technologies only induces a very small cost penalty, if any, on the total cost of electricity production" and that the safety, proliferation resistance, and waste

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[17] *Uranium 2001: Resources, Production, and Demand*, A Joint Report by the OECD–NEA and the IAEA.

[18] Comments on the MIT Report on *The Future of Nuclear* Power—An Interdisciplinary MIT Study, Nuclear Energy Division, Commissariat á l'énergie atomique, Paris, 17 September 2003.

management of the nuclear fuel recycle are favorable based on the French experience in fuel recycle in LWRs and on the merits of destroying plutonium through recycle.

The Role of Government and Industry in Bringing about Changes in the Deployment of Nuclear Power

Pre-Deployment Phases

Government has historically played a crucial role in the development of technologies that have brought about the current, relatively widespread deployment of LWRs. Early government-sponsored technology advances, particularly those related to naval propulsion, provided a technical foundation for the LWRs that make up the large majority of systems now deployed globally. Government has also provided assistance during demonstration phases. Industry then provided the capital and human resources. The ability of industry to undertake capital-intensive, long-term projects (such as the construction of new nuclear power plants) was facilitated by government (the regulator's) assurance of a reasonable return on the plant investment. Because power generation is being rate-deregulated, utilities, at least in many areas of the United States, must now bear the long-term financial and operational risks associated with large-scale, base-load power plants, such as nuclear plants.

It is argued that government should continue to facilitate private sector investment in long-term power generation. Such support needs to be justified by major societal benefits for which government is responsible (e.g., obtaining security of energy supply or meeting treaty commitments concerning reduction in greenhouse-gas emissions).

Deployment Support

A primary role of government during the deployment of nuclear facilities is to establish a transparent regulatory system of requirements and compliance measures that ensures the safety of the public. The government also plays a key role in the economic regulation of electricity generation, often through local jurisdictions (such as individual states within the United States). Even with the present trend toward rate deregulation, many elements of the former full-economic regulation remain. If rate deregulation is to fulfill its prime purpose of fostering competition, it is imperative that these remaining regulations provide an even playing field for all the competitors.

Long-Term Research, Development, and Demonstration

The government normally assumes the role of research, development, and demonstration (RD&D) of advanced technologies because the time scale to commercial deployment is too long for the private sector to obtain any return on the RD&D investment. When the goal is to develop highly innovative or revolutionary systems, private investment is reluctant to assume the financial risks. Government has a clear interest in ensuring that such developments meet public safety, environmental, and nonproliferation standards. Government funding of long-term RD&D for combustion-free, nuclear-power generation is needed to the point that the option for commercial deployment and private sector investment is viable.

The Role of International Bodies in Monitoring or Regulating Future Nuclear Power and Technology Deployment

The revelations arising from the Chernobyl accident have galvanized the IAEA and the international nuclear industry to develop common international standards for safe designs and operating practices, closing the gap between the former Soviet Union and Western world practices. Safety regulation still remains in the hands of national entities, but a new IAEA Safety Protocol is being implemented that provides for periodic peer review of each country's regulatory status and effectiveness, as well as its conformance with the IAEA general safety standards.

The IAEA carries out design evaluations, probabilistic safety assessment reviews, and operating plant reviews as important tools in strengthening operational safety and identifying standards needs. The formation of WANO has provided international industry peer reviews, technical support missions, benchmarking of best operating practices, training-program accreditation, and performance indicators, all leading to excellence in operation. Substantial additional effort is needed to achieve a uniform excellence throughout the world.

Implications of External Factors—Global Warming, Fossil Energy Limitations, and Security Concerns

Efforts to date to address global climate change have not produced the desired reductions in carbon emissions. Primary contributions to the reduction of emissions have been made by nuclear power plants (by avoiding emissions that would otherwise come from fossil plants) and by conservation aided by the recent slowdowns in the global economy.

Despite nuclear power's significant contribution to reducing emissions of carbon dioxide and other air pollutants, it has not been recognized at the Conferences of the Parties (COPS) to the United Nations Framework Convention on Climate Change (UNFCCC) as the Clean Development Mechanism (CDM) framework, one of the UNFCCC's methods allowed for achieving the required reduction. Today, about one-quarter of the world's carbon dioxide emissions come from the United States, one-quarter from the rest of the OECD countries, and the remaining one-half from the rest of the world. The world's total carbon-dioxide emissions are expected to grow from 21 billion tonnes in 1990 to 36 billion tonnes in 2020 (**Table B-2**).

Table B-2. Global CO_2 emissions by regions and by sector (million tonnes of CO_2) [Source: IEA, World Energy Outlook, December 2000].

Year	World Total	OECD Countries	Transition Economies	Developing Countries
1990	20,878	10,640	4,066	6,171
1997	22,561	11,640	2,566	8,528
2010	29,575	13,289	3,091	13,195
2020	36,102	14,298	3,814	17,990

For example, between 1973 and 1998, U.S. nuclear generation avoided the emission of 87.3 million tons of sulfur dioxide, more than 40 million tons of nitrogen oxides, and 2.47 billion tons of carbon. Nuclear power plants were responsible for nearly half of the total voluntary reductions in greenhouse-gas emissions reported by U.S. companies in 1998.[19] The present reluctance to permit nuclear plants to engage in emission trading should be eased in

[19] "A Healthful Dab of Radiation?," *Science*, October 17, 2003, p. 378.

the future to provide the incentive to increase their present contribution to reduced air pollution and greenhouse-gas emissions.

The dependence of many countries on foreign sources of oil poses a substantial future risk to their functioning economies, particularly with the unsettled conditions in the Middle East and Venezuela. The United States presently imports 60% of its oil from overseas, substantially more than when precipitous OPEC price increases disrupted the U.S. economy in the late 1970s. In part, because of the contribution of nuclear power, the electrical sector in the United States and other countries is relatively independent of overseas oil at present, in contrast to the transportation sector. But urgent development efforts should be initiated to provide fuels that can substitute for oil and gas in all sectors. Hydrogen fuel and electrified vehicles can meet such goals if they can be deployed economically. Nuclear power can provide the non-carbon-generating primary energy source through hydrogen and electricity production.

Future national security prospects can be greatly improved by providing ample energy globally, including nuclear energy. Abundant power globally will in the long term remove one of the prime causes of political unrest (low standards of living with no prospect for improvement) and its extreme ramifications in the form of terrorism and war.

The Level of Public Acceptance of Nuclear Energy Technologies

After initial enthusiasm, the public's opposition over the perceived safety of nuclear plants and radwaste disposal has been an impediment to gaining the strong national support needed to sustain a growing role for nuclear power. Poor reliability of nuclear plants in earlier years and highly publicized incidents requiring regulatory intervention have also reduced public confidence. In general, experience has shown that any accident or significant problem incurred by one nuclear plant is perceived by the public as a similar potential accident for all the other plants worldwide.

An underlying source of public unease is the fear of radiation. A contributing factor is the lack of scientific proof that radiation at very low levels is not harmful. To account for uncertainty in the health effects of low-level radiation, it is assumed in setting standards that a "linear hypothesis" applies, i.e., the damage to health is proportional to the radiation dose received, even when it is well below natural background levels. No data at these low levels substantiate the hypothesis. Yet, some have inappropriately multiplied very low individual doses by large populations to infer serious health problems. On the other hand, increased consideration is being given to the hypothesis that such low levels of radiation dose cause health benefits, as seems to be the case for low dosages of some chemicals and drugs. An increased level of research is warranted on the health effects of low-level radiation.

Other public acceptance problems arise from the military nuclear legacy. Examples are residual radioactive waste in decommissioned military facilities and sites, fully fueled decommissioned Soviet submarines, and excess weapon-material stockpiles. Although not arising from the civilian nuclear industry, their existence casts a shadow on the industry that will continue until the problems are being effectively addressed.

Necessary, but not sufficient, means of obtaining better public acceptance are in the hands of the nuclear industry. The present good record of safety and reliability must be maintained and where practicable, improved. When safety issues arise, they must be disclosed to the public fully and action taken promptly to ascertain root causes and expedite remedies. Continued effort is essential to disseminate accurate information on the progress and benefits of nuclear power. The future of civilian applications rides on public confidence that the benefits of nuclear technology substantially outweigh the risks.

Opportunities for Advanced Energy RD&D

Four major future opportunities exist for nuclear energy, each of which requires major R&DD effort:

1. Expansion of the end-uses of nuclear energy to transportation and industrial and residential heating through increased electrification, and through the use of high-temperature reactors;
2. Development of economic hydrogen-fuel production and desalination capabilities where a primary function of nuclear energy is to provide bulk power;
3. Closing of the nuclear fuel cycle to provide centuries of fuel sustainability;
4. Deployment of small, nominal-output nuclear plants that provide the benefits of nuclear power to smaller and less-developed countries.

Some of these goals can be achieved with conventional power plants where bulk electricity is the primary need, such as increased electrification, hydrogen production, and desalination depending on their cost. The other goals will require advanced reactor designs, including coolants other than water and gas. DOE has initiated the Generation IV and Advanced Fuel Cycle Programs to carry out the RD&D to realize those four opportunities while achieving economic competitiveness, fuel supply sustainability, high standards of safety and proliferation resistance, and effective waste management. A variety of reactor types are included in the Generation IV Program utilizing as coolants liquid metal (sodium and a lead bismuth alloy), gas (primarily helium), and light water and operating either in the thermal or fast spectral range. All but the light-water systems will operate at high temperatures to achieve greater efficiency.

A variety of fuel cycles are also under consideration in the Advanced Duel Cycle Program: plutonium and thorium recycle in both existing LWRs as well as in advanced plants with net fissionable material production capability. Advanced forms of aqueous reprocessing and innovative pyro–metallurgical reprocessing utilizing a metal fuel form are being pursued. Both processes would retain the actinides in the reprocessed fuel to improve proliferation resistance and minimize the long-lived radioactivity in the waste stream. International cooperation in these efforts is being fostered though the Generation IV International Forum. The IAEA, in cooperation with other member states, is also pursuing an advanced reactor effort (INPRO).

A new initiative is underway in the United States to introduce hydrogen as an alternative to oil products in the transportation sector. Nuclear power has the potential to contribute as a non-carbon-emitting hydrogen producer and this potential is also being pursued in the Generation IV Program. The simplest and proven method of hydrogen production is by the electrolysis of water, but the overall thermal efficiency, particularly with present LWRs, makes it too expensive. High-temperature, gas-cooled reactors (HTGRs) are more economic because of their higher efficiency, but even higher temperatures are probably needed. Accordingly, a specific plan within the Generation IV Program is to design and build a very high temperature gas-cooled demonstration reactor (VHTGR) at the Idaho National Engineering and Environmental Laboratory. Japan (JAERI) is well in the lead in developing the HTGR for this purpose and plans to put into operation the world's first nuclear-powered, steam-reforming, hydrogen production facility in 2008. Nuclear power will be in competition with alternative power generators for this application, where both efficiency and economy are key challenges. Major R&DD will also be needed on the hydrogen separation processes themselves, including the development of an economic and safe infrastructure for the delivery of hydrogen.

A small electric generator of nominal power output is needed to open the market to small countries or grids to help relieve the present disparity in providing the benefits of nuclear technology to the developing nations. The Generation IV Program is pursuing the concept of integrated, transportable power packages with various coolants that do not require re-fueling and could provide power over a 10-year period. Such a non-refuelable unit could have very high proliferation resistance.

Other Civilian Applications of Nuclear Technology

The Current Status

Radiation Applications

Overall Impact

In his Atoms for Peace address, Eisenhower specifically challenged scientists and engineers to harness the atom for humanitarian applications in medicine, agriculture, and other non-power aspects of direct benefit. **Table B-3** summarizes the economic and job impacts of nuclear technology in the United States for both 1991 and 1995 as compiled by Management Information Services.[20,21] Although the total impact, both in terms of dollars and jobs is most impressive, the impact of the atom is substantially larger in the non-power sector than in the sector comprising nuclear power. For both 1991 and 1995, the ubiquitous use of radioisotopes to serve a myriad of beneficial purposes yielded revenues and jobs well over three times that contributed by the nuclear generation of electricity.

Table B-3. Overall economic impact of nuclear technology in the United States (1995 data, based on multiplicative effects).

	Annual sales ($ billions)	Jobs (millions)
Radioisotopes	331	4.0
Nuclear energy	90	0.4
Total	421	4.4

Safety and proliferation concerns have recently arisen with respect to the utilization of radioactive sources: the hazards to the public from "orphan" sources and the possibility that radioactive sources might be incorporated by terrorists into conventional bombs and used as radiation dispersal devices (RDDs). Safe disposal of the radioactive wastes from these applications is becoming an increasingly serious problem. Disposal facilities have not expanded for many years so that universities, biotech and pharmaceutical companies, and medical centers are fast running out of places to dispose of their wastes.[22]

A summary is given below on how the atom has currently been harnessed globally for use in non-power applications. It is substantially longer than the summary of the current

[20] Management Information Services, Inc., *Economic and Employment Benefits of the Use of Nuclear Energy to Produce Electricity*, 1994.

[21] *The Untold Story: Economic and Employment Benefits of the Use of Radioactive Materials*, 1994.

[22] *A National Solution to a National Problem*, Radiation Solutions Magazine, American Nuclear Society, IL, Sept/Oct 2003.

status of nuclear power because of the variety of different technologies and their applications.

Medicine

Perhaps the most significant success story over the past half-century in harnessing radiation to serve humanity is in the field of medicine. Both the quality of life and longevity of citizens throughout the developed world have improved substantially within the 20th century, largely due to dramatic medical advances. Medical applications of nuclear technology have saved millions of lives over the 50 years of Atoms for Peace.

In the clinic, radioactivity is playing an ever-expanding role, having grown from occasional tests in a smattering of hospitals to the incredible level of 16 million nuclear medicine imaging and therapeutic procedures per year in over 3,900 nuclear medicine departments in the United States. In 1953, the dominant clinical usage was in the diagnosis and treatment of thyroid disease. Today, 45% of nuclear medical examinations involve the imaging of the heart and coronary arteries, and 38% are cancer-related, involving both diagnosis and treatment. What began in response to the thyroid gland's ability to concentrate iodide has now become a fascinating spectrum of markers that can target almost any organ and a rapidly increasing number of processes throughout the body. The magical quality here is being able to image the intensity and spacial localization of specific biochemical properties, allowing the clinician to find the cancer metastases, or to earmark the degenerate tangled fibrils of Alzheimer's disease in a particular part of the brain. Cardiovascular applications dominate because of the newfound ability to assess coronary artery blood flow and function through nuclear imaging methods.

Sterilizing Medical Equipment. Knowing that radiation in high enough quantities can kill microorganisms, the medical community quickly recognized the potential for employing certain types of radiation (mainly gamma radiation) to sterilize dressings, surgical gloves, bandages, plastic and rubber sheets, syringes, catheters, sutures, heart valves, and a myriad of other devices routinely used during medical procedures. Radiation is effectively used to sterilize a range of heat-sensitive items, such as powders, ointments and solutions, and biological preparations such as bone, nerve, skin, etc., used in tissue grafts. Today, well over half of all sterilized medical equipment used in modern hospitals is a direct result of radiation treatment.

New Drug Testing. Radioisotopes, due to their unique imaging characteristics (particle emission), are ideally suited to deal with testing new drugs—including material uptake, metabolism, distribution, and elimination of unwanted residues from the body. It is estimated that over 80% of all the new drugs eventually approved for medical use employ radiation techniques in testing. The IAEA has estimated that between 100 and 300 radiopharmaceuticals are in routine use throughout the world and most are commercially available.

Diagnostic Techniques. It is this element of medicine where radiation techniques have made their most significant contribution to enhanced health care. The earliest use of radiation in the medical field was employing portable x-rays sources in World War I, where such devices helped field surgeons save many lives. Dental x-rays, chest x-rays, mammograms, and a plethora of other tests are in routine use today in the medical and dental professions.

But x rays, useful as they are, provide only a snapshot of a particular piece of the anatomy. The imaging properties of radioisotopes and radiation allow modern nuclear medical specialists to measure the activity of some specific physiological or biochemical function in the body as a function of time. This has enormous implications, all the way from determining nutritional deficiencies to locating and identifying various types of cancer.

Two of the most common approaches used in modern diagnostic nuclear medicine are single photon emission computed tomography (SPECT) and positron emission tomography (PET). SPECT is widely used for routine clinical work because it is relatively inexpensive and utilizes radioisotopes available from nuclear reactors. Technetium-99m (Tc-99m), a 140-keV gamma emitter with a 6-hour half-life, is the most popular radioisotope used in this device. The SPECT system works by placing a solution containing a short-lived radioisotope such as Tc-99m into the patient. The patient stays in a fixed position and cameras (detector systems) rotate around the patient, picking up the gamma rays emitted by the Tc-99m circulating in the patient's body. By the clever use of microprocessors, the data collected by the cameras can be sorted out and the location of the Tc-99m radioisotope can be followed as a function of time. If bone cancer exists, the chemical carrier to which the Tc-99m is attached will tend to collect at the sites of the tumors, and tell-tale sharp images at those sites clearly reveal the problem. Whereas Tc-99m is by far the most popular radioisotope used for such purposes, some SPECT systems have been equipped with flourine-18 (F-18) embedded in 18F-deoxyglucose (18FDG). F-18 has a substantially more energetic gamma ray (511 keV), thus requiring a different detector system. Other radioisotopes, generally produced by nuclear reactors for such use, are iodine-131 (I-131), gallium-67, and thallium-210.

PET devices are based on the detection of a pair of photons emitted from positron annihilation. Very shortly after a positron is emitted from a radioactive substance such as F-18, it collides with an electron and the two particles are literally annihilated. The mass of the two particles is translated into pure energy and two 511-keV gamma rays move apart at light speed in precisely opposite directions. By surrounding the patient with special detectors, the location of the radioisotope can be pinpointed by determining counts recorded at exactly the same time (coincidence counting) at opposite sides of the patient. PET systems tend to be more expensive than SPECT systems, partly because of the sophistication of the counting system and partly because the radioisotopes that emit positrons typically have a very short half-life (minutes). Hence, they must be produced on-site by accelerators (usually cyclotrons) and administered to the patient with the proper chemical carrier very quickly. PET machines are becoming increasingly popular because they are more precise than most SPECT devices. Three-dimensional PET systems are particularly impressive and can provide the diagnostician excellent images. Radioisotopes often used in such devices, in addition to F-18, include carbon-11, nitrogen-13, and oxygen-15.

Nuclear diagnostics are now routinely employed throughout the developed world to determine anomalies in the heart, brain, kidneys, lungs, liver, breast, and thyroid glands. Bone and joint disorders, along with spinal disorders, also benefit directly from this routine use of radioisotopes.

Therapeutic Approaches. Until recently, the use of radiation to cure diseases has been limited. One of the first therapeutic uses of radioisotopes employed I-131 to cure thyroid cancer. Because the thyroid gland has a special affinity for iodine, it is a relatively simple and straightforward matter to have a patient drink a carefully determined amount of I-131 in a chemically palatable form of solution. The I-131 then preferentially lodges in the thyroid gland and the beta-emitting properties of this radioisotope subsequently target and destroy the thyroid malignancy. Because I-131 has a half-life of 8 days, it does its job and then effectively disappears within a few weeks.

Another widespread use of radiation is in the treatment of other cancers. Surgery, chemotherapy, and radiation (often in combination) constitute the principal venues of cancer treatment today. Most of the current procedures utilizing radiation to kill cancer in humans are based on delivering the radiation to the patient externally. This is called *teletherapy*. Accelerators are used to deliver either protons to the target or beta particles, which are normally directed onto a target that secondarily produces x rays. Whereas substantial benefits can be obtained by such treatment, it is essentially impossible to keep the radiation from killing or impairing healthy tissue in the immediate vicinity—especially if the beam must pass through healthy tissue to reach the malignancy. The two principal approaches underway to prevent radiation therapy from injuring healthy cells are (1) creating radioisotopes at the site of the malignancy, and (2) developing a method to deliver appropriate radioisotopes directly to the cancerous tissue.

An example of the first approach is called *boron-neutron capture therapy*. Boron is placed into the patient as part of a special chemical carrier such that it preferentially concentrates at the tumor site. A neutron beam is then focused on the boron, producing alpha particles that destroy the malignant cells only in the immediate vicinity of the concentrated boron. Because alpha particles are stopped at a very short distance from their point of origin (typically about one human cell), the intense radiation damage is very localized. Some healthy cells may be damaged by the neutrons passing to reach the malignancy, but special "beam tailoring" can be done to minimize this concern.

An example of the second approach is *cell-directed radiation therapy*. To attain the localized damage desired, either beta or alpha emitters are needed. For solid tumors, one method of getting the radioisotope to the target is direct injection, assuming the tumor is accessible. *Brachytherapy* is one well-founded application of this technique in treating prostate cancer. This is accomplished by encapsulating a small amount of a radionuclide such as I-125 or palladium-103 within a titanium capsule about the size of a grain of rice. These "seeds" are then placed directly into the prostate gland where they remain for life.

Another approach to cell-directed radiation therapy is to find a chemical that has a special affinity for the malignancy, and then attach the radioisotope to this special carrier. This is the *monoclonal antibody* (or "smart bullet") and is particularly suited for treating malignancies not confined to a particular spot. Leukemia and Non-Hodgkin's diseases are examples. Recent work employing the smart bullet approach has revealed some very impressive results. End-stage Hodgkin's disease has been treated with yttrium-90 (a beta emitter), with a positive response rate of over 80% (for patients who have failed all other known treatments). Patients with advanced stages of B-cell lymphomas treated with I-131 have a demonstrated survival rate of over 90%. Recent trials using an alpha emitter (bismuth-213) have shown remarkable results in treating leukemia.

Several specialized areas of treating specific abnormalities are developing on almost a constant basis. Most people are aware of the procedure called *angioplasty* (inserting a balloon into a clogged artery and passing it through in a "roto-rooter" manner to unclog it). Although this procedure has a high success rate and has prevented a plethora of heart attacks, there are several cases where the arteries slowly become re-blocked. Several years ago, it was discovered that lining the balloon with rehenium-86 made a huge impact in preventing re-closure of the arteries.

Another example of a specialty area is the treatment of arterio-venous malformation. This condition is a malformation of blood vessels characterized by a mass of unwanted arteries in the brain. A special mixture containing a radioactive powder is injected into the artery, causing an arterial occlusion, thereby stopping the blood flow into the unwanted vessels.

Although many of the above results are still in relatively early trial stages, the potential for success is substantial. Given that cancer remains a major concern in most areas of the world, and that it is the most prevalent childhood disease in the Western world, the incentive for further harnessing radiation in the field of medicine remains huge.

Agriculture

Today some one billion of people in the world (approximately one out of every five) go to bed hungry every night. Tens of thousands die every day from hunger and hunger-related diseases. There is an enormous need to find new ways to increase food production and deliver it to an increasing population with only minimum spoilage. The following paragraphs provide a glimpse of the contributions radiation makes in the constant quest for enhanced supplies of quality food.

Higher Crop Production. The demand for fertilizer, which is essential in modern agriculture practices to maximize crop yields, will continue to mount in order to provide food for a rapidly increasing world population. By attaching radioactive tracers to known quantities and varieties of fertilizers, it is possible to determine directly the associated nutrient efficiencies as labeled products are absorbed at critical locations in the plant. This technique reduces the amount of fertilizer required to produce robust yields, thereby reducing costs to the farmer and minimizing environmental damage.

Water is critically important for crop production. Neutron moisture gauges, which measure the spectrum shift resulting from the impingent of energetic neutrons upon protons, measures the hydrogen component of water in both the plant and the surrounding soil. As such, they are ideal instruments to help farmers make the best use of limited water supplies.

Another effective way to improve crop production is to develop new species—varieties that can better withstand heat or storm damage, exhibit enhanced maturing times (to escape frost damage and allow crop rotation), attain increased disease and draught resistance, provide better growth and yield patterns, deliver improved nutritional value, allow improved processing quality, and enhance customer acceptance.[23] Subjecting plants and seeds to carefully tailored ionizing radiation to create new combinations in their genetic makeup has resulted in improved strains of numerous crops. Many of these superior species now constitute a key part of modern agricultural commerce around the world. Over 30 nations have developed more than 2,250 new crop varieties in the past 70 years—with radiation being the key element in the development of 89% of this enormous new stock.[24]

The application of radiation techniques to the development of new crop varieties has likely provided the highest global economic value of any form of radiation. Mutant varieties (called *cultivars*) making major contributions to the global economy include grains such as rice, barley, wheat, beans, lentils, and peas. Other crops include new varieties of cotton, soybeans, sunflowers, and peppermint. New fruit varieties include apples, cherries, oranges, peaches, bananas, apricots, pomegranates, pears, and grapefruit. There is even one

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[23] "Induced Mutations and Molecular Techniques for Crop Production," *Proceedings of a Symposium* jointly organized by IAEA and FAO, Vienna, June 19–23, 1995.

[24] B.S. Ahloowalia, M. Maluszynski, and Karin Nichtertein, "Global Impact of Mutation-Derived Varieties," *Joint FAO–IAEA Division of Nuclear Techniques in Food and Agriculture*, International Atomic Energy Agency, Vienna, Austria, February, 2003.

cultivar for raspberries and grapes. Of the 2,250 new crop varieties noted above, 75% are crops of the type just mentioned. The other 25% are ornamental flowers, such as chrysanthemums, roses, dahlias, bougainvillea, begonias, carnations, alstroemerias, achimenes, streptocarpus, and azaleas.

Gamma rays are used in the majority of cases to change plant characteristics (64%) and x rays are employed in another 22%. The bulk of the remaining 14% is done via fast and thermal neutrons. To date, China has benefited the most from the utilization of radiation to improve crop species. As of 2002, nearly 27% of the crops grown in China were developed using radiation techniques. China is followed by India (11.5%), U.S.S.R./Russia (9.3%), The Netherlands (7.8%), United States (5.7%), and Japan (5.3%).

Rice is the major source of food for over 50% of the global population and is especially important in the Asian diet. Some 434 mutant varieties of rice have been developed, of which half were developed from gamma radiation.

Because of radiation, Thailand has become the largest exporter of aromatic rice in the world. During the decade from 1989 to 1998, Thailand produced $19.9 billion of milled rice! Barley is a prime ingredient in making malt. Mutant varieties such as 'Diamant' and 'Golden Promise' are two radiation products that have made a major impact to the European brewing and malting industry. This industry provided Scotland with a revenue of approximately $417 million over the last quarter century. Both the United Kingdom and Ireland likewise make wide use of 'Golden Promise' for their beers and whiskey.

Wheat is the staple grain for many countries, including the United States. In Italy, the Durham wheat 'Creso' mutant was developed via radiation. By 1984, this mutant reached 53.3% of the Italian market—such that over 50% of the pizza consumed today in Italy is the direct result of harnessed radiation!

A special high-yield cotton mutant, NIAB-78, was produced by gamma rays and released for commercial production in 1983. This variety has shorter stature (so that the nutrients go into the product rather than the stock), better growth, enhanced heat tolerance, and it is resistant to bollworm attack due to early maturity. It has had a pronounced impact in Pakistan, where their entire clothing industry was threatened by an insect infestation. Within 5 years of the release of this new, radiation-induced variety, the cotton production in Pakistan doubled. Within 10 years of release, this variety yielded over $3.0 billion in cotton production.

Improving Animal Health. One key application of radiation concerns the best way to feed animals, natural pastures or commercially prepared feeds. This is accomplished by labeling the feed with specialty radioisotopes, such as carbon-14, and then tracing the paths of the food within the animal's digestive system to determine where and how quickly the food is broken down into body tissues or milk. The nutritional value of the food is thereby determined.

In many parts of Asia, the primary feedstock for buffaloes and cattle consists of rice straw and native grass. This combination often lacks sufficient protein, energy, and minerals needed for a balanced diet. Employing tracer radioisotopes to determine the key nutritional deficiencies has been used quite effectively in places like India and Indonesia. In one example, scientists in Indonesia were able to develop a multi-nutrient block for buffaloes to lick. This increased buffalo weight gain at the rate of 3 kilograms per week and at the same time reduced their need for grass consumption by 80%.

Radioisotopes have also been used to develop vaccinations for certain animal diseases. A rather dramatic example is the approach used to fight rinderpest ("cattle plague"), a dreaded cattle disease that has devastated untold African farms for the past four decades. Millions of cattle have died from this disease. Punctuated by a series of rinderpest outbreaks in the 1980s, a combined effort from the IAEA, FAO, and a British laboratory was initiated to employ radioisotopes in developing an effective vaccination. They accomplished their mission in 1987. By the year 2000, use of this specially developed vaccine had eradicated this disease in 16 of the 18 African countries previously infested.[25]

Eradication of Pests. Estimates of harvest loss due to unwanted insects range from about 10% annually to as high as 30% in some of the developing countries. Conventional chemical treatments to control such insects often create environmental pollution and even toxic residues in our food chain. Further, many insects have developed enough resistance to insecticides to force the use of even higher quantities of insecticide to be effective.

One proven way to use nuclear technology in controlling or even eradicating unwanted insects is the sterile insect technique (SIT). This approach involves rearing a large male population of the unwanted insects, subjecting the unhatched eggs to sufficient levels of gamma irradiation to achieve sexual sterilization (but leaving other capabilities unchanged), and then releasing the hatched sterilized males into their native environment. When the sterile insects subsequently mate with the wild insects, no offspring are produced. In addition to being environmentally sound, this technique is often the only practical means to ensure pest eradication.

Since initial successful testing of this technique in the mid-1950s, the screwworm has been eradicated in both Mexico and the United States. The tsetse fly, which transmits disease in cattle and sleeping sickness in humans, once prevented the settlement and development of large areas of Africa. Fortunately, the SIT technique has successfully eradicated one species of tsetse flies in parts of Nigeria.

Perhaps the largest success to date in utilizing this technique is that achieved in Mexico against the Medfly (Mediterranean fruit fly) and the screwworm.[26] By 1981, essentially complete success was declared for the Medfly operation. By 1991, the screwworm eradication program had yielded some $3 billion in benefits to the Mexican economy.

Food Processing

Tragically, infestation and spoilage prevents at least one fourth of the annual food production in the world from reaching its citizens. The percentage of harvested seafood that never reaches a human mouth is even higher—sometimes well over 50%. This is particularly the case in countries with warm and humid climates, characteristic of many of the developing nations.

In addition to the spoilage of massive quantities, food can become unsafe for consumption due to contaminants such as insects, molds, and bacteria. The U.S. Centers for Disease Control and Prevention estimated in 1999 that approximately 5,000 Americans die each year from food-borne diseases, beginning with symptoms including nausea, cramps and diarrhea.[27] In addition to these deaths from eating contaminated food, some 30 million

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[25] Jihui Qian and Alexander Rogov, "Atoms for Peace: Extending the Benefits of Nuclear Technologies," http://www.iaea.or.at/worldatom/Periodicals/Bull371/qian.html, 2003.

[26] Uranium Information Centre, Ltd., Australia, http://www.uic.com.au/peac.htm, 2003.

[27] "Irradiated food, good; food borne pathogens, bad," *Nuclear News*, American Nuclear Society, July 2003, p. 62.

U.S. citizens become sick from food-related illnesses each year, and approximately 300,000 of these people are hospitalized.

Historically, food preservation methods have evolved from the earliest days of sun-drying to salting, smoking, canning, heating, freezing, and the addition of chemicals such as methyl bromide. Fortunately, food irradiation is now positioned to provide a substantially superior method.

Food irradiation involves subjecting the food to carefully controlled amounts of ionizing radiation, such as beta particles or gamma rays, to break the DNA bonds of targeted pathogens. This is especially effective in destroying the reproductive cycle of bacteria and pathogens. Such radiation can eradicate unwanted organisms and specific, non-spore forming pathogenic microorganisms such as salmonella. It can also interfere with physiological process such as sprouting in potatoes or onions. Thus, shelf life of many foods can be extended appreciably, and food-borne disease organisms such as E. coli (0157:H7) can be dramatically reduced. Beta rays are produced by acceleration while gamma rays are normally produced by the radioactive decay of cobalt-60. X rays can also be effectively used. They are normally produced by acceleration in which the beta rays are directed onto a target material such as tungsten that converts the energy into x rays.

During the irradiation process, prepackaged food is moved by a transport system into a thick-walled room that houses the irradiator. The food is exposed to the beta rays, x rays, or gamma rays for a pre-specified amount of time to receive the precise dose determined optimal for the particular type of food being processed. The food is then removed from the irradiation beam and placed onto a truck for delivery to the consumer. It is important to note that the processed food does *not* become radioactive.

At the doses prescribed, the beta, gamma, or x rays do not transform (transmute) the food into becoming radioactive. The goal of food irradiation is not to totally eliminate biological contamination, but rather to reduce it to about 0.001% of its original value (i.e., reduce the contaminants by about five orders of magnitude). It is important that a small residue of pathogenic microorganisms remains in a healthy body to keep its immune system functioning. Without an active immune system, humans would be forced to live in a completely sterile environment.

The ability of food irradiation to rid contaminated food of unwanted pathogens and bacteria is important. Humans are gradually becoming immune to some of the standard antibiotics, and many epidemiologists are giving more attention to improving the safety of our food, rather than attempting to deal with the sickness that follows in eating contaminated food. Another advantage of food irradiation is that it sterilizes food without altering its form or taste. The older methods of food processing, which rely on temperature extremes (heating or freezing), extreme drying or salting, or chemical treating, often change the nature and taste of the food.

As of 2000, over 40 nations have approved the use of food irradiation for at least some products. In addition to the United States, they include China, France, Germany, Great Britain, Israel, Japan, The Netherlands, India, and South Africa. Irradiated food is now accepted for situations where food sickness could have particularly catastrophic implications (e.g., astronauts and open-heart surgery patients). Groups that could particularly benefit from the large-scale employment of food irradiation include hospital patients, school pupils, and airline passengers (particularly for long, international flights).

Although widespread acceptance of food irradiation by the general public has been slow, there are several signs—particularly in the United States—that indicate consumer acceptance is not far away. Major supermarkets such as Safeway, Albertsons, Giant Eagle, and Winn-Dixie have signed on to offer irradiated meat at some of their stores. Dr. Elsa Murano, Undersecretary for the Food Safety and Inspection Service of the U.S. Department of Agriculture (USDA), reported at the First World Congress on Food Irradiation (May 5–6, 2003 Chicago) that the 2002 Farm Bill approved by Congress mandates that commodities such as meat and poultry treated by any technology approved by the USDA and the FDA to improve food safety must be made available to the National School Lunch Program.[28] She quickly pointed out that food irradiation is included in this mandate.

Industry

Process Control. Modern manufacturing succeeds when products can be turned out in high volume, high quality, and at low cost. This places a high demand on instrumentation that can measure and rapidly adjust for any variations from product specifications during production. Typical measurements often made in production lines include liquid levels, the density of materials in vessels and pipelines, the thickness of sheets and coatings, and the amounts and properties of materials on conveyor belts. Because radiation has the ability to penetrate matter, industrial measurements can be made using radioisotopes without the need for direct physical contact of either the source or sensor. This allows on-line measurements to be made, non-destructively, while the material being measured is in motion.

Level gauges generally operate on the principle of attenuation. A radiation source is placed on one side of a container being filled and a detector is located on the opposite wall. When the liquid rises to intersect the line between these two instruments, the signal seen by the detector drops dramatically. This is the technique used to guarantee proper filling of common soda cans. Gamma backscattering techniques are also used for some level gauge applications.

Radioisotope thickness gauges are unequalled in their performance and are used extensively in almost any industry involved in producing sheet material (sheet metal, paper, etc.). Modern steel mills utilize such gauges to accurately measure the thickness of rolled metals at every moment of the production process. This is likewise the case in paper mills, including the accurate measurement of wet pulp in the first stages of paper production. Such gauges are also frequently used in the food industry (including filling cereal boxes) and the oil industry, where determining the density of liquids, solids, or slurries is important.

Plant Operations Diagnostics. A plethora of radioactive tracer techniques have been employed to investigate reasons for reduced efficiency in modern plant operations. Tracers are now routinely used to measure flow rates, study mixing patterns, and locate leaks in heat exchangers and pipelines.

The petroleum industry routinely employs radioisotopes to locate leaks in oil or gas lines. For example, India recently completed a 140-kilometer-long crude oil pipeline and considered both a conventional approach (hydrostatic pressurization and visual inspection) and a radioisotope tracer technique to find the location of leaks. They chose the latter, which allowed testing to be completed in six weeks (relative to an estimated six months using hydrostatic pressure) and saved $300,000 in the process.

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[28] "Irradiated food, good; food borne pathogens, bad," *Nuclear News*, American Nuclear Society, July 2003, p. 62.

Materials Development. Unique properties of radiation have been harnessed to produce a wide variety of specialty products. Changes in molecular structure, including the inducement of desired chemical reactions, can be created in certain materials by appropriate exposure to radiation. For example, some polymers, whose cross-linkage is induced by radiation, can be tailored to shrink when heated. Such "heat shrink" products are now widely used in the packaging industry. Wire and cable insulated with radiation cross-linked polyvinylchloride exhibits excellent resistance to heat and chemical attack.

Radiation is being used at an increasing rate to cross-link foamed polyethylene for thermal insulation and wood/plastic composites cured by gamma irradiation. The latter products are gaining favor for flooring in department stores, airports, hotels and churches because of their excellent abrasion resistance, the beauty of natural grains, and low maintenance costs.

Many tire companies are now employing radiation to vulcanize rubber for tire production as an improvement over the conventional use of sulfur. Radiation is even used to "punch microscopic holes" in a special plastic to make filter material incorporated into dialysis units used for treating kidney patients. The list of applications is seemingly endless.

Materials Testing and Inspection. One of the earliest applications of radiation in industry was to measure engine wear within the automotive industry. By irradiating the surface of the engine part under investigation (such as a ring or a gear), that portion of the metal can be made radioactive. Hence, during operation any wear on that part results in some radioactive material being deposited in the oil lubrication stream. The oil is then readily analyzed to accurately determine the degree of loss of the metal (engine wear). Further, such wear can be determined while the engine is operating, without the need for dismantling and reassembly. The savings in both time and dollars to rapidly test new materials are readily apparent.

Corrosion in pipes is a common problem in the industrial world. By moving a gamma source on one side of the pipe and a detector on the other, precise analyses can be made of the corrosion patterns.

The activation property of radiation is extensively used to determine precise layers of special coatings, such as metal coatings to produce galvanized or tin-plated steel. By exposing the product line to a beam of certain radioisotopes, x rays characteristic of the coating material can be detected and used to confirm product quality.

Radiation is routinely used to check welds in crucial places such as airplane wings, housings for jet engines, and oil and gas pipelines. In most cases, a gamma source is placed on one side of the material being inspected and a photographic film is placed on the other. Flaws can be readily detected on the exposed film. With the advent of high-speed computational systems, new techniques are now becoming available that conduct such inspections without the need for film.

Other applications include testing of nuclear-reactor fuel assemblies, detecting flaws in gas turbine blades, controlling the quality of ceramics, and confirming the presence of lubrication films inside gear boxes or bearings. Radiography can provide three-dimensional imaging of objects. This process, called *computerized tomography*, is also used extensively in the field of medicine.

Energy industry (non-nuclear power). The coal industry, which currently accounts for well over half of the world's supply of electricity, benefits directly from using neutron gauges to measure and control the moisture content in coal and coke. Further, gamma sources assay the ash content as well as the combustion gases that go up the stack. Conventional devices, known as *scrubbers*, are widely used to remove large quantities of sulfur dioxide from the discharged flu gas. However, the byproducts of this process have no commercial value, thus causing additional waste disposal problems. Also, no reliable conventional process has been developed for simultaneous removal of both sulfur and nitrogen oxides in a single-stage operation. A new radiation technique, called *electron beam (EB) processing*, has been demonstrated to effectively remove both sulfur and nitrogen oxides in a single-stage process. By passing the gaseous sulfur and nitrogen pollutants under a strong beam of electrons, the pollutants become electrically charged and can then be collected. An additional attribute of this process is to convert these toxic substances into a commercially viable agricultural fertilizer.

The oil industry also heavily depends on radiation to conduct business. Finding new oil fields is a constant effort, especially as traditional sites become exhausted. Neutron probes are used to investigate oil-field test wells to determine the potential for economically viable oil deposits. Fast bursts of neutrons from a neutron generator are injected into the surrounding earth and the amount of hydrocarbons (oil bearing media) present can be determined by measuring the resulting slow neutrons detected at a known distance from the source. Gamma ray backscattering techniques can also be employed in a similar manner.

Efficient refinery operation is an important part of the oil industry. Whereas it is difficult to install and maintain diagnostic probes inside the distillation towers (due to the extreme environment), gamma probes can be rather easily installed on the exterior of the towers and then be moved up and down the tanks to easily record the composition of ingredients at various vertical levels. Any malfunctions within the tanks can be readily detected.

Personal Care and Conveniences

Those who wear either contact lens or glasses benefit directly from radiation. The saline solution used to clean and store contact lens is sterilized by gamma radiation. High-quality glass used in eye classes benefits from radiation due to the use of neutron probes in assuring the proper moisture content during the making of the glass.

Other examples include Band-Aids, where the gauzed part has likely been sterilized by gamma irradiation to ensure proper sanitary standards, and the thickness of the glue on the remainder of the band has likely been established by radiation thickness gauges. Sandpaper actually employs radiation in three steps of the manufacturing process. Step 1 is the use of radiation thickness gauges to assure proper thickness of the paper (or cardboard); step 2 is a similar gauging process to assure proper thickness of the glue; and step 3 is to assure the proper grit size.

Most cosmetics have benefited from gamma radiation before the product is placed on shelves in the department stores. The oils and greases required to achieve the colors and textures desired have a considerable propensity for attracting impurities. Hence, the final product is subjected to either beta or gamma irradiation to be sure no live parasites remain by the time the product is actually used.

One particularly useful feature of radiation is to change the molecular structure of some materials to allow them to absorb large amounts of liquid. Several industrial applications benefit directly from such transformed materials, such as air re-fresheners. This process is also being used to manufacture disposable diapers and tampons.

As these examples illustrate, the modern industrial world benefits enormously from the harnessing of radiation.

Public Safety and Other Applications

Radiation is used in an increasing role for public safety, including airport screening, smoke detectors, crime solving, deterrence of terrorism at points of entry, archeology dating, precious gem embellishments, etc. The use of americium-241 in smoke detectors has undoubtedly saved thousands of lives and associated property damage due to the avoidance of fire.

Radiation is even used in fields such as archeology and art. Artifacts made from materials such as wood or leather will often remain intact for long periods if left in their natural surroundings, such as the sea or the earth. Once exposed to air, however, they disintegrate. In this case, radiation techniques are used to provide long-term preservation. The ARC-Nucleart center in Grenoble, France, is an example of a conservation center where gamma irradiation is often used in two stages to preserve precious artifacts. Step one is to irradiate the artifact to kill all microorganisms that could cause decay. Step two is to impregnate the artifact with a polymer, then irradiate, and permanently harden it. Radiation is also sometimes used to authenticate rare paintings by using an x-ray fluorescence technique to determine the chemical consistency of the paint. Knowing the difference in paint ingredients in differing historical periods then allows definitive dating of the painting.

Not to be overlooked is the use of neutrons and gamma rays for a wide range of research tools to probe samples and to diagnose processes, both in living tissue and in inanimate objects.

Research Reactors, Radioisotope Generators, Accelerators, and Critical Facilities

Since the 1950s, research reactors and critical facilities have been deployed internationally, primarily to universities and research institutions, under conditions set by the Atoms for Peace Program and the NPT. They were used to develop the quantitative characteristics of the neutronics of the reactor core. They initially also served as important training aids to support early nuclear power plants, but are largely being supplanted in this function by full-scale simulators that cover the behavior of the entire nuclear plant. However, research reactors continue to serve significant education and research functions in many fields because of the unique properties of neutrons for probing materials. In addition, they are increasingly used for medical applications, particularly, together with particle accelerators, to produce radioisotopes that are used in imaging diagnostics. There are 671 research reactors worldwide, including operational reactors, those that have been shutdown or decommissioned, and those under construction or planned. Of these, 275 in over 60 countries are considered operating or operable, with 132 reactors fueled with HEU.[29] Proliferation concerns arose in the 1970s from the deployment of research reactors fueled with HEU because the fuel may be a source of weapon material. Actions underway to address these concerns are reviewed in Appendix C.

Production of radioisotopes is of obvious importance to the vast array of applications discussed above. Both research reactors and reactors devoted to isotope production are reducing in numbers, raising concerns on the adequacy of future supply. These reductions have been particularly severe in the United States, resulting in a greater dependence on overseas supplies.

[29] Research Reactor Database (RRDB), IAEA, http://www.iaea.org/databases/dbdir/db76.htm.

Space Power

For the last 40 years, nuclear power sources have served as large, long-lasting "batteries" for space missions. The U.S. space program has launched 23 spacecraft with nuclear power sources, and it is estimated 20–30 or more were launched by the Soviet Union in the Cosmos series of satellites. Space nuclear-power sources have included fission reactors, radioisotope thermal generators (RTGs), and radioisotope heating units (RHUs).

Both the United States and the Soviet Union launched spacecraft with fission reactors as power sources. The U.S. experience is limited to the single launch of the reactor SNAP-10A in 1965, while the Soviet experience is much greater with 31 low-powered reactors being launched between 1967 and 1988 in Cosmos missions related to the Radar Ocean Reconnaissance Satellites (RORSAT). Because weight minimization is a priority concern for space launches, the preferred fuel for such reactors is very high enrichment uranium-235.

RTGs have been the workhorse nuclear power supply for U.S. space missions. The primary material, plutonium-238, has a high heat generation rate of 0.56 Watts/gram and is used in conjunction with thermoelectric conversion hardware to produce electrical energy. The Soviet Union has also used RTGs in their program, including those fueled by polonium-210. RTGs are safe, reliable, and durable and can operate for decades under harsh conditions and without the need for maintenance or operator intervention.

RHUs provide heat to keep instruments or sensors at their proper temperature ranges. The typically are of low thermal power (e.g., 1 Watt), and are generally fueled by gram quantities of plutonium-238.

The Future of Other Civilian Applications of Nuclear Technology

Radiation Applications

Non-power applications of nuclear technology in medicine, agriculture, security, public health, and industry, already widespread in scope and geographically, are expected to advance rapidly. They have a socially beneficial, revenue-producing role that provides a substantial capability in R&D. Ventures more directly associated with human health are more easily deployed and are moving forward with greater public support than is generally the case for power applications Public confidence in non-power nuclear technology applications (nuclear medicine and agricultural applications) that enhance public health by saving lives, fighting deadly diseases, and increasing the abundance and quality of foods will likely increase despite some negative factors.

Continued, strong R&D efforts will further expand the applications, both in type and in increased effectiveness. There is a further opportunity to enhance this area by broadening the definition of the scope of basic human needs that might be served by R&D. Health, nutrition, and industrial efficiency has been the primary focus to date, but the application of basic nuclear science to the other human needs of shelter, family/community, security/conflict, work, and understanding may well yield even greater social benefits.[30]

Some elements of the fear of radiation have a negative effect on progress, e.g., the irradiation of foods to destroy dangerous bacteria and the adequacy of radwaste storage facilities. The lack of radwaste storage is particularly acute in the United States. On July 1, 2008, use of the disposal facility in Barnwell, South Carolina, will be restricted to only three

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[30] M. Krebs, Science Strategies, Presentation at Lawrence Livermore National Laboratory's Concluding Symposium of the Atoms for Peace after 50 Years Project, November 13, 2003.

states in the Atlantic Compact. As of that date, nuclear power plants, universities, medical facilities, and industry using radioactive materials in 36 states plus territories (including federal and state agencies—other than the DOE) will have no place to dispose of their Class B and Class C waste, which accounts for 97–98% of the waste.

One major impediment to the growth of nuclear medicine in the United States is the crumbling facility infrastructure. Over 90% of all medical isotopes in U.S. use are currently imported and the sources of radioisotopes for research are rapidly diminishing. The lack of reactors to provide the wide spectrum of neutrons necessary for the production of isotopes is of particular concern. Aside from small university research reactors, only HFIR, MURR, and ATR remain. They are aging and are restricted to a thermal neutron spectrum. The recent decision by the DOE to decommission the FFTF removes a major resource for the long-term production of a plethora of medical isotopes.

Lack of adequate radioactive storage and disposition capability are also deterrents to optimal progress. The threat of terrorist misuse of radiological sources in the form of RDDs presents a new challenge that must be addressed effectively to assure continual progress on beneficial uses. Strengthened and internationalized standards of safe handling and accountability are needed in light of past experience with some of these sources. Where economically practical, machine sources of radiation are to be preferred over radiological sources.

Non-power applications can be classified into two groups: those involving radioactive materials that continuously emit radiation (radiopharmaceuticals or radiological sources), and those that generate high-intensity beams on demand without the use of radioactive sources (electrons, x-ray, or MRI diagnostic equipment). The potential for misuse differs significantly between these types: the basic proliferation threat of the former being potential misuse of the materials, and of the latter the nuclear skills, knowledge, and facilities that could be used for illicit purposes.

Radioactive Materials Controls

A recent study[31] has concluded that a workable control regime can effectively address the potential threat of terrorist use of RDDs. Quoting from the study, "only a small fraction of the millions of commercial radioactive sources used globally, perhaps several tens of thousands, pose inherently high security risks because of their portability, dispensability, and higher levels of radioactivity. These more dangerous commercial sources containing a gram or more of radioactive material are primarily seven reactor-produced radioisotopes (americium-241, californium-252, cesium-137, cobalt-60, iridum-192, plutonium-238, and strontium-90)." In particular, sources used in medical applications are well protected and not a great concern for theft or diversion. The report finds that RDDs, including those using these seven radioisotopes, are not WMD but could cause widespread panic because of the general fear of radiation.

Only a few organizations in six leading radioactive source-producing nations (Argentina, Belgium, Canada, France, Russia, and South Africa.) distribute sources to tens of thousands of users worldwide. The report concludes that if export control standards are tightened and if it is certified that effective security measures will cover the sources in recipient countries, the exporting countries, together with the European Union and the United States as major users, could rapidly ensure that the considerable majority of high-risk radioactive sources in use around the world are properly protected against misuse.

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[31] Ferguson, Kazi, and Perara, Center for Non-proliferation Studies, 2002. See also C.D. Ferguson and J.O. Lubenau, *Issues in Science and Technology*, fall, 2003.

The actions recommended are of particular urgency because there are significant gaps in present export controls. For example, U.S. export rules permit the unlimited export of most high-risk sources under "general" licenses, to all destinations, except Cuba, Iran, Iraq, Libya, North Korea, and Sudan, permitting export of these sources without governmental review of the bona fides of end-users. Although the changes needed in export controls are practical if the suggested focus of effort is followed, a strong commitment is needed from the six supplier nations, including the United States and the European Union, to implement these changes. The United Nations and the IAEA can play an important supporting role.

Of particular concern from the standpoint of safety as well as misuse, and beyond the effectiveness of improved export controls, is the existence of as many as tens of thousands of disused sources. High disposal costs or lack of adequate repositories create pressures on end-users to dispose of these outside of regulated channels. The study finds that only a small fraction of these sources are high risk, with the preponderance in the states of the former Soviet Union. Additional national efforts are needed to recover the disused sources and place them in central safe and secure storage facilities.

Research Reactors, Radioisotope Generators, and Critical Facilities

The growth of research reactors and critical facilities will be modest, if not negative, over the next few decades. A negative impact is the need to convert those reactors now using highly enriched fuel to LEU fuel. There is also a need to improve the IAEA database on the status of these facilities, with due consideration to restricting information to potential proliferators or terrorists. Increased radioisotope production capacity should be provided.

Radioisotope generating reactor capacity is in serious decline and the aforementioned HEU to LEU conversion will probably reduce the number of research reactors that generate radioisotopes. This is a particularly acute problem in the United States, which is virtually without the ability to produce isotopes for medical applications. Most medical isotopes used in the U.S. come from Canada.

Space Exploration

NASA's 2004 budget calls for significant funding to support a new fission reactor and propulsion research effort, referred to as *Project Prometheus*. The idea of nuclear-powered vehicles appears to be gaining support as manned missions to Mars and Jupiter are being considered. But recent problems in the present manned space program may well defer those plans.

Conclusions

Figure B-5 summarizes the present world situation with respect to per capita nuclear power capacity, in terms of current population, on a cumulative country-by-country basis. It is not immediately clear what this plot might look like in the future. The present situation is that although nuclear power is growing in some parts of the world, its continued growth pattern is far from certain. Another serious accident, such as Chernobyl, could result in nations and their industries relying less on nuclear fission as part of their power generation mix. Economic concerns, delays in plant construction, or unacceptable solutions to the disposition of nuclear wastes could have a similar result, resulting in a future per capita nuclear power contribution that is lower than today.

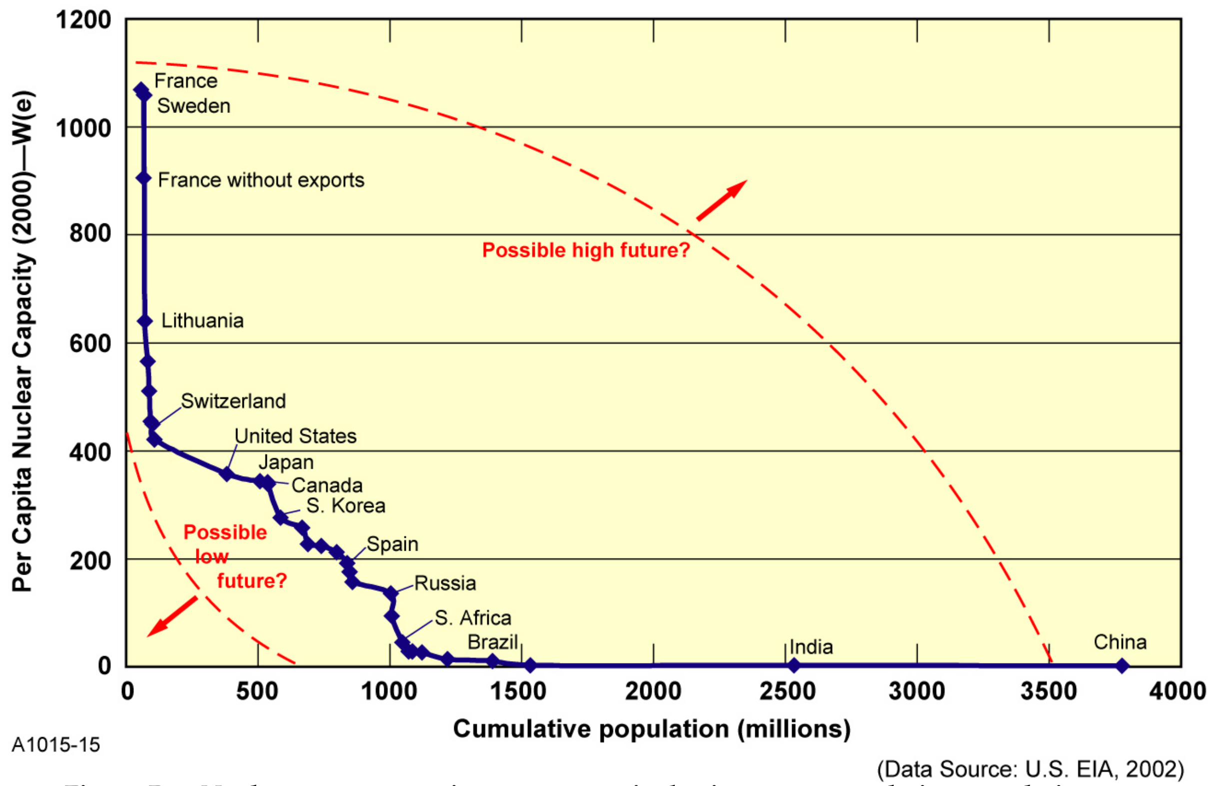

Figure B-5. Nuclear power capacity on a per capita basis versus cumulative population on a country-by-country basis.

On the other hand, public confidence in the benefits of nuclear power appears to be increasing. This may be the result of—

- Sustained safety, reliability, and nonproliferation records.
- The application of the latest technologies to enhance the performance of the proven components of the nuclear cycle in economics and nonproliferation terms.
- The need to deal with external forces such as population growth and poverty in the less developed countries and the related implications for international security.
- A decided response to air pollution and global climate concerns.

These factors may drive the per capita consumption higher than it is today, perhaps even significantly higher.

It is unlikely that the entire world will realize the electric power situation already achieved in France (much reduced dependence on imported energy)—the driving forces, such as the lack of indigenous fuel sources, for France and Japan are not the same across the entire globe—some countries have indigenous sources of power, in some cases even environmentally benign. In other words, nuclear power will always mean different things to different countries or regions. However, some countries could achieve the level of energy usage of France today and the future curve might have a high per capita capacity for the first several hundred million (billion) people and lower for the remainder. It is apparent from Figure B-5 that high-population countries such as India and China control the future shape of nuclear power worldwide.

One thing clear from Figure B-5 is that any increase in power capacity toward the possible high future in any reasonable timeframe (say 40 to 50 years) requires a substantial effort beginning now. Although speculative, the possible high future would require 6–7 times the current capacity of 359 GW(e). This is a formidable task in the timeframe of even four to five decades, emphasizing that serious consideration of possible technologies, financing routes, and governmental policies needs to begin immediately. The magnitude of this potential need is so great that early action is warranted even if nuclear average per capita consumption rates never increase. The expanded application of non-power nuclear technologies is less subject to uncertainty, but the uneven distribution of benefits around the world also pertains. Perhaps the biggest impacts are yet to come. Successful endorsement of food irradiation alone greatly increase the beneficial impacts achieved to date. Such non-power applications remain a challenging and rewarding field for the best and brightest of our next generation of radiation scientists and engineers. Yet, the deterrent to advances in non-power technology applications caused by radioisotope availability, safety, proliferation, and terrorist concerns also need to be remedied.

In light of the above findings, it is recommended that actions be taken to maximize the civilian benefits of nuclear technology while placing the highest priority on security and safety. The broad actions to maximize the benefits are to—

- Pave the way to near-term deployment of nuclear power generators of proven technology to provide a stronger, combustion-free energy portfolio and sustain the infrastructure to permit future expansion.
- Accelerate the licensing and construction of safe repositories for spent fuel.
- Define, in collaboration with representatives from the P-5 plus the major nuclear suppliers and users and the countries where nuclear power programs may rapidly expand, a nuclear-fuel-cycle program that both meets the various users' needs as they see them and minimizes the amount of weapon-usable materials and the number of locations where it is stored. This program should explicitly consider both international enrichment facilities and international spent-fuel repositories (permanent and temporary) to provide services to all NPT signatories pursuing civilian nuclear power programs. It should not insist on the U.S. once-through cycle as the *only* solution. It should be aimed at meeting the security needs of a world where many more nuclear facilities exist in developing countries, particularly in South Asia, Southeast Asia, and East Asia.

Addendum: Uranium Resource Estimates

Table B-4 summarizes information on the uranium resources and the annual uranium production capabilities of the principal uranium-producing countries compiled by the Red Book and the IAEA projections on uranium supply.[32] The uranium production capabilities include existing, committed, planned, and prospective production centers supported by known conventional resources [Reasonably Assured Resources (RAR) and Estimated Additional Resource-I (EAR-I)]. The production costs of $80 and $130/kilogram of uranium do not include exploration costs, which usually apply to undiscovered conventional resources (EAR-II) and Speculative Resources, as reported in the IAEA reference (see footnote) and listed in **Table B-5**).

Table B-4. Uranium resources and production capability (Year 2000).

Country	Natural uranium resources (1,000 tU) at production costs ($/kgU)						2000 production capability (1,000 tU/yr)
	< 80			80–130			
	RAR	EAR-I	Subtotal	RAR	EAR-I	Total	
Algeria*	19.5	—	19.5	—	—	19.5	—
Australia	667.0	196.0	863.0	30.0	37.0	930.0	7.6
Brazil*	121.5	75.0	196.5	0.0	0.0	196.5	0.08
Canada	314.6	122.4	437.0	0.0	0.0	437.0	10.7
Kazakhstan*	324.6	147.0	471.6	121.5	47.6	640.7	1.9
Mongolia*	46.2	15.8	62.0	0.0	0.0	62.0	0.0
Namibia*	107.9	68.1	176.0	23.4	12.5	211.9	2.7
Niger*	22.2	19.1	41.3	0.0	0.0	41.3	2.9
Russia*	103.5	27.4	130.9	0.0	0.0	130.9	2.8
S. Africa	231.0	66.8	297.8	59.9	9.6	367.3	0.8
Ukraine*	32.0	15.0	47.0	28.8	22.5	98.3	1.0
U.S.	104.0	—	104.0	244.0	—	348.0	1.5
Uzbekistan*	67.5	35.1	102.6	19.0	7.5	129.1	2.0
Others	81.0	77.2	158.2	63.2	88.5	309.9	2.1
Total	**2242.5**	**864.9**	**3107.4**	**589.8**	**225.2**	**3922.4**	**36.2**

* These countries reported in situ resources. They were adjusted to estimate recoverable resources using a recovery factor (0.75).

Table B-5. Reported Undiscovered Conventional Resources (1,000 tU)

	EAR-II (< $130/kgU)	Speculative resources (< $130/kgU)	Cost Unassigned
Total (in situ resources)	**2332**	**4438**	**5501**
Total (75% of in situ resources)	**1749**	**3328**	**4126**

In Tables B-4 and B-5, RAR refers to uranium which occurs in known ore deposits of such grade, quantity, and configuration that it could be recovered within the given production cost range with currently proven mining and processing technology. The EAR-I refers to uranium surmised to occur in unexplored extensions of known deposits in known uranium districts, and which is expected to be discovered and produced in the given cost range.

The EAR-II refers to uranium in addition to EAR-I expected to occur in deposits for which the evidence is mainly indirect and are believed to exist in well-defined geological trends or areas of mineralization with known deposits. Speculative Resources (SR) refers to uranium, in addition to EAR-II, thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discovered by existing exploration techniques.

[32] *Analysis of Uranium Supply to 2050*, IAEA, May 2001.

Very low-grade resources, not now economical for recovery or from which uranium is only recoverable as a minor by-product, are considered “Unconventional Resources” (e.g., phosphates, monazite, coal, lignite, and black shale). In addition, seawater contains about 3.3 parts per billion of uranium and a total uranium resource of about 4 billion tonnes. However, the cost of extraction of uranium from seawater is expensive, estimated[33] to be on the order of $500/pound of U_3O_8, in the same range of estimates by Japanese researchers[34] for commercial operation.

From Table B-4, the estimated 4 million tonnes of known uranium resources (the RAR + EAR-I) for production costs up to $130/kgU (or $50/lb of U_3O_8) cannot satisfy the projected future global uranium requirements up to 2050. The deficit between projected requirements and known resources of about 1 million tU could be higher if nuclear power is expanded more than the nominal growth rate per year. In that case, the EAR-II and the speculative resources listed in Table B-5 would have to be developed in a timely fashion to be a significant source of supply. Improved mineral extraction technologies that minimize radiation exposure to miners and reduce environmental degradation would need to be developed as well.

Projected Resource Adequacy and Cost of Uranium

The adequacy of uranium supplies is measured in two ways. The first measure is a direct comparison of resources with requirements. The second measure takes into account the fact that not all resources can be produced within the timeframe when the resource is required. The deficit between the requirements and production reflects the market situation and affects the uranium prices. It is difficult to predict market price trends because the selling price of uranium depends on when the sale is negotiated, when the uranium is to be delivered, and whether the price is for one-time, spot delivery or long-term supply. Nevertheless, the spot uranium price during the past decade has been kept low (at around $26/kgU, or $10/lb of U_3O_8) and relatively constant, due primarily to the secondary supply of uranium and, to a lesser extent, the supply of uranium produced from the former Soviet Union countries. The contribution from the secondary supply is expected to drop off by 2025.

To ensure a supply of relatively low-cost uranium resources for the future, it is imperative that development of resources is started in a timely manner such that it will be available to satisfy requirements efficiently. The timing when production centers are projected to be cost-justified to begin operations is an indirect indication of market price trends. **Table B-6**, taken from the IAEA report, gives the approximate year that production centers with different cost ranges are first cost-justified, assuming production derived from different confidence level resources. Table B-6 indicates production centers with costs exceeding $20, $30, and $50/lb U_3O_8 will not be cost-justified until about 2021, 2027, and 2034, assuming availability of only known conventional resources (RAR and EAR-I).

Resource	**> $52-$80/kgU (> $20-$30/lb U_3O_8)**	**> $80-$130/kgU (> $30-$50/lb U_3O_8)**	**> $130/kgU (> $50/lb U_3O_8)**
RAR	2019	2024	2028
RAR and EAR-I	2021	2027	2034
RAR and EAR-I and EAR-II	2021	2029	2041

[33] Benedict, Pigford, and Levi, *Nuclear Chemical Engineering,* 2nd Edition, McGraw-Hill, 1981.

[34] Takanobu Sugo, et al., “Evaluation of cost of seawater uranium recovery and technical problem toward implementation,” 1010 Technical Report, *Nihon Genshiryoku Gakkaishi*, Vol. 43, No. 10 (2001).

Appendix C: Cross-Cutting Issues

Introduction

Among the most critical dimensions of national security and international stability is ensuring that the essential ingredients of nuclear weapons do not fall into the hands of terrorists and that additional, "rogue" states do not develop nuclear weapons capabilities either for themselves or for transfer to other states or terrorists groups. Effective controls over the nuclear materials necessary for nuclear devices are essential to reduce the global nuclear risk and to support continued arms reduction. Ensuring environmental protection and protecting public health in managing all nuclear materials represent critical added dimensions. The quandary remains that nuclear materials provide positive public benefit by offering carbon-free electrical energy, nuclear medicine treatments, agricultural advances, and many other industrial applications. Therefore, ensuring nuclear materials are available for the beneficial uses while controlling the illicit ones is the major challenge.

The national security and civilian communities often are viewed as quite separate, although there are longstanding and intimate links between them. This appendix highlights three key areas where the linkages between national security and civilian applications are most direct and strongest: (1) the stewardship and controls of nuclear materials; (2) the governance of the "nuclear regime," that is, the set of policies, programs, international agreements, and actions to meet both defense and civilian objectives; and, (3) communication and public understanding of nuclear issues. In all three cases, challenges, issues, and linkages tie together progress and problems in defense and civilian affairs.

Several things have changed dramatically over the past 50 years that make revisiting our approach to these cross-cutting issues not only timely, but compelling. Among them are—

- The rivalry between two major powers and the resulting arms race has been replaced as the dominant threat by a much more complex and uncertain situation among nuclear-capable states as well as by threats arising from terrorist groups who may not be deterred from using weapons of mass destruction (WMD) if they can obtain them.
- Nuclear knowledge, once largely restricted to a few major states, has now diffused to the point where most states have or can obtain the nuclear knowledge necessary for both weapon and civilian applications. Where once all nuclear information was secret, much is now in the open.
- A situation in which the major countries were the only ones with Special Nuclear Materials (SNM) and the amounts were severely constrained has changed to a situation where many countries have substantial inventories of SNM (often within spent nuclear fuel) and large quantities of excess SNM are in both the United States and Russia.
- Relatively modest concerns about horizontal proliferation have been raised to a higher priority with respect to both additional countries and terrorist groups, with particular emphasis on the linkages between them.

- A world in which technical information and technical know-how slowly diffused has become one of instant communication, readily available computational capabilities, and relatively fast diffusion of technology.

We start our discussion of cross-cutting issues with a section on weapon-usable nuclear materials and their control. Weapon-usable nuclear materials are relatively difficult to make while most other ingredients that go into making nuclear weapons are relatively available. Therefore, the control of these materials must be the primary focus in any attempt to secure the benefits of nuclear technology while minimizing their risks. The technical and organizational facts regarding the supply of these materials and the control mechanisms available will be laid out.

The middle section addresses what to our mind is the key problem in controlling these materials, namely a governance structure that will both enforce control and also provide incentives and security guarantees that minimize demand. We note that, in the world of technical plenty, while supply controls are necessary, the demand for nuclear weapons ultimately determines whether these weapons and their associated dangers spread or not.

The final section of this appendix addresses another major cross-cutting issue—communication between the governments and other institutions charged with managing the nuclear situation and the various publics they serve. This issue is crucial to the ultimate goal of providing the benefits of nuclear technology while minimizing its risks. Without good, interactive communication, the confidence needed to pursue these benefits will be lacking, and the nuclear enterprise—now centered mainly in the democracies of the world—will fail. Because the relationship of nuclear technology and weapons is deeply inscribed in the public mind (for good reasons), effective communication must address this relationship in a reliable and persuasive way, particularly at a time when terrorist threats loom large in the public mind. Perhaps more important, trust-building measures must be an inherent part of the way the nuclear community does its business. An effective message will be of limited value if there is a lack of trust in the messenger.

Nuclear Materials and Their Control

The Situation

Several elements and isotopes can be used in nuclear weapons. Others are used in various devices for medical, agricultural, and/or industrial purposes. Most fortunately, these elements and isotopes do not occur in a directly usable form in nature and their creation is relatively difficult, time-consuming, costly, and potentially dangerous to those working with them. They are also subject to discovery should their creation be undertaken covertly, particularly if the operations are of significant scale. Most of the subsequent discussion will deal with those materials that are usable in nuclear weapons. Weapon-usable nuclear materials, either as raw material or as fabricated components, are required to make even a rudimentary nuclear device. With the basic technical information to construct a workable nuclear device available in the open literature or readily deduced from general principles by a technical group of modest size, controlling the availability of nuclear materials is the primary mechanism to prevent their misuse in nuclear weapons.

The two nuclear materials of special concern are plutonium (Pu) and highly enriched uranium (HEU). Either can form the core of a nuclear weapon. Because both materials are found in civilian and defense applications, the connection or "cross-cut" of the management of these materials is critical to shaping a successful nuclear regime.

Uranium, when mined, contains 0.7% of the fissile isotope uranium-235, and 99.3% uranium-238. Only the uranium-235 can directly sustain a chain reaction and serve as the fuel for a nuclear explosive device. To be effective, uranium for a weapon must be "enriched," that is, its proportion of uranium-235 must be increased dramatically. Highly enriched uranium can only be made by enriching either naturally occurring uranium, or by further enriching low enriched uranium (LEU) to very high percentages of uranium-235. Most nuclear power plants are fueled by LEU, uranium that has been enriched only to 2–3%.

Enriching LEU for nuclear-power-reactor fuel is processed commercially in only a small number of countries with advanced technical capabilities and substantial resources. Low enriched uranium cannot be used directly to make a nuclear weapon. While a significant technological undertaking, enrichment technology is feasible for many countries, and either overt or covert enrichment operations pose a threat particularly given the relative difficulty of passively detecting HEU. Concern also exists that countries interested in making small, but bomb-significant quantities of HEU can consider doing so with old, relatively simple, if inefficient techniques.

HEU is relatively difficult to track and easy to use in nuclear explosive devices when compared with plutonium. Thousands of tons of excess HEU now pose a particularly urgent problem. HEU can potentially be obtained by terrorists from several sources. Large stockpiles of excess HEU and weapon-grade Pu are in both the United States and Russia, and other countries with nuclear weapons may have smaller stockpiles of these materials. HEU also exists in nuclear fuel from naval reactors, research reactors and critical facilities associated with weapons programs. **Table C-1** indicates the total global inventory of HEU to be about 1,870 metric tonnes (MT), produced primarily in the United States and the former Soviet Union in support of their nuclear weapon programs. The United States and Russia have declared a total of 674 MT as available for disposition. Today, the United States is engaged in purchasing down-blended HEU from Russia as a fresh fuel supply to the U.S. nuclear power industry.

Table C-1. Global inventory of highly enriched uranium (units in metric tonnes, MT) [Report of French Parliament and Senate "Office Parlimentaire d'Evaluation des Choix Scientifiques et Technologiques," seance du 5 Avril 2001].

Country	**Estimated HEU Inventory (MT)**	**Declared Excess HEU (MT)**	**HEU Production End (Year)**
United States	750	174	1988
Russian Federation	1,050	500	1987
United Kingdom	21.9	None	1963
France	25	None	1996
China	20	None	1987??
India	Very small	None	on-going
Pakistan	0.2	None	on-going
Israel	Unknown	None	on-going
Total	**~1,870**	**≥674**	

Highly enriched uranium has been used to fuel research reactors, and although many have been refueled with LEU, many research reactors still have HEU cores, some with significant quantities, making them potential sources of weapon-usable nuclear materials. While 50 years ago there were relatively few research reactors, found for the most part in stable countries, today more than 275 research reactors are in over 60 countries, several of which are now seen as being less than fully stable. These reactors are often underutilized and in some cases continue accumulating spent fuel. Some of this fuel is barely irradiated and contains significant amounts of HEU (**Table C-2**). It should be noted that nuclear explosive devices could be made with HEU having less than 90% uranium-235, although it becomes increasingly difficult as the enrichment is lowered. Some "critical experimental facilities," where research is performed on the critical mass of various isotopes, also have significant quantities of nuclear materials of concern.

Table C-2. Research reactors and their types, power levels (in megawatts), and enrichments (>90%) by country [Nuclear Reactors in the World, IAEA, September 2000].

Country	**Reactor**	**Type**	**Power (MW)**	**Enrichment (%)**
Belgium	BR-2	H_2O	100	93
Canada	MNR	H_2O	5	93
China	HFETR	H_2O	125	90
	MJTR	H_2O	5	90
France	HFR	D_2O	58.3	93
	ORPHEE	H_2O	14	93
Germany	FRJ-2	H_2O	23	93
	BER-2	H_2O	10	93
Greece	GRR-1	H_2O	5	93
Israel	IRR-1	H_2O	5	93
Japan	KUR	H_2O	5	93
Kazakhstan	EWG 1	H_2O	60	90
Netherlands	HFR	H_2O	45	93
Romania	Triga-II	H_2O	14	93
Russia	IR-8	H_2O	8	90
	BR-10	FR*	8	90
	WWR-M	H_2O	18	90
	IVV-2	H_2O	15	90
	MIR-M1	H_2O	100	90
	IRT-T	H_2O	6	90
	SM-3	H_2O	100	90
	BOR-60	FR	60	90
South Africa	SAFARI-1	H_2O	20	93
United States	ATR	H_2O	250	93
	MIT R-II	H_2O	4.9	93
	NBSR	D_2O	20	93
	HFIR	H_2O	85	93
	U. M.	H_2O	10	93.15
	Fast Burst	FR*	10	93

* Note: FR—fast reactor.

Plutonium does not exist in nature (in any but the most minute, dilute quantities). Plutonium is made from uranium as part of the nuclear reactions that occur in nuclear reactors. Any reactor using uranium as fuel will make Pu from the uranium-238 by neutron capture. The resulting used or *spent fuel* can be found in power reactor cores, or in the spent fuel from production reactors, built expressly for producing Pu for extraction and subsequent use in nuclear weapon programs. Although there is a large and growing stock of Pu in spent fuel coming out of power reactors, it is far less readily usable for weapons than separated material, being in multitonne assemblies, mostly located and accounted for at known power plant sites. It is also highly radioactive and therefore rather self-protecting (though its self-protection decreases with time, halving about every 30 years). In addition, although weapon-usable, most of this Pu is much less suitable than weapon-grade Pu owing to its isotopic composition, Of course, committed adversaries may be willing to consider absorbing large doses in an effort to divert and convert useful quantities of Pu. It takes special equipment and know-how to chemically reprocess or separate the Pu from other materials in the spent fuel. Nonetheless, reprocessing knowledge is now widespread and the technology is within the capability of many countries and possibly some terrorist groups, should they have access to the materials. This constitutes a risk for a state that has civilian nuclear power plants and chooses to withdraw from the Nuclear Nonproliferation Treaty (NPT) and much less a risk for direct terrorist use.

The quantities, forms, and locations of weapon-usable nuclear materials have grown dramatically over the past 50 years, in both the defense and civilian arenas **(Table C-3)**. The production of Pu for nuclear weapons, particularly by the United States and the former Soviet Union, was massive during the Cold War. Today, we find very large quantities of excess separated Pu originally intended for or previously used in nuclear weapons, as both countries have reduced the size of their weapon stockpiles. Dismantled weapons result in many tons of excess Pu, a critical security concern in Russia given the uneven and less than adequate protections afforded to much of that material. The United States and Russia have each declared 50 MT of Pu as excess and signed a bilateral agreement to dispose of 34 MT from each excess stock. Putting that excess material into a form suitable for permanent disposal or using it to fuel existing nuclear power plants (and simultaneously making it highly radioactive and inaccessible for diversion) remains an important but slow-moving initiative.

Table C-3. Global inventory of separated civil plutonium (units in metric tonnes, MT)

Country	Those Declared in INFC549[a] (MT)	Estimates based on Open Source Information[b] (MT)
Belgium	3.3[c]	2.3
China	0.0	0.0
France	44.3	46.0
Germany	9.1[d]	32.0
Japan	37.4	39.1
Russia	33.4	32.2
Switzerland	0.6[e]	2.8
U.K.	62.4	68.7
U.S.[f]	4.65	4.65
Hold for others[g]	25.6	–
Other Countries (India, Italy, Netherlands, Sweden, etc.)[i]	–	3.23[h]
Total	**220.8**	**231.0**

Notes:

a. IAEA Information Circular 549 on “Communication received from certain Member States (MS) concerning their policies regarding the management of plutonium,” declared by nine MS since 1997.

b. Estimates of current inventory of global separated civil plutonium inventory, calculated by using open sources existing in the public domain.

c. Belgium did not declare plutonium holdings belonging to other countries.
d. Germany did not declare its plutonium held by other countries.
e. Switzerland did not declare its plutonium held by other countries.
f. Ex-defense plutonium not included.
g. Separated plutonium holdings at the reprocessing/fabrication facilities (in Belgium, France, and U.K.) that belong to other countries.
h. "Civil separated plutonium stocks—Planning for the future," *Proceedings of the March 14-15, 2000 Conference*, p. 39, ISIS, 2001.
i. Data tabulated for period at end of 1998.

More than 230,000 MT of spent nuclear fuel have been produced through the year 2000, containing approximately 2,000 MT of Pu. Approximately 10,000 MT of additional spent fuel is created annually. Civilian reprocessing of spent fuel in select countries will have separated in excess of 250 MT of this Pu by the end of this decade with current operations. The remainder is stored, most of it in pools or dry storage at the reactor sites. The slow-down in the growth of nuclear power plants has resulted in it being currently uneconomical for most of this spent fuel to be reprocessed to regain the unused uranium and the produced Pu for reuse.

The Current Control Regime

A clear and present danger is posed by already separated, weapon-usable materials, mainly from excess nuclear weapons with some from reprocessed civilian materials. The United States and the former Soviet Union have over 90% of the weapon-usable materials in the world, in the weapons and outside of them. Rightly or wrongly, the United States feels confident about the security of its own material. There have been more questions about the security of former Soviet material. Since 1991, the Nunn–Lugar program has spent about a billion dollars a year to assist Russia in stabilizing, transforming, and downsizing its nuclear weapon complex; securing its nuclear material, warheads, and technologies; limiting its production of fissile material; disposing of excess fissile material; and establishing transparency in the nuclear-weapon reduction process.[1] Of the Russian weapon-usable material, it is currently estimated that 100 MT are under comprehensive security upgrades, 122 MT are under interim security upgrades, and 378 MT remain to be upgraded.[2]

In a joint United States–Russia program, HEU is being blended down to low enrichments and used as fuel in nuclear power plants, greatly increasing its proliferation resistance.

As of 2002, 175 metric tonnes of weapon-grade HEU (out of 500 metric tonnes of the planned disposition) have been converted to LEU power plant fuel, eliminating the equivalent of 7,000 nuclear warheads. Russia is gaining substantial revenue by selling the blended-down uranium to the United States. A similar program has been framed to convert weapon-grade plutonium to civilian nuclear fuel but is moving very slowly. The process makes the plutonium highly inaccessible and self-protecting when it is in an operating reactor, and much less useful for a weapon when removed as spent fuel. The cost of converting the plutonium to fuel is much higher than that for uranium and requires subsidization by the United States and other G-8 countries.

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[1] Courtesy of Russian American Nuclear Security Advisory Council (RANSAC).

[2] See "Controlling Nuclear Weapons and Materials," *A Report Card and Action Plan*, Matthew Bunn, Anthony Wier, John P. Holdren. From the Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, March 2003, especially Chapter 5, Figures 5.1 on p. 79 and 5.6 on p. 99 (www.nti.org/cnwm).

The future of this program is unclear at the date of writing. The G-8 agreed to contribute $20 billion over 10 years to the effort, meant to help prevent terrorists from obtaining WMD through nonproliferation projects mainly in Russia. Because the 2002 G-8 summit, approximately $16 billion of the initial $20 billion has been pledged.[3] This is a good start, but we are very far from a smoothly running, efficient international machinery to account for and secure all of the separated weapon-usable materials from nuclear weapon stocks around the world.

Proliferation concerns arose in the Congress and the Executive Branch in the 1970s from the deployment of research reactors fueled with HEU because the fuel may be a source of weapon material. The Reduced Enrichment for Research and Test Reactor (RERTR) Program was initiated by the Department of Energy in 1978 to reduce the use of HEU in civilian programs by developing the technologies needed to convert foreign and domestic research reactors supplied by the U.S. from HEU to LEU fuel. Shortly thereafter, the Soviet Union initiated a similar program for the same reasons and with the same goals for the research reactors that it supplies with HEU.

The U.S. RERTR program is making progress toward achieving its objective. A total of 38 research reactors supplied by the U.S. (27 foreign, 11 domestic) have been converted from HEU to LEU fuel. Export of an estimated 3,300 kilograms of HEU, sufficient to construct a large number of nuclear weapons, has been avoided because of the foreign reactor conversions to LEU fuel. Ten foreign reactors supplied by the U.S. and 11 U.S. reactors remain to be converted. Successful development of a new monolithic uranium–molybdenum alloy fuel with a uranium density of about 16 grams/cubic centimeter would allow LEU conversion of even the high-power research reactors. In addition, 18 new research reactors in the United States, Canada, France, Japan, Australia, China, and 8 developing countries have been or are being designed to operate on LEU fuels developed by the RERTR program. Exports of over 400 kilograms of HEU have been avoided for the U.S.-supplied reactors in this group. A parallel program to return qualifying spent fuel of U.S. origin to the United States was begun in 1996 and has resulted in the return to date of over 4,000 fuel elements that initially contained about 1,100 kg of HEU. This take-back program is scheduled to end in 2006.

The Soviet reduced enrichment program has developed and is implementing the technologies needed to convert Soviet-supplied research reactors outside of Russia from fuels containing 80–90% enriched uranium to fuel containing 36% enriched uranium. The program to develop LEU fuel was interrupted in 1988 due to a lack of funding, but was restarted in 1996 as the "Russian RERTR" program in cooperation with the United States RERTR program. LEU fuel development and reactor analyses are currently in progress for potential conversion from HEU to LEU fuels of 11 reactors outside Russia and 11 reactors inside Russia. A Russian spent fuel take-back program similar to the U.S. program and with U.S. funding is being negotiated. The program would return to Russia most of the spent fuel of Russian origin from research reactors outside of Russia.

In March 2002, an agreement was reached between the United States, Uzbekistan, and Russia to return part of its HEU spent fuel to Russia in 2003. Other potential participants in this program include Yugoslavia, Ukraine, Kazakhstan, Belarus, and nine other countries. In September 2002, the United States and Russia announced that an accelerated effort would be made to develop the LEU fuels needed for LEU conversion of all U.S.-designed and Russian-

[3] Including $650 million from Canada, $1.2 billion from the European Commission, $1.8 billion from Germany, $890 million from France, $1.2 billion from Italy, $200 million from Japan, $750 million from the United Kingdom, and $10 billion from the United States. From International Response: "G-8 Set to Address Global Partnership Funding at Evian Summit" by Mike Nartker, *Global Security Newswire*, June 2, 2003.

designed research reactors. A new German research reactor has been fueled with HEU and started operation recently, but plans are being formulated to convert the fuel to LEU at a later date. With continued international cooperation under the RERTR program and with suitable export controls, research reactors—although fewer in number—will continue to accomplish their missions operating on LEU fuels in the future.

Separated, weapon-usable materials from the civilian nuclear fuel cycle come next as a concern. Nuclear energy currently accounts for approximately 16% of global electricity produced by 441 power plants with an installed capacity of 359 gigawatts-electric. The global population, currently at 6.3 billion, is forecast to grow to 8–12 billion over the next century. Energy demand is forecast to expand, from ~400 exajoules (EJ) today to greater than 1,500 EJ by 2100. This is to accommodate the increasing population as well as the increase in the Gross Domestic Product (GDP) worldwide. Nuclear technology, whether for energy applications or for medical, agricultural and industrial applications, will grow to meet increasing demands. How much growth will depend on the demand for these goods and services.

Nuclear power will be here for a long time and may increase in view of growing demand for electricity in developing countries and concern about pollution and global warming. To date, safeguarded nuclear power has not been a direct source of proliferation, but the threat could increase unless more intrusive modern safeguarding methods, including institutional controls, are introduced and widely adhered to, especially if the nuclear energy growth leads to a spread of reprocessing without measures to make it highly proliferation resistant. With no systematic approach, growth of nuclear energy leads to significantly increased quantities of weapon-usable nuclear materials in spent fuel, much of it in non-nuclear weapon states; a gradual lessening of self-protection of the discharged spent fuel, containing large quantities of Pu; and an ever-increasing burden of waste to be stored, transported, and then disposed of, in spite of the continuing difficulties of opening even a small number of repositories.

Stopping nuclear power would not be an effective way to minimize proliferation and stop the accumulation of spent fuel and radioactive wastes. Proliferation to date has made use of special purpose facilities or diverted research reactors; safeguarded power reactors are more difficult targets. Most important, a large global inventory of separated weapon-usable nuclear material (mainly Pu and HEU) already exists and will continue to grow due to an imbalance between its production and its utilization.

Fortunately, the great majority of nuclear materials in civilian fuel cycles has been and remains under effective International Atomic Energy Agency (IAEA) safeguards. The reporting requirements, inspections, and material protection, control and accountability features serve in these cases to preserve the confidence that these facilities and activities are being used as intended and that the materials have not been diverted to unauthorized uses. A very large portion of the Pu, for example, resides in spent fuel that is largely self-protecting due to its high levels of radioactivity and carefully and effectively monitored by the IAEA such that diversion by a country or sub-national group without detection is most difficult. This framework continues to provide a foundation of confidence that almost all the countries of the world with nuclear activities are conducting themselves in accord with international norms and expectations.

Troubling events of the past decade, including revelations arising from the First Gulf War, have led to needed initiatives to further bolster the reach and effectiveness of the IAEA in enhancing confidence in its effectiveness for those small but most important number of remaining cases where confidence is lacking. The IAEA's INFCIRC 540, for example, allows it to receive much more comprehensive declarations from cooperating countries regarding activities and facilities of interest and expands the opportunity for the IAEA to follow up on possibilities of covert facilities, including the provision of environmental sampling. The Physical Protection Convention further guides countries on what constitutes appropriate levels of protection of materials and facilities.

The IAEA's safeguards have long operated on the principle that countries are deterred from diverting materials or misusing facilities by a high confidence in their timely detection, though the response to such detection has always been unclear. Further, the presumption, or at least hope, has been that adequate physical protection by the host country counters potential terrorist ambitions. These principles remain the core of the IAEA's safeguards. Recent events show that the threats have continued to evolve: some NPT nations appear to be cheating the spirit and perhaps the letter of the obligation; small numbers of other countries are clearly troubling because they have not joined the NPT and have programs outside of international inspections; and the rise of fundamentalist terrorism raises the stakes enormously should they access materials or weapons. The new IAEA provisions are a first response to these threats.

More needs to be done to reach a safeguards regime and international nuclear regime that effectively counters these emerging threats and trends. Prospects for shared regional or international control of nuclear materials, facilities, and activities and the application of cutting-edge science and technology in sensors, information technology, data transmission, and instant communication may be among the ways to complement and even transform the security landscape. In conjunction, the careful but continued active development of international agreements, treaties, and cooperation may lead to circumstances where the potential continuation and growth of civilian nuclear activities may be undertaken in a new nuclear regime in which national security and international stability concerns are decreased, while energy and other human needs are better served.

Strengthening Safeguards and Export Controls

Serious questions have arisen as to the effectiveness of the United Nations' inspection and compliance processes after the discovery of the Iraqi nuclear program in 1991. The formulation of the Additional Protocol to the NPT after the Gulf War to permit unannounced IAEA inspections and provide for environmental sampling, wide-area monitoring, earth-penetrating radar, and the like, has helped to strengthen the monitoring and inspection function, but it is hardly sufficient and has yet to be ratified by many countries. Strengthening and broader ratification of the Protocol is an immediate need. A more formidable challenge is to provide enforcement teeth to the United Nations Security Council or some alternative body when non-compliance is discovered.

Although inspection and compliance are priority issues, the IAEA's efforts in setting standards for the protection and accountability of fissile materials should be continued and further strengthened in light of terrorist and rogue nation threats. Revision of the existing protocol on material protection should be extended to cover international shipments. These measures require additional resources for the IAEA.

Existing export controls are insufficient to prevent the proliferation of weapon-related materials and equipment. The IAEA has recognized the increased magnitude of this problem from rogue states and terrorists. The General Conference adopted a resolution [GC(44)/RES/20] in November 2000, forwarded to the United Nations

Secretary-General, covering its activities on "Measures against illicit trafficking in nuclear materials and other radioactive sources." These activities include establishing an illicit trafficking database and assessment program and defining a "Design Basis Threat" for establishing physical protection to prevent theft of nuclear materials.

Yet, the IAEA makes it clear that the primary responsibility for establishing export controls and protections systems lies with the individual states: "State systems of accounting for and control of nuclear material (SSAC) are fundamental to States' ability to fulfill their international obligations, be it in safeguards agreements with the agency, in the CPPNMM, in bilateral supply and co-operative agreements or in export control arrangements or to implement INFCIRC/225/Rev 4 (Corr.)."[4] This message is seemingly not being heeded as indicated by the paucity of signatories to the Additional Protocol and even the Convention on the Physical Protection of Nuclear Material to which only 45 of the 86 nations involved have signed as of April 2003.

Serious consideration should be given to the following means of strengthening the export control system:

- More accurate definitions should be developed of the materials and equipment with important proliferation potential.
- The commitments of United Nations' member states to more rigorous definition and enforcement of the international export control systems should be elevated by specific international agreements or protocols under the NPT umbrella.
- The adherence of states to such agreements should be monitored, non-compliance promptly identified and publicized, and enforcement measures agreed upon ahead of time and applied through agreed means.

The most startling change that has occurred in the 50 years since the Atoms for Peace speech has been the emergence of well-financed and highly organized terrorism on an international scale. Many of the institutional measures, even with the improvements suggested, do not effectively address threats from organizations that do not respect rules and agreements. To a somewhat lesser extent, the same limitations apply to rogue states. Of particular concern in this new situation is the possibility of exchange among rogues states and terrorist organizations of technology, materials, and equipment that aid in nuclear weapon acquisition or development. This possibility constitutes an added and powerful agreement for stricter, internationally agreed exports controls. We return to this topic in the following section.

Dispersal of Radioactive Materials

The U.S. Department of Energy (National Nuclear Security Administration) defines a Radioactive Dispersal Device (RDD) as any device that is intended to spread radioactive material. An RDD can be a nuclear explosive that does not give a nuclear fission yield, or any radioactive material used with a conventional explosive to cause harm through dispersion. The severity of an RDD incident is directly correlated with the amount, radioactivity, half-life, and dose-rates from the isotopes involved. An RDD is not a weapon of mass destruction. Emergency services can still fully respond to the event, unlike WMD that renders local, and perhaps regional, emergency services inoperable if they exist at all. Other than a fizzled nuclear explosion, the radioactive material in an

[4] Board of Governors General Conference, GOV/2001/37-GC(45)/20, Attachment, 14 August 2001.

RDD could be from a source used in medical or industrial applications (the IAEA has categorized these sources by their hazard to the public[5]), from a nuclear reactor or related operations, from radioactive material disposal sites, from orphaned or abandoned civilian sources, or could be uranium depleted in uranium-235 after enrichment. While the consequences of an RDD are substantially less than from a nuclear explosion, they may be very significant and steps should be taken, especially to prevent terrorist use of the materials. The IAEA has begun to develop programs that concentrate on increased cradle to grave tracking of materials, getting orphaned sources under tight control, and increasing oversight of personnel who handle materials.[6]

A recent study[7] has concluded that the potential threat of terrorist use of RDDs is sufficiently limited to make a control regime workable. The study states, "only a small fraction of the millions of commercial radioactive sources used globally, perhaps several tens of thousands, pose inherently high security risks because of their portability, dispensability, and higher levels of radioactivity. As a rule, these more dangerous commercial sources are those containing relatively large amounts of radioactivity (… in terms of mass, roughly a gram or more of radioactive material) of seven reactor-produced radioisotopes: americium-241, californium-252, cesium-137, cobalt-60, iridium-192, plutonium-238, and strontium-90." Only a few organizations in some six leading radioactive source-producing nations (Argentina, Belgium, Canada, France, Russia, and South Africa) distribute sources to tens of thousands of users worldwide. The report concludes that if export control standards are tightened and if it is certified that effective security measures will cover the sources in recipient countries, the exporting countries, together with the European Union and the United States as major users, could rapidly ensure that the considerable majority of high-risk radioactive sources in use around the world are properly protected against misuse.

The actions recommended are of particular urgency because there are significant gaps in present export controls. For example, U.S. export rules permit the unlimited export of most high-risk sources under "general" licenses, to all destinations, except Cuba, Iran, Iraq, Libya, North Korea, and Sudan, permitting export of these sources without governmental review of the bona fides of end-users. Although the changes needed in export controls are practicable if the suggested focus of effort is followed, a strong commitment is needed from the six supplier nations, including the United States and the European Union, to implement these changes. The United Nations and the IAEA can play important supporting roles. Of particular concern, and beyond the effectiveness of improved export controls, is the existence of as many as tens of thousands of orphaned or disused sources. High disposal costs or lack of adequate repositories create pressures on end-users to dispose of these outside of regulated channels. Only a small fraction of these sources are high-risk, with the preponderance of these in the states of the former Soviet Union. Additional national efforts are needed to recover the disused sources and place them in safe and secure storage facilities. Radioactive dispersal devices using any of the seven radioisotopes of most concern could cause widespread panic because of the general fear of radiation.

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[5] IAEA-TECDOC-1191, 2000.

[6] IAEA Bulletin 43/4/2001, 2001.

[7] Ferguson, Kazi, and Perera, Center for Non-Proliferation Studies, 2002; see also *Issues in Science and Technology*, Fall 2003.

Governance

The Implied Bargain

Eisenhower's Atoms for Peace speech is remembered for engaging the world, and the Soviet Union in particular, in a dialogue about arms control and the formulation of a nuclear regime in which national and international security concerns growing from this unprecedented emerging and frightening new weapon capability would be addressed while tapping the civilian promise of nuclear applications for the good of mankind. Out of it came a series of initiatives, leading 15 years later to the NPT, intended to allow the growth and spread of the beneficial uses of nuclear know-how (Article IV) while constraining the incentives and capabilities for nuclear weapons (Articles I, II, and VI).

In essence, a bargain was put forward: the nuclear weapon states at the time (the United States, the United Kingdom, and the Soviet Union) would undertake serious efforts to reduce and then eliminate their stockpiles of nuclear weapons, and at the same time, make available the knowledge applicable for the peaceful uses of nuclear power. In return, the non-nuclear weapon states would agree not to pursue the acquisition of nuclear weapons or the precursor capabilities, and would (somewhat later) allow an international organization—that in 1957 became the IAEA—to conduct inspections on national, sovereign territory to demonstrate that the peaceful nuclear activities and the materials involved, were not being diverted to weapon-related purposes.

The bargain proposed by President Eisenhower has been partly carried out. The ideas in the Atoms for Peace speech laid the basis for the subsequent, largely effective NPT as well as for much declassification of and assistance with civilian nuclear knowledge and technologies. This dual set of consequences has made the original speech controversial: was too much knowledge given away in return for too little international control? Most of what was "given away" would have been rediscovered anyway (much of it was), while the partially effective control regime arguably provided tools for managing the spread of nuclear technologies in the interest of peace and economic growth. Clearly, however, for the reasons given at the start of this appendix, we are in a different place now and the bargain may need revisiting.

Where Are We Now?

The last 50 years have seen a gradual spread in nations with nuclear weapons, other nations with nuclear knowledge and capabilities, and still others with nuclear-weapon intentions. Still, most nations of the world have forgone weapon development, most have signed and abided by the NPT, and some that have had programs or even weapons, have turned these capabilities off. Agreements to lower the number of weapons have been reached between the United States and Russia, and weapons are actively being dismantled though many remain. Nuclear power and technology have spread rather widely, bringing both benefits to mankind and a troubling dissemination of materials and expertise.

A number of individual bilateral and multilateral agreements have added to the original provisions. Of course, the NPT defines the major elements of the framework agreed to and adhered to by the great majority of nations, although troubling exceptions remain. Agreements in place have been successful in halting the testing, even underground, of nuclear weapons and *no first-use* declarations have been made by some states. The Nuclear Suppliers Group (NSG) agreements and export controls have attempted to limit the spread of sensitive technology.

The IAEA's traditional role of inspection and safeguards has in the main been successful, except in the relatively few cases where it ran into deliberate opposition from governments that would not meet their obligations under the NPT, to date principally Iraq, North Korea prior to its withdrawal from the NPT, and perhaps Iran at present. In such cases, the IAEA has no enforcement powers and must under its charter refer the situation to the United Nations Security Council.

Even taking these cases into account, it remains true that there has been no known diversion of weapon-usable nuclear material from safeguarded civilian facilities since the inception of the IAEA. The IAEA role has both been expanded and augmented by intelligence to provide better information and assurances that legitimate civilian sector and covert activities and facilities are not masking nuclear-weapon programs even as declared operations continue under IAEA safeguards.

Despite the relative success of the NPT and the IAEA, the possible coupling of weapon-usable material with terrorist activities lends a particular urgency in the minds of many to the need for stricter controls and more assured enforcement mechanisms. We note in particular a few especially outstanding problems that any improvement in governance of the global nuclear enterprise needs to address:

- Weapon-usable nuclear materials coming out of dismantled weapons create new security risks (as noted earlier) and require highly secure storage facilities and timely disposition under controlled and accountable conditions. It is not clear whether present provisions to that end are adequate. Political and economic problems exacerbate the control of potential "loose nukes."
- A few states with connections to terrorism are either outside the NPT altogether or may not be in compliance with their NPT obligations. Leakage of nuclear capabilities to terrorist groups may be the dominant security concern in some states today.
- The Comprehensive Test Ban Treaty, while not an arms limitation treaty, is viewed as part of the nuclear regime, and while adhered to by the Permanent Five (P-5), has not been ratified (and will likely not be) by all these parties.
- Effective enforcement methods require the concurrence and long-term commitments of the major powers. Triggers for enforcement action and the nature of appropriate actions remain a matter of disagreement among the major powers concerned. The recent divide between the majority of the United Nations Security Council and the U.S. government, leading up to the war in Iraq, calls this into stark relief.
- Spent power reactor fuel continues to accumulate throughout the world, with no early disposition in sight. Continued reprocessing adds to the growing stores of separated Pu as plutonium demand as fuel lags behind its production. While these stores consist mainly of highly exposed, less-efficient but quite usable plutonium, they exceed in tonnage the weapon-grade Pu.

Today's Major Challenge: Consensus and/or Lack of Consensus

In 1953, the Cold War was just beginning. Today, the Cold War is behind us and we face new challenges posed by the risk of proliferation and terrorism. Independent of the many possible paths for the future, we recognize that nuclear knowledge, nuclear civilian applications, and nuclear weapons are going to be part of the world for a long time, and we must achieve a situation where nuclear knowledge, technologies, and materials contribute to security, international stability, and their underpinnings of prosperity and free trade and travel. Realizing this goal requires an improved system of governance, effectively balancing the need for respecting and maintaining national sovereignty against the requirement for adhering to international obligations. Governance focuses on organizations and arrangements (both formal and informal) that define, improve, and enforce measures in today's and the future's political circumstances.

We now have nearly 50 years of experience in addressing governance through the United Nations and the IAEA and other agreements. The mechanism of this governance to date has been through the NPT and its associated institutions and agreements, including the no-first use assurances given by the nuclear weapon states (all partial assurances except for China's, which is asserted to be unconditional) and the NSG agreements. These remain the only widely accepted starting points, but they need supplementing as both the international security situation and the availability of technology have changed in a direction that could destabilize the accepted arrangements.

Yet, despite this experience and despite a relatively successful record up to a few years ago, there is today a clear and generally recognized crisis in nuclear governance, a crisis that affects the future of all the cross-cutting civilian and security issues we have cited. The crux of this crisis is a lack of consensus on how to address proliferation concerns among the major powers whose support of international efforts is necessary for effective governance of nuclear activities. The lack of consensus focuses on: what to do about non-compliance, what to do about non-adherence, and what to do about the possible leakage of nuclear materials and technologies to terrorist groups. The lack of consensus affects the actions of the major powers with respect to all of the states of concern. The key needs are outlined below:

The need for effective international agreements to prevent the acquisition or use of nuclear weapons. The most pressing issue today is the risk arising from the acquisition and use of nuclear weapons by terrorists or sub-national groups, probably with state aid. In addition, a small number of "problem" states seem to flaunt their desire to be at the edge of legal and moral norms. Almost everyone agrees that unsecured weapon-usable material is a threat everywhere. However, there is disagreement about just how serious is the threat from nuclear power-related activities, particularly in comparison with other routes to weapons and other WMD risks. How close to a weapons' capability can a state come before abrogation and/or covert programs become an issue? There are questions regarding both what constitutes a clear NPT violation and how to ensure that predictable, effective, and rapid enforcement will follow. There seems to be agreement that both need clarification to be able to deal with problem states.

The need for an effective and affordable regime for promoting and verifying safeguards compliance. There appears to be relative consensus that rather than a new framework for nuclear security, we should continue to build on and enhance the current NPT–IAEA–NSG regime with emphasis on implementation of INFCRC 540 and the Physical Protection Convention. However, there is disagreement on the urgency required in pushing for new security agendas. The IAEA is seen as generally effective in conducting its assigned safeguards responsibilities of reporting, bookkeeping, analysis and inspection, but even with the implementation of INFCIRC 540, it will fall short of providing adequate nonproliferation assurances, particularly with respect to the problem states and potential linkages between them and terrorist groups. Some feel the existing framework and conventions are sufficient and simply need methodical action, while others see a clear and present danger, particularly in the new threats that require much more near-term action. There is general concern that a way must be found to deal with states that adhere to the NPT (and presumably INFCIRC 540) only to subsequently withdraw and use acquired capabilities in possible weapons programs. There is agreement that in light of the limits on safeguards, export controls, etc., an effective and cooperative international intelligence community is crucial to adequately warn of illicit or dangerous activities that threaten international security.

The need for U.S. leadership. There is agreement that clear and consistent leadership by the United States is essential for the effectiveness of any important new initiatives. Much has been made of the singularity of American technological strength, both for international security and civilian applications. Yet within and among the world's democracies, great divisions exist over the proper roles of nuclear power and nuclear deterrent forces. Whatever policy outcomes the United States chooses to promote, it would benefit from a systematic vision of nuclear technology such as that contained in Eisenhower's Atoms for Peace speech, but reflecting on the needs of today's world and those anticipated over the next 50 years.

The need for comprehensive and coordinated nuclear materials management. There is general agreement that the quantity of excess separated civilian weapon-usable plutonium should be kept as low as possible, but also serious disagreement on the best path to achieve this goal. Some believe that the once-through fuel cycle is preferred to minimize the security risk, while others believe that recycling the material for reuse in generating civilian power is the appropriate path. There are even stronger disagreements on when such recycle is appropriate. Both sides use similar energy, economic, proliferation-resistant, environmental and waste management argument to bolster their conclusion. Once-through requires additional uranium enrichment and recycle requires plutonium separation. However, the primary issue is whether a nuclear future can be crafted so that national security concerns are reduced and international stability enhanced.

There does seem to be agreement that HEU is a priority risk, and that its existence and use should be limited to circumstances where it is clearly required, and that HEU in research reactors should be eliminated except where absolutely necessary. (Note: A new German research reactor, FRM-II, waiting final licensing, will be fueled with HEU from the United States and Russia).

There seems to be agreement that the program to secure excess Russian weapons material is moving too slowly, considering the risk, and requires immediate additional attention. However, there remains disagreement about the specific path to action even though the Department of Energy Record of Decision has laid out the courses of action after careful independent review.

There is growing consensus on the need for international control and management of materials and their disposal and the facilities that produce and/or store them. But there is disagreement on the extent of control. Some believe that regional spent fuel repositories should be pursued, while others feel that such schemes should be pursued only after national repositories are shown to be operational.

The need for a common vision on the future of nuclear power and the linkages to security concerns. There is disagreement regarding the future of nuclear power and the impact of the legacy of materials, facilities, and expertise on proliferation. Some believe that the threat requires more control than what is now the norm, while others believe that heightened attention to existing safeguards is sufficient.

There is disagreement on the degree of access to civilian technology and expertise that is both warranted and acceptable. Is the goal to have one set of rules for all, or will distinctions between those with full access and those with only limited access be the norm? Some would like to see a new distinction made between states that would have full access to all fuel-cycle activities and those that only have access to reactors. One side believes that Article VI requires full dissemination of civilian applications, albeit with full-scope safeguards. Some believe that the Article VI also requires the nuclear weapon states to fully disarm. The lack of consensus on the issues described above is masked by general statements, such as no major power or state in East Asia wants a nuclear-armed North Korea, or no major power or state in the Middle East wants a nuclear-armed Iran. Those statements are true, but they do not form the basis for consensual action. What matters is the priority given to nonproliferation objectives by the states concerned. The United States, which has pursued a policy of active intervention in those and other regions—a policy that would be seriously hampered by nuclear proliferation—generally gives nonproliferation top priority today. For China and South Korea, for instance, peace on the Korean peninsula is a higher priority objective. For Russia and perhaps other European powers, influence in Iran may be a higher priority objective. Indeed, the United States places such a high priority on Pakistani cooperation against al-Qai'da that this could diminish its efforts to prevent transfer of nuclear-weapon technology to North Korea.

This lack of consensus on priorities is nothing new. States for the past 50 years have often placed a higher priority on national goals other than nonproliferation or materials and technology controls. Nevertheless, something of a consensus was maintained among the world's major powers, making possible not only the NPT, but also such important agreements as those among the NSG. Three things are different today, however, and together, they make the lack of consensus both obvious and important:

- There is more uncertainty among the world's major powers regarding their place in the world and their ultimate security. The United States, clearly the world's strongest power, is concerned over maintaining its security, strength and leadership, particularly with respect to the ability to act decisively against threats such as WMD terrorists and states that support them. Russia is concerned over maintaining its major power status, and regaining its historic ascendancy over the "near abroad." China is immediately concerned over its ability to maintain the peaceful order it needs to continue its economic growth, particularly as regards Taiwan, where the One China Policy, long supported by the United States, has been newly challenged. France and Germany are concerned both over maintaining their influence on security and other matters, and keeping their alliance, which is crucial to their security, prosperity, and influence, as well as the future of the European Union, intact. Thus, jostling for influence over important strategic areas such as the Middle East and the Korean peninsula takes on greater significance than during the Cold War, when there were clearer limits on the possible changes in relative power.
- Nuclear capabilities, as pointed out, are considerably more widespread. Indeed, the recent trades of missile for nuclear technologies involving Pakistan, North Korea, and Iran show that assistance from the old nuclear "have" countries is no

longer necessary to develop nuclear-armed missiles. This independent capability seriously weakens the former NPT bargain as well as the clout of the NSG. In addition, nuclear power is anticipated to grow in countries such as China, India, and South Korea, which may not necessarily share U.S. priorities.

- The possible linkage of international terrorism with the more widespread nuclear and related capabilities raises the stakes for any worldwide governance system, leading the United States in particular to greater willingness to consider unilateral action. Loss of material and technology control via either loose nukes in the former Soviet Union, or proliferation to states that might not be able or willing to control their nuclear materials and technologies adequately becomes a far more urgent matter if there is a real possibility of al-Qai'da or a similar group obtaining this material and technology, and using them either to deter interference with their actions or for terror.

Some Issues for a Nuclear Regime Today

Short of regaining consensus on the priority to be given to nuclear material and technology controls, it is unlikely that any international regime to control nuclear materials and technologies—let alone oversee a growth in the nuclear power sector—will be successful in the tough cases where it needs to be successful. Regaining that consensus on the other hand means alleviating some fundamental insecurity on the part of states, and weakening the hold that terrorist groups have on some state governments. This in turn requires that some fundamental issues are addressed, with recognition that these are part of a suite of complex and dynamic interactions. We list the most important below, with no pretense at completeness:

- How will states provide for their own security and other central interests while preventing further proliferation, protecting against the use of nuclear weapons, and yet allowing for the possible expansion of nuclear power?
- The taboo on the use of nuclear weapons has been remarkably effective to date. This norm is an essential part of world security. Debate over different interpretations of current U.S. policy, which some assert couples a "preemption" doctrine with the anticipation of the possible wider use of nuclear weapons and thus may weaken this norm. Resolving this tension will require updating, expanding, and sometimes establishing a framework of clear, widely supported policies that provide incentives for states to cooperate in minimizing the nuclear danger.
- How can states, with limited resources to fight terrorist activities and safeguard nuclear materials, best be assisted in securing their materials and technologies?
- What is the future role of international inspections? Are the provisions of INFCIRC 540, even if they were to be universally adopted, sufficient to ensure that the United Nations and concerned members have clear warning of breaches of agreements to control nuclear materials and technologies? How are violations addressed and who addresses them?
- What should be done about the provisions of the NPT that serve as incentives for states to remain or come into compliance, such as Articles V and VI? What is the role of insecurity, and what security guarantees, positive or negative, truly change calculations? How confident can we be of nonproliferation as latent nuclear-weapon capabilities spread? Is the NPT still the right bargain to provide a foundation for international governance? If not, what is needed? Is there a role for international governance at this time?

The policies to address these and other issues must explicitly deal with NPT members who do not observe their obligations; NPT non-members; illicit trade in weapon-usable nuclear materials and weapon-manufacturing technologies; and the possibility of nuclear war, as in South Asia. For these policies to lead to effective international governance, leadership especially from the P-5 of the United Nations Security Council acting jointly is needed. If this cannot be done, the utility of the Security Council is decreased in dealing with the nuclear dangers just when it ought to be the greatest, and no other organization exists that could take its place with as broad a mandate or scope of representation.

Communication and Public Confidence

The Context for Trust

Making informed decisions in a democratic society normally requires a substantial degree of public consent. And consent largely derives from trust: trust in public officials and trust in the legitimacy of the decision-making process. Decision-makers may make unpopular decisions from time to time, and even be subsequently rewarded for what is later seen to be a courageous act. Sustaining decisions that play out over long time periods, however, necessitates that the public trusts the officials making such decisions, that they believe in large measure that they understand the issues involved, and that public concerns have been heard and addressed.

Levels of trust have been monitored in the United States in a variety of surveys over the past four decades. Typically respondents are asked to express their level of confidence (trust) in the people running a society's major institutions (e.g., their military, science, medicine, the press, and various branches of government). Since the 1970s, virtually none of these institutions has elicited a majority who say they have great confidence in the people running them.

"When citizens are asked about their confidence in the institutions themselves, not in the people running them, a similar pattern emerges. With some exceptions, similar deficits of public confidence in the performance of its institutions are found throughout the European nations and Japan."[8]

This might give some small degree of comfort to those dealing with nuclear issues, knowing that they do not stand alone in facing a deficit of trust. But it offers no relief to those who must fashion nuclear-related actions and policies and attempt to implement these in an atmosphere of mistrust, particularly in a context in which, "The failure of most institutions to attract majority confidence represents not a momentary spike of opposition, but the manifestation of a pattern that crystallized decades ago and had persisted to the present. Some students of institutional trust (Lipset and Schneider, 1987) have interpreted the data to reveal a three-decade-long downward trend in public confidence." Several institutions—most notably the military, the White House, and the Executive Branch of the government—experienced a sharp spike upward in confidence in the wake of 9/11. The most recent data show a decline from the extraordinary peak of that spike but levels of confidence are still generally higher than for the past three

[8] *One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste*, Report of the Committee on Principles and Operational Strategies for Staged Repository Systems, U.S. National Research Council, Washington, D.C., 2003.

decades.[9] Public acceptance of nuclear has shown some increase in the aftermath of the California energy crisis and the Northeast blackout, but has yet to outpace opposition.

The Nuclear Circumstance

Peaceful nuclear technologies developed against the background of fears related to nuclear weapons. Early proponents of nuclear power went to great lengths to distance nuclear reactors and other civilian applications from nuclear weapons in the public's eye. While there may be some subtle changes in public perception related to things nuclear today, public concerns are pervasive over nuclear safety and waste disposal (including the handling of nuclear waste), over nuclear terrorism, and site issues (NIMBY, "not in my backyard").

In the United States, no new nuclear power plants have been ordered and built since 1978. Many were cancelled due to a variety of causes, including unrealistically high demand projections, economic considerations, and licensing uncertainties. But effective and unrelenting anti-nuclear sentiments were also a key part of the equation. The record in other countries is mixed. Several major European countries are questioning their reliance on nuclear power, including Germany, Belgium, and Sweden, and some have had or are contemplating referenda that would set them on a course of reactor closures and ultimate total non-reliance on nuclear power. Much of this is driven by public anti-nuclear sentiment, including concerns regarding safety (driven in large part by Chernobyl), security, waste management, and the environment. Yet, this sentiment is not universal. Indeed on May 18, 2003, the citizens of Switzerland overwhelmingly rejected (with a margin of close to 70%) a national referendum to shut down all Swiss nuclear power plants.

Likewise, there are today no operating repositories anywhere for the permanent disposal of spent nuclear reactor fuel and other high-level radioactive wastes. There is a mixed record on progress here as well. Many countries with advanced nuclear programs (e.g., Canada, Germany, and United Kingdom) have suffered major setbacks in their attempts to site such a repository. Indeed, even in France the repository siting program had to be essentially restarted and nearly 60% of the French public believes that nuclear waste is not handled properly. Others, notably Finland, Sweden, and the United States continue to make progress. In fact, the U.S. program recently reached a critical milestone by receiving a majority vote on the selection of Yucca Mountain in Nevada for the site of its first high-level nuclear waste repository; however, opposition remains from elected officials in the state of Nevada, as well as from the general Nevada population.

Some consider this picture to be more balanced in view of the current status of nuclear power worldwide. Public trust allows over 100 plants in the United States and over 400 worldwide to operate, with dozens more currently under construction. Recent sales and license extensions suggest that these plants are viewed optimistically for the future. New nuclear power plants are being constructed in Asia, and Finland has recently decided to construct a new plant. At least one waste disposal facility is also accepted in the United States.[10]

There is also a clear asymmetry in nuclear applications of all kinds between the European countries where electric power growth is minimal and the financial and

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[9] "While Confidence in Leaders and Institutions Has Dropped from the extraordinary Post-9/11 High, It is Still Higher Than It Was for Most of the Late 70s, 80s, and 90s," Rochester, NY: Harris Interactive, 2003.

[10] Waste Isolation Pilot Plant (WIPP), Carlsbad, New Mexico.

physical infrastructure exists for several alternative routes to electric power, and the most rapidly growing countries of Asia, where the demand for electric power is growing rapidly and is slated to continue growing, and where the financial and physical infrastructures for satisfactory alternatives are inadequate. It is quite possible that this asymmetry in time will lead to the center of gravity of the civilian nuclear world shifting to Asia, where the center of gravity of economic growth and trade is already shifting. No serious consideration of the future governance of nuclear matters should overlook this possibility.

Much of the focus within the nuclear community for improving public attitudes and acceptance of nuclear activities continues to focus on supplying sufficient and effective public information, and on its need to provide sufficient opportunities for the public to participate in decision-making in meaningful ways. It seems clear that such efforts are a necessary part of an effective program to communicate with the public in ways that create understanding and help lay the foundation for informed dialogue and, hopefully, a measure of public acceptance. Professionalism is key in working with the public, and the discussion must be viewed as more than a one-way dialogue. There must be an emergence of acknowledged local experts and leaders who are viewed as “knowing” and “understanding,” who can communicate in a clear and concise fashion, and who are viewed as trusted sources of information. Critical to improving confidence and credibility is the development of a shared understanding of the benefits and risks to all affected and interested parties. However, poor communication of risk can destroy trust. Thus, it is imperative to achieve consensus on the risks and benefits. One note of caution must be voiced when claiming public acceptance on the basis of a lack of vocal or overt opposition. In most cases, levels of opposition have not been assessed nor has it been determined if they have permanently subsided. Additionally, it fully overlooks cases where public opposition has been quelled by actions of the state.

What is less clear is whether such activities are sufficient, or even the most important elements of such programs. “Trust is fundamentally asymmetric in two important ways: (1) trust-decreasing events have greater salience and therefore impact on perceptions than trust-increasing events,[11] and (2) trust is easily and quickly lost, even by a single event, but once lost is typically difficult to regain—if it can be regained at all.[12] It is unrealistic to expect a rapid turnaround in levels of trust in society’s major institutions.”

The pervasiveness of this problem is widely recognized in the social science and policy communities. Theoretical opinion among scholars in the trilateral initiative organizations (United States, Russia, the IAEA) has crystallized around the idea, codified in the National Research Council report on Understanding Risk, of an analytic-deliberative process of decision-making. The process involves the active engagement of both technical experts and stakeholders in procedures of analysis and deliberation in arriving at public policy decisions.[13] Other features have been identified as possible key features in nuclear programs where trust has been evident. Such features have included—

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[11] P. Slovic, “Perceived Risk, Trust, and Democracy,” *Risk Analysis*, Vol. 13, No. 6, p. 675, 1993.

[12] P. Slovic, “Perceived Risk, Trust, and Democracy,” *Risk Analysis*, Vol. 13, No. 6, p. 675, 1993.; Eugene A. Rosa and Donald L. Clark, Jr., **“Historical Routes to Technological Gridlock: Nuclear Technology as Protoypical Vehicles,” *Research in Social Problems and Public Policy*, Number 7, pp. 21-57, 1999.**

[13] Paul C. Stern and Harvey V. Fineberg, editors, *Understanding Risk: Informing Decisions in a Democratic Society*, Washington, D.C., National Academy Press, 1996.

- The need for the program is clearly established.
- Roles and responsibilities of the players are well understood.
- Respect of the need for societal consent is apparent.
- A clear, open, and transparent process is used in decision-making.
- There are many sequential steps taken as the program unfolds that include the possibility of altering or reversing course.[14]
- Program officials recognize that due deliberative process takes time and are willing to invest the time.

In addition, these three factors are important in achieving public confidence and support even when the above factors are evident:

- Responsible organizations are seen as competent by the public and have demonstrated their competence.
- Responsible organizations exhibit fiduciary responsibility by demonstrating their commitment to the best interests of the public as they implement their programs.
- Responsible organizations are willing to engage in frequent frank discussions with stakeholders and to adapt decisions to deal directly with stakeholder concerns and considerations.

Finally, as with good science, advocacy of nuclear power, must adhere to the following rules:

- Always tell the truth.
- Always under-promise.
- Treat your opponents' views with respect.
- Immediately correct mistakes to maintain credibility.

Some Issues for Today

There is universal agreement that a sufficient level of public acceptance is indispensable to the success of any program. But, it is not possible to characterize public acceptance in categorical terms. There is the possibility of taking the point of view that public acceptance is established when there is little public opposition, either directly or through activist organizations, to policies and procedures or when those who can stop a project choose not to. Yet this position attracts its own share of challenges, such as when to judge that levels of opposition have been validly addressed or how to determine that opposition has permanently subsided. Some key questions regarding both communication and public acceptance, and their relationship, remain:

- What are the risks associated with nuclear policies and technologies that evolve from a deliberative process between experts and stakeholders? How can this knowledge of risks better inform policy choices?

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[14] A similar step-by-step process for the disposal of nuclear waste is delineated in a recent National Academy of Sciences report: *One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste*, Report of the Committee on Principles and Operational Strategies for Staged Repository Systems, U.S. National Research Council, Washington, D.C., 2003.

- How do actual nuclear-related risks and benefits compare with perceived risks and benefits, and what are appropriate mechanisms for addressing this disconnect? (It may not be possible to close the gap and there is evidence showing that efforts can sometimes exacerbate rather than ameliorate the problem.) How do nuclear risks compare with non-nuclear risks? Does the public feel misled by the government or industry on nuclear issues? How do decision-makers regain lost trust?
- Are there actions that can be taken to better understand and deal with public concerns? Can they be effectively separated from concerns arising from a more generalized anti-nuclear agenda? What is an effective response to media coverage of nuclear issues?
- To what extent can scientific, technical, and institutional improvements enhance public communication and public acceptance? For example, what potential might there be in public acceptance to advances in nuclear technology such as "inherent reactor safety" or "proliferation-resistant design?"
- What are appropriate roles for governments to play in such public debates?
- What better roles can regulators, the scientific community, and non-government organizations play?
- To what extent can more complete information about national security, energy and other civilian applications of nuclear technology, and environmental concerns affect public sentiment?

Appendix D: History: 1953–2003

The Context of Eisenhower's Atoms for Peace Speech

The United States with the close cooperation of the United Kingdom developed the atomic bomb under emergency conditions during World War II under the Manhattan Project. The high level of secrecy maintained in this project and the pressure of events prevented an in-depth consideration of how to deal with atomic energy after the war. In fairness to the participants, even if more attention had been paid to this question, it is unlikely that a firm policy would have emerged, given the massive sea changes occurring in international affairs and in how the United States chose to engage in the world—a world that first learned about the atomic bomb on August 6, 1945, with the destruction of Hiroshima.

Some postwar planning had been done. For instance, the decision was made prior to Hiroshima to produce a selective, but still comprehensive, report on the science that led to atomic energy. Henry DeWolf Smyth of Princeton University wrote a large volume on the subject and on August 11, 1945, President Truman authorized its public release. Sunday newspapers on August 12 carried summaries and extensive excerpts of the Smyth Report. The United States already was beginning to grapple with the complicated issue of how much information to make public and what to conceal, with fear of proliferation in the background.

Japan formally surrendered on September 2, 1945. Two weeks later, at the University of Chicago, the first public conference in the United States was convened to discuss the implications of atomic energy. David Lilienthal, soon to become the first chairman of the Atomic Energy Commission and a key player in the Acheson–Lilienthal plan, was present at Chicago. At the same time, President Truman was conducting his first extensive private discussions with his senior cabinet advisers on how to approach atomic energy policy.

The Council of Foreign Ministers had been created to write the peace plans. The first meeting of the council ended in London in early October with no significant progress. The deep divide between the Soviet Union and the West was becoming evident. British authorities in communication with the Americans concluded that the unresolved status of the atomic issue made any meaningful process unlikely, and a summit between the Americans, British, and Canadians—the Manhattan Project partners—was scheduled for early November in Washington.

Meanwhile, discussions about the future of nuclear weapons intensified within the U.S. government. In a message to Congress on October 3, 1945, President Truman put in motion the ideas that ultimately led to the Atomic Energy Act of 1946. Truman's message is notable for containing the first official presidential reference to peaceful use of nuclear energy and its future control. Referring to atomic energy, he stated:

> The scientific and industrial knowledge on which this discovery rests…may someday prove to be more revolutionary in the development of human society than the invention of the wheel, the use of metals, or the steam or internal combustion engine…

and gave a warning:

> The release of atomic energy constitutes a new force too revolutionary to consider in the framework of old ideas. We can no longer rely on the slow progress of time to develop a program of control among nations.

And, in a prescient preview of the Nuclear Non-Proliferation Treaty (NPT), which would not come into being for another 25 years, he stated:

> The hope of civilization lies in international arrangements looking, if possible, to the renunciation of the use and development of the atomic bomb, and directing and encouraging the use of atomic energy and all future scientific information toward peaceful and humanitarian ends.

Truman, on the basis of ongoing consultations with British and Canadian authorities, proposed initiating "discussions with the United Kingdom and Canada, and then with other nations (including, at a minimum, the Soviet Union), in an effort to effect agreement on the conditions under which cooperation might replace rivalry in the field of atomic power." He emphasized that the discussions would not involve weapon-manufacturing information, but rather "the terms under which international collaboration and exchange of scientific information might safely proceed."

These references to international collaboration notwithstanding, Truman's message also proposed the creation of the U.S. Atomic Energy Commission (AEC), which would have the power "to direct future research and establish control of the basic raw materials essential to the development of (atomic energy) whether it is to be used for purposes of peace or war." In carrying out its mandate, the AEC was "to interfere as little as possible with private research and private enterprise…" Truman's message came at a time when the United States had a monopoly on nuclear weapons and a head start on nuclear development generally. His subsequent meetings with the prime ministers of the United Kingdom and Canada resulted in the Agreed Declaration of November 15, 1945 that called for international control of nuclear energy on the grounds of the revolutionary destructiveness of the bomb and the belief of the signers that neither countermeasures nor the maintenance of secrecy offered an adequate prospect of defense. At a meeting in Moscow in December, the Soviet Union agreed to help create a United Nations (UN) commission on atomic energy.

The Acheson–Lilienthal Report

To formulate American proposals on the policies that the UN commission should adopt, Secretary of State James Byrnes asked Dean Acheson to chair a committee, consisting of James Conant, Vannevar Bush, John McCloy, and Leslie Groves. Acheson subsequently appointed a board of consultants to work out the details of proposals to be submitted to the committee. The board of consultants was chaired by David Lilienthal, former head of the Tennessee Valley Authority, and included J. Robert Oppenheimer, the former scientific director of the Manhattan Project.

After six weeks of intensive work, the board presented the committee with a 57-page report on March 16, 1946 containing some startling conclusions about nuclear development and the risk of nuclear proliferation. They wrote—

> The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent. From this it follows that although nations may agree not to use in bombs the atomic energy developed within their borders the only assurance that that a conversion to destructive

purposes would not be made would be the pledged word and the good faith of the nation itself. This fact puts an enormous pressure upon national good faith. Indeed, it creates suspicion on the part of other nations that their neighbors' pledged word will not be kept. This danger is accentuated by the unusual characteristics of atomic bombs, namely their devastating effect as a surprise weapon, that is, a weapon secretly developed and used without warning. Fear of such surprise violation of pledged word will surely break down any confidence in the pledged word of rival countries developing atomic energy if the treaty obligations and good faith of the nations are the only assurances upon which to rely.

Such considerations have led to a preoccupation with systems of inspection by an international agency to forestall and detect violations and evasions of international agreements not to use atomic weapons. For it was apparent that without international enforcement no system of security holds any real hope at all. In our own inquiry into the possibilities of a plan for security we began at this point, and studied in some detail the factors which would be involved in an international inspection system supposed to determine whether the activities of individual nations constituted evasions or violations of international outlawry of atomic weapons.

We have concluded unanimously that there is no prospect of security against atomic warfare in a system of international agreements to outlaw such weapons controlled only by a system which relies on inspection and similar police-like methods. The reasons supporting this conclusion are not merely technical, but primarily the inseparable political, social, and organizational problems involved in enforcing agreements between nations each free to develop atomic energy but only pledged not to use it for bombs. National rivalries in the development of atomic energy readily convertible to destructive purposes are the heart of the difficulty. So long as intrinsically dangerous activities may be carried out 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. We emphasize this fact of national rivalry in respect to intrinsically dangerous aspects of atomic energy because it was this fatal defect in the commonly advanced proposals for outlawry of atomic weapons coupled with a system of inspection that furnished an important clue to us in the development of the plan that we recommend later in this report.

We are convinced that if the production of fissionable materials by national governments (or by private organizations under their control) is permitted, systems of inspection cannot by themselves be made "effective safeguards…to protect complying states against the hazard of violations and evasions.

It should be emphasized at this point that we do not underestimate the need for inspection as a component, and a vital one, in any system of safeguards—in any system of international controls. In reading the remainder of this section it is essential to bear in mind that throughout the succeeding sections of this report we have been concerned with discovering what other measures are required in order that inspection might be so limited and so simplified that it would be practical and could aid in accomplishing the purposes of security.

The remainder of this section, however, is concerned with outlining the reasons for our conclusion that a system of inspection superimposed on *an otherwise uncontrolled* *exploitation of atomic energy by national governments* (original emphasis) will not be an adequate safeguard.

The Baruch Plan

Meanwhile, President Truman with the advice of Secretary of State James Byrnes asked a World War I high official and Wall Street financier, Bernard Baruch, to head the American delegation to the United Nations talks. Baruch was selected in part because of the high respect accorded him by a number of key senators on both sides of the aisle. If the United States achieved its diplomatic goal of an international agreement to control atomic energy, the advice and consent of these senators would be crucial to ratification—something where Baruch's prestige was critical. Preliminary discussions on the atomic energy legislation and the concerns raised by a number of key senators with regard to approaches to the Soviets on a nuclear control plan pointed to the difficulties of ensuring Senate acceptance of any international scheme.

In preparing an American proposal on the basis of the Acheson–Lilienthal materials, Baruch and his team of advisers consulted widely in the U.S. government, producing a proposal that built upon but revised key elements of the earlier report. For instance, the notion of international ownership of the means of production of nuclear materials was scuttled due to the heavy opposition it was likely to encounter in the Senate. With President Truman's agreement, two provisions were added to address compliance concerns. First, the U.S. would propose that the UN Security Council veto be waived in alleged cases of violation of the proposed arrangement on international control, and second, the plan would unfold in a step-by-step fashion, with safeguards against non-compliance and with destruction or transfer to international control of the stockpile of American nuclear weapons and cessation of production of weapons reserved for later stages.

On June 7, 1946, President Truman formally approved the American proposal and the instructions to the American delegation. One week later, at the opening session of the UN Atomic Energy Commission, Baruch presented the American plan. The Soviets countered with a proposal that would have created a convention to outlaw the use and production of nuclear weapons with destruction of all existing weapons within three months of ratification of the convention. As the Cold War intensified, they further proposed that the atomic question not be dealt with except within the framework of general disarmament negotiations. Some critics of the Baruch Plan claim that it was non-negotiable from the start and that a plan closer to the original Acheson-Lilienthal proposal might have been more acceptable to the Soviets. Others, with strong support from what historians have learned with the end of the Cold War and the opening of Soviet archives, concluded that Stalin's objective was to achieve atomic weapons at any cost and that no international control proposal that stood in his way was acceptable. Already, the Cold War was setting in.

About a month after Baruch's presentation of his plan, Congress enacted the Atomic Energy Act of 1946 (sometimes known as the McMahon Act) which created the U.S. Atomic Energy Commission (AEC) and the Joint Committee on Atomic Energy (JCAE), and made secrecy and the non-sharing of nuclear information official U.S. policy by law. The authors of the act were either not aware of or ignored the United Kingdom's critical involvement in the Manhattan Project and thus created the dynamic for the their decision to acquire an independent deterrent. David Lilienthal was named the first chairman of the AEC, and, although the priority was making weapons, Lilienthal did appoint an Industrial Advisory Group and the AEC began a nuclear-power research program. In 1947, Congress authorized work on a nuclear submarine and a nuclear-powered airplane.

Industrial America's dislike of the AEC monopoly over the development of nuclear technology became increasingly profound as hype expanded in the print media about the future glories of nuclear power. (Autos would run for a year on a vitamin-sized nuclear pellet; there would be no more war over oil and gas resources, electricity would be too cheap to meter, etc.). The Industrial Advisory Group of the AEC took up the issue and recommended that the government share nuclear technology information with the private sector. Lilienthal agreed, and some of the stringent rules against sharing information contained in the McMahon Act were relaxed. Lewis Strauss, after taking the reins of the AEC a few months after Eisenhower's inauguration in May 1953, brokered a joint project between Westinghouse and Duquesne Lighting to build a small power reactor at Shippingport, Pennsylvania. The application for the plant was filed with the AEC in July 1953.

While this was going on in the United States, other nuclear nations were developing their own plans for power plants. The Soviets were on the verge of operating the first civilian nuclear-power station south of Moscow, and the British were building a 100-megawatt plant at Calder Hall that they thought could be the prototype for a commercial station. Concern was rising in the Eisenhower Administration and Congress that the United States was lagging behind in the race to demonstrate the first commercial nuclear plant and take the lead in the marketing of nuclear power stations. But this was not Eisenhower's highest priority at that point in his administration. National security was the top priority.

The U.S. nuclear-weapon monopoly ended on August 29, 1949 when the Soviet Union successfully tested its own fission weapon. Subsequent to this event, the Defense Department and the JCAE proposed major expansions of fissionable-material production facilities—an issue already under consideration since late 1948 when it became evident how critical the nuclear deterrent was to Western security. Truman took his first decision to expand the nuclear production complex in October 1949. By early 1950, Truman had decided to approve development of the thermonuclear bomb and in the two years after start of the Korean war in June 1950, a new wave of decisions followed, e.g., to construct a nuclear testing facility in the United States to hedge against the possibility that, in the event of a broader war, the test facilities in the Pacific might fall into enemy hands, to further expand nuclear production capacity, and to create a second nuclear laboratory in California to supplement the facility at Los Alamos.

As the crises of the late 1940s and the early 1950s unfolded, the United States undertook several reviews of its arms control policy. Although the discussions at the United Nations had turned into public relations battles, the United States was hesitant to break them off for political reasons, but at the same time held out little prospect for success. In early 1952, the United Nations was considering changing its organization for negotiating arms control. To help prepare the American position on that matter and to take a fresh look at the prospect for meaningful discussions, Secretary of State Dean Acheson established an advisory committee headed by Oppenheimer in April 1952. The panel filed its report on January 15, 1953, shortly before Dwight Eisenhower was inaugurated as President.

The Eisenhower New Look

The late 1940s were marked by a number of East–West crises: Soviet troops remaining in Iran, civil war in Greece, Soviet demands on Turkey, and so forth. In 1948, the prospect of war became very real when, in the aftermath of the coup in Czechoslovakia, the Soviets blockaded allied access to Berlin. By 1949, the North Atlantic alliance was born and that same year, the Soviets tested their first atomic bomb and the Communists won the civil war in China.

During this time, Dwight Eisenhower was in the process of becoming one of the most knowledgeable American officials on nuclear issues. He first had encountered the Manhattan Project during World War II when, as commander of the allied forces, he was briefed on the possibility that the Germans might oppose the allied invasion of Europe with radioactive materials scattered in the path of invading allied forces. After the war, Eisenhower became chief of staff of the army and found himself involved heavily in nuclear policy matters. When he left the army and went to Columbia University as president, Eisenhower still found himself in early 1949 commuting to Washington weekly to serve as the *de facto* chairman of the Joint Chiefs of Staff in their bitter budget debates which involved major nuclear issues. And when the Korean War broke out in 1950, President Truman selected Eisenhower to become the first Supreme Allied Commander, Europe, and to set up the military command structure for NATO. In all these assignments, Eisenhower stayed close to nuclear matters.

In 1952, Eisenhower asked to be relieved of his assignment to return to the United States to seek the presidency. His main concern was that the conservative wing of the Republican Party—the Old Guard—would turn away from an internationalist agenda. While accepting many of the aspects of the containment policy that the United States had pursued under Truman, Eisenhower was convinced that a more coherent approach to the long-term struggle was necessary—something that combined more constrained spending than NSC-68 portended, that balanced diplomacy with military power, and that made better use, at least in the short term, of the psychological advantages afforded by America's nuclear offensive power. On October 31, 1952, shortly before his election, the United States exploded its first thermonuclear device, "Mike," in a test at the Eniwetok Atoll. With a broad-based expansion of the American nuclear production program already underway and with a wide range of nuclear designs ranging from small battlefield weapons to massive thermonuclear bombs about to enter the American stockpile, Eisenhower took office as a wartime president with his most immediate task being the need to end the Korean War.

During the early months of the Eisenhower presidency, the new administration set in motion a number of reviews on budgetary policy, on how to end the Korean war in a fashion that minimized the changes of its resumption, of how to reorient American defense policy for the long haul, on how to reassure European allies, and on other pressing matters. President Eisenhower was deeply involved in these activities. They all formed part of the backdrop to his Atoms for Peace proposal.

The Oppenheimer panel's report concluded that the large increases in production of fissile material had made it virtually impossible to verify a nuclear disarmament agreement because of the uncertainty in accounting for all the material that had been produced. Seeing no immediate path to verifiable nuclear disarmament, the Oppenheimer committee's main recommendations were fourfold. First, publicly discuss the coming crisis; second, release information on the extent of the U.S. arsenal and its rate of weapon manufacture to both inform the public and to dissuade the Soviets from thinking that they might already have a "knockout" blow capability; third, begin negotiations with the Soviet Union on an arms control measure limiting each side's weapon stockpile and delivery vehicles; and fourth, build a broad range of military options to decrease reliance on nuclear weapons. Oppenheimer himself was especially concerned that the president should find some way to more accurately describe the dangers and opportunities of the nuclear age to the public—something Oppenheimer would pursue further in an article in *Foreign Affairs* magazine later in 1953.

When he first reviewed the Oppenheimer report as a newly inaugurated president, Eisenhower was impressed and asked his senior advisors to read it closely. As the events of the first year unfolded, one of those unanticipated turning points that dramatically changed the policy environment took place, in this case, the death of Joseph Stalin in March 1953. There had been essentially no American planning for this possibility, and over the course of a long weekend, Eisenhower's advisors debated what should be done immediately to take advantage of the change in Moscow with Stalin's demise. Largely on the advice of Charles Bohlen, the decision was taken not to float a dramatic new disarmament scheme because it would likely be misinterpreted by the new collective Soviet leadership. However, when the Soviets themselves launched a peace initiative, Eisenhower responded with a major foreign policy address on April 16, his "Chance for Peace" speech. In it, Eisenhower noted the "unprecedented money and armaments capable of inflicting instant and terrible punishment" and he offered to join the Soviets in disarmament talks on the condition that they show "deeds, not words."[1]

Operation Candor

As part of the follow-up to this speech, C.D. Jackson, a senior advisor who headed the Psychological Strategy Board, was asked to produce a presidential address on Oppenheimer's recommendation that some means should be found to discuss nuclear issues accurately and comprehensively with the public, a project that, Jackson dubbed Operation Candor. Working with the State Department, Jackson had completed a few drafts when the first Soviet test of a thermonuclear weapon was announced on August 12, 1953, just nine months after the first U.S. test the previous November.

Eisenhower's senior advisers were, for the most part, deeply pessimistic about the prospects of any meaningful nuclear discussions with the Soviets. Eisenhower himself did not share that pessimism. He hoped that some modest way might be found to engage the Soviet leaders in a step-by-step approach to controlling the nuclear arms race. What led Eisenhower personally to his Atoms for Peace proposal remains subject to speculation. While he was president of Columbia University, he had become friends with the physicist I.I. Rabi who, as an American delegate to the Firth General Assembly of the UN Educational, Scientific, and Cultural Organization held in Florence, Italy, in 1950 had advanced a motion to create regional research centers and laboratories—one of the initiatives that led in 1954 to the establishment of CERN, the European Organization for Nuclear Research. The idea of international scientific collaboration doubtless was one of the themes that Eisenhower had in the back of his mind.

Another theme was Eisenhower's personal concern that some means had to be found for sharing nuclear information with America's NATO allies—a matter that led Eisenhower to personally champion a change to the Atomic Energy Act in 1953. Eisenhower's papers reveal, as was part of his operating style, that his detailed discussions with corporate figures brought him into contact with American corporate leaders who viewed commercial atomic energy as a major growth area. And, as discussed earlier, Eisenhower was seeking some means to begin a broader discussion of nuclear issues that accurately described the dangers of the thermonuclear age while, at the same time, holding out hope for the future that nuclear technology and policy could develop without necessarily leading to a new world war. All of these themes and more apparently came together when, in September 1953, Eisenhower began to discuss with his advisers the outline of what became his Atoms for Peace proposal.

A key element of the idea was to have the United States and the Soviet Union begin to set aside agreed amounts of nuclear materials from their weapon stockpiles for peaceful

[1] Ira Chernus, *Eisenhower's Atoms for Peace*, Texas A&M University Press, College Station, 2002, p. 10.

purposes, i.e., to create a uranium "bank" administered by an international agency. Because it was thought at the time that the amounts of uranium in the world were extremely limited, Eisenhower believed the bank could theoretically reduce the threat of nuclear war by reducing weapon stockpiles, i.e., that there was, in essence, a zero sum game between uranium for peaceful purposes and uranium for weapons.

Eisenhower suggested to his Chairman of the Atomic Energy Commission, Lewis Strauss, that they come up with a figure of the amount of material to be turned over to the bank that the United States could handle from its stockpile "but which would be difficult for the Soviets to match."[2] No such bottom-line figure was ever proposed, mainly because there was no reliable intelligence as to Soviets' production capacity, and it began to become evident that there was much more uranium in the world than originally thought.

The Eisenhower bank proposal, made in September 1953, was worked on over the next three months by a group of advisers, who included Jackson, Strauss, and John Foster Dulles. Eisenhower's notion of an international agency devising methods for the allocation of contributed fissionable materials for peaceful purposes, including applications to agriculture and medicine, and especially "to provide abundant electrical energy in the power-starved areas of the world," contained no details as to exactly how such a program would be carried out.

A natural venue for the speech was the UN General Assembly, and while meeting with British and French leaders in Bermuda to discuss world problems, Eisenhower received a formal invitation from Secretary General Dag Hammerskjold to address the 470th Plenary Meeting of the General Assembly on December 8, 1953. Details of what Eisenhower would say were not released prior to the address. He began his comments by stressing American support for the United Nations and for the visions of peace and human dignity embodied in its Charter. He then proceeded to his main themes:

> I know that the American people share my deep belief that if a danger exists in the world, it is a danger shared by all; and equally, that if hope exists in the mind of one nation, that hope should be shared by all.
>
> …I feel impelled to speak today in a language that in a sense is new, one which I, who have spent so much of my life in the military profession, would have preferred never to use. That new language is the language of atomic warfare.
>
> …although our earlier start has permitted us to accumulate what is today a great qualitative advantage, the atomic realities of today comprehend two facts of even greater significance. First, the knowledge now possessed by several nations will eventually be shared by others, possibly all others. [para] Second, even a vast superiority in numbers of weapons, and a consequent capability of devastating retaliation, is no preventive, of itself, against the fearful material damage and toll of human lives that would be inflicted by surprise aggression.
>
> …To pause there would be to confirm the hopeless finality of a belief that two atomic colossi are doomed malevolently to eye each other indefinitely across a trembling world. To stop there would be to accept helplessly the probability of civilization destroyed, the annihilation of the irreplaceable heritage of mankind handed down to us generation from generation, and the condemnation of mankind to begin all over again the age-old

[2] Ira Chernus, p. 80.

> struggle upward from savagery towards decency, and right, and justice. Surely no sane member of the human race could discover victory in such desolation.
>
> Could anyone wish his name to be coupled by history with such human degradation and destruction. Occasional pages of history do record the faces of the "great destroyers," but the whole book of history reveals mankind's never-ending quest for peace and mankind's God-given capacity to build.
>
> …The United States, heeding the suggestion of the General Assembly of the United Nations, is instantly prepared to meet privately with such other countries as may be "principally involved," to seek "an acceptable solution" to the atomic armaments race which overshadows not only the peace, but the very life of the world. We shall carry into these private or diplomatic talks a new conception.
>
> The United States would seek more than the mere reduction or elimination of atomic materials for military purposes. It is not enough to take this weapon out of the hands of the soldiers. It must be put into the hands of those who know how to strip it of its military casing and adapt it to the arts of peace.

On the basis of these themes, Eisenhower went on to outline the details of the American proposal: for the transfer by the United States and the Soviet Union from their stockpiles of uranium and fissionable materials to an international atomic energy agency; of a scheme under the aegis of the United Nations for devising safeguarded methods of making the material available "*to serve the peaceful pursuits of mankind*"; of the particular need to expedite the goal of providing "abundant electrical energy in the power-starved regions of the world." He ended his speech to an enormous round of applause.

The speech was well received around the world, but the Soviets, while accepting talks, faulted the approach. In late December, meeting with the U.S. working group charged with seriously exploring what might now be done toward nuclear arms control, Eisenhower reiterated his willingness to abolish nuclear weapons separate from a general disarmament scheme, if fully reliable safeguards were feasible, which he recognized was not the case under existing conditions. Three years of difficult negotiations followed, the result being the foundation of the International Atomic Energy Agency in 1957.

Evolution of the Security Environment and Civilian Applications from 1954 to the Present

The Early Period, 1954–1960

East–West Competition, 1954–1960

During the 1950s, the American and Soviet nuclear stockpiles and postures expanded rapidly, as both sides raced to secure advantages. The arms race extended not only to nuclear weapons but also to a variety of delivery systems (bombers and especially missiles) and to defenses against both air and missile attacks. Several episodes—e.g., the Korean War (already discussed), the Taiwan Straits crises, the Indochina wars, the Suez and Hungarian crises, the Berlin crises, the Algerian crisis—spanned the era. As thermonuclear weapons entered the inventories, the threat of apocalyptic war took on a frightening new reality.

The process of de-colonialization gathered momentum during this time, offering another arena for East–West competition. The 1950s ended as they began, in a crisis mode. In the

Soviet Union, Khrushchev emerged within two years after Stalin's death as the new Soviet leader. His emphasis on nuclear planning was reflected, among other things, in creation of the Strategic Rocket Forces. Nuclear weapons dominated the strategic competition.

In late 1958 Khrushchev threatened to sign a separate peace treaty with East Germany and to unilaterally terminate allied rights in Berlin. In the ensuing confrontation, NATO quietly set up the Live Oak planning cell to prepare for a possible military clash over Berlin. In January 1959, Cuban revolutionaries led by Fidel Castro forced Battista to flee Cuba. The situation in Southeast Asia continued to deteriorate, and in August 1959, Laos declared a state of emergency.

On the positive side of the ledger, Western Europe had by the end of the decade largely recovered from the ravages of World War II and, despite recurring crises, NATO's confidence had deepened over the years. Moreover, American nuclear superiority and the debates over bomber and missile gaps, was a reality understood by President Eisenhower and his senior advisors. As a symbolic event closing out the decade, the first American intercontinental ballistic missile (ICBM), an Atlas, went on operational alert in October 1959, joining the Strategic Air Command bombers that had been on day-to-day alert since 1957. Earlier in the decade (January 1954), the *Nautilus*, the world's first nuclear-powered submarine, had been christened. Now it was about to be joined by the Fleet Ballistic Missile force. The first American submarine-launched ballistic missile, the Polaris, had successfully completed its first flight test from a submerged submarine in August 1959. The American nuclear stockpile that had numbered fewer than 300 nuclear weapons in 1950 now stood at over 12,000. By January 1950, the United States had conducted a total of six nuclear tests including the Trinity test of World War II. By December 1959, even with a testing moratorium in effect since late 1958, the United States had conducted a total of 194 nuclear tests.

Nuclear Testing, 1954–1960

In early 1954, Eisenhower approved Operation Castle in the Pacific, a test series that included thermonuclear detonations. On February 28, 1954, the United States conducted a test code-named *Bravo* that exploded with a force of 15 megatons, the largest yield ever tested by the United States and reportedly much larger than anticipated. The size of the yield, coupled with unexpected winds, resulted in radioactive debris that contaminated a Japanese tuna trawler, resulting in 23 cases of severe radiation poisoning and in one death. The resulting international furor led to the first widespread public campaign to end nuclear testing—a theme picked up by Adlai Stevenson in the American presidential context of 1956.

President Eisenhower at first resisted calls for an end to nuclear testing, whether through informal moratoriums or via negotiated settlements, unless a satisfactory inspection scheme could be worked out. There was strong sentiment on the part of Eisenhower and his senior advisers that the Soviets would take advantage of a test ban to covertly test nuclear devices. The principle behind Eisenhower's thinking, dating to the earlier Baruch plan era, was that the activities subject to any arms control agreement should be sufficiently transparent so as to give time to detect and respond effectively to cheating.

In June 1957, the Soviets began to publicly propose a number of initiatives intended to inhibit testing. Eisenhower responded with a counterproposal for a brief testing moratorium in exchange for future limits on nuclear weapons, and, one month later, extended the length of the proposed moratorium to two years if the Soviets agreed to cease production of nuclear weapons. The Soviets rejected the linkage. In October 1957, the Soviets launched

Sputnik—an event greeted in the West with dismay and fear, appearing as it did to undercut the presumption of Western technological advantage in the arms race. Meanwhile, Khrushchev kept up the public pressure by unilaterally announcing a test suspension in March 1958.

Out of this dynamic came agreement in early 1958 to convene a conference of experts in Geneva that summer, to examine options for technically monitoring a nuclear test ban. When the conference ended in August 1958, Eisenhower proposed that American–British–Soviet talks should begin on a permanent end to nuclear tests and, as a measure of good faith, announced that the United States would abstain from nuclear testing for a year from the date the talks began. At the end of October 1958, the Geneva Conference on the Discontinuance of Nuclear Weapons Tests held its opening session. The United States completed its last nuclear test of the Eisenhower administration on October 30—the day before the talks began. The Soviets joined the moratorium with their final test on November 3. The talks proceeded slowly through the remainder of Eisenhower's tenure in office.

Initially, the calls to stop nuclear testing were driven by public health concerns and by fears of an escalating arms race. By 1957 however, it became clear, as John Foster Dulles put it, that the United States had to deal with "the promiscuous spread of nuclear weapons throughout the world," and an end to nuclear testing began to be discussed as a nonproliferation tool. It was well understood that some nuclear weapons could be built without nuclear testing. After all, the first American nuclear weapon—the Hiroshima bomb—was an untested design. Constraints on nuclear testing might, however, discourage countries from pursuing more sophisticated nuclear weapons and also might serve as a political force that could work to erode political decisions in favor of proliferation.

The nuclear test talks continued inconclusively in the late 1950s. Eisenhower later would say that one of his greatest regrets as president was his failure to achieve a nuclear test ban.

Nuclear Proliferation, 1954–1960

During the Eisenhower years, the nuclear deterrent that the United States extended to its NATO allies and to Japan, South Korea, and Taiwan was institutionalized. The credibility of this deterrent became an important component of American security policy, not merely for the purposes of defending the allies but also to dissuade them from seeking to acquire their own nuclear stockpiles.

The most complex form of assurance was NATO, at the heart of which was the highly controversial question of German access to nuclear weapons. When Eisenhower left his post as SACEUR in 1952, he already was convinced that German rearmament was essential to the future of Western security. Germany regained its sovereignty under formulas underwritten by German and American assurances. West Germany pledged, as a condition of regaining its sovereignty, that it would not produce nuclear weapons and that it would rearm only within the collective structure. As NATO became more heavily dependent on nuclear deterrence, the issue of shared responsibility for deterrence became a pressing concern. Following the shock of Sputnik, the United States proposed and the allies agree that a stockpile of American weapons be established in Europe for NATO forces. While these weapons would remain under day-to-day control of American forces, they could be released by a presidential decision for allied use. The Europeans would provide and operate delivery systems. President Eisenhower secured a second amendment to the Atomic Energy Act to make this possible.

In December 1959, the North Atlantic Council called for a review of alliance objectives for the next 10 years. In support of this activity, Secretary of State Christian Herter (who had replaced Foster Dulles who had died of cancer) turned to the former head of the Policy Planning Staff in the early Eisenhower years, Robert Bowie, to suggest American initiatives. Responding to the new environment created in the aftermath of Sputnik, and to the evolving Soviet missile threat to Europe and eventually to the United States, Bowie submitted a report whose centerpiece was the concept of a NATO submarine force jointly financed, manned with mixed crews, and employing nuclear weapons provided by Americans, albeit still under ultimate American control. The scheme was seen to serve several purposes: to more deeply involve the allies in nuclear operations and to assure them of the strength of the American commitment; to discourage and possibly reverse the trend toward national nuclear forces (France was well along toward joining the United Kingdom as an independent nuclear power); to meet NATO requirements to counter Soviet missiles aimed at Europe; and to encourage further movement toward European integration. Eisenhower embraced this idea of a Multilateral Nuclear Force (MLF) and formally presented it to the North Atlantic Council in 1960.

France, China, and Israel all initiated nuclear weapon programs during the 1950s, for different reasons reflecting their national interests. In the national intelligence estimate prepared in the final days of the Eisenhower administration assessing the world situation, nuclear proliferation was identified as a major problem of the next decade with the possibility that additional nations would acquire nuclear weapon capabilities. France was known to have a program underway and China and Israel were strongly suspected of having programs. Others might enter the field, reported the estimate, if for no other reason than to counter the power and prestige of their rivals.

As already discussed, a moratorium on nuclear testing was still in place, and although the nuclear test talks were proceeding slowly, they at least were proceeding. In 1958, Ireland's foreign minister, Frank Aiken, began a campaign in the UN General Assembly to build support for an international regime to prevent further proliferation of nuclear weapons. The so-called "Irish resolution" initially called on the three nuclear powers not to supply other countries with nuclear weapons while the nuclear testing talks were underway. The reason the Soviets initially supported the proposal was the same as the reason the Americans initially opposed it—because of its implications for NATO's nuclear-sharing. As the 1950s ended, the sides were deadlocked on progress.

Civilian Applications, 1954–1960

History shows that military R&D and deployment provides the capability and incentive for civilian uses of related technology. The early phase of nuclear power was no exception to that rule. The origins of civilian nuclear-power technical development came from the development of power reactors for naval submarine propulsion.

The first milestone of that program was the successful operation of a full-scale prototype of the first nuclear submarine propulsion system at the Idaho National Reactor Testing Station in 1953 shortly before Eisenhower's Atoms for Peace address to the UN. In its first full-power operation, the pressurized, light-water-cooled reactor (PWR) ran at full power long enough to traverse the Atlantic Ocean underwater at the same speed as a surface ship, proving the revolutionary nature of submarine nuclear propulsion. The first nuclear submarine, USS *Nautilus*, was launched in January 1955, the forerunner of a fleet of nuclear-powered submarines and ships of major importance to U.S. defense and Cold War strategy. An alternative, sodium-cooled, thermal spectrum reactor was also successfully tested and powered a second nuclear submarine, the *Sea Wolf*, but from then on the Navy only used the light-water-cooled system.

The AEC fostered civilian nuclear-power development in parallel with this military development. In the fall of 1953, the AEC started a project to build a 60-megawatt-electric nuclear electric plant, powered by a PWR, at Shippingport in Pennsylvania. It was to be placed on the commercial grid and industrial participation was contracted for the project. The plant was completed and provided electricity to the grid in 1957.

The breeder reactor was given high priority for development because of its potential to provide abundant nuclear fuel for many centuries. An experimental, sodium-cooled, fast-spectrum reactor, the EBR-1, was brought to power in December 1951 at the Argonne National Laboratory facilities at the Idaho test station. It operated successfully, establishing the feasibility of the breeder concept and producing a small amount of electricity for the first time in history.

Similar activities were underway in Europe. The United Kingdom started construction of a dual-purpose (power and weapon plutonium production), gas-cooled reactor plant, Calder Hall, in 1953. The Soviets initiated operation in 1954 of its first nuclear electric power plant, APS-1. A dual-purpose unit, APS-1 produced 5 megawatts-electric and was graphite-moderated and light-water-cooled. The French followed the British approach, placing its first power reactor, G1, in operation in 1956.

All of these activities were marked by success and very rapid progress in reactor R&D and in plant construction that engendered considerable public and political enthusiasm for nuclear power. That many of these systems were dual-purpose and produced bomb-grade material did not quell that enthusiasm appreciably. It was in that atmosphere of success and enthusiasm that Eisenhower's UN address heralded the promise of worldwide benefits of peaceful uses of nuclear technology, including nuclear power. The enthusiasm of the international technical community was demonstrated by the UN sponsorship of the first international Atoms for Peace Conference held in Geneva in August 1955. The Conference initiated a massive transfer of technology, involving the participation of 1,500 delegates and 1,000 papers, the largest gathering of scientists and engineers the world had ever seen. This knowledge stimulated many individual nations to initiate research in nuclear energy for peaceful purposes.

Accelerated effort on civilian nuclear-power development quickly followed Eisenhower's proposal. In 1954, the U.S. Atomic Energy Act was amended to allow private ownership of nuclear power plants and leasing of nuclear fuels and to increase international cooperation in the development of peaceful uses of nuclear technology, including the transfer abroad of special nuclear and other materials.

To stimulate commercial nuclear-power development, Congress authorized the AEC in 1955 to enter into a Power Demonstration Reactor Program. Three proposals were submitted and accepted. Yankee Atomic, a consortium of 13 New England Utilities, joining with Westinghouse as the reactor supplier, built the Yankee Rowe 100-megawatt-electric PWR. Detroit Edison formed a broad-based industrial consortium (Atomic Power Development Associates) to build Fermi-1, a 100- megawatt-electric, sodium-cooled, fast-spectrum reactor. The Nebraska Consumers Public Power District, with Atomics International as the reactor supplier, built a 75-megawatt-electric, sodium-cooled, graphite-moderated reactor.

Two projects were also undertaken by utility companies with private financing only. Commonwealth Edison, with General Electric as the reactor supplier, built the Dresden-1 180- megawatt-electric, boiling-water reactor (BWR) near Chicago, based on Argonne National Laboratory's pioneering development work on the EBWR experimental reactor. The Consolidated Edison Company of New York, with Babcock and Wilcox as the reactor supplier, built the Indian Point-1 236- megawatt-electric PWR near New York that used thorium fuel rather than uranium fuel. The Dresden-1 plant began operating in 1959 and remained in successful operation for about 20 years. The Yankee Atomic plant (the Yankee Rowe plant) near Grove, Massachusetts, went on line in 1960 and operated successfully for 30 years. The other three systems were also completed and brought to power but did not achieve sufficient technical and economic success to warrant continued long-term operation.

The power demonstration program, in subsequent rounds, sponsored a wide variety of other reactor types and carried them through varying stages of development: the high-temperature, gas-cooled reactor (HTGR), the organic cooled reactor, the heavy-water-moderated, light-water-cooled reactor, and the molten salt reactor. A small demonstration plant or experimental facility was built for each of these types. In the case of the HTGR, the development subsequently progressed from the demonstration phase to the construction of a 400- megawatt-electric power plant, the Fort St. Vrain plant of Public Service of Colorado. None of the other concepts was chosen for commercial deployment.

During this same period, other applications of nuclear power were being pursued. A military-aircraft nuclear propulsion system, a nuclear rocket for space exploration, a mobile nuclear-power plant for remote military bases, and a nuclear propulsion system for commercial shipping. But the rapid success of the light-water reactor (LWR) for commercial electricity generation caused industrial interest to focus on the LWR plants, both the PWR and BWR types.

The Middle Period, 1960–1980

East–West Competition, 1960–1980

The year 1960 was a presidential election year in the United States. It did not begin auspiciously. In February, Russian Foreign Minister Mikoyan arrived in Cuba for a 10-day visit. A week later, France exploded its first atomic bomb at a test site in the Sahara Desert. In May, an American U-2 reconnaissance aircraft (still highly secret at the time) was shot down over the Soviet Union. To the embarrassment of the Eisenhower administration that first denied it was conducting aerial spying, the pilot (Francis Gary Powers) survived the event and was used by Khrushchev to launch a major propaganda campaign and as a pretext for walking out of the Paris summit. The Congo gained independence from Belgium in June and civil war broke out almost immediately, with Washington and Moscow backing different factions. In September, at the 15th Session of the UN General Assembly, Khrushchev launched a new propaganda campaign, calling for the destruction of all nuclear stockpiles and other weapons of mass destruction (WMD) within four years. In November 1960, John F. Kennedy was elected president of the United States, in the midst of this crisis atmosphere. By December, Communist guerrilla forces were advancing on the capital of Laos.

From 1960 through 1980, six American presidents—three Republicans (Eisenhower, Nixon, and Ford) and three Democrats (Kennedy, Johnson, and Carter) led the United States through the dangerous middle period of the Cold War. Khrushchev was ousted in 1964 and a single Soviet leader, Leonid Brezhnev, presided over Soviet politics during this same time.

The East–West competition became all the more complex as NATO evolved, as the United Nations expanded rapidly with the progressive independence of a number of former colonies, as the Arab–Israeli competition continued (with the 1967 war marking a major new departure in the confrontation), as the United States fought a major, exhausting war in Vietnam, as China challenged Moscow's leadership of the Communist movement, as the United States replaced the United Kingdom as the guarantor of stability in the Gulf, and as any number of other crises swirled around the margins of the East–West confrontation. Throughout this period, nuclear weapons remained at the heart of the competition, albeit with a new thrust to try to stabilize the central nuclear relationship through arms control. The Cuban missile crisis of 1962 reinforced this imperative.

The early 1960s, in the estimation of many scholars, are the golden age of arms control theory. The concept of stabilizing the nuclear competition through negotiated agreements became a major principle in American security policy. By 1969, the United States and the Soviet Union formally were involved in such negotiations, and in 1972 the first agreements were signed. The talks that led to the initial interim agreement on offensive arms (SALT I) and the Anti-Ballistic Missile (ABM) Treaty were carried over into the SALT II talks, resulting in a new treaty by 1979. They spanned the long period generally known as détente in East–West relations—an especially controversial period in American politics.

By the end of the 1970s, new challenges were on the horizon. The year 1979 began with the overthrow of the Shah's regime in Iran and the advent of a religious Shi'ite government. It ended with the Soviet invasion of Afghanistan, an action that (among other things) derailed ratification of SALT II.

Nuclear Testing, 1960–1980

The 1960s began with a nuclear-test moratorium being observed by the United States, the United Kingdom, and the Soviet Union. As noted earlier, France conducted its first nuclear test in early 1960. The nuclear test ban talks at Geneva recessed in December 1960 and their resumption was delayed until March 1961, to allow the new Kennedy administration time to review its policy. Kennedy clearly wanted a nuclear test ban and carried this message to his first meeting with Khrushchev in Vienna in the summer of 1961. The meeting ended coldly, however, with the Berlin crisis again at the center of relations, and when the Soviets resumed nuclear testing in September 1961, the Americans followed suit. When the Soviets resumed nuclear testing, they exploded a mammoth device of some 50 megatons, the largest nuclear explosion ever conducted (but by no means the largest physically possible).

After the Cuban missile crisis of 1962, the circumstances emerged for a new round of talks and, in 1963, a limited test ban treaty was signed in Moscow. The unclassified American records of the period reveal that one of Kennedy's main hopes in concluding this agreement was that it might contribute to constraining the nuclear ambitions of China.

China proceeded to its first nuclear test in October 1964, cessation of Soviet assistance and the limited test ban treaty notwithstanding. In 1974, India conducted what it advertised as a "peaceful" nuclear explosion in reaction to China's nuclear status. South Africa acknowledged in 1993 that it had acquired its first nuclear device in 1979. It is still a matter of debate whether the signal from the South Indian Ocean detected in 1979 by a U.S. Vela satellite was a South African or an Israeli test, or both.

Through the remainder of the period, further test ban talks were held. A threshold test ban treaty was signed in 1974, limiting underground tests to 150 kilotons, and a counterpart peaceful nuclear explosions treaty was signed in 1976, but the ratification of both was held in abeyance in the absence of verification provisions.

Nuclear Proliferation, 1960–1980

In December 1961, the UN General Assembly unanimously adopted a revised version of the Irish resolution, pointing the way to a nuclear nonproliferation treaty, but U.S.-U.S.S.R. disagreement on NATO nuclear-sharing arrangements for Germany continued to block any meaningful progress. The first Chinese nuclear test in October 1964 changed the dynamics of the debate. On October 18, 1964, President Lyndon Johnson went on radio and television to discuss Khrushchev's ouster on October 15 and the first Chinese nuclear test on October 16. In his address, he extended what appeared to be a major (if informal) security assurance, namely, "The nations that do not seek national nuclear weapons can be sure that if they need our strong support against some threat of nuclear blackmail, then they will have it."

The immediate impact of the Chinese test led to the creation of a blue-ribbon commission to advise the president on nonproliferation policy. The Gilpatric Commission (named after its chairman, the former deputy secretary of defense, Roswell Gilpatric) delivered its report to Johnson in January 1965, unanimously agreeing that "preventing the further spread of nuclear weapons is clearly in the national interest despite the difficult decisions that will be required" and that the president should commit the prestige of his office to this endeavor. By the summer 1965, as the United States became more deeply involved in Vietnam, Lyndon Johnson had decided to take the hard decisions needed to pursue a nonproliferation treaty, not the least of which was abandonment of the MLF concept. After June 1965, U.S. and Soviet positions began to converge; by August 1967, a partial U.S.–U.S.S.R. draft treaty was agreed to. In the spring of 1968, the NPT was submitted to the UN General Assembly, and on July 1, 1968, the NPT was opened for signature at Washington, London, and Moscow. That same day, American and Soviet authorities announced their intent to begin formal talks on strategic arms limitations.

In the NPT negotiations, the issue of security assurances had been discussed but not resolved, and the treaty itself included neither positive assurances (to come to the aid of a country threatened with nuclear weapons) nor negative assurances (for the nuclear powers to foreswear threatening non-nuclear states with nuclear weapons). On June 19, 1968, one week after the UN General Assembly resolution to recommend opening the NPT for signature, the UN Security Council adopted Resolution 255 that asserted that "aggression with nuclear weapons or the threat of such aggression against a non-nuclear-weapon State, would create a situation in which the Security Council and above all its nuclear-weapon State permanent members would have to act immediately in accordance with their obligations under the United Nations Charter."

Entry into force of the NPT was delayed, as was the beginning of the strategic arms talks, by the Soviet invasion of Czechoslovakia. Initially, the NPT was championed by the United States, the United Kingdom, and the Soviet Union. The other two nuclear weapon states, China and France, still protective of their sovereignty, viewed the NPT as they viewed the nuclear-test-ban treaties, as instruments they had not contributed to. When the NPT was signed in 1968, Israel already had developed nuclear weapons, and during the early years of the treaty, India and Pakistan would pursue nuclear weapons as well. What the NPT signaled was a desire on the part of most of the international community to establish a norm against nuclear proliferation. The NPT represented at best a loose compromise between those states that tentatively agreed to forego nuclear weapons and those states that were allowed to remain nuclear, but not forever (as recorded in Article VI).

The NPT also came to be viewed as the cornerstone of a broader regime of nonproliferation measures—measures that included nuclear-testing constraints; nuclear export restrictions; nuclear safeguards (the International Atomic Energy Agency, IAEA, that had resulted from the initial Atoms for Peace speech became an instrumental part of the network); nuclear assurances extended formally, informally, and through mechanisms such as nuclear-weapon-free zones, and the like.

Civilian Applications, 1960–1980

The successful operation of the PWR in the Yankee Rowe plant and the BWR in the Dresden-1 plant led to authorization of plants with higher unit power output to improve economic competitiveness against coal. The economy of scale achievable in the 500-megawatt-electric range was needed to reduce the capital cost of the nuclear plant per kilowatt produced. Thus, in a continuation of the power demonstration program, the San Onofre-1 PWR plant was sponsored by Southern California Edison with Westinghouse as the reactor supplier; the PWR Connecticut Yankee plant was sponsored by the Yankee Atomic group of New England utilities, again with Westinghouse as the reactor supplier; and the BWR Dresden 2 plant was sponsored by Commonwealth Edison with General Electric as supplier. Each of these plants operated successfully in the 400–500-megawatt-electric output range over many years.

The national nuclear power RD&D programs of countries outside the United States did not initially focus on the same systems as the United States. Canada developed a heavy-water-cooled and moderated reactor. France and the United Kingdom continued with natural-uranium, low-temperature, gas-cooled, graphite-moderated reactors. The Soviet Union continued development of its light-water-cooled, graphite-moderated reactor. Yet, a strong focus on light-water-cooled systems emerged in subsequent demonstration plants initiated by countries in Europe, many of which were built by and under technology licenses of U.S. reactor manufacturers.

Westinghouse took on contracts, working with the industrial organizations in the respective countries, to build PWR plants in the 200–300-megawatt-electric power range in Belgium, Spain, Italy, and Japan: the Ardennes plant (320 megawatts-electric) in France, a joint Belgian–French enterprise; the Trino plant (270 megawatts-electric) in Italy; the Jose Cabrera plant (150 megawatts-electric) in Spain; and the Mihama-1 plant (320 megawatts-electric) in Japan. Similarly, General Electric contracted for the construction of BWR plants in Germany, (the 240- megawatt-electric KRB-1 plant); in Spain (the 440-megawatt-electric Burgos plant); in Italy (the 150-megawatt-electric Senn plant); in India (the 200-megawatt-electric Tarapur I and 2 plants); and in Japan (the 340-megawatt-electric Tsuruga-I plant). Again, these projects were completed successfully. These plants have all had successful operating experiences over many years.

In spite of these impressive results, nuclear power was not projected to generate base-load electricity at a total cost equal to or less than coal whose costs had been coming down in this period. Because nuclear costs were not competitive and the technology new and unfamiliar, the U.S. utilities had little interest in taking the next step of authorizing a nuclear power plant on a straight commercial basis.

Two events had a major impact in changing nuclear power's position in the market. Cost competitiveness occurred through a major rise in coal costs, primarily caused by increased railroad transportation rates. The utilities concern about the unfamiliar technology was resolved by the decision by General Electric, shortly followed by Westinghouse, to offer utilities a fixed-price contract for a "turnkey" plant in which the reactor supplier would take on total responsibility to build and license the plant and then turn it over to the utility. The reactor supplier also offered to help provide for the training of reactor operators and other special nuclear skills needed by the utilities. In 1963, Jersey Central Power & Light Co. made a thorough economic analysis of a General Electric BWR turnkey offer for their Oyster Creek nuclear plant and declared that the plant would be more economical than coal. This led to a rapid expansion of commercial nuclear power.

By 1975, 55 nuclear power plants were in operation in the United States and 178 more were planned or under construction. With the exception of the original power demonstration projects, all of these plants were privately financed and fully commercial. The first eleven plants were turnkeys, ranging in output from 500 to 1,000 megawatts-electric. The record set by these first plants was encouraging. The earliest of them produced power in not much more than four years after they were authorized, and they operated with a high availability factor. The capital cost to the utility was in the range $100 to $250 per kilowatt-electric, and even counting the losses the reactor manufacturers absorbed, their total power costs were estimated to be less than equivalent coal plants. A typical example was the Ginna plant, a PWR built on a turnkey contract by Westinghouse Electric for Rochester Gas and Electric. The plant was authorized in 1966, obtained its construction permit in 11 months, and went to power 51 months after that initial authorization. It has continued to generate 600 megawatts-electric with a high average availability factor.

The success of these turnkey plants gave the utilities confidence to continue expansion of nuclear power generation in the conventional contracting form in which the primary financial responsibility is borne by the utility. These conventionally contracted plants took longer to build and cost more, but the 55 completed by the late 1970s continued to show a cost advantage over coal as well as with all alternatives except large hydropower plants. They also chalked up an unprecedented safety and environmental record. There were no deaths or injuries from radiation from them during this entire period and radiation emissions were approximately 100 metric tonnes lower than the standards allowed. The nuclear plants had a substantially better record than their sister fossil-burning plants and other comparable industrial activities in protecting construction and maintenance workers from non-radiation hazards.

A rapid expansion of the nuclear-power-plant export business occurred in parallel. Belgium, Brazil, Germany, Japan, Korea, Mexico, the Philippines, the Republic of China, Spain, Sweden, Switzerland, and Yugoslavia also saw the advantages of utilizing nuclear power for electric generation and turned initially to the United States to provide them with the equipment and the technology for their nuclear power plants. In the early 1970s, the French decided to focus on PWRs for their nuclear power expansion, signing a licensing agreement with Westinghouse to furnish the technology to build a large fleet of PWRs.

But the press of competition induced some suppliers to broaden the technology offerings to include “sensitive” technology pertaining to enrichment and reprocessing. In 1975, Siemens entered into a package contract with Brazil for eight PWR nuclear plants that included the transfer of enrichment and reprocessing technology. France entered into contracts with Pakistan and the Republic of Korea to build reprocessing plants. Although the agreements included special conditions framed to assure that the recipient countries would not use the technology to develop nuclear weapons, neither Brazil nor Pakistan had joined the NPT, eliminating third-party monitoring of compliance. The United States, both government and industry, raised major objections. The United States convinced South Korea and France to cancel their contracts, although by that time enrichment and reprocessing technology had already been transferred. Siemens did not cancel, but their enrichment technology (the Becker process) proved uneconomic and Brazilian interest in enrichment and reprocessing essentially disappeared. Only one of the eight Brazilian nuclear power plants in the Siemens package sale was built.

These problems and the nuclear explosive test by India raised major proliferation concerns. A focused international effort, the International Nuclear Fuel Cycle Evaluation (INFCE), was launched in 1977 to address nonproliferation in commercial nuclear-fuel recycle deployment. Sixty-six nations and five intergovernmental organizations participated. A massive report was completed in 1980 with many proposals for improved intrinsic proliferation resistance. But there was essentially no cooperative international follow up on those proposals.

An area that showed relatively little progress was the disposal of high-level radioactive waste from reprocessing plants on a large-scale demonstration. This lack of progress was not considered serious from a technical standpoint because extensive development and testing by the national laboratories had provided methods for the vitrification and encapsulation of high-level wastes, which would provide safe storage. In addition, the volume of high-level radioactive waste from the commercial program was small, and the military was storing large quantities of high-level radioactive waste seemingly successfully, even though the methods were more primitive than those developed for commercial high-level wastes. The public, however, was increasingly concerned about the safety of storing high-level radioactive waste and recognized the lack of a large-scale demonstration.

This surge of electric generation capacity brought with it the need for major expansion of enrichment capacity. A new complex of gaseous-diffusion-type enrichment plants was built by the AEC at Paducah, Kentucky and Portsmouth, Ohio and the throughput of the existing diffusion plants at Oak Ridge was increased. Development work was pursued on advanced forms of enrichment. In Europe, the centrifuge method was pioneered and a new high-capacity centrifuge plant (URENCO) was built. A large gaseous-diffusion plant (Eurodif) was also built under the sponsorship of several European countries.

The expectation that spent-fuel assemblies would be reprocessed and the uranium and plutonium in the spent fuel recycled into the existing light-water reactors led to the need to provide for commercial spent-fuel reprocessing. The first commercial reprocessing plant was built at West Valley, New York and it successfully reprocessed about 620 metric tonnes of plutonium from spent fuel. The plant was shut down for enlargement in 1972 and was never re-licensed and re-started because the cost of modifications to meet new regulations was prohibitive. A large-scale (5 tons/day) commercial reprocessing plant at Barnwell in South Carolina, designed and built by Allied General Nuclear Services, was essentially completed by 1975 but never put into operation because of the need to make a large number of costly changes to obtain an operating permit. General Electric also authorized a spent-fuel reprocessing plant located at Morris, Illinois, and it too was completed by 1975. However, the plant was not put into "hot" operation because pre-operational testing introduced concern as to the feasibility of the direct maintenance concept to which the plant was designed.

The West European development of reprocessing was much more successful. The United Kingdom (BNFL) completed the Sellafield reprocessing plant and a mixed plutonium oxide (MOX) fabrication facility and entered into contracts domestically and overseas to provide such services. The French (Cogema) built reprocessing and MOX-fuel fabrication plants and offered similar services. These plants were later used to recycle spent fuel in the French utility (EDF) PWRs.

The development of fabrication processes for MOX-fuel assemblies for recycle in U.S. LWR reactors showed initial favorable results. Several MOX reloads were fabricated and installed in U.S. reactors and performed successfully. Based on this experience, Westinghouse, General Electric, and Exxon decided to build MOX fabrication facilities. But these plans were dropped as the high costs of reprocessing were revealed.

In this period, the U.S. government initiated a major program in liquid metal (sodium)-cooled, fast-spectrum breeder reactor (LMFBR) R&D setting up an in-depth technical effort involving the national laboratories at Argonne, Oak Ridge, and Hanford to carry out in-depth R&D on reactor safety and neutronics, sodium behavior, and plutonium fuel characteristics. A small experimental LMFBR was built to verify that the intrinsic properties of plutonium fuel, the "Doppler effect," would prevent a runway reactivity excursion. A keystone facility for the effort was the Fast Flux Test Facility at Hanford to provide a test bed to establish the longevity and reliability of LMFBR fuel and to prove out reactor design, sodium thermal-hydraulics, and primary system materials reliability.

Work started on a 400-megawatt-electric demonstration LMFBR power plant (the Clinch River Plant), but concerns arose about projected costs and proliferation if the system were eventually deployed widely. The project was cancelled shortly after it received its construction permit.

The West European countries France, Germany, Italy, and the UK carried out cooperative RD&D programs on the LMFBR. The United Kingdom built an experimental reprocessing plant in Dounreay, Scotland, and the French built two small LMFBR plants, Rapsodie and Phenix. The Soviet Union also engaged in major LMFBR R&D, building two pilot plants. Japan also undertook LMFBR R&D, emulating the U.S. basic approach, building a test reactor on the pattern of the FFTF and experimental facilities for reprocessing and fuel fabrication. The Soviet Union also built two LMFBR units: a pilot plant and a 600-megawatt-electric demonstration plant (BN-600) that continues to operate today.

The results of all of these efforts were generally encouraging and the program moved to the design and construction of large LMFBR power plants. Building on the close RD&D cooperation during the construction of LMR pilot plants, a 1,200-megawatt-electric LMFBR, the French-designed Super-Phenix, was authorized. The plant was constructed by a French, Italian, German, Netherlands, Belgian, and U.K. consortium (NERSA). As Super-Phoenix neared completion, a European Fast Reactor Program was set up among France, Germany, Italy, and the United Kingdom to develop an advanced LMR as a follow-up to Super-Phoenix to strive for capital costs substantially lower than experienced with Super-Phoenix. But in the early 1980s, Super Phoenix experienced operational problems and its role was eventually reduced to a plutonium burner rather than a breeder. It was then decided to decommission Super-Phoenix, which led to national decisions by the European participants to curtail or discontinue LMFBR development.

Development of a Regulatory Framework

An essential need was to develop a safety regulatory framework to handle this expanded industrial effort. The AEC formed a reactor regulatory branch to review license applications and to grant construction and operating permits. It grew rapidly in the late 1960s and early 1970s to handle the heavy licensing workload and to develop a detailed body of technical regulations against which to measure the adequacy of the applicants' designs and operating capabilities. But concern that the AEC had a conflict of interest in carrying responsibility for both the promotion and regulation of nuclear power led to formation of the U.S. Nuclear Regulatory Commission (NRC) to handle regulation separate from the AEC.

Some of the AEC"s R&D functions were also transferred, mainly on the safety of LWRs, to assure the NRC's technical independence. Thus, a research branch to implement the R&D responsibility was established in the NRC along with the reactor regulator branch and inspection and enforcement branch. By 1975, there were about 3,000 permanent staff members at the NRC.

In sum, a massive expansion of this new industry had been successfully effected by the end of 1975. Fifty-five nuclear power plants were in operation in the United States and a similar number were operating overseas through U.S. exports and technology transfer. Major new manufacturing facilities had been built and were operating at full tilt. Expanded enrichment facilities were being completed. Fuel-fabrication plants for plutonium recycle were being designed. A fully staffed, independent regulatory commission was in operation. Orders were on the books for almost 200 more U.S. nuclear plants for the growth of electricity projected by both industry and government. But, in the latter half of this period of expansion, a series of problems began to emerge exacerbated by the dramatic fuel price increases of the OPEC embargo and Iranian revolution and the serious accident at the Three Mile Island Nuclear Plant.

Emergence of Major Problems

In-depth review of the licensing applications in the early 1970s led much more detailed statements of regulatory requirements entailing significant design changes. The licensing review process itself became prolonged because of the increasingly detailed nature of the reviews and the large number of applications being submitted at the same time. A significant increase in licensing requirements arose from the Calvert Cliffs case in which the courts interpreted the National Environmental Policy Act to require complex environmental evaluations and design changes during plant construction. Licensing changes often required modifications of equipment and systems. Outstanding examples of this were the development of more detailed emergency core cooling system requirements and the development of blowdown and seismic pipe supports, and safety equipment qualifications.

This was only part of the impact of a growing movement of environmental concern that affected all of industry, but the impact on nuclear power construction was especially severe. The eleven months required to obtain a license for the Ginna plant in 1970 stretched to three years and more by 1975.

In addition to construction delays caused by licensing changes, other design changes to remedy deficiencies in detailed engineering and equipment layouts were made while the plants were well into construction. Equipment modifications had to be made to reflect initial field-operating experience and to remedy incompatibility between nuclear steam supply system and balance of plant interfaces. The need to make these licensing modifications and design changes, combined with delays in getting design information and material to the construction sites, caused significant construction delays. The perceived need for capacity led to attempts to minimize such delays by using a larger workforce, re-ordering construction sequences to accommodate missing design information or materials, and the use of overtime and premium methods to expedite delivery of material and equipment.

The equipment and plant modifications and construction delays contributed to the mounting capital costs of nuclear power plants. In addition, double-digit inflation, which appeared in the early 1970s, raised the costs of every element of material and labor going into the construction job. Many utilities were unable to include construction work in progress in their rate base so that an ever-increasing investment had to be financed. Double-digit interest rates further increased financing costs.

The public hearing process had been established in the Atomic Energy Act to assure appropriate public participation in the decisions involving the utilization of nuclear power. Atomic Safety Licensing Boards were set up to carry out a quasi-judicial process to conduct public hearings before construction and licensing permits would be granted. This process became a growing cause of delays in obtaining construction and operating permits. In addition, injunctions were obtained through the courts that stopped progress in licensing or in construction.

Toward the end of this period of expansion, substantial field experience was gained from the plants that had come on line. Component reliability issues were emerging, a significant number of which were from non-nuclear equipment such as the turbine generators and transformers. However, two major ones were unique to the nuclear systems: the corrosion deterioration of steam generators in the PWR systems and the appearance of inter-granular stress corrosion cracking in the piping of the BWR systems. These reliability problems, both nuclear and conventional, combined to keep the average nuclear plant availability at a level of less than 70% with capacity factors running, on an average, less than 60%. These levels were substantially lower than the 80-percent capacity factors assumed in the economic projections when the plants were authorized. In addition to the costs of this unavailability, the cost of maintenance and repair were substantial and largely unanticipated.

Cessation of Growth and Increased Public Opposition

These emerging problems combined with a major unanticipated problem, the oil embargo, to halt summarily the rapid expansion of nuclear power in the United States. The sharp rise in the price of oil created a major worldwide recession causing substantial reduction in industrial activity and electricity demand. Another significant impact was price elasticity: the rise in the price of electricity caused a surge in electricity conservation.

The combination of these two factors drove the demand for electricity down and changed radically the projection of need for electric-generating capacity. For the better part of four decades, electricity demand had been increasing at 7% per annum, doubling capacity needs every 10 years. The effect of the oil embargo and cut-offs was to reduce that demand to the range of 1 to 2% per annum, making excess a substantial percentage of the already authorized base-load capacity. As this picture emerged, the U.S. utilities cancelled essentially every nuclear and coal plant that had been authorized but had expended only a small investment. Because the larger percentage of the new capacity was nuclear, a substantially larger capacity of nuclear plants was cancelled than coal plants.

The expectation that there would be upwards of 250 gigawatts-electric of nuclear-generated electricity operating in the United States in the mid-1990s plummeted to an expectation of 160 gigawatts-electric. For those nuclear plants in which a significant investment had already been made, utilities slowed construction or stopped construction temporarily because the plants would not be needed on the original schedule. These construction delays were a means of reducing the ultimate cost of producing power from the plants but raised the cost over what would have been incurred if the plants were built and put into use on the original schedule.

The high interest rates made construction delays of any kind, whether voluntary or involuntary, extremely expensive. In many cases, these spiraling of interest costs brought total financing costs to half of the capital cost of the nuclear plant. By 1979, the growth of nuclear power capacity was at a standstill. No order for a new nuclear power plant has been placed in the United States since 1978.

The Three Mile Island Accident and Its Impact

In March of 1979, a malfunctioning ion exchanger, combined with a valve misalignment, started a sequence of equipment malfunctions and operator errors that led to loss of core cooling on the Three Mile Island-2 (TMI-2) nuclear power plant near Harrisburg, Pennsylvania, causing gross melting of the core. Although the containment system prevented any radiation from escaping and so protected the safety of the public and the utility personnel, the accident had a serious financial impact on the plant owner and the U.S. utilities in general. It caused a reduction in the credit rating of all nuclear utilities and set off a new round of cost increases, particularly for those plants still under construction. Although the accident was bad news for the industry, there was good news in that the containment system successfully performed its function and vindicated the early decision to provide full containment for commercial nuclear power plants.

A special commission, the Kemeny Commission, was established to investigate the accident. The Commission concluded that its primary causes were deficiencies in management, both in industry and in the NRC, in operator training, and in the man–machine interfaces in the control room. It also highlighted the lack of effective communication of safety issues, particularly accident precursors, among the nuclear utilities. Contributory causes from equipment deficiencies were also identified, but were judged to be secondary.

For a year after the accident, a moratorium was placed on granting operating permits for new reactors. A major drop in availability occurred for all the reactors of the same basic design as TMI-2, the B&W once-through system, because of the need to shut down for a series of immediate inspections and modifications. All U.S. reactors suffered a reduction in availability, although not as great, for inspection and modifications.

The NRC developed a TMI action plan containing hundreds of pages and identifying a wide variety of changes in all U.S. power plants to incorporate the "lessons learned" from the accident. In addition to implementing the NRC-mandated changes, the utilities undertook several important new initiatives. A Nuclear Safety Analysis Center was formed at the Electric Power Research Institute to set up a system to evaluate all significant operating plant incidents, to identify potential accident precursors, and to disseminate those evaluations electronically to all the nuclear utilities in the United States. The Institute for Nuclear Power Operations (INPO) was formed as a central organization to establish operating standards, to define operator training requirements and accreditation, and to audit the operational effectiveness of all U.S. nuclear utilities.

The post-TMI changes on top of the already growing construction and financing costs put further financial burdens on the utilities that still had plants under construction. The time it was taking to get a nuclear plant into operation had now stretched out typically to 10 years and the capital cost had grown to the range of $3,000 per kilowatt-electric. Some plants had better records than this, but some had worse.

This cost escalation caused the cancellation of plants in which major investments had already been made. The cancellations occurred because it was judged that the capacity would not be needed so there would be no assurance of revenue from power production. Further, there was concern as to whether the investment would be allowed in the rate base even if the plants were completed.

The Late Period, 1980 to the Present

The End of the Cold War and its Aftermath

1980 was another American presidential election year. It also was a time of high tension in East–West affairs, intersected by the crisis caused by the fall of the Shah in Iran. The continued captivity of American hostages in Tehran dominated the news in the United States and the failure of an attempted rescue mission early in 1980 built onto the charges that the Republicans levied against the Democrats that military trends favored the Soviet Union. In November 1980, Ronald Reagan won a decisive presidential victory.

Virtually nobody at the time anticipated the major geo-political events of the next two decades, e.g., the peaceful demise of the Soviet empire, the reunification of Germany, the expansion of NATO, a major surge in proliferation of WMD, the rise of new forms of global terrorism, and America's ascendancy as the most powerful nation in history and the sole remaining superpower.

During the 1980s, American politics were dominated by the Republican Party with the election of Ronald Reagan in 1980, his re-election in 1984, and the success of Reagan's vice-president, George H. W. Bush, who won the presidency in 1988. At the same time, Soviet leadership went through turbulent times as the elderly Brezhnev (who had held power since 1964) finally died in November 1982, to be succeeded by Yuri Andropov who himself died in February 1984, to be succeeded by Konstantin Chernenko who died within a year (February 1985), to finally be succeeded by a young, dynamic leader—Mikhail Gorbachev—who launched the Soviet Union on a reform campaign that ironically turned into the Soviet Union's demise.

During the 1980s, the West held firm to its decision to deploy a new generation of nuclear systems into Europe if Moscow did not abandon its SS-20s. A double shock was delivered to the Soviets in 1983 when NATO not only remained united on its deployment decision in the face of a massive propaganda campaign, but the Reagan White House also announced the Strategic Defense Initiative, challenging Moscow to a new phase in arms competition. Gorbachev's response when he became leader was to seek a respite from the competition—a move that opened up the stalled arms control talks. Negotiations had been underway on theater nuclear forces since the last year of the Carter administration, and in December 1987, the INF agreement finally was signed. By that time, talks were well underway on a Strategic Arms Reduction Treaty (START). In the autumn of 1989, the unraveling of the Soviet empire picked up speed as the Berlin Wall came down, and by the end of 1990, the Soviet Union passed out of existence, to be replaced by the Russian Federation and its first president, Boris Yeltsin.

As the United States and the Russian Federation readjusted their relations, the START process gave way, when the Bush administration entered office in 2001, to a Moscow Treaty that re-focused the relationship away from large, formal arms control arrangements, and to American withdrawal from (hence the demise of) the ABM treaty. China has viewed this warily, as it continues to modernize its military forces.

The priorities of American national security, however, have shifted from the old bipolar framework in which peer (or near-peer) powers faced off against one another, to the more amorphous threats posed by regional and non-state actors—threats that intersect proliferation concerns.

Nuclear Proliferation, 1980–Present

As the Cold War was ending, a new type of threat emerged—the threat of regional powers with WMD programs seeking to dominate their region. Through most of the 1980s, Iran and Iraq had fought a bitter war that finally ended in a ceasefire. In August 1990, Saddam Hussein invaded Kuwait. President George H.W. Bush organized a coalition that ejected the Iraqi forces from Kuwait. When special weapons inspectors from the United Nations entered Iraq after the war, they discovered details of a massive WMD effort that had come close to producing a nuclear weapon. These discoveries highlighted deficiencies in the IAEA's inspection process.

Also in 1993, South African President F.W. de Klerk announced that South Africa had developed a "limited nuclear deterrent capability" but that in 1990 it was decided that all nuclear devices should be dismantled and destroyed.[3]

Belarus, Kazhakstan, and Ukraine agreed under pressure from both the United States and Russia to send their nuclear weapons back to Russia in 1992.

In 1992, Bill Clinton won the presidency, and in 1993, his Defense Department introduced a new term into the strategic lexicon when the Counter-proliferation Initiative was launched, in response to concerns that Iraq and other such "rogue" countries were aggressively seeking WMD. In 1995, on the 25th anniversary of its entry into force, the members of the NPT convened in a major conference not merely to review the status of the treaty but also to decide, per its initial terms, whether it should be extended beyond 1995. And if so, for how long. The conference resulted in an indefinite extension of the treaty.

By 1995, all five permanent UN Security Council members, who also were the only nuclear weapons powers recognized by the NPT, had signed the treaty. North Korea threatened to go nuclear in the early 1990s, was enticed back into the NPT with a framework agreement, and in 2003 has again ignited a crisis in withdrawing from the NPT. Israel, a suspected nuclear power since the early 1960s, remained outside the NPT. India also remained outside the treaty, and in 1998, India and Pakistan conducted nuclear tests and declared themselves nuclear weapon states. The unresolved status of the Israeli, Indian, and Pakistani nuclear weapon programs and challenges to the NPT by North Korea and Iran remain a pressing concern.

In late 1998, Saddam Hussein ejected UN weapons inspectors from Iraq. A new American president, George W. Bush (son of George H.W. Bush), narrowly won office in 2000 after the U.S. Supreme Court ruled on contested ballots in Florida. The al-Qai'da terrorist attacks on September 11, 2001 began the war on terror proclaimed by the United States. After first dislodging the terrorists from Afghanistan, the Bush administration in 2003 brought the Iraqi issue to a head by launching a pre-emptive war. As of November 2003, the coalition forces have not uncovered Iraqi WMD programs.

Subsequent to the 9/11 events and the war on terrorism, the Bush administration also adopted a new national security strategy that emphasizes and elevates the central threat posed by the nexus of terrorism and WMD, and that stresses the right to act preemptively against this threat (a claim that is both ambiguous and highly controversial).

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[3] M. Reiss, *Bridled Ambition*, Woodrow Wilson Center Press, Washington, 1995.

North Korea is thought in some circles to have acquired a nuclear weapon in 1992, and it acknowledged a nuclear weapon program in late 2002 and then formally withdrew from the NPT.

Nuclear Testing, 1980–Present

In 1982, the Reagan administration suspended negotiations on a Comprehensive Test Ban Treaty (CTBT) indefinitely while seeking to renegotiate the Threshold Test Ban Treaty (TTBT) and the Peaceful Nuclear Explosion Treaty (PNET) to include verification provisions. Moscow responded initially by submitting a draft treaty on testing to the UN General Assembly. In 1985, to dramatize its support for a CTBT, Moscow entered into a unilateral nuclear test moratorium that lasted from August 1985 to February 1987.

In 1986, the House voted to amend the FY 1987 Defense Authorization Act to deny authorization for American tests above 1 kiloton so long as Moscow did not conduct such tests. This began a process where Congress and the White House sparred on nuclear testing for the next several years. The political standoff was temporarily broken after the Soviets agreed, at the Reykjavik summit in October 1986, to negotiate new verification measures for the TTBT and PNET. Although these agreements were concluded, the Congress in the autumn of 1992 mandated an end to American nuclear testing by voting to withhold authorization and funds. The last American nuclear test—the 1,054th such test since the first Trinity explosion in 1945—took place in September 1992.

At the Vancouver summit in April 1993, Presidents Clinton and Yeltsin agreed to early multilateral negotiations on a comprehensive test ban and in August 1993, the Conference on Disarmament adopted a mandate to begin negotiations the following year. In October 1993, prior to commencement of negotiations, China conducted a new nuclear-test series. The United Kingdom's last nuclear test was in November 1991.

The CTBT negotiations formally commenced in Geneva in January 1994. In July 1995, the French announced a new nuclear-test series that lasted through January 1996 when France conducted its last nuclear test. China conducted a final nuclear test in 1996.

In August 1995, President Clinton dedicated the United States to attempting to achieve a test ban that denominated the threshold at zero yield. The CTBT was opened for signature in September 1996 and the United States was the first to sign. The Clinton White House submitted the CTBT to the Senate in September 1997, then it suffered an embarrassing defeat when the Senate voted in October 1999 not to consent to the CTBT.

By that time, India and Pakistan had conducted their 1998 test series.

As this report is being drafted, the CTBT remains in limbo. A CTBT Organization has been established in Vienna but to enter into force, the CTBT must be ratified by the 44 countries that in 1996 possessed nuclear research or power reactors. As of April 2003, 100 states have deposited instruments of ratification with the UN Secretary-General, but only 31 of the 44 states necessary (as described above) for entry into force have ratified the treaty. Of the P-5, France, Russia, and the United Kingdom have completed ratification; China and the United States have not.

Meanwhile, with a general moratorium on nuclear testing being observed, the United States is pursuing a "science-based" approach to maintaining its nuclear stockpile in which sub-critical testing of plutonium is permitted. Russia also claims to be performing sub-critical tests, although there is some question of whether more is involved in the Russian test program. It is unclear how long the fragile P-5 consensus to refrain from testing will remain, and of the states outside the CTBT, India and Pakistan—and now North Korea—may opt for a renewed phase in nuclear testing.

Civilian Applications, 1980–Present

The goals for the backend of the fuel cycle were changed drastically because plutonium recycle in LWRs was no longer a viable commercial activity in the United States. Thus, major effort was placed on providing for the storage of spent fuel in substantially greater quantities than originally planned for at individual reactor sites. A renewed effort was undertaken to demonstrate the large-scale disposal of high-level radioactive waste, where the form of this "waste" would now be the spent-fuel assemblies themselves. The Nuclear Waste Policy Act was passed to establish that the Department of Energy had the responsibility to implement this program and provide for the transfer of spent-fuel assemblies from individual reactor plants to a federal repository, probably an interim, monitored, retrievable storage facility. The spent-fuel assemblies would then be conditioned and transhipped to a permanent geologic disposal site. Significant progress was also being made in providing large-scale, highly reliable, dry storage for military high-level radioactive waste in a stable salt bed in New Mexico.

Companion legislation was passed to provide for the continued storage of low-level and intermediate-level wastes coming from nuclear plant operations. The legislation, the Low-Level Waste Policy Act, called for groups of states to set up regional compacts in a given region to provide a storage facility for nuclear plant low-level radwastes as well as for radwaste from hospitals and other industrial activities utilizing radioactive isotopes.

The market for enrichment services also changed considerably. The perceived uncertainty in U.S. export policies and the desire to participate in enrichment services motivated other countries to provide their own enrichment capability rather than continuing to rely exclusively on the United States. The less power-intensive centrifuge technology was developed in Europe and new enrichment plants were built. The Soviet Union became a potential supplier of enriched uranium to utilities in the West, including the United States. Excess enrichment capacity resulted. To adapt to these changes, the United States decided to retrench its gaseous-diffusion capacity by closing down some of the old facilities at Oak Ridge and relying more on the new ones in Kentucky and Ohio.

The LMFBR and HTGR programs were greatly reduced in pace and funding because (1) the expansion of LWR nuclear power had halted, making less urgent the introduction of capability to expand the nuclear fuel supply or to expand nuclear power application to a wider industrial sphere (the HTGR) and (2) the cost experience with advanced systems showed that capital costs were too high to expect introduction of the systems competitively, particularly since additional subsidized plants would have to be built to reduce the technical risks before the private sector would consider commercialization of the concepts. A major re-emphasis and redirection was taken, therefore, to find economic breakthroughs in the capital costs of these advanced reactors and fuel recycle systems.

In sum, by 1986, the impact of TMI seemed to have been absorbed and a substantially less ambitious program of nuclear power development was being pursued.

The Chernobyl Accident and Its Impact (1986 to present)

With improvements in 1984–85 in operational nuclear-power-plant performance, the industry moved into 1986 with expectations that the major reliability problems were being surmounted. Legislation had been passed to complete the development of both spent-fuel disposition and low-level waste storage, and the NRC had adopted a standardization policy that would make more predictable the licensing process for new plants. Work was underway to design future reactors and to define standardization processes to help reduce their capital costs. The overall picture seemed rosy.

Then a major accident occurred in the Soviet Union at the Chernobyl plant—a light-water-cooled, graphite-moderated reactor (RBMK) destroyed the plant and spewed radiation into the atmosphere. Great consternation arose among the public, particularly in those countries in Western Europe outside the Soviet bloc, amplified by the refusal of Soviet officials to reveal what had happened. Evacuations were carried out to protect families in surrounding communities radioactively contaminated. One-hundred thirty-four plant workers received heavy radiation exposures, and 28 died. It may cause additional cancer deaths in the long term, though these are unlikely to be detectable compared with cancer deaths from other causes. After years of evaluation, the United Nations concluded that, apart from increases in treatable thyroid cancer in children, "there is no evidence of a major public health impact." In addition, its economic toll has been in the billions of dollars in terms of loss of power capacity, disruption of the local community, and remedial action to repair the damage and stabilize the ruined plant.

Intensive investigations were held on the cause of the accident by the Soviets, the IAEA, and the world nuclear-power technical community. Because the reactor was unstable at low power and the control rods had a design flaw that increased the reaction rates when the rods were inserted, the reactor went on an uncontrolled power surge and destroyed itself. There was no containment system to prevent a release of radioactivity to the atmosphere. Because of these design flaws and the lack of containment, the Chernobyl RBMK, a design unique to the former Soviet Union, could never have been licensed for use in Western nations. In addition to these design weaknesses, serious operator errors were committed and crucial safety regulations were ignored.

Although the magnitude of harm to the public was much less than many other industrial accidents, there was a worldwide concern over a nuclear-power-plant accident that killed tens of people, overexposed thousands, radioactively contaminated substantial areas of land, and dispersed radiation beyond national boundaries. As a result, public concern continues as to the adequacy and safety of nuclear power plants throughout the world, independent of their design.

The nuclear electric utilities responded with a proposal to form an association to promote excellence and uniform standards in nuclear power operations worldwide. It was called the World Association of Nuclear Power Operators (WANO) and patterned after INPO in the United States. WANO is composed of four centers: Atlanta, Moscow, Paris, and Tokyo, with headquarters in London. An electronic reporting system has been established that advises all plants of safety incidents and provides up to date information on technical advances in operational standards and practices. Each center collects the reports of the plants within its jurisdiction and disseminates summaries to the other centers. The full costs of WANO are borne by the utilities.

A system of peer reviews of plant operations has been set up by WANO. Member nuclear plants are visited by experts, brought together from other nuclear plants, to assess safety and provide advice on improving safety. After the Chernobyl accident, the IAEA also placed a much greater focus on operational visits to Soviet-designed reactors and extensively assessed their safety through Operational Safety Reviews (OSART).

Deregulation of Electricity Generation

The movement toward deregulating electricity generation progressed in this period and has reached varying stages of completion in the different states of the United States and in other countries. This change had a major impact on nuclear power because it removed the assurance of a return on the utility's capital investment that had existed in the regulated system. Experience in deregulation to date in the United States has been that the operating plants have benefited because the embedded, so-called "stranded" assets were largely written off, either through the regulators or through divestitures and acquisitions among the nuclear utilities. The much lower amortization costs thus made the plants strong economic competitors. The changes in utility ownership resulted in a much smaller number of companies owning most of the nuclear generation capacity, reducing substantially the overhead costs and further improving competitiveness. The new competition also motivated the utility management to strive harder for lower operating costs and higher plant availability. In combination, these factors resulted in record high performance outlined quantitatively in the Civil Applications section of the main report.

On the other hand, the cost barrier for entry of new nuclear power plants to the deregulated market was raised. Loss of return-on-investment assurance meant that investors shied from capital-intensive plants and plants with long-term investment payoffs. Accordingly, there was a major shift to gas-fired units for base-load use, particularly with the low gas prices that had come about from dropping price controls in the oil industry. To enter this market, nuclear plants must provide a premium rate of return, requiring substantial further reductions in capital cost and shortening of construction time.

Recognition that a competitive market place requires renewed efforts to assure a future role for nuclear power, the industry engaged in further R&D to provide advanced LWRs, called the ALWR Program. But because of the need to minimize technical and operational uncertainties for investors, proven technology had to be utilized in this effort.

Standardized designs were developed that integrated the designs of the nuclear steam supply and balance of plant systems. These designs include large (1,300 megawatt-electric), evolutionary-type PWRs and BWRs, as well as mid-size (600 megawatt-electric) plants with passive emergency cooling features. The safety design exceeds the safety goals established by the NRC by a factor of 10. Major improvements in reliability and economy were incorporated from the extensive worldwide operating experience of current LWRs. Design certifications have been obtained from the NRC for two 1,300-megawatt-electric units, GE's ABWR, Westinghouse's PWR System 80-Plus, and the 600-megawatts-electric Westinghouse AP-600. The AP-600 differs from the others in the utilization of only passive functions (gravity and pressurized gases) for emergency cooling of the core and containment rather than electric-powered pumps and their associated valves and controls. Extensive testing of the passive cooling features confirmed the adequacy of their safety functions and NRC approved the design after carrying out independent confirmatory tests. Higher power versions of the passive designs are also under development to gain economy of scale: a 1,000-megawatt-electric PWR (AP-1000) and a 1,350-megawatt-electric (ESBWR).

The ALWR Program was an outstanding model of U.S. industry–government and international utility collaboration. This shared financial support has been an essential element of success. The Program was greatly enhanced by the technical participation and financial support of the international nuclear utilities in Europe and Asia. Two GE ABWRs have been built and placed into operation by Tokyo Electric Power in Japan and by the Korea Electric Power Company in Korea. Two more are being built by Taiwan Power Company for its next twin-unit nuclear plant.

HTGR development has also been continued with the expectation of economic competitiveness through the utilization of the direct helium cycle. Substantial testing of this new feature will be needed before NRC and investor acceptance.

Because of the interest in moving ahead with these new nuclear plants, DOE sponsored the development of a Near-Term Deployment Roadmap to provide a plan to build new nuclear plants in the United States in the next decade. The DOE program, the Nuclear Power 2010 Initiative, has been authorized by Congress to implement the Roadmap.

Appendix E: Keynote Address by Susan Eisenhower at the Concluding Conference of the "Atoms for Peace After 50 Years: The New Challenges and Opportunities" Project

November 13, 2003

Thank you for the chance to be here with you at Lawrence Livermore National Laboratory for this important anniversary. I must say I always knew that Dwight Eisenhower was a tough act to follow, but nevermore so than today and in front of this audience. I couldn't help thinking as I came in this morning and saw pictures of Edward Teller out in the hallway that he was one of the people who had some influence, I guess, over the direction that my life took in a rather interesting way.

Two big events happened as I was growing up. One was meeting Edward Teller when I was about eight or nine years old at a Christmas party that Jackie Cochran gave in California. I remember when we went into this party, it was on Christmas Eve, my mother pulled me aside and whispered, "Now, the man with the bushy eyebrows is the man who developed the hydrogen bomb," and my eyes got large and remained large ever since. The other important moment for me was the visit of Nikita Khrushchev in 1959 for the never-to-be-forgotten, two-week tour around the United States. During an impasse at Camp David, my grandfather decided the best way to see a breakthrough would be to board a helicopter with the Soviet Premier and bring him down to the farm at Gettysburg. There we sat on the front porch that was so beloved by my grandparents and had a very interesting tea with the Soviet Premier and the small group that came with him. He at that time had said that Eisenhower should bring his grandchildren to the Soviet Union, and I could tell instantly by looking at my parents' body language that this was a non-starter. After the meeting was over, we went out the front door and Khrushchev pulled a few things out of his pocket, four little red star pins that he placed on our blouses. The minute the helicopter took off, my mother said, "Give me those pins!" So, we took them off and she threw them away. We're still upset with her for that. They would have some historical value I suppose, but it was very clear that despite the fact that the Soviet Premier had been to the porch of my grandparents' house, he apparently was not a friend of the United States. We were admonished that evening at dinner that we should curb our enthusiasm that, indeed, this man did not wish the United States well. If he wasn't a friend of the U.S., why did he come in the first place? Such are the thoughts of children. But there we are.

Everyone in this room has reasons to be doing what you're doing. There may have been your own moments during the Cold War that set you on the path that you've been following. It has been a very moving fall for me to participate in a number of Atoms for Peace discussions because it truly was a revolutionary speech in many ways. It brought together so many important elements, not only related to our national security but also to our economic development, to create a strategic vision, not only for the United States but also for the rest of the world, this is indeed a great contribution. I guess I hadn't really focused on it too much until the beginning of this fall. Sometimes I've wondered to myself, would my grandfather be surprised that people all over the world have, perhaps, taken a few minutes of their day or maybe even a whole day to think about his seminal speech and the impact it has had on contemporary life? In an odd way, on the one hand, I think he would not have thought about it at all, being a modest person. On the other hand, what he had intended to do that day was clearly strategic in nature as he wrote, "It is with the book of history, not with the isolated pages, that the United States will ever wish to be identified."

And so, I'd like to offer some thoughts about what I think was behind the speech he gave and his thinking. I think nobody other than Dwight Eisenhower could have had quite as deep a sense of the contradictory nature of the atom. It's been pointed out by people who have participated in earlier conferences that Eisenhower had an intimate involvement with nuclear policy in a national security arena from the period of the Normandy invasion onwards. Either at high official levels or semi-official levels, he was deeply involved. But, not only that, this speech had tremendous overtones for the post-Colonial world. Eisenhower, as you know from the Suez period, had very strong—I don't know if this would be an appropriate way to put it—anti-Colonialist feelings. I think this was born largely out of two very impressionable tours in Panama in the 1920s and the Philippines in the 1930s. As a president, probably nobody had traveled and lived abroad as much as he did, including one stint in war-torn Europe after World War I and another stint, of course, after World War II. I think he understood the crucial nexus between national security and economic development for the post-Cold War world.

Furthermore, when he went to Columbia University, as president, he was exposed to a whole community of scientists whom he had obviously not known so well from his military service. These scientists made a very deep impression on him. In fact, there is a wonderful story about inviting Isidor Rabi to come up to the president's office and Eisenhower said to Rabi, "You know it is always a pleasure to meet such a distinguished employee of the university." To which Rabi said, "Mr. President, the faculty *is* the university." They developed an instant liking for each other at that moment and Rabi went on to play an important role actually in Atoms for Peace. Also, at Columbia University, Eisenhower had exposure to many industrialists who moved in New York circles and who also sat on the board at Columbia. All of these factors from his personal background did much to mold the construction of this speech and this initiative.

Today, even though we have deep-seated fears about rogue nations and individuals and the possibility that nuclear material might be used against the United States, or weapons of mass destruction, we do forget the potent anxiety and terror that existed in 1953. I think Eisenhower himself set out the statistics pretty well, but it was clear specifically, I think, that not only that Great Britain did test without any help from the United States, but I think obviously the developments in the Soviet Union were also critically important. Not only had they tested the atomic bomb, but they had also announced they had broken the United States' monopoly on the hydrogen bomb on August 19th just before President Eisenhower's Atoms for Peace speech.

Nobody knew more than Eisenhower what kind of destruction had occurred in the Soviet Union during World War II. As you well know, the Soviet Union lost more people than all of the other nations in the world combined during World War II. The whole area between the western part of Europe to Moscow was completely flattened. Yet, it was very clear that the Soviets could be utterly competitive in the nuclear area, underscoring that a nation's wealth was not a prerequisite for gaining nuclear knowledge or capability. I think that is an extremely important point. As a matter of fact, what's clear—and he says it in his speech—is that the estimate in 1953 was that soon (and possibly) all the nations of the world would have the capability of developing nuclear weapons. So given the fearsome power of the hydrogen bomb, and as I say, the other points that the president made in his speech, it's very clear that this required high-level presidential management—sooner rather than later.

Of course, I'm sure you've been discussing in the other workshops the inherent contradictions of the atom, but the president had to try to put together a number of audiences and a number of ways of looking at this. He had some very specific things he wanted to accomplish through this speech. He asked himself: what could be done to break the stalemate primarily between the United States and the Soviet Union on disarmament talks? And, it's interesting that Eisenhower wanted desperately to re-engage the Soviets in a fresh new way on this issue. And it's interesting to me, being married to a scientist and a physicist, that he saw the scientific community as the bridge to that opportunity. I think that Rabi played a very important role in this, because scientists have an ability to speak a kind of common language and the president was of the firm belief that if there was even the tiniest of starts in this area, it could evolve into something broader that could eventually lead to meeting the United States' objective in the arms control area.

Furthermore, the president worried and wondered about how the tide of nuclear proliferation could be stemmed. How could we slow down the number of countries that were likely to go nuclear? Eisenhower saw this proposal as a way to involve the developing countries, as I mentioned, and also to try to harness increasing resentment in the developing world at a kind of double-standard that had been imposed by the developed nations. He, himself, must have wondered how long the developing world would sit still as long as the nuclear club seized but restricted access to the benefits that nuclear power could promise.

And finally, how could the president enhance public understanding of this nuclear question and garner their support? Eisenhower asked C.D. Jackson, who was a major figure in his day, to gather some advisers and come up with a draft of this speech. (You would not have wanted to draft a speech for Dwight Eisenhower. I think you could tell from the way he delivered it that he actually was a writer and not a talker, and I identify with that. But, he was Douglas MacArthur's speechwriter during the '20s and '30s, and he knew how to spin a draft himself). C.D. Jackson took his group off to the Metropolitan Club, they used to meet early in the morning so it became known as Operation Wheaties. Operation Wheaties met for a number of months. Eisenhower wanted to make the Atoms for Peace speech the principal foreign policy address of his administration, but Stalin died first, and this opened the opportunity and the necessity, frankly, for his speech called "A Chance for Peace."

In any case, Operation Wheaties continued and the group came up with their best thinking. In typical Eisenhower form, he read it and thought that it could be improved upon. He recalled to a friend that "every version left listeners with only a new sense of terror. So, I began to search around for new kind of ideas that could bring the world to look at the atomic problem in a broad and intelligent way and still escape the impasse to action created by Russian intransigence in the matter of mutual or neutral inspection of resources. "I wanted additionally," he wrote, "to give our people in the world some faint idea of the distance already traveled by this new science, but to do it in a way that would not create new alarm." He also wanted to give the public a "certain knowledge" that the taxpayers' hard earned dollars would not be spent for destructive purposes alone and that there could be economic and social benefits from this pioneering research. "The atom," Eisenhower would later say, was "nonpolitical, neither moral nor immoral, only man's choice could determine the purpose for which it would be best used."

So, on December 8th, the president flew up from Bermuda, where he had briefed the British and the French on the speech. As he neared New York, Eisenhower decided that the draft of the speech was still not good enough and he instructed his pilot to circle New York for half an hour while he put the finishing touches on this speech. He said that it gave him great amusement to see Lewis Strauss, who was the Chairman of the Atomic Energy Commission, doing the mimeographing and stapling. In any case, as Air Force 1 touched down, the president as you saw him, arrived at the General Assembly—3,500 diplomats from 60 countries were in attendance. Lewis Strauss, who had actually done the mimeographing and the stapling, was sitting in the audience when that speech was given, and he described it this way. He said, "The speech was received, at first, with a very brief sound of indrawn breaths followed by a gigantic, collective sigh, and then wave after wave of applause." Strauss noted that even the Soviet delegation applauded enthusiastically.

Well, the president gave legitimacy to the international pursuit of atomic energy, but it also gave the United States standing in the developing world. This was a very critical point in the midst of the Cold War. As we all know, the heart of the proposal was the establishment of the International Atomic Energy Agency, to be stewards of this fund of excess fissionable material. Rabi was the man who was given the assignment by Eisenhower to try and find some way to give life to this new proposal, and according to Rabi's biographer, this suited him to the "T." Rabi said to the extent that ideas could be shared, ideas about nuclear reactors, about nuclear fission and fission products, about the effect of radiation on materials, about a whole range of topics, to the extent that informal judgments could take the place of paranoid uncertainty, then politics could be based on knowledge rather than assumptions. He and other world-class scientists were brought into the discussions about what to do next, and Rabi conceived the idea of an international conference on the peaceful uses of the atom.

Given the nature of the atom and the research underway, it might not surprise anybody in this audience that the scientific community was reluctant to produce papers for this effort, and so Rabi, having unique access to the president—as I'm very proud to say was true for many other scientists over the course of his administration—went to Eisenhower and complained that he deeply feared that this conference was going to be a total failure. The president's response to that was to pick up the phone and call John Foster Dulles and tell him to go up to the United Nations and to visit with Dag Hammarskjold on this issue and thus was born the series of international conferences under the auspices of the U.N.

The first conference on the peaceful uses of atomic energy, recalled Rabi, quote "made a very big difference. We and the Russians were forced to declassify a whole field of nuclear physics and technology in order to take a position at the conference. Declassifying the papers one by one would have taken forever; we simply opened up the field."

Nevertheless, at that particular first conference, 1,132 papers were actually presented in Geneva in August of 1955, with more than 3,600 scientists participating from 73 countries. The Russians were deeply impressed by the conference, too. Vladimir Vexler, a prominent physicist, called it "the first truly great international conference in the field of physics, a conference unique in history." He went on to say, "it is noted with satisfaction that scientists of the world easily found a common language." The conferences, as you will know, were again held in 1958, 1964, and 1971. Isidor Rabi, himself, regarded them as among his greatest career achievements. Furthermore, the process set in motion what Eisenhower had most desired, a way to engage the Soviet Union in the nuclear arena, a fresh new way, and in a way that would lead to cooperation, some of which helped with the early work on the nuclear test ban.

And so, in looking back, did Eisenhower know the historic forces he set into play? One can only imagine that he did. This was a man who by 1953 was already used to dealing with what I call "Big History." He was at the center of so much of that big history that he was used to thinking in big terms, in historical chapters and not pages. I think that there has been absolutely valid criticism about some of the trends that Atoms for Peace may have unleashed; it is true that nuclear materials and know-how, even if it's in the peaceful sector, have reached all parts of the world. But, could we imagine a world in which a proposal like this, a direction like this, might not have been taken? Quite frankly, the benefits that the atoms have brought to the world have been just too great when weighed against the risks, some risks, that we still today face.

Atoms for Peace, I would say, actually, rather effectively addressed the problem that concerned the president most, which was the prospect that soon, and possibly very soon, all of the world that desired nuclear weapons would have them. In fact, as we well know, there is a club, but the club of nuclear nations has been really rather limited when you acknowledge that nuclear technology is over 50 years old. I'm talking about nuclear-bomb technology. You could argue that it is extraordinary the club is as small as it is. Furthermore, no new nuclear weapon has been used since World War II and the nations of the world have essentially stopped testing. Nuclear electric power accounts for nearly one-fifth of the world's electricity, and nuclear power, it could be argued, has reduced global tensions by replacing oil in many applications and by providing much of the world's electricity that has been generated without the release of greenhouse gases or other destructive emissions. Many other nuclear and radiation-related technologies especially in radiopharmaceuticals and medical advances have saved millions and millions of lives from cancer treatments and other applications, and I need not go into the advances that have been made in agriculture and in other areas, especially in the developing world.

While Atoms for Peace, as well as the institutions it has created such as the IAEA and eventually the NPT, has come under fire recently, this is all constructive. The speech is 50 years old, and we are on a new threshold and new environment that opens the opportunity for reform and enhancement of those missions. We do live in different times, and it will be up to us to make something of this opportunity now.

Fifty years later, the nuclear dilemma is still with us. I personally was touched that Secretary Abraham and Minister of Atomic Energy, Alexander Rumyantsev were just at the U.N. last week. They were there, among other things, to commemorate the anniversary of this speech and to lay out their vision. Imagine how Dwight Eisenhower would feel today that 50 years later that the Secretary of Energy shared the podium with Russia's Minister of Atomic Energy. Indeed, Spencer Abraham called cooperation with Rumyantsev "exemplary" and the two went on to cite the many good things that have happened in the last 10 years to help secure nuclear materials, and to decrease the number of strategic nuclear warheads as envisioned in the Moscow Treaty. And a number of other measures have been taken.

Thought is being given to Atoms for Peace plus 50 years. I would add a few more points in closing. I don't think we've done enough with respect to increasing the decision time for a nuclear response. I think we also have to get a grip on tactical nuclear weapons, and therefore, it is with great pleasure that I will participate in the panel tomorrow. I also think that this conference has done much to talk about the potential of nuclear power, and again, we will talk about that tomorrow.

But just in closing, I would like to look back and think one more time about Dwight Eisenhower and what he had in mind. The speech was given 50 years ago, and I think, in looking at it, it really is a vision. But, it wasn't a blueprint. So, much remains for all of us to do. It is interesting that we did have these two major figures from the United States and Russia at the U.N. last week, but still, we are in desperate need for a new contemporary vision articulated at the highest levels of the United States government. I think that the effort to reconcile our national security relationship with the atom and the potential that the atom can bring in life-giving ways to ourselves and to developing countries around the world—these goals remain as valid as ever and so I would like to repeat what is the most important part of that speech. It is pure Eisenhower and I am very familiar with his writing. I know he wrote this himself when he said, "the United States pledges before you and before the world its determination to help solve the fearful atomic dilemma, to devote its entire heart and mind to find the way by which the miraculous inventiveness of man shall not be dedicated to his death but consecrated to his life." Thank you very much.

Appendix F: Participants

Workshop 1
Lawrence Livermore National Laboratory, Livermore, California, United States
April 8–10, 2003

Joonhong Ahn
Victor Alessi
Edward Arthur
Cynthia Atkins-Duffin
Frank Barish
Robert Barker
James Bodner
Chaim Braun
Paul Brown
Kim Budil
Kory Budlong-Sylvester
Robert Budnitz
Oleg Bukharin
George Bunn
M. Elaine Bunn
Elaine Chandler
Yoon Chang
P.R. Chari
Jor-Shan Choi
C.K. Chou
Dana Christensen
Thomas Cochran
Avner Cohen
Jay Davis
M. Scott Davis
Philippe Delaune
Lewis Dunn
Robert Eagan
Patricia Falcone
Alan Foley
Frank Gaffney
Richard Garwin
Jean-Claude Gauthier
Garry George
Victor Gilinsky
Charles Glaser
Emily Goldman
Thomas Graham
Richard Harknett
Christine Hartmann-Siantar
David Hill
Juliana Hsu
Fred Ikle
Thomas Isaacs
Neil Joeck
Mim John
Caroline Jorant
Kumao Kaneko
Michael Keifer
Stephen Kim
Peter Lavoy
Ronald Lehman
Carolyn Mangeng
Michael May
Thomas McCaffrey
Mort Mendelsohn
Patrick Mendis
Ralph Moir
George Moore
Clark Murdock
Michael Nacht
Cynthia Nitta
John Nuckolls
Ronald Ott
Cindy Palmer
Wolfgang Panofsky
Per Peterson
Joseph Pilat
Carl Poppe
Robert Powell
Victor Reis
Michel Richard
Brad Roberts
Scott Sagan
George Sakaldasis
Amy Sands
Jean Savy
William Schneider
Robert Schock
Wayne Shotts
Greg Simonson
Craig Smith
Henry Sokolski
John Taylor
Edward Turano
Eileen Vergino
Richard Wagner
Alan Waltar
Alan Wan
Bill Wattenburg
Leonard Weiss
Michael Wheeler
Chris Williams
Lowell Wood
Stephen Young

Workshop 2
Keidenran Conference Center, Gotemba, Japan
May 26–29, 2003

Tomoyuki Abe
Joonhong Ahn
Peter Airey
Kiyoto Aizawa
V.S. Arunachalam
Evgeny Avrorin
Richard Balzhiser
Burton Bennett
Chaim Braun
Yoon Chang
Tomoaki Chikugo
Jor-Shan Choi
Thomas Cochran
E. Linn Draper, Jr.
Tetsuya Endo
Didier Gambier
Jean-Claude Gauthier
Garry George
Kazuki Hamachi
I-Chow Joe Hsu
Thomas Isaacs
Neil Joeck
Caroline Jorant
Kumao Kaneko
Karen Kimball
Keiko Kito
Chang-Kun Lee
Ronald Lehman
Pete Lyons
Kevin Maher
Kazuaki Matsui
Mort Mendelsohn
Patrick Mendis
Kaichiro Mishima
Muneo Morokuzu
Sakae Muto
Nabojsa Nakicenovic
Nicole Nelson-Jean
Cynthia Nitta
Dominique Ochem
Yasunori Ohoka
Victor Reis
Masatake Sakuma
Yasuhito Sasaki
Tetsuo Sawada
Robert Schock
Seiji Shiroya
Craig Smith
Atsuyuki Suzuki
Tatsujiro Suzuki
John Taylor
Koichi Uchida
Kunihiko Uematsu
Mari Marianne Uematsu
Eileen Vergino
Alan Waltar
Leonard Weiss
Fumihiko Yoshida

Workshop 3
Commissariat `a l'Energie Atomique (CEA), Saclay, France
July 22–24, 2003

John Ahearne
George Apostolakis
Josette Aubigny
Bertrand Barre
Fanny Bazile
Carole Becquet
Patrice Bernard
Jacques Bouchard
Chaim Braun
Alain Bucaille
Robert Budnitz
Oleg Bukharin
Jean Cazalet
Alexander Chernyshev
Jor-Shan Choi
C.K. Chou
Dana Christensen
Thomas Cochran
Charlie Curtis
Tony D'Aletto
Philippe Delaune
Therese Delpech
Paul Dickman
Tetsuya Endo
Harold Feiveson
Pierre Frigola
Jean-Claude Gauthier
Garry George
Jack Gibbons
Victor Gilinsky
Mathilde Groizard
Sig Hecker
David Hill
Edouard Hourcade
Ron Hutchings
Thomas Isaacs
Neil Joeck
Caroline Jorant
Carol Kessler
Odile Landrin
Yves Le Bars
Chang-Kun Lee
Ronald Lehman
Ariel Levite
Rolf Linkohr
Elizabeth Lisann
Isabelle Maudez
Michael May
Charles McCombie
Patrick Mendis
Mary Cobb Neighbors
Cynthia Nitta
M. Muroya Nobuhire
Bruno Pellaud
Michel Picard
Joseph Pilat
Victor Reis
Michel Richard
Jeff Richardson
Bethsabee Roger
Eugene Rosa
Lev Ryabev
Jean Savy
Tetsuo Sawada
Roland Schenkel
Fritz Schmidt
William Schneider
Robert Schock
Lorette Sicard
Craig Smith
Henry Sokolski
Tatsujiro Suzuki
John Taylor
Terry Taylor
Claudio Tuniz
Eileen Vergino
Richard Wagner
Alan Waltar
Leonard Weiss
Yuri Yudin
Paul Zinner

Atoms for Peace after 50 Years Conference
University of California Center at Washington, D.C., United States
September 3–4, 2003

V.S. Arunachalam
Regis Babinet
Harold Bengelsdorf
Jim Bodner
Jacques Bouchard
Chaim Braun
Larry Brown
Robert Budnitz
Oleg Bukharin
M. Elaine Bunn
Yoon Chang
Jor-Shan Choi
Thomas Cochran
Avner Cohen
Charlie Curtis
Paul Dickman
Elizabeth Dowdeswell
Lewis Dunn
Harold Feiveson
Kevin Finneran
Frank Gaffney
Richard Garwin
Jean-Claude Gauthier
Garry George
Jack Gibbons
Thomas Graham
Todd Harding
John Harvey
Thomas Isaacs
Neil Joeck
Caroline Jorant
Ed Lacey
Mark Lagon
Ronald Lehman
Paul Longsworth
Monte Mallin
Patrick Mendis
Clark Murdock
Mary Cobb Neighbors
Michael Pakstys
Keith Payne
Joseph Pilat
Robin Pitman
Carl Poppe
John Reichart
Victor Reis
Joan Rohlfing
Robert Schock
Craig Smith
Henry Sokolski
Atsuyuki Suzuki
John Taylor
Terry Taylor
Eileen Vergino
Richard Wagner
Leonard Weiss
Chris Williams
Jon Wolfsthal
Paul Zinner

Atoms for Peace after 50 Years: The New Challenges and Opportunities
Closing Symposium, Lawrence Livermore National Laboratory
November 13–14, 2003

Peter Airey
Michael Anastasio
V.S. Arunachalam
Cynthia Atkins-Duffin
Debbie Ball
Robert Barker
Harold Bengelsdorf
Phil Bobbitt
Sally Bohawick
Keith Bradley
Kristie Branch
Chaim Braun
Paul Brown
John Browne
Kory Budlong-Sylvester
Jean Cazalet
Elaine Chandler
Cliff Chen
Ira Chernus
Jor-Shan Choi
C.K. Chou
Ronald Cochran
Cory Coll
J.D. Crouch
Philippe Delaune
Arden Dougan
Mona Dreicer
Bill Dunlop
Lewis Dunn
Susan Eisenhower
Rolf Ekeus
Kionna Elkow
Patricia Falcone
Brian Fearey
Larry Ferderber
John Foster
Garry George
Carol Gerich
Jack Gibbons
Victor Gilinsky
Thomas Graham
Siegfried Hecker
Paul Herman
John Holdren
John Holzrichter
Juliana Hsu
Thomas Isaacs
Neil Joeck
Celeste Johnson-Ward
Caroline Jorant
Kumao Kaneko
Carol Kessler
Stephen Kim
T.R. Koncher
Martha Krebs
Ronald Lehman
Genevieve Lester
William Lokke
Paul Longsworth
Robert Lull
Michael May
Thomas McCaffrey
Mort Mendelsohn
Patrick Mendis
George Moore
Todd Neal
Tuan Nguyen
Cynthia Nitta
Milo Nordyke
Ronald Ott
Wolfgang Panofsky
Alan Pasternak
Keith Payne
Bruno Pellaud
Joseph Pilat
Carl Poppe
Stephen Rademaker
Victor Reis
Jeff Richardson
Stacie Rodriguez
Eugene Rosa
Carol Sandoli
Robert Schock
Wayne Shotts
Leon Sloss
Chauncey Starr
Donn Starry
Warren Stern
Theodore Strickler
William Sutcliffe
John Swegle
Bruce Tarter
John Taylor
Terry Taylor
Ken Timmerman
Eileen Vergino
Richard Wagner
Alan Waltar
Alan Wan
Leonard Weiss
Roger Werne
Robert Wertheim
Michael Wheeler
Lowell Wood
Jay Zucca

Diffusion of Nuclear Technology

Year	Civilian	NPT and IAEA	Evolution of US Nuclear Doctrine	Military
1953	Eisenhower's "Atoms for Peace" speech			First thermo-nuclear explosion by USSR
1954			"Massive Retaliation"	US starts up Pu production reactors R, K, L, P US starts up Pu production reactors KE, KW, C
1955	First Soviet nuclear power plant in Obninsk Canada supplies India research reactor CIRUS			
1956	Canada agrees to supply India with research reactor followed by heavy water from US First in vitro diagnostic test with radioisotopes			
1957	Shippingport, the first US power reactor (shut down in 1982)	Euratom formed IAEA formed		First thermonuclear explosion by UK
1958	US supplies Belgium, Germany, Spain, Switzerland with research reactors UK completes its first dual-use, gas-powered nuclear power plant			
1959	US supplies Italy with research reactors			France explodes atom bomb
1960	US supplies Israel with research reactors			First French nuclear explosion
1961	First radioimmunoassays			Antarctica Treaty, NNWFZ in Antarctica USSR tests 50-mt device
1962	US supplies Taiwan and Korea research reactors			US, UK, and USSR sign the Partial Test Ban Treaty (PTBT) prohibiting nuclear tests in atmosphere, underwater, and outer space
1963	Westinghouse and GE of the US build LWR demonstration plants in Europe and Japan with indigenous industrial participation FDA approves controlling insects in flour and wheat by radiation US supplies Vietnam with research reactors First MOX used in BR#, Belgium Single-photon emmission computed tomography		"Flexible Response"	Israel operates a French-supplied reactor for Pu production Limited Test Ban Treaty (LTBT) open for signature
1964	India builds Trombay reprocessing plant US provides a research reactor to Iran			First nuclear explosion in China
1965	Soviet supplies the DPRK a research reactor, IRT-2 DPRK builds a research reactor at Yongbyon West Valley Reprocessing Plant complete US supplies Pakistan and South Africa with research reactors	INFCIRC 66	"Assured Destruction/ Damage Limiting"	
1966				First Chinese thermonuclear explosion
1967	US supplies Iran a research reactor		"Mutually Assured Destruction (MAD)"	Israeli nuclear device?
1968		UN G.A. approves NPT, 62 states signed		Tlatelolco Treaty, NNWFZ in Latin America First French thermonuclear explosion
1969	US completes first large commercial nuclear power plant US supplies India power reactor, Tarapur Canada supplies Taiwan a research reactor, TRR		"Sufficiency"	US ends visits of Israel Israel reaches nuclear ambiguity with US
1970		NPT in force		
1971				
1972				
1973	First myocardial scan during exercise stress test First oil shock Construction of US power reactor begins, (it cooled off after TMI in 1979) Japan negotiates with US on reprocessing spent US-origin fuel	INFCIRC 153		
1974	AEC splits into NRC and ERDA	INFCIRC 209 on Zangger Committee and Trigger List	"Essential Equivalence"	India explodes peaceful nuclear explosion
1975	Positron emission tomography	S. Korea joins NPT		S. Korea ends its secret nuclear weapon program
1976	France sells reprocesssing plant to S. Korea (later withdraws after US pressure) Germany sells 8 LWR power plants and reprocessing and enrichment technology to Brazil NRC issues GESMO rule-making	Japan joins NPT	"Rough Equivalence"	Taiwan ends its secret nuclear weapon program
1977	France contracts to furnish Tamuz-1 reactor to Iraq France sells reprocessing plant to Pakistan US Department of Energy formed FBR JOYO starts in Japan	N. Korea signs INFCIRC 66		
1978	DOE starts RERTR (US–USSR program to convert HEU to LEU)- US terminates Barnwell reprocessing plant, also terminates the Clinch River Breeder Reactor project	INFCIRC 254 on NSG guidelines and Trigger List		US Congress passes Nonproliferation Act
1979	N. Korea builds graphite-moderated, gas-cooled reactor Iranian revolution, 2nd oil shock Three Mile Island No new nuclear plant orders in the US		PD-59/ "Counter-vailing"	Pakistan succeeds in centrifuge enrichment, allegedly based on Urenco design stolen by A.Q. Khan Vela Incident
1980	IAEA organizes International Nuclear Fuel Cycle Evaluation (INFCE)	US signs Safeguards Agreement with IAEA (INFCIRC 288) INFCIRC 274, convention on physical protection of nuclear material		
1981			NSDD-13/ "Peace Through Strength"	Israel bombs Iraqi Tamuz I reactor
1982	US Congress passes NWPA			
1983	WHO, FAU, and IAEA adopts worldwide standard for food irradiation		Strategic Defense Initiative	
1984				N. Korea reactor construction discovered
1985		N. Korea joins NPT		
1986	FDA permits expansion of irradiation of US food supply Chernobyl			Rarotonga Treaty, NNWFZ in South Pacific
1987	US Congress passes NWPAA, designating Yucca Mountain as candidate repository			
1988				
1989	FDA approves first positron radio-pharmaceutical for myocardial perfusion imaging		"Weapons of last Resort"	End of Cold War Undeclared N. Korean refueling
1990				Algerian research reactor discovered
1991	Male screwworm irradiation yields $3 billion in economic benefits to the world ABACC between Argentina and Brazil for the exclusive use of nuclear energy	S. Africa joins NPT		Gulf War reveals Iraqi secret weapons program South Africa dismantles its weapons program N. Korea-S. Korea Denuclearization Agreement
1992	FDA approves monoclonal antibody radiopharmaceutical for imaging tumors	China, France joins NPT Belarus, Ukraine, Kazakhstan joins NPT		Belarus, Kazakhstan, and Ukraine agree to return to Russia nuclear weapons deployed in their territories Nunn–Lugar Science Centers Cooperative Threat Reduction N. Korea Pu reprocessing discovered Joint N. Korea–S. Korea Denuclearization on Korean peninsula N. Korea agrees to IAEA inspections five years after deadline
1993	US PDD-13, US Nonproliferation Policy (no reprocessing for the US, and not encourage other countries to reprocess)	93+2 Strengthened Safeguards		IAEA unable to verify DPRK's nuclear declarations Bangkok Treaty, NNWFZ in Southeast Asia; Pelindaba Treaty, NNWFZ in Africa
1994			Nuclear Posture Review	US–N. Korea Agreed Framework N. Korea freezes Pu production program US–Russia HEU blend-down agreement US "Megatons to Megawatts" Program starts US PDD-41 implements MCP&A with Russia on nuclear material
1995		NPT review conference adopts indefinite extension		
1996		9 countries adhered to INFCIRC 549 on separated Pu declarations		UN GA approves Comprehensive Test Ban Treaty (CTBT)
1997	Russia–Iran agreement to build Busher Japan Tokai accident	INFCIRC 225/ Rev 4 Physical protection of nuclear material and facility	Post-Cold War Deterrence with hedge	
1998		INFCIRC 540 Additional Protocol		India and Pakistan explode nuclear bombs UNSCOM withdraws all UN personnel from Iraq
1999	Japan Tokai criticality accident DOE implements GEN IV program	Japan ratifies INFCIRC 540		US Senate refuses to approve CTBT N. Korea allows inspection
2000	IAEA implements INPRO activity BNFL falsification of Japan MOX fuel data Slowdown of Japan's MOX use program			US-Russia Pu disposition agreement
2001				9/11 terrorist attacks
2002		188 parties to NPT China rectified INFCIRC 540. US AP sent to Senate for consent to ratify	Assure, Dissuade, Deter, Defeat Missile Defense	N. Korea admits to secret U enrichment program, expels IAEA personnel, and announces withdrawal from NPT
2003	Iranian enrichment plant discovered "Atoms for Peace: After 50 Years" project			War in Iraq N. Korea restarts Pu production reactor

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