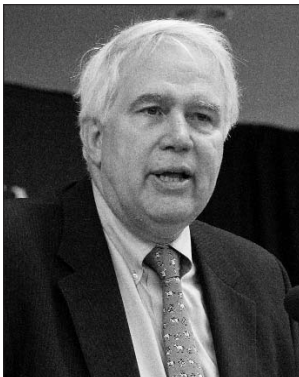


The Nuclear Future

Richard A. Meserve, Robert Rosner, Scott D. Sagan, and Steven E. Miller

This panel discussion was presented at the 1929th Stated Meeting, held at Harvard University on October 12, 2008. At this meeting, Richard Lester, Professor of Nuclear Science and Engineering at MIT, also spoke. His remarks will appear in a forthcoming publication.

Cooling Towers.
Photograph © W. Cody/Corbis



Richard A. Meserve

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We are in a time of great change in the nuclear world, a period termed by some as a nuclear renaissance. The Nuclear Regulatory Commission has received applications for 26 new nuclear power plants, and more applications are expected. The reactors may not all be built, but the applications show the high degree of interest in new construction in the United States. There are also extensive construction programs either underway or planned in China, Japan, Korea, Russia, the United Kingdom, and elsewhere. But really the most interesting dimension of the renaissance is the large number of countries that do not currently have a nuclear power plant and have expressed an interest in building one. Senator Sam Nunn and I were in Vienna about 10 days ago at a meeting in which the Director General of the International Atomic Energy Agency (IAEA) mentioned that 50 countries that do not now

have a nuclear power plant have come to the IAEA to explore the possibility of constructing a plant. He assessed that 12 of those countries are very serious about proceeding. The interested countries include the United Arab Emirates, which is clearly going to go forward; Thailand; Vietnam; the Philippines; Nigeria; Poland; Belarus; and many others.

In one sense, this is a great opportunity. We need to find carbon-free sources of energy in order to respond to the grave challenge of climate change. Nuclear power now provides 16 percent of the world's electricity, and it would be a wonderful thing, from the perspective of climate change, if we were able to develop nuclear energy further. But that is not to deny that there are other challenges that must be confronted – among them, the need to build and operate these nuclear power plants safely. Countries with experience

with nuclear power have learned that it is necessary to have a whole infrastructure in order to achieve safe operations – an infrastructure that includes an educational system, technical capabilities, a competent and independent regulator, licensees who are focused on safety, and so forth. Some of the countries considering nuclear technology do not have such an infrastructure.

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There is a waste challenge that must also be confronted. Spent fuel needs to be handled in an appropriate way so as to protect current and future generations from the long-lived radionuclides that are created by reactor operations. Adequate security must be achieved as well. More reactors in more places mean more target sets for terrorists.

Another consideration, and an important one, is the impact of nuclear development on proliferation. In this context, reactors themselves are not the problem. The problem is that, as more countries need nuclear fuel, there will be an inevitable demand for enrichment services. This means that the technology for enrichment could become more widespread. The same technology used to produce low-enriched fuel for nuclear reactors can be used to produce highly enriched uranium, a weapons-usable material. There also is the possibility that some of these countries may proceed with reprocessing – raising the possibility, if they use today's reprocessing technology, that they will produce separated streams of plutonium. Plutonium, of course, is also a weapons-usable material.

So we have a cluster of proliferation-related issues that must be confronted in a changed nuclear world. We have to approach these issues in the context of a frayed international nonproliferation regime. The North Koreans have already produced separated plutonium and it is proving very difficult to bring them back into the nonproliferation

regime. Iran is proceeding with enrichment, which gives it the technological capability to produce highly enriched uranium. And of course, we must view these changes in the overall context of a complete lack of progress in recent times on disarmament.

We thus are in a world with the possibility of great benefit and great importance of nuclear power because of climate change, but great challenges as well. We face the prospect, if we don't handle this well, of a world in which more countries have nuclear weapons – not a desirable state of affairs for anyone.

This is the context in which the Academy has launched its Global Nuclear Future Initiative, which has the basic purpose of exploring how to get the benefits of nuclear power while diminishing, to the extent possible, the corresponding risks. Approaching this problem appropriately necessarily involves people concerned about proliferation issues from the academic world and from the national laboratories. But to deal effectively with the problems, we need to bring in a much wider group of participants: the licensees and vendors of reactors; regulators; and, most importantly, people from the countries seeking to build nuclear power plants. It is important to have a discussion with the people we seek to influence at a very early stage. The Academy has the unique capability to convene people across a broad spectrum of disciplines and from all over the world, to get all of the stakeholders to approach these problems together, and to try to find a path to a safer world. Our panel this morning will set the backdrop for this new Initiative.



Robert Rosner

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It is clear that nuclear energy is getting a second wind on a worldwide basis, albeit the notion of a nuclear renaissance, at least as applied to the United States, remains far from realization. I think it is also fair to observe that the United States is playing an increasingly limited role as new countries are turning to nuclear energy for the first time. Now the obvious question: why is this so?

The notion of a nuclear renaissance, at least as applied to the United States, remains far from realization.

The international situation does vary from country to country, and it is a combination of four main drivers: 1) increasing energy and water demands, driven in large part by increased expectations for living standards in the developing world; 2) economics, or insurance against future price exposure driven by strained energy supply, fossil fuel price fluctuations in deregulated markets, and, of course, the cost impacts of climate considerations; 3) security of the energy supply; and 4) global climate change and worrying about how to increase carbon-free

base power. The terms of the discussion on a possible nuclear renaissance here in the United States are really very different from what they are abroad, so that is something that we are going to have to keep in mind. For example, it is certainly true that within the United States the issue of climate and global climate change is a main driver for rethinking the nuclear future, but that is not necessarily the case abroad.

What are the obstacles retarding growth? There is the issue of financing. The cost of a new nuclear plant today is a fair fraction of the total market capitalization of the companies that are likely to want to build them. For a company basically to bet its future – which is what it really amounts to – on a new nuclear plant is, of course, very problematic. There is the issue of human capital. We need to revive the discipline of nuclear engineering, both for designing and building new plants and for operating them safely and efficiently. Also related to human capital are the stringent quality demands for construction of new nuclear plants as well as the supporting infrastructure. This is a lesson that AREVA has been learning in Finland, that it is not enough to go in and take an existing construction trades workforce, accustomed to building apartment complexes or other kinds of power plants, and expect them to work effectively building new nuclear plants. AREVA has in part overrun its construction budget for the first of the Finnish plants precisely for this reason.

There is the issue of infrastructure and supply chain. The industrial infrastructure, not only in the United States but worldwide, is really quite limited and cannot presently support a renaissance, including, for example, the ability to make large reactor vessel forgings for the plants themselves. Furthermore, new countries that are looking at nuclear power plants often do not have the supporting infrastructure, including the electric grid, to sustain plants in this sort of gigawatt range. The other issues are spent fuel, nuclear waste disposition, nuclear licensing, and public acceptance. Public acceptance is not talked about much elsewhere, but I think it will be the main issue for the United States. The issue of international safety standards will depend on the countries that are interested in a nuclear renaissance providing the

human infrastructure to operate plants in a safe way and to deal with the disposition of the spent fuel afterward. There are the issues of the Nuclear Nonproliferation Treaty (NPT), too.

The national lab directors, about two years ago, organized themselves into the National Lab Directors Council, of which I serve as chair. Ten of these labs (there are 17 labs total in the Department of Energy system) participate in one way or another in nuclear power considerations. The Council has recently written a white paper addressed to the Secretary of Energy on the use of nuclear

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power that discussed what we view as the essential ingredients of any regime that takes reviving nuclear power in the United States as its goal. These include rebuilding the nuclear enterprise by rebuilding the manufacturing base and the necessary science and technology infrastructure, and training the next generation of scientists and engineers to carry out the research and development. It is one thing to try and replicate the French and the Japanese; it is another to think in truly revolutionary ways. Our foreign competitors have a huge investment in present infrastructure, the infrastructure necessary to support Generation III reactors, including the reprocessing. It would not be smart

for us to simply chase after them – we need to go around them and invest in a completely revolutionary technology. We do need investments on the research and development front here in the United States for Generation IV reactors, advanced safeguard technologies, and advanced nuclear fuel cycles.

There is also the issue of international engagement. It has been shocking to me personally to see the extent to which we have lost the edge in engaging internationally. Part of that, of course, is the fact that we have lost the technological lead, and in that respect, there is some question of whether people will pay effective attention to us if we are not perceived as technically competent.

Main drivers in the near term include the near-term expansion and life extension of plants, financial support for new orders, and cost-effective technical improvements for existing plants; an interim solution – interim storage – for used nuclear fuel; and, finally, a much more robust nonproliferation regime, which is a technical as well as political issue.

These considerations are largely well-known and understood by people within the technical and policy communities. But I think it is also unfortunately true that implemented public energy policies today, both here and abroad, have been largely at odds with these considerations; it is one of the tragedies that we are facing. Given the urgency imposed by climate change, by strong increases in energy demand worldwide, and by concerns related to energy security, I think it is high time that public policy and our technical understanding of the nuclear energy challenge align. I think this is indeed the intent of our meeting and our discussion.



Scott D. Sagan

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I will be speaking this morning about two serious problems: nuclear terrorism and illicit exports of nuclear materials or technology. These are serious problems today and will be, I believe, even more daunting in the future if new states develop power plants, uranium enrichment, or plutonium reprocessing facilities – new states that lack strong regulatory systems, security cultures, and have serious internal terrorist problems.

The danger of nuclear terrorism will be with us for a long time and we must reduce the risks to as low a level as possible. We need to remember that Al-Qaeda is not the only terrorist organization that has sought nuclear weapons; nor is it likely to be the last. We know that Osama Bin Laden issued a fatwa claiming that it was moral under Islamic principles to target innocent civilians and he called for the acquisition of nuclear weapons. We know that Pakistani nuclear scientists met with Bin Laden in Afghanistan prior to the 9/11 attacks. But not everyone remembers that other terrorist organizations in the past had similar ambitions. European left-wing radical terrorists reportedly attacked a U.S. military base in Germany in the 1970s, trying to steal nuclear weapons from our stockpile. The Aum Shinrikyo penetrated the Russian military, getting Russian soldiers to join their organization, and seeking access to nuclear weapons because they believed that an apocalypse would create a world in

which only true believers in their organization could survive and reach a higher plateau of moral standing. The founder of Aum Shinrikyo was not able to get nuclear weapons so he developed biological weapons, using anthrax unsuccessfully. He finally had to settle for the sarin chemical attacks in the Tokyo subway in 1995.

My central point here is that we should recognize that nuclear terrorism is not just an Al-Qaeda problem. We should assume that other terrorist organizations in the future will seek to steal materials to make nuclear weapons, and we must therefore maintain the highest standards of security for facilities worldwide. Increased security should be a top priority for any facility that produces or uses highly enriched uranium (HEU), since it is easier to make a primitive nuclear device from HEU than from other weapons-grade materials. But all plants and related facilities will have to have improved security in the future.

The second point I want to make is that we already have seen problems of illicit export of materials, with, for example, the A.Q. Khan network out of Pakistan. We know that officials at the Khan Research Laboratory (KRL), led by A.Q. Khan, developed a network of international actors who made an offer to Iraq (after the invasion of Kuwait but before the Desert Storm War of 1991) to give Saddam Hussein both a bomb design and centrifuge technology. Saddam Hussein actually turned down that offer, thinking that it was a CIA plant. But Libya did accept A.Q. Khan's offers for centrifuges and a bomb design. We found both in materials discovered in Libya in 2003. The bomb design found in Libya was of a relatively primitive model based on a Chinese weapon, but disturbing evidence now exists that more advanced designs have been found on some of the computers of European members of the A.Q. Khan network. We know that centrifuges were given to North Korea (we don't know whether the bomb designs also were passed on), and we know that centrifuges were given to Iran, but, again, we don't know the details about the bomb design.

What there is still great debate about is how to assess the cause of this. Was this negligence on the part of the Pakistani government, or was it complicity? Reasonable people, I think,

can disagree on what the balance is between these two options. But I want to make two points here. One, in a rare moment of candor, then-President Pervez Musharraf said he knew about A.Q. Khan passing things on; indeed, in his memoirs Musharraf writes:

I received a report that some North Korean nuclear experts had arrived at KRL [Khan Research Laboratory] and were being given secret briefings. I took it seriously. The head of our ISI [intelligence service] and I called A.Q. Khan in for questioning, and he immediately denied the charges. No further reports received, and we remained apprehensive.

Nuclear terrorism and illicit exports of nuclear materials or technology are serious problems today and will be, I believe, even more daunting in the future if new states develop power plants, uranium enrichment, or plutonium reprocessing facilities.

Is this complicity or is this negligence? I argue that, at a minimum, there was such an acceptance of corruption in Pakistan, that it could be called institutional complicity. When the Pakistani government does not react when a senior laboratory official becomes a millionaire and buys many properties at home and abroad, this goes beyond negligence. When the President simply accepts the word of A.Q. Khan, instead of his own intelligence reports, that goes beyond negligence. Indeed, in Islamabad a number of years ago I was given a brochure that the KRL scientists used to give to people selling dual-capable equipment that they said was perfectly fine, perfectly legitimate for civilian use. But on the brochure's cover, in the background, there is a missile with A.Q. Khan standing in front of it. A.Q. Khan's illicit sales activities were not a well hidden secret in Pakistan, and indeed A.Q. Khan advertised that he was getting away with quite a bit.

When I talked to members of the Strategic Plans Division in Rawalpindi, Pakistan, a number of them said, "Well, we're solving this problem. We are adding more security guards on our forces." And yet one of the problems with the A.Q. Khan force was that the security guards were corrupt. They were paid off; they had a so-called insider threat. Most people assume if you add more security guards, even if each one of them is only partially reliable, you automatically will become more secure. But, as I demonstrated in my article "The Problem of Redundancy Problem" from the journal *Risk Analysis*, if you assume that at least one of them is the insider who could cause a problem, adding more security guards may actually result in less security.

I will conclude by noting that we need more than better defenses, and we need more than better guards: we need better thinking and institutions to deal with physical security and reduce the risk of illicit exports. In September 2008, former Senator Sam Nunn and Director General Mohamed El Baradei of the IAEA announced the formation of WINS, the World Institute for Nuclear Security, for corporations to share best practices. The IAEA has a severely underfunded but important effort to try to create standards around the world, and the American Academy is starting a study of alternative ways of measuring or assessing security globally in terms of physical security and the risk of illicit exports. Because increased security is ultimately about developing new ideas, sharing knowledge, and creating better institutions, and not just a matter of more guards and fences, we need the kind of work that the American Academy has started though its Nuclear Future Initiative.



Steven E. Miller

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What you have heard from my colleagues on this panel is that we are heading into a new nuclear world, one that is going to involve more nuclear technology and more nuclear power that will spread more widely across more countries and regions, including many where it has never been present before. New actors and players will be relevant to our thinking about the safe, constructive use of nuclear power. In the context of this evolution, new kinds of problems will arise, or at least new priority will be given to problems that were regarded as lesser in the past, like nuclear terrorism and the problem of illicit nuclear supply.

Are we adequately equipped to manage effectively this new nuclear universe into which we are heading? The main international regulatory mechanism is something that is loosely called the NPT regime, which is a set of rules and institutions that have grown up over four or five decades, centered on the Nonproliferation Treaty, heavily reliant on the International Atomic Energy Agency, and with a lot of supplementary rules and institutions like the Nuclear Suppliers Group. How good is that regime in the face of the kinds of challenges that we anticipate coming down the pike?

If we look at the recent past, it is hard to avoid a somewhat gloomy answer. It has been a bad decade for the NPT system. If you go back almost exactly 10 years, the Indian and Pakistani nuclear explosions undermined the belief that a strong norm against nuclear acquisition had been established. It had been a long time since anyone had openly acquired nuclear weapons, and the thought was that this had become almost taboo. Suddenly this idea was punctured, and since then, of course, North Korea has also openly acquired nuclear weapons.

Are we adequately equipped to manage effectively this new nuclear universe into which we are heading?

We have also had, over the past 10 years and more, a series of three protracted nonproliferation crises, none of which has been successfully addressed. One was Iraq. The final result was war, which did reduce the proliferation risk, but at a price that was enormous and in a way that no one would regard as a desirable management technique for coping with nonproliferation challenges. We have had nearly 20 years of crisis with the North Koreans over their nuclear aspirations, and we are still in the midst of that melodrama. The outcome is uncertain, but the result so far is that North Korea is now a nuclear-armed state. It has tested a nuclear weapon and has withdrawn from the NPT – the first state ever to do so – creating, in my opinion, a whole series of unfortunate precedents. And we are still midstream in an ongoing Iranian crisis, in which Iran has been persistent in pursuing enrichment technologies that, whatever its intentions, will give Iran the technical capability to produce weapons material in the future if they choose to do so. Each of these examples is a tangled tale; but the underlying point is that the cumulative effect of the system's failure to resolve successfully any of these major challenges to the regime calls into question the adequacy of the nonproliferation system in coping with the most important tests. It is really the determined proliferators that we have to deal with if the regime is going to be effective.

We have also seen over the past decade the almost complete collapse of the multilateral arms control process. All of the ancillary agreements that were meant to buttress the NPT regime, like the Comprehensive Test Ban Treaty or the Fissile Material Cut-off Treaty, have been either stuck or stalled, thwarted or stymied, so there is no real progress, motion, or action on any of them. We also witnessed in 2005 the complete failure of the NPT Review Conference, an international gathering of NPT members that convenes every five years and often provides the opportunity to address constructively problems of global concern. But due to the collision between, especially, the United States and others, but more generally be-

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tween the West and the rest, we failed in 2005 to reach an agreement even for an agenda for the conference, much less any kind of constructive result. To all these woes it is necessary to add the startling revelations about the A.Q. Khan network, which was a fundamental challenge to the regime because it involved a sub-state actor that was willfully and intentionally seeking to subvert and circumvent the international constraints on nuclear technology around which the NPT regime is built.

These were a series of body blows to the regime. It hasn't failed or collapsed, but the regime is struggling to cope adequately with the current tests in front of it. Now we look to the future and imagine a world in which there are many more nuclear power reactors and much more widely spread sensitive nuclear technology and ask, is the current system – barely adequate, even inadequate in

some eyes, today – going to cope effectively down the road with a much bigger challenge?

The general lesson is that the NPT regime is built on two contradictions. First, it is meant to prohibit nuclear weapons for almost all signatories while legally codifying the nuclear weapons status of a handful of nuclear powers. The solution in the Treaty was Article VI, in which the nuclear five promised to work in good faith toward nuclear disarmament. There is ample evidence to suggest that large segments of the NPT community are growing frustrated with what they perceive as the failure of the nuclear weapon states to live up to their Article VI obligations. The Article VI controversy has been troublesome in the past but may be even more difficult to manage in the future as disgruntlement mounts and patience wanes.

Second, the NPT is meant to prevent nuclear proliferation while promoting the spread of nuclear technology. The magic wand to make that possible is Article III of the NPT, which calls for safeguards, inspections, and transparency. You are entitled, as a non-weapon-state signatory to the Treaty, to the full panoply of nuclear technology, so long as it is under safeguards and supervised by the IAEA system. What I fear we may be seeing is the slow-motion death of the safeguards regime, because it doesn't cope with covert programs. It wasn't intended or designed for that, but covert programs are a big part of what we are worried about. In the context of dual-use technologies – very much the realm of the Iran crisis – judgments about intentions are absolutely decisive, but safeguards give no definitive insight on Iranian intentions. We can only tell what their technological capacities are, and in conditions of suspicion and hostility, even technically adequate inspections may be politically insufficient. In the current crisis over the past four or five years, Iran has been the most heavily inspected party in the history of the IAEA system. Its declared facilities have been under comprehensive, full-scope safeguards, and I venture to say neither the United States government nor most other governments have been wholly reassured by that fact.

The Academy's Global Nuclear Future Initiative asks what can we do to strengthen the regime, to make it more effective, and to give it greater capacity to cope with the new nuclear world into which we are heading. That is the debate to which we are hoping to contribute. ■

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