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TECHNOLOGY | GOVERNANCE | GLOBALIZATION

Resilience
in a Turbulent World

Lead Essays

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Reginald Van Lee et al. Megacommunities

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Organization of the Journal

Each issue of *Innovations* consists of four sections:

1. Lead essay. An authoritative figure addresses an issue relating to innovation, emphasizing interactions between technology and governance in a global context.

2. Cases authored by innovators. Case narratives of innovations are authored either by, or in collaboration with, the innovators themselves. Each includes discussion of motivations, challenges, strategies, outcomes, and unintended consequences. Following each case narrative, we present commentary by an academic discussant. The discussant highlights the aspects of the innovation that are analytically most interesting, have the most significant implications for policy, and/or best illustrate reciprocal relationships between technology and governance.

3. Analysis. Accessible, policy-relevant research articles emphasize links between practice and policy—alternately, micro and macro scales of analysis. The development of meaningful indicators of the impact of innovations is an area of editorial emphasis.

4. Perspectives on policy. Analyses of innovations by large scale public actors—national governments and transnational organizations—address both success and failure of policy, informed by both empirical evidence and the experience of policy innovators. The development of improved modes of governance to facilitate and support innovations is an area of editorial focus.

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Erwann O. Michel-Kerjan and Debra K. Decker

Insure to Assure

A New Paradigm for Nuclear Nonproliferation and International Security

With large-scale disasters likely to be part of our future, and the potential for nuclear proliferation to cause such a disaster, can private market mechanisms such as insurance be structured to help avoid the disaster itself?

Until recently, few world leaders or thinkers would have pegged the accelerating rhythm of large-scale catastrophes as one of the greatest economic and social challenges confronting society. But one hallmark of this new century will be more and more such unthinkable events, previously unseen contexts, and pressure for individuals, private companies, and government authorities to react extremely quickly, even when they cannot predict the cascading impact their actions will have.

And we must think beyond financial crises: what about food security, intercontinental pandemics, mega-terrorism, and cyber attacks? Think about global warming, and large-scale natural disasters, as well as new types of war, international security issues, and—as this article addresses—nuclear proliferation. We will face more of the same mega-crises in the future, as well as brand new ones. Dealing with an average of one or two such catastrophes every 20 years is one thing; dealing with 10 or 15 on many different fronts simultaneously, as is currently occurring, is a whole different game. This poses a real challenge: how do we think col-

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lectively about these possible extreme events far in advance so we can manage them before they occur, and create the foundations for a more resilient society?

Some important questions arise when we think about assuring resiliency: Who should pay for the economic consequences of future catastrophes? What financial solutions can be developed *ex ante* to provide coverage against (and dispel!) some of the aforementioned global risks? What are the roles and responsibilities of the public and private sectors?[1]

Insurance has historically played a critical role in providing financial coverage to people and companies against possible losses that would be too large for them to support. By paying a relatively small premium, we transfer our risk to the insurers who have a much larger financial capacity to absorb this loss and who can diversify the risks more broadly.[2] Although insurance is today one of the world's largest industries, over the last several generations, as catastrophes have unfolded, the public has also come to expect more and more from governments in managing these catastrophic risks.

This is particularly true in the United States. In his insightful book, *When All Else Fails: Government as the Ultimate Risk Manager*, Harvard University's David Moss states that "risk management policies seem to occupy an unusually prominent place in America's political economy. A nation widely known for its anti-statist sentiments and its faith in limited government, the United States is nonetheless up to its elbows in risk management policies."[3] Actually, a telling statistic is the evolution over the past 50 years of the number of U.S. presidential disaster declarations (which allow Congress to vote for federal relief): the number rose steadily each decade, from 162 over the period 1955-1965 to 545 for 1996-2005. And in just the few years from 2006 to 2008, nearly 200 disasters have already received this designation. The number relates not just to the disasters but also to the politics of disasters, as the number of declarations typically rises in presidential election years when voters are being courted.[4]

With governments clearly pressed to provide post-disaster direct aid, they have realized the need to intervene pre-disaster to support public interests. One way they have done this is by supporting insurance mechanisms. Governments have developed these supports because private insurance markets either do not have the financial capacity to cover the extent of the catastrophe risks and/or because risk premium market pricing has not provided what buyers consider to be adequate levels of insurance at acceptable prices; that is, it is not seen as affordable. Some examples include:[5]

Hurricane risks in Florida: These are covered by private insurers and by a state-run company, Citizens, with Citizens now representing more than 30 percent of the market. All benefit from extremely advantageous reinsurance from the state-run reinsurer, the Florida Hurricane Catastrophe Fund.

Earthquake risks in California: Insurance is provided through the California Earthquake Authority, which is a risk-sharing arrangement between private insurers and the state.

Flood risks in the United States: The federal National Flood Insurance Program began in 1968, in response to the belief that flood peril was uninsurable by the private sector alone. Private insurers sell insurance policies and settle claims on behalf of the federal government. The program covers over $1 trillion in assets today.

Nuclear accident risks in the U.S.: The Price-Anderson Act was passed in 1957 to partially indemnify the nuclear industry against liability claims arising from nuclear incidents while still ensuring compensation coverage for the general public. The first $10 billion is industry-funded; over that amount the federal government provides indemnification to victims. The Act was last renewed in 2005 for a 20 year period.

Terrorism risks in many countries: In the post-September 11, 2001 environment, insurance against terrorist attacks in most developed countries is now also provided through a collaboration between private insurers and the government, with some type of backstop. Examples are inexpensive government reinsurance (e.g. Extremus in Germany, Gareat in France, Pool Re in the United Kingdom) or free reinsurance in the United States, where commercial enterprises can be covered under the Terrorism Risk Insurance Act (TRIA) for total industry losses up to $100 billion per year.[6]

Third-party liability for commercial air carriers worldwide: Such insurance is now also provided through collaborations between insurers and the government in most countries worldwide.

So, as risks are getting larger and more frequent, new types of collaborations have emerged to provide financial protection. They almost always involve both the private markets of insurance and reinsurance (the insurance for insurers) and the public sphere. Insurers provide important strengths, including their networks, their expertise in risk quantification and risk underwriting, and their quick claim settlements.

In addition to supporting risk insurance, another way that government has interceded pre-disaster is by leveraging its "convening role" to induce industry to consider systemic risks and to develop agreements around preparedness standards. In the United States, pursuant to public law and presidential directive, federal departments and agencies, working with state and local governments and the private sector, identified critical infrastructures and key resources where improved risk management is in the national interest. Industry sector coordinating councils were then established to partner with government coordinating councils to better manage risks. Also, in 2007, U.S. law mandated the development of voluntary private sector programs in preparedness accreditation and certification; coordinated through the U.S. Department of Homeland Security, such programs could affect investor preferences and reward the better prepared businesses.

Governments have clearly developed a role in insurance and planning when selected interests are affected. But they have not yet fully explored the role they could play in solving some of the most vexing public issues by supporting the development of new market products or techniques. Often the problems are com-

plex and require innovative public-private sector solutions. One such problem is a rather arcane but real one that may occur as demand grows for nuclear energy: the risks associated with the expansion of nuclear fuel enrichment and potential weapons proliferation. While much effort has been spent in the past decades to manage nuclear proliferation risks, we believe it is time for the private insurance sector and governments around the world to work together to provide additional security in areas they have not addressed before.

THE PROBLEM

Increasing Demand for Nuclear Energy

Increases in world population and per capita energy demand in the next few decades are estimated to cause global energy demand to increase by about 50 percent over 2005-2006 levels by 2030.[7] About half of this increase is expected to come from electricity requirements.[8] In addition, growing concern over the effects that carbon-based energy has on global warming has revived interest in non-carbon-based energy sources, including nuclear power. According to the International Energy Agency, electricity accounts for about one-third of global fossil fuel use and over 40 percent of energy-related emissions of carbon dioxide.[9] These are serious concerns.

To better understand this radical evolution, we must recall that until about 1975, nuclear reactors generated less than 5 percent of the world's electricity. Today, they provide 15 percent of a much higher level of world electric production, about 2,742 terawatt-hours annually.[10] Electricity from nuclear reactors is particularly important to parts of the industrialized world. It typically represents a significant portion of the electricity consumed in most Organization for Economic Cooperation and Development (OECD) countries: about 20% in the United States, 25% in Japan, 28% in Germany, 36% in South Korea and over 76% in France.[11] Although about 436 nuclear power plants currently operate in 30 countries, the United States, France, and Japan account for about half of them.[12]

However, energy needs are rising even faster outside OECD countries, mainly as a result of population growth, urbanization and industrialization, but also as new demands develop; for example, for more desalination to provide potable water.[13] Nuclear power is expected to satisfy part of this demand in the developing world.

Currently, the World Nuclear Association says an additional 44 nuclear power plants are in the process of being constructed, with another 110 planned and 272 proposed by countries ranging from China to South Africa to the United Arab Emirates.[14] These figures may be more industry aspirations than reality, but they do not even include potential nuclear electric production in Saudi Arabia and some other member states of the Gulf Cooperation Council, which have recently expressed interest in nuclear development. Overall, if these planned and proposed

reactors are built, the world would go from having 30 countries with commercial nuclear reactors to about 44—nearly a 50 percent increase.

Risks Associated with Nuclear Energy Expansion and the Notion of Fuel Assurance

The expansion of nuclear energy is not without issues, such as the somewhat unpredictable costs of building the reactors, concerns over safety (e.g., Three Mile Island, Chernobyl) and waste storage.[15] One additional concern is the development of the nuclear fuel itself, to which we now turn.

Most nuclear power reactors use low-enriched uranium (LEU) as fuel. This fuel is made by mining uranium ore, milling, converting, and enriching it, then fabricating it into fuel rods. The enrichment process involves increasing the percentage of the fissile isotope U-235 from its naturally occurring 0.7 percent of uranium to three to five percent of the material for electricity-producing reactors. A major concern is that the same process used to enrich uranium for fuel can be used to enrich it further to produce weapons-grade material.[16] Currently, only six countries have enrichment facilities supplying the commercial world market: France, Germany, the Netherlands, Russia, the United Kingdom, and the United States.[17] Thus the international community is thinking hard about how to manage the nuclear fuel market and is looking to different forms of fuel assurances to dissuade additional countries from launching their own enrichment capacity.

Debates about internationalizing the dangerous aspects of the nuclear fuel cycle were going on even before the International Atomic Energy Agency (IAEA) was established in the 1950s, but the issue was never fully resolved.[18] More recently, IAEA Director General Mohamed ElBaradei challenged the world to again tackle a crucial question: how could international controls over nuclear fuel, and increased assurance of fuel supplies, reduce the dangers in the nuclear fuel cycle? He commissioned an expert panel to define the best options. In 2005, the IAEA panel, known as the Expert Group, issued its report, "Multilateral Approaches to the Nuclear Fuel Cycle," which spelled out various options.[19] Other groups have also noted the importance of providing some degree of fuel assurance to dissuade states from enriching uranium; among them are the United Nations High-Level Panel on Threats, Challenges, and Change; the Weapons of Mass Destruction Commission; and the Carnegie Endowment for International Peace.[20]

It is often not in a country's economic interest to begin enriching its own uranium to make fuel for its nuclear reactors. Especially for smaller quantities, it is currently cheaper to buy enriched uranium from established producers in other countries, given industry returns to scale and the significant investments in technology that are required.[21] Still, some countries might decide to develop their own uranium enrichment capacity for at least three reasons:

- Having a full fuel cycle capacity makes the fuel supply more stable, both economically and politically, thereby providing more energy security and reducing the dependence on other countries.

- A government may justify such a move as part of the country's overall investment in new technologies and seek to offset some of the fuel enrichment overhead costs by selling enrichment services to other countries.
- Third, countries often see an enrichment capability as providing increased prestige and power on the international scene; they also get the option of a possible "breakout" to nuclear weapon capability once they accumulate supplies of enriched uranium.

Iran is already enriching uranium, and other countries with no or nascent facilities have shown heightened interest, from Argentina and Australia to South Africa and even Vietnam.[22] Brazil and Japan already have small enrichment plants, both to meet some domestic needs and under IAEA safeguards.[23] Though Japan and Brazil are not suspected of illicit activities, IAEA safeguards do not prevent countries from developing secret programs with the same technologies; nor can countries be prevented from withdrawing from that safeguards regime to undertake an atomic bomb program.

The goal of fuel assurances, and of the nuclear "insurance to assure" concept we introduce below, is to help reduce just the first incentive for countries to enrich uranium. And it is clear that should a country focus on the third incentive (the desire to develop nuclear weapon capability), our proposal would have limited effect except that such a country would find it even harder to justify its actions by claiming to feel threatened by potential disruption of its fuel supply.

It is true that the cost of sidelining a nuclear plant is very high. Considered from the standpoint of return on capital, a nuclear plant that does not run for six months might represent a loss of about $100 million to its operator alone.[24] But considering externalities (loss to those who need electricity, like industry and residential use), the costs of losing electric capacity can be much greater. As a reference point, the August 2003 North American blackout, which at its peak deprived 50 million people of electricity for several hours and lasted several days, cost the United States between $4 and 10 billion.[25]

No country has yet encountered major problems in its nuclear fuel supply specifically because of commercial disruptions. However, past political constraints on supply may be part of the motivation for countries like Iran to seek enrichment capability. Thus far it is unclear what other countries might be on the fence about acquiring a full fuel cycle and could be swayed not to enrich if an effective assurance mechanism could address the simply political risk. It is important for IAEA to identify these countries and the assurances they would need so that the best supply assurance mechanism can be crafted. Anticipating nuclear needs—not just for enriched uranium but also for fabricated fuel, transport, spare parts, etc.—and deciding whether and how government should help satisfy such needs is the best way to ensure that the industry develops in ways that serve the public's interests.

Several proposals for fuel supply assurance are currently receiving international attention.[26] So far, three methods for providing fuel assurances have the most salience: (1) The six countries that currently are engaged in commercial enrichment and the IAEA could provide joint guarantees on enrichment; (2) Regional

fuel centers could be established; (3) Most prominently, an IAEA fuel bank could stock low-enriched uranium, which could be fabricated to meet the supply needs of a country facing supply chain disruption for political reasons not related to proliferation concerns.[27] The United States and Russia have both already committed to stockpiling low-enriched uranium to assure fuel supplies.

Some of the proposed assurances may be necessary but may not be sufficient, given that the countries controlling enrichment processes would still be largely in control.[28] The proposals have some similar limitations, in that a country requiring fuel would likewise have to trust the six supplier countries or the IAEA, and some see the IAEA as already dominated by those countries anyway, in part because they provide much of IAEA's funding.

Also, these proposals might not provide sufficient assurance of overall continued nuclear plant operation. A problem arises, for example, if no fuel fabricator can or will make and arrange transport for the enriched uranium. Political interference could disrupt any part of the fuel supply and operations, not just the enrichment process, leading states to discount the value of any enriched fuel bank.

We turn next to our concept, which suggests a way to reduce the economic consequences for countries that might be deprived of fuel, and thereby to reduce countries' interest in developing their own enrichment capacity in the coming years.

A PROPOSED INNOVATION: INSURE TO ASSURE THE SECURITY OF ROBUST NUCLEAR ENERGY MARKETS

One possibility that, to our knowledge, has not been discussed so far would be to make use of the financial capacity of private insurance partners who could provide the financial base as well as expertise in managing large-scale risks. They could help develop an insurance mechanism that would provide economic compensation if fuel supplies were disrupted and would also allow nuclear plants to continue to operate or else provide compensatory payments. We first introduced this idea in December 2006 in a commentary in the *International Herald Tribune* and have since discussed its practicality with a number of people around the world.[29]

The insurance and reinsurance industry seems to be a very natural candidate for involvement in this assurance task. First, this sector has become one of the largest industries in the world—in 2007 ,the insurance industry had $4.1 trillion just in yearly insurance premium revenue, not including investment income.[30] Second, the specific core business of insurers and reinsurers is to deal with risk management and to optimize risk financing. Third, and importantly, insurers might be perceived as a less political third party on the international fuel demand/supply scene, thereby fostering higher levels of trust, together with customer and investor confidence.

Furthermore, the insurance market mechanism could address additional risks within the full nuclear fuel supply chain that might disrupt plant operation. These include transport, fuel fabrication, and provision of spare parts. Thus, the nuclear

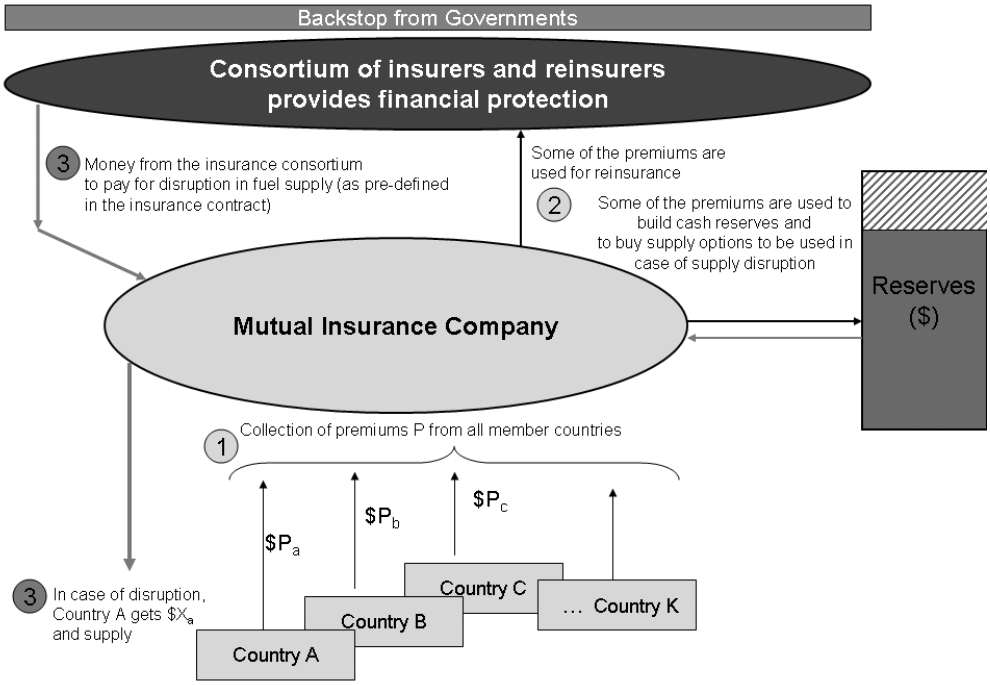

Figure 1. Insuring to Assure Fuel Supply.

plants (which are either privately held or government utilities) would be getting the assurance of operations that they want, with a higher level of confidence compared to what the community of concerned governments wants to provide: some assurance of enriched uranium.

How Could This Be Structured?

The proposed structure is shown in Figure 1. Countries that would like to participate would form a mutual insurance entity aiming **to insure in order to assure** fuel supplies. That's the first layer in the proposal. "Mutual insurance" is a type of insurance in which those protected by the insurance also share the risks of the other participants in the mutual. A mutual insurance entity would be established that could provide assurance for the full fuel cycle (i.e., enrichment, conversion, fabrication, and transportation) of nuclear utilities (public and private) against political interruptions and other risks (e.g., a major natural disaster) and could also provide insurance for some of the economic losses associated with temporary fuel supply disruption. The members of the mutual insurance company would be the countries that need enriched uranium for their nuclear plants (or the owners of these plants). They would pay premiums that the mutual would use to purchase financial coverage via insurance and reinsurance; that is the second layer in the proposal. The mutual could also establish a cash reserve. Given the space limitation here, we do not discuss pricing issues or the conditions on participation in the

mutual, though they are of course critical; a more detailed discussion is in Decker and Michel-Kerjan (2007).

The insurers/reinsurers, who would participate in the back-up consortium providing additional coverage to the mutual, would analyze the risks associated with a shortage in the supply of each specific type of fuel and end user. Based on these risk assessments, the entity would charge premiums to the mutual's member countries that use nuclear fuel (see Figure 1).

If this new entity is to provide more than just financial coverage, it could also use its cash reserve to purchase supply options and thus assure availability of fuel supply. This is important, as nuclear plants want to provide electricity and cannot easily otherwise compensate their end-users for blackouts. Ideally, member countries would also approve exports in advance without requiring the right to consent to the fuel supply options or to the new insurance facility directly purchasing electric supply off available grids. Insurance mechanisms, including contract options, could prove a useful part of the proposed assurances; they could also, if desired, provide the framework for managing the development of new supplies.

Managers of nuclear power plants have some discretion regarding the timing of fuel assembly change outs and the enrichment levels of the fuel going into the assembly. We believe these are economic decisions that can be compensated if the nuclear system does not operate at optimum capacity. It could also be possible to ask a fuel customer to forego his place in the fuel fabrication line in exchange for compensation; money and time are two variables that can be managed and insured.

To limit the exposure of both insurers and reinsurers to a level at which they would be comfortable participating, the entity might also benefit from an additional layer of protection through a federal backstop from all participating countries (see Figure 1). The terms of this additional coverage remain to be discussed.

The Indemnification Process

How would this process work in practice? If a state found its nuclear fuel prevented from delivery, the following would happen:

- The state would inform the mutual insurance entity.
- The entity would make a determination based on pre-established guidelines (including, for example, the state not being under UN Security Council sanctions)[31] and the nature of interruption in delivery; this decision would have to be made within an amount of time previously agreed under the insurance contract.
- The entity would compensate the insured and others affected by the replacement for any loss of efficiency beyond a previously agreed amount of loss.
- The insuring entity could help to ensure continued supply of electricity, i.e., by facilitating grid purchases while exercising its options and working with fuel suppliers, fabricators, and transporters to arrange a timely fuel delivery if, as described above, it had agreed to play that role in addition to economic indemnification.

If one country in the mutual were to prohibit delivery of nuclear-related goods or services to another country in the mutual because of political interference, it would be temporarily excluded from having its nuclear power guaranteed. That is, it could not provide nuclear supplies to others (so others would be less likely to buy from it) and it could not receive nuclear services from others. In other words, if Country A denies fuel or fuel services to Country B, Country A will lose its guarantee of receiving power supplies. In short, countries that use nuclear fuel–related goods or services for political leverage would not be allowed to participate in the mutual pool or to obtain insurance on supplies to their own utilities.

This arrangement would make it financially viable for the insuring entity to play the role of supply ombudsman. Suppliers would receive compensation for developing and setting aside some capacity or for working overtime to fulfill the supply need. The entity would define compensation schemes in advance so that every country covered by the consortium would know exactly what it would get for any delay in access to supply and the role the insurance consortium plays in facilitating the supply.

If the IAEA were to support the insurance entity, it could require that each member of the mutual have some political risk insurance on its nuclear fuel, perhaps based on the amount of enriched uranium used; this would prevent any adverse selection. That is, no state would gain an asymmetric knowledge advantage, that is buying more insurance knowing it needed it because its supplier was about to cut off supplies. Instead, the IAEA would, in essence, levy an insurance tax on participating members for the privilege of buying enriched uranium. This would help fund the insurance facility's purchase of options and of reinsurance.

An advantage of our insurance facility proposal is that it is universally applicable: states, including the major enrichment states, could recognize their dependence on international markets for different aspects of their fuel, from ore to fabrication, and elect to participate. This proposal would cover the full supply chain, not just enrichment.

Under this insurance proposal, a state would be less likely to use its nuclear fuel supplies for leverage against others; if it did, it would lose its own guarantees and also find that its actions had very little effect. Involving private insurers and reinsurers as part of the mutual equation also removes some of the politics: the mutual facility would automatically supply a utility when called upon to, unless *force majeure* (e.g., the UN Security Council) prohibited it from doing so. In addition, this facility could help foster private markets by using public trading platforms to make uranium purchases—thereby helping to further commoditize that market.[32]

Can This Control Enrichment?

We believe this proposal could complement other assurance-of-supply proposals already under consideration. As our proposal covers the full fuel supply cycle, not just enrichment, it would provide more assurance to countries needing fuel. Having a mutual mechanism in place that includes both the private industry and

a broad range of suppliers also provides more assurance by depoliticizing the insurance process. Including private insurers provides added contract security in terms of legal agreements. The insurance consortium might want to offer a full range of supply disruption guarantees, including some for certain commercial risks, which appear to be a growing concern. Thus, states should find they have good incentives to participate and will comply with the membership guidelines.

FINAL CONSIDERATIONS

Catastrophes that have unfolded over the past ten years have made it clear that we have entered a new era of large-scale risks. And with the growing globalization of social and economic activities worldwide, our planet is becoming more like a village. A still somewhat underappreciated feature of the 21st century is that risks are becoming more interdependent: what happens 5,000 miles away can ripple to us with great impact, whether it is a flu outbreak in China or Mexico, a financial crisis, or the development of enrichment facilities in an equally distant country.

In this turbulent era, a key question is who will pay for the economic consequences of these global risks when they occur and inflict significant losses. Looking at how most developed countries have responded to this challenge so far, it appears that many have opted for some type and extent of collaboration between government and insurance—one of the world's largest industries.

To date, however, no such collaboration has focused on what might very well be the ultimate global risk: nuclear proliferation. The debate about nuclear energy and proliferation has remained essentially among representatives of governments and international organizations. Thus it has failed to take advantage of the fact that private actors can help reduce public vulnerability. Indeed, it appears that the use of nuclear energy will continue to increase in the foreseeable future. And although we have focused here on state development of nuclear materials, such development is also inextricably linked to possible terrorist use.[33]

Here, we must ask how we can keep the bad "genie" in the nuclear bottle and still supply fuel. In the past, crucial answers have included successful nuclear fuel markets and the continuous monitoring and preventive actions by the international community. As economist Thomas Schelling stated in his Nobel Lecture in Stockholm in December 2005, "the most spectacular event of the past half century is one that did not occur. We have enjoyed sixty years without nuclear weapons exploded in anger."[34] As a result, the non-use of nuclear weapons since 1945 certainly remains the single most important phenomenon of the nuclear age.[35] Over the last several decades, more countries have actually become non-nuclear than have become nuclear. For example, Libya, Taiwan, South Korea, and others have renounced nascent nuclear weapons programs.[36]

However, the world is changing rapidly, and no one can predict the future. As the demand for nuclear fuel increases, additional assurances will be needed to keep the markets functioning safely and to monitor and/or limit potential new nuclear capabilities. If we want to ensure that only a limited number of countries have the

enrichment capacity that can then lead to nuclear weapons development, we must develop many complementary ways to reduce the incentives for them to do so.

We believe that governments and the international community should view the insurance industry as a serious partner in doing just that on the economic front. The initiative proposed here is an appealing way for IAEA and the international community to tackle the problem of fuel supply assurance. It involves experts in insurance/finance working to establish an international mutual pool providing nuclear fuel cycle disruption coverage, with insurance and reinsurance layers provided by the private industry and backed up by multiple countries.

This "insure to assure" proposal means that states are taking nuclear fuel off the sanctions table in cases where they might want to apply pressure to effect changes in a state; for example, on human rights issues or terrorist funding. It is allowing some preference to be given to nuclear power in efforts to expand electricity supplies. This preference recognizes several important facts: that nuclear expansion is inevitable as a base load source of fuel, that many want to keep nuclear as part of the carbon-reducing energy mix to help avoid human-induced global warming, and that mechanisms may be needed to reduce interest in fuel enrichment. It is one way to utilize market mechanisms to affect societal risk preferences. And it has one further advantage: such mutual international public-private partnerships are a means to develop confidence-building technical networks that can be important to a peaceful future.[37]

One question remains: if this is such a good idea, why isn't the market already doing it? Indeed, mutuals are not uncommon as insurance mechanisms and are known in the energy industry. But we believe that the nature of this proposal will require certain players to group together: the insurers (supply side professionals) and the nuclear utilities/states (including the newly emerging demand side interests). By logic, no individual player can lead the effort alone, especially given the necessary upfront costs in time and consultative fees to further this program. In addition, private markets will not move forward on this plan without states and international organizations playing some key roles. States will be needed to provide new contractual approvals for exports, certain organizations will be needed to facilitate contracting, and state subsidies may be needed to price the product attractively.

In other words, for the plan to succeed, international collaboration is needed not only among countries but also between the public and private sectors. This will take concerted leadership, and certainly a critical mass of key stakeholders willing to say yes. US President Barack Obama and Russian President Dmitry Medvedev, among other leaders who are seeking jointly to strengthen international nonproliferation, should look to the private sector to be a potential ally in that process.

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Endnotes

1. See Auerswald et al. (2006) for a discussion of various answers to these questions.
2. To illustrate the new era of costly catastrophes we have entered, we find one figure to be particularly eye opening: the 25 most costly insured catastrophes in the world between 1970 and 2008 (all adjusted to 2008 prices) all occurred after 1987. Furthermore, of these 25 events, 17 have occurred since 2001.
3. Moss (2002), p. 17.
4. Michel-Kerjan (2008).
5. Kunreuther and Michel-Kerjan (2009).
6. Kunreuther and Michel-Kerjan (2004, 2005); Michel-Kerjan and Pedell (2005, 2006).
7. OECD/International Energy Agency (2008b) estimates in its reference scenario that world primary energy demand will grow by 45 percent from 2006 to 2030. The U.S. Department of Energy (2008b) reference estimate from 2005 to 2030 for world marketed energy consumption is 50 percent.
8. U.S. Department of Energy (2008a).
9. This is based on 2005 data. OECD/International Energy Agency (2008a), Part I - I.23 [p. 65 of PDF].
10. This is based on 2005 data. OECD/International Energy Agency (2006), pp. 350, 361.
11. International Atomic Energy Agency (power plant info at www.iaea.org/cgi-bin/db.page.pl/pris.nucshare.htm).
12. World Nuclear Association (2009).
13. World Nuclear Association (2008).
14. World Nuclear Association (2009).
15. Many issues must be weighed. See MIT (2009) for the latest information on the economics of nuclear power, particularly on the persistent uncertainties regarding capital and financing costs. See also Joscow (2006) for consideration of the impact U.S. government regulation has on the economics of nuclear power development. For an economic model depicting how sales generate negative externalities on non-purchasers as applied to international nuclear weapons acquisitions (which can be considered analogous to acquisition of latent nuclear capabilities), see Jehiel et al. (1996).
16. LEU is defined as uranium containing more U-235 by weight than is naturally occurring but less than 20% U-235. High-enriched uranium is uranium with 20% or more of the isotope U-235, although weapons-grade uranium is typically considered enriched to more than 90% U-235.
17. World Information Service on Energy (WISE) (2009).
18. Study and discussions predate even President Dwight D. Eisenhower's 1953 proposal for an international fuel bank.
19. International Atomic Energy Agency (2005).
20. United Nations (2004); Weapons of Mass Destruction Commission (2006); Perkovich et al. (2005); Arbatov and Dvorkin (2006).
21. Von Hippel (2008).

22. Broad and Sanger (2006). Interest is fluid in various countries. For example, Australia's new Labor government is not as enamored of nuclear expansion as the previous one; however, industry interest persists, the national limitation on mining has been lifted, and we expect some will continue to be interested in moving toward Australian enrichment.
23. Japan's enrichment plant at Rokkasho-mura is currently intended to help supply a portion of the country's domestic needs (see Japan Nuclear Fuel Limited, www.jnfl.co.jp/english/uranium.html). Brazil's Resende enrichment plant is also for domestic needs (see: World Nuclear Association, Nuclear Power in Brazil, March 2009, www.world-nuclear.org/info/inf95.html). Enrichment facilities to serve nuclear weapons capabilities exist in China, Pakistan, and India; the enrichment facilities for nuclear weapons in North Korea and Israel are not known.
24. Von Hippel (2008). This is based on a 1,000 MWe reactor costing $4 billion (Harding, 2007) with a 5% real return on capital (i.e., corrected for inflation). Coal and gas plants cost substantially less to build but more to run. See also MIT (2009) and its supporting working papers, which estimate that the base case overnight cost (not including construction time and financing costs) per kilowatt in 2007 dollars is about $4,000 for nuclear, $2,300 for coal, and $850 for gas; with fuel costs at $.67/mmBtu for nuclear, $2.60/mmBtu for coal, and $7.00/mmBtu for gas.
25. U.S.-Canada Power System Outage Task Force (2004), p. 1. This involved an area of 50 million people and affected 61,800 MWe.
26. Simpson (2008) recaps the most current supply proposals. We consider only ways to increase assurance of fuel supplies so that countries do not feel compelled to establish their own enrichment facilities. Others are looking at ways to handle the back end of the fuel cycle. See Wolfsthal (2004), Müller (2005) and Braun et al. (2008) for some broader thinking on these issues.
27. The Nuclear Threat Initiative (NTI)—backed by investor/philanthropist Warren Buffet—made a generous pledge of $50 million to IAEA to help create such a low-enriched uranium stockpile that has been matched with approximately $100 million in total pledges from the United States, the European Union, the United Arab Emirates, Kuwait, and Norway, in descending order of contribution (International Atomic Energy Agency, 2009). The expected 50-60 metric ton stock of enriched uranium would be enough to fuel a typical power reactor or provide three annual re-loads; see Holgate (2006).
28. The OECD Nuclear Energy Agency has established an expert group to consider nuclear energy and security of supply.
29. Decker and Michel-Kerjan (2006).
30. Swiss Re (2008).
31. Details would need to be agreed upon but consideration should be given to the structure of other commodity market programs in designing the approach (e.g., the arbitration program and other aspects of the London Metals Exchange).
32. In Decker and Michel-Kerjan (2007), we discuss in detail the practical feasibility of this proposal from the perspectives of the fuel suppliers, insurers, and reinsurers, and IAEA and member states.
33. Allison (2005, 2006); Lugar (2005); Levi (2007).
34. Schelling (2005).
35. Tannenwald (2007).
36. Bunn (2008).
37. Slaughter (2004).

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