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Nuclear Power for the Developing World

Small modular reactors may be attractive in many developing nations. Here is a blueprint for how to build them efficiently and ensure maximum safety.

In the United States and much of the developed world, nuclear power raises deep misgivings among many decisionmakers and ordinary people. Concerns about safety have been rekindled by the Fukushima Daiichi nuclear disaster in Japan. There are also long-standing worries over proliferation and spent fuel management. And the technology has proven expensive: its high capital costs, combined with restructured electricity markets that place heavy emphasis on short-term economic gains, cheap natural gas in the United States, and the absence of a serious commitment to greenhouse gas emissions reduction, make nuclear power uncompetitive in many markets. The four new reactors being built in the United States today are in states that have vertically integrated power companies, where public utility commissions can approve the addition of the cost to the rate base.

But nuclear power is not dead. Seventy nuclear reactors are under construction worldwide. Twenty-seven of those are in China, ten are in Russia, and six are in India. With few exceptions, these new reactors are of the large light water type that dominate today's commercial fleet, producing roughly 75% of the electricity in France, 20% in the United States, 18% in the United Kingdom, and 17% in Germany.

The same holds true when it comes to the development of new reactor designs. Some limited work continues in the United States, but efforts by its Department of Energy to rekindle interest among commercial players have seen limited success. Germany, once a leader in advanced reactor designs, closed its reactor development laboratories some years ago, ending all such research. Its labs now focus only on reactor safety for select advanced designs. However, China, India, Korea, and Russia continue to support vigorous development and demonstration programs.

As developed countries come to appreciate the magnitude of the effort needed to fully wean their energy systems off of carbon-emitting energy sources, there is a possibility that they will see a resurgence of support for nuclear power—presumably using safer and lower-cost technologies. In the meantime, the rest of the world will continue its present building boom and push on with the development of new designs.

Thinking small

Many proponents of nuclear power believe that the technology's problems can be solved through innovation. Some have held up a vision of small modular reactors (SMRs), capable of producing 5 megawatts to 300 megawatts of electricity that would be manufactured on a factory production line and then shipped to the field as a complete module to be installed on a pre-prepared site. Proponents argue that factory manufacturing would not just reduce costs; it could also result in dramatic improvements in quality and reliability. Moreover, if these SMRs could then be returned—still fully fueled—to secure facilities at the end of their core life, the risk of proliferation could be better managed.

It is a lovely vision, but its realization lies decades in the future, if it is even possible. Estimates of the capital cost per megawatt of first-generation light water SMRs lie a factor of two or three above that of conventional reactors. Of course, since SMRs would be much smaller, the total cost would be much lower;

hence, choosing an SMR would not be a "bet the company" decision. But few firms in the developed world are likely to be interested, absent a significant price on carbon emissions, or perhaps a new business model that incorporates other uses for a small-scale reactor (such as water desalination or hydrogen production) in tandem with electrical generation.

The same may not be the case across the developing world. If the cost of more advanced small modular reactor designs can be brought down, even to the range of conventional reactors, many nations may find SMRs an attractive way to meet their growing demands for electricity or process heat, and may find the smaller size more compatible with their smaller, less-developed electricity grids.

While the vendors involved in nuclear technology are responsible for innovating on the construction front to bring down SMR cost and construction duration, vendors and regulators share the burden of innovating on both the deployment and institutional fronts. A number of SMR mass deployment strategies have been proposed, ranging from business-as-usual to a build-own-operate-return (BOOR) strategy. Under business-as-usual, countries that choose to host SMRs would assume all responsibility for safety and the security of nuclear materials. Under a BOOR strategy, nuclear suppliers—perhaps backed by sovereign states and accredited through an internationally sanctioned framework—would provide, operate, and take custody of SMRs, thus assuming responsibility for the plant and all parts of the fuel cycle.

When questioned, even proponents of the BOOR strategy admit that, ultimately, nations that choose to deploy nuclear power plants must accept at least some of the responsibility associated with the technology. However, the strategy may be a way of reducing these responsibilities for customers who want clean energy, but cannot afford to fully build the technical and social institutions needed to responsibly manage nuclear power.

Regardless of deployment strategy, the institutional paradigm must change in a world with many SMRs. Host nations in the developing world could help, but, if this is to happen, delivering this change would mainly be the responsibility of national policymakers in nuclear supplier states, primarily China, France, Korea, Russia, and the United States, working within the framework of the international nuclear control regime. If coming decades do see a growth in SMRs across the developing world, three issues become critical: emergency response, liability, and proliferation.

Emergency response. Both light water SMRs and more advanced ones adopt a range of passive safety features. These are intended to reduce the probability of a major accident and, if abnormal conditions do develop, to increase the "coping time" available to operators to address the problem. Some designs eliminate on-site fuel handling; others rely on air-cooling instead of water-cooling, which reduces the need for elaborate plumbing and emergency power to cool the core after an accident. Some designs propose a fleet management approach where, as with many aircraft jet engines today, the reactor's supplier can see everything an on-site control room operator sees. In an emergency, the supplier could provide advice to local operators, or even override local operators and take control. Nevertheless, the core of any SMR will contain highly hazardous materials. However remote the possibility, a major disaster could result in the release of significant quantities of these materials to the environment.

> The international community should urgently act to create a global control and accounting system for all civilian nuclear materials.

Few developing countries have, or are able to develop, the capacity to respond appropriately to a major accident. While commercial suppliers might adopt a BOOR approach, it seems most unlikely that they would include full-scale emergency response as part of the package. Suppliers backed by a capable sovereign nation, such as China or Russia, might supply a more credible capacity, but this does not solve the more general problem.

Liability. Efforts to develop a global liability regime, or to ensure that all reactors are covered by the arrangements that currently exist, must be accelerated. That said, if SMRs are to see mass deployment, alternative arrangements must be made for those smaller nations that cannot afford the liability caps that existing conventions prescribe. No global third-party nuclear liability regime exists. There are multiple conventions that states subscribe to, but given that some subscribe to none, substantial gaps exist in the current international framework. More than half of the world's commercial nuclear fleet is not covered by any liability regime currently in effect. These reactors are in large countries such as Canada, China, and India that acknowledge that liability ultimately rests with the sovereign.

The main conventions at the moment are the Paris Convention, enacted in 1960, and the Vienna

Convention, enacted in 1963. The Paris Convention, as updated under the Brussels Supplementary Convention of 1963, stipulates a liability amount of approximately $450 million. The Vienna Convention, as updated in 1997, specifies a liability limit of approximately $450 million. (The actual amounts under both conventions vary based on changes in currency valuations; the figures given reflect valuations as of mid-October 2014.) More recently, some efforts have been made to increase the liability amounts in acknowledgment of the potentially devastating effects of nuclear accidents. A revision to the Paris Convention was proposed in 2004 that would raise the liability amount to approximately $900 million (at current currency conversion rates), though this has yet to come in force. Also, the United States led an effort that in 1997 resulted in the establishment of a third convention, called the Convention on Supplementary Compensation that stipulates a liability of $900 million. In a major development, the Japanese Diet approved the ratification of this Convention in late November, which means it will enter into force three months after Japan deposits its instrument of ratification with the International Atomic Energy Agency. Only six countries have ratified the Convention on Supplementary Compensation thus far but, if it fulfills its promise of streamlining liability claims in the event of an accident, that will steer more countries towards signing and ratifying it.

Depending on the location of a potential accident—in other words, given the liability regime in effect—claims of damages can be filed against a reactor's operator or its supplier, or against national authorities. Allegedly wronged parties in neighboring countries could file these claims as well, raising questions of which courts can exercise jurisdiction in which cases. Since these claims can involve thousands of cases and stretch into the tens of billions of dollars in the case of large nuclear accidents, commercial operators carefully investigate liability law in jurisdictions where they contemplate building plants. Suppliers and operators that choose to embark on plants in nations that neither subscribe to international conventions nor have well-developed national liability regimes are usually state-owned or state-affiliated enterprises in rich developed or developing nations. It is generally assumed that the lion's share of the liability for an accident in such jurisdictions rests with the sovereign.

National nuclear liability laws vary greatly. For example, some countries do not hold nuclear operators strictly liable for nuclear incidents. The amount of money in different nuclear insurance pools differs, and some countries do not extend financial protection to cover grave natural disasters. Harmonizing liability law by convincing states to subscribe to a single convention eliminates some of the uncertainty that prevents nuclear operators from pursuing builds in certain countries, and precludes the sort of extended, high-level political discussions between governments that are currently necessary for exporter and host nations to commence a nuclear power plant project. They also increase liability amounts, cover a wider range of damages, and explicitly declare that "grave natural disasters" are no grounds for exoneration. Nuclear liability law has yet to be harmonized within the European Union, let alone globally, and movement toward this goal has been very slow. In all likelihood, it will remain so.

Some existing nuclear energy states have not ratified any of the conventions, including India, China, South Africa, and Canada. Most of the developing world has yet to ratify any. Efforts to modernize the nuclear liability regime have thus far involved steering countries toward ratification of a single convention. But even if this happens, some developing nations considering a nuclear program probably could not afford the liability amounts for which they would be responsible under any of the conventions, and especially the revised Paris Convention or the Convention on Supplementary Compensation. In the event of a major accident, these nations might well default. In addition to the sociopolitical and economic implications, such a default could place an even greater burden on institutions that provide development aid, diverting much-needed funds from investments in capacity building. Global conventions on nuclear liability must recognize that recovering from accidents involving SMRs will entail smaller sums of money than the hundreds of millions of dollars currently prescribed. Alternative liability arrangements must be made for developing nations that are seeking to deploy one or several SMRs, as opposed to multi-gigawatt conventional plants. We describe alternative arrangements later; regardless of the form they ultimately take, liability considerations should certainly be a part of any future SMR deployment agreements and should be codified in international energy policy.

Proliferation. If SMRs are to be fueled in the field, as will be required for virtually all designs now in advanced stages of development, there is a possibility that spent fuel could be diverted for use in weapons programs, or for the construction of “dirty bombs.” Also, the mass deployment of SMRs might open new pathways for proliferation that will need to be managed. For example, the potential growth of the nuclear-trained workforce will broaden the population of people who have a detailed understanding of this technology.

Some suppliers have dismissed this concern, arguing that proliferation is “a uniquely American preoccupation.” However, it would become an international concern overnight if diversion were ever to occur. In our view, it is far better to find a comprehensive way to address the problem now, than try to patch things up if a diversion occurs after many SMRs have been deployed under a business-as-usual scenario.

New tools and more resources are needed to assess and manage the risk of proliferation. This is true not only for SMRs, but also for the world nuclear enterprise writ large. A recent report by the National Research Council (*Improving the Assessment of the Proliferation Risk of Nuclear Fuel Cycles*) clearly articulates the serious limitations of all present assessment tools.

Until better tools are developed, there are three common-sense steps that could be taken to manage the risk of proliferation from the mass deployment of SMRs. First, the international community should urgently act to create a global control and accounting system for all civilian nuclear materials. This system must incorporate as many nuclear isotopes as possible, and it must be easy for inspectors from the International Atomic Energy Agency (IAEA) to access and query. Second, preference must be given to SMR designs that minimize the need for on-site fuel handling and storage—in general, the fewer times the fuel is handled, the better. And third, nations must recommit to tackling the waste question, by consolidating existing stockpiles or establishing permanent repositories. A global, internationally supervised approach to waste management, of the sort proposed years ago by Chauncey Starr and Wolf Häfele, is highly unlikely. The historic reluctance of the United States to cede any sovereignty in such matters, and the rapidly decaying relationship between Russia and the West, pose enormous challenges on this front. National or regional facilities may be possible, of course, though the danger always exists of rich neighbors coercing poorer ones into inappropriately hosting storage facilities.

Preparing for nuclear reality

Even given the challenges that remain, it is likely that many countries in the developing world may want to push forward with installing and operating SMRs. To better assist with and control such mass deployment of SMRs, new institutional arrangements are needed that would globalize standards regarding the type of SMRs that can be deployed and how to respond to potential accidents and reduce the probability of proliferation. We were able to explore alternative institutional arrangements at a workshop we organized in Switzerland with the International Risk Governance Council and the Paul Scherrer Institut. The workshop, which was supported by the MacArthur Foundation, brought together forty experts from eleven countries, nine SMR vendors, and all major nuclear supplier states.

As a first step toward this goal, a radical modification of the certification and licensing process must be developed and adopted. Many countries that could be interested in SMRs do not even have a nuclear regulatory authority. The movement in the United States toward certifying a design and then licensing site-specific modifications is welcome and provides a good starting point for streamlining the SMR deployment process. Unfortunately the U.S. Nuclear Regulatory Commission (NRC) is currently unequipped to assess any designs, especially non-light water ones, in a timely way.

If the industry takes every new idea to mean a protracted, expensive struggle with the regulator, it will instead design-out these innovations. To be sure, vendors with novel ideas must be prepared to defend these ideas. At the same time, regulators must acknowledge the nuclear innovator’s dilemma, and be equipped to step out of their comfort zone when evaluating designs. While many officials in the United States keep referring to NRC certification as “the gold standard,” many of the nation’s allies and rivals disagree with that characterization. And, if the agency does not develop the capability to assess advanced designs, it runs the risk of becoming less and less relevant as China, Korea, and others certify and market their own designs across the world.

Ideally, designs should first be certified and built in their home country. Another nuclear supplier state should then certify the design. Certification from regulators in two reactor-supplying states would assure inexperienced customers of the design’s viability. What is radical about this idea is that the host nation’s regulator would not undertake the design certification process itself, saving both the supplier and the host nation time and money. The staff of a newly established national regulator should engage in an intensive education program with the regulators who certified the design. The details of this process should be stipulated in multilateral agreements involving the exporting nation, the host nation, and the IAEA. Material generated during the original design certification process would be shared with the host nation's regulator. Therefore, the relatively inexperienced host nation regulator would only be responsible for approving site-specific changes to the standardized design. This plan requires not only collaboration among national regulators, but also a permanent forum to facilitate and support the process: the IAEA should assume this role.

It is highly unlikely that the IAEA would be granted the authority and resources needed to certify SMR designs, though some developing countries might consider that a more credible stamp of approval than what we suggest above. Regardless of who certifies the design, in a business-as-usual world, vendors would be responsible for paying the cost of design certification, as they do now. The same would hold in a BOOR world, although granting the IAEA an expanded mandate under this regime implies that suppliers would have to obtain certification of good design and operational practice from the agency, for which they would pay an annual fee.

We believe that streamlining the certification and licensing process is as effective a course of action as can be achieved in today's multipolar world. It would enable developing nations, including those countries that do not have the capability to certify a nuclear reactor design, to exploit civilian nuclear power in a much safer way. The alternatives include business-as-usual at one end of the spectrum, which constitutes a high barrier to entry and confines nuclear power to existing nuclear energy states, and at the other end a fully internationalized regulatory regime, which is highly unlikely given current attitudes to national sovereignty.

As a second step, the development of a robust international crisis management infrastructure is essential if SMRs are to see wide deployment. Momentum for such evolution has been growing since the Fukushima-Daiichi nuclear accident, which demonstrated that even developed nations need international support to respond to accidents. The need is exacerbated by the fact that SMRs might be deployed in countries that are challenged by human capital, organizational, and physical resource constraints.

The IAEA, or leading nuclear supplier states, must establish a far more effective accident evaluation and response team. This team should include a multidisciplinary group of experts in emergency management, diplomacy, nuclear power, risk assessment, and risk communication. The team would be responsible for a diverse range of tasks, including advising and assisting in the preparation of nuclear plants that lie in the path of anticipated natural disasters, coordinating the international response to nuclear accidents, and communicating with the public in real time in the event of such accidents. The latter requires the development of instruments that communicate the level of risk and the appropriate course of action depending on the emergency faced: the IAEA's International Nuclear Event Scale is of little use in anything but a retrospective capacity.

The team would also need to maintain good relations with nuclear regulators and emergency managers throughout the world, which is why housing it within the IAEA, with its reach and influence, would be the preferred approach. And if it is not granted the power to requisition assets or deploy them from a purpose-built stock, it must dedicate staff to liaising with major powers' armed forces, with leading providers of humanitarian relief, and with shipment and logistics companies. In the case of a nuclear emergency, the humanitarian response that would need to be mobilized is significant enough to overwhelm existing humanitarian aid organizations, and to divert substantial resources from other crises. The development of such purpose-built, fully funded international response teams would go some way to preventing this.

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On the level of plant operators, it is imperative that the World Association of Nuclear Operators strives to achieve the level of information sharing, inspection technique development, and operator training that has been so successfully exhibited by the Institute of Nuclear Power Operations in the United States. The institute's efforts have shown that safety and reliability can come before issues of propriety: information-sharing works in the interest of all plant operators, and thus of the nuclear industry and the public at large.

On the level of individual contracts, these should be preceded by multilateral agreements among

SMR exporters, host nations, and the IAEA that explicitly address the need to create a level of emergency response capacity in the host nation commensurate with the level of risk created, through training in disaster risk management.

This proposed framework offers several benefits. It means that additional exports would require improved emergency response capacity, sustaining the relationship between exporter, host, and the IAEA. It would also facilitate both the standardizing of emergency response procedures and the updating of existing procedures as operational experience with SMRs increases. Moreover, the framework has the added advantage of working in both a business-as-usual world and a BOOR world. Finally, maintaining robust international and national emergency response measures would force the world to abandon the myth of absolute safety, and therefore complacency. As mentioned earlier, every nation wishing to purchase an SMR must accept some of the responsibility that comes with a nuclear power plant, and that includes developing a level of emergency response and crisis management infrastructure robust enough to cope with the effects of potential accidents, aided by the sort of international support that we have proposed.

Third, given the high liability amounts stipulated in existing conventions, the international community would be well advised to develop some form of shared international liability cap, specifically for SMRs, to address the smaller consequences of accidents involving these reactors and the enhanced level of safety they incorporate. It is worth noting, for example, that a reactor's decommissioning funding allowance in the United States is based on the size bracket in which it falls (there are two). Although such an international approach is wise, we consider it unlikely to be adopted. Alternatively, national nuclear industries can force such efforts into being as each lobbies its government to share liability for their products with customer nations. Obviously, such lobbying efforts would be more successful if SMRs become competitive, and significant demand can be demonstrated from overseas customers.

As for funding these efforts, it is worth exploring the development of shared regional liability caps, or "endowments" to be managed by bodies set up specifically for this purpose, with their assets dedicated to responding to regional nuclear accidents. Many nations share grid infrastructure with their neighbors; regions are becoming electrically more interconnected. For example, since the United Arab Emirates plans to feed power from its reactors into a Gulf Cooperation Council grid, perhaps those nations that benefit from nuclear power while hosting no plants should contribute to mitigating the consequences of a nuclear accident in their region. The same might be possible in the East African Community or the Economic Community of West African States, should Kenya or Nigeria build an SMR. The level of each country's contribution could reflect the share of the plant's power output that it consumes. Alternatively, ex-ante bilateral agreements with powerful neighbors, or with the exporting nation, could take some of the financial burden off of the host nation, preventing financial ruin in the case of an accident.

Roadmap for institutional change

Three common threads interweave these issues. First, each of the above challenges requires a well-resourced and resolute IAEA. The agency currently lacks the resources and trained personnel to provide the level of supervision and oversight needed to sustain a safe and secure build-out of large or small reactors on the scale required to decarbonize the global grid. Many of the changes we propose will require vendors, operators, or sovereigns to pay a one-time or annual fee, either to support licensing and certification efforts or to support training of local responders, as well as a rapidly deployable international emergency response capability. In cases where the IAEA shoulders the burden of facilitating or supporting these efforts, it should receive appropriate compensation.

Second, smaller nations cannot afford the liability caps that existing conventions prescribe. Moreover, they are interested in smaller, safer reactors. Recovery from an accident involving an SMR will, in all likelihood, entail fewer resources than recovery from large reactor accidents. Any credible institutional arrangement will require the establishment and maintenance of either international or regional SMR liability pools, or perhaps both. This requires careful assessment of the willingness to pay of both host and exporter nations, and of the amount of liability that the private industry (through insurers and re-insurers) is willing to assume. Because that depends on many factors, ranging from the level of risk posed by an SMR (this differs depending on design, certification, and deployment strategy) to location, we suggest changing the focus from ultimately arbitrary "liability caps" to building and carefully managing endowments.

We recommend the establishment of an

international SMR liability pool that must be paid into by host and exporter nations before an SMR is brought on-line. Deposits from intergovernmental and private entities would supplement these funds, as would annual deposits from SMR operators. The levels could differ depending on the risk posed by the SMR and deployment location and, if a region is organized enough to demand additional coverage, a similar regional endowment could be established to supplement the international one. Such collaboration is not unheard of. Sixteen Caribbean nations joined together in 2007 to form the Caribbean Catastrophe Risk Insurance Facility, which was developed and partially capitalized by the World Bank and the government of Japan. Other nations and organizations have also contributed to this trust fund, including Bermuda, Canada, the Caribbean Development Bank, the European Union, France, Ireland, and the United Kingdom. It is unclear if nuclear insurance policies would gain similar access to traditional and capital markets, and whether risk pooling would lower premiums to an extent that would justify the development of this facility, but it is an approach that should be explored.

Third, bilateral and multilateral initiatives are needed to improve regional and international collaboration, standardize procedures globally, and accelerate the development of infrastructure necessary to exploit nuclear power responsibly. It is easier to incorporate norms in overarching international conventions if a critical mass of countries already subscribes to them. SMRs perhaps represent the industry's best chance of achieving this standardization. Building large reactors in emerging nuclear energy states requires decadal or multi-decadal collaboration between exporter and host nation on many fronts, from the political to the financial to the technical. For many emerging nuclear energy states, these acquisitions would be a once-in-a-generation undertaking, if at all possible. As such, the standardization process has been extremely slow. Smaller reactors that prove to be economically attractive, less complex, and shippable worldwide could alter this paradigm.

We have avoided proposing revisions that would require overarching international treaties, simply because we do not see the political will that would be needed to develop a new, comprehensive, and multilateral regime for the 21st century. Perhaps only a shock, such as another major nuclear accident or a serious proliferation incident, can generate that political will. For example, if there is a serious enough diversion of nuclear materials by a state or non-state actor, this might catalyze the development of a global, comprehensive nuclear material control and accounting system. Advocates of such a system have outlined its necessity for decades. If our assessment is correct, it is a poor reflection on the state of national and global affairs that only a nuclear disaster could galvanize such action.

Although it is not yet clear what multilateralism in a multipolar world will look like, it will probably be messier than today. Bottom-up approaches to harmonizing global standards and enhancing the control regime, despite their messiness, might hold the greatest likelihood of success. And, since it is highly unlikely that the United States, Europe, or Japan will become major SMR exporters, these players need to use what soft power they have to help craft as strong a nuclear control regime for SMRs as is possible. This is especially true now that relations between major nuclear supplier states are becoming increasingly frayed, especially those between Japan and China, Korea and China, France and Russia, and the United States and Russia.

There is an urgent need to raise living standards across the developing world. If SMRs cannot be part of a portfolio of future energy technologies, it is difficult to see how this can be achieved without a massive increase in future emissions of carbon dioxide. While the suite of energy sources needed to mitigate global emissions does not need to be identical everywhere, it does need to consist of low-carbon sources. It is highly unlikely that all but the richest nations of the developing world will seek to build and run large nuclear power plants. But with a few far-sighted and uniformly positive changes to the institutions that govern the technology, small modular reactors could prove to be a valuable part of the mix in some countries.

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