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Developing legal and regulatory frameworks for small modular nuclear reactors

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The civil nuclear community is abuzz with discussions of "small modular nuclear reactors" (SMRs). *What are these reactors? What benefits do they have? Who is developing them? Can they really be deployed on barge, underground, on the seabed? By when? Are there potential impediments to the deployment of SMRs?*

Such fascinating conversations are taking place all over the world. While this article will consider some of the answers to these questions, the fundamental question posed here is: *What needs to be done on the legal and regulatory side to facilitate deployment of SMRs and, in particular, access to SMRs by newcomer nuclear countries?* Our answer is: *More. And, right now.* We say "right now" based on two factors – first, swift action is needed to enable fulfillment of reported commercial development timelines by potential SMR vendors. Second, the ability for nuclear energy to fulfill its potential as a contributor to the achievement of climate change mitigation goals could rest, at least partly, with the successful and timely deployment of SMRs.

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What are SMRs?

The IAEA states that small modular reactors, or "SMRs", are "newer generation reactors designed to generate electric power up to 300MW".[2] Common characteristics of SMRs include modularisation and advanced safety features.[3]

The report of the IAEA on *Advances in Small Modular Reactor Technology Developments* considers SMRs in the following categories:

– water cooled (pressurised and boiling water reactors) - land based;

– water cooled (pressurised and boiling water reactors) - marine based;

– high temperature gas cooled reactors;

– fast neutron spectrum (gas, sodium and lead bismuth cooled reactors);

– molten salt reactors; and

– other.[4]

SMR technologies differ widely in terms of power range, coolant, applications and intended deployment scenarios. Some SMR designs are "evolutionary", meaning they are designs which have been developed based on reactor designs in operation today, while others are considered "revolutionary" because they utilise new technologies. Some are intended for single-unit deployment, while others are designed as multi-unit facilities.

The heterogeneous nature of "SMRs" needs to be kept in mind when we consider regulatory frameworks and licensing approaches.

What are the potential benefits of SMRs?

While each SMR technology offers its own set of potential benefits, below we list some generalised potential benefits of SMRs:

– **Smaller size:** SMRs can be deployed in countries with small or weaker electricity grids or with smaller electricity needs, as well as by customers without grid connection. This may enable new markets and customers to consider nuclear energy as a generation option.

– **Simplified design:** Some SMRs utilise simplified designs and passive safety systems in comparison to large-scale units. Simplified designs may be less costly to manufacture and maintain and more straightforward to operate. Such designs include simplified power conversion systems, less extensive supply chains and a reduction in the number of sub-contractors needed in the construction phase.

– **Modularity and factory manufacture/ fabrication:** Some SMRs are modular, meaning self-contained units that are largely standardised and factory built. Modular units may be assembled in factories and transported to the site. The benefits of modularity and factory production should include minimised onsite construction, reduced capital costs and a reduction in the length of construction schedules and overall deployment timelines.

– **Multi-unit and incremental deployment:** Some SMRs can be deployed as a single unit or in twin or multi-unit plants. Multi-unit plants may be able to cumulatively provide the same megawatt output as a single large reactor. Individual units may by constructed incrementally over time, with the ability to match increases in electricity supply with electricity demand. The deployment of individual units in a phased fashion should reduce up-front capital commitments and allow phased financing.

– **Load-following:** Some SMRs are designed with the objective of providing simpler and more flexible load-following capabilities. The operational ranges of SMRs are wider than for large plants, with some SMR designs presenting high load-follow capabilities - 20% to 100% of daily power variation of nominal capacity. Load-following incorporates additional incentives for a sustainable/decarbonised power portfolio, such as nuclear plus renewables. In a scenario with considerable deployment of intermittent electricity sources, load-following would allow nuclear power to balance, adjust and stabilise overall power generation.

– **Safety:** Simpler designs of SMRs and passive safety features lead to a lower core damage frequency. Many designs utilise passive and inherent safety features. For example, some SMR designs allow for the reactor coolant to flow through the core by natural circulation and are not reliant on AC or DC power for safety. Deployment in a water pool and underground are envisaged for many designs, reducing the likelihood of an airborne radiation release.

– **Nuclear proliferation and security:** Below ground containment or even submersion on the seabed may aid in resistance to natural as well as human hazards and interventions. Operation without onsite refuelling, may also quell some security and proliferation concerns.

[2] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).

[3] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).

[4] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).

- **Economic:** SMRs should require smaller upfront capital costs in absolute terms, due to the size of individual units and, therefore, a smaller amount of committed finance should be required and put at risk. The ability to deploy units incrementally also means that units could be financed in phases. Revenues from the first unit could finance and/or secure finance for subsequent units. Economies of scale and n-th-of-a-kind project risk reduction could be achieved through deployment of multiple units (a "fleet approach"). Other economic benefits may derive from factory manufacture/fabrication and standardisation.
- **Operations:** Most SMRs are intended to have simplified and more automated operation and maintenance requirements and may utilise shared control rooms, all of which may result in a reduction to the number of human resources required during operation and maintenance, presenting the potential of lowering operational costs.
- **Applications:** In addition to electricity generation (including replacing old fossil-fired plants), SMRs may be suitable for co-generation, including process heat for industrial uses and district heating. Other applications may include sea water desalination, hydrogen production, refineries, mining installations and marine applications, such as icebreaking or shipping.
- **Siting:** SMRs may be suitable for deployment in remote locations, to which supply by other power sources is difficult, including off-grid locations. Such deployment may benefit remote communities, mining installations and military bases. Some SMRs are to operate on a barge and move to different locations, while others are intended to be anchored to the seabed, kilometres offshore, with electricity transmitted to land by underwater cable. Due to their smaller size, reduced land footprint and lower risk, emergency planning zones around SMRs may be permitted to be smaller compared to large reactors, potentially enabling the siting of SMRs closer to the demand centres for electricity or process heat.
- **Fuel supply:** Many designs come with pre-installed fuel and many SMR designs can operate for longer periods than large units before refueling. Some are capable of unit-by-unit outages for refueling and maintenance. Alternatively, for some SMRs onsite refuelling is not envisaged at all and the entire module may be returned to the factory for refuelling.
- **Decommissioning:** Some SMRs may allow for simplified site decommissioning, which is largely limited to disconnection and removal of the entire module from the site.

While renewable energy sources will undoubtedly continue to play an essential role in efforts to achieve global climate change mitigation goals, SMRs could contribute to reliable, cost-effective, decarbonised and sustainable power systems. Together, renewable and nuclear energy could facilitate the achievement of several Sustainable Development Goals, particularly the interrelated goals of Affordable and Clean Energy (Goal 7) and Climate Action (Goal 13).

Who is developing SMRs?

The IAEA states that there are currently approximately 50 innovative SMR concepts at different stages of research and development.[5] These concepts are currently being developed in established nuclear countries around the world.

In the Russian Federation, Russia's Rosenergoatom received an operating licence for its floating nuclear power plant, Akademik Lomonosov, in June 2019. The Akademik Lomonosov hosts two 35 MWe KLT40-S reactors and is expected to generate electricity from December 2019.

Two industrial demonstration SMRs are in an advanced stage of construction in:[6]

- Argentina: CAREM, an integral PWR; and
- People's Republic of China: HTR-PM, a high temperature gas cooled reactor.

The remainder of the SMR designs are in varying stages of design, development and licensing. See the IAEA's report, *Advances in Small Modular Reactor Technology Developments*, for further information on particular SMR concepts.[7]

[5] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).
[6] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).
[7] IAEA: Advances in Small Modular Reactor Technology Developments. 2018 Edition (Vienna: IAEA, 2018).

What are the potential impediments to deployment of SMRs?

Setting aside issues of policy, public acceptance and energy planning, one of the primary impediments to deployment of SMRs is the investment of the financial and human resources necessary to take a design from concept to commercialisation. This task is particularly challenging with so many SMR designs being conceptualised and the need to overcome significant regulatory barriers to market entry.

Indeed, prior to SMR deployment, customers must seek the approval of the host country's nuclear regulatory authority. Of course, this is the case for the conventional large reactor technologies, as well as SMRs. However, with many SMRs presenting regulators with novel approaches in design, safety systems and/or deployment scenarios, the licensing process, at least for first-of-a-kind projects, could be lengthy and costly, particularly where extensive modelling, testing and validation are necessary. Many vendors are having their designs reviewed in a "design licensing" process in their home country or a third country that has such a review process in their licensing framework. This design review process aims to demonstrate design validity and reduce the time and cost of subsequent licensing processes.

Historical and recent large reactor construction projects have continued to demonstrate that regulatory frameworks and licensing processes impact commercialisation costs, project schedules and project budgets. For SMRs, they have the potential to be particularly impactful where primary drivers of project economics are linked to standardised designs and multi-unit deployment.

In established nuclear countries, regulators must consider whether and, if so, how existing legal and regulatory frameworks applicable to large nuclear reactors need to be modified for SMR licensing. Newcomer nuclear countries contemplating SMRs face the multiple hurdles of developing an appropriate SMR legal and regulatory framework and undertaking the first in-country SMR licensing process through a nascent regulatory institution with limited human resource experience in these activities.

Framework nuclear laws should be just as comprehensive for SMRs as for large power reactors, and they should be implemented by independent nuclear regulatory bodies that have adequate financial and human resources. However, the structure of an SMR licensing process and some of the regulator requirements that will underpin it may warrant re-consideration, in particular, to realise projected SMR benefits, as well as to appropriately address some of the innovations presented by SMR designs.

Bearing in mind that SMRs are heterogeneous and so not all issues below will arise for each SMR, the legal and regulatory infrastructure for SMRs may need to be reconsidered in the context of the following:

- **Design certification:** For multi-module facilities, can design certification be undertaken for individual units as well as multi-module facilities?
- **Licensing process:** Is incremental licensing in stages (eg. site, design, construct, operate, decommission) or one-step licensing most appropriate for SMRs?
- **Licensing approach:** Are prescriptive or non-prescriptive (goal-setting, performance- based) licensing approaches best suited to SMR licensing?
- **Multi-module licensing:** For multi-module facilities, is a construction licence required for each individual unit or the multi-module facility? Or do we need a hybrid approach offering a "master" licence for the facility, with sub-licenses for each module?
- **Load following:** Can load-following be contemplated early and integrated into the licensing process so that further licences are unnecessary?
- **Off-site/foreign country manufacturing:** What are the regulatory implications of significant offsite manufacturing, fabrication and fueling/refueling? How will host country regulators ensure sufficient oversight of safety and quality management when such processes are performed in manufacturing and fabrication facilities in foreign countries? What is the role of the nuclear regulatory body where such manufacturing and fabrication facilities are located? Do the regulatory requirements of both countries apply? How should/could they intersect?
- **Export controls:** Do existing export control regimes contemplate, and are they suitable for, export of fully fabricated and fueled units to the host country? For SMRs that do not contemplate refueling, how would existing export control regimes treat the re-transfer of units containing spent nuclear fuel?
- **International transportation:** Do existing international transportation standards and requirements need to be re-considered for transportation of fully fabricated units, fully fueled units and units containing spent fuel? Do further intersections with existing maritime laws need to be considered?

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[8]For example, see the work of the Design Change Management Task Force of the World Nuclear Association's (WNA's) Cooperation in Reactor Design Evaluation and Licensing (CORDEL) Working Group. In particular, see publication *Aviation Licensing and Lifetime Management – What Can Nuclear Learn (January 2013).*

- **Deployment scenarios:** What safety, security and non-proliferation considerations arise for below grade reactor designs, for floating SMRs, SMRs anchored to the seabed and for SMRs in other remote locations? What emergency planning considerations arise from these diverse deployment scenarios?
- **Nuclear liability:** Are the principles of international and domestic regimes for third party liability for nuclear damage suited to SMRs or do we need to re-consider some principles, such as minimum liability limits and financial security requirements for individual/multi-unit plants?
- **Passive safety systems:** How can the challenges of licensing new passive safety systems be managed where it will be necessary for reactor modelling and use of a test facility to support the license application and, thereafter, testing during reactor commissioning to demonstrate that passive safety systems perform as required?
- **EPZs:** Can the size of emergency planning zones around SMRs be reduced to reflect their lower risk profiles and, if so, to what size? Consequently, can they be sited closer to population centres?
- **Control rooms:** Can multiple SMR units be operated from one central control room with an individual operator responsible for operating multiple units? Can regulators be assured that operating an SMR with such a staffing plan is safe in all conditions, including emergency situations, through detailed human factor studies, task analysis and scenario demonstrations?
- **Fees:** Should regulatory fees be assessed on a per-unit, per-facility or per-megawatt output basis?
- **Decommissioning:** Are decommissioning requirements, including funding schemes, suited to scenarios where modules are physically removed from the site, possibly without spent-fuel unloading? Are exiting laws, regulations and export controls permissive of the re-transfer of units and spent nuclear fuel to the country of origin? How will such take-back/dismantling arrangements be treated in the country of origin?

As can be seen from the non-exclusive list above, some regulatory issues raised by SMRs may be generic, meaning applicable to all SMR designs, while others may be design and/or deployment scenario-specific for which bespoke approaches may need to be developed.

The process of answering the above questions has commenced in some countries. It is possible that regulators around the world may approach and answer the above questions in different ways, potentially being influenced by historical national approaches to nuclear regulation and licensing. Clearly this would generate additional complexities to be navigated by SMR vendors and customers contemplating international deployment.

Changes to and the development of new laws and regulations require thorough review and analysis, with significant investment of time, expense and human resources. Where cross-border issues arise and multiple regulatory regimes are potentially relevant, the challenges are increased.

The ultimate question becomes: *Will we be able to efficiently resolve the legal and regulatory issues presented by SMRs so as to support SMR commercialisation and deployment on anticipated timelines, including in newcomer nuclear countries, while maintaining optimal levels of global nuclear safety, security and non-proliferation?*

What can be done?

We offer the following thoughts on possible actions and next steps:

- **National leadership:** We need continued leadership. Certain countries are actively and purposely leading licensing efforts. Hopefully these efforts will be continued and expanded, including through national collaboration.
- **International leadership:** We also need ongoing leadership in multinational forums that can facilitate information exchange. The IAEA is providing valuable assistance and facilitating avenues for knowledge sharing and transfer, including between experienced and newcomer countries. It is imperative that these efforts continue and expand in the area of SMRs and it is important that they do so in a way that merges technical, economic and legal competencies.
- **Harmonisation:** Harmonisation should be a common goal. Many SMRs rely on standardisation of designs and factory manufacture to achieve economic competitiveness. However, without harmonisation of regulatory frameworks and licensing processes in the vendors' and customers' countries, such standardisation may be difficult, if not impossible, to achieve.
- **"Regulatory export":** The export of SMRs may need to include the export of regulatory and licensing models and licensing experience. This is becoming an increasingly common request by newcomer customers to facilitate large reactor export and results in significant cooperation between host country and vendor country regulatory bodies. It would be beneficial to deepen and broaden this cooperation and information exchange in the context of SMRs. Of course, it must also be ensured that host country regulators are equipped to make independent licensing decisions.

– **Precedents:** When looking at regulatory and licensing models, newcomer countries should think about precedents from established countries, particularly those of the vendor's home country. Some countries utilise more prescriptive regulatory approaches than others. A less prescriptive approach or even a non-prescriptive (goal-setting, performance-based) approach may facilitate SMR licensing in some customers' countries. However, it could also be said that a relatively prescriptive approach or even a standardised "off the shelf" set of regulations adopted by the host country would result in an advantageously high level of regulatory certainty for a vendor and its customer and facilitate design standardisation. For newcomer nuclear countries, an "off-the-shelf" model may prove attractive and effective to facilitate SMR licensing. However, this approach would be best suited to a country where deployment of a single SMR technology is envisaged, because the down-side to the approach could be a lack of flexibility of application of such a regulatory regime to different SMR technologies.

– **Cooperation:** Maximum regulatory cooperation between the host country and a foreign regulator with SMR licensing experience should be encouraged. This can be achieved by way of formal cooperation agreements between regulators which encompass human resource development and capacity building, robust information exchange, personnel secondments and mobilisation of experienced foreign technical support organisations.

– **Design certification:** Some countries are said to be considering the acceptance of a design certification given by a regulator in an established nuclear country. In practice, this concept is not straightforward as where "design certification" exists in a country's licensing regime, the level of review undertaken and the legal status of the outcome of the process is different. For example, the US Nuclear Regulatory Commission's (**NRC**) standard design certification is final and binding and can be referenced in subsequent licensing actions before the NRC, while the outcome of the UK's Generic Design Assessment process, the Design Acceptance Confirmation, will be taken into account by the Office for Nuclear Regulation (**ONR**) in a subsequent licensing process and should reduce regulatory risk but it is not legally binding on the ONR. In principle, the concept of acceptance of a foreign design certification certainly warrants further consideration.

– **International licensing:** International licensing concepts have been proffered for the civil nuclear sector and analogies drawn to the aviation industry where international standardisation and harmonisation of design approval and change management procedures have been adopted. It may be that SMRs are a catalyst for further consideration of this concept at the international level.

Conclusion

Nuclear legal and regulatory regimes need to evolve to simultaneously maintain responsible nuclear and radiation safety regulation while facilitating advantageous technological innovation. In the context of SMRs, we have an immediate opportunity to embrace this challenge, recognising that SMRs offer a positive contribution to energy, sustainability and climate challenges worthy of the effort. Policy makers, legislators, regulators and industry will need to work together, drawing on conventional, experienced and innovative thinking if we are to see widespread access to and fulfilment of the promise of SMRs.

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