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PROLIFERATION RESISTANCE CONSIDERATIONS FOR REMOTE SMALL MODULAR REACTORS

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ABSTRACT – Remotely located Small Modular Reactors at the low end of energy production (on the order of 10 MWe, referenced here as Very Small Modular Reactors or VSMRs) present unique proliferation resistance advantages and challenges. Addressing these challenges in the most efficient manner may not only be desirable, but necessary, for development of this technology. Incorporation of safeguards considerations early in the design process (Safeguards by Design) along with safety, security, economics and other key drivers, is of importance. Operational Transparency may become an essential aspect of the safeguards approach for such systems.

1. Introduction

Small Modular Reactors (SMRs) are an enabling technology that supports all four pillars of the Government of Canada's four-tiered "Northern Strategy": sovereignty, environment, economic development, and self-governance.[1]

Increased proliferation resistance is a goal of advanced nuclear reactor design; for example, it is one of the technology goals of the Generation IV International Forum (GIF).[2] The ability of SMRs to meet these broad expectations of advanced reactor design is clearer in some cases than in others, and proliferation resistance is one case where either ambiguity exists due to the early stage of development, or a known gap exists that will require a technical solution.

For example, SMRs that incorporate a sealed core will present a high level of resistance to the threat of both technology misuse and material diversion. On the other hand, a sealed core is also resistant to monitoring and verification.

This paper provides a non-comprehensive assessment of proliferation-resistance issues facing SMRs, particularly as they relate to remote deployment in significant numbers throughout the Canadian arctic. The size of such units is expected to be on the order of 10 MWe (30 MWth), in accordance with typical heating and electricity supply needs of remote mining, military, and municipal operations. In this aspect Canadian deployment of SMRs in the arctic will differ from most other jurisdictions in the world (a notable exception being northern Russia[3]), where unit powers at least an order of magnitude greater make more sense. In this paper the SMRs in this smaller size range will be referred to as Very Small Modular Reactors (VSMRs).

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[1] "Canada's Northern Strategy: Our North, Our Heritage, Our Future", published under the authority of the Minister of Indian Affairs and Northern Development and Federal Interlocutor for Métis and Non-Status Indians, Ottawa, 2009, available at: www.northernstrategy.gc.ca.
[2] "A Technology Roadmap for Generation IV Nuclear Energy Systems", published by U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum, 2002, available at: www.gen-4.org/PDFs/GenIVRoadmap.pdf.
[3] A.P. SHADRIN, "On the prospects of mini nuclear power plants (MNPP) in the Far North of the Republic of Sakha (Yakutia)", Proceedings of the Joint Symposium on *Energy Links Between Russian and East Asia: Development Strategies for the XXI Century*, Asia-Pacific Economic Cooperation (APEC), Irkutsk, 2010.

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2. Proliferation resistance and IAEA safeguards

"Proliferation resistance" is "that characteristic of a Nuclear Energy System that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices."[4] Proliferation resistance has both *intrinsic* components, such as the attractiveness of the nuclear material for diversion or the amenability of its operation to undetected and undeclared uses, and *extrinsic* components, such as the amenability of its design to inspection and safeguards implementations.

The International Atomic Energy Agency (IAEA) in Vienna provides international verification of nuclear activities in a Host State, through the implementation of nuclear safeguards that include inspections to verify facility design and nuclear material inventory, and also instrumentation and other measures that provide "continuity of knowledge" between inspections. The IAEA safeguards system is viewed as a key instrument of non-proliferation, and cooperation between stakeholders can make implementation of this safeguards system more cost-effective and minimize its impacts on operations

3. Impact of VSMRs on proliferation resistance and the implementation of safeguards

VSMRs have the following characteristics that potentially impact the implementation of safeguards:

- *Low thermal signature*. Having a thermal footprint similar to other energy technologies deployed in remote northern locations implies that it will be challenging to use satellite or other forms of remote sensing to verify operation. However, indirect indicators such as "lights on" or the operation of powered equipment in the absence of alternative power sources may be useful.
- *Remote location with limited access*. Difficult access to the facility sites themselves provide a measure of proliferation resistance by increasing the cost and difficulty of diversion or covert misuse. On the other hand the difficult access also applies to safeguards inspectors, increasing the cost and reducing the potential for unannounced inspections. This could be mitigated by reliable year-around off-site monitoring of redundant authenticated sensors (see Section 4).
- *Number of reactor sites*. VSMRs lend themselves to distributed installation, implying that many sites could require inspection, all with the issues of difficult access and inspection described here.
- *Long-life reactor core, possibly sealed*. Reduced core access and reduced refuelling frequency makes misuse of operation and diversion of spent fuel (respectively), much more difficult. However, this will need to be reconciled with the current IAEA practice of annual physical inventory of each reactor core, performed when access to the core is possible.
- *Advanced fuel cycle*. In some cases the nature of the fuel cycle will be unfamiliar to the IAEA, and require significant analysis to understand the most efficient and effective safeguards approach. This presents an opportunity for safeguards experts to collaborate on the design.
- *Enrichment*. Reactors designed to minimize size (and thus transportation costs) and maximize time between refuelling will require significant levels of enrichment, typically encountered in research reactors (e.g. up to 20% LEU). Widespread popularity of such reactors would therefore increase the amount of enriched uranium on the planet, and might provide incentive for new enrichment facilities, which are "dual-use" technology. When designs require uranium enriched above 20%, the issue becomes even more politically challenging to address.
- *Excess reactivity*. A reactor designed for low refuelling frequency would require excess reactivity and burnable absorbers. Such a core might tolerate target irradiation without

[4] "Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems," Rev. 6, prepared by the Proliferation Resistance and Physical Protection (PR&PP) Evaluation Methodology Working Group of the Generation IV International Forum (GIF), 2011, available at: www.gen-4.org/Technology/horizontal/index.htm.

significantly affecting key operational parameters, and from an observer's viewpoint, neutronic management with burnable absorbers would look similar to neutronic management with target material. Verifying that there is no possibility of access for target insertion or removal could be a design requirement. Potentially, these concerns could be mitigated with a pre-operation design verification activity by the IAEA coupled with reliable sealing and surveillance measures.

- *Fuel element size*. Depending on design, core length could be significantly smaller than conventional designs, leading to shorter fuel elements with two opposing impacts on diversion difficulty: small size tends to render concealment easier, while increasing the number of elements that must be successfully diverted to achieve a significant quantity of material. Reduced refueling frequencies and sealed cores can mitigate some of these issues.
- *Spent fuel storage geometry*. Should spent fuel be stored at the site, smaller elements would most likely need to be stored vertically for cooling purposes, with a strong economic incentive to stack fuel and reduce the storage footprint. This geometry potentially challenges the current safeguards inspection activities due to lack of direct-line visibility from above. Adding IAEA safeguards requirements to the design requirements can potentially lead to an alternate optimal design.
- *Fissile inventory*. VSMR core loads, whether in sealed-core designs or otherwise, will be small compared to conventional power reactors, providing an additional barrier to diversion or misuse (tempered somewhat by the potentially significant quantity of sites, and therefore total inventory under similar conditions in one state).
- *Environmental considerations*: It is typically difficult to maintain reliability of communications and power supply at remote northern sites. Such infrastructure would necessarily need improvement in support of a distributed network of VSMRs, but the situation will continue to present a diversion pathway opportunity that depends on loss of IAEA instrumentation or time needed to affect repairs. Presumably the use of VSMRs would only be considered if reliability issues could be substantially mitigated.
- *Contingency planning:* Contingency planning can take into account the fact that natural hindrances would impact both adversary and normal operations in similar ways. Contingency planning has an opportunity to address the health & safety, security and safeguards issues as an interrelated set. Including safeguards (and other) considerations in the emergency response planning can avoid some of the issues and reduce the impact of others.

4. The importance of Safeguards by Design

"Safeguards by Design" is a concept which encourages the earliest possible inclusion of safeguards considerations in the design process of Nuclear Energy Systems, in order to achieve greater efficiency and effectiveness of the safeguards implementation.[5,6] Safeguards by Design was introduced by the IAEA as a way of achieving safeguards goals with limited resources, particularly in light of a possible expansion of the global nuclear industry in terms of both number and types of reactor installations.[7]

It is conceivable that Safeguards by Design will not just be desirable, but necessary, in the development of VSMR technology, given the considerations raised in the previous section. In other words, just as it becomes increasingly important to take into account security, environmental, economic, and social acceptance considerations into the design process, so does it become important to factor in proliferation

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[5] M. STEIN, M. MORICHI, L. VAN DEN DURPEL, T. KILLEEN, B. MORAN, "The role of industry in safeguards by design," Symposium on *International Safeguards – Preparing for Future Verification Challenges*, IAEA, 2010.

[6] T. ELLACOTT, J. CASTERTON, M. KENT, "Safeguards by design: The Canadian experience," Symposium on *International Safeguards – Preparing for Future Verification Challenges*, IAEA, 2010.

[7] "Considerations for Safeguards by Design", IAEA Nuclear Energy Series No. NG-T-3.3, IAEA, Vienna (in publication for 2013)

resistance. This doesn't just mean aspects that aid the application of safeguards themselves, but aspects that make the technology less attractive to proliferation interests.

For example, the safeguards implementation in remote VSMRs could take greater advantage of the operator's own data, a concept known as Operational Transparency.[8] With an authenticated data stream extracted from the operational systems, monitored remotely with trending and analysis software, the IAEA might directly monitor the operation of multiple sites, potentially circumventing many of the challenges listed above that are related to operational misuse. This is an area of current development.

5. Conclusion

Very Small Modular Reactors (VSMRs) offer a number of advantages to remote development such as in Canada's north, and proliferation resistance will need to be considered at an early stage of the design process (Safeguards by Design). Certain features of VSMRs offer potential advantages to safeguards implementation, while others present challenges that may not have been widely appreciated to date in the discussion of SMR implications. Consideration of security and safety needs in an integral approach along with safeguards (the "3S" approach), particularly in contingency planning, will lead to efficiencies. Operational Transparency allows high-level remote monitoring that presents a significant barrier to misuse scenarios, and can improve confidence in the authorized usage.

[8] J.J. WHITLOCK and D. TRASK, "Operational Transparency: An Advanced Safeguards Strategy for Future On-Load Refuelled Reactors,", Proceedings of the *International Conference on the Future of HWRs*, Ottawa, 2011.