Safeguards Instrumentation for Future Nuclear Fuel Cycles

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Abstract

In the frame of the Generation IV International Forum (GIF), the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), and, more recently, the Global Nuclear Energy Partnership (GNEP), experts discuss the future use of nuclear power by addressing a variety of areas, ranging from new nuclear reactor technologies to international fuel cycle models. Aside from economic and inherent safety issues, considerations on proliferation resistance have gained increased international attention and importance for the feasibility of nuclear fuel supply and fuel cycle services models. Proliferation resistance is ruled by both intrinsic and extrinsic factors. Intrinsic factors are related to the quantities and quality of nuclear materials used in any given nuclear facility and the ease with which both materials and technologies could be withdrawn from the installation. Extrinsic features stem from institutional barriers against diversion or misuse and relate mainly to the application of International Atomic Energy Agency (IAEA) safeguards. Looking forward towards future nuclear technologies, the question arises how these will impact the future safeguards culture and supporting instrumentation. The paper addresses this question and discuss some future aspects of safeguards by extrapolating and expanding on the evolution of safeguards from a material and technology based control system to an information driven approach. Furthermore, factors will be outlined that may impact not only the development and implementation of future safeguards instrumentation, but also the design of future nuclear reactors. Features of safeguards instrumentation may be ranging from remote interrogation capabilities to multipurpose, synergy-enabling functions, i.e., the consequences of an expected increase in a global nuclear market within a ‘nuclear renaissance’ on future safeguards instrumentation will be highlighted. Also, the need for early involvement of all concerned parties, especially treaty verification authorities, will be discussed. Considerations on how the non-proliferation community can best become prepared for the technological needs of the future will conclude the paper.

Keywords: proliferation resistance, safeguards, technologies, nuclear renaissance

Introduction

The high cost and limited availability of fossil fuel resources as well as climate change concerns have prompted government leaders world-wide to review their nuclear power generation programs or to investigate avenues to initiate such activities. Under the banner of a Nuclear Renaissance, industrial players support such tendencies by promoting the inherent security of modern fuel cycle facilities and nuclear reactors and by introducing new, advanced means of reducing both the amount and the danger of the generated nuclear waste.

At the same time, the international community along with non-proliferation authorities strives to guide the expanding use of nuclear energy within the spirit of Atoms for Peace and the Non-Proliferation Treaty (NPT) by enhancing the control and the safeguarding of sensitive technologies and materials. In this context, multi-national approaches including the Global Nuclear Energy Partnership (GNEP) as well as fourth generation, proliferation resistant nuclear reactors under GIF and INPRO have been much discussed in recent years.

Neither the establishment of new, multi-national fuel cycle models nor the design, development, and construction of new reactors is a short-term endeavor; the international community is planning for what is to come in two decades and beyond. This horizon naturally poses a broad range of challenges, especially when addressing the question of how it will impact non-proliferation policy and the verification of safeguards commitments compliance, but it also offers some opportunities worth exploring.

The NPT verification authority, the International Atomic Energy Agency (IAEA), has the mission to verify the correctness and completeness of signatory states' declarations about their peaceful nuclear programs. To this end, IAEA inspection personnel has access to declared facilities to check, applying the most effective and efficient combination of all safeguards measures. One such measure that supports inspectors is safeguards instrumentation that is either installed operating in unattended mode at nuclear facilities or is carried into the field for attended operation. Under the Additional Protocol, IAEA inspectors' access rights include searching for undeclared nuclear facilities and activities.

Looking ahead towards the implementation of new fuel cycle models and the accompanying increased safeguards responsibilities, the future cousins of today's instrumentation are likely to play an increasingly important role. This is an area where some appealing opportunities can be realized if the opposing challenges can be successfully addressed. The following paper will first investigate some of the factors that will impact the development of future non-proliferation policy to show the multi-dimensional nature of the related challenges. It will then explore what features need to be designed into instrumentation to support meeting such challenges. Some questions and concerns on the future instrumentation development path will be raised next. Recommendations, as far as it is possible at this early stage, as to how the international community can best approach the development task will conclude the paper.

Factors Potentially Impacting Safeguards

The term Nuclear Renaissance implies a significant increase in the use of nuclear power world-wide, and indeed more and more countries have identified atomic energy to be a viable addition to or expansion of their electricity portfolio to counter increased prices of fossil fuels and climate change concerns. Further, the globally progressing industrialization increases the need for baseline electricity production capacities. This future expansion of nuclear activities will likely lead to the globalization of the nuclear energy market which will also affect international non-proliferation policy.

One push is to concentrate sensitive nuclear technologies such as enrichment and reprocessing by introducing multi-national fuel cycle approaches (MNAs) where a few supplier countries offer nuclear services to recipient countries. Their success will depend heavily on how much assurance of supply of nuclear fuel to recipient countries such models can credibly guarantee; otherwise, the incentive to develop national fuel production capabilities will remain. The implementation of MNAs leads to safeguards being applied in nuclear weapons states (NWS) if they are a supplier country as they take on fuel cycle services for a NNWS that is under full scope safeguards obligations. Such a shift might support a different movement towards the implementation of comprehensive safeguards as a universal standard for all NPT signatory states, including NWS.

The implementation of safeguards is not a static approach, but rather of a very dynamic nature with the flexibility to adapt to changes within the non-proliferation regime and treaty compliance verification efforts. One such currently ongoing transition is driven by the implementation of the Additional Protocol and Integrated Safeguards. In the practical sense, this means that the safeguards system is shifting from a quantifiable declaration-and-verification regime to a more information-driven, qualitative approach with extended access rights on the part of the IAEA (Complementary Access (CA)). In the effort to verify both the correctness and the completeness of a NPT signatory state's declarations, traditional safeguards measures are re-evaluated and complemented by other information sources to detect undeclared materials and activities in addition to diversion and misuse of declared ones.

This is a significant shift in the safeguards culture that is likely to continue throughout the next two decades and will apply the state-level approach where countries are evaluated as a whole, allowing for the concentration of inspection resources in a more focused manner. As such policies develop, they have to be flexible enough to adapt to changes in regional political structures, as well. For example, as national barriers disappear within the European Union, Integrated Safeguards and the state-level approach have to be modified accordingly. How this will evolve over time is very difficult to judge as it depends not only on the political development of the EU as an entity, but on its future expansion, as well.

Lastly, the development of new nuclear technology will impact safeguards and non-proliferation policy, as well. Fourth generation nuclear reactors strive to offer higher Safeguardability and inherent proliferation resistance and such advantages will certainly impact the safeguards regime that controls such installations. But nuclear developments are not restricted to such technologies that facilitate easier implementation of safeguards; as new technologies become available for sensitive activities such as separation and enrichment (e.g., laser technologies), non-proliferation policy and safeguards have to be adapted to cover all technologies and materials of concern.

Policy decisions always have an impact on how safeguards are implemented influencing the decisions about the set of tools that supports them. When looking at the possible developments in safeguards policy, it is worthwhile to investigate what features safeguards instrumentation should have and how it can best facilitate the actual implementation of efficient and effective safeguards.

Future Safeguards Instrumentation

The implementation of the Additional Protocol charges the IAEA with the detection of undeclared nuclear materials and activities. Foremost stands the expanded use of information technology based resources such as open source information analysis and satellite imagery. Furthermore, this has also a direct impact on the instrumentation that safeguards inspectors deploy during their inspection visits, especially sampling and in-field analysis tools.

For traditional safeguards, instrumentation is designed for applications such as verification of declared material including isotopic compositions, monitoring of specific operational activities (e.g., open core operations), and keeping materials and access points under seal. During Additional Protocol, or Complementary Access inspections, the nature of instrumentation that is required is fundamentally different. The inspector has limited or no knowledge about what to expect; therefore, the instrumentation required to support him/her must be portable and much more versatile than installed monitoring systems or even the portable traditional systems that are designed to verify declared materials.

Furthermore, the location where measurements are made or samples are taken during Complementary Access inspections is of critical importance for later analysis and cross-matching with other information sources such as satellite imagery, wide area monitoring, or open sources. This implies the need for better data management and location tagging capabilities, if possible. Installed, unattended instrumentation will undergo changes as well, as new technological approaches become available and the shift towards an information driven, qualitative assessment allows for the drawing of state-level conclusions about the absence of undeclared nuclear materials and activities in addition to the correctness and completeness of declarations.

The development of advanced and fourth generation reactor models has interesting consequences for safeguards instrumentation, as well. The implementation of safeguards measures during the design of such installations can alleviate the impact of treaty verification efforts on the operation of a nuclear installation today. To mitigate the need to pull cabling, retrofit the facility to provide the infrastructure for instrumentation, easier implement remote monitoring, and reduce on-site inspection time are all factors that will be appreciated by the operator.

In domestic safeguards systems, instrumentation does not necessarily have to operate for safeguards purposes only. There is a broad range of possible synergies, especially when the application of equipment is evaluated prior to the completion of the design of a facility. Surveillance cameras, for example, produce image data that IAEA inspectors use to draw conclusions about the correctness of declared and the absence of undeclared activities. Such image data are of interest to other concerns at a nuclear installation. First of all, it could be used to support physical protection measures as it might give an indication on insider or collusion threats. Next, it could strengthen personnel safety measures if image data analysis capabilities that can detect smoke or indication for other hazardous situations are added. Also, image data can provide a management tool if the operator can use image data to see if personnel are properly trained, rules are obeyed, and procedures (e.g., two-person rule) are followed.

In international safeguards there are concerns that the IAEA cannot share its data with the operator. However, new instrumentation could have the capability to generate different datasets specifically for each interested party that only contain the data necessary for their specific purpose. Such data would have to be independently authenticated to ensure their integrity. But if such requirements can be fulfilled, the same instrumentation could be utilized by multiple parties for various purposes.

With the shift of safeguards towards Integrated Safeguards and state-level conclusions, the question arises as to whether or not there will be a need for surveillance in future safeguards applications. Such discussions are mainly driven by the resources needed to operate a surveillance infrastructure not only for the equipment, but also for the image data analysis, field maintenance and support, and the frequency with which their data need to be extracted and reviewed. If multiple parties shared the benefits of surveillance, however, it could advance to be a feature implemented easily during the design with its cost shared among the users, thus becoming a true Safeguardability benefit.

Also, other instrumentation can be envisioned for synergies with new safeguards approaches. New measurement techniques that might have the potential to replace swipe sample taking and allow for immediate analysis could be added to the safeguards portfolio. Following the shift towards information-driven safeguards, such technologies can be envisioned in a portable form, as well. As an example, laser spectroscopy measurement techniques can be deployed to immediately detect and analyze the presence and enrichment of U-235 in a given UF6 sample. Such a technology could be used in portable applications to detect undeclared enrichment programs at undeclared sites or enrichment higher than declared at declared facilities. But it could also be employed in a fixed installation for continuous, on-line measurement.

If the measurement accuracy of such an approach is comparable or better than the currently used mass spectrometry, safeguards authorities will not be the only parties interested in it. Facility operators will have a similar if not larger interest in using the same technology for their quality assurance and cost-effectiveness qualities. Again, synergies between multiple users can be realized, the implementation facilitated during the design of the instrumentation, and the cost shared among the beneficiaries; thus truly offering Safeguardability attributes.

Overall, if instrumentation can support a multi customer approach and can be implemented early in the design of nuclear facilities, it can enhance safeguards as well as the State System of Accounting and Control of the host country. It also offers the opportunity to conduct safeguards related process monitoring in closer cooperation with the operator of a facility, thus realizing development and operational synergies.

Future Instrumentation Development Paths

When looking at the potential developments that might impact both safeguards and non-proliferation policy and the development of instrumentation, one should also ask the question whether the existing infrastructure to support research, development, and manufacture is appropriate for the emerging challenges. Currently, safeguards instrumentation is produced for a niche market with high reliability and tamper indicating requirements that have little applicability for other markets. If the usage of instrumentation is expanded towards more joint use and multi customer approaches, the market might expand accordingly.

The IAEA's support structure in place today outsources the development and production of safeguards instrumentation, often sponsored by Member States Support Programs (MSSPs) with IAEA experts developing the user requirements and overseeing project progress. If multi-customer scenarios with larger equipment quantities installed but also multiple party inputs to the user requirements emerge, this infrastructure might have to change accordingly. The question is whether more development effort should be spent by the IAEA itself as opposed to the external outsourcing approach that is used today. Should the IAEA conduct research and development in accordance with both internal and external requirements input and then identify suitable partners for commercialization? A different approach might be to shift more development responsibilities to the nuclear plant operator as the primary owner of the instrumentation while ensuring that IAEA requirements are 100% implemented. Either scenario would certainly affect the way the IAEA works with MSSPs.

Moving from a quantitative to a qualitative safeguards approach will also enhance the importance of identifying new technological developments and existing fields of technical solutions towards safeguards. Through its Novel Technology program the IAEA already identifies new and creative ideas to address new and existing challenges, and this area will see a further increase in activity as new, cooperative approaches emerge. A development path that involves a network of partners, those that provide new solutions and those experienced in safeguards to implement them into instrumentation and solutions ready for fielding, will be needed. Here, the IAEA has a strong foundation of research and development institutions and private industry to build upon.

Conclusions

The changing safeguards culture and the shift towards information-driven safeguards is a complicated concept that bears both challenges and opportunities. Synergetic instrumentation installed in future nuclear fuel cycle facilities that support both the operator and safeguards authorities can be envisioned to realize such opportunities while addressing the challenges. But its benefits need to be carefully balanced against implementation difficulty and cost; only if a benefit exists for both sides, treaty compliance verification authorities and operators, the implementation will be possible. If joint use, data sharing, and synergies can be realized while all security and data integrity concerns are addressed, the instrumentation will be a valuable addition for all parties involved.

Decisions on how to best proceed towards the new safeguards regime cannot be made by safeguards authorities alone. Rather, the early involvement of all participants to jointly decide on a course of action will promise the greatest chances of a rewarding result. This also needs to be a continuous process. As quantitative elements decline and qualitative elements increase, careful discussion of all stakeholders is needed to adapt existing agreements to changes in the non-proliferation regime and to the availability of new technologies. Also, what might be identified as an approach with high synergies between operators and safeguards for new nuclear reactors might not be applicable for existing facilities if cost and effort of retrofitting exceed the advantages of new instrumentation.

In support of new, proliferation-resistant fuel cycles and multi-national approaches, the goal should be to set a new standard for future nuclear safeguards while carefully measuring the interdependencies with other critical factors such as physical protection, environmental concerns, personnel safety, quality assurance, and economic sustainability. Only a balanced approach with input from all stakeholders can facilitate a swift and synergetic implementation.