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Investigating 3S Synergies to Support Infrastructure Development and Risk-Informed Methodologies for 3S by Design

M. Suzuki, Y. Izumi, T. Kimoto, Y. Naoi, T. Inoue, B. Hoffheins
Nuclear Nonproliferation Science and Technology Center, Japan Atomic Energy Agency
2-4 Shirane, Shirakata, Tokai-mura, Naka-gun 319-1195 Japan

suzuki.mitsutoshi@jaea.go.jp

Abstract

In 2008, Japan and other G8 countries pledged to support the Safeguards, Safety, and Security (3S) Initiative to raise awareness of 3S worldwide and to assist countries in setting up nuclear energy infrastructures that are essential cornerstones of a successful nuclear energy program. The goals of the 3S initiative are to ensure that countries already using nuclear energy or those planning to use nuclear energy are supported by strong national programs in safety, security, and safeguards not only for reliability and viability of the programs, but also to prove to the international audience that the programs are purely peaceful and that nuclear material is properly handled, accounted for, and protected. In support of this initiative, Japan Atomic Energy Agency (JAEA) has been conducting detailed analyses of the R&D programs and cultures of each of the "S" areas to identify overlaps where synergism and efficiencies might be realized, to determine where there are gaps in the development of a mature 3S culture, and to coordinate efforts with other Japanese and international organizations.

As an initial outcome of this study, incoming JAEA employees are being introduced to 3S as part of their induction training and the idea of a President's Award program is being evaluated. Furthermore, some overlaps in 3S missions might be exploited to share facility instrumentation as with Joint-Use-Equipment (JUE), in which cameras and radiation detectors, are shared by the State and IAEA. Lessons learned in these activities can be applied to developing more efficient and effective 3S infrastructures for incorporating into Safeguards by Design methodologies. They will also be useful in supporting human resources and technology development projects associated with Japan's planned nuclear security center for Asia, which was announced during the 2010 Nuclear Security Summit.

In this presentation, a risk-informed approach regarding integration of 3S will be introduced. An initial examination of incident probability and postulated consequence analyses, which are tools familiar to the nuclear safety culture, will be applied to predict and evaluate inherent uncertainties of proliferation and security risks. A performance-based evaluation methodology will be presented for pursuing an effective and efficient implementation of 3S.

1. Introduction

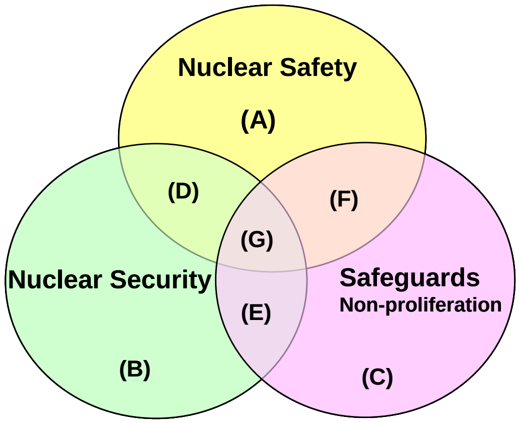
As a result of greenhouse warming and increased energy demand, a global trend to introduce nuclear power into both developed and emerging countries has been growing and with that increasing concern from the international society about the consequent impact on the non-proliferation regime. Introducing non-proliferation mechanisms in an efficient and effective manner will require not only a balance between peaceful use of nuclear energy and nuclear non-proliferation, but also inter-cooperation between safety, safeguards, and security (3S) practices and implementation. Fostering a 3S understanding and culture will be important for establishing a stable foundation from which to successfully implement and sustain nuclear energy programs and maintain public acceptance of them.

The 3S initiative launched at the Hokkaido Toyako summit of 2008 by G8 countries focused on three (safety, security, and safeguards) of the nineteen infrastructure elements of the Milestones in the Development of a National Infrastructure for Nuclear Power by IAEA [1]. The initiative was partly driven by the fact that although multilateral legal frameworks have already been established in individual "S" regimes, the emerging nuclear countries are struggling with lack of national legal and technical expertise and shortages in available international resources that help to establish these essential domestic elements.

2. Initial outcome of 3S study

2.1. Gap analysis of 3S

Based on a survey of present 3S activities nationally and internationally, the authors have analyzed the interrelationships of each "S" and investigated synergistic effects. Focusing on a difference between implementation measures of each "S", synergy and conflict are investigated and are shown in a Venn diagram of 3S, Fig. 1. As an example, confinement, containment, and protection of nuclear materials are equally important for 3S, therefore Joint-Use-Equipment (JUE), such as remote monitoring cameras might be shared. Passive and inherent mechanisms, such as double-entry doors, could satisfy both security and safety objectives, and sharing nuclear facility process data systems could enhance the efficiency of safeguards and safety. On the other hand, emergency response requirements in facilities, such as multiple access and escape pathways, could pose potential conflicts between safety and security.



(A) Emergency core cooling system for nuclear power plant, (B) Barrier at the facility entrance, (C) Authenticated apparatus

(D) Double-entry doors to keep negative pressure and prevent radioactive release
(E) Management of nuclear material using containment and surveillance and remote monitoring camera
(F) Management of nuclear material for criticality and accounting control

(G) Possible monitoring camera for multipurpose use, such as joint use of equipment

Fig. 1. A Venn diagram of sets of 3S

We identified three issues that challenge promotion of the 3S initiative. Firstly, we must allay the concern of emerging nuclear countries that implementing 3S does not constitute additional obligations for the existing regulatory framework. An inclusion of security and safeguards in conjunction with safety is important for overcoming growing security threats and increasing proliferation risks. An effective and efficient introduction of 3S measures is indispensable for those countries. Secondly, each individual "S" has a different history and development process. For example, the nuclear safety culture is advanced and well established, but this is not the case for security and safeguards. Nevertheless, the 9/11 terrorist attacks in the United States and the recent behaviour of specific countries, which has fuelled growth in proliferation concerns, justify development and implementation of countermeasures against the security and safeguards threats. Security and safeguards lessons-learned and experienced from these events are valuable for incorporation into updated procedures and practices. Finally, it should be noted that coordination between each "S" is lacking because they developed independently in response to historical events and because they are often regulated by different institutions. Communication between 3S organizations and cultures is deficient and there are few, if any, technical experts who are competent to bridge all three areas..

Maturity levels and modalities of the individual S areas are also different. Nuclear safety-related accident information is shared by all countries and safety culture concepts of "safety first" and "defence in depth" are well established. In contrast, incident information for nuclear security events is generally not shared because of the inherent need for secrecy. Security culture has been defined by multinational discussions at the IAEA and the IAEA, along with assistance from related organizations, such as World Institute for Nuclear Security (WINS), should disseminate the principle concepts and encourage the development of a security culture in the relevant institutions of every country. Moreover, although the Comprehensive

Safeguards Agreement (CSA) and Additional Protocol (AP) are arranged for the safeguards area, many countries have not ratified the AP and a safeguards culture is not as uniformly established everywhere.

To propel the 3S initiative forward, Japan Atomic Energy Agency (JAEA) has proposed a 3S promotion plan, which includes infrastructure development of security and safeguards, development of a 3S culture, and a design approach for the enhancement of 3S.

2.2. Infrastructure development

At the Nuclear Security Summit in April, 2010, the former prime minister Hatoyama announced Japan's contributions for strengthening the capacity-building and human resource development necessary for ensuring nuclear security. The major commitment is that Japan will this year establish a regional centre for strengthening nuclear security, tentatively named the "Integrated Comprehensive Support Centre for Nuclear Non-Proliferation and Nuclear Security for Asia" with the aim of institutionalizing support for nuclear security on a permanent basis and contributing to strengthened nuclear security in Asia and other regions. This initiative is led by JAEA, which is actively establishing the scope and operation of the centre with support from other domestic organizations and international collaborations. The centre will be located in Tokai-mura, Ibaraki. The framework for the centre is shown in Fig. 2.

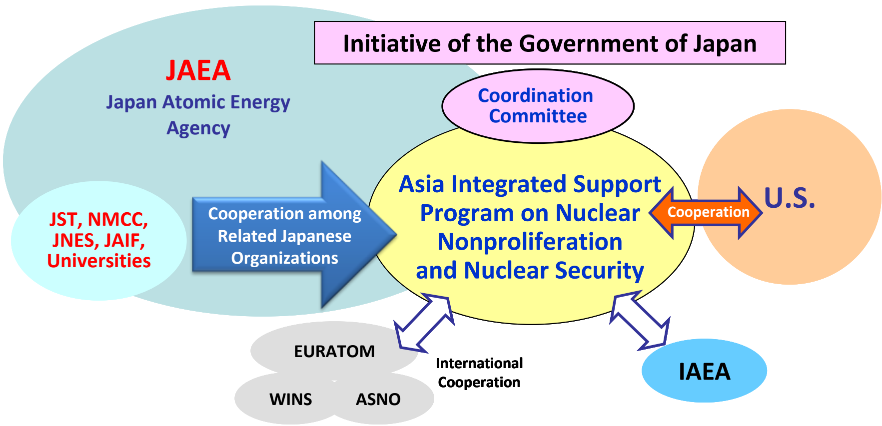


Fig. 2. JAEA's Role on Asia Integrated Support Program

JAEA has been conducting a yearly State System of Accounting for and Control of nuclear materials (SSAC) training course under the framework of the Japanese Support Program for Agency Safeguards (JASPAS). In the last fifteen years, the total number of trainees from Asian, Asia-Pacific and former Soviet Union countries reached about 200. The precedent program began with the South Asia countries of Vietnam, Thailand, and Indonesia. After surveying research on nuclear non-proliferation, JAEA held several expert meetings in these countries, and, in close communication with working-level staff members, investigated needs and priorities. Based on the JAEA's broad R&D activities in the nuclear energy field as well as the long compliance with IAEA safeguards, various efforts to establish regulatory frameworks and capacity building in those countries have been carried out. Building on this experience, Japan's new Asia support centre will provide training courses on nuclear security, and safeguards using mock-up nuclear facilities and classroom lectures. The centre will also provide assistance for infrastructure development on these issues for emerging nuclear countries. JAEA has been hastening to arrange an initial structure of the centre, which will be operational by this year.

2.3. Non-proliferation culture

After the Chernobyl accident in 1986, the IAEA developed the safety culture [2] and similarly the security culture [3]. As shown in Fig. 3, the human factor greatly contributes to human error in safety, as well as to all nuclear security events, which can be traced to unintentional personal errors as well as deliberate malicious acts. It is incumbent on leadership and management to resolve issues related to complaints about inadequate organizational procedures and management failure. In a similar manner, the necessity of a non-proliferation culture is justified by the potential for deliberate behaviour on the part of a state or by individuals, which could result in diversion and misuse of nuclear material. While institutions and their employees should be forced to comply with the laws, regulations, rules, and so on, human behaviour cannot be completely controlled. In nuclear facilities, even a small number of malicious and intentional acts could induce irretrievable consequences and tremendous casualties. Therefore, establishing strong cultural norms, strict codes of behaviour and enforceable penalties are important for deterring intentional acts by organizations or individuals.

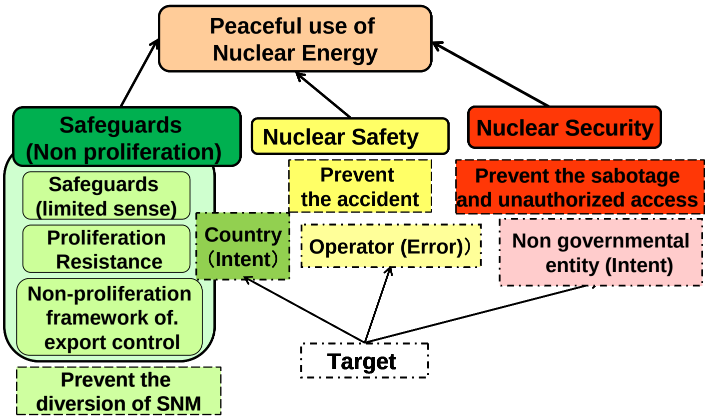


Fig. 3. Non-proliferation culture to enlighten mental modality

At JAEA, the President's Award and Recognition System (PARS) has been newly established to propagate non-proliferation consciousness across the JAEA worker population. The aims of the PARS include raising the level of personal accountability and fostering an enhanced understanding of non-proliferation through new employee training, increased teaming and cross-fertilization across all "S" areas. Until now, the individual "S" experts came from different parts of the organization and there were few occasions in the past for teaming or other forms of coordination. Although attempts to share knowledge and experience between different units inside the organization might encounter bureaucratic difficulties, we are nevertheless encouraged to utilize the PARS to facilitate and improve internal communication and cooperation.

3. Risk-informed approach for 3S synergy

3.1. 3S by design

One of the most promising synergies resulting from the integrated 3S consideration is the adoption of a 3S by Design (3SBD) approach for new nuclear facilities. An incorporation of 3S synergism into the conceptual design and system development phase increases regulatory effectiveness as well as operational efficiency, and also reduces expensive and time-consuming retrofitting. This benefit of the concept of 3SBD was recently pointed out [4], and the Safeguards by Design (SBD) approach has been discussed extensively. Primarily, one must take into account the difference between the global governances in 3S. International safeguards has been implemented by the IAEA and the IAEA has clear responsibility for verifying a State's compliance with the NPT treaties and agreements, while its role in safety and security is limited to regulatory standardization for the State's authorities and advisory recommendation. This means that there is no one authority for governing safety and security worldwide. Therefore, in order to achieve the 3SBD synergy, the first challenge would be to achieve international consensus among the IAEA and Member States for the realization of the SBD approach, which is still being discussed and shaped [5].

Institutionalizing 3S will require, among other technical and institutional issues, harmonization of the risk-notions embedded in each of the "S" areas. In safety, probabilistic assessment methodologies have been developed by the long historical trials and discussions. The classical approach is to estimate the frequency of accidents from the historical data and analyze the accident sequence with event trees and fault trees based on these procedures. Because of the recent concerns about nuclear security, a similar probabilistic assessment has been extended for use in developing guidelines for protection of nuclear power plants against sabotage [6]. Although conventional vulnerability assessment in physical security is well developed on a deterministic and prescriptive basis, the inherent difficulty in determining the frequency of terrorist attack by malicious acts is undertaken by the conservative estimate in which the initial probability is assumed to be unity as in the case of a postulated accident in safety. On the other hand, safeguards effectiveness is defined in proliferation resistance (PR) evaluation as an extrinsic barrier, and diversion pathway analysis is used to investigate proliferation risk of the nuclear cycle. Initial efforts for harmonization between reliability and safety, and PR and physical protection (PP) are initiated under the Generation IV (GEN IV) international framework [7]. Likewise, integrated measures and methodologies could be developed to evaluate an optimized balance between the 3S requirements and performance objectives, as shown in Fig. 4.

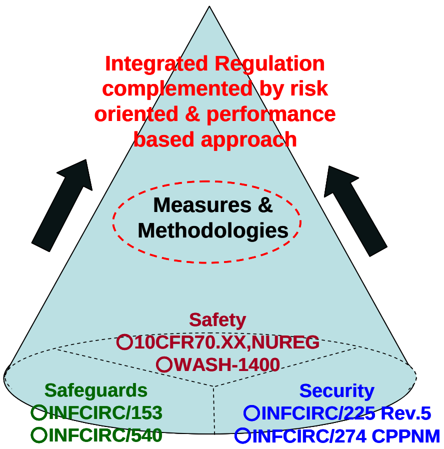


Fig. 4. Integrated regulation by risk informed & performance-based approach

3.2. Assessment methodologies

A major difficulty encountered in applying probabilistic methods to safeguards is determining the initiation of diversion and misuse. In safeguards, the diversion of nuclear material and misuse of technology are induced by the motivation of states and intentional acts of facility operators, therefore extrapolating from historical incidences and predicting intentional human acts is generally very difficult. In comparison with security, after assuming that the most upstream initiation event is deterministic, like the postulated accident in safety, the event sequence is analyzed probabilistically on a basis of the plant layout, system design and structural robustness. Candidate tools for proliferation assessment were broadly surveyed [8]. Well-known international PR methodologies include the checklist approach developed in the IAEA-led Innovative Nuclear Reactors and Fuel Cycles (INPRO) program, and a qualitative and quantitative risk-informed methodology was developed in the GEN IV's Proliferation Resistance and Physical Protection Working Group (PR&PP WG) [9]. To assess 3S risks, several mathematical tools were mapped according to incident frequency and governing laws, Fig. 5.

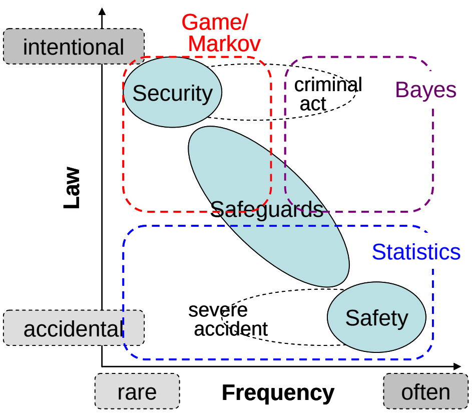


Fig. 5. Mathematical model and assessment methodologies for 3S

Note that the Markov model, developed by the PR&PP WG, has shown good performance for evaluating PR of an entire nuclear fuel cycle, but is not adequate for comparing implementation procedures defined by conventional safeguards criteria. In addition to the incidence probability, there is another uncertainty related to proliferation risk compared with risks for safety and security. Metrics are used by safeguards to improve the chances of detecting the diversion of sufficient nuclear material for making a nuclear bomb. These are the significant quantities and timeliness goals that underline the basis for Nuclear Material Accounting (NMA). Based on inductive and deterministic logic, NMA is managed within this limit as a first principle in safeguards. The IAEA has classified threshold values for nuclear material losses for each type of facility and process. However, as the amount of nuclear material increases for some large-scale facilities, measurement error becomes large, and because it is important to control the mass measurement within the absolute threshold of NMA, a probability distribution of the measurement error of NMA has to be considered in conjunction with the incidence frequency. This two-dimensional distribution of both incidence and measurement error probabilities is a unique feature of safeguards for assessing the proliferation risk as shown in Fig. 6. Recently, other risk-informed approaches have been studied including one for achieving high reliability safeguards for remotely-handled nuclear materials [10], and a JAEA study, which has pursued the sophisticated methodology for the two-dimensional probability distribution, has been explored.

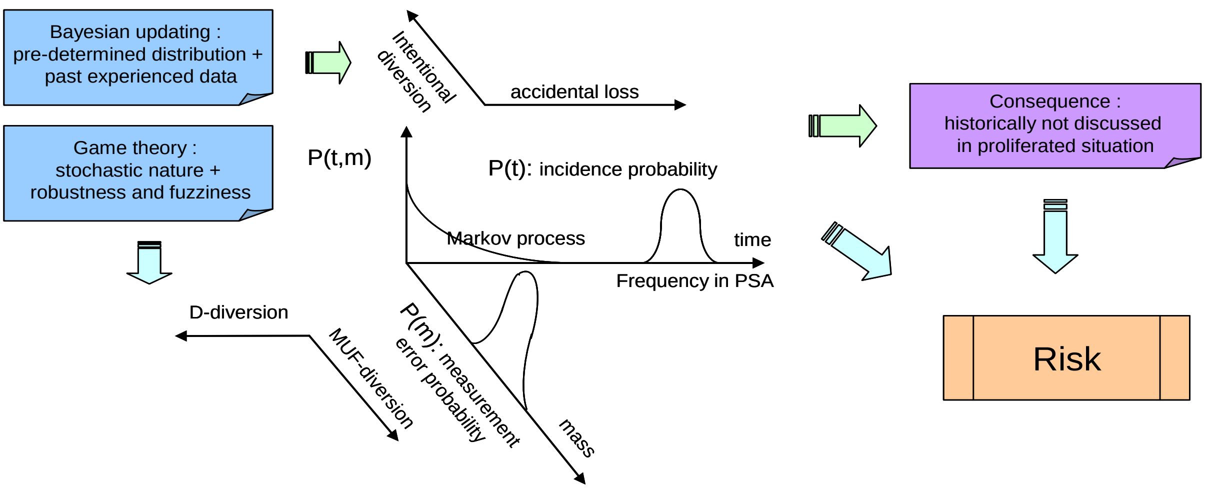


Fig. 6. Uniqueness of risk assessment applied to safeguards

3.3. Advanced process monitoring

Quantification of process monitoring (PM) has been investigated to demonstrate its possible use not only as a supplementary measure but also a substitution for traditional safeguards measures, such as nuclear material accounting (NMA), trend analysis, containment and surveillance (C/S), and so on. Multivariate statistical analysis is a powerful tool for monitoring a large number of process signals coming from an entire plant and for detecting abnormalities in plant operations. On the contrary to the theoretically derived criteria based on the unrealistic diversion and misuse assumption, a powerful computer simulation can be used to construct a prior probability distribution derived from possible scenario repetition. Furthermore, the historical data is utilized to determine a false alarm rule and generate a notion of a safeguards envelope beyond which the plant is operating abnormally.

Simulation and modelling based on proliferation pathway analysis and sensor response is compared to self-authenticated process monitoring data. The Markov Monte Carlo simulation using a random generator serves to investigate a sequence of an incidence. The probability distribution can be calculated without an unrealistic assumption. For the sake of substituting Near Real Time Accounting (NRTA) with PM for the abrupt diversion, the quantified PM signals are used to form the safeguards envelope in a real time basis. As shown in Fig. 7, the multivariate analysis applied to the PM signals and the broader dynamic range with real time assessment can resolve a risk-informed safeguards assessment with the data-driven alarm rule.

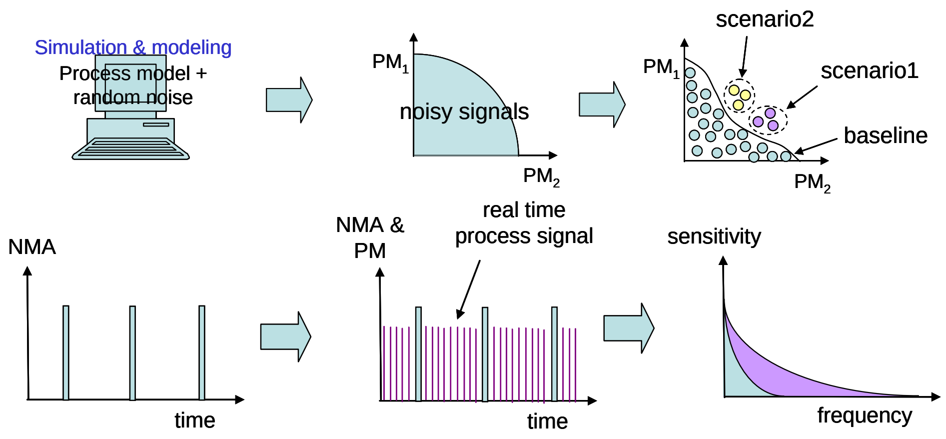


Fig. 7. Benefit of advanced PM

Although the risk-informed safeguards assessment is a promising approach to pursue a performance-based and resource-saving implementation of the IAEA safeguards, it has still remained in its infancy and an international discussion seems to be far from real. However, cooperating with the advanced PM application explored by the Next Generation Safeguards Initiative (NGSI) by the US Department of Energy (DOE), a more rational and risk-based assessment harmonized with other “S”, safety and security, could be explored for future more complex nuclear fuel cycle systems. A comparative study of these methodologies with IAEA safeguards criteria will be useful in planning safeguards for the Japan’s Fast Reactor Cycle Technology project as well as supporting more effective and efficient future IAEA safeguards elsewhere.

4. Conclusions

The following points are present as concluding remarks and summary of the initial outcomes of the 3S initiative by JAEA.

- Based on Japan’s lessons-learned and long experience in 3S, JAEA has been carrying out various efforts to support emerging nuclear countries in establishing the required infrastructure and human resources to assure transparency and confidence in the use of nuclear power in those countries.
- In conjunction with the IAEA, JAEA has developed a fully-matured experience in organizing and conducting SSAC training courses in several Asian countries and will build on this experience with the formation of its Asia support centre to extend the scope of assistance to the nuclear security and other nonproliferation activities.
- A domestic implementation of the international 3S initiative, endorsed by Japan and other G8 countries, is JAEA’s PARS program, which was established to encourage and reward cross-training and coordination across all of its safeguards, security, and safety organizations in order to create momentum toward a more completely informed nonproliferation culture.
- In a 3SBD approach based on fruitful synergies, it is imperative to incorporate the risk-informed requirements for each “S” area in order to pursue a more efficient and effective regulatory framework. JAEA has analyzed the underlying concepts and methodologies for each of the “S” areas and performed a preliminary assessment of how to approach an increased harmonization of the three “S” areas and proposed a number of interesting studies to advance the state-of-the-art in safeguards system design.
- Increased harmonization and integration of “S” infrastructure, culture and risk-informed methodologies through domestic and international cooperation and collaborations will be challenging, but the efforts promise large effectiveness and efficiency benefits for the safe, secure, and peaceful operation of existing and future nuclear fuel cycle systems.

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