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THIRD INTERNATIONAL MEETING ON NEXT GENERATION SAFEGUARDS (NGS3): SYNOPSIS OF THE SAFEGUARDS-BY-DESIGN REACTOR WORKING GROUP CONCLUSIONS

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ABSTRACT

The Third International Meeting on Next Generation Safeguards (NGS3) was held in Washington, DC on 14-15 December 2010 and focused on the Safeguards by Design (SBD) concept. The IAEA has described the Safeguards by Design (SBD) concept as an approach in which "international safeguards are fully integrated into the design process of a new nuclear facility from the initial planning through design, construction, operation, and decommissioning." The United States Department of Energy has initiated a project by way of its Next Generation Safeguards Initiative (NGSI) to establish a global norm for the use of SBD. The NGSI SBD program is being developed in parallel with a similar effort at the IAEA, while taking into account the IAEA's SBD achievements and future plans. The NGSI program is pursuing the establishment of a SBD global norm through DOE laboratory studies, international workshops, engagement with industry and the IAEA, and setting an example by way of its use in new nuclear facilities in the United States. This paper will report on the discussion topics and present details of the final recommendations of the NGS3 Reactor Working Group. This working group had representation from industry, government, and former IAEA inspectors from around the world. The working group discussed how to make reactor design more amenable to both domestic and international safeguards requirements. Among the key issues the group concluded that the IAEA and nuclear industry should consider an improved means for identifying and tracking nuclear fuel from manufacture to disposal, new facility designs need to take into consideration the space, utility, and other requirement for installing IAEA seals, surveillance systems, servers, and conduit for on-site storage of and possible remote transmission of safeguards data, the need to verify and track MOX fresh fuel and CANDU spent fuel in unattended mode and the IAEA should define these specific requirements and make them available to the broader international safeguards community and nuclear industry through publications and especially through joint forums that share the latest developments in safeguards technology and approaches with nuclear facility operators and facility designers.

INTRODUCTION

The *Third International Meeting on Next Generation Safeguards*, hosted by DOE/NNSA's Office of Nonproliferation and International Security (NIS) on December 14–15, 2010 at the Washington Hilton Hotel in Washington, D.C., was a two-day technical meeting to discuss implementation of the Safeguards by Design (SBD) concept. There were approximately 100 meeting participants from 13 countries, comprised of safeguards policy and technical experts from government and industry. Representatives also were present from the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), the European Atomic Energy Agency (Euratom), and the International Atomic Energy Agency (IAEA).

The primary objective of this meeting was to exchange views and provide recommendations on implementation of the SBD concept for four specific nuclear fuel cycle facility types: gas centrifuge enrichment plants, Generation III (Gen III) and Generation IV (Gen IV) reactors, aqueous reprocessing plants, and mixed oxide (MOX) fuel fabrication facilities. The general and facility-specific SBD documents, generated from the four working groups and circulated for comment among working group participants, are intended to provide a substantive contribution to the IAEA's efforts to publish SBD guidance for these specific types of nuclear facilities in the near future. This paper describes the Reactor Working Group and its efforts in SBD for Gen III and Gen IV reactors.

This effort was an extension of DOE/NNSA's Next Generation Safeguards Initiative (NGSI) program to study and identify SBD best practices and lessons learned, to engage industry on facilities planned in the United States, and to coordinate with the IAEA on the development of practical guidance documents for the application of SBD. A fundamental objective of this meeting was to advocate the need for SBD and to help the IAEA promote and institutionalize the concept of SBD as a tool for increasing the effectiveness and efficiency of international safeguards. Central to this effort is the argument that consideration of safeguards early in the facility design process can reduce the safeguards burden for both the operator and the IAEA.

BACKGROUND ON THE SAFEGUARDS BY DESIGN CONCEPT

The IAEA describes SBD as a concept in which facility designers and operators consider broad international safeguards requirements and features "from initial planning through design, construction, operation, and decommissioning." The objectives of SBD are to make the implementation of IAEA safeguards more effective and efficient and to help operators minimize costly and time-consuming redesigns and retrofits. The achievement of these goals could save States, industry, and the IAEA time, money, and effort – a mutually beneficial endeavor.

Often in the past, nuclear facility designers have added safeguards features to their plants following design completion or even after construction. Under the SBD concept, States, industry, and the IAEA would discuss safeguards requirements early in the design phase. Early coordination and planning could influence decisions on key design features, such as chemical processing, equipment design, material storage and handling arrangements, and facility layout, in a manner that facilitates the effective and efficient implementation of safeguards. Thus, SBD has the potential to have a significant impact on the nonproliferation field by promoting intrinsic facility features that enable enhanced safeguards and thereby reduce the safeguards cost to the operator and the IAEA.

To address this long-term issue, the IAEA, DOE/NNSA, and other stakeholders recently have begun promoting the concept of Safeguards by Design. In October 2008, the IAEA hosted an international workshop to discuss how safeguards implementation could be improved through facility design and operations. One important recommendation from the meeting, published in "Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA

Safeguards" (STR 360)[1], was that the IAEA should continue engaging all stakeholders in the SBD process and create expert working groups on, *inter alia*, SBD principles based on facility type. The IAEA, with assistance from the European Commission Support Programme, currently is developing a document that will lay out the fundamental design features and measures that facilitate the implementation of international safeguards. The IAEA also has discussed plans to prepare facility-specific guidance based on Member State experience and expertise.

To complement these efforts, DOE/NNSA commissioned a U.S. National Laboratory team in 2008 to study the implementation of Safeguards by Design in support of NGSI efforts to strengthen international safeguards worldwide. These studies focus on best practices and lessons learned from former IAEA inspectors and include draft guidance documents for designers of different types of nuclear facilities. The studies aim at further assisting the IAEA in defining overall objectives and developing practical guidance for the application of Safeguards by Design.

According to the IAEA Power Reactor Information System database there are 444 nuclear power plants units in operation worldwide, as of May 2011.[2] Additionally, there are 64 nuclear power plant units under construction. Roughly half of these are in Non-Nuclear-Weapons States and will be subject to IAEA safeguards and routine inspection. This underscores the importance of implementing SBD in the design and construction of these new facilities. Not only are safeguards experts noting the importance of safeguards in the design of new reactors but a report by the American Academy of Arts & Science (AAAS) entitled *Nuclear Reactors: Generation to Generation*[3] presented six key reactor attributes:

1. Cost effectiveness
2. Safety
3. Security and nonproliferation
4. Grid appropriateness
5. Commercialization roadmap
6. The fuel cycle – front end and back end

Safeguards are a key piece of the third attribute and also of the sixth attribute. Fuel cycle developments in the front and back ends of the fuel cycle will also need to encompass SBD because of the sensitive technologies with proliferation potential inherent in uranium enrichment and plutonium recycling. Hence, we see SBD as a key piece of future development of the fuel cycle and new reactors.

With nonproliferation concerns such as espoused by AAAS above in mind, safeguards equipment experts at AREVA/Canberra and the IAEA have put forward the idea of integrating Safety, Safeguards, and Security features into the facility design at an early stage, a process that they have termed "3S."[4] What matters most about both of these ideas is the similarity of the vision. A more effective integration of the nuclear safety, safeguards, and security elements should occur in the design of nuclear facilities and that this integration process should address the requirements of the domestic nuclear regulatory and the IAEA, and that this should occur at a very early stage in the design process. According to Atomic Energy of Canada Limited (AECL), U.S. DOE/NNSA, and others, the expected benefits of implementing Safeguards-by-Design are that it will:[5]

- **Enhance nuclear safeguards,** by reducing the risk of the diversion of nuclear material and spread of nuclear weapons through enhanced detection; as the number and variety of nuclear facilities increases worldwide.
- **Reduce the cost to the IAEA** of implementing nuclear safeguards, while also increasing safeguards effectiveness.
- **Minimize construction project risk**; i.e. potential cost overruns and start-up delays that might otherwise result as a consequence of designing and implementing safeguards measures after the facility is fully constructed.

Another important expected benefit from implementing Safeguards-by-Design is that it will ensure **that the safeguards measures do not interfere with planned operation of the facility**.[6]

With a goal to get more interactions of government, international inspectorates, laboratories, and nuclear operators and designers, the U.S. DOE National Nuclear Security Administration (NNSA) Office of NA-24, in support of the NNSA Next Generation Safeguards Initiative (NGSI) funded and promoted the NGS3 workshop with the key objective of increasing the effectiveness and efficiency of international nuclear safeguards.[7]

FUNDAMENTAL POINTS OF DISCUSSION

As is typical of technical workshops on nuclear safeguards, the discussion ranged from first principles and IAEA safeguards objectives to current and future reactor designs and specific issues regarding the implementation of IAEA Safeguards measures. To help focus the discussion, Paul Pan of Los Alamos National Laboratory presented work commissioned by NNSA on SBD as envisioned for LWRs, specifically for Gen III reactors.[8] The presentation also included insights from the Finnish experience in building the Olikiluoto 3 LWR and the need for SBD.[9] From the presentation, the working group focused on SBD for Gen III LWRs and framed them and subsequent discussion about Gen III and Gen IV reactors in light of the following key points:

1. The IAEA has a leadership role in promoting Safeguards-by-Design
2. Gen III and III+ reactor and plant designs are relatively mature
3. How applicable are the IAEA safeguards requirements in Nuclear-Weapons States (NWS)

The Reactor Working Group participants came from diverse backgrounds, which included: national and international governmental officials, representatives from the IAEA, former IAEA inspectors, nuclear safeguards consultants, nuclear safeguards specialists and scientists from U.S. National Laboratories, and representatives from the international commercial nuclear industry. Consequently, they held differing views on how best to implement Safeguards-by-Design for new nuclear power plants. The Reactor Working Group participants engaged in considerable discussion on how to effectively and efficiently implement Safeguards-by-Design in current (Gen III and III+) and future generations of nuclear reactors and power plants (Gen IV). Table 1 below lists the participants in the Reactor Working Group.

Table 1: Reactor Working Group Participants

Charles Hess (The Shaw Group)
Orpet Peixoto (Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials)
Ana Claudia Raffo-Caiado (U.S. DOE Oak Ridge National Laboratory)
Nu Hoai Vi Nguyen (Vietnam Agency for Radiation and Nuclear Safety)
Bo-Young Han (Korea Atomic Energy Research Institute)
Edward Wonder (QinetiQ North America)
Michael Zentner (U.S. DOE Pacific Northwest National Laboratory)
William McTigue (URS, Washington Division)
Hyun-Chul Kim (Korea Institute of Nuclear Non-Proliferation and Control)
Eleanor Dixon (U.S. DOE/NNSA Office of NA-22)
Robert Sanders (Enercon)
Hirofumi Tomikawa (Japan Atomic Energy Agency, Washington Office)
Sean Dunlop (U.S. DOE/NNSA Office of NA-24)
Craig Everton (Australia Safeguards and Non-Proliferation Office)
Thomas Ellacott (Canadian Nuclear Safety Commission)
Paul Pan (U.S. DOE Los Alamos National Laboratory)
Philip Casey Durst (Durst Nuclear Engineering/Consultant for U.S. DOE Idaho National Laboratory)
Brian Boyer (U.S. DOE Los Alamos National Laboratory)
Kory Budlong-Sylvester (U.S. DOE Los Alamos National Laboratory)

However, the participants recognized and acknowledged that the IAEA must lead this effort by articulating the relevant safeguards requirements and providing guidance through the State Regulator/State System of Accounting and Control (SSAC) to the commercial nuclear industry in how best to implement these requirements. This workshop intended to help the IAEA formulate this guidance to the commercial nuclear industry by providing feedback from the designers and operators of the plants as well as SSACs. Many participants emphasized that the IAEA should make the proposed recommendations and conclusions for SBD a mandatory requirement rather than a preferred option for reactor construction, design and operation. Otherwise, the working group felt that this input will be viewed merely as ideas and suggestions and no serious modifications by reactor designers would result. The working group felt that the IAEA needs to make a business case for showing gains for the designers and operators for having modifications to enable SBD.

Since the Gen III and Gen III+ reactor and plant designs are relatively mature, the following two key trains of thought emerged. First, industry representatives indicated that there is not a great deal of latitude for accommodating design changes in the current reactor designs. However, the designs of the Small Modular Reactors (SMRs), High Temperature Gas Reactors (HTGRs), and Gen IV reactors in general are still evolving. Consequently, there is an opportunity to incorporate and standardize safeguards features in these designs. Second and related to this point, former IAEA inspectors noted that the current safeguards approach for most nuclear power plants depends on proven containment and surveillance systems (e.g., seals and digital surveillance camera systems), and nuclear material accounting measures, which have been implemented by the IAEA at over 200 nuclear power plants worldwide for decades. Most working group participants do not expect the established safeguards measures to be a challenge to implement in the Gen III and Gen III+ reactor designs because of any concerns of safety impacts, intrusiveness of the measures, and cost to the facility.

Having this forum in the United States with industry representatives familiar mostly with U.S. domestic requirements for safety, security and safeguards, discussion resulted on the applicability of IAEA safeguards requirements in Nuclear Weapons States (NWS) such as the U.S. The industry representatives wanted to understand what the business case would be for putting in features in reactors for use in NWS that on the surface would find to be superfluous. Other participants noted that even in the case of NWS, the IAEA still has the right, under the Voluntary Offer Safeguards Agreements (VOA), to inspect nuclear facilities selected from the country's Eligible Facility List (EFL), which generally includes most civil nuclear facilities in the country. Some working group members made note that if the reactor designs incorporate IAEA safeguards requirements in NWS deployment, it could facilitate the export of these reactors to Non Nuclear-Weapons States with mandatory IAEA safeguards for commercial facilities.

It should be noted that one of the key features that were of interest to the participants was how to handle material accountancy during transfers. This was of special concern for movements of spent fuel or fresh MOX fuels and the design of Interim Spent Fuel Storage Installations (ISFSIs), typically dry storage facility on the nuclear power plant site, but outside of the spent fuel pond. The designers, as represented by Charles Hess of the Shaw Group, expressed the view that safeguarding of ISFSIs needs to be considered with safeguarding the reactor in a holistic safeguards approach for the site. If the IAEA has safeguards requirements for ISFSIs, industry will need to know them. Thirdly, designers do not "consider" safeguards measures. These measures are either part of the basis for the design, or they are not. Hess believed that the Reactor Working Group should recommend a mechanism or process for updating and implementing the latest safeguards requirements for operating nuclear power plants, and those undergoing the construction and operating licensing process. With the reactor accident at Fukushima Daiichi in April 2011, there will probably be a push to have more spent fuel moved outside of spent fuel pools and stored in dry storage at ISFSIs for safety and security factors. Building in SBD to enable efficient and effective verification of the transfer of spent fuel from ponds to casks and verification of the casks and the possible reverification of material within the casks should be emphasized.

RECOMMENDATIONS

In summarizing the recommendations from the Reactor Working Group for this workshop, it is useful to restate the objective as noted in the agenda that set the tone for NGS3. The agenda stated that the objective was "to compile a collection of design-related suggestions and recommendations for practical application of Safeguards-by-Design in reactor facilities, focusing on Gen III/III+ designs and generic reactor features applicable to Gen IV reactors."

In General, the NGS3 Reactor Working Group recommends that:

1. Nuclear facility designers need the collective domestic safeguards, international safeguards, security, and physical protection requirements early in the design stage. It is inefficient for the designer to address these issues as separate design requirements involving separate stake-holders. (The IAEA is currently updating the Nuclear Safety and Security Series of documents, which provides guidance to industry in these areas. The IAEA should consider folding the safeguards requirements into this guidance document, or issuing a comparable document to present safeguards requirements to the nuclear industry in the same manner.)
2. Nuclear facility designers provide for the space, utility, and other requirements for installing IAEA seals, surveillance systems, fuel flow monitors, and conduit for the possible remote transmission of safeguards data.
3. The IAEA update these specific requirements and make them available to the broader international safeguards community and nuclear industry, through the State Regulator/SSAC.
4. The IAEA and international safeguards partners (including IAEA Member State Government Agencies, National Laboratories, State Regulator/SSACs, and commercial equipment suppliers) establish an annual joint forum for sharing the latest developments in safeguards technology and equipment with nuclear facility operators and facility designers. This would enable nuclear facility operators and designers to become aware of promising technology and equipment that could address challenging safeguards issues more efficiently. This could function for the operators in the safeguards realm as World Association of Nuclear Operators (WANO) functions in the safety realm. WANO's mission[10] is stated to be "to maximise the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices." Hence, the forum described above could set a similar mission for safeguards best practices in industry. Even for NWS this forum could be useful as it could assist the NWS in standardizing and improving material control and accounting measures in reactors.
5. International safeguards partners support the IAEA by preparing a business case that shows the clear advantages to the commercial nuclear industry of implementing Safeguards-by-Design by showing that the cost of incorporating safeguards measures in the design stage is cheaper and less disruptive than implementing safeguards measures and features after the plant begins construction or operation.

For Nuclear Reactors in particular, the NGS3 Reactor Working Group recommends that:

1. The IAEA make greater use of the nuclear power plant operator's instruments for the purpose of nuclear safeguards, particularly for monitoring reactor power output and verifying the ID of fuel assemblies. The plant operator's refueling machines can automatically track the ID of a specific fuel assembly as the plant moves fresh fuel from fresh fuel storage to the core, and as the plant removes spent fuel to its final resting

position in the spent fuel storage pond. This information would enhance the continuity of knowledge of the fresh, core, and spent fuel without revealing any sensitive information about the plant. Similarly, plant instruments used to monitor the combined power production and output of the reactor could be used to verify the total reactor thermal power production and operating periods, as declared by the plant operator. In such cases, the IAEA would need a means to independently verify the data from the plant instruments in question or means to authenticate the data stream.

2. The IAEA and nuclear industry improve the identification and tracking of nuclear fuel assemblies from cradle to grave. The IAEA currently identifies fuel assemblies at LWRs by visually verifying the engraved serial number, which is typically only part of the complete number. Verification of the assembly number becomes difficult when the assembly is highly irradiated and heavily oxidized. There has been talk of some form of tagging the fuel elements with a nonintrusive and unique marker that could be imbedded at the fuel fabrication facility and travel with the fuel until final disposal in a repository or reprocessing.
3. Designers of nuclear power plants design the spent fuel storage ponds, transfer canals, and spent fuel transfer systems so that spent fuel transfers can be easily monitored by the IAEA. Design issues include providing a clear line-of-sight for IAEA surveillance cameras to cover the pond and transfer canal, minimizing the number of baskets, containers, or casks for transferring spent fuel, and designing the transfer of spent fuel to casks for monitoring by IAEA surveillance systems up to and including remote monitoring and verification of the spent fuel in the transfer process.
4. The verification of spent fuel transfers from the spent fuel pond to interim spent fuel storage facilities is made more efficient. Facility designers and the IAEA need to optimally address this issue, which will become more important as more spent nuclear fuel is transferred to interim storage, instead of long-term storage in geologic repositories. Issues that need to be addressed include optimally verifying the spent fuel transfers, maintaining the continuity of knowledge on the spent fuel in interim storage, and re-verifying the spent fuel if the continuity of knowledge is lost. So called "smart" spent fuel storage facilities may maintain the continuity of knowledge of stored spent fuel more effectively and are worth testing and consideration.
5. Nuclear power plant designers incorporate a dedicated area in the spent fuel pond to permit verification and/or re-verification of spent fuel, apart from the main spent fuel storage racks. The IAEA has difficulty verifying long-cooled or low burnup fuel by Cerenkov glow when the fuel is among brighter spent fuel assemblies. Also, more precise non-destructive assay (NDA) for detecting the potential removal of spent fuel pins can require a location away from the main body of stored spent fuel.[11, 12] Lastly, the plant operator's proposed spent fuel storage and movement procedures need to be discussed in advance with the IAEA to determine if the continuity of knowledge of the spent fuel can be maintained during nominal operations.
6. The IAEA make the safeguards requirements for Interim Spent Fuel Storage Installations (ISFSIs) known to the nuclear industry, through the State Regulator/SSAC possibly through the annual forum on safeguards practices described above.

7. With the use of MOX fuel planned for Gen III/III+ reactors, the IAEA and partners in safeguards and operations should develop an unattended system to verify the receipt and unloading of fresh MOX fuel into fresh fuel storage, to reduce increasing IAEA on-site verification efforts inherent with safeguarding MOX fuel.
8. The IAEA moves to use more advanced C/S measures with unattended and remote verification features to maintain the continuity of knowledge of fresh MOX fuel in storage at the reactor. This would reduce the increasing field inspection effort by the IAEA for the verification of MOX fuel at LWRs. The introduction of MOX fuel for fueling light water reactors has resulted in a greater inspection effort by the IAEA, because of more stringent IAEA verification requirements for MOX fuel and proliferation concerns with the use of MOX fuels.
9. The IAEA should reconsider the definition of an "item" in special cases involving verified spent nuclear fuel. A verified basket of spent CANDU fuel could be considered an item, as opposed to the individual spent CANDU fuel bundle. Similarly, a container of spent fuel in an interim spent fuel storage facility, which has been verified and monitored by the IAEA prior to welding and encapsulation, could be viewed as an item. Reconsideration of these points would permit more efficient use of IAEA resources, especially in the case of re-verification.
10. The IAEA and State Regulator/SSAC should evaluate and consider promoting the use of the most current burnup codes for calculating and declaring the nuclear material and fissile content of spent nuclear fuel, and should inform plant owners and operators which codes are recommended. Obsolete and improvised spent fuel burnup codes are still being used in some cases. This leads to an increased shipper/receiver difference (SRD) when the spent fuel is sent from the reactor to a reprocessing plant with the nuclear material declared based on a potentially obsolete burnup code.

CONCLUSION

The Third International Meeting on Next Generation Safeguards NGS3 Reactor Working Group formulated recommendations on how to make reactor design more amenable to both domestic and international safeguards requirements. NGS3 was notable in that is brought in not just U.S. and other government's safeguards experts, the IAEA, and U.S. laboratory experts but industry experts in design and operation who could communicate the needs of plant operators for safe and economic operation and vendors for streamlined, safe, and economic construction and installation of nuclear power plants. This diverse group of experts concluded that for nuclear power plants of the Gen III/III+ and Gen IV designs the IAEA and nuclear industry should consider an improved means for identifying and tracking nuclear fuel from manufacture to disposal and need to take into consideration the space, utility, and other requirements for installing IAEA seals, surveillance systems, servers, and the conduit for on-site storage of and possible remote transmission of safeguards data in these new facility designs. The working group also focused on the need to verify and track MOX fresh fuel and CANDU spent fuel in unattended mode to better use both operator and inspector resources. One of the main desires from industry was that the IAEA should define specific requirements compiled from meetings such as NGS3 and other safeguards working groups and make them available to the broader international safeguards community and nuclear industry through publications and especially through joint forums that share the latest developments in safeguards technology and approaches with nuclear facility operators and facility designers. The designers especially desired this guidance with respect to integrating safeguards into ISFSIs which are being built to store spent fuel that can no longer be stored in spent fuel ponds in reactors and because of safety and security concerns will be place in dry storage casks.

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