Building Future Safeguards Capabilities
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Editorial Note

I. Abbreviations

ABACC	Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials
APSN	Asia Pacific Safeguards Network
CTBTO	Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
EC	European Commission
ECFA	Egyptian Council for Foreign Affairs
ESARDA	European Safeguards Research and Development Association
EU	European Union
IAEA	International Atomic Energy Agency
DDGO	Office of Deputy Director General
SGAS	Safeguards Analytical Services
SGCP	Safeguards Concepts and Planning
SGIM	Safeguards Information Management
SGIS	Safeguards Information and Communication Systems
SGOA	Safeguards Operations ‘A’
SGOB	Safeguards Operations ‘B’
SGOC	Safeguards Operations ‘C’
SGTS	Safeguards Technical Support
SGIV	Office for Verification in Iran
INMM	Institute of Nuclear Materials Management
JRC	Joint Research Centre
MSSP	Member State Support Programmes
OPCW	Organisation for the Prohibition of ChemicalWeapons
TechSec	Technical Secretary
UNODC	United Nations Office on Drugs and Crime
UNSSS	UN Security and Safety Service
VCDNP	Vienna Center for Disarmament and Non-Proliferation
VERTIC	Verification Research, Training and Information Centre
WIN	Women in Nuclear
WINS	World Institute for Nuclear Security

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[CHA-S1] Keeping Pace with IT Security

Quantum Computers and Preparing Future-Proof Encryption

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After making computer chips with the smallest possible transistors, researchers and technologists are pursuing new technologies including qubits - the beginnings of practical quantum computers. This paper addresses the advantages that quantum computers have over today's classical computing; how internet and email security would be impacted; and how we could start securing our systems and servers with post-quantum encryption (PQE). An overview is provided of expected developments in the next few years (mainly in chemistry and other research problems), and why Google and Akamai are already evaluating present-day solutions to the future post-quantum encryption problem. Meanwhile, NIST is currently evaluating multiple proposals for a PQE standard, especially lattice-based encryption.

Industrial Cyber Security Standard - IEC 62443

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Under the European NIS Directive, operators of critical infrastructure are required to implement appropriate organizational and technical arrangements according to the “state-of-the-art”. In determining the state-of-the-art, particular reference must be made not only to relevant international, European and national norms and standards, but also to comparable procedures, facilities and modes of operation that have been successfully tested in practice.

As a standard for IT risk assessment and state-of-the-art IT risk treatment, ISO / IEC 27001 is recommended as an information security management system (ISMS). However, this cannot be applied by critical infrastructure operators (KRITIS). Instead, assessment of the appropriateness of the risk treatment or measures for KRITIS must be based upon not impacting upon or causing disruption to society’s security of supply.

In-depth industry-specific safety standards are available, with international emphasis on IEC 62443. This standard defines the roles of manufacturers, integrators and plant operators, as well as technology for the design of zones and transitions, i.e., security design.

The paper will consider implementation of the European NIS Directive, the OVE drafts “Life cycle requirements for safe product development (OVE EN 62443-4-1)” and “Requirements for components of industrial automation systems (OVE EN 62443-4-2)” and the international standard ISA / IEC 62443 -3-3. It concludes with a practical example of network security implementation according to IEC 62443 in the pilot factory 4.0 of the Vienna University of Technology.

A Proactive Approach: Stopping Insiders' Threats with Machine Learning Technology

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Insiders' threats initiated covertly or overtly are foremost challenges for nuclear safeguards and security. In safeguards, covert insiders' activities include theft and diversion of special nuclear materials; misuse of process and equipment; deliberately tampering with IAEA surveillance equipment; or systematic concealment of malicious activities for nuclear weapons development. With the advance in digital and cyber technologies, malicious insiders' activities become ever more sophisticated and difficult to uncover, hampering efforts by the international safeguards regime.

A "game changer" involving the recent malware attack against the TRICONEX safety system at an industrial complex in the Middle East serves as a wakeup call for the cyber defense of malicious attacks initiated externally or by insiders. The attack was the first to target an engineering system dedicated to protecting people and the environment. Though not successful, the implications cast a long shadow over questions on the adequacy of a defense based on cyber analysts adopting information technology (IT).

A defensive approach with IT based on lessons-learned (after an attack) is problematic, and hence inadequate, as insiders are always steps ahead of defenders. In the long run, an artificial intelligence (AI) approach based on machine learning would be proactive and preferred. Such a defensive approach is now possible due to the advances in AI technologies, aided by the exponential increase in the ability to collect big data and to perform massive computations.

A machine learning approach would trace the attack vectors and identify defensive tasks, and show how many of these tasks can be automated and even deployed in real time to catch the insiders/intruders before any damage is done. For example, machine learning would be able to identify unusual traffic on the network, and shut down these connections as they occur. It can identify abnormal standard operating procedures requested by insiders attempting to steal sensitive information or materials, and sound an alarm to alert the plant responders to prevent the theft. Also, machine learning implemented for containment and surveillance would recognize patterns of concealment by insiders, and alert the IAEA to the malicious activities.

Safeguards Information Security in Practice at Nuclear Regulatory Authority

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The security of information related to safeguards has been carefully ensured at the Nuclear Regulatory Authority, Ghana. An integrated management system is currently under development at the Authority, which is integrating the various procedures and strategies for ensuring effective implementation of the regulatory mandate. The classification of correspondence is carefully undertaken to ensure that safeguards-related data does not get into the wrong hands. The measures taken to secure safeguards information associated with the conversion of Ghana Research Reactor-1 from high-enriched uranium to low-enriched uranium fuel is presented. The improvements in securing safeguards information envisaged from implementation of the integrated management system are also presented.

[CHA-S2] Human Resources – Taking the Initiative

Principles and Attributes for Positive Safeguards Culture within the State

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The international safeguards community has not yet established an official definition for safeguards culture. So, some experts have proposed definitions and the role of safeguards culture for the attention of national and international safeguards communities. 'Safeguards culture' is aimed at raising awareness of safeguards requirements and functions and strengthening the technical capacity of staff to meet those requirements in order to improve safeguards implementation within the State.

This paper introduces the challenges facing safeguards culture which must be recognized, understood and overcome for nuclear newcomer States, especially developing countries, to maintain and improve the effectiveness and efficiency of safeguards implementation in the State. These challenges include: Management systems; Leadership behaviors; The Guidance or code of conduct that should be available to all staff concerning safeguards culture; Assessment methodologies; Continuous improvement and learning; and the national culture's influence on safeguards culture.

The paper also introduces proposed principles and attributes for positive safeguards culture within the State, the first principle being Leadership behavior. Leaders significantly affect safeguards culture through the priorities they establish; the behaviors and values they promote; the reward systems they administer; the trust they create; and the context and expectations they establish for interpersonal relationships, communication and accountability. Leaders define Policy statements and attribute: individual roles, responsibilities and authorities; work environment; resources; recognition of the complexity of safeguards issues; and promotion of safeguards and associated knowledge.

The second principle is Personal accountability, reflecting the fact that individual staff members accept responsibility and take ownership of their performance and decisions so that accountability becomes a fundamental part of the safeguards culture. Attributes are personal commitment to and accountability for safeguards; collaboration and co-ordination of activities; and moral courage.

A third principle is to encourage assessment and learning, at all levels in the organization, to avoid "blind spots" and identify areas for improvement. Attributes are: qualitative evaluation; learning from experience, fostering exchanges and increasing knowledge; and a knowledge management programme.

The principles and attributes that could help turn challenges into opportunities, to further strengthen safeguards culture, are considered in detail within the paper.

APSN Surveys for the Coordination of Training Efforts in Asia: Results and Challenges

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This paper considers the efforts of the Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (hereafter ISCN) on behalf of the Asia-Pacific Safeguards Network (hereafter APSN) in supporting safeguards development in the Asia-Pacific region. In particular, this paper describes ISCN's activities to perform training needs and training providers' surveys, with the objective of facilitating needs analysis; identifying potential gaps in the provision of training; and assisting training providers to optimize their use of existing training capabilities to meet those needs. The baseline training needs and training providers' surveys conducted by the U.S. DOE/NNSA International Nuclear Safeguards and Engagement Program (INSEP) in 2011 are described and then the follow-up surveys of 2015, performed by ISCN, and their results are succinctly explained. A new survey was conducted in 2017 (and expanded in 2018) aimed at countries with Small Quantities Protocols in their safeguards agreements. The results of these surveys and the follow-up actions mandated by the APSN are also included in this paper.

Enhancing SSAC's Capabilities - The Nuclear Regulatory Authority Experience

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The Nuclear Regulatory Authority (ARN) is the national governmental organization in charge of the regulation of nuclear activities in Argentina, and is independent of any entity dedicated to the use or the promotion of nuclear energy in any of its forms. ARN was created in 1997 by the National Nuclear Activity Act (Law No. 24.804), which established its mission and responsibilities. This autarchic entity within the jurisdiction of the Argentine Presidency has competence on radiological and nuclear safety, physical protection, safeguards and nuclear non-proliferation.

As the authority responsible for safeguards implementation, the ARN attaches great importance to assuring efficient and effective safeguards through robust capabilities of the State System of Accounting for and Control of Nuclear Material (SSAC) and a strong connection with external relevant institutions. To fulfill its mission, ARN is committed to continuously develop its own human capacity and outreach to licensees and relevant stakeholders, assuring a clear understanding of safeguards obligations and responsibilities.

From an international perspective, ARN maintains interactions with several organizations through mechanisms such as the Cooperation Protocol with the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials; the Agreement with the United States Department of Energy concerning research and development in nuclear material control, accountancy, verification, physical protection, and advanced containment and surveillance technologies for international safeguards application; and the Argentine Support Programme to the International Atomic Energy Agency. These partnerships foster collaboration in safeguards implementation through tailored training and activities on safeguards approaches, measurement techniques, containment and surveillance, the conduct of domestic/regional inspections and the role of a SSAC in implementing international safeguards, among others.

The paper focuses on ARN's interfaces in safeguards capacity-building activities conducted during the past four years. It describes the experience gained through in-house training, facility operator engagement and collaborative actions within the above-mentioned frameworks, while sharing the lessons learned.

Integrating Non-Proliferation and Safeguards into the Mandatory Curricula of Undergraduate STEM Programs

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The majority of undergraduate science, technology, engineering, and mathematics (STEM) university programs worldwide lack recurring mandatory course content related to non-proliferation and safeguards. To address this educational gap, a set of Integral Non-Proliferation Introductory Teaching and Learning (INITIAL) classroom and laboratory modules have been developed. The INITIAL modules are intended to introduce sustainable safeguards content into mandatory curricula of STEM undergraduate programs in order to highlight the fact that non-proliferation topics (e.g. international safeguards verification) directly rely on many of the fundamental and applied technical topics undergraduates are currently studying. The INITIAL class module is a one-lecture primer (slides and problem sets) that allows for simple integration into mandatory introductory undergraduate STEM courses. The INITIAL laboratory (neutron, gamma, and reactor) modules are a more technically advanced safeguards-based experimental addition that can be integrated into to upper–level undergraduate mandatory laboratory courses that utilize equipment or facilities commonly available to STEM university programs e.g. basic radiation sources, detector systems or, in some cases, research reactors.

Since 2015, over 30 INITIAL implementations by early-career safeguards researchers (recently expanded to various US national laboratories) have occurred, providing sustainable academic course content for university programs that have no mandatory course content in this topical area. According to compiled surveys, many of the students that were exposed to INITIAL reported that they are more likely to pursue careers in safeguards post-INITIAL lecture or lab. The universities continue to deliver INITIAL content long after the first engagement, reaching over 1000 (otherwise unexposed) students. Thus, INITIAL module implementation is actively addressing the challenges of reaching and recruiting. Because the modules are fully customizable to the academic background of the audience, the INITIAL framework can be tailored for implementation abroad. This creates an effective knowledge transfer framework that is designed to continue long after the first engagement.

Advancing Safeguards One Person at a Time: Developing “Safeguards Champions”

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Success in nuclear safeguards implementation depends on many factors, from trained staff to an effective regulatory framework to availability of necessary equipment and many other typical infrastructure-related aspects. Often, however, that success depends on long-term commitment and advocacy by a dedicated individual, or a “champion”. While ample technical guidance and courses address safeguards infrastructure, little literature or discourse exists on the role of leadership in safeguards and those who champion safeguards causes. Who are these safeguards champions? What does it mean to be one? What are the circumstances that lead to the emergence of such champions? Why are they so important and what is their impact on developing effective safeguards in an organization, or even country?

The constrained resources of most training providers limit their ability to maintain frequent and long-term engagement in countries and necessitate increased reliance on trusted individuals with strong safeguards knowledge within an organization. In some cases, these specialists become “champions” for promoting and sustaining safeguards and are distinguished by not only their technical knowledge but also political and management savvy, as well as personal commitment. As these individuals retire or pursue other assignments, they leave a challenging void to fill not only in technical knowledge, but also in their unique ability to keep safeguards on the radar of their respective organizations and governments. Rather than rely on the chance that such a person will emerge within an organization, the global community can make a concerted effort to recognize and develop safeguards champions to address a critical gap in succession planning and sustainability.

In the past decade, the concept of “organizational” and “transformational” champions has been popularized by leadership development experts and embraced by industries seeking innovative leadership models to advance and strengthen their position in a globalized environment of competing priorities and rapid change.

The paper introduces the leadership concept of a “safeguards champion” and how it can benefit the safeguards system and be applied in safeguards-focused organizations globally. The authors examine existing leadership concepts and gather practical information from influential safeguards leaders in Asia and North Africa. This preliminary exploration can encourage a broader discussion of the safeguards champions and serve as the basis for designing future training by national and international training providers, including the IAEA, to develop the next generation of inspirational and dedicated safeguards leaders.

Outreach Education and Training in Nuclear Safeguards and Non-Proliferation of the European Commission, Joint Research Centre

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The Nuclear Security Unit of the Department of Nuclear Security and Safeguards of the Joint Research Centre of the European Commission, in close collaboration with the Training and Knowledge Management Working Group of the European Safeguards Research and Development Association (ESARDA), provides annually a one-week well-established specialized course on Safeguards and Non-Proliferation. For almost the last two decades, this course has taken place in Ispra (Italy) and is open to audiences of an average of 50 students, in particular nuclear engineering students, but also to young professionals in nuclear regulation or operations and international relations. The course is best known as the ''ESARDA Course'' and aims at complementing not only nuclear engineering studies by including nuclear safeguards and non-proliferation in the academic curriculum within Europe, but also to contribute to efforts of international organization such as the IAEA, JAEA, etc, to enhance and harmonize safeguards and non-proliferation approaches. It combines lectures from experts with group exercises and offers also an exam and essay compilation to the students seeking for academic recognition.

Due to its success, the ESARDA Course has been outreached, with financial support of DG DEVCO under the Instrument for Nuclear Safety Collaboration, over several regions worldwide. This paper reports, in particular, on the feedback from the one-week course which was organized in Pretoria (South Africa) in February 2018 for the Southern African region (13 participating countries). The way the course was tailored with respect to original content, to best fit the needs of the region and the intention to make it a sustainable initiative in the region, is included. The follow-up activities in this region and transfer of this course to other regions (Northern Africa and Caucasus, for example) will also be discussed.

Canada's Experience with Building and Maintaining Safeguards Capability

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Maintaining a competent and capable workforce for the purpose of safeguards implementation in a State with a broad and diverse nuclear fuel cycle presents unique challenges. The Canadian Nuclear Safety Commission (CNSC) has turned to a combination of strategies to address safeguards human resources challenges. This paper explores a number of these strategies, including: safeguards inspector training and certification; safeguards knowledge management through the post-retirement engagement of experienced professionals; a commitment to new graduate development; cross-training between nuclear material accountancy and safeguards field operations roles; temporary staff assignments; and outreach to universities and licensees to build capacity beyond the CNSC. The paper relates the CNSC's experience with these strategies to build and maintain safeguards capability in Canada.

[CHA-S3] Globalization and the Changing Supply Chain for Knowledge, Expertise and Goods

The Use of Trade Statistics to Map States' Nuclear-Related Industrial Capabilities

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State Evaluation Groups in the IAEA Department of Safeguards analyse safeguards-relevant open source information on States' nuclear-related industrial capabilities, including the nuclear-related equipment and materials they can make use of either through indigenous manufacture or import. This analysis is performed in the State evaluation process for States with comprehensive safeguards agreements. Open source trade statistics can provide insights into the global trade flows of nuclear-related equipment and materials, and the underlying industrial capabilities of States as possible users or manufacturers of such goods. This paper describes preliminary results of the collaborative work between the IAEA and the Joint Research Centre of the European Commission on the development and application of visualization tools to open source trade statistics to support the nuclear-related industrial capability assessment in the State evaluation process. Methods for statistical trade data analysis, including the Revealed Comparative Advantage index, were explored to determine the relative strength of States as exporters or importers of classes of products which are considered to be of relevance to the assessment of States' nuclear-related industrial infrastructure and capabilities.

Additive Manufacturing: The Future for Safeguards

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Additive manufacturing is described as a transformative technology that will allow objects with complex topologies and 21st Century materials to be produced locally. The impact on safeguards is not yet clear, as the technology is just beginning to impact industry. Exactly what the technology will be able to produce in the near future of relevance to nuclear safeguards is unclear; especially if it allows States to solve manufacturing challenges posed by technology controls.

This paper addresses four key points: given how additive manufacturing is developing, what it will be possible to produce with this technology by 2025; whether additive manufacturing provides developing nuclear States with access to new capabilities; how technology controls may be undermined by allowing States either to outsource production or produce traditionally manufactured items using additive techniques; and the policy responses that are available and appropriate to meet this challenge.

Mapping Technology and Knowledge Transfer Networks

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The scope and volume of transnational nuclear-related trade and knowledge flows are expanding to new countries and regions with nascent nuclear-related industries and research establishments, presenting new safeguards challenges. In this paper, we describe a method of using publicly available data to map the national and regional networks that States use to trade in nuclear materials and technology, and to transfer nuclear-related tacit knowledge. Analysing the structure of the networks themselves can determine crucial nodes and links within the networks, chokepoints and focal points for trade and knowledge flows, and the relative importance of different suppliers, knowledge and trade brokers, and buyers. In terms of safeguards analysis, this presents a low-cost way to identify initial areas of interest in nuclear knowledge aggregation, and in nuclear-related trade flow and emerging roles in the nuclear supply chain. This is a particularly useful method to use with countries with nascent nuclear industries, and we provide examples of the analysis with reference to regional knowledge and trade networks in Southeast Asia. While the network analysis method is agnostic as to data sources, in this paper we use data from UNCOMTRADE, Web of Science, and several other public databases.

Responding to Verification Challenges caused by Increasing Nuclear-Related Trade

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Nuclear trade analysis has effectively strengthened international safeguards for more than a decade. Supported by the IAEA Member States, nuclear trade analysis was a departmental response to the revelation of proliferation networks in the early 2000s. The collection, analysis and synthesis of trade-related information with information from open and other sources has diversified and enhanced the verification of completeness of States' declarations, thus improving assurances of the absence of undeclared nuclear material and activities.

The key trade analysis products in the context of safeguards State evaluation are assessments of nuclear-related trade flows, nuclear-related industrial infrastructure, IAEA Technical Cooperation, and ad hoc trade and procurement-related analysis. In 2017, ca 90 such reports were provided to safeguards State evaluation groups (SEGs), in addition to direct SEG trade updates.

Proliferation risks show no sign of decreasing in the future. Recent nuclear energy production projections point to a continuous increase, where even a low case scenario is ca 8 % increase over the next decade. The growth in legitimate nuclear-related trade will also increase the concerns of mis-use, illicit trade and proliferation. Resilient proliferation networks are constantly adapting to avoid strengthened export controls and pose a continuous challenge for global non-proliferation. The presentation describes the role of IAEA trade analysis in support of safeguards State evaluation, in addition to its sources of information and partnerships in countering non-traditional proliferation risks – by further diversifying and improving departmental trade analysis competence.

The Changing Architecture of Nuclear Trade: Trends in Manufacturing Base Supply and Demand

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Substantial counter-proliferation resources are spent trying to identify and prevent the diversion of dual-use goods to illicit nuclear programs. Since 2004, all countries have been required to have in place export controls on dual-use goods. Because not all trade flows can be followed, tracking the flow of nuclear dual-use items can be prioritized by focusing on so-called 'choke-point' goods: key items that proliferators seek, that are assumed to be particularly difficult to obtain. Demand and supply determines whether any item is a choke-point for a nominal illicit nuclear program. Proliferators, having chosen a pathway to nuclear weapons - say, uranium enrichment by gas centrifuge - need certain materials and goods to build that pathway. There is a worldwide supply base of commercial manufacturers which can make these materials and goods. When supply is significantly less than demand, an item becomes such a choke-point. To date, no comprehensive study has established how widely potential choke-point items are produced.

This paper is based on research that attempts to fill this gap. The authors have researched and characterized the manufacturing bases for 26 proliferation-sensitive technologies. The research deliberately examines a diverse range of nuclear-related goods: from simple commodities to elaborately manufactured precision items, with supply chains ranging from the short and simple to the long and complex.

From these technology reports, an aggregated picture of the global manufacturing base for proliferation-sensitive items has been built, which is described in this paper. Its objective is to be of use to non-proliferation, counter-proliferation and export control practitioners, and to add to research in the field.

Emerging Dual-Use Technologies and Global Supply Chain Compliance

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With the progress of technologies for telecommunication, synthetic biology, chemistry, additive manufacturing and nanoscale processes, many opportunities arise, allowing more effective and innovative production and the achievement of results with great potential both on the technical and commercial sides.

At the same time however, rapid technological developments may create opportunities and vulnerabilities that can be exploited for illicit procurement activities seeking sensitive items for proliferation programmes.

The strategic trade control framework should evolve with the same pace. Enforcement and traceability of intangible technology transfer controls may become much more challenging, while at the same time improved approaches to internal compliance must be developed by suppliers and technology holders.

Potential Proliferation Indicators through Analysis of Trade in Non-Controlled Industrial Goods

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Any State's ability to carry out an indigenous, proliferation programme is directly related to its industrial and technological capabilities. Open source trade statistics can provide valuable insights into the global trade flows of nuclear-related equipment and materials, and the underlying industrial capabilities of States as possible users or manufacturers of such goods. It is postulated that monitoring of trade data for non-controlled items can be useful in better understanding a State's potential to undertake nuclear fuel cycle related activities. The paper describes the logic for the selection of a groups of products that require similar industrial and technological capabilities to those required for the different stages of the nuclear fuel cycle on the basis of the international nomenclature for the categorization of trade.

[CHA-S4] Non-proliferation and the Globalized Marketplace

UAE Nuclear Export Controls: a Success Story

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Due to its strategic location between East and West, the large number of ports and free trade zones and a business-friendly environment, the United Arab Emirates (UAE) has long-been one of the world's major trade hubs - and a target for illicit nuclear procurement networks.

More recently, following the requirements of United Nations Security Council Resolution 1540, the UAE has successfully enhanced its nuclear export controls. The first step was the creation of a Committee for Goods and Materials Subject to Import and Export Control (The Committee) in 2007. In 2008, the UAE evaluated the potential benefits of nuclear power. A year later, the UAE decided to embark on a peaceful nuclear programme by awarding a contract to Korea Electric Power Corporation (KEPCO) for the construction of four APR-1400 reactors at Barakah, implementing the "Gold Standard" of non-proliferation. The Federal Law by Decree No. 6 Concerning the Peaceful Uses of Nuclear Energy (The Law) was issued in 2009, establishing the Federal Authority for Nuclear Regulation (FANR) as the UAE's regulator. The UAE voluntarily committed to abide by the Nuclear Suppliers Group Guidelines. FANR assumed the responsibility for nuclear-related export controls and issued the Regulation on the Export and Import Control of Nuclear Material, Nuclear Related Items and Nuclear Related Dual Use Items (FANR-REG-09), which specifies FANR's licensing, reporting and inspection requirements and forms the legal basis for controlling all nuclear-related imports, exports, re-exports, transits and trans-shipments in the UAE.

FANR has established a methodology based on Harmonized System Codes to identify potentially regulated items and control their transfer. FANR also conducts regular outreach activities, organizes workshops with international attendance and collaborates with various countries in the area of nuclear export controls. Owing to FANR's close cooperation with the UAE's different customs authorities and State Security, several unlicensed trans-shipments of proliferation concern have successfully been intercepted and seized.

Australian Counter-Proliferation Architecture, Collaboration, Challenges and Opportunities

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The Australian government's approach to countering the proliferation of weapons of mass destruction involves coordination across multiple agencies from different portfolios with competing priorities. Through a series of reviews the structure of this whole-of-government approach has been modified to ensure an efficient and effective prosecution of the counter-proliferation (CP) task. The paper will examine the evolution of Australia's CP efforts, global future CP challenges, and how Australia works collaboratively with the IAEA's Department of Safeguards to advance our mutual interests.

[CHA-S5] Engaging Non-traditional Sectors in Safeguards

Exploring Disruptive Technology for Safeguards Verification

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The U.S. Department of Energy, National Nuclear Security Administration (NNSA), Office of Non-Proliferation and Arms Control, Safeguards Technology Team (SG Tech) has established a forward leaning R&D program in anticipation of rapid technological advances in nuclear power and nuclear material production, and the consequent opportunities for and challenges to safeguards verification. Specifically, many new projects are based on technologies and discoveries from research sectors not traditionally associated with safeguards tools and methods, such as advances in lasers, data visualization, additive manufacturing for detector parts, and know-how from high-energy physics. Other example efforts include: 1) innovative detector materials such as stilbene and pulse-shape discriminating plastics; 2) battery-free, wireless tags for inventory monitoring and tracking in harsh environments; 3) non-invasive acoustics methodology under evaluation as an on-site inspection tool to verify D_2O concentration; and 4) NuGoo, a method for acquiring environmental samples using a peelable gel to extract microscopic amounts of nuclear material from rough surfaces, such as wood or concrete.

SG Tech establishes its projects and project teams from the U.S. Department of Energy National Laboratories and other U.S. agencies, U.S. academia and the U.S. private sector. It works closely with the IAEA Department of Safeguards' managers and end users to align its program to meet pressing verification needs, and quality, performance and reliability standards. SG Tech also engages and invites willing partners through NNSA's bilateral agreements to test and validate these concepts.

The European Safeguards Research and Development Association (ESARDA) - Communication, Coordination and Collaboration in Safeguards

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ESARDA, the European Safeguards Research and Development Association, is comprised of European organisations actively involved in the research and development (R&D) of nuclear safeguards. The control of civil nuclear material is mandatory within the EU territory in line with the Treaty establishing the European Atomic Energy Community ("Euratom Treaty", 1958) and the Treaty on the Non-Proliferation of Nuclear Weapons (1970). ESARDA was formed in1969, with the purpose of facilitating collaboration in R&D in the field of safeguards and in the application of such R&D to the safeguarding of source and special fissile materials.

ESARDA includes regulatory authorities, facility operators, research centres and universities. The principal issues addressed by the Association are co-ordination of research, frequent exchange of information and joint execution of R&D programmes. ESARDA also strives to fulfill an educational role and to reach the general public. To this end, the following activities take place:

1) Annual Meetings and Symposia, providing an opportunity for collaboration and information exchange. Alternating with open symposia, biennial internal meetings take place where all Working Groups (WGs) convene.

2) Dedicated WG activities. ESARDA consists of nine WGs, being the "backbone" of ESARDA, with active members and observers.

3) The one-week ESARDA Course, complementing nuclear engineering studies by including nuclear safeguards in the academic curriculum.

4) Technical publications. The ESARDA Bulletin contains scientific and technical articles relating to safeguards and verification. The ESARDA website features, inter alia, the latest issues of the Bulletin, the symposia proceedings, as well as information about WGs, symposia and other relevant events.

Today, ESARDA is more active than ever, due to lively cooperation among its members and strong linkages to other safeguards-related organisations, such as the Institute of Nuclear Materials Management (INMM), and the pro-active tackling of newly emerging issues through its diverse WGs.

Cross-Sector Collaboration to Develop New Tools for Communication to Non-Experts

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The N Square Innovators Network (NSIN) was created in 2017, to build a cross-sector community of innovators with the collaborative spirit, ingenuity and commitment necessary to accelerate progress towards agreed nuclear non-proliferation, security and disarmament goals. At the center of the NSIN is a small group of partners with diverse expertise, spheres of influence, networks and constituencies - not limited to the nuclear sector. The NSIN comprises four cross-sector teams, each with a different focus. One team is focused on verification and consists of members from the Rhode Island School of Design, the Princeton Nuclear Futures Lab, the Nuclear Threat Initiative, Veilos, N Square, Singularity University, and the Skoll Foundation.

A key problem identified by the “Verification Team” is that there are people outside of the nuclear safeguards community who may have solutions, ideas or frameworks to contribute to the various challenges inherent in the fuel cycle verification process. However, because they are unaware of the challenges, and may not understand verification or safeguards, they do not know how to contribute. In addition, the experts involved in international safeguards struggle with messaging to lay-audiences and other non-experts about the ins and outs of their verification mission.

Utilizing proven innovation methods such as human-centered design, design-thinking, and systems-thinking, the Verification Team is working to better articulate problems and opportunities so that people without expertise understand the issues and feel empowered to contribute. The goal of the group is to create tools and messages necessary to communicate about verification in plain-speak, in order to highlight pathways for potential engagement that might lead to new approaches or methods.

One successful outcome for this effort may be to help both public and non-expert decision-makers better understand the importance of credible verification regimes, the mission of the IAEA within those regimes, and the value of supporting the IAEA to carry out its mission.

The Role of Professional Societies in Effective Communications for International Safeguards: How the Institute of Nuclear Materials Management Supports Existing and Emerging Nuclear Materials Stewardship Communities

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[9] *Pacific Northwest National Laboratory*

The Institute of Nuclear Materials Management (INMM) is an international professional society dedicated to “the safe, secure and effective stewardship of nuclear materials and related technologies through the advancement of scientific knowledge, technical skills, policy dialogue, professional capabilities, and best practices.” The Institute executes its mission through six technical divisions, the largest of which is International Safeguards. While the contributions of the Institute’s members are high in impact and global in reach, a key aspect of INMM’s ability to promote the mission and identify the needs of the nuclear materials management community is its ability to effectively communicate. INMM seeks to build and strengthen the relationships between policy and technical communities working in the nuclear materials management field, as reflected in the Institute’s Strategic Plan. In the paper, the authors describe how INMM is working to broaden and enhance its communications platforms in service of strengthening international safeguards, developing effective messaging, and identifying methods to meet the evolving needs of the nuclear materials management community. The vision for INMM communications will be described along with how that vision will impact the existing and emerging nuclear materials stewardship communities.

Nuclear Safeguards Communication in Thailand

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The Kingdom of Thailand has been signatory to the NPT since 1972, with a Comprehensive Safeguards Agreement (CSA) and Additional Protocol (AP) in force since 1974 and 2017, respectively. Safeguards implementation has been performed mostly in the form of providing and receiving of information, i.e. NMA reports, Notification letters and Forms. Safeguards-relevant communication between the State authority responsible for safeguards implementation (SRA) and the International Atomic Energy Agency (IAEA) is one of the key elements for effective safeguards implementation. The Office of Atoms for Peace (OAP) acts on behalf of the Kingdom of Thailand as SRA.

In the past, OAP has provided all types of information through official channels, i.e. OAP to Ministry of Foreign Affairs to Permanent Mission in Vienna and to IAEA, and vice versa for information from the IAEA to OAP. These involve paper-based documentation and traditional logistics such as air mail and FAX. Unfortunate experiences involved late submission and risks of exposure of sensitive or confidential information.

The IAEA developed Computerized Secure Communication (SC) as a platform to exchange information between States and the IAEA; in operation now for some time. In 2017, the IAEA launched the State Declaration Portal (SDP) as a complementary platform to SC, to exchange information between States and the IAEA. OAP installed the SC in November 2017 and was granted access to SDP in July 2017. By utilizing SDP and SC, OAP is able to (a) drastically shorten the information submission time to the IAEA; and (b) receive information from the IAEA almost instantly. The systems also allow restricted access by State parties, to receive a copy or a notification of the transfer of information at the time that the information is exchanged.

Advantages of using these two systems include (a) reducing the risk of unnecessary sharing of sensitive and confidential information; and (b) significantly decreasing the transfer time between OAP and the IAEA, which is preferable in submitting AP declarations in that the IAEA will acknowledge the submission by the IAEA “Receive” time and not the “dispatch” time as in the case of NMA reports.

Safeguards by Design (SBD) in Nuclear Engineering Design Courses - Engaging Universities in SBD

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Engaging professionals across the breadth of the nuclear industry to educate them on international safeguards objectives and methodology is logistically challenging, especially in the United States, where individuals may not interact with the International Atomic Energy Agency (IAEA) and are not as familiar with implementing international safeguards. However, incorporating international safeguards concepts into the mandatory curriculum of nuclear-related university degree programs around the world, complementary to nuclear safety and security concepts, could reach individuals who will go on to be professionals acting in a variety of roles across the nuclear industry (e.g., developing nuclear-related advanced technologies, designing or operating nuclear facilities, serving as State regulators). This would ultimately lead to more effective and efficient safeguards, including helping to move safeguards by design from a concept to a standard practice, as future designers, operators, and State regulators would be familiar with international safeguards. This could also address human resource challenges by developing a broader base of individuals knowledgeable about the IAEA mission from which to draw future safeguards inspectors and analysts. In order to implement this idea, the Y-12 National Security Complex in Oak Ridge, Tennessee, in conjunction with the Center for Nuclear Security Science & Policy Initiatives (a research institute associated with Texas A&M University), targeted nuclear engineering undergraduate students taking the mandatory design course at Texas A&M and the University of Tennessee. The project objective was to introduce safeguards by design concepts to individuals who are planning to work in a broad range of nuclear-related careers. The paper describes the project methodology, which included developing and presenting lectures on safeguards to the design classes and mentoring teams working on design team projects that incorporated safeguards. The paper also identifies lessons learned while incorporating safeguards topics into nuclear engineering university degree programs.

EC-JRC Initiatives to Sustain Excellence and Diversity in Science

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The Joint Research Centre of the European Commission (JRC) introduced with its strategy 2030 new initiatives to provide staff with skills and competences sustaining and expanding scientific excellence, stimulating eagerness to learn and intellectual curiosity. This facilitates transferring and sharing of knowledge and skills across nuclear and non-nuclear research areas, and also with partner DGs, Member States and international organisations such as the IAEA. The Exploratory Research Programme (ER) and the Centre for Advanced Studies (CAS) aim at injecting new ideas and transdisciplinary thinking into the organisation. The Collaborative Doctoral Partnership (CDP) brings young researchers into the JRC, while the Visiting Researcher Programme (VRP) encourages staff mobility. JRC is in the Consortium for ENEN+ mobility grants for career opportunities in the nuclear fields. By granting open access to selected JRC Research Infrastructure, the JRC reaches out to academia, research organisations, industry and the private sector. The JRC's Art and Science programmes allow scientists to collaborate with artists. While each initiative meets its own target, it is the interactions between them that create a diverse pool of researchers in a multi-disciplinary environment. The EC has set a target of 40% women in management positions and fosters initiatives for 'Women and Girls in Science'.

Only organisations that build on the collective intelligence of their staff will be able to meet the challenges of this century. While embedded in a well-defined legal framework, European and international nuclear safeguards rely on scientific/technical support, innovation and highly-skilled staff. Examples will be given on how the JRC initiatives are engaging people in topics that are growing safeguards challenges, such as big data, machine learning, shared ledger, nano technologies and others. These JRC initiatives have the potential of setting an exciting example to the benefit of the IAEA and Member States in building future safeguards capabilities.

Australia's Experience with Engaging Researchers Outside the Traditional Safeguards Community

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The continuing effectiveness of safeguards is achieved by the combined effort of the IAEA and Member States to keep pace with evolving challenges in verification, as well as opportunities from emerging technologies and analytical techniques. Safeguards is a niche area for research and development but it can benefit from the support of researchers in many technical fields. In recent years, the IAEA has begun pursuing innovation by conducting broad searches for novel technologies developed outside the traditional safeguards community, and then considering how these technologies could be applied to safeguards. For this approach to work, it is necessary to engage effectively with researchers that do not have prior experience servicing safeguards needs. A key challenge is raising awareness of safeguards among these researchers and providing compelling reasons for them to focus their attentions on safeguards R&D needs.

The Australian Safeguards and Non-Proliferation Office (ASNO) helps to bring the IAEA together with R&D leaders in Australian research institutes, universities and other agencies to assist the IAEA to meet its R&D needs. ASNO helped to broker a partnership between the IAEA and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), a broad-based national research organization with limited prior exposure to safeguards. This partnership led to the IAEA introducing the Zebedee 3D hand-held laser mapping device into inspections in 2016, just a few years after CSIRO invented the device. CSIRO went on to host the IAEA's Robotics Challenge in November 2017, which saw robotics experts from around the world build their own robots to assist the IAEA with inspections. University researchers in Australia are also getting involved in safeguards R&D, including research on natural language processing for the IAEA Content Reification Engine (ICORE) and blockchain technology for nuclear material accounting. This paper focuses on the challenge of communicating with R&D leaders that have relevant technical expertise but do not have prior knowledge of safeguards. It will discuss how (and why) research institutes and universities in Australia are getting involved with R&D for safeguards and how Australia is helping to engage support from these non-traditional audiences.

[CHA-S6] Capacity Building – National Initiatives

Algerian Experience in Training Program of Safeguards Personnel

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The purpose of this paper is to describe the Algerian experience in a safeguards training program. Qualification and training of nuclear facilities personnel is very important for both international and national safeguards implementation. To meet this need, COMENA has launched a training program dedicated to prepare nuclear facilities staff with relevant competence and skills in order to maintain a sustainable effective State System of Accounting for and Control of Nuclear Material. The first Algerian safeguards training program was implemented by the COMENA in 2014. A group of trainees was selected from candidates who were master or engineer graduated, in physics, chemistry or engineering.

The aim of this training program was to prepare and to strengthen the nuclear facilities personnel in building-up knowledge, skills and attitudes required to conduct successfully the safeguards-related activities, in particular those relating to the management of the accounting for and control of nuclear materials at the level of facilities.

The training program was developed according to the systematic training approach. This methodology is based on the following five steps: analysis, design, development, implementation and evaluation.

This training consists of classroom lectures, practical and laboratory exercises, technical visits at nuclear facilities and evaluation of the trainees. Topics of the training program include basic courses on the nuclear fuel cycle and specific courses concerning the accounting for and control of nuclear material system.

In order to familiarize representatives of the SSAC and operators with application of Non Destructive Assay methods for verification of nuclear materials, the participants were trained to use NDA techniques, instruments and equipment for this purpose.

As further enhance their technical skill, the trainees attended some short courses organized at the Nuclear Research Center of Draria on the fundamentals of inspection. The objective was to provide participants with fundamental skills and practices to plan, conduct, and report on nuclear security and safeguards inspections.

Respecting a systematic approach to continuing training, in the last two years some trainees have also attended the safeguards courses (Accounting for and Control of Nuclear Material) organized by the IAEA.

Strategy for Strengthening Training and Qualification for U.S. Nuclear Regulatory Commission's International Safeguards Analysts

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Challenges associated with strengthening international safeguards implementation in the United States of America (U.S.) are being addressed through a progressive training and qualification program at the Nuclear Regulatory Commission (NRC). The basis for this program utilizes a qualification plan specifically designed to ensure the U.S. NRC International Safeguards Analysts, Import and Export Analysts, and Nuclear Materials Management and Safeguards System Analysts are evaluated against a standard of knowledge outlined in a qualification plan. The knowledge standard is designed to qualify analysts to effectively represent NRC and U.S. interests in domestic and international meetings on non-proliferation issues, and to ensure the NRC and its commercial licensees comply with international treaties and agreements. The scope of the program plan includes initial training on the NRC and its domestic regulatory responsibilities, then focuses on required core training for each analyst position. The course focus provides trainees with an opportunity to understand how the U.S. State System of Accounting for and Control of nuclear materials was established and how it is now being maintained. This paper will examine the strategy used to develop and then satisfy the requirements for the training and qualification program.

Strengthening Safeguards Capabilities within Public Company Nuclear Facilities of Serbia

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Public Company Nuclear Facilities of Serbia (PC NFS) is the only nuclear operator in Serbia. It was founded in 2009, under the Law on Ionizing Radiation, together with the Serbian Regulatory Body. Since its establishment, PC NFS has continued all nuclear activities previously managed by Vinca Institute of Nuclear Sciences: two research reactors (RA- final shut down and RB- zero-power critical assembly, operational but currently not licensed); radioactive waste management facilities including old Hangars H1 and H2 (with legacy waste), new Hangar H3 (for the storage of intermediate and low level radioactive waste) together with the secure storage for the high-activity sealed radioactive sources; and closed uranium mine Kalna are all part of the Company.

This paper will provide techniques, developed within the Department for Development and Application of Nuclear Technologies, for the characterization of nuclear materials in support of strengthening nuclear material accountancy and control (NMAC) capabilities within PC NFS. We will also provide our experience in preparation of data for the inventory lists provided to our Regulatory Body.

Training for new staff in charge of NMAC was developed in collaboration with the Department for Development and Application of Nuclear Technologies and the Department for Nuclear Security within PC NFS. This has made a significant contribution to strengthening our human resource capabilities in this area, and the current status will also be provided in this paper.

Capacity Building in the UAE's Young Nuclear Workforce

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Staff turnover is a critical factor to consider in workforce planning, especially in the nuclear industry where specialist knowledge is costly, mission critical and difficult to replace. Mitigating the effects of staff turnover is essential for the efficient and effective functioning of a nuclear organization. The Federal Authority for Nuclear Regulation (FANR) recognized at an early stage that its unique composition required a special focus on creating a turnover-resistant organization that is able to sustainably support a long-term nuclear energy program. In addition to creating a happy, stimulating and recognition-based working environment, FANR has adopted a two-pronged approach to mitigating the impact of staff turnover. Firstly, the organization has embraced "Emiratisation" - the strategic capacity-building initiative of the UAE Government – and coupled this with expert foreign assistance to formulate a solid foundation for capacity building. Secondly, the rapid growth in Emirati nuclear knowledge is integrated with experience and knowledge from international sources utilizing knowledge management (KM) tools for knowledge capture, retention and transfer.

The KM processes are integral to FANR's Integrated Management System (IMS), which is aligned with FANR's objectives. The Knowledge Resource Matrix contains comprehensive information about the processes in three major categories: Human Capital (Competences), Structural Capital (K-Products, documents, standards) and Relationship Capital (External knowledge). The approach helps to uncover knowledge contained in each FANR management process and establishes a solid base for knowledge transfer to newcomer staff. FANR continues to explore the concept of push strategy (codification approach) in creating a shared virtual platform between FANR, the IAEA and assisting third parties. This revolutionary concept demonstrates how an electronic KM system could link to an innovation management system.

FANR strongly believes in the importance of KM and allocates significant resources to researching novel and effective means of institutionalising KM to support a sustainable nuclear regulatory program.

Strengthening of the National Safeguards System through an Integrated 3S Approach: a Cuban Perspective

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The paper describes the nuclear infrastructure developed over more than 30 years in Cuba and how the implementation of IAEA safeguards has taken place since Cuba's Comprehensive Safeguards Agreement and Additional Protocol came into force.

The National Centre of Nuclear Safety is the national regulatory body with regulation, authorization and control responsibilities. A control regime has been established for the peaceful and secure use of radioactive materials, including nuclear materials. Each system has its own mechanism, but to avoid duplication they make uses of synergies in their control.

Since 2010, an integrated nuclear security support plan has been implemented in Cuba. As part of the national security regimen, it has followed a preventive approach with multi-institutional cooperation. A proper combination of "defense in depth" and "graded approach" principles for multiple layers of security detection architecture has been developed, with a positive impact on security of radioactive materials, including nuclear materials. The mechanism for the import/export control of materials and equipment relevant to safeguards has been enhanced.

The paper also highlights potential good practices for States with Small Quantity Protocols when implementing their safeguards commitments. As a conclusion, safeguards implementation in Cuba has been strengthened by taking advantage of synergies between developed safety and security mechanisms.

Optimizing SSAC Human Resources of ARNR in the Hypothesis of a Nuclear Program

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The Uruguayan Regulatory Body (ARNR) has 14 technical staff. All staff have undergone Radioprotection training, provided by the IAEA and other international organizations, each in several specific fields but with all knowledge gained then shared among the wider ARNR staff.

Even though Uruguay currently has no nuclear programme - nor uranium mines; nor manufacturing of materials or equipment listed under Annexes I and II of the Additional Protocol - the country still deals with some safeguarded material, including 80 grams of ^{239}Pu and, predominantly, depleted uranium used in shielding. Uranium of other origins has also come under safeguards, such as depleted uranium found amongst metallic scrap during routine controls.

Three ARNR staff members specifically reside within Uruguay's SSAC, but all technical staff are aware of the key issues and activities and, in fact, many of the staff have performed duties related to safeguards: some in preparation of Safeguards Reports to the IAEA; others in duties of seizing or transporting orphan nuclear material.

Whilst eventual future needs for a Nuclear Power Plant have been discussed, at the moment there is no Government plan that includes nuclear power. Even so, ARNR has participated in some international technical projects related to nuclear power, for example concerning competence building in nuclear reactors regulatory staff (FORO), which lead to IAEA TECDOC 1794. This Guidance included a description of the basic staff required for nuclear reactor licensing, and is a major reference for ARNR to be used should the need arise. In the hypothetical situation of a Uruguayan nuclear power programme in the future, safeguards human resources would be a critical issue so, in this hypothesis, ARNR's strategic view includes optimizing the use of its technical staff. This strategic view, together with current multi-purpose staff experience and guidance provided by TECDOC 1794, postulates giving SSAC and Safeguards competence (inside ARNR, by internal knowledge transfer) to some 3 - 4 of the 28 staff dedicated to Nuclear Regulation. Their work would synergize with a hypothetical Safeguards Department including 3 or slightly more persons, in order that every regulatory duty could be addressed. In this way, the use of ARNR staff with certified safeguards competence would be optimized against a background of a predicted scarcity of such staff by 2020.

The Education and Training Offer in Nuclear Safeguards within the EURATOM Research and Training Project “ANNETTE”

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The ‘Advanced Networking for Nuclear Education, Training and Transfer of Expertise’ (ANNETTE) is a Horizon2020 project aimed at advanced networking for nuclear education, training and transfer of expertise. Four partners (the Belgian nuclear research centre SCK•CEN, the European Commission Joint Research Centre, Uppsala University, and Forschungszentrum Jülich) contribute to the ANNETTE project to provide education and training (E&T) in nuclear safeguards. The activities are supported by the European Safeguards Research and Development Association (ESARDA), in particular within the Training and Knowledge Management (TKM) Working Group.

The foreseen E&T offer in nuclear safeguards consists of:

- a training course as part of the ANNETTE European Master Programme for Continuous Professional Development;
- a contribution to the ANNETTE Summer School on Nuclear Technology, Nuclear Waste Management and Radiation Protection;
- and a Massive Open On-line Course (MOOC) on “Introduction to Safeguards”.

In addition, four thematic workshops will be given by SCK•CEN and Forschungszentrum Jülich. The target audience for these activities is young professionals and young researchers, with all activities to be completed before December 2019. In this contribution, we describe the overall E&T offer in nuclear safeguards within the ANNETTE project and present the preliminary outcomes from the activities carried out so far.

An Integration of Nuclear Safeguards with Nuclear Security

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In recent years, the need to achieve a better integration between two basic pillars of nuclear energy - safeguards and security (2S) - has become widely recognized. This paper proposes an integration of 2S such that there is no overlap or omission of important responsibilities. An effective implementation of 2S assures the commitment of a State to peaceful use of nuclear energy, and integrating the two can optimise the available resources, techniques and expertise within a State. Various examples of 2S integration are presented in this paper. Implementing integrated 2S by design, and coordinated use of surveillance systems and nuclear material tracking systems in a nuclear facility, ensures effective utilization of resources with shared responsibilities. The integration of 2S in the field of nuclear material accounting and control not only promotes the timely detection but also prevents diversion of nuclear material. An integration of export control with safeguards strengthens the State's non-proliferation objectives.

International cooperation plays a vital role in improving the effectiveness of integration between nuclear safeguards and security. This paper will highlight commonalities between the objectives of various international binding and non-binding instruments like CPPNM, UNSCR 1540, ICSANT, Code of Conduct on safety and security of radioactive sources etc. with safeguards. In addition, the coordination of global centres of excellence (COE) with State R & D initiatives would enhance the State's capabilities in containment and surveillance systems, physical protection systems, various verification mechanisms and nuclear forensics systems etc. Responsible sharing of information e.g. best practices, implementing experiences, security breach incidents, nuclear accidents, nuclear material theft etc. can provide a platform to develop response mechanisms to protect the human environment from acts of terrorism.

Development of Safeguards Infrastructure for the Nuclear Power Programme in Ghana

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The Nuclear Regulatory Authority, Ghana (NRA) was established to provide for the regulation and management of activities and practices for the peaceful use of nuclear material or energy, radioactive material or radiation; to provide for the protection of persons and the environment against the harmful effects of radiation hazards; to ensure the effective implementation of the country's international obligations and for related matters. A Safeguards and Non-Proliferation Department facilitates the implementation of Ghana's safeguards and Additional Protocol obligations. The NRA has collaborated with the International Nuclear Safeguards Engagement Program of the United States and the United States Nuclear Regulatory Commission in the development of our Draft Safeguards Regulation, which is currently undergoing review. The partnerships developed and the collaborations with the Customs Division of the Ghana Revenue Authority are discussed. The assistance received in training and human resource development in safeguards are also presented.

The Role of the Russian Methodological and Training Center in the SSAC of Russia

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The Russian Methodological and Training Center (RMTC) was created at IPPE in the framework of the international program of cooperation with the EC and the USA and is the basic organization of ROSATOM, not only for providing personnel training in the areas of nuclear material control and accounting (MC&A), but for improvement in SSAC infrastructure and nuclear facilities systems. RMTC performs training in all aspects of NMCA and conducts about 25 courses per year, with one third of them involving nuclear materials and measurement instruments. Russian and foreign specialists and IAEA inspectors receive training at RMTC.

RMTC methodological support includes:

- Regulation and guidance development for agencies and facilities;
- Support for ROSATOM in control of NMCA facility systems;
- Development, testing and implementation of non-destructive analysis (NDA) of nuclear materials mass and content in accounting items, accumulation and hold-up; and
- Implementation of non-destructive analysis of solution level and density.

RMTC has laboratories for the practical exercises and research works involving technical instruments used for NMCA:

- NDA laboratory; and
- Bar-code laboratory.

The laboratories have modern equipment, software and samples. The NDA laboratory has a wide set of reference and working uranium and plutonium samples of different isotopic composition and mass.

The paper presents the main outcomes of RMTC development and activity, and the experience of cooperation with the IAEA.

Safeguards Capacity Building – Argentine Experience

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In 1994, the Argentine Nuclear Regulatory Authority (ARN) and the U.S. Department of Energy (DOE) signed a Cooperation Agreement for international safeguards research and development in the areas of nuclear material control, accountancy, verification, physical protection, and advanced containment and surveillance devices.

Over the past 25 years, this collaboration agreement has aided the Safeguards Control Division of ARN in safeguards staff development. The subjects of cooperation and training subjects included safeguards concepts applied to uranium enrichment technologies; containment and surveillance; statistics for safeguards applications; and non-destructive assays, among others.

Cooperation focused on human resource development improved the application of safeguards in the national context, and also evolved into a joint activity including the scheduled training of other national safeguards personnel of the South American region.

This paper will present an overview of the cooperation actions carried out, the resulting impact on the Argentinean safeguards community, and how this long-term endeavor strengthens safeguards application in the country and in the region.

Education and Training Activities of the International Nuclear Non-Proliferation and Security Academy of the Republic of Korea

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The objective of this paper is to explain the education and training activities within the safeguards area of the International Nuclear Non-Proliferation and Security Academy (INSA) of the Korea Institute of Nuclear Non-Proliferation and Control (KINAC). The importance of human resource development (HRD) activities on safeguards increases more and more in international society as the possibility of nuclear crises in Iran and DPRK continues.

The paper will be developed in the following ways. Firstly, a short history of safeguards in the Republic of Korea (ROK) will be given, which will show why and how the ROK has increased its HRD efforts. Secondly, the detailed efforts of the ROK to build a center of excellence (COE) in Korea, in conjunction with the 2nd Nuclear Security Summit (NSS), will be described with a brief explanation of its main activities, direction and perspective. Thirdly, the detailed activities of INSA will be presented, including international training courses; domestic courses; and awareness courses. Finally, the outlook for HRD activities with respect to safeguards will be covered.

[TEC-S1] Recent Examples of Innovation in Safeguards

Analysis of Selected Unmanned Aerial Systems Applications for International Safeguards

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Unmanned aerial systems (UAS) are becoming increasingly prevalent and have experienced rapid growth due to advancements in navigation and control technology. This has resulted in cost reductions that have seen small, agile UASs emerge as a multi-billion-dollar commercial market. Novel UAS applications for industries and government agencies are created almost on a daily basis. Based on expert assessment, UASs could be used as a platform for the deployment of a variety of monitoring and inspection technologies for IAEA safeguards activities. This project focuses on analyzing the potential of applying UAS technology for safeguards use. This includes an investigation of the current state of readiness and commercial availability of UAS technology with associated detection and monitoring systems mounted onboard, potential implications of the introduction of UAS technology on safeguards operational effectiveness and efficiency, and the impact on operations at nuclear facilities.

Four applications were selected for in-depth analysis based on the investigators' consideration of these characteristics, a previous prioritization survey given to safeguards experts, and optimal technical and safeguards application variety. The four applications were: collection of detailed site information (site evaluation); survey of mining and concentration activities; verification of container inventory (nuclear material accountancy); and tag/seal verification (containment and surveillance).

Autonomous Mobile Directionally and Spectrally Sensitive Neutron Detectors

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The paper examines the potential of swarms of autonomous, mobile, directionally and spectrally sensitive neutron detectors ("Inspector Bots") to facilitate efficient and effective IAEA inspections. The inspection scenarios under consideration are 1) detection of undeclared withdrawal stations in the centrifuge halls of gas-centrifuge enrichment plants and 2) detection of the introduction of low-enriched UF_6 at feed stations in such plants. A preliminary light-weight gamma inspector bot has been constructed, carrying three miniature Geiger-Müller counters, for the purpose of prototyping search algorithms and intra-swarm communication. It has been shown to be capable of detecting check sources in the laboratory. The concept for a directional neutron detector in the form of a two-foot high, 8" diameter cylinder of polyethylene moderator, containing three boron-coated-straw neutron counters at a radius of 3", located 120° apart, is presented. This detector can be integrated onto a medium-capacity robot with Mecanum wheels for arbitrary direction of motion, including rotation. MCNP studies show that such a detector system provides both high sensitivity and directionality, making it practical for robot swarms to survey a large cascade hall for undeclared withdrawal stations during a Limited Frequency Unannounced Access, and for robotic Unattended Monitoring Systems to detect the introduction of low-enriched UF_6 in declared feed stations before a fraction of a Significant Quantity of highly enriched UF_6 is produced. The ratio of signals in the three detectors also provides neutron spectral information, making it possible to detect the presence of shielding. It is planned to test the sensitivity of the neutron detector, the stability of its directional indication, and its ability to detect shielding using a moderated and unmoderated ^{252}Cf source.

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Robotics Challenges for Radiological and Nuclear Reconnaissance Applications

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Natural disasters, industrial catastrophes and terror acts pose an unpredictable yet significant risk to the lives and prosperity of the world's population.

The ability to properly assess these situations, especially in combination with radiological / nuclear (RN) threats, remains a significant challenge.

Several incidents in the past decades (Fukushima, Chernobyl, Asse, Majak, Windscale) have underlined the need for robotic platforms that can assist operations in scenarios which are hazardous for human personnel to enter.

Since the late 1980s, robotic solutions have been utilised in many of the response efforts to such incidents, demonstrating their potential to reduce the risk of loss of life, reduce response times and gather essential data.

Robots can be employed in a wide array of relevant and otherwise potentially dangerous tasks including search and rescue, disrupted area mapping, radiation measurement, structural damage assessment, reconnaissance, and manipulation tasks.

Although robotics research has produced impressive results in general, there is still significant room for improvement with respect to the use of robotics in radiological and nuclear related applications. One major problem with R&D in this very specialised field of robotics is the lack of possibilities to test equipment in a realistic environment, especially with regards to radiation sources.

Another challenge is to compare various unmanned systems in the field of outdoor robotics. Robotic competitions have become a common means of evaluating the performance of robotic techniques as well as a tool for trend-setting.

ELROB and EnRicH are two successful examples of such outdoor robotics competitions, aiming to assess the capabilities of robotic systems in realistic disaster response scenarios.

A newcomer to the scene is the IAEA robotics challenge, held for the first time in 2017. The event has a slightly different emphasis, however, and focuses mainly on indoor and structured scenarios. The paper will give detailed insight into these three robotics events that include applications in the RN field.

Robotics for Safeguards Inspection - Drum Store Inspection

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All over the world, stores of waste are kept in steel drums that are crammed in sheds multiples high and deep, often preventing a thorough inspection of the contents of the drums or the use of containment measures like seals. This paper aims to explore robotic systems that can provide a comprehensive and autonomous coverage of such hazardous environments, keeping human inspectors out of harm's way. This is achieved by firstly 3D-scanning the entire area, in order to create a 3D map that allows 3D positions to be tracked, and then using the robotic system to inspect the drums. In this paper, the Data 61 innovation network of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) proposes two robotic systems: (a) one for the top of the drums to be inspected; and (b) the other for an in-layer inspection through pallets.

The Through pallet inspection robot is a small robot that is able to move through the pallets where a forklift's tines sit in order to gather information. This robot would have to be very narrow (<100mm) and long in order to bridge gaps, and navigate through misaligned pallet sections. Tracked wheels would provide sufficient traction and distributed loading even in the case of slippery and uneven surfaces.

In both of these cases the robots would be tethered so that a reliable communication and data transfer is maintained, and the robots could be pulled back via the tether if anything goes wrong. These systems would have a 3D Lidar to map, localize themselves and gather data, cameras to gather visual information on the pallets and barrels, as well as radiation dosimeters or spectrometers for determining levels of radioactivity and identifying the presence of specific radionuclides. This data would all be stored/viewed from within the 3D point-cloud so that the location information is correctly associated.

These systems of robots will give access to an area that was inaccessible in the past, with the potential to assist in both inventory verification inspections and complementary access activities under the Additional Protocol.

Soft Robotics for Safeguards Applications in Radiations Environments

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To improve inspection capabilities, limit inspectors' exposure to radiation and minimize the number of repetitive tasks that are done by hand in a growing number of facilities, the IAEA has welcomed the investigation of robotics for safeguards applications. Traditional hard robotics have long been employed in the nuclear field. However, electronic failure in high radiation environments can severely limit their operating time. The developing field of advanced soft robotics, which employs soft materials such as silicone polymers, and soft actuators such as liquid metals, has the potential to leverage the capabilities of remote technologies while minimizing the failure rate common to hard robotics. Idaho National Laboratory has partnered with Oregon State University's (OSU) School of Nuclear Science and Engineering (NSE) and Oregon State University's Robotics departments to develop and test a prototype soft robotic arm for international safeguards applications. The soft robotics manipulators under investigation offer significant dexterity and mechanical compliance with high degrees-of-freedom, allowing for large contact-area, multi-point gripping, which is particularly advantageous for grasping and emplacing objects. This technology has potential applicability in a range of safeguards inspection tasks, including tag and seal application, environmental sampling and spent fuel verification. The research currently underway at Oregon State University includes the design and construction of a prototype soft robotic arm that can operate underwater, with integrated touch and deformation sensors to enable closed-loop control of grasping and turning. Testing of the material includes examining the effects of high radiation environments on the system components including: impacts to system function; potential activation of the effector; material degradation with exposure to various radiation fields; and the potential for material reuse.

Radar Imaging for Reliable Safeguards in Harsh Environments

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Optical Sensors have become established as an excellent source of information for environmental detection and safeguards applications. However, relying on optics makes surveillance systems susceptible to visibility restrictions caused by external light sources, dust, smoke or strong radioactive radiation. Radar imaging can obtain 3D images of the environment, unaffected by optical visibility issues as demonstrated for automotive sensing. Additionally, effective shielding of radar sensors can protect them from external radiation, making them a promising option for surveillance in nuclear sites.

Integrated radar technology can provide 3D imaging with modules which can be easily implemented on robotic systems. Such multi-channel radar imaging technology (MIMO) was developed in the Horizon2020 project ‘SmokeBot’. A radar module with 24 transmitter and 24 receiver elements was developed for 3D imaging with better than 1 degree angular resolution. However, radar can provide more than images. Tracking the phase of each voxel in a moving image allows detection of vibrations down to the micrometer range. Characteristic movements of persons can be detected, as well as vital parameters such as heartbeat or breath. The radar vision system can therefore not only see shapes, but also characterize movement patterns making it perfect for security surveillance.

The presentation will introduce radar imaging by comparing its features with optical technology. MIMO is presented in detail, including imaging results from the SmokeBot project. The talk will provide perspectives on radar technology for safeguards applications, to give an impression of the outlook for the technology.

Laser-Based Measurement Tools for Future Enrichment Plant Safeguards

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The International Atomic Energy Agency (IAEA) has a long history of testing and using laser-based technologies for a variety of safeguards applications. Notable laser-based on-site applications include: 3-dimensional laser range (3DLR) instruments, used for facility design information and verification (DIV); laser measurements to verify unique labels and detect signs of tampering; and laser spectroscopy, for non-contact process monitoring. The IAEA is also evaluating analytical laboratory instruments, such as laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) for interrogating individual particles to determine uranium isotopic ratios in collected environment samples. Recent laser technology advancements will likely continue to fuel future IAEA adoption of new and novel laser-based safeguards tools. The Pacific Northwest National Laboratory (PNNL) is currently developing one such tool, called laser ablation, absorption ratio spectrometry (LAARS), for quantitative measurements of uranium material. LAARS uses three tunable diode lasers to simultaneously measure atomic ^{235}U and ^{238}U absorption in an ablation plume created by a fourth pulsed laser. Commercial availability of compact pulsed ablation lasers and the extreme wavelength accuracy and stability of PNNL's tunable diode laser architecture play a pivotal role in achieving high fidelity LAARS assay measurements. The LAARS method is ultimately targeted for either on-site or laboratory-based ^{235}U relative abundance measurements of destructive assay (DA) samples in support of uranium enrichment plant safeguards. DA samples are currently collected on-site, and then shipped to an analytical laboratory for mass spectrometric assay, because the measurement uncertainty requirements for this application are quite challenging. This paper will present the key elements of the LAARS laser system design, recent assay results on collected uranium hexafluoride (UF_6) DA samples, and future operational configurations that may provide immediate on-site DA inspection results or rapid laboratory DA sample screening to prioritize further analysis by mass spectrometry.

Development of a New Confocal Macro X-ray Fluorescence Spectrometer built on a 3D Printer

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For 3D analysis of elementary composition on surface and depth layers of objects with irregular spatial shape, a new type of confocal macro X-ray fluorescence (CM-XRF) spectrometer was designed and built. A simply constructed 3D printer was applied as the moving system for the basic devices of the XRF spectrometer. The SD detector and the low-power air-cooled X-ray tube (4W) were mounted on a vertically moving console and the sample is fixed on the x-y stage of the 3D printer that translates it in horizontal directions within 20 cm lengths. For both excitation and secondary X-ray beams, a new collimator system was planned on the basis of Monte Carlo simulation, performed using the MCNP6 software package, in order to create a macro confocal measuring set-up. The minimum step-size was 100 μm and the spatial precision of the positioning of each mechanical stage (x-y-z) of the 3D mechanical structure was about 5 μm. The minimum achieved diameter of the focal spot of the confocal measuring arrangement was found to be 480 μm, using aluminum tubes as collimator. The measuring confocal spot at the cross-junction of the excitation and secondary fluorescence X-ray beams was positioned on the sample surface by application of two laser beams and a built-in digital microscope. The positioning optical system, together with the MC-XRF spectrometer, were fixed on the horizontal arm of the 3D printer which could be moved in a vertical direction. The XRF and optical positioning system elements were mounted on additional mechanical moving stages for fine manual setting the confocal geometrical set-up. The analytical capability and geometrical resolution of the MC-XRF spectrometer were determined in x-y-z directions and the MC-XRF spectrometer was tested with some analytical applications.

This work has been carried out in the frame of OAH-ABA-23/15-M, OAH-ABA-14/16-M projects supported by Hungarian Atomic Energy Authority and VKSZ-14-1-2015-0021 Hungarian project supported by the National Research, Development and Innovation Fund.

Tamper-Indicating Enclosures with Visually Obvious Tamper Response

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We are developing “bleeding” materials (analogous to visually obvious bruised skin that doesn’t heal) that provide inspectors with the ability to readily recognize, using simple visual observation, that penetration into a material used as a tamper-indicating enclosure has been attempted without providing adversaries with the ability to repair damage. Such a material can significantly enhance the current capability for tamper-indicating enclosures (TIEs), used to support treaty verification regimes. Current approaches rely on time-consuming and subjective visual assessment by an inspector, external equipment such as eddy current or camera devices, or active approaches that may be limited due to application environment. The complexity of securing whole volumes includes: (1) enclosures that are non-standard in size/shape; (2) enclosures that may be inspectorate- or facility-owned; (3) tamper attempts that are detectable but difficult or timely for an inspector to locate; (4) the requirement for solutions that are robust regarding reliability and environment (including facility handling); and (5) the need for solutions that prevent adversaries from repairing penetrations. Our approach is based on a sensor compound within a microcapsule that changes color irreversibly when the microcapsule is ruptured. We are investigating 3D printing of the microcapsules as well as a spray coating formulation.

The anticipated benefits of this work are passive, flexible, scalable, cost-effective TIEs with obvious and robust responses to tamper attempts. This results in more efficient and effective monitoring, as inspectors will require little or no additional equipment and will be able to detect tamper without extensive time-consuming visual examination. Note that, if desired, an autonomous system with a spectrometer could also detect the color change. Applications can include custom TIEs (cabinets or equipment enclosures), spray-coating onto facility-owned items, spray-coating of walls or structures, spray-coatings of circuit boards, and 3D printed seal bodies.

Impact of the Unattended Combined Measurement System (UCMS) on Safeguards Effectiveness and Efficiency

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In 2014, the European Commission designed and implemented a composite detection system to verify operating records relative to the shipment of PuO_2 packages from the production facility to the storage area of a reprocessing plant at Sellafield, UK. The Unattended Combined Measurement System (UCMS) was installed with the support of the plant operator, did not require the presence of inspectors on-site, and has been successfully operated for the last four years to validate the declarations over remote data connectivity with Euratom headquarters.

Comparing the implementation of safeguards before and after the UCMS active commissioning, the paper analyses its impact in terms of effectiveness and efficiency, safeguards confidence, and resources allocation. The authors discuss the lessons learned in terms of technological implementation and experiment how future safeguards approaches might benefit from detection systems integrated with machine learning algorithms and remote data connectivity. Specifically, data analyzed by means of artificial intelligence were found to provide a valid assistance to the inspection process.

Safeguards at Post-Accident Facilities - Case of Fukushima Dai-Ichi Site

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The accident at Fukushima Daiichi Nuclear Power Station, triggered by the Great East Japan Earthquake and the subsequent Tsunami in March 2011, had a major impact on safeguards at the site. JSGO and the IAEA, together with the Nuclear Material Control Center, Tokyo Electric Power Company and Japan Atomic Energy Agency, have been tackling the challenges posed by the accident, such as the difficulty in accessing the nuclear material at the site. From the day of the earthquake, JSGO and the IAEA started discussing how to deal with the challenges and, in May 2012, jointly formulated the Fukushima Task Force, in order to develop a holistic approach to safeguards implementation measures; to monitor the recovery of safeguards; to facilitate discussion of relevant issues; and to consider possible approaches to tackle longer-term safeguards challenges. As a result of close collaboration, all the fuels stored in the Units 4 - 6, the Common Spent Fuel Storage and the Cask Custody Building have been successfully re-verified. A special arrangement, called Short Notice Operational Support Activities, and radiation monitor and surveillance cameras outside the reactors have been introduced to confirm non-diversion of inaccessible material at the site. Fuels in the spent fuel ponds in the Units 1 - 3 are supposed to be removed starting from 2018, and necessary safeguards measures will be applied accordingly. The damaged core material in the Units 1 - 3 poses difficulties in the longer-term. A special sub-group has been established under the Task Force to address the difficulties. Close coordination with the IAEA, and technical support from competent institutions in Japan, are essential to cope with the difficulties. The paper analyzes the discussion between Japan and the IAEA on safeguards implementation at the Fukushima Daiichi after the accident, and summarizes the main lessons learned for safeguards implementation at post-accident facilities.

The ‘BigLock’ Smart Locking System

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In 2013, the specialists of JSC IPK STRAZH (Russia) developed the BigLock smart locking system (hereinafter referred to as the System), based on the GLONASS/GPS technology.

This System consists of a central database server, mobile workplace, software and communication systems (a GSM cellular communication channel using 3 mobile operators, a satellite communication link and an electronic locking/sealing device (ELSD). The ELSD itself is made up of two components: the Sirius reusable electronic unit; and a Sprut-777 standard disposable seal, combined into a single locking/sealing module during seal installation.

The mobile workplace makes it possible to simplify the process of seal installation: the user only has to read the electronic unit and seal bar codes and enter the item ID number by hand or by voice. The system operates in real time, which enables the user to monitor the ELSD condition through transit, and, if the seal is tampered, an alarm signal will immediately pop up in the personal cabinet, showing the location coordinates and time of the alarming event. Also, additional remote sensors (humidity, temperature, gas and other transmitters) can be used to monitor the parameters of the item sealed.

Furthermore, the System may bring additional benefit to continuity of knowledge, including by enabling the routes and timing of item transfers to be followed.

The System has been commercially operated for more than three years; from April 2016 it has been successfully used to track more than 14 000 items within domestic and international transfers.

Nuclear Inspections in the Matrix: Virtual Reality for the Development of Inspection Approaches in New Facility Types

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Virtual reality (VR) environments have been successfully used to support a variety of applications relevant to nuclear safeguards, safety, and security, including IAEA inspector training, dose estimates for personnel, and facility evacuation planning. There are two particularly relevant challenges for VR: first, simulating the functionalities of the radiation detection equipment that an inspector might use, ideally in real-time; and, second, enabling interactions with this virtual equipment so that the experience becomes truly immersive and meaningful. In this paper, we report results from the use of multiplayer VR applications in simple inspection exercises. The VR application includes a number of functional replicas of inspection devices, and a two-layered radiation simulation. The simple layer is used to estimate realistic count rates in Geiger and neutron counters. The complex layer uses a hybrid approach combining pre-computed radiation signatures and detector response functions, based on MCNP Monte Carlo simulations combined with deterministic methods to handle shielding and attenuation effects. This will allowing the movement of sources, detectors, and shielding materials during the exercise.

We make a case for exploring the further potential of VR environments to support innovations in developing facility architectures, nuclear safeguards and verification protocols for treaties that do not yet exist (such as an FMCT); and for future tasks such as establishing verification measures related to weapon-origin fissile materials (as envisaged for material declared excess for weapon purposes), the application of safeguards to former weapons-related facilities or materials, and verification protocols verifying the absence of treaty accountable items or materials. Virtual environments, in particular, could make critical contributions to the development of effective inspection protocols without running the risk of exposing proliferation-sensitive or classified information, which would be a plausible concern in inspection trials in physical facilities. Virtual environments can also offer levels of accessibility and flexibility typically much more difficult to achieve in actual facilities, and they can allow for more substantial collaboration amongst research groups and governments working to find solutions to existing verification challenges.

Augmented Reality Off-the-Shelf Technologies for Enhancement of On-Site and Post-Inspection Processes

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Visualization of data is almost the last step in the long process of sensing data by humans before data indication. Most important and complex data are processed by human eyes: this explains why different concepts of delivering data directly to eyes overplaying a real world view were introduced over recent decades. Mainly these were military projects, so it is hard to estimate their payoff/cost ratio and they were never widely presented to the public. But today, such technologies appear from IT giants as well as innovative middle-size companies, and it is even possible to buy first generation consumer products. Safeguards inspector activities are always subject to thorough preparation, whilst budget and time constraints, responsibility to make measurements, collect samples and retrieve necessary data from containment and surveillance equipment, leave relatively few opportunities to observe and save visual information that could be of interest to the analyst. This is especially the case at a time when the number of facilities under safeguards is rising and new types of facilities are waiting for licensing and safeguards, whilst the Department of Safeguards has no additional resources.

As an example of a potential technology solution, Microsoft HoloLens augmented reality glasses could be used to enhance the effectiveness of the inspector's onsite work, save time and provide the analyst with data not previously collected. Wearables give the opportunity to work with equipment and receive necessary information without interruption of work, just on top or inline of the real environment. Nuclear materials measurements, calculations, digital containment devices access, barcode information etc could be received without additional external displays and related time to process it. Built-in cameras, depth sensors and other optical electronics could build 3D models of surroundings and send this data for later processing or to real-time comparison of changes in design. Voice recognition could help find and visualize necessary data. Since the IAEA modernized legacy containment and surveillance systems information communication, it could be possible to use such secured communication channels for future real-time highly visualized communication of inspectors with headquarters. All these improvements would make decisions about results more reliable and inspection processes faster and more effective.

Virtual Reality: ISCN's Effective Capacity-Building Tool

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Capacity-building is an important area, to be continually reinforced in order to maintain the successful operation of an entity or organization. The depletion of capable human resources due to retirement, ill-health and other unavoidable conditions should be addressed. Valuable knowledge and experience should be shared in a certain way; with ease of comprehension and information retention. Virtual reality (VR) is one tool that can be used in response to the urgent need to capture knowledge and experience from relevant resources. In 2016, the Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN) of the Japan Atomic Energy Agency (JAEA) invested in virtual reality knowledge management technology to equip its Center of Excellence. The ISCN has developed a VR system that provides a three-dimensional computer-generated training environment, which can be explored and interacted with by an individual. Through this VR system, the participant becomes part of a virtual world, immersed within the environment. While there, the individual is able to manipulate objects or perform a series of actions.

This paper describes how virtual reality is being used by the ISCN as an effective capacity-building tool. It will also describe the approach to how the knowledge and experience for a specific subject matter are conveyed through the use of virtual reality. The effectiveness of the tool has been demonstrated since its introduction through application on several occasions within the training course for the State System of Accounting for and Control of Nuclear Material (SSAC). Use of the VR tool brings benefits from zero exposure to radiation within a suitable environment for the participants training, whilst enabling the learning of safeguards concepts and associated nuclear material verification measures.

iDROP, a Promising Virtual Reality Tool to Assist Operations in Nuclear Facilities

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Virtual Reality (VR) is increasingly used in industry to optimize design processes and procedures. It is therefore an obvious consideration for these technologies to be used to support nuclear operations; to solve design scenarios, operational safety and operator training issues. For the past 10 years, the CEA has been developing a tool, called iDROP, which includes VR technologies. This is a unique tool that combines, in a single piece of software coupled with immersive technologies, all the features required to simulate interventions (remote handling or with direct contact) in ionizing environments. In particular, the tool provides for teleoperation during remote interventions, and access for human interventions, while evaluating the doses associated with these operations.

iDROP provides several modules: first, it offers a dose calculation module, based on MERCURE 6.4, which has been optimized for real-time calculations and calculates the dose received by a point in space using the linear attenuation method. Since the calculations are performed in real time, the dose rate and cumulative dose vary instantaneously depending on movements and changes in the environment. The second feature involves physical simulations and kinematic chains. This module solves classical mechanics problems in real time, preventing interpenetration between 3D objects. This module also simulates the robot's kinematic chains and rapidly helps to check the work area's accessibility for these devices. iDROP comes with a module for simulating human movements and verifying the accessibility of worksites and workstation ergonomics for operations carried out by humans. Finally, the main value of this software is the fact that it can be used with VR devices (stereoscopic system, motion capture system and force feedback interfaces), offering a full-scale 3D user experience. This paper first describes the features of the iDROP platform and then lists the benefits of using this tool to prepare for nuclear operations.

Human Performance Testing for Cognitive Science-Informed Information Provision for International Nuclear Safeguards Inspectors

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International nuclear safeguards inspectors have access to more potentially-relevant safeguards information than ever before. Traditional safeguards data sources including State declarations, previous inspection results, and inspector observations are complemented with myriad open sources including news media, overhead satellite imagery, trade data, scientific publications, and even social media information. However, cognitive science and anecdotal evidence agree that the mere availability of more information is not necessarily useful and can result in confusion, errors, frustration, or other symptoms of information overload.

The presentation of safeguards information for inspectors working in the field should enable, rather than distract or overwhelm. If successful, the presentation of information for inspectors working in the field should facilitate more timely, accurate, and situationally aware inspection activities. In this paper, we describe human performance studies conducted at Sandia National Laboratories which were informed by research in the domains of cognitive science and international nuclear safeguards. We have targeted initial human performance experiments in three areas: visual inspection, wayfinding, and knowledge transfer for safeguards. We will describe the motivation, methods, and results of our initial human performance experiments, and outline proposed follow-on human performance experiments that will allow us to make broader recommendations for information provision for in-field international nuclear safeguards inspections.

3S Integration to Support Efficient and Effective Implementation of Key Safeguards Requirements: an Overview of Emerging State Practices

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This paper will argue that integrated approaches to nuclear safety, security and safeguards (3S) are important to support effective implementation and efficient investment of resources in developing countries. The paper will also identify a series of key legislative and regulatory steps countries can take in this direction as they set out to establish or overhaul their regulatory frameworks.

Many successful case studies of 3S integration focus on States with large nuclear industries and regulatory bodies, aiming to solve problems of coordination and duplication of work. By contrast, developing countries often concentrate responsibility for these policy areas within the same bodies because of constraints on the availability of economic resources and expert staff. However, most of the international assistance currently on offer to these countries maintains the separation between safety, security and safeguards, and does relatively little to explore the potential synergies.

VERTIC has a long-established expertise in providing legislative and regulatory support to countries on the implementation of requirements arising from nuclear safeguards and nuclear security. Drawing on our knowledge, and on the experiences of some of the countries we have worked with, we aim to provide an overview of emerging State practices, supplemented and organised through our own analytical work.

Looking at the role of national legislation and regulatory bodies, the paper will identify common requirements and recommendations across safety, security and safeguards, based on international agreements, best practices and guidance issued by the IAEA and other bodies. The paper will then identify implementation “building blocks” such as legal provisions, organisational principles, and regulatory practices that States can put in place to fulfil key obligations across the three areas. This could help countries with limited resources to minimize waste and duplication of work, and improve the effectiveness of their regulatory framework. These “building blocks” do not represent a complete model of legislation or regulatory system, but rather a starting point for countries to build on.

Given the scope of the Symposium, the paper will focus specifically on functions and “building blocks” of particular importance for safeguards implementation.

UAE Safeguards: A Frontline in Nuclear Non-Proliferation

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The United Arab Emirates (UAE) is a nuclear newcomer State that actively supports the international nuclear non-proliferation regime and has acceded to and ratified key international treaties and agreements – including an Additional Protocol (AP) to its Comprehensive Safeguards Agreement (CSA). The responsibility for satisfying these obligations inevitably resulted in challenges for FANR as the UAE made AP declarations and transitioned from safeguards based on a Small Quantities Protocol (SQP) to today's full-scope CSA implementation.

Overcoming these challenges, to keep pace with a rapidly developing nuclear energy program, required a well-managed approach. The approach included early recruitment of experienced staff with safeguards and export control competencies. Development of the State System of Accounting for and Control of nuclear material (SSAC) involved regular engagement with the IAEA, contracting software venders to develop information management systems, and identifying declarable AP activities and holders of nuclear material. Collaboration with the IAEA included technical meetings to develop and monitor an implementation roadmap, making subsidiary arrangements, delivering national workshops, and employing state-of-the-art containment and surveillance systems at the Barakah Nuclear Power Plant. The UAE's success in establishing a peaceful nuclear energy program with a strong safeguards function also benefitted from adopting the IAEA milestones approach. Engagement with national and international partners, in conjunction with specialised Emirati development programs, provided important contributions to sustainable capacity building. Establishing arrangements with national competent authorities for short-notice access of safeguards inspectors was essential to ensuring that IAEA verification activities proceeded without delay.

Implementing a nuclear non-proliferation program that meets a State's international obligations requires significant resources, forward planning and a commitment from Government. By meeting these requirements, developing a close partnership with the IAEA and embracing a policy of transparency, the effectiveness and efficiency of the UAE safeguards system was ultimately confirmed by the IAEA International SSAC Advisory Service (ISSAS).

Plutonium Diversion Detection Training (PDDT) for IAEA Inspectors at the Idaho National Laboratory

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Detecting diversion of nuclear material from nuclear fuel cycle facilities is one of the main objectives of safeguards under a comprehensive safeguards agreement. Effective detection approaches rest on three essential components. First, a well-reasoned verification plan which is based on a perceptive analysis of the facility's operating and accounting documents and includes both an efficient sampling plan as well as a judicious distribution of resources that takes into consideration the available time and working constraints (e.g. security, safety and plant schedules). Second, a sound knowledge of the physical properties of the nuclear material to be verified combined with an in-depth technical understanding of the measurement systems (e.g. neutron and gamma detectors) used for the verification activities including hands-on experience with the factors that affect the measurement results in terms of biases and uncertainties. Third, a practical experience of the statistical tools that can be used for the consolidation and evaluation of the verification data. Due to time constraints and other limitations, the stratification and sampling approach implemented at a facility is usually designed beforehand by senior inspectors and the detailed evaluation of inspection data, including potentially challenging measurement data, is performed at Headquarters by senior inspectors and/or specialized analysts. Safeguards inspectors therefore have few occasions to deploy the full range of competences that they are expected to acquire, maintain, and upgrade throughout their professional life. While a wide variety of theoretical and practical training courses allow them to strengthen and refresh their knowledge of specific topics, the Plutonium Diversion Detection Training course (PDDT) offers the participants a unique occasion to put their multidisciplinary training into practice through the simulation of all aspects of a practical inspection at a plutonium plant. The extensive and versatile inventory of the Idaho National Laboratory facilities makes it possible to create a number of inventive diversion and falsification scenarios which the IAEA trainees are challenged to detect and foil, while complying with the strict safety, security and access constraints that are enforced at facilities holding sensitive nuclear material.

3D Mapping and Visualization of Radioactive Sources for Nuclear Safeguards Applications

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At Lawrence Berkeley National Laboratory, we have developed the nuclear Scene Data Fusion (SDF) capability, which enables visualization of radioactivity in indoor and outdoor environments. By generating a 3D map of a scene using the compact, lightweight system, Localization and Mapping Platform (LAMP), SDF detects and characterizes gamma-ray radiation sources (compact or distributed). LAMP and SDF have been integrated with two commercial gamma-ray imagers to enable demonstration of this advanced capability in safeguards scenarios. The 3D model, produced onboard using contextual sensors (e.g., LiDAR) and Simultaneous Localization and Mapping (SLAM) algorithms, will enable IAEA inspectors to easily orient their location relative to the location of radioactive sources within a given environment. For example, characterization and change detection (i.e., establishing a baseline radioactivity map on an initial inspection, then in subsequent inspections determining whether there are any differences) of waste pits, design information verification (DIV), mapping and detecting anomalies in storage vaults, locating voids in UF6 cylinders, characterization of waste drums, and materials accountancy are all likely applications where SDF will provide significant advanced capability. We have successfully demonstrated this mapping and visualization concept in various environments, including UF6 cylinders in a fuel fabrication facility, mapping contamination in evacuated Fukushima Prefecture communities and within the Fukushima Dai-Ichi Nuclear Power Plant. In addition, SDF has been demonstrated with a number of gamma-ray imagers and detectors deployed on a range of platforms including hand carried, and unmanned ground and unmanned aerial vehicles. Our current integration of SDF/LAMP with commercial gamma-ray imaging systems demonstrates the flexibility of this technology and will enable the advanced mapping and visualization approach for international nuclear safeguards applications to be explored.

[TEC-S2] Automating and Optimizing Data Collection and Processing at HQ

Using Machine Learning and Natural Language Processing to Enhance Uranium Mining and Milling Safeguards

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The recently-developed IAEA Content Reification Engine (ICORE) is used to examine open source reporting and utilise machine learning algorithms to help identify indications of undeclared nuclear fuel cycle activities. At present, when observing mining and milling processes, ICORE does not have a discrete discriminator between uranium mining and other mining processes, apart from the obvious terms 'uranium' or 'nuclear'. Therefore, in an Australian Safeguards Support Programme project, machine learning will be used to evolve safeguards technologies within the uranium mining and milling fields. This will be through the identification of unique discrete terms that differentiate uranium processes from other mining processes. The intent is to support ICORE through natural language processing rules for mining and milling in support of detecting undeclared nuclear activities.

Advanced analytics through machine learning can support current safeguards mechanisms by improving automation and thus increasing the size of the dataset analysed. However, this analysis is dependent on the quality of the training data sets developed to support the machine in its learning. Therefore, a thorough understanding of the language used in the mining sector for uranium mining and milling processes and discriminating this language from the processing of other minerals is required, in order to have the detail to build a natural language processing algorithm.

Australia has approximately one third of the world's recoverable uranium resources and also has a responsible mining sector. Therefore, in bringing together Australian academia, the mining industry, the Australian Safeguards and Non-Proliferation Office (ASNO) and the IAEA, an interrogation of literature, open source documentation and industry engagement can assist in building a solid natural language processing data set to employ within ICORE and support the enhancement of IAEA tools, to strengthen safeguards and maintain the peaceful uses of nuclear technologies.

Semantic Graphs for Safeguards Data Integration, Pattern Matching, and Event Classification

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The data collected for analysis of safeguards-relevant information is complex and heterogeneous in nature, ranging from in-field measurements, satellite imagery, reports, declarations, and other open sources related to a State's nuclear activities. As part of ongoing International Atomic Energy Agency (IAEA) verification activities for nuclear facilities and State evaluations, inspectors and analysts must correlate and analyze these data, which is often a highly manual and time-consuming process, especially with increasing data volume and varying data types, formats, and frequencies.

To help the safeguards inspector and analyst more efficiently review data, semantic graphs are used to intuitively integrate these heterogeneous data, classify safeguards-relevant events of interest, and identify anomalies. Low level data and their relationships are generalized and abstracted as graph nodes and edges, incorporating different data sources, all in a single data structure. Multifaceted graphs can be constructed that merge data from different domains, representing relationships that may be physical, temporal, administrative, or even social. For this paper, an exemplar of in-field containment and surveillance and non-destructive assay (NDA) measurements are used for a safeguarded nuclear facility to create a model of the movement of nuclear materials in containers and casks. By converting in-field safeguards data into a semantic graph and ingesting into a graph database, it is shown how semantic queries are used to match the model against clusters of data to identify, segment, and classify patterns in the data that match the profile of a material movement, whether declared or not. That is, the spatiotemporal relationships inherent in safeguards data are analyzed to extract higher order meaning to find patterns in vast amounts of data. This semantic graph methodology can be applied to ingest data and identify other safeguards-relevant events inside nuclear facilities and at the State evaluation level to help discover complex and subtle activities.

Exploring Strategic Partnerships Between Algorithms and Analysts: Information Analysis Systems in an Age of 'Big Data'

Author(s): Matthew Moran[1]

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The paper explores the utility of algorithmic approaches to the exploitation of open-source information (OSINF), outlining both some of the benefits and challenges encountered. The paper then moves to consider, at a conceptual level, how algorithms can be effectively integrated into the work of analysts, drawing on insights from the field of cognitive engineering. This field has grappled with the challenges of human-computer interaction for decades and holds important lessons in this regard. The paper concludes by arguing that if OSINF is to be exploited effectively for non-proliferation purposes in the age of Big Data, there a need for more interdisciplinary and empirical research.

Autonomous Systems, Artificial Intelligence and Safeguards

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This study explores the mission space and key safeguards challenges confronting the International Atomic Energy Agency (IAEA) today and how the status quo may be impacted by autonomous and artificial intelligence (AI) technologies, e.g. technologies that learn, examine, and take action (autonomy), or methods that utilize Machine Learning (ML) and intelligence exhibited by machines (AI). Principle issues include the operational value of these systems to safeguards, risks and challenges of deployment (e.g., trustworthiness, security), and the likelihood of adoption in the near- to medium term (2-10 years). The study establishes a set of criteria to identify autonomous and AI methods that could impact IAEA safeguards verification activities in the next decade. The criteria are informed by specific safeguards outcomes the IAEA wants to achieve e.g., efficiency, maintaining continuity of knowledge (CoK) on nuclear materials, or identifying anomalies in large amounts of data. The study develops and assesses an inventory of technological methods based on these criteria. The framework for evaluating the methods that could address safeguards challenges consists of five elements: 1) identification of principle safeguards verification challenges; 2) development of criteria that the identified methods would need to address; 3) development of an inventory of methods that could address the safeguards challenges; 4) safeguards use cases; and 5) technical evaluation and analysis of the selected systems. While the study considers the broader subject of autonomy, it should be noted that most of the methods identified in the inventory consist primarily of AI and its underlying ML capabilities which could enable autonomous systems in the future. Use cases identifying scenarios in which the selected technologies could be deployed inform the potential application space and serve as a foundation for analyzing impact. Finally, an evaluation of two specific methods assesses how they might benefit or challenge IAEA safeguards activities.

Big Data Analysis for Non-Proliferation Purposes

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This submission will present the findings of more than one year of work at King's College London to develop a big data platform for non-proliferation analysis. The presentation will present findings around the use of natural language processing, machine translation and other automatic tools for information extraction; advanced visualisation and search techniques for data discovery. The presentation will conclude with recommendations on how such capabilities can complement existing IAEA activities.

OSIS 2.0: Optimizing Analyst-Driven Automation of Open Source Information Collection and Processing for Safeguards State Evaluation

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Collecting and processing open source (OS) information is an important aspect of the IAEA’s mandate to implement safeguards based on all relevant information related to States’ nuclear activities. Since the mid-1990s, the Division of Information Management (SGIM) has been collecting OS information into an internal database, the Open Source Information System (OSIS). In the early stages, the SGIM collection and review process was predominately manual with classic internet searching, PDF printing, and running scripts for uploading files to the OSIS database. Over time, the process has undergone numerous improvements to include elements of automation in order to increase efficiency against an ever-growing stream of open source information. While automation has unarguably been welcome for many of the processing steps, it has been essential to keep the analyst involved at key decision-making points such as judging information for relevance, categorization, and further distribution. With the technological advancement of computing and machine learning during the past five years, however, more options for additional automation of data processing have become available. In 2016, SGIM embarked on a project to integrate and further automate the continuous monitoring, collection, and processing of OS information. This paper describes the process that culminated in the launch in early 2018 of OSIS 2.0, an in-house developed tool that has provided numerous improvements, including: automation of manual steps of collecting and formatting files; creation of a centralized space for analysts to collaborate on information collection and processing; and, improvement of the categorization and distribution capability. Furthermore, automation has enabled analysts to focus efforts more on analysis than collection and processing. The paper will also discuss possible next steps in integrating additional information collection processes into OSIS 2.0 and how far automation can be taken before it starts to have a diminishing effect on reliable information collection and processing.

Report on an International Workshop on the Applicability of New Tools and Technologies for Non-Proliferation

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On 19 April 2018, King's College London, in partnership with the Centre for Non-Proliferation Studies (CNS), held a workshop on new tools and technologies for non-proliferation verification at the Vienna Centre for Non-Proliferation and Disarmament. This presentation reports upon the key findings of the workshop, which focused on advances in remote sensing; collection and management of unstructured data; and multimedia information and data fusion. The presentation concludes with recommendations on how such capabilities can complement existing IAEA activities.

The STEPS Project: Re-engineering, Upgrade and Integration of Safeguards Statistical Tools

Author(s): Jacques Baute[1]; Claude Norman[1]; Robert Binner[1]; Mika Nikkinen[1]; Jan Wuester[1]; Agatha Christina Walczak-Typke[1]; Kamil Krzysztoszek[1]; Sebastien Richet[1]; Jonetta Gar-Yan Ng[1]; Oleksandr Maistrenko[1]

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This paper describes the IAEA Department of Safeguards' efforts to modernize statistical analysis tools used in planning and evaluating IAEA safeguards activities through the Statistical Testing, Planning, and Evaluation of Safeguards project (STEPS). In the evolving world nuclear landscape, the IAEA needs to continue to draw soundly-based safeguards conclusions and to maintain confidence that States are abiding by their safeguards obligations. This endeavour brings about numerous and complex challenges, inter alia, the need for the Department of Safeguards to collect, process and analyse an increasingly large volume of data from diverse sources and to maintain its effectiveness under static resource conditions. These multiple challenges call for the use of state-of-the art, versatile and increasingly performant statistical methodologies and tools for the collection, consolidation, evaluation and presentation of data from different sources, e.g. State declarations, inspector verification activities and other relevant information, and for the planning of safeguards activities and the determination of their effectiveness and efficiency.

[TEC-S3] Advancements in Instrumentation, Data Processing and Analysis

Building Safeguards Technologies using Open Source Software and Hardware - Learning from the Maker Movement

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Safeguards technologies are typically developed by the Agency and national support programs. More and more, they rely on extensive software and information technology usage. Especially in these fields, recent years showed the advance of new approaches to foster innovation. There is increased use and development of open source software, where not only a software package is shared freely, but also the underlying source code. It is now a widespread way of developing and distributing new software. Similar to the software engineering process, hardware designs can be shared under open hardware standards. This, together with the maker movement, created very efficient innovation environments for people to develop new tools and projects.

In this paper, it will be analyzed how lessons learned from these areas could be applied to the development of new safeguards technologies. Open source approaches could potentially increase the number of participants helping develop tools. At the same time, they would allow to put verification and monitoring tools under external scrutiny, thus increasing trust and transparency. Lastly, they could increase the actual user community by lowering costs and access barriers to tools, helping capacity building as well as the daily operation. The paper will introduce the open source approaches and the maker community and discuss how safeguards technologies would benefit from integrating those ideas. As an actual example, a prototype gamma spectrometry information barrier, which was built using open source software and open hardware, will be introduced. In the end, the paper will lay out ways to implement the discussed approaches.

Estimation of Dead-Time Loss for High Neutron Count-Rates and associated Multiplicity Correction using Multi-Channel List-Mode Data

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Neutron multiplicity counting is a technique widely used in safeguards for the determination of mass of fissile material. The multi-channel list-mode recording of neutron data provides a large amount of data, the analysis of which provides increased possibilities due to the exact time and channel information. Here, a new method for dead-time correction in neutron multiplicity counting is presented. The enhanced analysis possibilities are used to calculate a second pulse train containing estimations of pulse losses at specific positions. The system calibrates itself by calculating the probabilities of dead-time loss using some basic properties of the Rossi-Alpha distribution. This is done with actual measurement data, provided the amount of data is large enough to result in good statistics. The histograms of Reals plus Accidentals (R+A) and Accidentals (A) obtained by multiplicity counting are corrected using statistical methods; Singles, Doubles and Triples are calculated later from these corrected R+A and A histograms.

Improved Cherenkov Light Prediction Model for Enhanced DCVD Performance

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The Digital Cherenkov Viewing Device (DCVD) is an instrument used to verify irradiated nuclear fuel assemblies in wet storage based on the fuel's Cherenkov light emissions. The DCVD is frequently used for partial defect verification, verifying that 50% or more of an assembly has not been diverted. The verification methodology is based on comparison of the measured Cherenkov light intensity to a predicted intensity, based on operator declarations.

For the last five years, a dedicated PhD project at Uppsala University has been aiming at enhancing and improving the verification capabilities when using the DCVD. The project is now approaching its end, and this paper summarizes the comprehensive work performed regarding improving the prediction capabilities.

A new prediction model has been developed, considering more fuel assembly details to ensure more accurate predictions. With the new model, the irradiation history of an assembly, the assembly design and the contributions from gamma and beta decays are taken into account. The model has also been extended to account for the radiation from neighbouring fuel assemblies, which can enter the assembly being measured and contribute to the measured Cherenkov light. The performance of the prediction model and the neighbour intensity prediction model has been validated against fuel measurements by the IAEA at a PWR facility with short-cooled fuel. The results show that the new model offers an improved prediction capability, allowing the fuel inventory to be verified with no fuel assemblies being identified as outliers requiring additional investigation. A simplified version of the prediction model will be implemented in the next DCVD software version, making it available to IAEA inspectors.

This development of the DCVD capabilities are in line with the fourth theme of the IAEA safeguards symposium, "Shaping the future of safeguards implementation", by resolving challenges related to the DCVD and by extending the capabilities of the instrument.

IRAP: a New System for Integrated Analysis and Visualization of Multi-Source Safeguards Data: Challenges and Techniques

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Unattended monitoring, video surveillance and automated review have become increasingly important for nuclear safeguards over the last 20 years. An increasing number of such systems, providing a huge amount of information to inspectors, combined with the need to optimize human resources in operational units, made it necessary to develop an automated data review platform, supporting inspectors in their daily work. The capacity to collect, store and transfer data has been growing rapidly, but the ability to analyze these huge quantities of data has developed at much lower speed. This has resulted in new challenges in the visualization and analysis process, as nuclear inspectors depend on information "available" in the data. IRAP, the "Integrated Review and Analysis Package", is a software system for making unstructured raw data available to various data visualization and review tools. Raw data is collected from many different sources such as radiation monitors, electronic seals and surveillance systems. The system is designed to structure and perform interpretation of massive amounts of data based on the inspectors' judgement using means of visual representations combined with advanced scientific methods like ORIGEN (Oak Ridge Isotope Generation), FRAM (Fixed-Energy, Response Function Analysis with Multiple Efficiency) or INCC (IAEA Neutron Coincidence counting). A future approach combines data analysis techniques with image processing tools: the proposed method in combination with new reporting tools will enable extraction of the most relevant information from provided datasets. This paper presents an overview of challenges and techniques of the IRAP development, based on a partnership agreement between European Atomic Energy Community (EURATOM) and the IAEA initiated in 2013. It describes the state-of-the-art and points to the most likely future challenges and development directions in the coming years.

Developments in Fresh Fuel Collar Measurements with Fast Neutron Detection

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The neutron coincidence counting (NCC) method has been applied for many years in nuclear safeguards. This method is beneficial in allowing large items, such as fuel assemblies, to be interrogated evenly, leading to precise and accurate non-destructive assay measurements of fissile materials. Traditionally NCC has been performed with helium-3 detectors with measurements of thermalized neutrons and has worked very successfully. Currently, however, it is common practice to add burnable neutron poisons into fuel matrices which adds an additional influence into the assay measurements which has to be considered and addressed with ultimate effects of large extensions of measurement times or by large correction factors.

CAEN S.p.A and the IAEA are currently applying a novel approach to solve this problem of measuring fuels containing burnable poisons. The use of fast neutron detectors coupled with fast digitizing electronics and bespoke software and analysis algorithms allow NCC to be performed with fast neutrons. A series of optimized digital filters including time-coincidence, pulse-shape discrimination, pile-up and cross-talk rejection, are used on-the-fly to isolate coincident neutrons produced in the same fission with very high precision and at very high detection rates. The outcomes are that fuel assemblies can be assayed quickly, precisely and without large correction factors, thereby greatly improving the performance of fresh fuel collar measurements. The recent developments of the fast neutron coincidence collar (FNCL) and performance of the system are discussed.

Fast Neutron Collar Tests at Nuclear Fuel Fabrication Plant in Brazil

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New generation fresh fuel assemblies contain more burnable poisons (gadolinium, Gd), to compensate for the reactivity and adjust the distribution of power in the reactor core. However, the presence of Gd hinders measurement of the uranium quantity using the traditional Uranium Neutron Coincidence Collar (UNCL) in safeguards applications. This non-destructive system, based on passive and active measurements, is used to determine the linear mass of fissile isotopes (^{235}U) in fresh fuel assemblies and can operate in “fast” and “thermal” modes. In thermal mode, the presence of neutron poisons affects the thermal neutrons since the thermal neutrons are captured, and the measurement result must therefore be corrected using the Gd content declared by the operator, thus generating a possible diversion scenario. To solve this problem, the International Atomic Energy Agency (IAEA) has developed the Fast Neutron Collar (FNCL). This new equipment has low dependence on Gd content, better accuracy and shorter measurement time compared to UNCL. As part of an IAEA project, the Safeguards Laboratory of the Brazilian Nuclear Energy Commission, in collaboration with the Brazilian Nuclear Industry (INB), the Brazilian-Argentinean Agency of Accounting and Control of Nuclear Materials (ABACC) and the IAEA, has tested this new prototype using fresh fuel assemblies, under the Brazilian Support Program to IAEA Safeguards (BRZ SP). The aim of this work was to evaluate the performance of the Fast Neutron Coincidence Collar to measure the linear mass density of ^{235}U in fresh PWR assemblies, independent of the presence of gadolinium, as part of the homologation of this equipment for safeguards use. The paper presents the main results of the tests. The preliminary results indicate that the FNCL can be used for safeguards measurement of ^{235}U mass in fresh fuel assemblies containing burnable neutron poisons without requiring declaration by the operator of the Gd content.

Improved Analysis of Verification Data Using List Mode Neutron Data Collection

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Neutron timing information in the form of shift register data, which consists of total neutron counts and coincidences, has been utilized for safeguards verification measurements for decades. Mass determination of uranium and plutonium oxide is enabled by measurement of coincident neutron count rates, as this signature of fission can be used to determine fissile mass. While the shift register provides valuable information about neutron behavior in an item, that information is extremely limited. In typical systems, all detectors must be fed into the shift register as a combined signal, and the time domain of analysis must be pre-selected. Additionally, only multiplicity analysis and coincidence counting can be applied to shift register data.

Advances in data collection and storage technology enable a transition from shift register to list mode neutron data collection for verification measurements. List mode neutron data is a record of the time of arrival of every neutron in every detector channel. While this is a data-intensive shift, the possibilities for application of advanced data analytics methods are vast, as will be demonstrated. Rather than considering all channels together, each detector can be treated independently, allowing for cross correlation analysis of fission neutrons and creation of coincidence matrices, providing useful geometric information. In addition, signatures from several different neutron timing distributions (i.e. multiplicity, Rossi-alpha, time interval, etc.) can be combined and analyzed for better characterization of challenging items (spent/fresh fuel, unknown geometries, loss of continuity of knowledge, etc.) where shift register analysis has proven ineffective in the past. Importantly for continuity and comparison to previous methods, obtaining list mode data still allows for all of the same analysis as shift register data; therefore, in transitioning from shift register to list mode, no information or analysis capabilities are lost. This paper will show advantages of using list mode data for verification measurements using fresh and spent fuel neutron list mode datasets.

Verification Data Pattern Recognition and Change Detection at the Neutron Instrument Level

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As the pressure on International Atomic Energy Agency (IAEA) safeguards resources increases, there is a drive to essentially “do more with less.” New ways of using current verification instrumentation and visualizing the collected data are needed, coupled with maintaining and sustaining the current safeguards instrumentation fleet. This paper explores how to innovate with current safeguards neutron instrumentation using data-driven algorithms at the instrument level. A concept is described for upgrading current neutron counting systems with modern electronics by leveraging electronics developments in other fields (e.g., high-energy physics) to facilitate full list mode data acquisition and, therefore, expand existing analyses to pattern recognition and change detection at the instrument level. The aim is to advance correlated neutron counting by improving the reliability of detecting nuclear material diversion and, at the same time, to improve the sustainability of those systems. It is likely that upgrading existing systems with new hardware and software is more cost-effective than replacing systems with other novel systems that might meet this need. A specific project example is highlighted in which a system was upgraded by retrofitting the standard uranium neutron collar detector with new electronics; as a result, verification data can be analyzed in new ways. A new neutron analysis method, the “List Mode Response Matrix”, has been developed to analyze every pulse train from the detector array and thus enable the verification of spatial information about the assay item for safeguards inspections. This project has improved the reliability of resolving individual fuel pin locations within a given fresh fuel assembly and the percentage of partial defects detected. Herein, the overall concept of upgrading current neutron counting systems is discussed with respect to the potential increase in analysis capabilities. In addition, the details and results of the list mode collar project are discussed.

Disparate Data Integration for Advanced Facility Monitoring

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The International Atomic Energy Agency (IAEA) must ensure the peaceful use of all nuclear materials with a budget that has been compared in size to that of the police department in Vienna. This includes, for example, coverage of nearly 1,300 nuclear facilities spread around the globe and verification of over 200,000 significant quantities of nuclear material. The amount of information the IAEA collects is on an upward trajectory, and data overload is poised to be an ever-increasing stress on the IAEA's ability to perform its safeguards mission. Los Alamos National Laboratory (LANL) has been investing over the past several years in experimental studies within a number of its unique facilities to characterize activity patterns and operational modes using automated methods for disparate data integration. Building on the success of these preliminary studies, there is currently an effort funded by LANL's Laboratory-Directed Research and Development (LDRD) program to develop a testbed at one of the Laboratory's radiological facilities for advancing this work, specifically aimed at safeguards-relevant data streams. The overarching goal of this work is to develop and experimentally validate methods to improve the efficiency and effectiveness of safeguards verification at nuclear facilities, which will allow the IAEA to better utilize the data it is already collecting. This paper describes work that has been done to date as well as implications for future areas of research.

[TEC-S4] Visualization for Information Integration

Visualizing Safeguards Data in a Geographic Information System

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Geographic Information Systems (GIS) are widely used to improve access to and comprehension of spatial-temporal information. The IAEA, through their MOSAIC project, developed the Geobased Data Integration (GDI) portal using the ESRI ArcGIS software platform. ESRI ArcGIS is widely used in the GIS community and it has the capacity to integrate and manage vastly different sets of data. Therefore, GDI has the capacity to add new features and grow in its utility to the safeguards inspectorate.

This paper, in responding to the Symposium's examination of how novel visualization techniques for different data sources can be applied to safeguards, proposes enhanced concepts for incorporating and integrating data sets available to the Agency in GDI. With a particular focus on visualizing the flow of nuclear material accountancy data in GIS, the paper will explore how GIS can improve information sharing across stakeholders in the Department of Safeguards, leading to more effective analyses, safeguards implementation, and maintenance of historical safeguards knowledge.

Interactive Data Visualization Techniques in the Statistical Analysis of Multi-Source Data

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Significant challenges present themselves to evaluators of bulk handling facilities under safeguards. Evaluations require the accurate matching of inspector and operator-provided data, variation across time and space of the packaging of materials within a facility, multiple strata, and sophisticated statistical tests that often need to be applied in an investigative and iterative fashion. We present a number of data visualization techniques and charts integrated into an evaluator workbench. These techniques support the iterative and multi-actor collaborative evaluation process. In addition to the use of charts as visualization tools, charts that support "drag-and-drop" grouping, and then reflect those changes back into the dataset underlying an evaluation, will be demonstrated.

3D Technologies for Nuclear Safeguards Applications: Current and Future Developments

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3D technologies have been used in nuclear safeguards verification for several years. Applications include design information verification, where laser scanners acquire 3D models of nuclear facilities with millimeter accuracy to verify the design information provided by the operators. Several technological developments are currently changing the 3D landscape: 3D imaging systems are getting smaller, faster and cheaper; automated processing algorithms - including machine learning - significantly accelerate the processing pipeline; and related technologies such as augmented and virtual reality are becoming mature and can be used with large amounts of 3D data. These developments will enable a wider use of 3D technologies in current safeguards applications and also open the way for new uses in nuclear safeguards. Examples include: accurate 3D scanning can be applied at dry storage facilities to verify that containers have been immobilized between inspections; continuous 3D imaging can complement or replace standard video surveillance, reducing the work load for video review and automatize the verification of material flow, for example in encapsulation plants; automated 3D data acquisition and processing – potentially using autonomous platforms and drones – will increase the efficiency for design information and verification; mobile 3D mapping and localization enables location-based services and augmented-reality applications during on-site inspections; and the acquisition of as-built 3D data and high-resolution imagery allows the use of virtual reality technologies for training and the preparation of on-site visits. The paper provides an overview of current advances in 3D and related technologies and illustrates how they might be applied to nuclear safeguards in the short and medium term.

Developing a Tool for Acquisition Path Analysis and Strategy (TAPAS)

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Acquisition Path Analysis (APA) is the key element in developing a State-level approach. Based on the State's nuclear fuel cycle and related technical capabilities, the APA generates a list of acquisition paths ranked by their attractiveness for the State. Based on this, the Agency establishes the technical objectives and identifies the safeguards measures for a State. A standardized, transparent and reproducible approach for conducting the APA will help ensure consistency and non-discrimination in safeguards implementation at the State level. Therefore, the authors proposed a formal approach, using a three step methodology: network modelling, network analysis and strategic assessment. First, the process starts by considering nuclear fuel cycle and related technical capabilities of the State to obtain the edge weights of the network. Second, the network is analyzed by enumerating all acquisition paths sorted in order of attractiveness for the State. Third, game theory is used to model the decisions made by the IAEA and the State. As a solution, a Nash-equilibrium can be found that provides an indicator on the effectiveness of the implemented safeguards system. While this approach was implemented as a prototype software, the given paper presents a concept as well as a first working draft for an improved software implementation, using the web framework Django. By means of database techniques, it is ensured that multiple users can access and modify data without loss of data integrity. Furthermore, a user concept will be presented which guarantees a fit to purpose identity and rights management. It will be shown that the software is capable of data administration of all entities in the class diagram; modelling acquisition networks by assessing the attractiveness of each process step; and calculation and visualization of all paths of an acquisition network.

Capabilities of the Acquisition Path Analysis Tool (APAT) for Integration of Multisource Data

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The International Atomic Energy Agency (IAEA) continually seeks to improve its safeguards implementation to better utilize the expertise of Agency staff. With the State-Level Concept, there is a paradigm shift from a prescriptive approach to safeguards implementation to one that allows for more flexibility in optimizing IAEA resources. This evolution in safeguards improves the IAEA's ability to consider the State as a whole through a more integrated evaluation process. The Acquisition Path Analysis Tool (APAT) has been developed at Los Alamos National Laboratory as a prototype system to demonstrate the usefulness of this kind of tool to support planning, implementation, and evaluation of the State-Level Concept. APAT is analysis software that represents the nuclear fuel cycle as a directed graph based on the IAEA Physical Model and provides users with a mechanism for integrating all information compiled through the State evaluation process. It allows for the evaluation of plausible acquisition paths for fissile material in a State, prioritizes them based on safeguards relevant information, and provides users with a dynamic suite of tools for planning, implementation, and evaluation of verification activities. The goals of APAT are to improve resource allocation for more efficient and effective safeguards and contribute to increased consistency and transparency in assessments. This paper describes APAT's key capabilities and its relevance to the State-Level Concept.

[TEC-S5] Improving Cooperation and Coordination in Safeguards R&D

Development of the IAEA Safeguards System and the Role of National Support Programmes in this Process

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The Safeguards system has been constantly evolving since its inception in the 1960's. This is necessary to keep up with the emerging technical (for example, advent of new types of nuclear facilities), institutional (establishment of NPT (Non-Proliferation Treaty), conclusion of various international agreements demanding IAEA control) and economic (increase of the quantity of nuclear material and number of nuclear installations, to which IAEA safeguards are to be applied, while the financial, technical and human resources are limited) challenges. These challenges require constant evolution, improvement and optimization of the system, first and foremost in professional and technical terms. This report shall use this particular angle to examine the mechanism of support programmes as the main path of assistance to the Agency in implementing the safeguards and to show the role of member-states in the process of development of the safeguards system. In particular, the report shall demonstrate one of the oldest national Support Programmes viz. the Russian Support Programme to IAEA safeguards. It will explain its priorities, articulate active tasks and present administrative mechanisms for programme management and interaction during its implementation with the Secretariat. The report shall highlight the efforts to assist the Secretariat in establishing, first and foremost, a technically experienced, highly qualified inspectorate and giving an opportunity of training foreign specialists in the field of accounting for and control of nuclear materials as well as joint work with the Secretariat to build and develop in Russia pool of experts for work in the field of IAEA safeguards and to train Junior Professional Officers. The report shall draw conclusions on broad options available to IAEA member-states for rendering assistance to the Agency in carrying out one of its statutory functions of implementing IAEA Safeguards.

The IAEA Robotics Challenge – Demonstrating Robots for Safeguards Inspections

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IAEA safeguards inspections often involve inspectors making repetitive, time-consuming measurements of nuclear material in parts of nuclear facilities that may be difficult to access or have elevated radiation levels. Advances in the field of robotics have opened up the possibility that autonomous systems could assist inspectors to complete repetitive inspection tasks more efficiently and consistently. This could free-up inspectors to concentrate more on other aspects of the safeguards mission, and help the IAEA to cope with the ever-increasing volumes of nuclear material under safeguards.

The IAEA Robotics Challenge, co-hosted by the Data61 innovation network of Australia's Commonwealth Scientific and Industrial Research Organisation, took place in Brisbane in November 2017. The Challenge aimed to facilitate the development of new robotic systems to help the IAEA conduct inspections. Twelve teams of robotics experts from nine Member States each designed their own robots and brought them to Brisbane where they were required to autonomously navigate inside simulated nuclear facilities and carry out inspection tasks. In order to make the Challenge accessible to robotics experts with varying degrees of prior knowledge of safeguards, the Challenge was precisely defined by breaking it up into specific usage scenarios (such as navigation in the presence of obstacles, automatic recognition of items of nuclear material to be verified, and decontamination of the robotic system). A panel of experts evaluated the robotic systems based on their capability to fulfil the inspection scenarios.

The Robotics Challenge demonstrates the benefits of looking beyond traditional procurement channels to use crowdsourcing for the development of new technologies for verification. Among the systems demonstrated in the Challenge, unmanned surface vehicles for verifying spent fuel in ponds appear particularly promising. As a next step, the IAEA may work with selected robotics teams and Member States to conduct proof-of-concept deployments in real spent fuel ponds. The IAEA may award purchase agreements to the teams with the best robotic designs. This paper will discuss the lessons learned from conducting the Challenge and the prospects for robotics in safeguards inspections.

JRC Euratom Research and Training Programme in Support of Euratom and International Safeguards Regimes

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The European Commission Joint Research Centre (JRC) plays a crucial role in research and training for both Euratom and IAEA safeguards regimes. However, the mission of the JRC is much broader, with three quarters of its activities carried out in non-nuclear fields; working on a number of policy issues ranging from food security to machine learning, from nanotechnology to Earth observation. The availability of multidisciplinary knowledge and the JRC's unique position at the science-policy interface brings challenges as well as opportunities in addressing EU policy priorities. Coordination remains crucial for efficient delivery of results.

In the context of increasing demand and limited resources, issues of prioritization were addressed in the JRC's long term planning which, together with organisational changes, enabled JRC staff to work in a more integrated and efficient way. To enhance multi-disciplinary approaches, ten 'priority nexus' were defined that linked different research areas (e.g. non-proliferation with cybersecurity, protection of critical infrastructure and CBRN security) to benefit from each other through knowledge transfer. With emphasis on a collaborative approach, the majority of JRC projects are now implemented in partnership with other European Commission services, EU Member States, Euratom partner countries, or International Organisations.

Enhancing synergies with EU Member State institutions is one of the JRC priorities, together with opening JRC research infrastructure to European research organisations and continuing support to operation of the European Safeguards Research and Development Association (ESARDA). Cooperation under R&D agreements with key international partners (i.e. the United States and Japan) goes beyond research; with joint training and outreach activities being an integrated part of the coordination mechanism.

This paper will discuss techniques used in order to coordinate JRC nuclear safeguards research, including sound planning; organisational structure; communication; fostering cross-domain collaboration; and efficient use of resources while taking into account relevant knowledge from across the scientific community.

R&D on NDA Techniques for Nuclear Safeguards and Security in JAEA-JRC Partnership in Ispra

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Development of new non-destructive assay (NDA) techniques to characterise nuclear or other radioactive materials, for both nuclear safeguards and security, is challenging for many research organizations. In this regard, the Integrated Support Center for Nuclear Security and Nuclear Non-proliferation of the Japan Atomic Energy Agency (ISCN JAEA) and the Nuclear Security Unit of the Joint Research Centre of the European Commission (EC JRC) have undertaken collaborative research in this field. Recently, their efforts have intensified with development of the delayed gamma-ray spectrometry technique (DGS). DGS is based on measurements of gamma-ray spectra of relatively short-lived fission products, produced by neutron irradiation of nuclear material (NM) samples under analysis. After successful experimentation with this technique, carried out with the PUNITA D-T neutron generator [1], and in view of further fine-tuning of the technique for applicability to nuclear safeguards, new Monte Carlo model-based theoretical simulations were developed. Intensive experiments are currently being performed using an ISCN JAEA DGS experimental system operated within the JRC PERLA laboratory at Ispra (Italy).

Promising experimental results will be presented, including investigation of other test configurations for higher sensitivity of the technique, from the standpoints of high efficiency gamma-ray detection or medium energy-resolution and possibly enhanced fission yields from interrogated NM under analysis. Besides the validation of a new NDA technique, this work will contribute not only towards validation of the theoretical model but also the gathering of new nuclear data. In particular, data obtained at high gamma energy, in the range 3-6 MeV, will open new research opportunities such as enhancing high-energy detection systems.

[1].
https://www.epj-conferences.org/articles/epjconf/abs/2017/15/epjconf-nd2016_09018/epjconf-nd2016_09018.html

Defense Nuclear Nonproliferation (DNN) Safeguards Research and Development: Providing Capabilities that Shape the Future

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The National Nuclear Security Administration's (NNSA) Defense Nuclear Non-Proliferation (DNN) Office of Proliferation Detection funds research and development (R&D) that improves the efficiency and effectiveness of current safeguards and efforts to strengthen existing safeguards measures to detect material diversion in declared facilities. DNN R&D develops advanced tools and methods to provide for comprehensive monitoring, detection and analysis of civilian nuclear fuel cycle programs. Sponsored research provides confidence that special nuclear material (SNM) is not being diverted or misused for the proliferation of nuclear weapons. A safeguards-specific goal is to develop and demonstrate new technologies and capabilities to cooperatively quantify and track SNM throughout a nuclear fuel cycle and detect any illicit diversion of these materials. These goals align with those of the International Atomic Energy Agency's recently released Research and Development Plan, "Enhancing the Capabilities of Nuclear Verification by making use of scientific and technological innovation, and to enhance the readiness of technology and support new verification missions." [1]

DNN supports research and development of technologies and methodologies that can significantly improve or enhance nondestructive assay methods, provide effective containment and surveillance, process and environmental monitoring, and destructive analyses. This paper will provide an overview of the DNN Safeguards R&D program; highlighting efforts that are currently underway and others that are in the initial stages of R&D.

[1] International Atomic Energy Agency, Department of Safeguards, Research and Development Plan, "Enhancing Capabilities for Nuclear Verification", January 2018.

The Belgian Support Programme to IAEA: Past, Present and Future

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Established in 1982, the Belgian Support Programme to IAEA is managed by the Belgian Nuclear Research Centre SCK-CEN. The contributions are in-kind, and typically in the form of providing expert advice on different topics or providing access to existing facilities.

In this paper, we give first a brief overview of past and current tasks of the Belgian Support Programme to IAEA. We then show how the current tasks fit the IAEA's Development and Implementation Support Programme for Nuclear Verification 2018-2019 and the Research and Development Plan. We also propose areas where we envisage contributions in the coming years, according to the existing expertise at the Belgian Nuclear Research Centre SCK-CEN.

An Example of International Collaboration: the Evolution of Active Neutron Interrogation Collar Methods for Modern Fresh Fuel Assemblies

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Global modern nuclear fuel designs are trending to higher enrichment with a larger number of burnable fuel pins to more fully extract the available energy via higher burn up. These design changes challenge current fresh fuel safeguards measures and provide one example of how safeguards adaptation is needed to address industry development. We will present a concept of how a collaboration that leverages facilities and expertise, using international resources effectively and with strong stakeholder involvement, can generate a robust technical safeguards solution. We will present an example of a decades-long collaboration among instrument developers, regional inspectorate, fuel fabricators, and multi-discipline technical experts to address the modern fuel design safeguards challenge. Specifically, we will present a coordinated effort to develop a detailed MCNP model of a reconfigurable fuel bundle and perform measurements on that bundle with an active interrogation collar (UNCL). The UNCL was developed to assay the linear density of fissile mass in fuel assemblies for prevention of nuclear material diversion. Accurate calculation of fissile mass requires an understanding of instrument response in the event of scenarios that include pin diversion, variation of burnable poison, and pin substitution. In the framework of a collaboration project between the US Department of Energy and the National Nuclear Energy Commission of Brazil (CNEN), a research activity is ongoing to develop a reconfigurable short fresh fuel assembly of modern design for calibration and research; model the fuel bundle and predict the UNCL detector response. This assembly, constructed at Nuclear Industries of Brazil (INB), is supported by detailed destructive assay measurements of the nuclear material and detailed engineering drawings. Comparative measurements have been made at INB between production assembly and certified reference short fuel bundles. The short bundle will also be available at CNEN for training, substitution, and other research studies.

Assessment of the Multi-State Collaboration on Geological Repository Safeguards

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In 1988, several States began activities supporting the International Atomic Energy Agency (IAEA) in developing safeguards policy and approaches for the application of safeguards for the final disposal of spent fuel in geological repositories. These activities were coordinated through IAEA Member State Support Programmes, including the multi-Member State Programme for the Development of Safeguards for Geological Repositories (SAGOR, 1994-2004) and Programme for the Application of Safeguards to Geological Repositories (ASTOR, 2005-2017). The SAGOR Programme included a diversion path analysis for spent fuel disposal facilities, determination of safeguards technical objectives, and identification of potential safeguards measures for meeting those objectives. The ASTOR Programme supported the IAEA in assessing how the safeguards measures could be effectively implemented and provided recommendations with respect to the development of applicable technologies. The SAGOR and ASTOR Programmes not only provided an international forum for developing model safeguards approaches, but also allowed the participating States to exchange information on safeguards-relevant aspects of their programmes which provided for better understanding of different design options and differences of perspectives regarding safeguards measures and approaches. The paper will present the author's perspectives on the strengths and weaknesses, as well as successes and failures, of the multi-Member State SAGOR and ASTOR Programmes that developed model safeguards approaches for encapsulation plants and geological repositories.

International Database of Gamma-ray Spectra for U and Pu Isotopic Analysis

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An international database of gamma-ray spectra acquired on uranium, plutonium and mixed oxide (MOX) materials has been developed under the auspices of the International Working Group on Gamma Spectrometry Techniques (IWG-GST) as an online repository to test and validate codes developed for U and Pu isotopics determination from gamma-ray spectrometry. Such a database of reference spectra will be useful for both code developers, to benchmark their newly-developed code or version and thus improve software quality assurance, and end-users, such as Safeguards organizations, operators of the nuclear fuel cycle and R&D institutions, to compare different codes for their own needs and thus understand their capabilities and limitations. The database of uranium, plutonium and MOX reference spectra has been structured according to three main sections: good quality spectra; lower quality spectra; and unusual spectra. In a first step, the spectra collected from IWG-GWT members, together with information on sample composition (reference values) and measurement configuration, were gathered according to the detector type, electronics settings and nuclear material category (U enrichment, Pu burnup, Pu/U mass ratio). Criteria were then defined to populate the three main sections. An automated interface, AutoISOPLUM, was developed by IRSN: to extract the parameters of interest of each collected spectrum; compare them to the agreed quality acceptance criteria; and help in spectrum categorization. The online repository is hosted by the European Safeguards Research and Development Association, and accessible on registration through a common username/password. The paper describes the purpose and background of the International database, its structure, content and access modalities.

[TEC-S6] Integration and Evaluation of Verification Data

Optimal Scheduling of Inspections: Models and Approaches

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A facility is considered the operations of which are subject to agreed rules. Since the Operator of this facility may have an interest in violating these rules, an Inspectorate verifies the Operator´s adherence to these rules. A mathematical analysis of the conflict between the Operator and the Inspectorate requires assumptions concerning the inspection philosophy, timing, planning and more.

In this paper, we first introduce the four dimensions which can be used to classify inspection games over time. Thereafter two inspection games are analyzed in which the Operator's illegal activity needs to be detected within a critical time. Both inspection games differ only by one assumption and its consequences on the optimal inspection strategies are shown. Finally a quantitative assessment of effectiveness and efficiency is presented, and some problems of implementing optimal inspection schedules are discussed.

Examining Inspection Frequency under the State-Level Concept

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Over the past two decades, the IAEA has been moving away from mechanistic, criteria-driven safeguards in favor of the more holistic approach that looks at State-level acquisition paths and focuses on achieving generic and technical objectives. This process began under integrated safeguards and is being expanded and strengthened through the application of the State-Level Concept (SLC). One aspect of State-level safeguards implementation is the need to optimize the frequency and intensity of inspection activities based on safeguards-relevant information, such as the type of safeguards agreement in force for a State and the nature of the State's nuclear fuel cycle and related technical capabilities. Under integrated safeguards, consideration of these factors led to relaxed timeliness goals in certain cases for States with a Broader Conclusion.

However, even as the IAEA moves away from criteria-based timeliness goals, it may still be useful to have a concrete, objective, and consistent framework to determine detection timeliness goals for technical objectives. This would assist in safeguards planning and would provide a defensible link between the IAEA's inspection activities and the fulfilment of technical objectives. Consistent with the SLC, such an approach should allow for flexibility and differentiation based on the findings of acquisition path analysis and other appropriate considerations. A formal framework for determining timeliness goals would also help the IAEA communicate how it determines the optimal mix of safeguards measures while ensuring objectivity and non-discrimination among States.

In this context, the paper focuses on the development of an analytical basis to assist in determining inspection frequency for declared facilities along prioritized acquisition paths. The paper demonstrates this analytical basis using a set of case studies applied to notional States. The selected case studies are intended to be representative of a range of scenarios of nuclear fuel cycle sophistication, from States with relatively low technical capability (e.g., having only a research reactor with production of medical and industrial isotopes) to States with a complete nuclear fuel cycle. Future areas for exploration may include (1) how the IAEA can characterize its confidence in the lack of undeclared activities, and (2) evaluating the effectiveness of this approach using an expanded probabilistic assessment.

Change Detection for Item Difference in Verification Data with Unknown Groups

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This paper describes two change-detection examples that arise in safeguards data evaluation. Example one arises in IAEA verifications, where short-term systematic errors can change over time in operator and/or inspector data. Typically, it is assumed that the short-term systematic errors change from inspection period to inspection period. In some data sets, however, it appears that the short-term errors have changed at other times, so change-detection methods can be used to detect the change times.

The paper introduces a simple lag-one differencing method to estimate the random error standard deviation, and then uses the estimated random error standard deviation to calculate a change-detection threshold in a moving-window method to detect shifts in the short-term error. Performance results on simulated and real data are presented.

Example two arises in process monitoring data, where the background data is often challenging because it can arise from a mixture of many component effects. Therefore, some process monitoring data, such as the measured volume differences in tank-to-tank transfers, are multi-modal mixtures of distributions rather than uni-modal normal distributions. Change detection can be approached in any of several ways in such process monitoring data, depending on the type of change to be detected.

Hybrid Top-down/Bottom-up Uncertainty Quantification for Nuclear Material Accountancy

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Measurement uncertainty quantification (UQ) is important for IAEA nuclear material accountancy (NMA). A measurement's relative standard deviation (RSD) is used to determine sample sizes and alarm thresholds, but RSD estimates are noisy. When the RSD is overestimated, larger sample sizes are required to provide credible assurance of non-diversion. When the RSD is underestimated, the rate of false alarms and follow-up investigations will increase. Therefore improved RSD estimates help inspectors and evaluators provide credible assurance using appropriate resources. This paper describes techniques to improve RSD estimates by combining top-down and bottom-up uncertainty quantification approaches.

In UQ for NMA, bottom-up approaches begin with RSD estimates for fundamental measurands (e.g. gross weight or composition). These fundamental RSD estimates are propagated upward to estimate the RSD for measurands such as fissile mass. The resulting RSD is typically precise because the specified conditions of the measurement are known. Unfortunately the bottom-up RSD is often inaccurate because it does not include all error sources and therefore underestimates the true RSD.

In contrast, top-down approaches evaluate a series of measurements to infer the derived-measurand RSD. IAEA evaluators currently use top-down SD estimates because they are less prone to omit relevant error sources and so are typically more accurate than bottom-up estimates. However in some cases the top-down RSD estimate has poor precision because the available data are few in number or were generated in dissimilar measurements.

This paper presents "hybrid" approaches proposed by IAEA evaluators to combine top-down accuracy with bottomup precision. Two of the hybrid approaches are discussed at length; others are briefly discussed.

In the approaches discussed at length, the top-down RSD is partitioned into a "light" component (estimated via bottom-up) and a "dark" component (the difference). Then a RSD is calculated by adding the dark variance to the measurement's bottom-up variance. The hybrid RSD is accurate but also accounts for measurement-specific conditions. An example is given based on uncorrelated measurements of a standard; extension to the evaluators' use cases remains future work. A similar approach using approximate Bayesian computation (ABC) is also demonstrated.

Evolving Statistical Methodologies for Safeguards

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Statistical methodologies for safeguards were developed at an early stage of safeguards' history and are rooted in the criteria-driven, facility-based approach which has long underpinned the International Atomic Energy Agency's (IAEA) conclusions. While their principles and approaches remain generally valid in the framework of a State-level evaluation, their scope, previously restricted to material balance areas (MBA) within facilities, needs to be expanded to include the analysis of nuclear material flows, inventories and balances for a whole State, taking into account the increasing use of random inspection schemes in State-level approaches (SLA) and the implications for the statistical analysis of data collected according to these patterns. In addition to this undertaking, which poses a number of methodological challenges, new approaches are needed to address increasingly large and diversified data flows, to optimize the distribution of limited statistical analysis resources, to align them with the State-level technical objectives (TO) identified through the acquisition path analysis (APA) performed by the State evaluation groups (SEGs) and to develop probabilistic methods for the quantification of their targeted and achieved attainment. In addition, statistical evaluation results of State declared and verification data need to be consolidated and compared to information from other sources. Last but not least, considerable progress was made in the field of information technology (IT) and statistical methodologies since they were first applied to safeguards several decades ago. The current migration of the IAEA safeguards IT platform under the Modernization of Safeguards Information technology (MOSAIC) project has provided a unique opportunity to adapt and evolve methodologies and to integrate them into new software tools. This paper reviews the efforts undertaken in recent years by the Nuclear Fuel Cycle Information Analysis Section within the Safeguards Department Division of Information Management to review, upgrade, consolidate, and evolve safeguards statistical methodologies and describes the progress accomplished to date.

Towards International Target Values 2020

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Nuclear material accountancy (NMA) for safeguards involves quantitative verification by independent measurements of nuclear material quantities declared by States. The effectiveness of these verifications strongly depends upon the quality of both the facility operator's declarations and the inspector's verification measurements. A reference system is therefore needed to assess the quality of measurement results and compare them with international standards. In the 1970s, the international Atomic Energy Agency (IAEA) defined a set of international standards of nuclear material accountancy consisting of values of the measurement uncertainty δE (relative standard deviation) expected for closing a material balance, for different types of facilities. While they may be used as global limiting criteria in material balance evaluations, these values have not been revised and they do not provide the reference framework that is needed for assessing the measurement uncertainties associated with specific measurands, e.g. weight, volume, concentration, abundance, nor with specific material types encountered in nuclear fuel cycle facilities or specific destructive analysis (DA) or non-destructive assay (NDA) methods. In 1979, the Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the European Safeguards Research and Development Association (ESARDA) opened the way by presenting to the IAEA and EURATOM a list of “Target Values” for uncertainty components in DA methods. The concept of international target values (ITV) was born from the expansion and refinement of this initiative and the first IAEA safeguards technical report 1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials is now regularly reviewed on the basis of a 10 year cycle. The review of the last issue International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials (Safeguards Technical Report (STR)-368) is foreseen to be completed in 2020. It is planned to expand this issue to include more detailed information about bulk (weight, volume) measurement uncertainties, a section dedicated to laboratory performance targets and a summary of methodological developments accomplished in the last decade in the field of uncertainty quantification.

Fields of Poppies: A Novel Visualization for Understanding Top-Down Measurement Uncertainty Components

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Estimated nuclear material measurement uncertainties are fundamental to the International Atomic Energy Agency's (IAEA) statistical evaluation of nuclear material balance for the purposes of detection of diversion, establishing rejection limits for nuclear material measurement verifications, and sample size calculations used in the planning of inspections. These uncertainty values are determined in a data-driven, top-down method using the relative difference of operator declared values and inspector measurement results. The total uncertainty values, in terms of relative standard deviations (RSDs), are decomposed into four components: random and systematic components for both operator and inspector. Because of the complex relationships among the four error components and the total uncertainty, comparing different values and their potential impact on statistical analyses based only on tables of numbers can be very difficult. This paper introduces a completely novel data visualization called Poppy Diagrams that makes it possible to compare multiple measurement uncertainties and their component distributions. This visualization has been implemented in the newly re-engineered statistical software STEPS of the Safeguards Department's Nuclear Fuel Cycle Information Analysis within the Division of Information Management (SGIM-IFC).

[TEC-S7] Blockchain and Safeguards

IT Security and Consensus Mechanisms in Private Blockchains

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In 2017, a study by the Pacific Northwest National Laboratory explored the potential of blockchain (distributed ledger) technology for safeguards applications. Starting from an analysis of the IAEA's requirements for new technologies, this study concluded so-called consortium systems (more commonly called *private blockchains*) might improve on solutions currently used. The paper aims to highlight which issues need to be considered when evaluating the benefits and risks inherent in private blockchains. Special attention will be given to IT security matters.

Since blockchain solutions store information in a distributed fashion, a process for ensuring consistency and validity of the data copies, called *consensus mechanism*, lies at their core. Whereas bitcoin's proof-of-work is often berated due to its energy consumption and limited throughput, the use of private blockchains allows for much more efficient procedures. It is crucial, however, to understand that these rely on certain assumptions about the underlying network and the participants involved in the blockchain. The most important of these assumptions concerns the fault-tolerance the procedures can ensure. While it is not hard to design a consensus mechanism that works well in propitious circumstances, making it resilient to faulty behaviour, which may stem from technical failures but also be deliberately induced by an attacker, is a much more challenging task.

Fortunately, a number of research works has addressed just this question. The paper will provide a high-level overview of the available techniques and the security guarantees they offer. It will stress which matters need to be accurately modelled before choosing a blockchain solution. In a somewhat broader sense, it will also clarify certain popular misconceptions about blockchain technology in general.

Blockchain and Safeguards Information Management: The Potential for Distributed Ledger Technology

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The network ability of blockchain technology to manage and self-audit large volumes of data in a shared, secure and transparent manner has potentially far-reaching value for the way safeguards information is collected, processed, and analyzed. The Stimson Center, in partnership with the Stanley Foundation, held a series of workshops in 2018 from Vienna to the Silicon Valley to discuss this potential. The findings and recommendations in this paper consider the ecosystem of safeguards information management, specifically the landscape of factors determining how safeguards data is inputted, processed and accessed, and how distributed ledger technology (DLT) could be applied, if at all, to provide greater efficiency, data reconciliation, accuracy and trust.

The paper also touches upon the potential for DLT to be applied to export controls and supply chain auditing.

Identifying Safeguards Uses for Blockchain Technology

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In 2016, the Office of International Nuclear Safeguards at the National Nuclear Security Administration (NNSA) within the US Department of Energy (DOE) commissioned the Pacific Northwest National Laboratory (PNNL) to explore the potential implications of the digital currency bitcoin and its underlying technologies on the safeguards system. The authors found that one category of technologies referred to as Shared Ledger Technology (SLT), also known as the blockchain, offers a spectrum of benefits to the safeguards system. The subsequent analysis suggested that both the International Atomic Energy Agency (IAEA) and Member States can use SLT to promote efficient, effective, accurate, and timely reporting, and increase transparency in the safeguards system without sacrificing confidentiality of safeguards data. This increased transparency and involvement of Member States in certain safeguards transactions could lead to increased trust and cooperation among States and the public, further strengthening the international safeguards system. However, additional research was necessary to understand the precise safeguards problem that would most benefit from a blockchain solution. To that end, in 2018, PNNL initiated a follow-on study that examined specific safeguards use cases for blockchain applications. While the intent is to identify at least one safeguards problem that would benefit from a blockchain solution, findings may also suggest safeguards would not benefit from the technology. The proposed presentation will describe the methodology developed in 2016 and the findings from the follow-on study.

Evaluation of a Blockchain-based Nuclear Materials Accounting Platform in Australia

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To explore opportunities in nuclear materials accounting on a shared ledger platform, a blockchain-based solution to reporting nuclear materials was developed and compared to a materials reporting portal on a centralised platform. A blockchain is a type of shared ledger technology, which enables an immutable, objective electronic record to be established by and read by parties who do not necessarily have mutual trust. Detailed encryption key privileges control access to different types of information, and simple automated judgements or pre-agreed transactions can be executed automatically through smart contracts. Two inherent features of a blockchain are consistency and immutability of electronic data held between multiple parties, which may improve trust and transparency between licensor/licensees participating in nuclear materials accounting. However, many perceived advantages may actually relate to associated benefits of transitioning paper- or email-based reporting practices to electronic, online, portal-based solutions, and not directly to the blockchain technology itself.

The purpose of the present research was to perform a trial while separating this important confounding factor. Australia has recently transitioned its NUclear Material BAlance Tracking system (NUMBAT) to a new database that allows permit holders to record nuclear material inventory and inventory changes through an online portal. As a centralised platform, NUMBAT provides a useful point of comparison for evaluating the potential of a shared ledger platform. The shared ledger system was built to hold materials-accounting data conforming to Code-10 XML on a permissioned blockchain and, besides the unique features arising from its blockchain file structure and permission control, to otherwise match user requirements of NUMBAT, the centralised solution. This paper will share the results and conclusions of comparative evaluation of the two systems, performed during trials at the University of New South Wales, Sydney, by nuclear safeguards professionals and other nuclear experts.

Blockchains for Safeguards: Technical, Legal and Political Considerations

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Blockchains constitute novel combinations of distributed databases, cryptography, and computer interaction protocols. The original Blockchain was developed to support the peer-to-peer digital currency Bitcoin, but the relevance of this technology is now being explored in a diverse range of information-intensive industries and activities. This paper will consider how recent advances in blockchain technology might substantively contribute to effective safeguards. The paper will also consider some of the potential legal and political obstacles to the adoption of blockchain-based safeguards systems.

The Conceptual Introduction of the Internet of Things (IoT) and Blockchain Technology in Nuclear Material Accounting and Control at Facilities

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The purpose of this study is to propose ideal applications of novel technology in nuclear safeguards, suggest possible scenarios for application at nuclear facilities and evaluate advantages and challenges when using the new concepts.

Numerous nuclear material accounting reports are submitted to the IAEA, supplemented by accountancy records, supporting documents and source data prepared by the facilities. Due to the vastness of data, the Agency and State authority need significant resources to ensure the consistency and integrity within the data. In addition, accidental or intentional human factors can affect the preparation of the reports.

The introduction of shared-ledger (blockchain) technology combined with the Internet of Things (IoT) can provide possible solutions.

The IoT application, in producing data, reduces the engagement of human factors and increases reliability and accuracy of the information. National accounting reports (ICR, MBR, PIL) mainly require the elemental weights of nuclear material and their measurement can be automated using chemical sample analysis, weight measurement with electronic balance, non-destructive assay (NDA) and barcode systems in the case of using shipper values.

The reliability of data can be ensured through the blockchain technique. Moreover, the data self-checking function developed by the smart contract application of blockchain greatly reduces the efforts of the State authority and the IAEA to achieve consistency and integrity. The database becomes more reliable only when combined with IoT, since the input data should increase confidence.

Based on these concepts, two possible scenarios are developed for a hypothetical nuclear power plant and a fuel manufacturing plant. The efficiency and cyber security aspects of these novel technologies are thoroughly evaluated. The results show that the application not only enhances efficiency by streamlining preparation of reports but also improves the quality of the data. However, considerable efforts are needed to prevent cyber-attack against the blockchain database.

Distributed Ledger Technology used in Nuclear Non-Proliferation Safeguards?

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Blockchain, and distributed ledger technologies more generally, are getting a lot of visibility in the financial world these days, being considered as real game-changers. However, their recent evolutions (multi-channel ledgers, smart-contracts etc.) are still not well known or understood. They may have a huge potential to change the way we will deal tomorrow with different types of transactions and transaction validation. However, before using the technology or exploring its applications, the transposition of financial-oriented distributed ledger concepts towards safeguards concepts should take place, and the efficiency impact should be understood. Once the potential in the safeguards context is well understood, safeguards business processes should be analysed in detail in order to find the optimal places for implementing the technology and maximising the efficiency gain. A market survey will lead to a choice of the best solution to be used for the development of a real testbed for end-to end testing.

The paper will present the methodology developed and used at JRC together with the first results and findings. How to evolve from a testbed, mimicking a specific and concrete situation, towards analysing and concluding the usefulness of distributed ledger technologies in more general, and overarching issues, will be presented and discussed. Special attention will be paid towards encryption, robustness and immunity from cyber threats, automation, the efficient use of the block chain and smart contracts and scalability.

[TEC-S8] Collection, Processing and Analysis of Surveillance Data

Using Deep Machine Learning to Conduct Object-Based Identification and Motion Detection on Safeguards Video Surveillance

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Video surveillance is one of the core monitoring technologies used by the IAEA Department of Safeguards at safeguarded nuclear facilities worldwide. Current IAEA image-review software has functions of scene-change detection, black image detection and missing scene analysis, but their capabilities are not optimum. Because of this limitation, detection of safeguards-relevant events heavily depends on inspectors' visual examination of surveillance videos, which is a time-consuming process prone to errors. To improve the process, we are developing a deep machine learning technique to detect objects of interest in video streams and conduct object-based motion detection. We hypothesize that deep machine learning is effective in solving problems with multi-dimensional features/parameters such as different geometries of casks and fuel assemblies and different configuration settings from one facility to another. A trained deep machine learning algorithm can process video streams automatically to flag, locate, and identify objects of interest in the images. The initial focus of our research is for application at nuclear reactors, such as pressurized heavy-water reactors, where video surveillance is broadly deployed. In a proof-of-concept experiment, we trained and tested a computationally efficient convolutional neural network (CNN) – You Only Look Once (YOLO) – with data collected at a test bed at Brookhaven National Laboratory (BNL). This quick study showed promise for high precision and real-time identification of target objects and sequences for image resolutions comparable to those of the IAEA's surveillance system. Currently, we are tuning our model with representative training data sets, which are being collected at simulated nuclear facilities at Sandia National Laboratories (SNL) and BNL.

In this paper, we will discuss the development of the CNN model and report the results of this study in detail. Our tuned model and algorithm could eventually be integrated with IAEA image review software to significantly reduce the inspector image review burden.

IRAP: a New System for Integrated Analysis and Visualization of Multi-Source Safeguards Data: Challenges and Techniques

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Unattended monitoring, video surveillance and automated review have become increasingly important for nuclear safeguards over the last 20 years. An increasing number of such systems, providing a huge amount of information to inspectors, combined with the need to optimize human resources in operational units, made it necessary to develop an automated data review platform, supporting inspectors in their daily work. The capacity to collect, store and transfer data has been growing rapidly, but the ability to analyze these huge quantities of data has developed at much lower speed. This has resulted in new challenges in the visualization and analysis process, as nuclear inspectors depend on information "available" in the data. IRAP, the "Integrated Review and Analysis Package", is a software system for making unstructured raw data available to various data visualization and review tools. Raw data is collected from many different sources such as radiation monitors, electronic seals and surveillance systems. The system is designed to structure and perform interpretation of massive amounts of data based on the inspectors' judgement using means of visual representations combined with advanced scientific methods like ORIGEN (Oak Ridge Isotope Generation), FRAM (Fixed-Energy, Response Function Analysis with Multiple Efficiency) or INCC (IAEA Neutron Coincidence counting). A future approach combines data analysis techniques with image processing tools: the proposed method in combination with new reporting tools will enable extraction of the most relevant information from provided datasets. This paper presents an overview of challenges and techniques of the IRAP development, based on a partnership agreement between European Atomic Energy Community (EURATOM) and the IAEA initiated in 2013. It describes the state-of-the-art and points to the most likely future challenges and development directions in the coming years.

Implementation Experiences on IAEA Remote Monitoring in India

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Transmission of 'attended and unattended information generated by Agency surveillance or measurement devices' is a provision as per Article 6 of the Additional Protocol to India's Safeguards Agreement INFCIRC/754. Facilitating remote monitoring in one of India's safeguarded facilities is the result of such an efficient approach to safeguards implementation through innovation and cooperation with State authorities and operators to enhance efficiency in IAEA verification activities. The paper describes the implementation methodology of remote monitoring (referred to as remote data transmission) in detail, highlighting benefits such as reducing the Agency's burden with respect to physical verification activities and finances etc. Remote data transmission was implemented in the facility from the beginning of 2017. The service uses a public internet connection with hardware encrypted (using the Agency's encryption hardware) signal transmission over a virtual private network. A dedicated broadband telephone connection provided by one of the State's internet service providers is used for transmitting the data (a standalone connection, outside of the facility's common service). The speed of connection is nominal, of the order of 2 MBPS. A similar hardware decryption system, along with a network (internet enabled) server, is installed in the Department of Atomic Energy (DAE), the Safeguards implementation authority in India, so that the seal information of the safeguarded facility is shared with DAE after the verification process in IAEA headquarters is completed. The seal information from the facility is uploaded to the IAEA server on a daily basis, using the Agency's secure hardware, and the Agency sends the information back to DAE, India, on a monthly basis after receiving the monthly declaration from India. This paper provides the technical details of the remote monitoring system which has been successfully established since its installation in 2017. The paper also addresses the details of discussions with the Agency on information security issues, and the philosophy of layered data encapsulation which includes state-of-health (SoH) check status etc, apart from the basic seal data information. An overall block schematic of the remote data transmission, as well as practical implementation issues such as internet disruption from the service provider side, hardware related problems etc, will be detailed in the paper.

VideoZoom Roadmap

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Surveillance streams contain thousands of images. Inspectors review them in order to find the safeguards-relevant events. Only a small fraction of the images is expected to be safeguards-relevant. Inspectors need tools to focus their attention directly to the relevant parts of the surveillance stream. The VideoZoom approach to reviews detects scene changes on the whole image plane. Changes are summarised and rendered at different levels of abstraction in layers of summaries, each layer revealing complementary information about the changes. By means of a zooming interface, the reviewer navigates the summaries and decides which to examine in full. Reviewers can make best use of their time by investigating what really requires their attention.

Building on this concept, extensions to VideoZoom can be envisaged - to increase the efficiency of video reviews even further by employing video retrieval techniques to model and find events, so that an inspector looking at a specific event can quickly preview all other occurrences based on their similarity. Similarity is measured by comparing image features extracted during video summarization. The accuracy of retrieval results can be improved by ‘implicit’ relevance feedback based on the inspector’s navigation pattern (e.g., user clicks, dwell time), as well as image annotations which are an integral part of the video review process. We can use this relevance information to re-rank video parts by image feature re-weighting. Machine learning algorithms can be used to determine refined feature weights whereby events recommended for review become closer to those under analysis.

Finally, a smart interface to interrogate summaries would avoid zero-result queries by employing a faceted-search approach, similar to that used in e-commerce sites: at any point during the review, the interface would show, in a look-ahead perspective, the distribution of ranked events to elicit the inspector’s interest and possible follow-up.

[TEC-S9] Collection, Processing and Analysis of Satellite Imagery and Open Source Image Data

Change Detection Using Sentinel-1 Synthetic-aperture Radar on the Google Earth Engine Platform

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The European Commission's Copernicus mission regularly releases SAR data from the Sentinel-1 satellites. These data have proven valuable for nuclear non-proliferation verification activities by offering analysts medium resolution datasets for site monitoring at no cost. This paper describes a change detection algorithm based on an omnibus likelihood ratio test statistic for the equality of several variance-covariance matrices following the complex Wishart distribution, with an associated p-value and a factorization of the test statistic. The algorithm runs on Sentinel-1 datasets provided by the Google Earth Engine (GEE) repository using a JavaScript API or a local Docker engine and web browser. By using this cloud computing platform, analysts relinquish the burdensome storage and computation needs from their local network. Examples in the nuclear fuel cycle are used in the paper to illustrate the benefit of this change detection algorithm for analysts.

Integrating Visual Data into Safeguards Implementation and the State Evaluation Process

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[4] *Sandia National Laboratories*

To implement State-level safeguards effectively, the IAEA Department of Safeguards seeks to obtain and make use of all safeguards-relevant information available about each State. This requires going beyond textual information to incorporate different forms of media that potentially contain safeguards-relevant content. This may include static images, such as photographs, schematics, or drawings, but also video, animation, and other (related) visual media. Visual information may have intrinsic safeguards value, distinct from the accompanying text, caption, or file description.

Safeguards analysts routinely engage in a number of discrete information collection and analysis tasks as part of the State evaluation process and preparations for in-field verification activities. All of these tasks stand to benefit from incorporating visual data, which may help safeguards staff better understand locations, processes, or technologies of safeguards relevance. In order to make effective use of visual data for safeguards, it has to be collected, processed, analyzed, and integrated with other safeguards-relevant information of different modalities. Commercial software tools and applications are available to facilitate many of these tasks. One important element of evaluation that needs to take place is assessing the integrity of an image or a video, i.e., to determine whether it has been digitally altered, copied from elsewhere, or presented out of context. Data authentication helps ensure that all the information used by the Department of Safeguards, including open source multimedia data, is stringently assessed for source and content credibility, in addition to safeguards relevance.

The paper suggests specific safeguards uses for visual data, focusing on data obtained in open sources. It demonstrates that integrating multimedia data strengthens the Department’s ability to evaluate safeguards activities in a State and to prepare for field verification activities. Furthermore, the paper discusses preliminary results of an evaluation of several digital forensic software and services for data integrity validation.

Leveraging Computer Vision for Imagery Analytics

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This paper will explore the potential applications and limits of computer vision for analyzing satellite imagery and ground imagery for safeguards purposes. The paper will first detail the current state of the art as it relates to computer vision for three main tasks related to ground and satellite imagery analysis: land classification, change detection, and object identification. The paper will consider the availability of both ground and satellite imagery and, in particular, the effect of higher revisit rates from small satellites on machine learning prospects. Under the banner of computer vision, this paper will then explore the available toolkits and machine learning algorithmic approaches to these tasks that might be useful in a future context. This paper will then examine how these techniques may be leveraged for informing safeguards assessments at the IAEA. Finally, the paper will evaluate both the technical and practical limitations of incorporating computer vision-based imagery analytics into safeguards.

Detection via Persistence: Leveraging Commercial Imagery from Small Satellites

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Sandia National Laboratories and BlackSky Geospatial Solutions Inc. are engaged in an exploratory effort to examine how the capabilities emerging in the small satellite industry, combined with the unique non-proliferation and analytical capabilities at a U.S. national laboratory, can improve remote proliferation detection (PD) and other fields such as safeguards. The effort seeks to leverage capabilities such as adaptable, automated, high-sampling over surrogate sites with increased frequency and rapid revisit rates based on events unfolding on the ground. Such capabilities could be utilized for pattern-of-life analysis or to detect key remotely observable signatures, such as the construction of facilities not included in an onsite inspection or a safeguards design information questionnaire. Companies such as BlackSky are developing the next generation of small satellite systems capable of collecting those signatures. Distinguishing factors of BlackSky include their rapid revisit rates (up to 30 imaging opportunities/day by 2020), individual satellite tasking, and publicly accessible, low cost images, delivering 1m resolution shots at $400/image or less. The increased revisit rates will allow constellations to conduct near real-time activity monitoring of specific geolocations. BlackSky and Sandia also have unique data fusion capabilities. BlackSky can collect large numbers of images, produce correlating reports with photos, create custom alerts, and allow customers to task their satellites if an image is not archived. Sandia maintains strong non-proliferation and data analytics expertise, particularly in machine learning algorithms, change detection, remote sensing data acquisition, modelling and simulation, and neural networks. This paper explores a public-private partnership that leverages these unique capabilities to provide access to mature, deployed technology that, if successful, could provide access to a vast expansion of tools and techniques for safeguards at a fraction of the cost of current government-sponsored systems for a fixed period of time, freeing governments from long-term, costly, and oversubscribed programs.

Exploitation of High-Frequency Acquisition of Imagery from Satellite Constellations within a Semi-Automated Change Detection Framework for IAEA Safeguards Purposes

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The development of constellations of small satellites that offer not just daily imaging, but possibly tens of images per day for any site, has the potential to fundamentally change the monitoring of nuclear fuel cycle related sites using remote sensing. Many organizations are currently building such constellations of satellites, including Planet, BlackSky and Earth-i. These constellations are already providing vast quantities of data, but the imagery's spatial, spectral and radiometric properties are not equivalent to that of precision satellites, for example those operated by DigitalGlobe and Airbus. Therefore, the usefulness of high-frequency acquisition imagery for safeguards applications is evaluated, and a semiautomated change detection framework proposed. The framework includes automated procedures for importing of images, co-registration, three-dimensional projection, and normalization of imagery. After pre-processing, new images will be compared to a large data stack of hundreds or even thousands of previously acquired images of the site. Differentiating safeguards-relevant change from other spurious or changes of less interest will require methodological development in timeseries analysis, expert and machine learning methods, and GIS integration. Once changes have been identified using automated methods, the locations will be flagged, with a rating according to the type of change, and the specific nuclear fuel cycle stage. Alerts will then be sent to the image analyst responsible for the site, for expert review. The analyst will evaluate the accuracy of the alert, thus allowing the system to learn. Implementing the proposed system will require overcoming not only technical, but also procedural challenges, including dealing with issues such as vendor data licensing and data security. The benefits of a semi-automated change detection system could include greater efficiencies in dealing with the large volumes of imagery, more rapid response to changes, and a richer view of site activities such as traffic volume and movement.

Safeguards and Multimedia Data: Appraisal of New Techniques

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Open Source information plays an important role in International Atomic Energy Agency (IAEA) verification activities. The IAEA's organisational capacity for monitoring textual data is already highly developed. In contrast, the burgeoning category of accessible, digital data in multimedia formats, such as pictures, video and audio files, has presented a more challenging target for efficient monitoring in a verification context.

New technologies, e.g. automated audio transcription and extraction of data in multiple languages, would provide greater sophistication and reach for IAEA verification activities, enabling its analysts to efficiently collect, process and analyse greater quantities of multimedia data. Similarly, developments in Optical Character Recognition (OCR), e.g. in identifying, capturing and transcribing embedded text in video files, would enable useful incremental improvements in the systematic incorporation of multimedia data into verification analysis.

In this paper, we assess the suitability for verification analysis of a range of commonly-available open license and commercially-developed tools for analysing audio and video data. The paper adopts a use-case approach in order to test the efficacy of tools and techniques in scenarios directly relevant to IAEA Safeguards research, and by benchmarking the viability of these tools according to their demonstrated Safeguards-relevant applications.

Change Detection Methods in SGIM/ISI for Radar Images

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Change-detection analysis of radar imagery can indicate subtle change, for example, it can reveal tracks of disturbed earth that can be associated with vehicle movements across unpaved roads in the period between collection of the two images. Identifying changes of interest in radar imagery is challenging, and thus difficult to automate, because these changes of interest must be differentiated from changes due to instrument effects, scattering effects (speckle), variations in backscatter (scattering from features of different type or shadow), image-processing effects and background environmental variations. The paper has three goals: (1) describe change-detection methods for radar data with attention given to confidence measures, (2) describe some of the types of changes that radar can detect, and (3) illustrate the performance of change detection algorithms, including results from a new statistical change detection algorithm and a supervised Machine Learning (ML) algorithm.

[NEW-S1] The Safeguards Challenges of New and Advanced Reactors - Partnerships

Stand-Off Nuclear Safeguards and Monitoring for Remote Micro-SMRs

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Remotely-located Small Modular Reactors (SMRs) at the low end of energy production (of the order of 10 MWe, referenced here as Micro-SMRs) present unique challenges to nuclear safeguards and security [1]. These challenges include: geographic isolation and distribution; lack of strong thermal or radiation signature; lack of access to core for monitoring; aqueous fuel forms; and harsh environmental conditions. Addressing these challenges in the most efficient manner will be necessary for the timely development of Micro-SMR technologies. Incorporation of safeguards considerations early in the design process (safeguards by design) along with safety, security, economics and other key drivers, is of importance. The array of advanced fuel cycles under consideration for SMR implementation present little experience base in the international safeguards and security community [2].

Safeguards by design raises the possibility of increased monitoring of operational data for verification purposes (operational transparency), with associated cyber security, unattended monitoring, and stand-off verification requirements.

This paper discusses and presents the possibility of stand-off monitoring of sealed core SMRs with the use of large-area neutron detectors outside shielding, at distances of 10 to 100 m from the reactor core, to track changes in reactor power and fissile isotope inventory. The state-of-the-art of this novel technique will be described, along with perspectives on how this technique could address the IAEA's timeliness goals to detect the movement of significant quantities of undeclared nuclear material. Suggested methodologies for implementing this technique in an effective manner will also be provided.

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Challenges and Notional Solutions for the Application of Agency Safeguards on Transportable Small Modular Reactors

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IAEA safeguards for light water power reactors (LWRs) allow inspectors to provide the international community with a high degree of confidence that nuclear material located at the reactor site has not been diverted to nuclear weapons, other nuclear explosive devices, or purposes unknown. IAEA safeguards for sealed, transportable small modular reactors (SMR), however, are not as well-developed as those for LWRs. Further still, SMRs that are designed to be supplied sealed and fully-loaded to an NPT non-nuclear weapon state (NNWS) party pose even greater safeguards challenges for IAEA inspectors. While the IAEA must verify that all nuclear material contained in such SMRs is accounted for, and any NPT NNWS party that manufactures and/or imports such an SMR must accept safeguards measures necessary to do that, the fact that the reactor is sealed means that neither the IAEA nor the NNWS will have the access to material and facilities in the NNWS normally available for design information reporting and verification and nuclear material measurements. This paper outlines possible elements that could be included in the IAEA's safeguards approach for such factory-loaded and sealed SMRs in NPT NNWS parties. The authors hope to show that a high degree of confidence can be achieved by using a comprehensive set of safeguards activities, approaches, and equipment at both the manufacturing facility and at the site of deployment. To accomplish this objective, safeguards approaches must be developed for the reactor at its deployment site and at the manufacturing facility during the initial fueling and any subsequent fueling and refueling of the reactor.

Addressing Non-proliferation Needs in Advanced Reactors

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In the United States and elsewhere, dozens of innovative start-up companies and other stakeholders are pioneering new nuclear reactor designs that promise to lower risk and cost and reduce deployment barriers. The authors have been studying the implications of international deployment of advanced reactors, which present a variety of different safeguards challenges. For example, the IAEA has no experience applying safeguards to a commercial molten salt reactor, and the liquid fuel used by some designs presents a larger deviation from other types of reactors in the sense that a traditional item accountancy approach will not work. The study is also intended to influence reactor designers while their concepts are still at an early stage, especially as U.S. companies may not be thinking about IAEA safeguards during their design process if their first deployment is intended to be in the United States. If these reactor designs do not incorporate safeguards-by-design principles, future international deployments could involve retrofits at the plant site and added burden on the IAEA and the host state.

This paper will present interim findings and recommendations from the ongoing study and discussions with IAEA staff. In particular, it will include preliminary recommendations to the U.S. Department of Energy concerning R&D priorities for advanced reactor safeguards technologies.

Contribution of the ROK for Supporting Establishment of National Safeguards Systems through Bilateral Cooperation in the Middle East Region

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The objective of this paper is to explain the efforts to support establishment of national safeguards systems in the Middle East area by the Korea Institute of Nuclear Non-Proliferation and Control (KINAC). The importance of exchange of information on SSACs and national safeguards systems through bilateral cooperation with newcomer countries which are unfamiliar with safeguards is increasing, in part following decisions by both the UAE and Saudi Arabia to develop nuclear energy programs.

The paper will be developed in the following ways; firstly, a brief history of supporting activities of the Republic of Korea (ROK) to the countries in the Middle East region for their safeguards-related needs will be presented. Secondly, through describing the detailed efforts of the ROK to contribute to the establishment of national safeguards systems in the Middle East region. Thirdly, the detailed analysis of safeguards-related needs through a milestone approach to infrastructure development will be reported. Finally, the future contribution plan of the ROK to support capacity building of newcomer countries in the field of safeguards will be covered.

[NEW-S2] The Safeguards Challenges of New and Advanced Reactors

Molten Salt Reactors and Associated Safeguards Challenges and Opportunities

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Molten Salt Reactors (MSRs) were first proposed at Oak Ridge National Laboratory (ORNL) shortly after World War II to power military aircraft and were followed by the development of civilian MSR programs, also at ORNL, from the mid-1950s to the mid-1970s. Although the development of the concepts ended in the late-1970s, a wide variety of new MSR technologies are now being developed and are gaining international interest and momentum towards deployment. ORNL continues to be actively engaged in the development of the underpinning science and technology of MSRs, including leading and managing the US national programs. The programs include the evaluation of the associated safeguards challenges and opportunities. As a follow on to our paper at the IAEA Emerging Technologies Workshop in 2016, here we present an update on the evaluation of the specific safeguards concepts and approaches, and potential promising safeguards technologies.

A number of previously-reported technical factors impacting the safeguards of MSRs include: (1) the homogeneous mixture of fuel, coolant, fission products, and actinides; (2) continuous variation of isotopic concentrations in the fuel salt, including removal (passive or active) of fission products, rare earth elements, and noble metals; (3) the potential for online reprocessing whereby some fraction of the inventory can be removed while the reactor is operational; and (4) unique refueling schemes including the ability to continuously feed the core with fresh fissile or fertile material. This necessitates the use of sophisticated modelling and simulation tools for tracking the isotopic masses and signatures throughout the reactor and associated auxiliary processing, and as a function of time as the fuel salt evolves. This paper presents the early results of that analysis and demonstrates how the data is used to underpin the assessment of the necessary safeguards approaches, and instrument and technology challenges presented by MSRs.

Safeguard Challenges and Consideration on Nuclear Safeguards for HTR-PM

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The high temperature reactor-pebble bed modular (HTR-PM) is the first commercial demonstration nuclear power plant of modular HTR under construction in the world. And it is expected to be commissioned by the end of 2018. As a new type of nuclear power plant, on one hand, the safeguard of the nuclear plant will adopt the measures, such as isolation, which are effective for the safeguard of the conventional nuclear plant; on the other hand, since the reactor of HTR-PM differs from the PWRs, it brings some differences in the field of nuclear material accounting. These characteristics such as the pebble bed reactor and the continuous refueling, lead to the difficulties in tracing the pebble in the reactor and the measurement of the burnup history. It is difficult to follow the existing framework to accomplish the nuclear material accounting for the pebble bed HTR. However, the HTR fuel pebble is not attractive for the nuclear proliferation, because it is difficult for the proliferator to reprocess of the TRISO particles in the fuel pebble.

In order to facilitate the safeguard of the HTR-PM, the Institute of Nuclear and New Technology(INET), as designer of HTR-PM, together with the operator, Huaneng Shandong Shidao Bay Nuclear power Plant Company (HSNPC), had proposed some procedures and measures, that is easy to perform and effective, considering the character of the HTR-PM and the existing nuclear accounting framework. In this paper, the principle of the nuclear accounting of HTR-PM and some special measures such as the partition of the accounting regime and the burnup evaluation are presented. And although there are some challenges to accomplish the safeguard of a commercial pebble bed HTR for the first time, there still have some methods to overcome the problems, and ensure the security of the HTR-PM power plant.

Wet Solid Radioactive Waste and Shielding as Alternate Detective Measures

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Research reactors with thermal power of 25 MW or less are assumed incapable of producing 1 Significant Quantity (SQ) of Pu or 233U per annum. The purity of plutonium with respect to 239Pu content varies with fresh fuel type, neutron flux and irradiation time. An increase in irradiation time results in the build-up of 240Pu.

The International Atomic Energy Agency (IAEA) uses Technical Objectives (TOs) and Measures to confirm that the reactor was neither operated, including in terms of shut-down period, in a manner sufficient to produce 1 SQ of Pu or 233U from the core fuel, nor used for unrecorded irradiation of fertile materials to produce Pu or 233U. The paper suggests alternate measures, that correlates wet solid radioactive waste and shielding with reactor power, to attain these two TOs at the IAEA State Level Approach.

Activation products resulting from different sources and components are carried by the fluid inventory of both Primary Cooling System (PCS) and Heavy Water System (HWS). The activation products result during normal operation accumulate in the Ion-Exchangers (IXs) bed and filter as a wet solid radioactive waste over a given period of time. The Primary Cooling System consists of the Pool Water Management System (PWMS) and the Hot Water Layer System (HWLS). The relationship between the activity of total activation products and the thermal power of the reactor is studied and plotted as a characteristic curve of the reactor. The difference between measured and calculated values is an indication of unrecorded operative power and falsification of records; Unrecorded irradiation of fertile materials and their removal took place. The depth of light water above the spent fuel assembly in the service pool is a shielding requirement analyzed as another possible indicative measure. The suggested approach is applicable to all research reactors, in particular new advanced research reactors. The calculation and analysis were carried using MCNP5 Monte Carlo Code. Additionally, ORIGEN-ARP, ORIGEN-S and TRITON modules from Scale6 package and both QADS and QAD-CGGP modules.

Molten Salt Fast Reactor in Generation IV: Proliferation Challenges

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Within the Generation-IV International Forum (GIF), research is performed on molten salt reactor (MSR) concepts. Two fast spectrum MSR are being studied, which are large power units with a homogeneous core: the two fluid 3000MWt MSFR in France, Euratom and Switzerland as well as the single fluid 2400 MWt MOSART in the Russian Federation. R&D studies are on-going in order to verify that fast spectrum MSR systems satisfy the goals of Generation-IV reactors in terms of sustainability, safety, waste management and non-proliferation.

The IAEA defines proliferation resistance as a nuclear power system's capacity to prevent the theft or undeclared production of nuclear material as well as difficulty in use of the technology in respect of procuring a nuclear weapon. GIF has proposed a methodology that should allow the analysis of proliferation resistance issues in systems under development. An initial application of this methodology to the MSFR and MOSART is presented here, including an analysis of both the reactor plant and the fuel processing units, these being located in-situ in these concepts. For this initial study, we have focused our attention on a portion of the methodology retained by GIF. This consists of defining a threat, then analyzing the system's response by identifying: the system elements; the targets involved and the pathways for achieving the proliferant objectives. Counter measures are then proposed as obstacles on the pathways identified. Because the MSFR and MOSART are in the design phase, we have adopted a gradual approach to the issues, focusing on the seemingly most dangerous situations.

This first study case concentrates on the threat represented by a State that wishes to acquire nuclear weapons, and plans to obtain nuclear material from a power plant site based on MSFR and MOSART reactor plants and subsequently process the nuclear material in a concealed installation. More specifically, this study focuses on the threat that fissile material be diverted in such a situation. The purpose of the paper is to work out design recommendations for the elements of the system.

On the Correlations of Burnup and Material Amounts in PB-HTR Material Accounting

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The pebble bed high-temperature reactor (PB-HTR) presents new challenges for nuclear safeguards and material accounting. From the point of view of material accounting, the most important issue is to determine the amounts of the key isotopes of uranium and plutonium. Since there is no practical isotopic measurement of the irradiated fuel elements of the PB-HTR, by far the best approach to determine the isotope amounts in the PB-HTR fuel is through burnup calculations and simulations over the actual fuel recycling process within the reactor. In this work, burnup calculations based on neutronics analysis of the HTR-10, a test PB-HTR located at Beijing, China, are implemented over different operational and shutdown statuses, using different depletion codes including KORIGEN and VSOP. Correlations of burnup values and material amounts in the fuel elements are concluded according to the calculation results. These correlations build a bridge between the normal operation of the PB-HTR and the application of safeguards. Future work will focus on modular PB-HTRs for commercial plants, such as the HTR-PM.

Proliferation Resistance and Safeguardability of Very High Temperature Reactor

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Since the accident at Fukushima Dai-Ichi Nuclear Power Plant in March 2011, Japan's reliance on nuclear energy has decreased. The Very High Temperature Reactor (VHTR) has inherent safety, enabling mass production of hydrogen for a future hydrogen-based society as well as power generation. Development plans for practical application of VHTR have been rapid since the Fukushima disaster, and have drawn attention around the world. Therefore, it is very important to consider the safeguards framework of VHTR before its future exploitation.

In this study, we evaluate the proliferation resistance (PR) of VHTR in order to analyse diversion/acquisition paths and we reflect the outcome in the design of a safeguards approach, using an estimation method recently developed in JAEA for the gamma-rays emitted from spent fuel. For this purpose, we firstly evaluated the intrinsic PR of plutonium (Pu) material against various burnups using some PR evaluation methods. In addition, we assessed the safeguardability of the pebble bed type VHTR (PBR). The PBR loads new fuel online, in the form of spheres, at the top of the reactor and discharges spent fuel spheres with high burnup from the base of the reactor. Given such an online refueling, it is not possible to implement item-based safeguards. As the safeguardability was assessed, we revealed the necessity for a new type of burnup monitoring technology, to measure the burnup level of fuel spheres just after discharge, taking into consideration the threat of diversion/ weaponization scenarios particularly with spent fuel at lower burnup. Therefore, we developed an advanced burnup monitoring method.

In this paper, we show the results of the PR evaluation and propose an advanced burnup monitoring technique as part of a new safeguards approach for VHTR.

High Temperature Gas-Cooled Reactor (HTGR) with Pebble Fuel - Its Accountancy and Verification

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The HTGR with pebble fuel is a typical reactor of the generation IV nuclear energy system, and a module facility in China will commission in the coming years. China has offered to open this facility to the implementation of safeguards by the International Atomic Energy Agency. This paper will discuss an approach for the accountancy system of the module facility and, also, develop some of the verification background to support domestic nuclear material control and international safeguards inspections.

In contrast to the characteristic safeguards consideration of *items* within a conventional PWR, and the *bulk* feature of an enrichment facility, the HTGR's fuel is considered as dualistic: a bulk state in receipt, storage and shipment, but an item state inside the reactor. In general, the accountancy should be based on the accounting (i.e. number) of pebbles, but with consideration of the weights of the elements and isotopes for each batch for transfer and storage. As there is an, albeit extremely low, probability of damaged pebbles and/or malfunction of the pebbles counting equipment, an imbalance in the HTGR's accounting data may arise after a period of operation. An appropriate updating criteria, including MUF evaluation criteria if applied, will therefore need to be developed to meet the requirement of material balance.

Another important consideration is on-site inspection, given the nature of the facility as one with dual-appearance nuclear fuel characteristics. The fresh fuel will be received in cylinders, as a batch, but the amount of nuclear material cannot be considered simply as the total of the batch of cylinders because, for each cylinder, the amount of nuclear material is calculated based on the pebbles; not as a whole but as individual items inside the cylinder. Therefore, the sampling method should be based on the cylinders in a batch together with the number of the pebbles inside the cylinder.

Concerning the graphite moderator balls, the facility may not intend to include them within its accountancy records. However, there is a potential concern, including from a safeguards perspective, due to the possibility of a radiation monitor failure during their transfer. As to spent fuel, whilst a qualified measurement system is required, the accountancy issues should be the same as those in the case of PWRs.

Identifying Preliminary Criteria for Safeguarding Advanced Nuclear Reactors

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Climate change and the urgent need to reduce carbon emission globally forecast a significant rise in the interest of advanced nuclear reactors. The contributed paper presents the results of a dedicated study of proliferation resistance of the main technologies for advanced nuclear reactors. Much of the current safeguards system has been developed and implemented for the water-cooled reactors that dominate the nuclear energy landscape. Advanced nuclear reactors are distinctly different compared with light-water reactors, with the use of different coolants and a broader spectrum of fuel compositions. Some advanced reactor designs employ a fast neutron spectrum, often associated with an ability to create plutonium. The variety of advanced reactor designs and their coolants present challenges to the existing safeguards regime. Some of the designs allow for on-line fuel processing and unique refuelling schemes. These features may require updated or new tools for nuclear accountancy and control as well as built-in technological features to prevent malicious use of the facility. The paper communicates the results of an overview of the most prominent advanced nuclear reactor designs, in which their proliferation resistance is assessed in comparison with the implementation of IAEA safeguards at a light water-cooled reactor (LWR) fuelled with low enriched Uranium, as established in States with comprehensive safeguards agreements and additional protocols. Advanced nuclear reactor technology is presently being developed in several countries, with prototype reactors being projected and, in some cases, constructed.

MYRRHA Safeguards Approach by Design

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Once started as a small irradiation facility, which was already based on the accelerator-driven system concept and had a dedicated objective to produce radioisotopes for medical purposes, the purpose of our MYRRHA programme is to demonstrate the ADS concept at pre-industrial scale, to demonstrate transmutation and - as the reactor is a fast neutron source – to also serve as a flexible multipurpose irradiation facility.

The Belgian Government granted in 2010 a dedicated five-year budget to support the MYRRHA programme; this support has been renewed for 2015 – 2017. In the meantime, the MYRRHA team has developed a detailed implementation strategy, with a phased approach to reduce the technical risk, to spread the investment cost and to allow a first R&D facility to be available by 2024.

In this new approach, the MYRRHA facility will start with the 100 MeV accelerator (phase 1) and will be followed by the 100-600 MeV accelerator section (phase 2) and the reactor (phase 3). Phase 1 is aimed for construction and commissioning by 2024 and will represent a stage-gate for the decision to implement the two following phases. This scenario allows the spreading of investment costs, but also minimises the risks (i.e. accelerator reliability and reactor innovative design options). This scenario has been confirmed with the Belgian Government representatives in charge of the MYRRHA programme.

Given the large quantities of nuclear material present in the core and the adjacent storage facilities, it is of utmost importance to develop a good safeguards approach for the MYRRHA facility. The safeguards approach should evolve with the evolving design of MYRRHA by the application of Safeguards-by-Design. Several points of attention have already been identified and possible solutions have been described.

In this paper, we present the present status of the MYRRHA programme and the perspective for implementation from 2015 on. The safeguards points of attention are discussed, together with the solutions that have been developed. Given the fact that the MYRRHA design is work in progress, this applies also for the development of the MYRRHA safeguards approach.

International Safeguards for Microreactors: Opportunities and Challenges for the International Atomic Energy Agency

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The last 15 years have witnessed increased investment in small-modular reactors (SMRs) as a cost-effective, flexible, and potentially safer alternative to large-scale nuclear generation. Part of this trend has been renewed interest in a sub-category of ultra-small SMRs known as microreactors, which produce no more than 10 MWe. Many microreactor designs embrace novel features or operation concepts, including rapid deployment, easy transportation of main components or an entire unit, unattended operation, minimal onsite fuel storage, or factory construction and refueling. These reactors may be particularly useful for remote operating locations, low-capacity electric grids, or when reactor transportability is required.

Since these features would mark a considerable departure from current nuclear power plant (NPP) design and operations, it is important to evaluate how microreactors may affect the International Atomic Energy Agency (IAEA) safeguards system. This paper reviews current and historical microreactor concepts from the open literature and then performs a deep-dive safeguardability assessment of the 4 MWe U-Battery high-temperature gas reactor design. It examines how low nuclear material quantities, long refueling intervals, and sealed storage locations typical of microreactors may affect inspections, while evaluating how Safeguards-By-Design might help to address potential IAEA needs.

Beyond these technical questions of safeguards implementation, microreactors may also affect safeguards at broader systemic and policy levels. For example, a widespread deployment of microreactors could require substantially greater safeguards resources than a similar generating capacity concentrated at large NPPs. Traditional IAEA practices for design information reporting and verification might not apply well to mobile, factory-fabricated reactors. Furthermore, simplified reactor designs — fabricated, delivered, and possibly owned and operated by a foreign supplier State — may lower the barriers-of-entry to nuclear power development. This could compress the development milestone process for nuclear newcomers or lead to novel regulatory concepts. This paper examines how the Agency might address each of these challenges through existing authorities and implementation of new technical or policy approaches.

Design Solutions for Nuclear Transportable Power Plants with SMRs to Facilitate the Application of IAEA Safeguards and Support the Non-Proliferation Regime

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With the growing demand for electricity, there is an increasing interest in designs of small reactor plants, which enable the power supply to a consumer in areas remote from large electric grids as well as reduction of production costs.

The orientation towards the use of such reactors in foreign countries stimulates Russian developers to search for technical solutions aimed at facilitating implementation of IAEA safeguards at these facilities.

A key feature of contemporary Russian small modular reactor designs is their possibility to be manufactured and loaded with nuclear fuel at specialized enterprises, with further movement to the operating site of the consumer.

The paper shows that this feature and the modular structure of the plant used for Russian transportable small modular reactor designs with factory fuel loading excludes uncontrolled access to nuclear material during the processes of movement and operation of the plant, while nuclear and radiation hazardous operations, including refueling upon the completion of the core campaign (refueling period is about 10 years), and the final stage of decommissioning can be performed exclusively at specialized service centers.

In this connection, the main emphasis in the application of IAEA safeguards, during the operation of such plants, can be placed on containment and surveillance measures.

Non-Proliferation Aspects for Transportable Nuclear Plant Lifecycle

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A new trend in the development of nuclear energy is the use of small modular reactors (SMR) as an energy source for remote regions. A particular direction of this trend involves innovation projects with transportable nuclear power plants (TNPP), which are factory-fueled and thereafter utilise a sealed core with sufficient fuel resources to enable exploitation for 10 years without reloading or storage of spent nuclear fuel at the site. Such nuclear installations have additional proliferation resistance. However, at the earliest (conceptual) stage of such projects, it is advisable to use the "safeguards – by design" approach developed by the IAEA to enable optimized safeguards implementation for these installations.

In this paper, approaches to implement IAEA safeguards measures for TNPP are considered: to satisfy to the maximum extent the requirements of current Agency documents (CSA, VOA etc.) taking into account the requirement to minimize the Agency's expenses and inspectors' efforts using modern methods and remote monitoring means.

Using a hypothetical floating TNPP, the paper will discuss possible combinations of collaboration between the countries involved in realization of such projects (i.e. supplier and host countries), with the aim to support effective and efficient implementation of IAEA safeguards measures.

Protactinium presents a Challenge for Safeguarding Thorium Reactors

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Since their conception in the 1950s, thorium reactors have been pursued as safer and cleaner alternatives to uranium-fueled reactors. Thorium fuel cycles have the potential to be more proliferation-resistant compared to traditional uranium-plutonium fuel cycles, as they could produce less weapons-usable plutonium, and the fissile ^{233}U generated will be protected by co-production of the highly radioactive ^{232}U isotope. Isotopically pure ^{233}U is an attractive material to potential proliferators.

The IAEA has specified that a significant quantity of ^{233}U is 8 kg [1]. The proliferation risks of thorium reactors depend on the amount of ^{232}U present, which varies drastically based on reactor design, fuel burnup, initial fuel composition, and neutron flux and spectrum. While ^{232}U complicates handling ^{233}U, it is unlikely that a typical reactor will generate ^{232}U content high enough to meet IAEA requirements for reduced physical protection [2].

This presentation will describe the major pathways by which ^{232}U is produced in thorium reactors. It will then describe how these pathways might be circumvented. Chemical reprocessing of recently discharged spent fuel would change the quantity of ^{232}U in the final ^{233}U product. Protactinium-233 (half-life = 27 days) is an intermediate formed in the production of ^{233}U. Separation of protactinium during chemical reprocessing would be straightforward and may happen by accident. Chemical isolation of ^{233}Pa, intentional or inadvertent, results in the production of isotopically pure ^{233}U. In the future, IAEA Safeguards must verify that ^{233}Pa is not being diverted from thorium reactors. Therefore, despite their potential for proliferation resistance, thorium reactors will present unique safeguards challenges.

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Fast Reactors, Fuel Cycles and the Problem of Nuclear Non-Proliferation

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In the 60 years of its existence, world nuclear power has passed a long way in its development and has reached a wide geographical spread. Currently, there is quite intensive effort to development the nuclear power technology of Generation IV with better nuclear safety and economical features.

Among these technologies, there are innovative nuclear energy technologies based on fast neutron reactors and closed nuclear fuel cycles. Commercial operation of such types of nuclear reactors, especially together with their nuclear fuel cycle facilities, is a new approach in the world's nuclear power industry. Thus, it requires consideration in the context of the nuclear non-proliferation regime and IAEA safeguards implementation with respect to both fast neutron reactors and related nuclear fuel cycle facilities.

In connection with this, some important features of fast neutron reactors are considered in this paper and elements of possible safeguards approaches for such reactors themselves, as well as their nuclear fuel cycle facilities, are discussed based on nuclear energy technologies developed in Russia.

A short history of fast reactor technology development in Russia and the achievements in this field are presented in the paper. Some features of possible options for launching fast reactors using plutonium fuel and enriched uranium are presented as well. An attempt is made to outline and compare the peculiarities of both on-site and off-site centralized organization of nuclear fuel cycle infrastructure for fast reactor related facilities that are considered important for the implementation of IAEA safeguards.

Alternative Fuel Cycle Materials Verification and Monitoring Using Advanced High-Dose Neutron Detectors

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The development of advanced sustainable nuclear fuel cycles relying on used nuclear fuel is one of the key programs pursued by the United States Department of Energy to minimize waste generation, limit proliferation risk and maximize energy production using nuclear energy. Safeguarding of advanced nuclear fuel cycles is essential to ensure the safety and security of the nuclear material, yet it introduces new challenges associated with novel methods of its handling and processing, and variety of nuclear material forms. Development of technologies tailored specifically for such applications is therefore needed.

Non-destructive assay (NDA) systems currently in use to safeguard used fuel typically employ fission chambers or ^{3}He-based tubes for neutron detection. The purpose of this work is to develop and evaluate technology adequate for the unique challenges of advanced nuclear fuel cycle materials that, in addition, offers potential to exceed performance parameters of the standard NDA systems. The novel technology is based on boron-lined parallel-plate proportional counters and features inherent capability to operate in high neutron count rates and high gamma-ray backgrounds encountered in used fuel and pyro-processing applications. Its design characteristics can be used to minimize gamma-ray sensitivity and to extract average neutron energy information from the multi-plate design.

This high-dose neutron detector (HDND) is currently under development at Los Alamos National Laboratory and was evaluated with a range of process materials at Idaho National Laboratory. A versatile, miniature version of HDND for process monitoring is also currently under development. The HDND demonstrated a capability to operate over a range of six orders of magnitude of gamma dose rate with good neutron detection performance. This paper will describe the detector design optimization for advanced fuel cycle applications and the performance results.

Safeguards Challenges and Safeguards Technology Needs Assessment for Leading Thorium Fuel Cycles

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Several thorium fuel cycle variants are currently being actively pursued by the global nuclear energy community. These variants have short-, medium-, and long-term deployment pathways in a variety of reactor types, including thorium-fueled molten salt reactors. Those pathways in turn give rise to a variety of fuel designs, fuel cycle facilities, and nuclear material processing requirements. These emerging fuel cycles will impact the technical implementation of safeguards, and they already raise questions about the applicability of current verification technologies. To address this issue, research is being performed to produce a detailed safeguards technology road map. It will include a needs assessment of the detection research and development (R&D) necessary to transition the current safeguards technology toolkit to meet the verification needs of thorium fuel cycles, and to formulate the scientific basis for building new instrumentation to fill any potential capability gaps. The purpose of this technology road map is to define and inform on the safeguards technology needs for thorium fuel cycles, reflecting only the leading candidate thorium fuel cycles prioritized based on implementation timescales and the current direction of international programs. This work provides a guide to the priorities for future directed R&D needed to bring the technology readiness levels (TRLs) of safeguards detection solutions in line with the higher TRLs of the most promising thorium fuel cycles. Herein, a summary is presented of thorium fuel cycle options and activities currently underway worldwide, which provides the technical basis for the needs evaluation. The key synergies and differences between these fuel cycles and current conventional uranium- and plutonium-based fuel cycles will be discussed from a nuclear material accountancy and detection standpoint. Reactor inventory calculations, fuel cycle simulations, and conclusions from the safeguards technology needs assessment will be presented, together with plans for experimental validation.

[NEW-S3] Experiences in Safeguards by Design for New Facility Types

Getting Ready for Final Disposal of Spent Fuel in Finland – Lessons Learned down the path of the Safeguards-by-Design Cooperation

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The spent nuclear fuel geological disposal systems in Finland are soon entering the implementation phase, with the start of construction of the encapsulation plant. This calls for parallel identification of adequate safeguards measures and applicable techniques by the relevant regulatory bodies and safeguards authorities.

Multi-party cooperation is indispensable in this challenging task, and the inspectorates of the international safeguards authorities (IAEA and European Commission) have liaised from the inception stages with the national safeguards authorities and the operators of the new installations in Finland. Safeguards-by-Design principles are being employed in a jointly developed process, aiming to assure the safeguardability of the novel installations.

Safeguards-by-Design addresses the complexity of the facilities and is expected to allow for an effective and efficient safeguards implementation making use of synergy effects between the needs of operators, State regulators, EURATOM and the IAEA at the earliest stage possible. Practically, we apply a consultative process of design shaping, through which a geological disposal system becomes inherently safeguards-ready.

The paper presents the major components of the proposed safeguards system and the participatory process of its development and implementation, as well as its interplay with safety and security aspects of the geological deposition and isolation of the spent nuclear fuel.

Incorporating Safeguards by Design Concepts in 700 MW Indian PHWR KAPS-3&4

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The IAEA had been implementing safeguards in India since 1971. In 1988, another safeguards agreement, for implementation of safeguards in NPPs built in cooperation with the USSR, came into force. Consequent to international civil nuclear cooperation, India signed another safeguards agreement, INFCIRC/754, with the IAEA in 2009. All the safeguards agreements of India are INFCIRC/66-based. While the implementation of safeguards in Kudankulam commenced during the construction stage, subsequent safeguards since 2009 on the NPPs offered to the IAEA under INFCIRC/754 have been on operating plants. The task has been quite challenging, for both India and the IAEA, and the task has been accomplished quite satisfactorily.

When India decided to offer two of its new 700 MW NPPs, namely KAPS 3 and 4, for safeguards, the decision was made to take full advantage of the Safeguards-by-Design (SBD) concept which offers inherent cost and technical benefits. Many first-of-its-kind features including SBD were incorporated into the new reactor design. All the major safeguards requirements were documented early in the design phase. These safeguards requirements were considered during design development for the facility. The developed design was evaluated using a Safeguardability Assessment (SA) process to ensure that the IAEA safeguards requirements and goals could be met.

Incorporating safeguards measures early in the design phase has many benefits. It enhances the safeguardability of the nuclear facility. It makes safeguards implementation more efficient and cost effective, for the IAEA as well as for the State. The paper presents details of SBD concepts and the SA process applied in the design of KAPS 3&4, together with the various benefits of integrating the SBD concept in KAPS 3&4 at the design and construction phases.

Experiences and Challenges of Safeguards by Design for J-MOX

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J-MOX construction commenced in October 2010, in accordance with the permission granted following an application submitted in April 2005 for a MOX fuel fabrication business license (J-MOX license) under the system of conventional regulatory requirements in force at that time. With the Great East Japan Earthquake in March 2011 as a turning point, the New Regulatory Requirements (New Regulation) was enforced in December 2013, and JNFL submitted an application seeking permission for modification of the J-MOX license to the Nuclear Regulation Authority (NRA) in January 2014. Further to this application for modification to the license, JNFL submitted the eighth amendment in December 2017; to extend the schedule of construction completion from 2019 to 2022. Further amendments will be expected to cover all countermeasures in conformity with the New Regulation.

As for the safeguards for J-MOX, JNFL had begun to study the safeguards design independently in the 1990’s, to clarify “Preparatory measures” which are essential and quantitative factors to be reflected on the plant designs (e.g. layout, ventilation, electric, process control, etc). Based on the submission of the J-MOX license application, official meetings with the IAEA began in 2005, with most of the inspectorate’s equipment specified through a number of official meetings. However, it is becoming clear that changes to the plant designs associated with the New Regulation will impact upon the design of some of the safeguards equipment.

This paper introduces the experiences and challenges of “Safeguards by Design” for J-MOX from the operator’s viewpoint.

Starting from Scratch – Safeguards by Design work in the Hanhikivi-1 NPP Project

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Fennovoima Ltd is building an AES-2006 NPP in Pyhäjoki. The Hanhikivi site is a green field, without any kind of former industrial activities located nearby. The plant supplier is RAOS Project (a subsidiary of Rusatom Energy International), and the project is now in the licensing phase. Construction of the plant is to start after granting of a construction license by the Finnish Government, scheduled for 2019, with commercial operation in 2024.

Since Fennovoima is a new utility and Hanhikivi is a new site, the safeguards work was started from scratch. From the beginning of the project, the idea has been to include the “Safeguards by design” (SbD) concept in the plant project. The plan supplier agreed in the EPC contract to include the detailed safeguards requirements as part of their responsibility.

Within the SbD framework, Fennovoima and the plant supplier have been cooperating to include the necessary requirements in the plant licensing. In practice, this meant inviting the plant supplier, the Finnish Regulator (STUK), the IAEA and European Commission to the same table for discussions. The first meeting, held in October 2017, was successful, and the SbD work continues as a part of everyday work.

Even though Fennovoima will not possess actual nuclear materials for a couple of years, the company needs to prepare the systems and procedures, to have them ready and running prior to the arrival of nuclear material. Meanwhile, the safeguards work also includes the control of Nuclear Use Items (mostly data and equipment), creating procedures and instructions and training people.

During the safeguards work, STUK, the IAEA and European Commission have been of great assistance by providing the necessary training and guidance.

New Safeguards Tools for Research Reactors

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This paper will explore novel methods to strengthen the safeguards approach for new research reactors through early dialogue and collaboration among key players. Interest in this topic was stimulated by the observation that most historical cases of non-compliance have involved research reactors. While the diversion from or misuse of research reactors was often discovered years after the fact and was usually a relatively small part in a broader pattern of non-compliance, these cases are an indication that the safeguards measures applied at these facilities have been insufficient for early detection and deterrence of such non-compliance. This paper argues that it is time to begin a new dialogue among key stakeholders to improve safeguards effectiveness by exploring new opportunities for collaboration among the various stakeholders (State authorities, facility operators, safeguards inspectors, facility designers and safeguards technology developers). Drawing on safeguards approaches commonly applied elsewhere, the paper will consider new ways of monitoring reactor power and neutron fluence, including through the placement of hafnium coupons or wires in the reactor core, which could be sampled and analyzed as a consistency check for operator power declarations. Another potential measure is the use of mailbox declarations for certain reactor operations, such as the movement of fuel, targets and associated containers, combined with random infrequent inspector verification. Environmental sampling could also be used at key points, including hot cells and waste tanks. Applying these tools selectively, in ways that take into account facility-specific features and opportunities for enhanced collaboration with operators and State authorities, could improve effectiveness of safeguards at detecting early indicators of non-compliance without significant impact on safeguards resources or facility operations.

Safeguards by Design for Storage and Disposal of Nuclear Waste

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The concept of safeguards by design (SBD) is important in ensuring nuclear facilities are designed to effectively and efficiently support IAEA safeguards implementation, without placing undue constraints on operations. There has been much work on SBD for nuclear production facilities (particularly enrichment and reprocessing plants) and for new reactor designs, but little at the very back-end of the fuel cycle. SBD is important at the very back-end of the fuel cycle as design decisions for disposal facilities need to consider the context for an extended period of institutional (operational and regulatory) controls following site closure. Unlike other facilities, disposal sites cannot be ‘decommissioned’, as waste will remain in-situ even after the supporting surface infrastructure is removed. Instead, disposal sites enter a post-closure phase, where institutional controls are maintained for an extended timeframe until free-release of the site. This may initially include active measures, such as ground water monitoring and site surveillance, until radiation hazards have diminished enough to allow for passive-only measures, such as land-zoning restrictions. Engineered and geological barriers are also necessary, to provide safety functions for hundreds of years at low-level waste repositories through to 100,000s years for intermediate and high-level waste repositories.

In some cases, it may be possible to achieve termination of safeguards by diluting or conditioning nuclear material into a practicably irrecoverable state, but this can have significant volumetric impacts. In cases where termination is not appropriate, facility designers and national authorities need to consider how to manage requirements for safeguards, security, safety and environmental protection.

Australia is establishing a low-level waste repository and co-located intermediate-level waste store at a volunteer site for its relatively small holdings of radioactive waste. This paper looks at the safeguards requirements for both storage and disposal facilities and discusses Australia’s experience in considering the impact of different safeguards strategies in integrating with other regulatory requirements. In particular, the paper considers the type and extent of institutional controls for disposing of nuclear material in low and intermediate-level waste repositories.

Safeguards by Design for the Indonesian Experimental Nuclear Power Reactor - A Case Study

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Indonesia has always developed the application of nuclear energy for peaceful uses only. Related to the fulfillment of its national energy policy, Indonesia plans to build nuclear power plants on a small power scale, selecting the Pebble Bed Reactor-type for this purpose. Indonesia, as a signatory State to the Comprehensive Safeguards Agreement since 1980 and its Additional Protocol since 1999, has implemented an SSAC system in its existing nuclear facilities. Furthermore, in the new-build reactor development plan, Indonesia will consider a regulatory basis and practical strategy of Safeguards by Design from the beginning of the projects. In this paper, we will discuss the preparation of safeguards by design for the Pebble Bed Reactor including the challenges in implementation of safeguards by design in the country. More detailed analysis will focus on an explanation of the role of safeguards by design in the existing regulatory system, such as regulations; licensing and inspection activities; and expanding the regulatory requirements in the future.

Implementation of Safeguards Measures at the High Temperature Gas-Cooled Reactor Pebble-Bed Module (HTR-PM) in China and Proposed Safeguards by Design for Units to be Exported to Other States

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The International Atomic Energy Agency (IAEA) is developing safeguards measures for the High Temperature gas-cooled Reactor Pebble-bed Module (HTR-PM) under construction in the People's Republic of China (China), which is under a voluntary safeguards agreement (VOA) with the IAEA. China has successfully operated an experimental prototype 10 MWth high temperature pebble-bed reactor (HTR-10) since 2000. Based on the experience gained with HTR-10, China has designed and is constructing a Demonstration HTR-PM at Shidao Bay in China's Shandong province, which comprises twin HTR-PM reactor modules driving a single 211 MWe steam turbine. The Chinese HTR-PM was added to the list of eligible facilities for IAEA safeguards and the IAEA selected the facility for the application of safeguards in September 2017. Since the design of HTR-PM was complete and the field construction work is almost completed, the development and application of international safeguards measures to the facility have presented challenges to both operators and the IAEA. As there has been no IAEA safeguards experience at the HTR-PM, China expressed interest to work closely with the IAEA to develop safeguards measures for the HTR-PM. Currently, safeguards measures are under discussion for the HTR-PM with the China Atomic Energy Authority (CAEA) and the IAEA. To date, a number of aspects that are important for an optimized safeguards implementation for this type of reactor have been identified, and might be considered for potential modification of the design for the future export market. This paper describes the HTR-PM fuel handling characteristics, provides a summary of the current status of the application of safeguards measures under development by the IAEA, and discusses safeguards-related research topics for potential modification of the design for the future HTR-PM export.

[NEW-S4] Safeguards for New and Operational Facilities and Cooperation between States and IAEA Safeguards

Cooperation between Germany, the European Commission and the IAEA in Safeguarding Spent Fuel Intermediate Storage Facilities

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In phasing out nuclear energy production, the German nuclear reactors will be successively disconnected from the power grid, the last ones by the end of 2022. It is foreseen that all spent fuel assemblies will be loaded into casks by the end of 2027. After their transfer to spent fuel storage facilities (SFSFs), the SFSFs altogether will have a static inventory of more than 1,000 casks. A geological repository for high active waste is planned to be commissioned around the year 2050. The paper addresses safeguards challenges and possible innovative solutions resulting from this situation: Keeping Continuity of Knowledge (CoK) of verified spent fuel. The verification of sealing systems currently used at German SFSFs is a very arduous task, due to the densely arranged casks in a spatially limited storage configuration. The specific conditions of an intermediate SFSF in static operation entail the need for technical solutions to ease the verification of the casks and to minimize the radiation exposure of the inspectors and facility staff. Furthermore no sufficiently precise method is currently available for re-verification of closed spent fuel casks in SFSFs. This will become a pressing issue once the reactors have been decommissioned, because opening spent fuel casks is currently only possible in the cask loading position in a reactor. Therefore, the investigation and development of potentially suitable technologies for re-verification in case of loss of CoK, is required. As one specific method muon tomography will be discussed. In addition, the ongoing re-organization process of the SFSFs due to the transition of the ownership of the SFSFs from the German utilities to the state-owned Gesellschaft für Zwischenlagerung mbH (BGZ) in 2019 is considered. Finally, the distribution of inspection resources on reactors, SFSFs and research labs will have to be reconsidered, because acquisition paths become obsolete due to the decommissioning of reactors.

Status of Nuclear Reactors, Nuclear Fuel Cycle and R&D Facilities in Japan

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The Fukushima Accident, following the East Japan earthquake and tsunami of 2011, has affected Japan's nuclear energy policy. In Japan, as of March 2018, 5 units out of 50 nuclear power plants are in operation, and 2 out of more than 10 research reactors and critical assemblies are in operation. Following the Fukushima Accident, JAEA has been reviewing its mid–term nuclear R&D plan, and has decided to decommission 44 out of 99 facilities, including the sodium-cooled fast reactor Monju; Fast Critical Assemblies, JRR-4; Tokai Reprocessing Plant; and the Plutonium Conversion Development Facility.

On the other hand, other facilities including the advanced high-temperature gas reactor (HTTR) remain in JAEA's mid-term R&D plans. JAEA is also developing an Accelerator Driven System (ADS) for the next generation of nuclear fuel cycle.

This paper provides background information on the symposium theme "explore challenges and opportunities for safeguarding new reactor design" and "safeguards challenges associated with increasing decommissioning activities".

Status of typical JAEA facilities:

Facilities to be decommissioned - Fugen, Monju, FCA, TRACY, JRR-2, JRR-4, TPL, CPF, TRP, PCDF, JMTR, DCA, MMF, AGF, NEP, Conversion

Facilities required in midterm nuclear R&D plan - JRR-3, NSRR, STACY, BECKY WASTEF, Tandem, PPFF, PFPF, Joyo, HTTR, FMF

Implementation of Safety, Security and Safeguards in the Finnish Encapsulation Plant and Geological Repository Project from the Operator's Perspective

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[1] *Posiva Oy*

Finland has progressed in planning for the geological disposal of spent nuclear fuel into the construction phase of the geological repository. The outline schedule for the project was set in the 1980's and the site selection process culminated in 2001, when the Finnish Parliament ratified the decision to site the geological repository at Olkiluoto, in western Finland. Licensing of the facilities advanced significantly in 2015, when the Finnish Government granted the construction license for Posiva, the company responsible for the overall implementation of the project.

The Finnish solution for the final disposal is based on a facility complex consisting of an above-ground encapsulation plant and an underground disposal facility. The two facilities will be connected by a vertical shaft transferring the encapsulated fuel into the repository. Implementation of safeguards started in parallel with the excavations at the site. Safeguards measures in the early phase consist of careful documentation of the excavated spaces and seismic monitoring of the activities at the site. These measures ensure that the underground premises are excavated as declared, and that any other works that may compromise the integrity of the geological containment are excluded. These same techniques are utilized for safety and security purposes, to monitor and protect the facility. Development of the safeguards measures for the new type of facilities has benefited from interactive communication between the international and national regulators and the operator. Integration of the safeguards instrumentation into the facility structures is foreseeable in around 2023, when the commissioning tests are planned to commence. The start of operation of the repository is scheduled for 2024, providing Posiva receives the operation license as planned.

Safeguards for New Types of Nuclear Facilities and Campaigns in Canada

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New challenges for safeguards are emerging as a result of proposals for new types of nuclear facilities and decommissioning activities. The Canadian Nuclear Safety Commission (CNSC) is currently reviewing a number of projects that require or will require innovative safeguards solutions. These projects include a long-term waste management facility, which will contain uranium-bearing wastes; decommissioning activities at nuclear laboratories and research reactors; the development of a deep geological repository for spent fuel; and vendor design reviews of small modular reactor designs. This paper will identify some of the common themes for the safeguards challenges associated with these projects.

Regulating the First Spent Fuel Final Repository in the World – Finnish Pioneering Solutions

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Finland is the first country in the world to license a spent fuel final repository. This has required almost 40 years commitment to develop and regulate. Production of nuclear power generates spent nuclear fuel and other nuclear waste, which has to be managed safely. The Finnish policy for a safe end-solution is disposal in our bedrock. The strategy to implement this was set by the Government in 1983. Posiva and nuclear power plant licensees, who are responsible for nuclear waste management, have developed the final repository in accordance with Government strategy. Posiva Ltd (Posiva) submitted the construction license application (CLA) at the end of 2012, and the Radiation and Nuclear Safety Authority of Finland (STUK) gave its statement and safety evaluation report to the Ministry of Economic Affairs and Employment (MEAE) in February 2015. The construction license for Posiva was granted by the Government in November 2015.

STUK's review encompassed aspects of safety, security and safeguards. In all of these areas, disposal of spent nuclear fuel provides a new and unique challenge, where almost no prior experience or examples existed. For safeguards, the final repository is also challenging for international organizations like the IAEA and the European Commission. The new safeguards approaches for the encapsulation plant and the repository are under development. Also, because there is no possibility for reverification of the disposed spent fuel, a method that is able to verify the spent fuel assembly at pin level prior to disposal, has been developed. STUK has been at the forefront of developing the regulatory approach for a final repository. This work has generated experience and examples that can benefit others planning for spent nuclear fuel disposal. Safeguards by Design (SbD) and the practical technical cooperation between operator, regulator and international organizations in the very early phase have been essential to meeting the safeguards challenge of a spent fuel final repository.

A Proposal of Decommissioning Procedures for Bulk Facilities

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Old nuclear facilities, in the final stage of their lifecycle, will move to a decommissioning phase in the near future. Under the Additional Protocol to safeguards agreements, the IAEA has a right and obligation to confirm the decommissioned status of such facilities. However, confirmation measures for these facilities have not been established and are still under discussion. The Safeguards Agreement and Additional Protocol suggest that the IAEA should confirm two conditions; the first is that all nuclear materials have been removed and the second is that all essential equipment has been taken away from the facility or dismantled and destroyed to an extent that the facility is rendered in-operable.

At physical inventory taking during the operation stage, nuclear materials in bulk facilities have been recovered from the processes as practical as possible, but several quantities must be retained as residuals. These are usually represented as a negative MUF in the final material balance when the residuals will be recovered. The negative MUF could normally contribute to reduce the cumulative MUF calculated through the lifetime of the facility. However, the cumulative MUF may not be evaluated as zero due to measurement errors through the lifetime of operation, unrecoverable waste and other reasons.

According to the Safeguards Agreement, a location using more than 1 ekg of nuclear material is defined as a facility and facilities with a content and throughput less than 5ekg of nuclear material are categorized as facilities that are inspected less than once a year. From this context, even if the final inventory approaches zero, the decommissioning procedure could not be completed until the cumulative MUF was less than 1 ekg.

In this paper, we discuss the decision-making process for quantity requirement and determining factors for completion of decommissioning.

New Technologies for Safeguards Implementation: A Case Study for Improving Measurement of Bulk Uranium

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While safeguards by design is now a standard practice for new facilities, Canada's nuclear industry includes large facilities at the front-end of the fuel cycle – parts of which were built before safeguards were a consideration. A complicating factor is that many of these facilities have very large throughputs of nuclear material. This paper describes processes and considerations that need to be taken into account in performing a Physical Inventory Taking in such plants. The Canadian Nuclear Safety Commission (CNSC) leveraged the Canadian Safeguards Support Program (CSSP) to launch a project to develop techniques to more accurately determine the volume of in-process powders to determine more precisely the mass of the nuclear material. This paper considers the use of 3D laser scanning technology for volume determination within a vessel, as well as best practices for collaboration between the State Regulatory Authority (SRA), International Atomic Energy Agency (IAEA), and operator.

Evolution of Material Balance Evaluation at Gas Centrifuge Enrichment Plants

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As the economic and logistical landscape of the uranium enrichment industry has dramatically changed since the start of the decade due to various concurring events, this has brought additional challenges to safeguarding these types of facilities, in particular to performing material balance evaluation (MBE).

Gas centrifuge enrichment plants (GCEP) have had to adjust their operations models to the market conditions by adapting new production and material flow regimes, as well as different material inventory management schemes, in an overall effort to mitigate the effects of the uranium enrichment industry's changes on the plants' economics.

The paper reviews the impact that these changes have had on the IAEA's MBE activities. It then describes how the IAEA has evolved the MBE analysis to maintain the confidence level in its MBE conclusions. In order to reach this goal, the IAEA has developed analytical approaches and indicators for finer sensitivity to changes in the plants' operations, and has increased its understanding and characterization of all material flows. The paper concludes by presenting an overview of expected future challenges and how the IAEA is planning to approach these.

[NEW-S5] Safeguards Techniques for New Facilities and Campaigns

Safeguards Usability of Monitoring for Safety at the Olkiluoto Repository Site

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Monitoring of a geological repository is based on IAEA safety requirements for disposal of radioactive waste. Therefore, at the Olkiluoto repository site, the operator Posiva Oy runs a multidisciplinary monitoring programme targeted at studying environmental impact, improving the understanding of the natural properties of the site, verifying favourable conditions for long-term safety, and developing methods for monitoring the performance of engineered barriers. In this presentation the usability of the data produced by the monitoring programme is assessed for the implementation of nuclear safeguards, primarily to detect the excavation of any undeclared underground premises.

Microseismic monitoring was launched before the beginning of the underground construction at the Olkiluoto repository, to locate seismic events in Olkiluoto and its surroundings, and the findings are already used in implementing national safeguards. The monitoring system and located events are also reported by the operator in the updates of the BTCs to the European Commission and further to the IAEA as Design Information, although there is no safeguards requirement for this kind of monitoring. The geoscientific programme was revised in 2016, for the next construction period of the Olkiluoto repository. In the current assessment, it is concluded that automatic hydraulic head measurements in deep drillholes and land use monitoring also produce relevant data for safeguards, to draw conclusions on the integrity of the rock formations around the repository as a containment and surveillance measure.

The inclusion of results from hydraulic head and land use monitoring for the implementation of national and IAEA safeguards, i.e. in the generation of findings of the national system, could apparently be achieved by examining material and reports that the operator already delivers for other purposes.

Study on the Applicability of an Ultrasonic Inspection Technique to Improve the Continuity of Knowledge for Geological Disposal Canister Containing Spent Fuel

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The Government of Japan has initiated a research study for the direct disposal of spent fuels (SFs) in stable deep geological formations from the standpoint of securing a broad range of options according to the Strategic Energy Plan issued in 2014.

In this study, SFs are disposed of in a geological repository after encapsulation in a disposal canister, with the disposal canisters managed under IAEA safeguards to provide a credible assurance of non-diversion. Once SFs are encapsulated with rim welding, it is impractical to re-verify the SFs directly and a robust CoK (Continuity of Knowledge) measure is required. The CoK has to be maintained for a long period, taking into account retrieval of SFs based on a national strategy. In order to satisfy these requirements, we focused on observation of the inside weld zone using an ultrasonic inspection technique. The closed weld incorporates unique natural characteristics (blowholes, beads, cracks etc.), such that they may be used for canister identification and as a measure to confirm maintenance of CoK. Alternatively, artificial characteristics applied inside the weld may be more practical, because the size, number and distribution etc. of natural characteristics are uncertain. Therefore, we also studied size, depth, array and distance of artificial characteristics that would have no effect on the integrity of the weld, for the purpose of identification and confirmation of CoK. We studied the applicability and capability of the ultrasonic technique by performing a simulation of ultrasonic waves and by measuring a test piece with artificial characteristics. Finally, we concluded that the ultrasonic inspection technique could be applied for long-term CoK of the disposal canister.

This paper provides the results of the study on applicability of natural and artificial characteristics of the inside weld with application of an ultrasonic measurement technique as a verification measure.

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Performance Requirements of Technical Measures for Geological Repository Safeguards

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In 1988, several States began activities supporting the International Atomic Energy Agency (IAEA) in developing safeguards policy and approaches for the application of safeguards for the final disposal of spent fuel in geological repositories. These activities were coordinated through IAEA Member State Support Programmes, including the multi-Member State Programme for the Development of Safeguards for Geological Repositories (SAGOR, 1994-2004) and Programme for the Application of Safeguards to Geological Repositories (ASTOR, 2005-2017). The SAGOR Programme included a diversion path analysis for spent fuel disposal facilities, determination of safeguards technical objectives, and identification of potential safeguards measures for meeting those objectives. The ASTOR Programme supported the IAEA in assessing how the safeguards measures could be effectively implemented and provided recommendations with respect to the development of the measures. Some verification technologies have been developed in support of geological repository safeguards; others are currently under development. However, performance requirements that must be met by the safeguards measures for implementing effective safeguards at encapsulation facilities and geological repositories are not known to have been developed. These performance requirements are needed by the developers of verification technologies to guide development of the necessary monitoring systems. The paper reviews the model safeguards approaches for spent fuel encapsulation plants and geological repositories and recommends performance requirements for each of the applicable safeguards measures.

A Generic Safeguards Approach for a High Level Waste (HLW) Repository in Germany

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The Act on the Organizational Restructuring in the Field of Nuclear Waste Management in Germany became effective on 30 July 2016. The act provides that a federally owned company, the Bundesgesellschaft für Endlagerung (BGE mbH) is formed to carry out the operative tasks of identifying the location for a High Level Waste (HLW) repository, the construction and operation of repositories (Konrad, Morsleben) and of the Asse II mine. The operative tasks that have been carried out by Bundesamt für Strahlenschutz (BfS) and the tasks of the Asse-GmbH and DBE now are concentrated in the BGE. Experiences in the past with repositories such as the Asse II mine and the Morsleben repository highlighted potential safeguards requirements such as containment considerations, penetrations, camera views, lighting, sealing, locations of potential measurement stations and cabling pre-installation. Ideally, inclusion of these features in the design of the future HLW repository will lead to substantial benefits in time and cost for the constructors. Besides a continuous interaction and collaboration by providing information to the safeguards authority in order to meet the requirements of the relevant safeguards agreements, early consideration of such features will help to avoid construction delays and increasing costs associated with the addition, changes, or retrofitting of safeguards equipment late in the construction phase of a repository and will also facilitate the licensing process.

Furthermore, the implementation of the Safeguards by Design approach in order to integrate inter-national safeguards requirements into the design process of a repository, from the initial planning through design, construction, operation, and decommissioning, are going to be considered but any final safeguards approach is a facility-specific combination of safeguards measures and depends on many factors. Therefore, it is important to understand the interplay between operational and regulatory requirements in order to produce an optimum design.

In this presentation, the site selection procedure of the planned HLW repository and the implementation of safeguards will be discussed. It will report on the status of the site selection process in Germany and the safeguards approaches. Furthermore, some experiences gained with repositories in operation will be highlighted.

Comparison of Detection and Location Capabilities of Surface and Subsurface Microseismic Monitoring Algorithms for the Purpose of Monitoring Underground Storage Facilities

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The purpose of this paper is to present how the aggregation of various microseismic monitoring techniques can help build underground nuclear waste storage hidden surveillance and alerting systems. To achieve this goal, the paper incorporates several techniques developed and adopted in a number of scientific and commercial applications, which are aimed at environment protection, microearthquake monitoring, perimeter protection, defense from the intruder and oil and gas recovery stimulation. The combination of techniques will provide effective discrimination of the objects circulating in and around the area to be monitored, identify their spatial disposition within a coordinate system connected to the area of interest, and generate alarm notifications. To monitor underground resource, conventional seismological algorithms are utilized to filter out regional and global seismicity, including data retrieval from national, international, and global seismological agencies.

Locating moving objects is done using custom software providing discrimination of dynamically changing (and buried in microseismic background) seismic patterns of wide class of moving physical objects (car, trucks, aircrafts, human, animals, and more). Once the object is detected, a microseismic monitoring subsystem (comprising conventional or advanced azimuth-slowness estimators in conjunction with statistically optimal microseismic locators) takes over the processing lead providing tracing and timing of an object trajectory.

Nuclear Safeguards Verification of Modelled Partial Defect PWR Fuel using Multivariate Analysis

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Co-author(s): Sophie Grape[1]; Carl Hellesen[1]

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Multivariate analysis (MVA) is an analysis approach, whereby multiple signatures are analyzed simultaneously using algorithms capable of identifying structures in the data that are otherwise not easily identified. We have applied MVA to nuclear safeguards, by constructing a modelling tool that has the capability to analyze both passive gamma spectroscopy signatures and passive neutron signatures. Compared to traditional safeguards analysis, where a small number of gamma energies are selected and analyzed separately from the neutron signature, this approach opens up the possibility to select an arbitrary number of gamma transition lines and to relate the gamma response with the neutron response.

In this paper, spent nuclear fuel of 17x17 PWR-type with a wide range of fuel parameter values are modelled in Serpent2. The measurement responses from two passive measurement techniques are also modelled: that of a high-purity germanium detector and the Differential Die-Away Self-Interrogation (DDSI) prototype instrument.

The objective of the paper is twofold: i) to apply MVA to modelled intact spent nuclear fuel in order to investigate the capability to determine initial enrichment, burnup and cooling time; and ii) to apply MVA to modelled fuels with different kinds of partial defect. Results from the simulations will be shown and the capability of using MVA for the verification of spent nuclear fuel using the described signatures will be evaluated.

Muography of Spent Fuel Containers for Safeguards Purposes

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Verification of heavily-shielded spent fuel containers in case of loss of Continuity of Knowledge (CoK) is a challenge for the safeguards inspectorates. Stores with such containers are regularly equipped with at least two layers of containment and surveillance (C&S) technology. While this approach has proven to be very reliable, failures cannot be completely excluded and reverification options are currently not satisfactory. The growing number of spent fuel containers in intermediate storage sites stored for tens of years increases the probability of loss of CoK. The ultimate minimum requirement in terms of the detection limit for potential re-verification techniques would be the detection of one Significant Quantity of nuclear material missing, which is roughly comparable to 1 PWR or 4 BWR spent fuel assemblies. Cosmic muons can penetrate metres of dense material and therefore can be used to image the contents of spent fuel held in heavily-shielded containers. Recent development of innovative imaging techniques using cosmic muons and muon trackers (muography) offers unique opportunities for safeguards. The National Institute of Nuclear Physics (INFN) in Italy has built a prototype of a drift tube detector with the purpose to study the behaviour of such a detector in the proximity of spent fuel containers and demonstrate that it can record muon tracks with high efficiency, even in the presence of the radioactive background produced by them. The prototype detector consists of a single muon tracker based on eight layers of eight 2 metre-long drift tubes. The detector has been successfully tested in a radiation-free environment and field tests in proximity of a CASTOR® container loaded with spent fuel have confirmed the capability of the system to reconstruct muon tracks even in presence of a substantial radioactivity.

Nuclear Safeguards Verification of Modelled Spent BWR Fuel using a Multivariate Analysis Approach

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Co-author(s): Carl Hellesen[1]; Li Caldeira Balkeståhl[1]; Sophie Grape[1]

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In the field of nuclear safeguards, analysis of data using multivariate analysis (MVA) techniques is currently being researched. Earlier work has analyzed passive gamma spectroscopy signatures from PWR fuels using MVA techniques, for example, to evaluate the capability of determining initial enrichment, burnup, and cooling time; to classify fuels as UOX or MOX; and to identify partial defects on the level of 30%.

In this work, we will analyze passive gamma spectroscopy signatures combined with neutron signatures from spent BWR assemblies using MVA techniques, in order to assess the verification capability with respect to these fuels. MVA is used to analyze modelled data from intact spent nuclear fuel, in order to determine initial enrichment, burnup and cooling time of the fuels. The most important nuclides to classify BWR and PWR fuels are presented and compared with results from the literature. A limited sensitivity study is presented to assess the impact of axial heterogeneity of BWR fuels. It is shown that axial profile of the void content should not be neglected when analyzing the signatures from the fuel. Finally, the challenge of verifying "atypical" fuel assemblies, such as rod cassettes containing rods removed from other fuel assemblies due to some failure is introduced, and the gamma efficiency curve of such cassette is compared to intact fuel assemblies.

The spent fuel inventories of 8x8 BWR-type fuels are computed for various initial enrichments, burnups, and cooling times using Serpent2 to obtain the gamma and neutron signatures. The geometric efficiency curve of a passive gamma spectroscopy measurement of the fuel is computed with an in-house point kernel gamma attenuation analysis program. The simulated dataset is used for the training of a random forest regression model, in order to make predictions of the burnup and cooling time for unknown test fuel samples.

Cosmic-Ray Muography

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Cosmic-ray muography uses naturally-occurring background radiation in the form of cosmic ray muons to passively inspect the contents of complex structures that cannot be imaged using conventional techniques such as X-rays. Cosmic muons are approximately 10,000 times as energetic as a typical X-ray and as such can penetrate shielded containers and much larger structures. This technology has recently become more widely known when it was used to discover a new chamber in the Great Pyramid of Khufu in Egypt. Due to the nature of the interaction between muons and matter, muon radiography is especially suited to image material with high density and high atomic number Z inside shielded containers. This capability of muon radiography is very well aligned with the monitoring requirements for the growing number of heavily shielded spent fuel containers in intermediate storage sites. Their verification is a challenge for the safeguards inspectorates, and muon radiography may be a technology that can help to address this challenge. This paper will not review the underlying physics, but give an overview of the current state-of-the art in muography, drawing on results from an IAEA Consultancy Meeting in September 2017 and a Royal Society Workshop in May 2018.

Investigation of a Novel Detector to Detect Partial Defects in PWR Spent Fuel Assemblies

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In accordance with IAEA safeguards, the correctness and completeness of spent fuel assemblies need to be verified before they are stored inside disposal casks. The correctness is verified by measuring initial enrichment, burn-up, and cooling time. The completeness is verified by detecting partial defects within a spent fuel assembly. Conventional detectors for spent fuel verification, SMOPY, DCVD, and FDET, have limitations on partial defect detection. The goal of this research is to develop a novel fast partial defect detector for PWR fuel assemblies, SPDD. The proposed detector is inserted inside guide tubes of a spent fuel assembly and measures passive gamma intensity. The detector incorporates photodiode composite scintillators to convert the passive gamma into an electric current. SPDD detects a partial defect by the following process:

1. The SPDD current distribution at each guide tube location is estimated using operator-declared information and computational codes (SCALE-TRITON, MCNPX);
2. The SPDD-generated current is measured at each guide tube location; and
3. The estimated and measured current distributions are compared in order to evaluate the completeness of a spent fuel assembly.

This research assessed the performance of an SPDD using two test case assemblies: Westinghouse 14x14 type; and PLUS7 (16x16) type. The results from this SPDD performance analysis indicated that SPDD can be used to detect partial defects in PWR spent fuel assemblies. The technique has potential for application, in particular, for assemblies stored inside SMR spent fuel pools in remote areas.

Muon Imaging for Safeguards Applications

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Because of the very high penetrating power of the high energy muon, muon imaging can be used to image large and dense objects where other techniques such as x-ray imaging often fail. Another advantage of this technique is that it can use naturally occurring cosmic-ray muons as the probe to do muon imaging. There are several ways muons may interact with matter which can be used for imaging, these include: multiple scattering, energy loss and production of secondary particles, and beam intensity loss (absorption). Due to the technical difficulty of measuring muon momentum, it is not easy to use the energy loss of each individual muon to reconstruct an image. Muon multiple scattering imaging and muon absorption imaging are the most popular techniques. Muon multiple scattering imaging can be used to deal with relatively small objects, such as shipping containers, whilst muon absorption imaging is better-suited for larger objects, such as volcanos. Both the muon multiple scattering and absorption imaging systems need muon tracking detectors. If additional detectors, such as neutron detectors, are used to detect the secondary particles caused by muons, tomography images can be formed by using these tagged muon tracks. In this paper, the capabilities of different muon imaging techniques are reviewed and new combined imaging techniques proposed for potential safeguards application.

Development of a Nuclear Fuel Safeguards Verification Technology for New Facility Types

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With the buildup of spent fuel inventories around the world from decommissioning activities, a tool for the efficient and effective verification of a variety of fuel types for long-term disposition is needed. Fast neutron emission tomography is a promising imaging technology that can address this problem and has been under development at Oak Ridge National Laboratory for the past two years. The goal of this capability is to detect the removal or substitution of individual fuel pins in spent nuclear fuel assemblies for international safeguards applications. The present imaging technique is based on neutron emissions originating primarily from curium-244, which is produced predominantly at the end of the exposure cycle. As a result, this technique may be sensitive not only to fuel pins that are removed or substituted subsequent to all irradiation, but also to fuel pins that are substituted and subsequently irradiated. At present, a laboratory prototype imager is under construction. The purpose of the prototype is to demonstrate an imaging capability sufficient to resolve individual fuel pins using commercially available boron straw detectors that can withstand the high gamma ray dose from a typical spent fuel assembly. To achieve both practical measurement durations and sufficient resolution to discern individual pins, the prototype imager employs a novel collimator design where the slits of a parallel-slit collimator are rearranged to distribute them around a ring surrounding the target fuel assembly. This paper will report on simulations and experimental results undertaken to converge on a final design, image reconstruction of sample fuel types of interest, and challenges associated.

Verification of Spent Nuclear Fuel Using Passive Gamma Emission Tomography (PGET)

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After several decades of collaboration with several Member-State Support Programmes, the IAEA has authorized for inspection a passive gamma emission tomography (PGET) capability for the underwater verification of spent nuclear fuel. In a single five-minute measurement, the PGET system integrates three inspection methods: gross neutron and gamma-ray counting; medium-resolution gamma-ray spectrometry; and imaging of the gamma-ray emission from a two dimensional cross section of the fuel assembly. The tomographic images created by PGET enable a partial-defect detection capability for spent fuel verification, which in many cases provides single defective pin detection. The PGET has been deployed four times to spent fuel ponds in Finland and Sweden and performed inspections on WWER-440, BWR, and PWR fuel assemblies with burnup in the range 5.7 – 57.8 GWd/tU and cooling times from 1.9 – 26.6 years. PGET has demonstrated a capability to allow detection of single or multiple missing or replaced pins in all fuel types examined to date. The ability to verify the content of closed containers has also been shown. Integrated neutron detection allows simultaneous consistency check of radiation history. The PGET system is intended to be used in combination with other instruments for verification of spent nuclear fuel. Possible plutonium diversion scenarios include collection of a few pins from many assemblies, or many pins from fewer assemblies. For the case of small defects spread over many assemblies, only a few spent-fuel assemblies need to be verified to ensure a high probability of detection using the PGET. A coordinated verification with the Digital Cherenkov Viewing Device (DCVD) then provides a high probability of detection for larger defects. Used in concert with the full set of verification tools, the new PGET device improves the capability to provide comprehensive verification across diversion scenarios.

[NEW-S6] Nuclear Newcomers – Strategies and Experiences with Enhancing Safeguards Infrastructure in Support of Nuclear Power

Effective Implementation of Safeguards by Design at Nuclear New Builds

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Historically, safeguarding nuclear facilities was often considered after completion of the facility design, or even after construction of the facility. Incorporating safeguards early in the design process can enhance the safeguardability of a nuclear facility by influencing and becoming part of the intrinsic design.

Considering International Atomic Energy Agency (IAEA) safeguards verification requirements at the design stage, allows for inclusion of concepts that maximize efficiency and minimize inspection impact. Design changes during the design development and later design phases tend to be very costly.

In this paper, a proposed approach for efficient implementation of Safeguards-by-Design (SbD) early into the design process for nuclear new builds is proposed. The proposed approach describes the involved parties, their roles and responsibilities, ways of coordination and collaboration as well as main areas to be considered. International best practices in this regards are also presented and discussed.

Embracing Nuclear Safeguards Culture in Kenya

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Kenya is a small quantity protocol country. However, it is an embarking nation. The Nuclear Non-Proliferation Treaty (NPT) came into force in Kenya on 5 May 1970. Kenya's Comprehensive Safeguards Agreement and Additional Protocol entered into force on 18 September 2009. The Government has designated the Radiation Protection Board to act as the Safeguards Regulatory Authority (SRA) and to implement Kenya's obligations under the IAEA safeguards agreements. The obligations include accurate and consistent safeguards reporting; and supporting IAEA Safeguards activities, such as safeguards inspection, among other obligations. Kenya has established and maintains a State System of Accounting and Control for its existing small quantities of nuclear materials.

Over the years, safety culture has been promoted in the country. Nuclear security has steadily gained momentum due to the terrorism risk in Kenya. Safety and security culture seemed to have overridden safeguards culture. However, pursuant to implementing a Nuclear Power Program, Kenya has taken positive steps towards embracing a strong safeguards culture.

This paper will share with the international community the challenges faced in embracing a safeguards culture, and positive steps Kenya has undertaken to embrace safeguards culture as part of implementing its Nuclear Power Program.

Bangladesh's Approach to Safeguards on Nuclear Materials: A Newcomer's Insight

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As Bangladesh recently gained the graduation status of LDC, its demand for electricity is expected to increase to meet the growing criteria of the status. Seeing such possibilities, Bangladesh adopted the strategy of utilizing nuclear energy for power generation a decade back, to mitigate the growing need of the country's energy requirements. Most of the commitments in regard to this have been fulfilled. The country has entered into the nuclear club as the 34th State using nuclear energy for power. Bangladesh is in the process of constructing a nuclear power plant with two nuclear reactors of 1200 MWe capacity each through technical cooperation from the Russian Federation. As a peace-loving nation with its commitment to the IAEA's motto 'Atoms for Peace', international treaties and conventions, Bangladesh has promised to ensure protected use of nuclear materials for power generation.

Nuclear non-proliferation and non-diversion of nuclear materials to unauthorised uses will be the prime factors in its commitment to the international community. As a newcomer in the faculty of nuclear energy, Bangladesh is forming its safeguards mechanism involving the relevant stakeholders in this regard. As a beginner's tool, safeguards in Bangladesh's perspective are regarded as a common/multilateral platform of both safety and security personnel/departments to maintain an effective 3S relationship. A unified approach confirming effective nuclear materials accounting and control, nuclear security culture, robust physical protection measures and response forces, development of an efficient nuclear workforce, regional and international cooperation are some of the areas of major opportunity for safeguards operation. Bangladesh's approach to safeguards would continuously improve through evaluation, and substantive measures would be in place before completion of nuclear facilities in the country.

Establishing a State System of Accounting and Control of Nuclear Materials for Embarking Countries – Case Study of Ghana

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In Ghana, regulation of nuclear activities is done by the Nuclear Regulatory Authority (NRA). The NRA was established by an act of parliament; Act 895 (2015). The Authority was staffed in January 2016 by transferring staff from the Ghana Atomic Energy Commission. The NRA was mandated by the Act to develop and enforce a regulatory framework to control all nuclear and radiological activities with relation to safeguards and non-proliferation, safety and security. To accomplish its mandate on safeguards and non-proliferation, the Authority is in the process of establishing a comprehensive State System of Accounting and Control of nuclear materials (SSAC). This system encompasses national and international verification systems based on nationwide inspections and evaluation of reports and data from stakeholders. This information is managed at a centralized national database of nuclear materials, activities and nuclear-related activities. During its establishment, the NRA has had its share of challenges and opportunities, with human resources and equipment considered as major challenges. With respect to opportunities, it has been possible to integrate provisions of the Additional Protocol into the SSAC. Ghana is systematically controlling all possible nuclear materials in the country and reporting to the International Atomic Energy Agency. In doing so, it is noted that improvements in the IAEA's reporting system have made it much easier to report to the IAEA on nuclear activities.

Implementation of IAEA safeguards at the Belarusian NPP

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[1] *Belarusian NPP*

Issues concerning application of IAEA safeguards at the Belarusian NPP which is currently under construction are considered within this paper.

In accordance with the requirements of the regulatory documents of the Republic of Belarus, a system of accounting for and control of nuclear material has been established at the Belarusian NPP, namely: a structural subdivision and responsible personnel have been defined; functions and responsibilities have been assigned; documents and regulating procedures for maintaining the accounting and control system have been developed; the boundaries of the MBA and KMP have been defined; and the preparation of the final DIQ is in progress.

The systematic and successful development of procedures for accounting and control at the facility level and their implementation ensures that the Republic of Belarus discharges its international commitments.

Rescinding from SQP to Full Scope CSA: Safeguards challenges of the national authorities from nuclear power embarking countries/Jordan

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Pursuant to Article III of the Nuclear Non-Proliferation Treaty (NPT), each Non-Nuclear-Weapon State (NNWS) party to the NPT is required to conclude a Comprehensive Safeguards Agreement (CSA) with the international Atomic Energy Agency (IAEA). Many States with CSAs have little or no nuclear material or nuclear activities in their country and may be eligible to conclude a protocol with the IAEA which holds in abeyance most of the provisions set out in Part II of INFCIRC/153 (Corr.). The standard text of a 'Small Quantities Protocol (SQP)'was made available to States which have less than specified quantities of nuclear material and no nuclear material in a nuclear facility as of 1974. Some of the States that have concluded a CSA with an original SQP have decided to embark on a civil nuclear programme. Once a State with a CSA and a SQP based on the original text (GOV/INF/276/Annex B) exceeds the specified limits of nuclear material in paragraph 37 of INFCIRC/153 (Corr.), or introduces nuclear material in a nuclear facility the SQP automatically becomes non-operational. As a consequence, the safeguards procedures in Part II of the State's CSA will full apply. In the case of Jordan, the intention to develop a civilian nuclear power programme was officially raised in 2007. And from the first moment of the governmental decision to embark on a nuclear programme, a plan for developing the necessary legal and regulatory framework and for putting in place and empowering competent authorities responsible for implementing the related set of laws and regulations was established and implemented. Today, the Energy and Minerals Regulatory Commission (EMRC) is responsible for the implementation of Jordan's safeguards agreements as well as the implementation of nuclear safety and nuclear security requirements.The paper discusses the process of scaling up of an SQP safeguards infrastructure to be able to address any challenges and to meet all safeguards requirements that are deriving from a nuclear power programme. It also describes the legal, administrative and technical challenges that Jordan faced during the rescission phase of its SQP and the full implementation of the full Comprehensive Safeguards Agreement. The feedback and lessons learned from the process are also discussed.

New Build, New Safeguards – Barakah

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The Emirates Nuclear Energy Corporation (ENEC) began the construction of Unit1 of the Barakah Nuclear Energy Plant in 2012, with Units 2, 3 and 4 following in 2013, 2014 and 2015 respectively. The United Arab Emirates was already party to the NPT, had a comprehensive safeguards agreement in force and ratified an Additional Protocol.

A Department of Safeguards and Export Control was established by ENEC in 2012 and tasked with creating a Safeguards Plan which would oversee the implementation of Safeguards during construction and commissioning through to operations of this extremely large project.

The paper will describe how ENEC and Nawah Energy Company (ENEC subsidiary) tackled the challenges, gained new experiences and learned many lessons in building the Safeguards program for Barakah, including:

The procurement of a bespoke Nuclear Material Accountancy and Control computer system. The production of Safeguards and Export Control Procedures within the Company management system. Technical and training visits to the reactor vendor in the Republic of Korea. Benchmarking visits to reactors in Finland and Korea. Use of IAEA Member State support programme for education and training. Early technical engagement during construction with the IAEA and the UAE Regulator on containment and surveillance (C&S) installation. Liaison with Barakah based management and the UAE nuclear regulatory authority (Federal Authority for Nuclear Regulation, FANR) to support the provision of Additional Protocol site declarations, Design Information, IAEA Containment & Surveillance equipment installation, facilitation of inspections including security and safety requirements. Liaison with other Government organisations on Export Control arrangements.

The Barakah project is the most significant nuclear new build in the Region. Consequently the UAE is fully committed to transparency and adherence to the requirements of the Nuclear Non-Proliferation Treaty. The paper will outline the measures that ENEC/ Nawah have taken in building the Safeguards program for Barakah Nuclear Energy Plant supporting the UAE to gain high confidence in its Non-Proliferation credentials.

[NEW-S7] Safeguards on Spent Fuel and Decommissioning

Cask Sealing Procedure Applied in NPP Dukovany

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For many years, the Czech Nuclear Power Plant Dukovany operator has cooperated with the IAEA in the area of safeguards. The facility, with VVER 440 reactors, is suitable for performing different activities; both technical equipment tests and safeguards inspector training. Besides these activities, the Agency and the operator agreed on a special procedure for spent fuel cask sealing. The operator has been authorized to attach one electronic and one optical seal onto the cask lid. The electronic seal is consequently interrogated before shipment from the reactor facility and repeatedly after receipt in a storage facility. The seal record is remotely verified in the Agency headquarters. The optical seal image is recorded in a special camera and kept for later verification. The procedure is an example of effective cooperation leading to reduction of inspections and costs.

Disposal of Spent Nuclear Fuel in Sweden: Safeguards Considerations

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[1] *Swedish Radiation Safety Authority*

Sweden is in the final stages of planning and licensing an encapsulation plant and a geological repository that together will process and dispose of all spent nuclear fuel from the Swedish nuclear programme. If approved and built, the two facilities will handle and deposit about 150 copper canisters per year for about 40 years. Each canister will have 12 BWR or 4 PWR spent fuel assemblies. This paper presents an outline of the proposed encapsulation plant and geological repository, possible national measures in support of international safeguards, and those implemented for domestic nuclear material control purposes. Only the operational phase of the geological repository is considered.

Model safeguards approaches for encapsulation plants and geological repositories were presented by the IAEA in 2010 and 2011. However, these model approaches are partly outdated and do not fully reflect the current (not yet finally formulated) policy of the IAEA, the findings of SAGOR I-II or the provisions of the Additional Protocol. They can, therefore, not be used directly as a basis for any detailed technical preparations by Sweden.

Of particular interest for Sweden would be information about the IAEA's approach for maintaining continuity of knowledge for the daily spent fuel movements for verified assemblies until they are placed in the copper canisters and for the welded copper canisters until they - still inside their transport casks - reach the underground areas of the repository.

Swedish national measures for domestic nuclear material control purposes will mainly be based on a paper trail verification system that will ensure that all deposited spent fuel is correctly declared. This system will be supported by data from measurements performed for safety purposes by the operators of the two facilities.

Effective Access Monitoring at Geological Repositories: A Systems Study

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Access points at a geological repository (GR) for the disposal of spent nuclear fuel and other nuclear wastes present potential diversion paths for nuclear material. Such access points can include one or more ramp entrances for fuel-emplacement and construction operations, elevator shafts for moving personnel and equipment, ventilation shafts, and other design features that can provide access to and from the GR's underground workings.

While considerable attention and effort has gone into identifying long-term surveillance measures for monitoring activities at or near a GR, much less progress has been made on identifying reliable containment and surveillance (C/S) measures that can dependably detect movements of materials through the variety of GR access points. Furthermore, given the likely lack of C/S measures underground, GR access points will require unprecedented reliance on C/S measures to maintain continuity of knowledge (CoK) on nuclear materials buried underground, especially during operations when people, equipment, and materials will be entering and leaving the repository. Reliable and redundant C/S measures will be required for all declared access points leading from the repository's surface to its underground. Declared access points will require C/S measures such as radiation detectors and surveillance cameras, but could also include complementary or novel methods to increase confidence in maintaining CoK on nuclear materials emplaced underground.

Sandia National Laboratories has performed a system study of conventional and potentially novel C/S measures that can be applied to a geological repository with multiple access points to optimize the application, placement, and use of C/S measures. The study helps to inform decisions about implementing efficacious safeguards technologies at geological repositories as part of an overall safeguards-by-design approach.

Challenges and Advancements in Spent Fuel Safeguards in the European Union

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Spent fuel arising from nuclear power plant operation is accumulating, and most of it is currently stored until a decision is taken on the strategy for disposal. Safeguards inspectorates are facing a growing challenge to verify large numbers of spent fuel assemblies being loaded into dry storage casks – as a result of reactor shutdown or owing to capacity issues in wet storage pools.

The Euratom safeguards would like to send an open message to the nuclear community, asking to invest in research for developing processes that have the potential of considerably reducing the ever-increasing inspection effort on spent fuel verification, while ensuring comprehensive, transparent documentation for future generations. The paper focusses on verification challenges.

Euratom safeguards is currently involved in ongoing efforts of the safeguards community to improve effectiveness and efficiency of inspections, by innovating the verification methods and the data flow infrastructure. In this context, we have defined building blocks of a new comprehensive concept, involving new instruments (like the Passive Gamma Emission Tomographer – PGET), new and automated approaches in data evaluation (e.g. for FDET measurements) and remote data transmission, controlling measurements, seals and surveillance.

This comprehensive unattended verification concept has considerable potential for optimising the use of human resources and safeguards effectiveness, while maximising the efficiency of verifications in similar installations and at encapsulation plants and geological repositories (EPGRs), where thousands of spent fuel canisters will have to be verified prior to final disposal e.g. in Finland, where these installations will become operational in the next decade.

In this paper, we present the lessons learned from in-field experiences and the perspective advantages of a comprehensive remotely-controlled safeguards approach.

Verification of Spent Nuclear Fuel Using Passive Gamma Emission Tomography

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[1] *International Atomic Energy Agency*

After several decades of collaboration with several Member-State Support Programmes, the IAEA has authorized for inspection a passive gamma emission tomography (PGET) capability for the underwater verification of spent nuclear fuel. In a single five-minute measurement, the PGET system integrates three inspection methods: gross neutron and gamma-ray counting; medium-resolution gamma-ray spectrometry; and imaging of the gamma-ray emission from a two dimensional cross section of the fuel assembly. The tomographic images created by PGET enable a partial-defect detection capability for spent fuel verification, which in many cases provides single defective pin detection. The PGET has been deployed four times to spent fuel ponds in Finland and Sweden and performed inspections on WWER-440, BWR, and PWR fuel assemblies with burnup in the range 5.7 – 57.8 GWd/tU and cooling times from 1.9 – 26.6 years. PGET has demonstrated a capability to allow detection of single or multiple missing or replaced pins in all fuel types examined to date. The ability to verify the content of closed containers has also been shown. Integrated neutron detection allows simultaneous consistency check of radiation history. The PGET system is intended to be used in combination with other instruments for verification of spent nuclear fuel. Possible plutonium diversion scenarios include collection of a few pins from many assemblies, or many pins from fewer assemblies. For the case of small defects spread over many assemblies, only a few spent-fuel assemblies need to be verified to ensure a high probability of detection using the PGET. A coordinated verification with the Digital Cherenkov Viewing Device (DCVD) then provides a high probability of detection for larger defects. Used in concert with the full set of verification tools, the new PGET device improves the capability to provide comprehensive verification across diversion scenarios.

[SGI-S1] Enhancements and Innovation in Sample Collection and Analysis

Technical Support from the IAEA for Improvement of Operator's Analytical Quality for Safeguards

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The Plutonium Fuel Development Center of Japan Atomic Energy Agency (JAEA-PFDC) received Japan's first plutonium in 1966 and commenced research to develop plutonium fuel as a key objective of the Japanese nuclear fuel cycle. Since then, fundamental research with plutonium-bearing materials, and the development and fabrication of mixed uranium-plutonium oxide fuels, has been carried out.

When the new MOX fuel fabrication facility started its operation and handling of plutonium was increased, the IAEA recommended JAEA-PFDC to improve the accountancy system. JAEA-PFDC conducted a series of discussions with IAEA measurement experts to identify more appropriate measurement methods and analytical instrumentation for its accountancy system. Isotope dilution mass spectrometry (IDMS) was identified as a good solution and was implemented in 1996. This method significantly reduced the Operator-Inspector plutonium bias at JAEA-PFDC.

It is essential that the Operator's measurement quality be continually reviewed and improved for effective and efficient implementation of international safeguards. In this context, and recognizing the excellent technical cooperation with IAEA measurement experts, JAEA-PFDC has continually worked to improve its measurement system.

This paper will present examples of continual measurement improvement by JAEA-PFDC, and the benefit and effectiveness of technical support from the IAEA towards this goal. One such example is the project to introduce large-size dried spikes made from Japanese plutonium source material to secure a sustainable accountancy analysis. Assistance from the IAEA and its network of analytical laboratories for the characterization of the Japanese plutonium standard material was an essential part of the success of this project. Another example is participation in the IAEA nuclear material round robin, which provides external verification of JAEA-PFDC measurement quality. Finally, JAEA-PFDC is an accredited laboratory (ISO 17025) for the IDMS method, and as such it is mandated to continually improve the quality and reliability of its measurement results for accountancy.

Contribution of Interlaboratory Comparison in the Production of a ^{243}Am Spike Certified Reference Material

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In 2009, the International Atomic Energy Agency (IAEA) expressed the need for an Americium standard, and particularly one with a certified ^{243}Am content. Thereafter, the Commissariat à l'Energie Atomique et aux Energies Alternatives/ Direction de l'Energie Nucléaire (CEA/DEN) of Marcoule and the Joint Research Centre of the European Commission (EC-JRC) in Geel carried out a collaborative project for the production of a certified reference material (CRM), enriched in ^{243}Am.

The initial starting material was supplied to the JRC-Geel by the CEA/Laboratoire d'Analyse d'ATalante (L2AT) for dilution, dispensing and characterization. In parallel to the certification, CEA's Commission d'ETAblissement des Méthodes d'Analyse (CETAMA) organized an interlaboratory comparison (ILC) using that same material as the test sample prior to the issuing of the certificate.

The measurands in the ILC were the ^{243}Am, ^{241}Am and total Am amount content, as well as the n(^{241}Am)/n(^{243}Am) and the n(^{242m}Am)/n(^{243}Am) isotope ratios. This ILC had a double objective: firstly, it was a proficiency test (PT) for the laboratories and, secondly, an external check for the characterization values established by the JRC-Geel.

This PT has demonstrated the necessity of an external check on characterization values obtained by a certification procedure. Here, it has strengthened the confidence in four of the characterization values - corresponding to measurands ^{243}Am; ^{241}Am content; and total Am amount content; and n(^{241}Am)/n(^{243}Am) isotope ratio - which will therefore be integrated as certified values. However, it has also enabled the rejection of a characterization value for the n(^{242m}Am)/n(^{243}Am)) ratio. The "excess variance" weighted mean obtained by the ILC is used instead as an indicative value for n(^{242m}Am)/n(^{243}Am) in the certificate for this reference material.

Strengthening Safeguards Laboratories - A Benefit to the IAEA

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A key topic in international safeguards is the work in preventing the further spread of nuclear weapon technology and nuclear materials. High performance analyses play an important role in enabling the detection of undeclared nuclear activities. Such analyses require comparison between different producers of analytical results. Within the European Commission Support Programme, the JRC Karlsruhe has been demonstrating that the technical competences in safeguards laboratories are to the benefit to IAEA. It will be shown that direct contact between inspectors and applied nuclear scientists brings scientific excellence at the working level. Furthermore, frequent and informal contacts between inspectors and R&D staff are essential to enhance scientific/technical capabilities for the IAEA and the safeguards community. Specific examples include:

- Participation in inter-laboratory exercises, provided by the IAEA, allowing the safeguards community to gain confidence in the results produced by different laboratories.
- Reference materials produced by the IAEA, known as Large Size Dried (LSD) spikes, are verified by JRC Karlsruhe and other laboratories to offer assurance for U and Pu content analyses.
- The experience gained from operating the Euratom safeguards on-site laboratories OSL/LSS since 1999. This activity has provided sustainable information and experience, which fed into the on-site laboratory at the Rokkasho Reprocessing Plant in Japan.
- The COMPUCEA technique, which was developed in Karlsruhe for in-field measurement in support of inspections, was transferred to the IAEA and is now a Class A method used in international safeguards.

Furthermore, such collaborations facilitate non-conventional combinations of measurement techniques, used in safeguards and nuclear forensics to obtain more comprehensive safeguards information.

Shaping Together the Future of the Hybrid K-Edge / K-XRF Technique

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The Joint Research Centre (JRC) and the International Atomic Energy Agency (IAEA) organized a workshop on the Hybrid K-Edge/K-XRF (HKED) technique in Karlsruhe, Germany, from 23 - 25 April 2018. The HKED technique is a key method for safeguards nuclear material accountancy at bulk-handling facilities. It allows one to measure uranium and plutonium concentration in liquid samples with uncertainties down to about 0.2% and 0.7%, respectively. The workshop brought together users of the Hybrid K-Edge / K-XRF (HKED) technique to discuss topics of common interest, such as performance and maintainability of HKED hardware and software, analytical performance of HKED, specific HKED applications and future developments. Particular focus was given to possible future collaborations. The workshop consisted of presentations and discussions on the above topics and also included a live demonstration of the HKED setup installed at JRC-Karlsruhe. To facilitate discussions, each participant was asked to present the HKED hardware and software used in their laboratory, the types and numbers of samples they analyse by HKED, their uncertainty requirements for HKED and any current or anticipated challenges/problems. A set of HKED spectra was distributed to the registered participants for independent analysis. The results of these analyses were shared during the workshop so that participants could benefit from each other’s experiences. The paper presents the outcomes of the workshop. The workshop will contribute to a common understanding of the current status of the HKED technique worldwide, and to addressing current and future challenges of the HKED technique.

Japanese SSAC Contribution to the International Target Values (ITVs)

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The International Targe1 Values (ITV) are now a widely used reference in the field of safeguard, not only from the verification perspective but also from the point of view of quality control at nuclear fuel cycle facilities. Japan has participated in the discussions since the first ITV version published in 1993 until the current 2010 issue . With various kinds of nuclear facilities being subject to full scope safeguards by both IAEA and the Japanese state system of accounting for and control of nuclear material (SSAC), Japan can provide a large amount of source data for the ITVs based on inspection activities. The main features of the Japanese SSAC contributions and of its cooperation with the IAEA in the context of the ITV revision will be presented in the paper.

When Non-Significant Measurement Values have been Censored

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Laboratories and industry are often confronted with problems of detection of very low concentrations or activities, when looking for traces that are sometimes at the limit of the performance of equipment and available methods of analysis. This is particularly true when looking for pollutants and micropollutants in the environment, whether in the case of chemical, biological, radiochemical or nuclear measurements.

Current practices tend to impose censorship or substitution of these non-significant measurement values. This leads to biases in the totals displayed; particularly when accumulation of these low level measurement values must be determined, and when the non-significant measurement values are the majority. Examples are:

- annual statements of chemical or radiological release from an industrial site;
- measurements of radioactivity carried out for environmental monitoring;
- characterization and accounting of waste for a storage site;
- the balance sheet for an individual's dosimetry; and
- imbalances in material in production plants.

In this case, the analysts and the inspectors don't know that measurement values have been censored or substituted, making it particularly difficult - or impossible - to analyze these datasets in a meaningful way. However, it is possible to detect such practices using statistical and mathematical tools or data analysis algorithms. Then, the inspector may ask for more information.

Through an educational presentation and some examples, this presentation shows clearly the value of information contained in non-significant measurement values, and the importance to detect substitution or censure practices, in particular when there is an accumulation.

Inter-Laboratory Comparison for Trace Analysis: EQRAIN Traces Proficiency Testing Organized by CETAMA

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One of the missions of the Analysis Method Establishment Commission (CETAMA) is to supervise the organization of Inter-Laboratory Comparisons (ILC) for the nuclear industry and for environmental or safeguards public organizations. These ILC programs, called “EQRAIN” (i.e. the French acronym for Quality Assessment of Analytical Results in the Nuclear Industry), are organized every year or every two years on uranium, plutonium and anions or cations; at a trace level in solution for the latter.

Notably, the EQRAIN traces ILC concerns laboratories implementing inductively coupled plasma atomic emission spectroscopy (ICP-AES) or mass spectrometry (ICP-MS) and willing to estimate the accuracy of their measurements for trace elements at concentrations between 0.1 and 15 mg/L. For the 23rd edition, the multi-elemental standard solution contains 15 elements requiring measurement: Al, B, Ca, Cr, Cu, Fe, Ga, K, Nd, Rh, Si, Sr, U, Zn and Zr. The challenge for the laboratories is to evaluate the performance of their methods and equipment for the determination of these elements in solution, and to meet the requirements of quality management and accreditation body.

The “target” elements are chosen by partners during working group (WG) meetings dedicated to Atomic Emission Spectroscopy (WG6) and Mass Spectrometry (WG12). The results of the ILC are presented every year during joint WG6-WG12 meetings, in which the performance scores are discussed anonymously. It also provides the opportunity to run a variance analysis on both techniques, ICP-AES and ICP-MS, for the 15 elements and to highlight evolution in their performance.

Finally, during our last meeting, the idea came to organize a future ILC on trace elements contained in a uranium matrix composed of a 10 g/L uranium solution in acidic medium. The implementation of such an ILC is currently subject to a feasibility study and would be a follow-up to the proficiency test run in 2012 by CETAMA at the request of the IAEA. A total of 15 elements, between 1 - 100 ppm relative to uranium, would have to be analyzed, and will be chosen between alkaline, alkaline earth, transition metal, platinum metal and lanthanide groups.

Separation Technique using Single Column Chromatography for Safeguards Verification Analysis of Uranium and Plutonium in Highly-Active Liquid Waste by Isotope Dilution Mass Spectrometry

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Verification of uranium (U) and plutonium (Pu) is a vital component of the safeguards inspection activities of the IAEA in nuclear fuel reprocessing facilities. As part of this task, U and Pu are accurately analyzed, even if only small quantities are present – for example in radioactive waste such as highly-active liquid waste (HALW). To determine U and Pu contents in HALW, isotope dilution mass spectrometry (IDMS) with ^{233}U and ^{242}Pu spikes is generally the most reliable and widely applied analytical technique. However, IDMS requires U and Pu to be isolated from the sample in order to achieve the highest level of accuracy. In addition, fission products (FPs) require removal in advance of operations inside a glove box in order to minimize the radiation dose. The removal of FPs requires chemical processes, involving several separation steps such as ion-exchange or solid phase extraction, to be undertaken by tedious manipulator operation inside a shielded cell.

In this study, a separation method based on single-column extraction chromatography has been developed for safeguards verification analysis of U and Pu in HALW by IDMS. The commercially available TEVA® resin was selected for extraction chromatography with sequential separation of U and Pu. The U is chromatographically separated from FPs by nitric acid, while Pu(IV) is adsorbed on the resin. After that, Pu is eluted by being reduced to Pu(III). The method has successfully achieved the separation of U and Pu from FPs with sufficient recovery and decontamination factors to allow subsequent analysis by IDMS. The column dose rate, after the removal of FPs, is reduced to the background level. The analytical results obtained by the developed method are in good agreement with those from the conventional method. The developed method provides simple and rapid separation compared to the conventional method. Subsequently, it is expected that the new method can be applied at the joint IAEA/Japan on-site analytical laboratory.

This work has been carried out as part of the Japan Support Programme for Agency Safeguards (JASPAS).

Alternative Destructive Analyses (DA) Methods for Safeguards

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The National Nuclear Security Administration's Office of Proliferation Detection's (PD) mission is to advance U.S. capabilities for detection of nuclear weapons development activities, including material production and movement. Nuclear Safeguards resides in PD's Office of Nuclear Non-Proliferation Research and Development (DNN R&D). DNN R&D Safeguards focuses on the basic research needed for developing and demonstrating new technologies and capabilities that: 1) Improve the efficiency and effectiveness of current safeguards and 2) Strengthen existing safeguards measures to ensure timely detection of material diversion and undeclared material production.

Traditional destructive analysis methods require extensive efforts for obtaining samples, preparing samples, and analyzing samples. These efforts are both costly and time consuming; and have motivated several past R&D efforts toward minimizing sample preparation times and developing portable systems that can be applied in the field. The limitations of past R&D efforts (ie. mass spectroscopy) led DNN Safeguards R&D to investigate four laser-based DA options. Each of the options being investigated is required to have minimal to no sample preparation and, when complete, be implemented as a fieldable system. The four methods currently being investigated are:

- Handheld Operation for Uranium Sampling (HORUS), a fieldable method based on the Argentine-Brazilian Agency for Accounting and Control of Nuclear Materials Cristallini technique (ABACC-Cristallini technique).

- A fieldable atomic beam laser spectrometer for isotopic analysis that can measure isotopic composition of uranium samples with high sensitivity, resolution, and speed.

- A field-deployable High Performance InfraRed (HPIR) analysis technique for real-time uranium isotope measurements.

- Laser Induced Spectrochemical Assay for determination of Uranium Enrichment (LISA-UE)

This paper will discuss the basic science and the results to date associated with each of these alternative DA methods.

Determining Uranium Mass in Powder Samples with Spectral Radiography

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An important dimension of safeguards innovation is leveraging emerging technologies in other domains and bringing them to bear on safeguards problems. The International Atomic Energy Agency (IAEA) is responsible for verifying the mass of elemental uranium in various forms (powders, pellets, scrap) as part of inspections in different facilities. Current methods require in-field dissolution chemistry, which imposes operational challenges and requires chemistry experts. A method that could non-destructively measure materials such as powders in their original form could streamline inspections, reduce burdens on operators and inspectors, and be complementary with existing methods. Spectral x-ray radiography, an emerging technique from medical and industrial imaging, was adapted to quantify uranium mass in powder samples. A new laboratory-based system is presented, which includes a high count-rate x-ray detector, a 160 kVp x-ray generator, and a custom material estimation algorithm. The detector measures the energy spectrum of x-rays transmitted through a sample with a pixelated CdTe array. The energy spectra of each pixel are processed with the material estimation algorithm to calculate the elemental mass of the uranium in a powder sample. This paper provides an overview of the spectral radiography approach, initial results from a lab-based system, and plans for integrating a fieldable system

A Combined Method of TIMS and HRGS for Rapid Determination of Pu Concentrations in Safeguards Samples at the On-Site Laboratory in the Rokkasho Reprocessing Plant

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A new method that combines thermal ionization mass spectrometry and high resolution gamma spectrometry (TIMS-HRGS) has been developed for rapid Pu concentration assay. The new method determines Pu concentration in safeguards samples by isotope dilution mass spectrometry with $^{238}Pu/^{239}Pu$ and $^{241}Pu/^{239}Pu$ from HRGS and $^{240}Pu/^{239}Pu$ and $^{242}Pu/^{239}Pu$ from TIMS. The new method was applied to pure Pu and U-Pu mixed solution samples with U/Pu ranging from ~1 to ~2. The relative bias between the traditional and new methods for Pu concentration assay is within 0.10% for both the pure Pu and mixed U-Pu samples. Since no chemical separation is required, the combined TIMS-HRGS method reduces analysis complexity and improves the timeliness of processing and reporting sample results for safeguards verification without compromising the precision or accuracy of the results.

Optimization of SEM and EDX Measurements for Swipes and Samples containing Uranium by MATLAB

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As a safeguards tool, the micro-analysis of particles and swipes is routinely used by the International Atomic Energy Agency (IAEA) to verify the absence of undeclared nuclear activities in States subject to comprehensive safeguards. This can be achieved by Scanning Electron Microscope (SEM) combined with Energy Dispersive X-ray (EDX).

Various SEM images can be analyzed with the help of image analysis software. Image processing is used to describe the material’s size, shape and surface morphology on a micro- or nano-structure level. However, digital image processing remains a challenging domain of programming for several reasons. This work deals with the use of image processing to enhance image contrast, analyze and develop a model for size estimation in micro-scale using MATLAB functions with the aid of Smile View software compatible with the JSM 6510 LV model SEM/EDX instrument. Uranyl nitrate hexahydrate samples, from the safeguards destructive assay chemistry laboratory, and swipes, from the glove box used for handling uranium samples, were used in the study.

The developed method overcomes problems that face Smile View software in that it can be used to measure the length between two points in micro-scale, depending only upon the scale of magnification. In contrast to Smile View, it can also readily be used to measure the area of analysis with excellent precision and accuracy. This model uses available software and does not need any specialized, complicated or expensive software. It can be applied to any sample image, and is especially useful in the case of swipes that contain very small particles of intense brightness at higher magnifications, for which the eye faces difficulties in determining the particles borders. Such particles can be enhanced using MATLAB, and noise can be removed.

The final aim of this paper is to highlight the role of mapping in showing the distribution of any element located in the sample. EDX is used to analyze nuclear materials on the swipes, providing elucidation of the structure together with a map of each element, enabling a study of their presence and distribution, and thus providing valuable information concerning sample homogeneity.

SIMS Application to Determination of the Age of Uranium Materials on the Results of Microparticle Analysis

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The age of uranium materials (i.e. time after the last purification) is one of the characteristics which may be determined for safeguards purposes [1]. Reliable techniques are already developed for determination of the age of these materials using ICP-MS [2]. But the results from such a bulk method are significant only if the microparticles from a single uranium source material (i.e. single purification date) are present in the analyzed sample.

Verification results of the age determination by bulk analysis can be provided using SIMS. The purpose of this work is estimation of the SIMS measurements ability to distinguish two different uranium materials, with different manufacturing dates, in one mixed sample by using measurements of the ion current ratio of ^{230}Th to ^{234}U.

In this work, the ratio of ion currents of ^{230}Th and ^{234}U was measured in fragments of a fuel pellet which was made by mixing two materials – depleted uranium and low enriched uranium. ICP-MS analysis of this ratio illustrated the sample heterogeneity: measurements on different fragments gave different results and were in the range from 9×10^{-6} to 1.1×10^{-5}. According to these results, it became apparent that each of the two components had its own value of ^{230}Th to ^{234}U ion current ratio. Therefore, comprehensive characterization of the sample required determination of each component.

A Cameca IMS-1280 with multi-collector was used for this purpose. The ratio of ^{230}Th to ^{234}U ion currents was estimated for microparticles in a size range from 3 µm to 10 µm. Two groups of results were identified. The first group contained particles of low enriched uranium. This was characterized by ratios from 1×10^{-5} to 9×10^{-5}. The second group contained particles of depleted uranium, this group was characterized by ratios from 3×10^{-4} to 5×10^{-4}.

[1] G. Tamborini, Doctorate Thesis, University of Paris, 1998

[2] Z. Varga, G. Surranyi. Production date determination of uranium-oxide materials by inductively coupled plasma mass spectrometry// Analytica Chimica Acta 599, 2007, p.p. 16-23

Determination of Trace Amounts of Plutonium Isotopes in Environmental Samples containing Uranium and Plutonium Particles using ICP MS

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Laboratories of the IAEA Network use thermal ionization mass spectrometry (TIMS) for determination of isotopic composition of trace amounts of plutonium in environmental samples. But in the case of analysis of a lot of samples, a higher capacity method should be used; such as an inductively-coupled plasma mass spectrometry (ICP MS).

ICP MS has a significant obstacle for correct measurement of plutonium isotopic composition; namely the presence of uranium in the samples. Hydride ions, $^{238}UH^{+}$, contribute to the ion current in the mass range 239. Moreover, some of the ions of ^{238}U contribute to the ion currents in the mass range 239-242 amu due to “tails” of the peaks in the mass spectrum. The relative amount of such ions in all ^{238}U ions are from 10^{-8} to 10^{-4}, and they increase detection limits of plutonium isotopes and deteriorate accuracy of measurements.

An approach is proposed to reduce the uranium amount in preparations. First, the fragments with the largest amount of plutonium are identified by alpha-autoradiography. Second, chromatographic separation of uranium and plutonium is completed using a column filled with anion exchange resin. This allows purification of the dissolved fragments from uranium at the level of 5×10^{4}, while the loss of plutonium is no more than 40%.

All measurements were carried out using the Thermo Element 2 mass spectrometer. Model preparations with uranium content ranging from 1×10^{-5} μg to 1mg were used (similar to the uranium content in real samples). The relative content of plutonium and uranium in all model preparations varied in the range (CPu/CU = 0.001 … 1000).

The detection limit for all plutonium isotopes in the absence of a significant amount of uranium in the sample is about 0.01pg. Analysis of model preparations with a content of uranium about 1mg (as the most unfavorable case) resulted in the following detection limits for plutonium isotopes: ^{239}Pu – 2.52pg; ^{240}Pu – 0.15pg; ^{241}Pu – 0.06pg; and ^{242}Pu – 0.03pg. The minimum content of plutonium, sufficient to measure the ratios $^{240}Pu/^{239}Pu$, $^{241}Pu/^{239}Pu$ and $^{242}Pu/^{239}Pu$, is in the range from 5pg to 15pg (depending on the plutonium isotopic composition).

Analysis of Single U-Rich Particles by Fission Track Laser Ablation ICP-MS

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The paper presents a feasibility study of combining a fission track (FT) method that was developed at the Research Center Rez, Czech Republic, and laser ablation – multi-collector – inductively coupled plasma mass spectrometry (LA-MC-ICP-MS) that is currently developed at the IAEA Environmental Sample Laboratory for the analysis of single U-rich particles. Typically, particles with sizes in the low and sub-μm range cannot be identified with cameras mounted in laser ablation systems. In order to avoid the determination of "mixed" isotopic compositions from two or more neighboring particles that were collected by swipe sampling during nuclear safeguards inspections, the locations of particles of interest need to be identified prior to the LA-MC-ICP-MS analysis. Applying the fission track technique as pre-identification method is regarded as advantageous over SEM mapping as the fission tracks that are generated by fission fragments after irradiation of fissile material in a nuclear reactor do not only provide information about the particle location but also allow an estimation of the enrichment. Here, the particle locations that were identified with FT were confirmed by scanning electron microscopy (SEM) to improve relocation accuracy. The relocation accuracy between the SEM and the laser stage was better than 20 μm. Subsequent U isotope ratio analyses by LA-MC-ICP-MS of pre-selected particles having different enrichments (NU, 1 % and 3 % enriched) demonstrates the applicability of the presented FT-LA-MC-ICP-MS approach for identifying different particle populations present on one substrate.

Age-Dating of Uranium Particles

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Analysis of environmental samples provides detailed technical information useful in the verification of a State's nuclear declaration. Analysis of particulates provides highly specific information on materials, painting a detailed picture of ongoing facility activities and enabling reconstruction of historical activities. Additional useful information can be gleaned from a determination of uranium purification date. Large geometry SIMS enables precise measurement of uranium and decay daughters enabling direct computation of the purification date of uranium in particulate collected in environmental samples. Accurate purification measurements are dependent on extremely tight control of all instrument operating parameters and a good understanding of the element relative sensitivity factors, instrument detector background, potential interferences, matrix effects, and the statistics and proper interpretation of low-to-zero counts of the uranium daughters. The methodology described was successfully applied to uranium particle standards, process uranium materials, and on particles collected from environmental swipes. Enrichments of particles measured ranged from LEU to HEU and equivalent particle sizes ranged from a few tens to around one micron. Results showed excellent agreement with known purification dates. The project also demonstrated potential utility of combining isotopic and other data to determine appropriate clusters for data aggregation. Aggregating data from clusters of related particles can provide a pseudo-bulk result that significantly reduces the measurement uncertainly associated with the individual particles.

Establishing Production and Provision of Microparticle Reference Materials for Particle Analysis through Collaboration

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Quality Assurance and Control (QC) of analytical measurements on safeguards samples are of utmost importance to maintain the International Atomic Energy's credibility with its Member States. For measurements of individual micrometer-sized particles, collected by inspectors on swipe samples, reference materials in particulate form are needed to implement a robust QC system.

For this purpose, trilateral cooperation between the Office of Safeguards Analytical Services of the International Atomic Energy Agency (IAEA-SGAS), the European Commission - Joint Research Centre Unit G.2, Geel, Belgium (JRC-Geel) and Forschungszentrum Jülich, Germany (Jülich) was established. The overall aim of the cooperation is to qualify Forschungszentrum Jülich as a laboratory for the provision of reference materials under the IAEA's Network of Analytical Laboratories (NWAL). One essential milestone in the qualification process is the development and implementation of a reliable procedure for producing uranium microparticles. Meeting the IAEA's requirements with respect to uranium microparticle production, the procedure established in Jülich over the past six years now produces samples that consist of uranium microparticles with well-defined properties; such as monodisperse particle size distribution and consistent isotopic composition. The role of the JRC-Geel in this cooperation is twofold: First, JRC-Geel prepares and certifies the uranyl nitrate base solutions used in particle production, taking into account the specifications provided by the IAEA. The isotopic compositions of the base solutions are first verified by IAEA-SGAS and then used at Jülich as a feed solution to produce the microparticles. Second, samples prepared by the Jülich procedure can then be certified for the uranium isotopic composition and possibly content by a team of JRC-Geel and IAEA analysts. Future research activities will focus on the production and characterisation of microparticles with defined mixed elemental compositions, such as *Ln*/U, Th/U and Pu/U microparticles.

Isotopic analysis of U-Pu mixed particles using Large-Geometry Secondary Ion Mass Spectrometer (LG-SIMS)

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[1] *IAEA*

In line with the Development and Implementation Support Programme project plan, Environmental Sample Analysis Techniques, the Office of Safeguards Analytical Services (SGAS) is preparing for new verification challenges by expanding its contribution to the Environmental Sampling Programme in the area of particle analysis. In 2017 a feasibility study was carried out by SGAS to demonstrate a new method, based on LG-SIMS, for the determination of isotopic and elemental abundances in U-Pu mixed particles. This technique is now under development at the SGAS Environmental Sample Laboratory (ESL). A range of reference materials in the form of fuel-grade, pure PuO_2 (NBL CRM 122 and NBL CRM 136) and reactor-grade, mixed U-Pu oxide (UKMOX10) particles were used to calibrate and test the method. It was then applied to weapon-grade, mixed U-Pu containing particles originating from the Thule accident (Greenland, 1968) and a glass from the Trinity test site (USA, 1945). Results were compared to the results that had appeared in relevant literature. An anonymous Environmental Sample containing around 200 pg of Pu was eventually analyzed by LG-SIMS and results were compared to those reported by the IAEA's Network of Analytical Laboratories (NWAL) using the reference technique for particle analysis for U and Pu isotopes based on Fission-Tracks combined to Thermo-Ionization Mass Spectrometry (FT-TIMS). The main limitation of the developed method appeared to be related to the substantial formation rate of ^{238}U hydride ions during the process of secondary ionization of ^{238}U that may compromise the determination of ^{239}Pu for mixed particle with $^{238}U/^{239}Pu$ above 15.

[SGI-S2] Establishing and Strengthening State and Regional Systems of Accounting for and Control of Nuclear Material (S/RSACs)

Guidelines for the Application of EURATOM / IAEA Safeguards for Small Holders of Nuclear Materials from Romania

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In the case of the Romanian National LOFs MBA (WRMZ), the National Commission of Nuclear Activities Control (CNCAN) acts as the nuclear operator. The obligations of the nuclear operator are to maintain a reliable nuclear material accountancy and control system for the entire MBA; prevent the diversion of nuclear materials from their intended and declared uses; fulfill all the reporting requirements to EURATOM concerning nuclear safeguards; and to prepare for, and provide assistance to, nuclear safeguards inspections.

Based on the provision of European Union safeguards legislation and Romanian Law no. 111/1996, republished, with subsequent amendments and additions, CNCAN has issued a guidelines document for application of safeguards to the small holders of nuclear materials in Romania. The Guidelines describe how small holders of nuclear materials should undertake safeguards activities in Romania in accordance with the requirements of EURATOM / IAEA / CNCAN. The Guidelines are applied by all small holders of nuclear materials in Romania and:

- Provide for safeguards in all small holder activities involving nuclear materials;
- Ensure an appropriate communication interface between Romanian small holders of nuclear materials and CNCAN, in order to fulfill the deadlines and the corresponding quality control of all safeguards requirements assumed by Romania through membership of the European Union, namely, requirements under the Treaty establishing the European Atomic Energy Community; and
- Provide a framework for the small holders of nuclear materials to allow the best conditions for safeguards inspections performed by EURATOM / IAEA / CNCAN inspectors.

In addition, the Guidelines describe the measures that the licensee must take to ensure the physical protection of radioactive sources, radiological equipment and chemical compounds containing nuclear materials.

Russian Federation System of State Control of Nuclear Materials and its Role in IAEA Safeguards Implementation

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Russia possesses a unique nuclear infrastructure that does not have an analogue in the world. Some of the exceptional properties are listed below:

- The nuclear fuel cycle is complete within the State - from ore mining and nuclear fuel production, of all types, to decommissioning and waste disposal.
- There are huge distances between the nuclear facilities (e.g. the distance between Smolensk NPP and Bilibino NPP is over six thousand kilometers).
- There are a wide variety of shapes and types of nuclear materials, as a result of the variety of nuclear energy facilities and research reactors.
- State residence of nuclear material owned by the State, domestic companies and foreign companies.
- State residence of nuclear material under international obligations (e.g. IAEA Safeguards)

These and other exceptional properties have required establishment of the State Control System of Nuclear Materials (SCSNM), which takes into account international requirements but still acquires its own unique traits. In particular, along with traditional functions associated with SCSNM, the Russian Government empowered the system with the following functions:

- Security of nuclear material - prevention and detection of loss, illegal use or theft of nuclear material.
- Control of nuclear material circulation.
- Implementation of international agreements on control of nuclear material.

An independent and important field of activity of the SCSNM is development of the conditions for IAEA safeguards implementation.

Implementing Safeguards within the Kingdom of Morocco: Achievements and Challenges

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The Kingdom of Morocco has a Comprehensive Safeguards Agreement with the IAEA which has been in force since 1975. It also has an Additional Protocol (AP), in force since 2011.

Morocco concluded subsidiary arrangements with the IAEA in 1984. These arrangements have identified the Ministry of Energy and Mines as the National Competent Authority. Since its Small Quantities Protocol was rescinded in 2007, Morocco has submitted on a regular basis the required information and reports. It also hosts IAEA verification activities. Furthermore, Morocco has submitted information required under Article 2.a of the AP since 2011 and hosted one Complementary Access (CA) in 2012.

However, in the absence of relevant regulations allowing the establishment of an SSAC until 2012, the declarations made by Morocco in the framework of its Safeguards Agreement concerned only the Maamora Nuclear Research Centre (CENM). As a result, there was only one MBA reported to the IAEA.

After the entry into force of the AP, a CA was performed at CENM in 2012, and it was suggested that Morocco set up three MBAs: two at CENM, with the third one bringing together the remaining nuclear material located in Morocco. However, given the lack of regulations, it was difficult to meet IAEA requirements.

In 2014, the Kingdom of Morocco promulgated a comprehensive law addressing, inter alia, safeguards. The law has created a unique and independent regulatory body: the Moroccan Agency for Nuclear and Radiological Safety and Security (AMSSNuR). The law also states that AMSSNuR is the SRA with regard to the Safeguards Agreement.

As part of the upgrading of the national regulatory framework, AMSSNuR has elaborated regulations on safeguards, which it has submitted to the Government for approval in 2018.

The implementation of regulations and the updating of the Subsidiary Arrangements will enable AMSSNuR to put in place the necessary procedures to allow operators and individuals carrying out activities under the AP to submit the required reports and information in the proper format within set deadlines. It will also facilitate access for IAEA inspectors to locations identified by the IAEA. Thus, Morocco will be able to fully meet the requirements of its Safeguards Agreement.

Updated Relevant Thailand Regulatory Framework in the Nuclear Energy for Peace Act (2016) Regarding Nuclear Safeguards and Additional Protocol

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Thailand has implemented the Comprehensive Safeguards Agreement since 1974, and signed the Additional Protocol in 2005 to affirm its transparency in the peaceful use of nuclear energy. The legal framework was restructured in order to strengthen the national nuclear regulation. The Nuclear Energy for Peace Act (2016) displays numerous changes from the previous Atomic Energy for Peace Acts (1961 and 1965) to ensure that Thailand has effective law and regulations to enable the implementation of safety, safeguards and security. The IAEA Model Additional Protocol, recommendations and guidance were taken into account during the drafting process of the Act and subsidiary regulations. Details of Thailand's updated regulatory framework regarding Nuclear Safeguards and the Additional Protocol will be provided in this paper.

UAE Safeguards Implementation: A Roadmap to 3S Information Management

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Information management (IM) is a vitally important element of an overall State System of Accounting for and Control of nuclear material (SSAC). Efficient and effective IM supports a State in submitting timely, correct and complete information to the IAEA pursuant to its international obligations arising from a Comprehensive Safeguards Agreement (CSA) and an Additional Protocol.

The Federal Authority for Nuclear Regulation (FANR) recognized that developing fit-for-purpose IM systems takes considerable experience, time and effort. FANR therefore developed a stepwise approach that ultimately aims to achieve the vision of a fully integrated 3S (safeguards, safety and security) regulatory system. This approach resulted in a set of deliverables that each supported FANR's operational needs. The incremental approach addressed time constraints imposed by a rapidly developing nuclear energy program and supported capacity building for sustainability of IM systems. FANR has completed three of four phases in its roadmap for delivering the required safeguards systems. Phase 1 addressed capturing basic information relevant to safeguards implementation and was achieved using standard office software. Phase 2 consisted of developing bespoke software - the Emirates Integrated Accountancy System (EIAS) – that provides sophisticated functionality associated with nuclear material accounting and standard regulatory processes – inspection and licensing. Phase 3 provided for the preparation of "Code 10-formatted" IAEA accounting reports as the UAE made the transition from SQP-based safeguards to full-scope CSA implementation in early 2017. Attention is currently focused on Phase 4 – a 3S regulatory IM system. Phase 4 (currently known as e-Licensing) builds on lessons learned from preceding phases and includes online access for both FANR and licensees.

Developing complex safeguards IM systems poses significant challenges. However, with forward planning, stakeholder engagement and strong Government leadership, FANR continues to both succeed in meeting its international safeguards obligations and support efficient application of IAEA safeguards in the UAE.

Updating the Domestic Compliance Program to Strengthen Canada's State System of Accounting for and Control of Nuclear Material

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The Canadian Nuclear Safety Commission (CNSC) is the State Regulatory Authority (SRA) in Canada and has the mandate to ensure the successful implementation of the Canada-International Atomic Energy Agency (IAEA) Comprehensive Safeguards Agreement and Additional Protocol. A strong and reliable State System of Accounting for and Control of Nuclear Material (SSAC) is essential for an SRA to implement safeguards effectively and efficiently and to be a reliable partner for the IAEA. For this reason, Canada published a new comprehensive regulatory document on safeguards and nuclear material accountancy in February 2018, which consolidated all safeguards regulatory requirements into a single document. This necessitated an update to the safeguards compliance verification program and the development of new evaluation instruments for the conduct of verification assessments and audits. The revisions to the compliance verification program now under way are aimed at ensuring that compliance activities cover all safeguards regulatory requirements with a frequency commensurate with risk and with licensees' compliance histories. So as not to duplicate effort, the CNSC's compliance program will complement the IAEA's own program while also strengthening the safeguards programs of licensees. This paper will describe Canada's regulatory framework, its approach to compliance, and the systematic approach the CNSC has taken in the development of an updated safeguards compliance verification program.

Steps in Bridging Gaps of Safeguards Activities for Developing Countries

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The challenges encountered by national institutions in implementing safeguards in developing countries are overwhelming. In most of these countries, safeguards activities over the years have not been a major priority to most communities and governments which have unavoidably become issues of global concerns. According to the International Energy Agency (IEA), about 1.6 billion people do not have access to energy.

In recent years, due to this insufficient energy availability, many developing countries have expressed interest in the development of their first nuclear energy power plant to address their energy needs. These mining and manufacturing industries also serve as repository for nuclear materials. This paper looks at challenges encountered by developing countries in organizing, structuring, monitoring and inspection of facilities within the framework of the NPT.

The lack of awareness of safeguards activities in these countries significantly impede the compliance and control of information and the reporting system for developing countries to declare nuclear activities as required by parties. Political will and knowledge on the use and implementation of safeguards have been identified as complicating factors in these countries in this regard. To reduce the barriers, the study employs the use of a combination of strategies necessary to engage public awareness, and ensure national government and stakeholders' involvement to improve accuracy in inventory. Additionally, this will enhance inspection and robust reporting system that is driven by modern technology. The removal of these barriers will provide benefits to developing countries and national governments to generate a comprehensive inventory and information flow for recording purposes.

[SGI-S3] Establishing and Strengthening State and Regional Systems

Strengthening SSAC Capabilities through the Establishment of a Safeguards Laboratory (SGL)

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Algeria has fully supported the implementation of safeguards, as required by its Comprehensive Safeguards Agreement (CSA) with the IAEA, since 1996. The Atomic Energy Commission (COMENA) is designated as the competent authority for the implementation of this agreement; indeed, COMENA is responsible for Safety, Security and Safeguards.

The State System of Accounting for and Control of nuclear material (SSAC) is composed of many components. It is more effective and efficient to address individual components, rather than the entire system at one time. With the objective of strengthening the system as a whole in mind, nuclear material accountancy is one of these components.

The control and accountancy of nuclear material forms part of the requirements of the CSA, and COMENA periodically takes, through its SSAC, an exhaustive inventory of its materials and record changes between inventory periods.

To better perform these activities, the accuracy of inventory declaration is a national and international requirement. To assist in this respect, COMENA has set up the safeguards laboratory (SGL) as a technical support structure for the SSAC. The methodology applied at SGL is in compliance with International Atomic Energy Agency (IAEA) guidelines. The SGL's staff perform independent material characterization, maintain non-destructive assay equipment, and facilitate practical training of inspectors. The SGL supports the training of national inspectors in practical terms, by applying safeguards inspection methodologies and measurement techniques, and also trains operators to implement procedures, control monitoring and accounting at the nuclear facility level.

Under the framework of cooperation between COMENA and (INSEP) / NNSA/DOE, a joint roadmap was established in order to define the capacities and the needs of COMENA for the enhancement of the COMENA SGL. National inspector training in the field of safeguards was also included.

In order to maintain operational sustainability at the SGL, it is necessary to have qualified staff, adequate equipment and techniques that meet the requirements of international standards. The purpose of this paper is to describe the experiences and the role of the SGL in order to improve and enhance the capabilities of the SSAC, inspections, verification and control of nuclear material.

Achieved Progress and faced Challenges in Implementation of the Safeguards Obligations in the Republic of Azerbaijan

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The Republic of Azerbaijan joined to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1992. Agreement between the Republic of Azerbaijan and the International Atomic Energy Agency (IAEA) and the Protocol thereto (Small Quantities Protocol) for the application of safeguards in connection with the NPT concluded on 31 May 1999. On 8 May 2014, the President of the Republic of Azerbaijan signed a decree on establishment of the “National Centre for Nuclear Research” Closed Joint Stock Company, under the Ministry of Communications and High Technologies of the Republic of Azerbaijan, for the use of nuclear technologies for peaceful purposes. Taking into account of this decision provisions related to equipment of the Centre with a nuclear research reactor and other essential facilities that meet modern requirements, in consideration of the Small Quantities Protocol conditions and in accordance with the IAEA Board of Governors decision regarding relevant protocols, the Government of the Republic of Azerbaijan officially proposed to rescind the aforementioned Protocol. The rescission agreed upon in the Exchange of Letters entered into force on 15 July 2015, the date of the IAEA’s reply to the Republic of Azerbaijan confirming the rescission. Since that date, all obligations specified in the NPT have been extended to the Republic of Azerbaijan. The paper will describe the progress achieved and the existing difficulties associated with the full implementation of the relevant safeguards obligations.

Safeguards and Additional Protocol Implementation in Niger: Prospects and Challenges

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A key aspect of the implementation of a safeguards agreement and Additional Protocol, as a commitment to a State's obligations under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), is its contribution to nuclear security worldwide.

Niger has signed and ratified the legal instruments of the safeguards agreement and its Additional Protocol with the IAEA and has put in place a national system of accountancy and control of nuclear material (SSAC) in accordance with the requirements of these agreements.

To comply with the legislative standards, Niger established a Nuclear Regulatory and Safety Authority (ARSN), in December 2016, whose Article 22 provided for a Department of the SSAC.

Niger has uranium mines, oil exploration companies that use nuclear materials as radiation sources and is engaged in a project to develop a nuclear power program.

To meet its international legal obligations, Niger regularly provides the IAEA with safeguards-relevant information via the SSAC according to the following steps:

- collection of information at the level of holders and producers of nuclear material;
- treatment of the information collected to verify its accuracy and completeness; and
- compilation, encryption and sending of information to the IAEA.

Annual physical inventory verification (PIV) missions for nuclear material are carried out by IAEA safeguards inspectors.

The level of cooperation between the SSAC and stakeholders is a key factor for the effective implementation of safeguards, requiring concerted action by the State, the facility operators and the IAEA. In addition, the creation of a sub-regional network to promote the Safeguards Agreement and Additional Protocol under the auspices of the IAEA can be a very effective solution to improve the system. Sharing experience and teamwork are two of the elements that can help encourage innovation. Niger, given its geographical situation, the porosity of its borders, the lack of a nuclear safety culture and the emergence of insecurity caused by terrorist groups on both sides of its borders, faces risks and vulnerabilities in nuclear security.

Thus Niger faces many challenges to nuclear safeguards and security. To meet these challenges, Niger needs capacity building to provide well-equipped security and nuclear safeguards personnel.

Malawi's Experience in the Implementation of Safeguards: Achievements and Challenges

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The paper presents a situational analysis and experiences of Malawi in implementation of safeguards. The paper is divided into three parts. Firstly, the paper provides a background to the country in relation to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Secondly, the paper introduces the efforts Malawi has made to fulfil its domestic obligations under the NPT and, finally, the paper discusses the implementation of safeguards outlining some of the challenges and solutions developed in national accounting of nuclear material.

Malawi is a party to the NPT, as well as the Treaty of Pelindaba – a regional nuclear weapon free zone treaty. The country concluded a Comprehensive Safeguards Agreement (CSA) and Additional Protocol. Making strides to provide a conducive environment for the implementation of safeguards, Malawi developed and enacted the Atomic Energy Act in 2011. Part thirteen of the Act, Sections 66 to 69, makes provisions for the peaceful use of nuclear material, prohibits proliferation activities and provides for application, and cooperation in the implementation, of safeguards. The Act also makes provisions for accounting of nuclear material and monitoring of facilities in Malawi.

Malawi possesses a nuclear mine, situated in the northern part of the country, called Kayelekera Uranium Mine. Mining has been in operation since 2009 but, currently, operations have been halted due to the low price of uranium. The country accounts for the nuclear material produced and exported from the country. Initially, nuclear material was accounted for through paper trails. However, in order to ease the reporting of information, the IAEA with support from Member States developed an online system which has simplified reporting and enabled effective implementation of safeguards.

Implementation of Safeguards in Georgia

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Georgia has taken significant steps for the implementation of its safeguards agreement. In 2016, with the support of the IAEA, national training on the “Implementation of Safeguards in Georgia” was conducted, encompassing both theoretical and technical components (spectroscopy, searching). A legislative act was adopted, defining the rights and obligations of the Government as well as licensees - “Procedures for Carrying out Nuclear Non-Proliferation Safeguards”. Seminars for the organisations in possession of nuclear materials were conducted to review and implement the Act. In 2016, Georgia exported highly-enriched nuclear material to the producing country, thus becoming an HEU-free State. Meanwhile, the US NRC has supported the introduction of “NUCMAT” software for accountancy and control of nuclear materials.

Development of Safeguards in Bolivia

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In Bolivia, the Bolivian Nuclear Program (PNB) has been established as the country is expected to make incursions into the nuclear issue, initially projecting the construction of a research reactor.

In this sense, Bolivia must abide by international conventions such as safeguards, with Bolivia also Party to the Treaty for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (”Treaty of Tlatelolco”) in which it is expressed (Article 13) “each part The contracting party will negotiate multilateral and bilateral agreements with the International Atomic Energy Agency (IAEA) for the application of its safeguards to its nuclear activities ….”. The IAEA is authorized to conclude agreements of this nature.

The Bolivian Institute of Nuclear Science and Technology (IBTEN), Competent National Authority for the safe control of the use of radioactive material and ionizing radiation generating equipment, has submitted to the higher authorities, for evaluation of corresponding instances, a proposed safeguards agreement dated 2 April 2018, which can serve as the basis for approaches with the IAEA. In this way, the fulfillment of agreements to carry out the Bolivian Nuclear Program is in progress.

Application of Safeguards in Venezuela through Protocols with Small Quantities

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The International Atomic Energy Agency (IAEA) promotes in its Member States the peaceful uses of nuclear energy and radioactive materials, proposing mechanisms based on the provisions of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) that provide guarantees and avoid the diversion of this type of material that can otherwise be used in weapons and other explosive devices.

The non-nuclear-weapon States, which have established protocols in their Comprehensive Safeguards Agreements with the IAEA, generally possess quantities of depleted uranium used as shielding in activities of the medical and industrial sectors and therefore do not maintain compliance with certain procedures that are included in the safeguards agreements. However, they must cooperate in its application and provide guarantees that they respect their safeguards commitments. For these cases, the mechanism called Small Quantity Protocols (SQPs) has been established, with the purpose of reducing the burden of applying safeguards and maintaining the integrity of the accounting system of nuclear material.

Venezuela signed a Comprehensive Safeguards Agreement with the IAEA in 1982, which presented the initial report of the existing material in a Research Facility that is inspected annually by safeguards authorities. However, the accounting system for nuclear material did not consider the use of nuclear materials in activities in the medical and industrial sectors. In this sense, at the initiative of the National Regulatory Authority, registration of the information required by safeguards was proposed regarding the material associated with the locations outside of facilities (LOFs), using PPC, supported by existing synergies in the regulatory system that considers the technological and physical security in the control of the unauthorized use of nuclear materials and radioactive sources.

State Competent Authority and Sustainability of Safeguards System for Iraqi Facilities

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Under the Constitution of Iraq and in implementing its commitments, the Law of National Monitoring Authority on Non-Proliferation of Nuclear, Chemical and Biological Weapons No. (48) 2012, tasks the Iraqi National Monitoring Authority (INMA) with responsibility for the following:

- Implementing and following up on Iraq's obligations related to bilateral, regional and international conventions and international resolutions relevant to non-proliferation of WMD;
- Issuing and following up effective national procedures for inspection, verification and monitoring applicable for all governmental and non-governmental organizations;
- Implementing export and import control measures and developing and maintaining a control list of materials and equipment consistent with relevant requirements of international export control regimes. Establishing a national database for these activities in coordination with international organizations to exchange data, serving national security interests;
- Standing arrangements;
- Conducting inspections, including collection, analysis and transfer of samples inside and outside Iraq;
- Conventions and treaties that Iraq has signed, approved or has in process; and
- National Procedures for the nuclear non-proliferation system in Iraq.

INMA has responsibility for the application of safeguards in Iraq, including establishing a National System for Accounting and Monitoring Nuclear Materials to:

- Identify nuclear material positions within and outside nuclear facilities under Iraq's safeguards system;
- Provide official permissions to use nuclear source materials inside the nuclear facilities and outside nuclear facilities (universities, research centers);
- Ensure efficient physical protection for the nuclear materials; and
- Prepare design information for the nuclear facilities, identify and record types of containers and monitoring devices.

INMA has issued a regulation for using, handling and transportation of nuclear material under safeguards and the Additional Protocol. It has established an information system for all nuclear activities and materials related to the non-proliferation regime. The Authority has identified locations and sites of relevance to Iraq's AP declaration, collected and prepared national lists and transferred all information to the relevant forms for reporting under the Additional Protocol.

INMA is involved with arrangements for the prompt notification of losses, unauthorized use, and removal of nuclear material.

The paper describes the role of the INMA in verification and the implementation status of UNSCR 1540 (2004).

Establishing Safeguards in the Republic of Sudan

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Sudan is party to Treaty on the Non –Proliferation (NPT) since 1968 and has signed the comprehensive safeguard agreement SCA since 1977(INFCIRC/245) and the small quantities protocol SQP (old text) since 2005. The Nuclear and Radiological Regulatory Control Bill, 2015, which approved recently in last Jan 2017 are Addressed clearly Safeguards. some efforts were done regarding to safeguards issue in Sudan for example A technical committee which has been formed by the Secretary General of Sudanese Nuclear & Radiological Regulatory Authority (SNRRA) including many organization, had studied the relevant treaties and international conventions and provide a comprehensive technical report (included safeguards) to the main stakeholders in the same side A national workshop, organized in cooperation with international atomic energy agency (IAEA) on the safeguards agreement in Sudan, 17-18April 2017), encouraged Sudan to conclude the AP and amendment text of SQP.

According to the nuclear Act 2017 the Safeguards Department has many Responsibilities the one of this is establishing and Strengthening State Systems of Accounting and Control for Nuclear Materials (SSAC) in Sudan also Many efforts done by SNRRA regarding to that and followed the IAEA publication as essential guideline and some countries experiences to be as basic steps to establishing and strengthening system to effective control of nuclear materials and activities in Sudan but still have many challenges.

Accession to the Safeguards Agreements: Sharing Ghana's Experience from the Historical Perspective

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Since the early 1970s, Ghana has been an important player in international cooperation on nuclear non-proliferation. Ghana has been a committed signatory of the nuclear Non-Proliferation Treaty (NPT) since 1968, and further demonstrated its commitment to the peaceful uses of nuclear technology by signing the Safeguards Agreement in 1975, and the Protocol Agreement in 2004. Although Ghana operated no research reactor, and had no nuclear regulator at the time of signing the NPT, it now operates a 30 kW Miniature Neutron Source Reactor (MNSR), Ghana Research Reactor-1 (GHARR-1), which was acquired in 1994. In 2017, the High Enriched Uranium (HEU) core of GHARR-1 was converted to a Low Enriched Uranium (LEU) core under the direction of the Global Threat Reduction Initiative (GRTI) in furtherance of Ghana's commitment to peaceful uses of nuclear technology. Two years before the core conversion project, Ghana established an independent nuclear regulator, called the Nuclear Regulatory Authority.

Ghana's long and rich experience in peaceful uses of nuclear technology provides a knowledge base that is well recognized by the IAEA and the US Department of Energy/National Nuclear Security Administration; a knowledge base that has served as a source of information, motivation and support for African Member States that are yet to accede to a safeguards agreement.

This paper provides a historical perspective to Ghana's experience, capacities, and lessons learned from the inception of its nuclear program, through its accession to, and implementation of, various international nuclear agreements, to the administration of safeguards.

An Overview of Important Features of India's Safeguards Agreement (INFCIRC/754)

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The IAEA contributes to nuclear non-proliferation through safeguards designed to verify States' undertakings not to use safeguarded items for proscribed purposes. While the legal framework for IAEA safeguards includes the IAEA Statute, safeguards agreements, protocols to these agreements, and subsidiary arrangements, the States' undertaking is realised through its national legal and regulatory mechanism. The Indian Atomic Energy Act, 1962 provides the legal framework for all aspects related to development of nuclear and radiation technologies including their security, safety and safeguards. Rules and guidelines issued under this Act include those related to export controls. The Nuclear Controls and Planning Wing (NCPW) set up in the Department of Atomic Energy (DAE) is responsible for implementation of India's commitment related to nuclear safeguards, export controls and nuclear safety and security.

India concluded a fresh safeguards agreement (INFCIRC/754) with the IAEA in 2009. As of 2018, 24 nuclear facilities are under IAEA safeguards including 6 fabrication facilities, one AFR, one SNM storage facility and 16 Thermal nuclear power plants. More than 75% of nuclear power generation is expected to be under IAEA safeguards as compared to 65% in 2014 demonstrating India's non-proliferation credentials but also its commitment to meet its energy requirements through enhanced green energy production and reduction in carbon footprint. Another interesting point is nuclear power plants outside IAEA safeguards did not increase, whereas those under safeguards increased by 15%.

Prior to the 2009 agreement, India had a number of safeguards agreements with the IAEA, based on the IAEA Safeguards Document INFCIRC/66/Rev.2. The Safeguards Agreement INFCIRC/754 is also an INFCIRC/66 type agreement but with many additional features. Some of them are the result of the IAEA's efforts to bring uniformity to subsidiary arrangements and structure and format for reporting requirements. Other features reflect India's readiness to extend the provisions of INFCIRC/754 to previous safeguarded facilities. Further, India is the only INFCIRC/66 country with an Additional Protocol in force. The paper dwells on some of the important features of INFCIRC/754.

Strengthening National Safeguards Implementation Infrastructure and Building Future Safeguards Capabilities in Myanmar

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Myanmar has had a Comprehensive Safeguards Agreement and a Small Quantities Protocol in force with the International Atomic Energy Agency (IAEA) since 20 April 1995. The next steps in strengthening international safeguards in Myanmar are ratification of the Additional Protocol and introduction of Integrated Safeguards. Currently, the Division of Atomic Energy (DAE) is the State authority responsible for Safeguards implementation in Myanmar. To enhance safeguards effectiveness and to raise awareness, the DAE is endeavoring to: release information to the media for public awareness; engage in national and international events; translate technical documents into the national language, and exchange knowledge with relevant stakeholders.

In order to strengthen its national nuclear-related legislation, the DAE has completed the drafting of Myanmar's comprehensive Nuclear Law covering Nuclear Safety, Security and Safeguards (i.e., 3S strategy). Furthermore, the development of a number of regulations, namely Nuclear Safety Regulation, Nuclear Security Regulation and Safeguards Regulation, will follow. Myanmar, a State with very limited quantities of nuclear material, is aware of the importance of physical protection of both nuclear material used for peaceful purposes and of nuclear facilities used for peaceful purposes. Physical protection plays an important role in supporting global nuclear non-proliferation and counter-terrorism objectives. Myanmar, therefore, acceded to the Convention on Physical Protection of Nuclear Material (CPPNM) and its amendment on 6 December 2016. Moreover, Myanmar has expressed a political commitment with regards to the Code of Conduct on Safety and Security of Radioactive Sources.

Challenges being encountered include the development of a legal framework; the implementation of safeguards regulations; not having available sufficient safeguards experts; a lack of financial resources; and infrastructural problems. Strategies to address these challenges include enhancing future safeguards capabilities by making every effort to provide nuclear non-proliferation and safeguards training for young up-and-coming Myanmar nationals. Furthermore, the DAE places top priority on providing for development of the necessary legal and regulatory infrastructure for safeguards, and to strengthen the State System of Accounting for and Control of Nuclear Material (SSAC).

Tunisia's Plan to Develop a New Legal and Regulatory Framework to Bring the Additional Protocol into Force

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This paper describes Tunisia's efforts to establish a new nuclear legislative and regulatory framework. In particular, this new comprehensive nuclear law will help to bring into force the Additional Protocol that was signed on 24 May 2005 but not yet ratified.

Tunisia has always supported the international community's efforts in strengthening the international safeguards regime. However, the Additional Protocol is not yet ratified due to an existing legal and regulatory system that is not suitable for the effective implementation of the Additional Protocol provisions.

In 2008, the National Atomic Energy Commission took the decision to establish a national legal and technical expert committee, to be in charge of establishing a new legislative and regulatory framework for peaceful uses of nuclear energy. This decision was later approved by the Board of Ministers.

The expert team prepared and submitted to the Government a draft of a comprehensive nuclear law that dedicated a whole chapter to Safeguards and Monitoring of Nuclear Material Import and Export. It includes provisions establishing a national system for the implementation of the Additional Protocol. The law also provides for the creation of the National Nuclear Safety Commission, which will be the new independent regulatory authority in charge of safeguards, among other responsibilities. This new law will be supported by several decrees and provisions to define obligations, targeted activities, materials, technologies, roles, responsibilities and procedures. The decrees of application will provide detailed regulatory provisions that will constitute a clear basis for an effective implementation of all obligations under the Additional Protocol.

The National Nuclear Safety Commission, to be established by the adoption of the comprehensive nuclear law, shall publish the forms, methods and procedures, and deadlines for submitting different Additional Protocol declarations and related guidance documents.

By the adoption of this legal and regulatory framework, Tunisia will be in a good position to bring its Additional Protocol into force.

Development of a Comprehensive Safeguards Regulatory Document for the Canadian Nuclear Industry

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The Canadian Nuclear Safety Commission (CNSC) is the State Regulatory Authority (SRA) in Canada and has the mandate to ensure the successful implementation of the Canada-International Atomic Energy Agency (IAEA) Comprehensive Safeguards Agreement and Additional Protocol. The CNSC uses a variety of regulatory tools to implement safeguards requirements, including, inter alia, regulations, licence conditions, and regulatory documents. Up until February 2018, the CNSC used regulatory document RD-336, "Accounting and Reporting of Nuclear Material", to place safeguards requirements on appropriate licensees. This was superseded by REGDOC-2.13.1, "Safeguards and Nuclear Material Accountancy". As part of the CNSC's policy to review regulatory documents on 5-year intervals, a review of RD-336 was undertaken in 2016. The decision was made to transform it from a document specific to nuclear materials accountancy to one which includes all safeguards requirements. The opportunity was also taken to consolidate reporting requirements and to introduce graded safeguards requirements wherever possible. A drafting team comprising safeguards experts and regulatory policy experts engaged in a year-long drafting process which included multiple internal reviews by CNSC staff and management, followed by a stakeholder consultation process. This paper will describe the CNSC's regulatory philosophy and regulatory framework, and the scope of the modernization of safeguards requirements which have been undertaken in the production of REGDOC-2.13.1.

Regulatory Infrastructure in Nepal

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In Nepal, nuclear technology is being applied in areas such as medicine, academic research, agriculture, industries (quality control and analysis), mining (survey), and veterinary (animal and fish diseases). A survey carried out in 2016 showed that 48 organizations possessed radioactive sources. However, Nepal does not have adequate regulatory infrastructure in place to regulate the facilities and practices.

Nepal has a National Nuclear Policy, 2007, which recognises the value of the peaceful use of nuclear energy for economic and social prosperity and the outcomes achieved so far from its study and research for these purposes. Similarly, Radioactive Materials Regulatory Directives, 2015, is implemented in order to protect human health, environment and security from possible hazardous effects due to unauthorized use of nuclear materials, through regulation of import; export; transportation; storage; and use of nuclear materials, and ensures that the country abides by its international commitments.

The Ministry of Education, Science and Technology is the main body responsible to utilise and promote, control and regulate nuclear technology; to implement and regulate policy, law and standards relating to atomic energy; and to deal with treaty, agreement, protocol, liaison and coordination with international organizations related to the ministry.

A draft bill for a Nuclear Safety Act is in progress and expected to be approved during the year 2018. This will make the necessary legal provisions for the beneficial, safe and peaceful uses of nuclear technologies and ionizing radiation; and for the protection of people, property and the environment against possible harmful effects of ionizing radiation. Meanwhile, Awareness Campaigns regarding safety, security and safeguards in relation to nuclear materials have been conducted in several parts of the country, and data collection on equipment incorporating or using radioactive sources, to prepare a national register, is ongoing.

The future plan and programs are focused on enactment of the Nuclear Act as soon as possible; establishment of the authorities as prescribed by the Act; preparation of an action plan to implement the Act; developing and attracting skilled technical manpower; and capacity building of the existing regulatory infrastructure through training and workshops.

Strategic Plan for Safeguards Implementation in Nigeria

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The Nigerian Nuclear Regulatory Authority (NNRA) was established by the Nuclear Safety and Radiation Protection Act 19 of 1995 with responsibility for nuclear safety and radiological protection regulation in Nigeria. The NNRA is required by law to perform all necessary functions to enable Nigeria to meet its international and national safeguards obligations in the peaceful use of nuclear technology. The NNRA has established and is maintaining the Nigerian System of Accounting for and Control of Nuclear Material.

With the review of the Nuclear Safety and Radiation Protection Act 19 of 1995, the NNRA has developed the Nuclear Safety, Security and Safeguards Bill. This bill gives the legal backing to the establishment of a State System of Accounting for and Control of nuclear material (SSAC) and further strengthens the implementation of the SSAC in Nigeria.

Nigeria is genuinely concerned with ensuring the correctness and completeness of her declarations to the IAEA. In this regard, the NNRA has further developed the Nigerian Nuclear Safeguards Regulations 2018. This Regulation strengthens the implementation of INFCIRC/358 and INFCIRC 358/Add. in Nigeria. As part of the regulatory requirements for safeguards in Nigeria, the NNRA is planning to conduct domestic inspections, which shall be independent of the IAEA. This will provide an interface for the Authority and facility operators and better understanding of the responsibilities in the provision of correct and complete information to the IAEA in a timely manner. With the cooperation of international partners (IAEA/USDOE/INSEP), Nigeria has developed the “Strategic Plan for Safeguards Implementation in Nigeria”. The strategic plan is being implemented based on an action plan spread over a five-year period and will be continuously reviewed as the need arises.

This presentation will discuss the strategies for effective safeguards implementation in Nigeria. It will also discuss the importance of international cooperation in sustaining the national nuclear safeguards regime.

Implementation of a Comprehensive Safeguards Agreement and Ratification of an Additional Protocol: the Case of Senegal

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The implementation of Senegal's obligations under its Comprehensive Safeguards Agreements (CSA) in connection to the NPT has begun to be systematically addressed by the creation of a competent national regulatory authority – the Autorité Sénégalaise de Radioprotection et de Sûreté Nucléaire (ARSN) – in 2011.

Since then, many efforts have been made by Senegal to achieving the ratification of the Additional Protocol (AP) to its CSA, the submission of the initial report on nuclear material and the initial set of AP declarations.
The purpose of the paper is to describe the efforts made by the Senegal with the help of the IAEA, US DOE and the non-governmental organization VERTIC for an effective implementation of the CSA with a modified Small Quantities Protocol (SQP) as well as for the ratification of the AP and its implementation.

The experience gained by Senegal in training safeguards inspectors of the regulatory authority, in establishing the initial nuclear material inventory in the country and in sensitizing the different national stakeholders may be useful for States that share a similar situation with Senegal.

Reinforcing Nuclear Safeguards Effectiveness through Collaboration

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The Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) was created on July 1991, as a directive of the "Agreement for the Exclusively Peaceful Use of Nuclear Energy" (Bilateral Agreement) between the Republic of Argentina and the Federative Republic of Brazil. In December 1991, the Republic of Argentina, Federative Republic of Brazil, ABACC and International Atomic Energy Agency (IAEA) for the Application of Safeguards in Argentina and Brazil became signatories to the Quadripartite Agreement.

Since the adoption of the Quadripartite Agreement, the application of safeguards in Argentina has made significant progress, mostly as a result of its cooperation activities. The IAEA, ABACC and the Nuclear Regulatory Authority of Argentina (ARN), which is the responsible organization for safeguards activities within Argentina, work in close association to strengthen safeguards implementation. This cooperation-based scheme has proven itself as a fundamental pillar in improving the effectiveness of the application of safeguards in the country and region.

This paper describes the application of safeguards in Argentina and specifically highlights improvements implemented in recent years; thus increasing both the efficiency and effectiveness of the safeguards regime. Some examples include the development of new technologies, such as the 2D-Laser curtain barrier, and new methodologies, such as the ABACC-Cristallini method for UF6 sampling. The status of ongoing cooperation activities and future challenges are also presented.

Enhancing Productivity and Efficiency in Safeguards Implementation through Upgraded Collaboration between the IAEA and Member States

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The IAEA faces increasing safeguards challenges and opportunities these days. Nuclear material, facilities and LOFs under IAEA safeguards have increased radically in the past decade, while the financial and human resources available to the IAEA have not followed the trend. In order to ensure the IAEA fulfils its safeguards mission, the IAEA plans to strengthen partnerships with States in its long-term strategy.

Article three of INFCIRC/153 stipulates that "the Agency and the State shall co-operate to facilitate the implementation of the safeguards." The Service Series 21 specifies that the "IAEA and the SRA should work together to reduce duplication of efforts, minimize errors, avoid miscommunication and implement effective procedures."

There are various types of collaboration between the IAEA and States, including support programmes, implementing 'safeguards by design' principles, State efforts to facilitate IAEA verification activities, translation of open source information from local language to English and joint use equipment.

This paper proposes further collaboration through support to IAEA inspection activities by State inspectors, while ensuring the IAEA's capability to draw soundly based safeguards conclusions. For example, in environmental sampling, the "clean guy" could be played by a State inspector, while the "dirty guy" must be an IAEA inspector.

Authenticating the quality of work by the State inspector is key to ensuring the soundness of safeguards conclusions. In the case of JUE, technical authentication is always assured by the Safeguards Technical Support Division of the IAEA. Similarly, in order to make sure that support by the State inspector is soundly based, some mechanism by which to certify their work is essential. Possible ways to assure this include certification by the IAEA, through participation in ICAS, a safeguards traineeship program, or SSAC training courses. The conditions for collaboration should also be coordinated and documented between the IAEA and States.

[SGI-S4] Tools, Approaches and IT Systems for State Safeguards Reporting

Benefits of using a Declarative Web Portal to make the Additional Protocol Declarations- Application with the French Portal PASTEL

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This paper presents the French Additional Protocol (AP) declarative web portal PASTEL and its benefits. In order to support IAEA mandates, France, as a Nuclear Weapon State and important nuclear industrial actor, has decided to develop an Additional Protocol web portal to be more efficient and improve this declaration. This portal was developed in 2014 and used for the first time in 2015. On one hand, this paper presents the technical organization put in place to declare and explain the reasons that led France to develop such a device. Then, it explains how the portal allows France to carry out its obligations thanks to a specific tool. On the other hand, it focuses on the French experience and the lessons learnt by the use of PASTEL for three years. The paper outlines web portal benefits with a study of registrants' behavior. This study shows that PASTEL is a time-saving way to declare for both registrant and State authority and improves efficiency. One of the biggest challenges is to make the registrant aware of its role in the AP declaration. If training and documentation is an answer to this challenge, we will show that the portal ergonomics and design can be also an important way to communicate with registrants.

The Safeguards State Declarations Portal: A Perspective from the Safeguards Department of the Nuclear Regulatory Authority, Ghana

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As part of the Member States' obligations under safeguards agreements, reports are submitted periodically to the IAEA. These include nuclear material accountancy reports, as well as Additional Protocol declarations. Ghana, being a Member State, fulfills these obligations yearly as required and ensures that its accountancy system is accurate and kept up-to-date. The introduction of the Web-based portal for submitting declarations is a welcome idea, which Ghana's safeguards department seeks to effectively use in its reporting to the IAEA. Despite a few challenges with the use of the software during the initial stages of its introduction to the department, the portal has been quite helpful in offering the State a more effective and convenient way of communicating with the Agency.

This review seeks to look from the perspective of the State authority to the benefits and challenges, as well as ways of improving the software for the benefit of all who use it.

Experiences of Vietnam in Applying Information Technology to Streamline and Simplify Its Safeguards Implementation Processes: Benefits and Challenges

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In the light of global public concern regarding the misuse of nuclear material and proliferation, implementation of the IAEA safeguards system is clearly important. Vietnam signed a Comprehensive Safeguards Agreement (CSA) in 1989, and an Additional Protocol (AP) in 2007, and they came into force in February 1990 and September 2012, respectively. Since these times, with continued support from the IAEA, Vietnam has fulfilled its obligations under the CSA and AP. By "State as a whole" considerations in the implementation of safeguards for Vietnam, the IAEA had drawn the broader conclusion for Vietnam in 2014, and reaffirmed it in 2015 and 2016. The Vietnam Agency for Radiation and Nuclear Safety (VARANS) is the State Responsible Authority (SRA) for safeguards in Vietnam. VARANS has to: 1) perform safeguards verification activities for nuclear facilities and LOFs; and 2) develop national reports and declarations that are required by the IAEA. These processes initially comprise of collecting and validating information from the licensees and from VARANS' database for license and inspection. The reports and declarations may be submitted in many ways including official email, printed copy, and encrypted channel. In cooperation with the IAEA and the U.S., Vietnam has applied new methods for its safeguards implementation. On one hand, the U.S has supported Vietnam to develop the Vietnamese Information Management System (VIMS) in order to facilitate nuclear facilities and LOFs in Vietnam to submit their reports online. By using VIMS, VARANS is able to establish a comprehensive and unified database system; consequently, the processes for verification and report development will be simplified. On the other hand, the IAEA and Vietnam began use of the State Declaration Portal (SDP) for the submission of all reports, declarations, and associated information from Vietnam since the end of 2017. All of these submissions can be done rapidly, securely, and conveniently by using only this portal instead of using official email, printed copy, and encrypted channel. This paper seeks to share the benefits and challenges when applying the above tools in Vietnam for the practical implementation of safeguards. Based on these experiences, potential options were proposed from the perspective of improving the effectiveness and efficiency of safeguards implementation.

Use of an Electronic Reporting System to Increase the Efficiency and the Effectiveness of Safeguards Implementation

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Data security issues continue to be an overarching factor in cooperation between the IAEA and States involved in safeguards implementation. Information provided by a State regarding its nuclear activities represents a significant part of the information used by the IAEA for safeguards implementation. The improvement of existing means for communication and data transmission simplifies and improves the implementation of safeguards.

Historically, the Agency received information from France as hard copies, which were manually transformed by the IAEA into code 10 format and then loaded into the Agency's information system. France, looking at new ways of working smarter, proposes the submission of notifications in digital format, with the objective of creating a more effective and efficient system while at the same time, maintaining the security of prescribed information. France has already implemented an electronic reporting system to exchange data and information with the European Commission.

Receiving this information in code 10 format similar to ICRs will significantly streamline the existing procedure. This digital format could enable the IAEA to process the information more efficiently, and provide future opportunities for the Agency to improve the resolution of transit matchings.

This electronic approach would establish a secure transmission channel, which could be used as an alternative option for the exchange of information.

Finally, the scope of this project emphasizes the importance of international cooperation and the need to maintain and improve the exchange of data, to increase the efficiency and the effectiveness of safeguards implementation.

This paper aims to provide an overview of the project: the solution approach; the European Commission's feedback on its experience; the security of data and the secure exchange of confidential information; and the benefits realized by both sides through effective cooperation.

The State Declarations Portal: Shaping the Present and improving Communication in the Future

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On May 31, 2017, the IAEA launched the Safeguards State Declarations Portal (SDP), a new and innovative web-based system that supports information exchange between SRAs and the Department of Safeguards. The deployment of SDP is associated with all three Symposium objectives: innovate, partner, and improve.

The year since SDP has gone live has provided time to review lessons learned and to implement improvements by engaging with the Safeguards community and sharing experiences. The Symposium is an excellent venue for discussing ways to streamline, simplify, and improve future communication using SDP.

Member States who already use SDP – with fuel cycle capabilities varying from limited to complex – will be invited for the panel discussion, including Australia, Turkey, Botswana, Ghana, Thailand, Canada, Switzerland and others.

A pilot project is underway with Canada to explore the potential for streamlining reporting and improving communication between Member States and the IAEA.

Improving SSAC Capability through the Application of an Appropriate NMAC Software: Experience of the Czech Republic

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The core objective of this paper lies in introduction and demonstration of detailed technical features and capabilities of the “SFG - Safeguards application for managing the SSAC”, the software used in the Czech Republic for maintaining the SSAC at both State and operator level. The application, which was created in the early 1990’s and updated several times, has been effectively used by the SRA to manage NMAC and reporting functions, as well as utilising its capability in support of overall safeguards implementation (with regard to all IAEA, Euratom and national obligations). The paper explains the benefits provided by using the SFG in streamlining of day-to-day SRA regulatory operations in the area of NMAC; controlling export and import of other specified items; and submittal of required declarations to the IAEA. Preparation of supporting documents for IAEA verification activities and national inspections in the context of this application is also touched upon. Structurally, the history and purpose of the application is fully explained, then its scope and coverage are addressed, followed by monitoring of exempted, terminated and pre-34(c) nuclear material and finally its compatibility and security aspects are examined. The key functionalities of the SFG will be demonstrated during an ESPACE presentation.

NUCMAT: Integrated National-Level Nuclear Materials Inventory Management Software

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The main purpose of the development of the NUCMAT software is facilitation of the implementation of an integrated national-level nuclear materials inventory management system in countries with different nuclear programs. NUCMAT is a comprehensive software for accounting for and control of nuclear materials that has three main pillars: 1) Safeguards - Accounting for and reporting of nuclear materials in full compliance with IAEA requirements and regulations; 2) Nuclear Security - Interfacing between nuclear material accounting and protection of nuclear material; and 3) Cyber Security – Providing protection for sensitive data in a multiuser environment against external attacks and insider threats. NUCMAT may be used at both the State and facility/LOF levels, using either a single server or distributed network configurations through protected communication channels. Besides all IAEA-required reports, NUCMAT allows the user to generate additional free format reports to facilitate regulatory body/IAEA inspections, as well as nuclear security efforts. Reports generated by NUCMAT are fully compatible to pass QA/QC control through the IAEA QCVS program.

To support nuclear material protection efforts, NUCMAT provides the user with a recoverable history of each nuclear material, with an exact specification of the location as well as comprehensive, traceable log information. In NUCMAT, strong multi-layer means were deployed to guarantee secure storage and transfer of sensitive information.

National Nuclear Forensics Library as a System for Nuclear Materials Accountancy and Control

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This paper describes the prototype Romanian National Nuclear Forensics Library as a system assisting in conducting nuclear forensic interpretation and formulating of findings which can also support accountancy and control of nuclear materials. The development of this library started from Romanian's participation in the ITWG's Galaxy Serpent 2 internet-based exercise, where countries had to organize the provided data in an appropriate manner from which to draw nuclear forensics-like conclusions. The platform was created using MySQL for the database, and PhP programming language for the user interface. It is stored offline, and the data is protected by username and password. The prototype, called NNFL-RO, is only focused on known nuclear materials available in the Physical Inventory List (safeguards depository) of IFIN-HH. However, its expansion to the broader national level in foreseen in the near future.

Managing the Interface between NMAC and Nuclear Security within Public Company Nuclear Facilities of Serbia

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Public Company Nuclear Facilities of Serbia (PC NFS) is the only nuclear operator in Serbia. It was founded in 2009, under the Law on Ionizing Radiation, together with the Serbian Regulatory Body. Since its establishment, PC NFS has continued all nuclear activities previously managed by Vinca Institute of Nuclear Sciences: two research reactors (RA- final shut down and RB- zero-power critical assembly, operational but currently not licensed); radioactive waste management facilities including old Hangars H1 and H2 (with legacy waste), new Hangar H3 (for the storage of intermediate and low level radioactive waste) together with the secure storage for the high activity sealed radioactive sources; and closed uranium mine Kalna are all part of the Company.

The paper will present our efforts in strengthening the NMAC system within PC NFS through enhancing the cyber security system in cooperation with various international organizations. We will also provide coordinated actions between safeguards and nuclear security experts in solving various issues which have led to the enhancement of NMAC systems. Self-assessment methodologies, developed by the safeguards and nuclear security experts, will also be provided.

NUMBAT: Lessons Learnt from Australia's Database Development

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The Australian Safeguards and Non-Proliferation Office (ASNO) manages Australia's compliance with safeguards obligations through a system of permits for the possession of nuclear material under Australia's safeguards legislation.

Collating and balancing reports on nuclear material held by multiple Locations Outside Facilities (LOF) locations is a resource-intensive challenge. Australia has about 110 LOF locations, holding approximately 2,500 batches of nuclear material in total, and one nuclear facility. Most LOF locations have little to no experience with safeguards and it takes about eight person-weeks each year to balance all LOF inventories and submit relevant reports to the Agency. This is a significantly greater effort than for Australia's nuclear facility, given the variability in the quality of accountancy practices across these LOF locations. Such effort is disproportionate to the very low risks of LOF nuclear inventories, but LOF management can be made less resource-intensive if more effective tools can be developed.

ASNO has embarked on a substantial project to upgrade its IT infrastructure, covering management of inventory, permits and inspections, and the tracking of Australian uranium exports under bilateral nuclear cooperation agreements. ASNO has transferred its existing NUclear Material Balance And Tracking (NUMBAT) database to a new platform and introduced a web portal for permit holders. The database directly links permit inventory and transactions to the auto-population of labelled XML reports to the Agency, making Australia one of the earliest adopters of XML formatting. The web portal enables permit holders to update permit details, and submit inventory changes to ASNO.

The new database was developed by a small dedicated database development team, using an agile scrum approach. This comprises individual sprints focused on a distinct piece of functionality. This was more effective than previous database upgrades that used a waterfall approach. After individual sprints, ASNO did user-acceptance testing of live scenarios which then informed the design of subsequent functionalities. ASNO continues to work with the database team to complete all functionality by 2019. This paper will share lessons ASNO has learnt with this database upgrade project – what worked, and what didn't.

Pre-NRTA Systems: Opportunities and Challenges

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[2] *CTE*

The principle of verification of the accounting declarations of the ORANO SET GBII enrichment plant is based on a physical control of the uranium masses and isotopic contents, and by sampling on the incoming and outgoing containers of the installation stored on the park since the last routine inspection. An annual inventory of the installation completes this scheme.

A computer network collects physical tracking data from the operator. These data are then processed by specific software developed by the European Commission Joint Research Centre of lspra. This software allows for monitoring of the operator's activities in connection with the collection of precise weighing data. Measurements from mass spectrometers allow determination of the ^{235}U concentration within UF_6 from cascades.

Thanks to this acquisition network, verification of the monthly accounting declarations of the containers can be carried out on the basis of three components: precise weighing data from monitoring of the weighing station; on measurements from mass spectrometers; and on cross-checks between the isotopic contents and declared/calculated masses. The physical data are all available in the network database and, therefore, accessible for audit by EURATOM and IAEA inspectorates.

The network therefore makes it possible to envisage changes in the practices of the current control approach, taking into account in particular the possibilities offered by computer analysis. To date, the EURATOM information system has been used successfully during the last four annual inventories. Its implementation during monthly inspections should allow greater reliability and greater flexibility for both inspectorates and the operator.

At the ORANO reprocessing plant in La Hague, a data transmission system connecting to the Euratom review room in Luxembourg is being set up. The raw data, collected in real time, will then be developed and sent through VPN with a slight delay.

The purpose of the presentation is to take stock of the opportunities that these pre-NRTA systems represent and the challenges that must be overcome, particularly in terms of data protection and cybersecurity.

Control and Accounting of Nuclear Material of the Republic of Uzbekistan

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Control and accounting of fissionable nuclear materials is based on the following documents: "IAEA safeguards. Guidelines for State Systems for Control and Accounting of Nuclear Materials" and "Regulations on the Structure of the State System for Control and Accounting of Nuclear Materials", adopted by the Resolution of the Board of the Regulating Authority of the Republic of Uzbekistan.

Control and accounting of fissionable nuclear materials provides for reliable and timely information about quantity and distribution of nuclear materials, timely detection of losses, non-authorized use or theft of fissionable nuclear materials.

Control and accounting of nuclear materials at the WWR-SM reactor INP AS RU are carried out constantly from the moment of the first receipt of nuclear fuel. Until 1991, quarterly control and accounting of nuclear materials was carried out in collaboration with the Ministry of Atomic Energy and Industry of the former USSR. Since 1994, all documents containing information about the accounting of nuclear materials are submitted to the Republic of Uzbekistan's State Inspectorate, "SANOATGEOKONTEXNA-ZORAT", and further communicated by official channels to the IAEA.

The main tasks for the control and accounting of nuclear materials in the Republic of Uzbekistan are to improve the regulatory legal framework of the Republic of Uzbekistan for countering the illegal circulation of nuclear materials and radioactive substances.

Questions on control and accounting of nuclear materials outside facilities have been resolved, with all the owners of nuclear materials identified, with measurements on nuclear materials carried out to more accurately determine the mass and other characteristics.

It is planned to discuss the possibility of a training course on the ORIGEN and TRITON software to provide practical research information to the specialists of the research reactor on the implementation of IAEA safeguards, particularly methods for calculating the burnup of ^{235}U and plutonium recovery. Training in the various methods for calculating the burnup of ^{235}U and the production of plutonium will be used at WWR-SM to provide more accurate record-keeping of nuclear materials.

[SGI-S5] Streamlining Information-related Workflows: Small Holders/LOFs and AP Declarations

Creating Digital Site Maps for the Additional Protocol

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The German Support Program has been working alongside the IAEA Department of Safeguards to enhance the methods for submitting site maps required under Article 2.a.(iii) of the Additional Protocol. The experience and results of this cooperation have exposed new requirements and workflows for site operators and State or regional authorities to submit site maps compatible with current geographic information systems (GIS) data standards. The authors used an open source GIS web server to demonstrate the ability of site operators to capture, maintain and submit the relevant map data and associated tabular information such as building use and descriptions. Transferring web services from site operators to the IAEA is a potential approach for providing site maps and is therefore explored in this paper. The paper also highlights some of the efforts made under the German Support Program to convert existing maps to GIS formats, as well as examination of the Protocol Reporter 3 and European Commission's Additional Protocol Editor (CAPE) software to submit such data.

10 Years of the Additional Protocol Informational and Analytical System of Ukraine

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The Additional Protocol to the Safeguards Agreement (INFCIRC-540) entered into force in Ukraine in 2006. Ukraine, which has an extensive nuclear program and participated in the USSR's nuclear weapons program in the past, submits declarations under all paragraphs of Article 2.a of the Additional Protocol.

At the stage of preparation of the declaration of the State on the Additional Protocol, and before the information is entered into the Protocol Reporter and submitted to the IAEA, the State Authority Responsible for Safeguards Implementation (SRA) collects information from licenses and declarants. The SRA analyzes and verifies the data, to be completely sure of its relevance, as well as the conformity of the current changes in the declaration to the information that has been provided earlier. For this purpose, namely for simplifying collection, validation and submission of declaration information, the "Additional Protocol Informational Analytical System" (APIS) was developed for the State Nuclear Regulatory Inspectorate of Ukraine in 2008.

The APIS, as an application of the IBM Lotus Notes DB Management System, uses the capabilities of this DBMS to work with and visualize information flows, for example: the APIS realizes the possibility of working with text fields of almost "unlimited" size, performs context search, and implements the mechanism of attaching and downloading files, including MS Office applications. The APIS contains "official" information imported from or submitted to the IAEA files, as well as site maps and reference information (comments and explanations).

The APIS has been operated by the State Nuclear Regulatory Inspectorate of Ukraine for 10 years. During this period, no negative comments were received from the IAEA on the quality of declarations format, and no changes were made to the program code of the APIS. Now we can say that the use of APIS has significantly simplified the process of preparing declarations and their quality. APIS capabilities, such as contextual search and the possibility of using various criteria for data selection and visualization, allow for a comprehensive analysis of information and provide the necessary information base for the preparation of annual submissions to the IAEA.

State Declarations Portal and Protocol Reporter 3: Experiences of Turkey

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Turkey is the first State that implemented State Declarations Portal (SDP) for its nuclear material accounting reports and Additional Protocol (AP) declarations. Also, Turkey had tried to use Protocol Reporter3 (PR3) since first it was announced and delivered to Turkey. However, there are some problems experienced by Turkish Nuclear material accounting and control (NMAC) officers. The aim of this paper is to introduce, Safeguards System in Turkey briefly and then to share problems faced with Protocol Reporter2 (PR2) and PR3 and best practices about SDP.

Implementation of Additional Protocol in Serbia

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The Safeguards Agreement concluded between the Socialist Federal Republic of Yugoslavia and the IAEA was signed in May 1972, and put into force in December 1973. The agreement continues to be applied in the Republic of Serbia by succession, to the extent relevant to its territory. Serbia has also signed, in July 2009, the Protocol Additional to the Agreement for the Application of Safeguards in connection with the Treaty on Non-Proliferation of Nuclear Weapons. It is currently in the status of preratification.

According to the new Law on Radiation Protection and Nuclear Safety of 2009, a regulatory body was founded by Governmental decision. The Serbian Radiation Protection and Nuclear Safety Agency (SRPNA) provides the conditions for effective implementation of radiation protection and nuclear safety measures, when carrying out radiation practices and nuclear activities. As such, SRPNA is also responsible for the implementation of safeguards and Additional Protocol provisions in Serbia.

Since its formation, SRPNA has been actively involved in promotion of the Additional Protocol, with a goal to inform all relevant stakeholders and institutions in Serbia about their responsibilities according to AP provisions. A number of outreaches and workshops (WS) have been conducted: AP introduction WS; WS for high-level policy makers; Complementary Access introductory WS; AP-related web site, etc.

Serbia received significant support from the United States Department of State, the International Atomic Energy Agency and the European Commission to organize and conduct these activities. Through international collaboration, SRPNA staff have also received extensive training concerning the AP, which has enabled SRPNA staff to perform further education regarding the AP.

Thailand's Additional Protocol: Experience and Challenges

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As a State party to the Nuclear Non-Proliferation Treaty (NPT), Thailand has implemented the Comprehensive Safeguards Agreement (INFCIRC/241) since 1974. In order to fulfill international obligations under the NPT and to provide transparency on nuclear energy uses, Thailand signed the Additional Protocol on 22 September 2005 and prepared the regulatory legal framework and implementation for ratification. After 12 years' work conducted by the Office of Atoms for Peace (OAP) and relevant authorities, the Additional Protocol entered into force on 17 November 2017. National and international support, experiences, challenges and procedures to implement the Additional Protocol in Thailand will be explained in this paper.

Safeguards and Additional Protocol Reporting Regime at Nuclear Regulatory Authority

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The Nuclear Regulatory Authority Act, 2015, (Act 895) established the Nuclear Regulatory Authority (NRA) as the Competent Authority for Safeguards and Additional Protocol reporting and regulation in Ghana. A reporting regime has been established drawing experience from the previous regulatory system under the Ghana Atomic Energy Commission. The regime addresses safeguards and Additional Protocol reporting needs of the NRA. A Draft Safeguards Regulation is currently under review, which was developed with assistance from the International Nuclear Safeguards Engagement Program (INSEP) and United States Nuclear Regulatory Commission, and provides the framework for implementing the reporting regime. Inventory Change Reports, Material Balance Reports, Special Reports and Additional Protocol Reports are addressed in the Draft Safeguards Regulation. The use of the State Declaration Portal and Protocol Reporter 3 are discussed. The paper presents the current reporting regime on safeguards and the Additional Protocol in Ghana.

Streamlining and Simplifying Collection, Validation, and Submittal of Information to the IAEA

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The majority of States that have an Additional Protocol (AP) in force face some challenges in collecting the information necessary to prepare their declarations pursuant to Articles 2 and 3 of the AP. Moreover, the declarations constitute a “Highly Confidential” communication between the State and the IAEA, and submission by email is very insecure.

One possible method for collecting safeguards-relevant information is to establish a National Safeguards Working Group, including ministerial institutions. Such a working group could be a good channel of communication between operators and the State Regulatory Authority (SRA). The members of the working group should be invited to participate in regular meetings.

To report State declarations under an AP, the IAEA Department of Safeguards’ Declared Information Analysis Section has developed the Protocol Reporter Version 3, known as PR3. The PR3 is a computer software programme developed and provided by the IAEA. Cambodia has begun to use this new software tool since December 2016, finding it easier to use than the previous version (PR2). After generating a declaration in the electronic file, it can be encrypted to be more secure and then sent to the IAEA via the State Declaration Portal (SDP). The SDP offers States and Regional Authorities a new and efficient method to submit declarations and communicate with the Department of Safeguards’ Declared Information Analysis Section. The portal keeps track of communications while reducing paper-based processes and manual data entry, saving time and effort for all. In addition, it is a secure channel for timely communication between States and the IAEA.

Preparation of Additional Protocol (AP) Declarations using Protocol Reporter 3 and Attached Digital Declaration Site Maps for the AP Article 2.a.(iii): Experiences of AP Workflows from Finland

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Finland, as a 'non-Side-Letter State' (non-SLS), acts as a pilot State for other non-SLS to European Atomic Energy Community (EURATOM) and has gained experiences in testing and evaluating Protocol Reporter 3 (PR3) software and Digital Declaration Site Maps (DDSM) through the ongoing International Atomic Energy Agency (IAEA) Member State Support Programme (MSSP) task. In 2018, Finland provided Additional Protocol (AP) declarations under INFCIRC/193/Add.8 to EURATOM and the IAEA in PR3 format and an Article 2.a.(iii) test site map for a selected site using DDSM submission for the first time. Ultimately, Finland plans to adopt DDSM for all its main sites in order to submit the site maps in a digital, spatial format compatible with the IAEA's Geospatial Exploitation System (GES). Finland's experiences have assisted the IAEA with starting the development of a special template for the PR3 software, and refining DDSM submission workflows, especially for non-SLS, to support their reporting obligations to EURATOM and the IAEA. The paper outlines the steps, benefits and challenges of the AP workflows based on the experiences of the State or regional authority responsible for safeguards (SRA) and site operator in Finland. These include the preparation and submission of PR3 and DDSM data. In particular, the paper highlights the findings of the operator's workflows to convert their existing site map into the DDSM format, and the SRA's efforts to exploit Geographical Information Systems (GIS) software for establishing capabilities to analyse operators' DDSM data. The paper also presents initial experiences in pilot uses of PR3 software when importing and adjusting legacy data from Protocol Reporter 1.

Future of Safeguards: Use of New Information Technologies to Improve Information Exchange between Canada and the International Atomic Energy Agency

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Canada has one of the largest fuel cycles subject to a Comprehensive Safeguards Agreement and an Additional Protocol in the world. The Canadian Nuclear Safety Commission (CNSC), as the State Regulatory Authority (SRA) for Canada, is responsible for ensuring that the International Atomic Energy Agency (IAEA) receives the large number of reports and documents required to support safeguards in the country. These reports and documents include nuclear material accountancy State reports, design information, operational reports and Additional Protocol declarations, as well as near real-time accountancy information to support Short Notice Random Inspection (SNRI) regimes across much of the fuel cycle. As a result of the need to process such information, the CNSC is interested in leveraging technology to the extent possible. In this paper, we review the use of innovative technologies and tools. In many instances, Canada has played an important role either in supporting development and/or being an early implementer. The technologies and tools on which this paper will focus include: the IAEA's State Declarations Portal (SDP), Protocol Reporter 3 (PR3) software for Additional Protocol declarations, and Digital Declaration Site Maps (DDSM). Canada will review its experience with these tools and with its own domestic tools (including development of its own e-business suite for nuclear material accountancy reporting) in improving information exchange between the IAEA and an SRA.

Implementation of the Additional Protocol in Cote D'Ivoire: Review and Prospects

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The State of Côte d'Ivoire has a comprehensive safeguards agreement (CSA) that entered into force on 8 September 1983. The protocol additional to the safeguards agreement (AP) entered into force on 5 May 2016. As a result, the following activities were carried out over three (3) years, from 2016 to 2018:

- In accordance with paragraph 32 of the CSA, Côte d'Ivoire has submitted twelve (12) accounting reports on the nuclear material within its territory. These reports are of three (3) types: ICRs, PILs and MBRs.
- Pursuant to articles 2 and 3 of the protocol additional to the safeguards agreement, Côte d'Ivoire provided information to the IAEA in an initial set of AP declarations; this consisted of eleven (11) declarations regarding the locations of specified sites (use of each building under article 2.a.(iii)). Seven (7) updates were submitted under article 2.a.(ix)(a) of Annex II of the AP regarding the export of non-nuclear equipment.
- Regarding complementary accesses, pursuant to Article 4.a.(i), Agency inspectors conducted one mission to verify the absence of undeclared nuclear material and activities in a laboratory at the site. Effective administrative measures were implemented to facilitate IAEA inspection missions.
- On 14 May 2018, the General Part of the Subsidiary Arrangements was re-submitted to the Authority for Radiation Protection, Nuclear Safety and Security (ARSN) for signature.
- With the support of the US International Nuclear Safeguards and Engagement Program (INSEP), a workshop was held in Côte d'Ivoire on the preparation of the initial set of AP declarations.

The experience acquired by the State's regulatory authority in the implementation of the CSA and the AP is useful for States in a situation similar to Côte d'Ivoire.

Extending Protocol Reporter 3 into a Universal AP Reporting Tool that Supports EURATOM AP Workflows

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Twelve Non-Nuclear Weapon States of the European Union (EU) have delegated the implementation of provisions of the Additional Protocol (AP) to the European Commission of the EU through side letters (‘Side-Letter States’), whereas some other EU Member States, ‘non-Side-Letter States’, have opted for direct declaration to the IAEA of parts of the AP. A deep analysis of the workflow of AP declarations is a prerequisite to adapt the Protocol Reporter 3 (PR3) software to the needs of these States and thus to support the European Atomic Energy Community (EURATOM) States in their reporting using the new PR3 format. Additionally, the proposed format of Digital Declaration Site Maps (DDSM) attached to declarations under the AP Article 2.a.(iii) is discussed in the paper.

Impact of PR3 on the Quality and Consistency of AP Data and on Workflows

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The paper describes in detail the impact of using the new input system for Additional Protocol (AP) Declarations, Protocol Reporter 3 (PR3). The authors explain the benefits regarding quality, consistency and workflow to the users and the impact on the further data analysis.

Lost in Translation: Improving the accuracy of the offline automatic translations of the Additional Protocol declarations

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States with Comprehensive Safeguards Agreements (CSAs) and Additional Protocols (APs) in force are required to submit declarations to the International Atomic Energy Agency (IAEA) providing information about all steps of their nuclear fuel cycle, from uranium mines to nuclear waste, on a quarterly and annual basis. While the majority of States submit their AP declarations in English, a significant number provide their declarations in Russian, French and Spanish. Given that the official translations provided by the staff of the Agency's Division of Conference and Document Services (MTCD) take time, the Department of Safeguards recognized that there was a potential for efficiency gains in providing the reviewers of AP declarations with a tool performing automatic translation in order to get a general overview of State-supplied information. The paper describes the results of the collaborative work between the Department of Safeguards, MTCD, and an external vendor of the automated translation tool on the development of the customized Safeguards-specific dictionary, its integration with MTCD's Safeguards-relevant translation memories, and the deployment of the tool within the user interface of the Additional Protocol System (APS). The automated translation tool enables the users to understand the general idea of the State-supplied information as soon as the new declarations have been uploaded to APS. This allows for more efficient prioritization of the requests for the official translation to MTCD and thus contributes towards more effective State evaluation process. The project has special significance in proving the possibility of designing and developing the translation capabilities of APS within the IAEA's secure Integrated Safeguards Environment, which does not allow access to the Internet. The solution developed during this project is flexible enough to be used in other areas of Safeguards work where quick translations of sensitive documents are required.

Implementing a Modified Small Quantities Protocol in the U.S. Caribbean Territories

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The Agreement between the United States of America (U.S.) and the International Atomic Energy Agency (IAEA) for the Application of Safeguards in Connection with the Treaty for the Prohibition of Nuclear Weapons in Latin America (Treaty of Tlatelolco) (Information Circular (INFCIRC)/366) entered into force on 6 April 1989. When INFCIRC/366 was signed, the U.S. and the IAEA also concluded a Small Quantities Protocol (SQP) to the Agreement that held in abeyance a majority of the IAEA reporting and access requirements. In 2005, the IAEA identified proliferation concerns associated with holding most of the requirements in abeyance through an SQP, and has since urged States with an original SQP to adopt the amended model SQP.

In 2016, the U.S. and the IAEA agreed to implement the modified SQP (ModSQP). The U.S. Nuclear Regulatory Commission (NRC) initiated rulemaking to revise Title 10 of the Code of Federal Regulations (10 CFR), Part 75, "Safeguards on Nuclear Material - Implementation of Safeguards Agreements Between the U.S. and the IAEA," to incorporate the new requirements of the ModSQP. Preparations for the implementation of the ModSQP have included interagency coordination within the U.S. Government, and interactions with IAEA staff to finalize the Subsidiary Arrangements (SA) for the ModSQP and the Location Outside Facilities Attachment (LOFA). In addition, the State system of accounting has directed the Nuclear Materials Management and Safeguards System (NMMSS) to implement reporting requirements to satisfy the commitments of the SA and LOFA. Consultation between NMMSS and the IAEA resulted in an acceptable draft initial Physical Inventory Listing (PIL) that will serve as a template for subsequent annual PILs. NRC staff and analysts from NMMSS held a workshop in Puerto Rico for NRC licensees impacted by the proposed changes in 10 CFR Part 75, focusing on the new reporting requirements for licensees that will come into effect when the Agreement enters into force.

This paper will address the implementation of the ModSQP in the U.S. Caribbean Territories, including challenges in coordination with NRC internal and external stakeholders.

Safeguards with Minor Holders – from Headache to the Optimal Safeguards Implementation

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Regulatory control measures for nuclear materials (nuclear safeguards) at the national level in Finland are a prerequisite for the peaceful use of nuclear energy in accordance with agreements on nuclear non-proliferation, mainly described in the Non-Proliferation Treaty (NPT). The national-level regulatory control of safeguards is implemented by STUK, including measures for minor nuclear material holders.

STUK maintains a national nuclear materials accountancy system, including the minor nuclear material holders. STUK verifies that the nuclear activities in Finland are carried out in accordance with Finnish nuclear legislation, European Union Safeguards Regulations and international agreements. According to the STUK requirement in Guide YVL D.1, the minor nuclear material holders are requested to prepare nuclear material handbooks. STUK approves these handbooks and the responsible person for safeguards. In the case of minor nuclear material holders, the relevant requirements are carefully discussed together, to ensure a clear understanding of the needs and expectations to be fulfilled.

Minor nuclear material holders mostly have small quantities of nuclear material, mostly exempted and with no inventory changes. Finding a reliable path to implement all of the necessary safeguards measures can be challenging. However, STUK has already taken the essential steps to assist these holders in fulfilling their safeguards obligations. There were a total of 13 minor nuclear material holders in Finland by the end of 2017. Most of these holders had been granted a derogation in respect of reporting frequency by the European Commission. Almost all of them have nuclear material in the form of depleted uranium, as shielding material around transport casks for radioactive sources. The number of minor holders has dropped since the year 2000, as STUK has made systematic efforts to clarify requirements and simplify declarations to achieve best practice.

LOF Management in Australia

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Locations outside Facilities (LOFs) hold limited quantities of nuclear material, but States may have many LOF locations to regulate. Often, States have many more LOF locations than nuclear facilities, generating a large administrative volume for the Safeguards Authority, even with a relatively static inventory. The challenge for each Safeguards Authority is to set up infrastructure with processes in place to streamline the regulation and management of nuclear material within LOF locations.

Collating and balancing the reports on nuclear material held by many LOF locations can be challenging. In the case of Australia, there are about 110 LOF locations holding over 3,000 batches of nuclear material. It takes the Australian Safeguards and Non-Proliferation Office (ASNO) about eight person-weeks for each annual reporting campaign, to collate and analyse inventory reports, and then to balance the inventory and inventory changes to close the material balance period. To make this process more efficient, ASNO has a project in place to substantially upgrade its database and permit holder portal called NUclear Material Balance Tracking System (NUMBAT). The first phase of the recently upgraded database addressed many of these challenges in strengthening IT infrastructure and streamlining the process of gathering information.

In addition to inventory management, there is also the challenge of managing information flows for Additional Protocol (AP) reporting. Functionality for collating and reporting for the AP is currently not included in NUMBAT, but is planned for later phases of the database development. ASNO uses the IAEA's Protocol Reporter III software for collating information for AP declarations, but the collection of information is done through a combination of permit conditions, paper-based forms, open-source research, and targeted enquiries. This paper will describe the mechanisms ASNO has put in place to streamline this process.

Practical Considerations for Location Outside Facility Designation and for Efficient Safeguards

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To determine the most suitable designation when applying safeguards to entities that possess nuclear material, consideration should be given to various factors including operational activities and the quantity of nuclear material present. By choosing the appropriate designation, and thereby ensuring that the safeguards activities conducted are sufficient, the State Regulatory Authority (SRA) can contribute to the optimization of the State System of Accounting for and Control of Nuclear Material (SSAC) within its jurisdiction. Beyond simply designating an entity as either a facility or a Location Outside Facility (LOF), the Canadian Nuclear Safety Commission (CNSC) has identified and employed changes to simplify and streamline safeguards implementation for LOFs. Such changes derive from numerous years of experience applying safeguards at LOFs and critically assessing the approaches taken in light of feedback received from various stakeholders including CNSC staff, operators and the International Atomic Energy Agency (IAEA). The current initiative to optimize safeguards implementation for LOFs focuses on three primary areas: reviewing the approach taken when applying safeguards to locations with very small quantities and little movement of nuclear material; ensuring that safeguards are applied pragmatically to existing and future LOFs; and reassessing the use of a national LOF.

In this paper, the evolution of the application of safeguards at LOFs in Canada will be described and will culminate with the approach currently in place. Additionally, the types of entities that are typically involved, the challenges they characteristically encounter, and the measures the SRA is taking to try to alleviate these challenges will be addressed.

Absolute Method for Characterization of Disused Depleted Uranium Containers

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Depleted Uranium (DU) is encountered in various applications as radiation shielding in industrial containers used to transport radioactive materials. Disused containers of depleted uranium used to transport ^{192}Ir sources have been characterized. That characterization was carried out by gamma spectrometry (NaI detector) in combination with the MCNP method. The MCNP method has been used for modelling the assayed container samples, the experimental setup and the measuring system to calculate the absolute efficiency of the detector at energy lines 185.71 kev and 1001.3 kev, specific for ^{235}U and ^{238}U, respectively. The calculated absolute efficiencies have been used with experimental results to estimate the masses of ^{235}U and ^{238}U. The samples depletion has been estimated by calculating the masses of ^{235}U and ^{238}U using the absolute method, and compared with declared values.

[SGI-S6] ISSAS Missions and SSAC Self-Assessment

Assessment of Nuclear Facility's Safeguards System by Using Safeguards Performance Assessment Indexes

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In 2015, the Hungarian Atomic Energy Authority (HAEA) introduced Safeguards Performance Assessment Indexes (SPAI) to evaluate the annual performance of a facility's nuclear safeguards system. The aim of the development of these indexes was the timely observation of changes and deviations from the optimal operation, and the early identification of issues to provide the possibility to prevent more serious deviations and a timely response.

The parameters included in SPAI were developed for the assessment of performance: these are already available and easily accessible and collectable from the inspections (records), licensing procedures and submitted reports. In general, the HAEA does not have to use additional resources or collect additional information, only the available data and their circumstances have to be assessed and analysed.

The areas assessed by SPAI for nuclear facilities cover three major parts of the facility safeguards system, namely (i) safeguards organization; (ii) operation of the safeguards system; (iii) safeguards licensing procedures.

The evaluated parameters include e.g. educational requirements for safeguards staff, quality of safeguards reporting for IAEA and EC, and results of safeguards inspections etc.

The HAEA first used the SPAI to assess the safeguards system of the nuclear power plant in Hungary. However, from 2017, other nuclear facilities (research reactor, training reactor, storage facility) were evaluated by using the indexes.

Based on the experiences since 2015, the early results have been promising. The method may be used for example to alert our authority when a decrease in the number of safeguards staff of the facility can cause weakening of the safeguards system.

The Safeguards Performance Assessment Indexes as metrics proved to be very useful tools for the regulatory assessment of how safeguards are managed and operated at the facility level.

Developing an SSAC Self-Assessment Tool for Operators and Regulators

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State Systems of Accounting for and Control of Nuclear Materials (SSAC) are the organizational arrangements at a national level that enable countries to manage their nuclear materials and meet their international safeguards obligations to the International Atomic Energy Agency (IAEA). As such, SSAC performance can play an important role in determining how the IAEA allocates and spends its resources within and across countries. Therefore, it is important to identify methods and tools that will help State Regulatory Authorities (SRAs) and the operators that support the SSAC to conduct effective self-assessments of their own safeguards performance and ensure that lessons learned inform improvements in organizational performance. Enabling an SSAC to understand why it is performing inefficiently can help it allocate resources more effectively to better support IAEA safeguards implementation. In collaboration with international consulting firm Environmental Resources Management (ERM) and a U.S. based nuclear fuel cycle facility, the Pacific Northwest National Laboratory (PNNL) developed a prototype self-assessment tool for nuclear operators and regulators. This presentation will describe the multi-year effort while emphasizing the steps the team took to align the framework with relevant IAEA self-assessment tools. It will also present feedback from an operating facility that tested the prototype tool in 2017.

Nepal's Experience in Regulation

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Radiation technology has been used in Nepal for a long time. Nepal has signed Treaties to ensure safe and peaceful uses of nuclear material and technology. However, it still does not have a robust licensing regime.

Nepal has a National Nuclear Policy and Regulatory Directives, but none of these have any binding force.

Therefore, Nepal urgently needs a Nuclear Safety Act, which is in progress to be approved. Gradually, key factors including rules and regulations, procedures, technically-skilled manpower and awareness among the stakeholders are being established for implementation of the Act.

In this context, Nepal's experience in regulating nuclear facilities and practices without an Act could be a lesson to some countries, whilst other countries' experiences could help Nepal to ensure safe and peaceful use of nuclear material/technology. Experience sharing is one of the best ways of safeguarding.

Strengthening Moldova's Safeguards Implementation Infrastructure

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The Republic of Moldova, being a State with a Small Quantities Protocol, is committed to fulfilling its safeguards obligations. The Republic of Moldova is party to the Treaty on the Non-Proliferation of Nuclear Weapons and has in force a Comprehensive Safeguards Agreement with the International Atomic Energy Agency, a modified Small Quantities Protocol, and an Additional Protocol. The Republic of Moldova fulfills its obligations through establishment of a State System of Accountancy and Control of nuclear materials, and reporting of import and export of nuclear material, specified equipment and non-nuclear material pursuant to its Comprehensive Safeguards Agreement and Additional Protocol. In 2013, the Republic of Moldova hosted an IAEA International State System of Accounting and Control of Nuclear Material Advisory Service mission. The findings and recommendations from this interaction served as a good basis for developing the necessary infrastructure for safeguards implementation.

The paper describes capacity building within the National Agency for Regulation of Nuclear and Radiological Activities (designated as Moldova's nuclear regulatory authority related to the implementation of safeguards); and development of regulatory infrastructure for safeguards implementation, as well as problems encountered in fulfilling its obligations under its Comprehensive Safeguards Agreement, modified Small Quantities Protocol and Additional Protocol.

[SGI-S8] Improvements in the Field: Enhancements to Measurement Techniques

Features of Statistical Tests adopted in the Near Real Time Accountancy System

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Generally, uncertainty of material balance (σMUF) of large bulk-handling nuclear facilities will be relatively large as a consequence of the high throughput of nuclear materials. In order to establish and to apply an effective and accurate material accountancy system to such facilities, the Safeguards by Design (SBD) concept should be introduced prior to construction of the facilities. As a part of this, studies based on computer simulation are useful for designing the material accountancy system. The Nuclear Material Control Center (NMCC) has therefore developed a computer simulator for nuclear facility processes, including calculation of material flows and inventories in each process, and also calculation of measurement data with error propagation for a model large-scale MOX fuel fabrication plant.

As the safeguards measures applied to a plutonium handling facility should achieve not only the quantity goal but also the timeliness goal for Pu, a Near Real Time Accountancy (NRTA) system has been developed to achieve both goals, with frequent closing of material balance - without the need for a clean-out of the process - and frequent evaluating of dynamic MUF (MUFd) which, unlike traditional MUF, includes residues of material as a holdup. NMCC has conducted various studies of NRTA applications and used the developed simulator to identify features of detection capabilities from statistical tests adopted in the NRTA, e.g., the availability to select sectors to consider as a process unit within the accountancy area for consideration of σMUF, and confirmation of detection capabilities regarding various sequential statistical tests for nuclear material loss.

From these studies, it is expected that the MUF residual (MUFR), which is the eliminated unknown bias from MUFd, will be a relatively sensitive indicator for detection of nuclear material loss.

In this paper, features of detection capabilities regarding sequential statistical tests e.g., MUFR Test, CUMUFR Test, Truncated Sequential CUMUFR Test and Page's test in comparison with the detection capabilities of traditional statistical tests using MUF will be reported.

Potential of Simulation Tools for NRTA

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For the design of purification cycles using liquid-liquid extraction techniques, a process development approach based on process modelling was chosen. This approach involved the development of a qualified simulation tool, which had been successfully used for process flowsheet design of industrial plants, and safety analysis of plant operation. Possible software applications to aid plant operation using this qualified simulation code were proposed, including: automatic flowsheet calculations; simulation tools for process monitoring or control; and as a diagnostic tool. This third application allows detection of the occurrence of a process malfunction from data obtained in monitoring the state of process parameters. A combination of calculations, using the process simulation code and neural network techniques, is used to determine the nature of the malfunction (i.e. which operating parameter has changed), the amplitude of the parameter change, and the time at which the malfunction has occured. Such a diagnostic application is possible because of the reliability and speed of the process simulation. The tool's ability, following detection of a malfunction, to identify the changes in operating parameter responsible for the malfunction using an appropriate process monitoring treatment could be an example of a feature of interest for NRTA purposes.

This paper will present the process simulation tool and the diagnostic tool, to illustrate what could be achieved using existing qualified simulation tools. There are still further developments required, but the application is considered worthy of further consideration.

Material Balance Evaluation at Bulk-Handling Facilities in the Decommissioning Stage or Partially Shutdown

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Currently, several bulk-handling facilities (BHF) in Japan are in the decommissioning stage, in preparation for their planned permanent shutdown, while others have suspended part of their operations. The operational status of these BHF may be different, but the material balance evaluation (MBE) challenges are similar: In both cases, facilities may retain large amounts of static material and/or recovered nuclear material.

During the decommissioning stage and partial shutdown, large amounts of material can remain static; operators can decide not to re-measure it, and instead base the related declarations on measured values from previous physical inventory takings (PIT) or on estimated values. Facility operators may also clean out, recover and measure (or estimate) material that had not been accessible during operations. For MBE, operators need to provide updated information in the design information questionnaires (DIQ), including the actual operational conditions and the sources of measurement uncertainty during the decommissioning and shutdown phases. Evaluation of statistics, such as the MUF or the Difference Statistic, may not lead to a sound conclusion if the condition of the facility is not fully understood, hindering a proper estimation of the operator's measurement uncertainties. Furthermore, the MUF evaluation may be affect by the increase of static material in the inventory, the estimated increase in inventory due to recovered material and the convolution of MUF between shutdown and operating processes.

It is therefore necessary to obtain accurate, detailed and complete information regarding the decommissioning process or shutdown operations, including the operator's nuclear material accounting and measurement procedures taking into account other relevant information, such as sampling procedures.

In this paper, we will present a case study of MBE at a BHF under decommissioning, based on Nuclear Material Control Center's (NMCC) and the IAEA's experiences. Finally, we will propose a consistent approach to MBE that incorporates the above information for facilities under decommissioning or partially shutdown.

An Improvement of Maintainability and Reliability for Safeguards Equipment in RRP

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At the Rokkasho Reprocessing Plant, MOX powder is converted from Plutonium-Uranyl nitrate solution by microwave heating. In this conversion process, large amounts of bulk plutonium material are treated. Therefore, a Neutron measurement system with high accuracy, called Plutonium Inventory Measurement System (PIMS) has been introduced for material accountancy and inspection purposes. PIMS consist of ^{3}He neutron detector, metal/optical fiber cable, HUB and evaluation system. HUB is designed with HV/LV power supply, data acquisition and signal conversion and is the most important device on PIMS. In order to maintain uninterrupted material accounting, verification activities and measurement accuracy, it is necessary to keep spare electronics components for HUB in a healthy state at all times and it is vital that immediate repair should be conducted when a problem occurs.

However, this equipment was imported in 2000 and, now, it is impossible to procure spare components due to the end of production. Therefore, there is concern that malfunction of the equipment may seriously affect the material accounting and verification activities in future. In addition, when PIMS fails, a protracted maintenance period is necessary to find out the malfunction point on electronics components and diagnose a cause of the problem. For this reason, in order to improve maintainability and reliability of PIMS, we are now planning to conduct a new HUB design, including the self-diagnostic function and new signal protocol.

JNFL will continue to provide design information in a timely manner and conduct coordination of improvement of SG equipment, for completion of system installation in 2021, with the cooperation of IAEA and Japan Safeguards Office.

Concepts for and Demonstration of Gamma-ray Process Monitoring for Reprocessing Facilities

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Safeguards practices instituted by the International Atomic Energy Agency (IAEA) for reprocessing facilities address both techniques used for nuclear material (NM) control and accountancy (MC&A) and methods to maintain continuity-of-knowledge (CoK). Intense protocols have been developed to verify the declared composition and content of the NM solutions through Destructive Analysis (DA) performed on samples taken at Flow Key Measurement Points (FKMPs). A Solution Monitoring and Measurement System (SMMS) is installed across FKMP tanks to measure the solution density and volume. The results of these measurements are used to determine the operational status of the facility and for inspectors to verify quantities, maintaining CoK. To improve safeguards verification capabilities and to reduce the amount of time that IAEA inspectors are required to be at a facility, the Japan Atomic Energy Agency (JAEA) has been developing improved plutonium monitoring capabilities. One of these is a multi-scope concept to continuously monitor purified Pu and U solutions as well as spent nuclear fuel solutions by measuring the NM gamma rays (GRs) both at the solution tanks and along the transfer pipes. A demonstration of a GR pipe-monitoring concept was performed at the JAEA Plutonium Conversion Development Facility, and confirmed that in-line solution monitoring enables both real-time flow measurements and Pu isotopic composition determination (of purified-solution batches) through passive non-destructive assay of the NM between FKMPs. The pipe-monitoring GR spectrum, flow-rate, volumes, and process timing would then be compared to similar measurements collected by established methods at the FKMPs to provide comprehensive CoK in an unattended, on-line mode. To further improve safeguards capabilities, a concept was developed to provide continuous composition verification by measuring the high-energy (>3-MeV) delayed GRs from short-lived fission products from fissile nuclides generated by neutron self-interrogation of the solution in the tanks.

This paper will describe an overview of the JAEA gamma-ray process-monitoring concept, a summary of the pipe-monitoring demonstration, and the delayed gamma-ray development efforts and technologies to expand safeguards capabilities at reprocessing facilities.

Feasibility Study Result of Advanced Solution Measurement and Monitoring Technology for Reprocessing Facility

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The IAEA has proposed, in its Research and Development plan (STR-385), the development of technology to enable real-time flow measurement of nuclear material as part of an advanced approach to effective and efficient safeguards for reprocessing facilities. To address this, JAEA and JNFL had previously designed and developed a neutron coincidence based non-destructive assay system to monitor Pu in solution directly after a purification process. To enhance this technology for entire reprocessing facilities, as a feasibility study, JAEA has been tackling development of a new detector to enable monitoring of Pu in solutions with numerous fission products (FPs) as a joint research program with the U.S. DOE. In this study, the High Active Liquid Waste (HALW) Storage Facility in Tokai Reprocessing Plant (TRP) was used as the test bed.

The design information of the HALW storage tank and radiation (type and intensity) were investigated, to develop a Monte Carlo N-Particle Transport Code (MCNP) model. Then, dose rate distribution inside the concrete cell where the HALW tank is located was measured, to enable design of new detectors and check the integrity of the MCNP model and its applicability. Using the newly-designed detectors, gamma-rays and neutrons could be measured continuously at the outside/inside of the concrete cell, to optimize detector position and the radiation characteristics.

The applicability as a Pu-monitoring technology was evaluated, based on the simulation results and gamma-ray/neutron measurement results. We have found that there is a possibility to monitor the change of Pu amount in solution by combination of gamma-ray and neutron measurements. The results of this study suggest a feasibility study into the applicability and capability of Pu monitoring to enhance the entire reprocessing facility handling Pu with FPs. In this paper, a summary of the project will be presented.

25 years of NRTA as an IAEA Safeguards Tool

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In order to address large flows and inventories of sensitive nuclear material, Near Real Time Accountancy (NRTA) was introduced in the mid 1990’s as a complementary safeguards verification method for MOX facilities in Japan and, to a lesser extent, for some fuel fabrication plants.

This move was possible once computational capabilities reached a sufficient level to allow on-site calculation prior to inspection. A special expert system associated with Q+E (Database editor) was designed.

Although NMAX (an NRTA program that produced sequential statistical evaluation of the MUF, the operator-inspector difference statistic D and the IMUF) was satisfactory for those facilities, the proprietary aspect of NMAX, the lack of new developments, the ageing Q+E and the concomitant development of new Windows platforms soon rendered it obsolete.

In 1997, it was decided to move to a more integrated replacement of the NMAX software system using Oracle/SQL/PL-SQL and, in 1999, the NRTA software for the two Japanese MOX facilities was redesigned internally by the IAEA.

This move to an integrated software tool (also called NMAX) opened the scope for further development and, for the first time, complex algorithms specific to the Tokai Reprocessing Plant (TRP) could be put in place, taking into account the measurement error covariance matrices associated with the vessel calibrations.

Various developments took place and are still on-going to cover the Rokkasho Reprocessing Plant (RRP) in Japan.

A specific NRTA system was also designed to address the downblending of high enriched uranium associated with the START agreements in the United Sates.

The experience gained, particularly on specific signatures and ad-hoc algorithms, is presented in detail.

Characterization of CdZnTe Gamma Detector for Monte Carlo-based Efficiency Calibration of In-situ Gamma Spectrometry of Radioactive Waste Materials

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A new gamma spectrometry method was developed for determination of isotope-selective activities of radioactive waste materials in order to support waste management. Investigation of radioactive materials is often performed under in-situ measuring conditions, especially in the nuclear energy industry. Therefore, the applied gamma spectrometer must be portable and easy to handle, and good energy resolution is required for the appropriate analysis of the complex gamma spectra. In the case of general in-situ measuring set-up, the empirical efficiency calibration of the detector is not obviously available. However, the Monte Carlo simulation technique offers an excellent solution for this problem of quantitative gamma spectroscopy. A proper input model, of both the detector and the whole measuring set-up, is crucial for the accurate determination of the activity of radioactive samples. If simulated and measured gamma spectra fit well, this is a sensitive indicator of the reliability of the input model. In order to construct the initial simulation model of the investigated gamma spectrometer, its geometrical parameters as published by the manufacturer were applied. For improvement of effectiveness of the simulation calculations, these were then compared to the results of empirical efficiency calibration measurements. These experiments were conducted with standard point-like radioactive sources. To improve the agreement between the calculated and the measured efficiency values, the sensitive volume of the detector crystal was mapped by scanning it with collimated gamma beams of ^{241}Am and ^{58}Co sources in transmission measuring mode. The precise movements of the gamma-sources were performed using a 3D translation stage having 100 µm steps. The characterized gamma-ray spectrometer was applied to analyse different (liquid, solid) waste samples. According to the comparative analysis of the results, good agreement was found between the Monte Carlo calculated specific activities and the results of gamma spectroscopy measurements carried out with a certified portable HPGe detector.

This work has been partly carried out in the frame of VKSZ-14-1-2015-0021 Hungarian project supported by the National Research, Development and Innovation Fund and OAH ABA-29/17-M Hungarian Atomic Energy Authority.

Enhancement of Peak to Compton Ratio (P/C) using a New Array Design for Safeguards Applications

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This paper focuses on installation of a new geometry and array of detectors to investigate reduction and suppression of unwanted noise and background to enhance the peak to Compton ratio (P/C). This objective positively affects the accuracy of nuclear material assay for safeguards. The new array consists of three sodium iodide (NaI) detectors; one of them is in the annular perpendicular position and the others are guards surrounding the main Hyper-Pure Germanium Detector (HpGe). The optimum configuration for the array was selected to maximize P/C, and minimize noise and the Compton continuum produced by higher-energy gamma-rays. Enhancement of P/C was investigated using the radioactive source ^{137}Cs. It was observed that the new array configuration enhanced P/C compared to a single HPGe detector in the range 387.6±6.12 to 1001.12±7.4. The design was also investigated and applied to special nuclear materials (SNM) at the ^{235}U photo peak of 185.7 KeV. The system gave improved performance for the SNM samples measured at 185.7 KeV, with a maximum difference of 17.6%. The results are presented, discussed and interpreted.

Development of Active Neutron Non-Destructive Assay (NDA) Techniques

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The Japan Atomic Energy Agency (JAEA) and the Joint Research Centre of the European Commission (EC-JRC) are jointly developing non-destructive neutron-interrogation assay techniques; for nuclear material accountancy, applicable to both low and highly radioactive nuclear materials (NMs), and for nuclear security purposes (such as detection of nuclear and explosive materials). The techniques being developed are Differential Die-Away Analysis (DDA), Delayed Gamma-ray Analysis (DGA), Neutron Resonance Transmission Analysis (NRTA), and Prompt Gamma-ray Analysis (PGA). These techniques are used to mutually complement each other. In order to realize the concept, a multipurpose integrated system has been proposed and design work has been performed. Development of each technique is being carried out within the collaboration.

As the first step, an integrated DDA and PGA system has been constructed using a high intensity DT neutron source at the NUCEF facility of JAEA. Test measurements have been carried out to demonstrate that a plutonium quantity of 0.002 - 1 g in a small volume (vial size) can be detected by DDA, and that prompt gamma rays from nitrogen (contained in high explosives) and other elements contained in chemical warfare agents are detectable by PGA. DGA test experiments were performed using samples with different ^{235}U:^{239}Pu mass ratios at JRC Ispra, to confirm a potential for analyzing the concentration of fissile nuclides such as ^{235}U and ^{239,241}Pu. Development of NRTA was done at JRC Geel and Kyoto University. Usefulness for quantification of special NMs was examined. A size reduction study is now in progress.

One of the applications of these techniques in nuclear safeguards is in NM accountancy for present and future nuclear fuel cycles, including those for accelerator-driven systems. Measurements must be performed in an environment that is highly radioactive due to fission products and long-lived minor actinides. In a reprocessing plant, for example, NDA measurements are required to be performed on both low and highly radioactive NMs (e.g. spent nuclear fuels, MOX and purified nuclear fuels after the removal of fission products and minor actinides). The developed techniques can cover the whole range of NDA measurements required.

New Software for HKED Densitometer of RT-1 Plant

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The Hybrid K-Edge/K-XRF (HKED) densitometer for measurements of U and Pu concentration in input solution was installed in the radiochemical plant RT-1 analytical laboratory of the "Mayak" site in 2007. The English version of the HKED software, developed for the OpenWMS hardware platform, has a difficult and complicated interface and lacks an option for Pu concentration calculation in XRF and Hybrid modes. The OpenWMS hardware has not been supported for more than ten years and has not satisfied the analytical laboratory requirements. For these reasons, the new software was developed by IPPE and Mayak specialists. The new software was designed for a Windows platform, tailored to the HKED construction features and preferences of the analytical laboratory specialists.

The paper presents a description of the main functions and test results of the new software.

Activity Quantification with the SPIR-Ace Radionuclide Identification Device

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Mirion Technologies, with the acquisition of Canberra, is currently in the process of merging the best technologies from their combined portfolios. The SPIR-Ace is one product receiving such treatment. The SPIR-Ace is a scintillator-based portable Radionuclide Identification Device (RID) in an IP64-rated enclosure that has been tested to show ISOCS compatibility. With options that include alpha, beta and neutron detection, this comprehensive device meets or exceeds ANSI N42.34, IEC62327and IAEA NSS 1 for detection of radionuclides. This modernized platform adds accessibility to contemporary portable systems such as GPS, accelerometer positioning, and wireless communications that allow remote reporting.

Recently, Mirion has characterized both the NaI and LaBr3 detectors for ISOCS efficiency calibrations, allowing the development of a platform that both identifies radionuclides and quantifies the activities with accuracy that is consistent with the Inspector 1000 products. Initial testing has shown the SPIR-Ace able to quantify known quantities of mixed nuclide radioactivity contained in a standard drum to within 25% or better of the certified activity, in a 10 minute sampling time.

The SPIR-Ace allows for the same performance in activity calculation that has been established with the Inspector 1000, and combines it with a modern platform that complies with regulatory needs found in many countries. It allows for remote monitoring and reporting and has been deployed on remote stations that are either static or in motion. Safeguards applications could make significant use of the wide range of capability found in this small device.

A New Technology of Neutron Multiplicity Counting for Nuclear Safeguards

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A new technology has been established for neutron multiplicity counting, for nuclear material accountancy in safeguards, with the optimal design of a device. Related performance testing indicated the operating state of this device to be completely normal, and all indications were acceptable. Meanwhile, some related research for neutron multiplicity counting was completed, which included simulated measurements in the laboratory for source ^{252}Cf and plutonium standards. The experimental results showed that the detection efficiency of the new device is better than 15%, the relative standard deviation of measurements is 5.65%, and the measurement accuracy is better than 90%. Under conditions of long-time signal collection, the results proved that the device based upon new technology has the capability to take the place of ^{3}He detector-based neutron multiplicity counting, and accomplish the quantification tasks for nuclear material accountancy in nuclear safeguards by neutron multiplicity analysis.

Passive Neutron Counting and Gamma Segment Scanning for Waste Measurement

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Nuclear material accounting and control will remain an important measure for the nuclear safeguards system. According to the requirements of safeguards and national nuclear material control, measurements of nuclear material contained in waste are necessary, in order to reduce the material unaccounted for (MUF) at nuclear fuel cycle facilities. Determination of the quantity of nuclear material in the waste, which is produced at the end of the process of nuclear material production and treatment, is always a challenge to the facility. The accurate measurement of solid waste by α/γ equipment can not only protect the ecological environment, but also obtain great economic benefits.

This paper describes the design of an equipment structure with improved detection efficiency from the design of the α equipment. Meanwhile, from the design of the collimator of the γ equipment, the interlayer crosstalk is reduced and thus the accuracy of analysis is improved. The paper describes the method of analysis, its calibration, qualification of the equipment and the prospect for its application.

Investigation of a Dynamic Measurement Methodology for Fast Detection of Gross Defects in Regularly Distributed Nuclear Material Samples

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Fast detection of gross defects in regularly distributed nuclear material (NM) may be achieved by employing dynamic measurements. In some cases, the use of non-destructive static measurements (in which the measuring device and the measured sample are located in fixed positions during measurements) may not provide sufficient information about a measured item. This may occur due to attenuation and/or screening effects. Consequently, it might be necessary for the material to be moved or rotated in order to obtain more informative results. Meanwhile, the measuring device should record and in some way enable interpretation of the time and hence position-related measurement signal.

While using scanning gamma-ray measurement techniques, the response of a measuring system to radiation emitted from a regularly-distributed rotating NM results in a spectrum with a specific pattern. This pattern could represent a signature for a NM sample measured with specific setup configuration and dynamic parameters. Any deviation from this signature may indicate some defect in the measured material.

In this work, a Non-Destructive Dynamic (NDD) method is investigated to detect gross defects in a regularly-distributed NM (fuel assembly of EK-10 type). Different scenarios were considered and studied using the MCNP5 Code. The results showed that the investigated method could be easily applied to detect gross defects in regularly-distributed NM samples.

Development of the NDA Technique for Verification of a Critical Assembly with Partial Defect Test

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At some locations, such as the critical facility Hyacinth [1] (JIPNR-Sosny, Belarus), the operator imposes some limitations on the availability of individual fuel cassettes for partial defect test verification. Due to the nuclear safety considerations the cassettes may not be extracted and the fissile material within the critical assembly shall be verified “as a whole”.

To overcome the above challenge, new NDA method was developed in cooperation between the IAEA and JIPNR. The method is based on determination of the Reactivity Ratios (RR) at several sub-critical states and the comparison of the measured RR with the quantities, predicted by numerical model calculations for the declared configuration of the critical assembly. RR are inversely proportional to the ratios of net neutron count rates, measured during verification. The merit of the technique is its non-intrusiveness and a relative simplicity due to a weak dependence of the RR on the neutron detection efficiencies and the interrogation source term.

This paper describes the arrangements, equipment, data acquisition and analysis, as well as the results obtained with the method for the fast critical assembly at the Hyacinth facility. Validation of the method for the critical assembly in its thermal configuration is planned in 2018-2019.

Subject to successful demonstration of the method’s conclusiveness and reliability, the IAEA will consider implementation of the technique at the critical assemblies and the research reactors in other Member States with safeguards agreement in force.

Uranium Enrichment Measurement in UF_6 Cylinders by HRGS: an Evaluation of the Measurement Uncertainty

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The paper presents work performed at IRSN to optimise the traditional enrichment meter method, applied to uranium enrichment measurement in 30B and 48Y UF_6 cylinders by high resolution gamma spectrometry, to evaluate the parameters influencing the measurement result and the associated uncertainties.

Calibration between the uranium enrichment and the net count rate of the 185.7 keV gamma-ray in a collimated geometry is performed at IRSN using four U_3O_8 standards (^{235}U from 0.7 to 89%) and a weighted least-squares linear regression. In order to reduce the container inspection time on-site, the net count rate of the 185.7 keV gamma-ray from the UF_6 container is measured in a non-collimated geometry. Therefore, several corrections need to be done.

These corrections are due to differences in: 1) the attenuation of the gamma-rays between the container wall of the U_3O_8 reference material and the container wall of the 30B or 48Y cylinder; 2) the measurement geometry (with collimation for the U_3O_8 standards and without collimation for the UF_6 containers); 3) the physicochemical differences between the standards and the items to be measured; and 4) eventually, in the detection efficiency of the gamma spectrometry system after its transport from IRSN and relocation on-site for inspection purposes.

Some assays perfomed on site using 30B and 48Y UF6 containers (^{235}U from 0.3 to 5.5%) showed:

1. the necessity to perform a container thickness measurement (ultrasonic gauge) on each item, to correct the measurement for container wall attenuation effects; and
2. the low impact of the measurement position on the enrichment recorded at seven positions on a container (a specific spectrometer support was manufactured to allow measurements on the top, side or front of a container).

These tests were used to evaluate a calibration transfer factor, estimate the measurement time, evaluate the uncertainty component of each parameter of influence, and finally the measured uranium enrichment uncertainty.

HA-AWCC Instrumentation Test prior to Hot Commissioning for Characterization of Uranium Residues from the ^{99}Mo Production Process in the Republic of South Africa

Author(s): Tebogo Mokgobi Leshilo[1]

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^{99}Mo is produced by the irradiation of high- and low-enriched uranium (HEU and LEU), resulting in an accumulation of uranium residues as waste from the ^{99}Mo production process. These residues are highly radioactive, with surface exposure rates of up to 100 R/h, and are stored in stainless steel canisters. The ^{235}U content of these uranium residues must be characterized or quantified for State and International Atomic Energy Agency (IAEA) safeguards purposes. Conventional neutron counting techniques, such as Active Well Coincidence Counting (AWCC), are incapable of quantifying the ^{235}U content of the uranium residue due to the high level of radiation emitted and moisture that might be present.

In 2010, the High Activity-Active Well Coincidence Counter (HA-AWCC) was designed and developed by non-destructive assay experts from Oak Ridge National Laboratory (ORNL, USA), the South African Nuclear Energy Corporation SOC Limited (NECSA, RSA) and the IAEA, with the purpose of quantifying the ^{235}U content in the uranium residue.

In this work, the set-up of the HA-AWCC instrument, as well as its behavior during hot commissioning pre-test activities, will be discussed. The HA-AWCC tests included background measurements; neutron counting measurements with californium (^{252}Cf) sources of activities 11.5 and 30 µCi; and high voltage plateau measurements, as well as a cold canister run. The HA-AWCC instrument is expected to play a critical role in the characterization and quantification of safeguarded uranium residue material by the State Safeguards Authority.

[SGI-S9] Performance Monitoring in Safeguards

Visualization of Data for Enhanced Safeguards Communication and Analysis

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Visualization of complex and large data sets has emerged as a powerful mechanism for both improving internal analyses and communicating findings to stakeholders. In support of the Symposium theme of leveraging technical advances for safeguards applications, in particular the analysis, integration and visualization of multi-source data, this paper examines the analytical and communicative benefits of using data visualization tools. The goal of this paper is to explore ways to make the data already available to the IAEA Department of Safeguards and to Member States more meaningful, ultimately to improve the effectiveness, efficiency, and understanding of the international safeguards system.

This paper will explore and demonstrate the value-added potential of visualizing trends in data over time using Tableau software and publicly available and simulated safeguards information similar to the types of data that are available to Member States, in the annual Safeguards Implementation Report (SIR), and to State Evaluation Groups (SEGs).

Visualization of verification activities can help SEGs evaluate how effectively safeguards measures are meeting technical objectives along different acquisition paths. Furthermore, visualization may aid in examining trends in nuclear material holdings at different locations in the State, variances in sampling results, and other data most typically represented numerically.

The SIR primarily presents data to Member States in numerical format. However, the specific number is usually less meaningful than seeing that number in context. For example, the number of inspections in a country in a given year is more meaningful when compared with the numbers of inspections in other countries, or the trend in inspections over time. Visualizing simulated SIR data in Tableau will show how the data already released to Member States by the IAEA can better communicate safeguards activities.

Performance Monitoring through Quality Control for Enhancing the Effectiveness of IAEA Safeguards Implementation

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The International Atomic Energy Agency (IAEA) has implemented a Safeguards Quality Management System for more than a decade. This system promotes the development of optimized processes for implementing the IAEA's safeguards verification mission in order to ensure that safeguards resources are best used to support the IAEA's conclusions on the peaceful use of nuclear material. In addition to assuring that it is implementing efficient processes, the IAEA needs to perform performance monitoring to determine how effectively safeguards measures and analyses are conducted in the field and at Headquarters. An ineffectively performed activity at any stage of safeguards implementation – planning, conduct, assessment or evaluation – could result in a diversion of nuclear material or an undeclared activity not being detected. Quality control measures are already applied to several safeguards activities, e.g. analytical laboratory measurements, metal seals verification, and camera surveillance data reviews. The development of further quality control tests for safeguards implementation would permit the IAEA to conduct performance monitoring of specific safeguards activities, identify where further improvements may be needed, and provide information to Member States on the effectiveness of IAEA safeguards. Examples of such tests could include checking that annual implementation plans are complete, verifying that inspection activities are appropriate and conducted according to procedures, and confirming that inspection data is correctly recorded and analysed. Annual publication of the quality control performance metrics would provide States with assurance that the published safeguards conclusions are correct and soundly based. The paper will describe quality control and performance monitoring activities that could be undertaken by the IAEA.

The Role of Performance Targets in Safeguards

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This paper discusses the role of performance targets in the safeguards system, including as drivers for improving effectiveness and efficiency of safeguards and the productivity of collaboration between the IAEA and facility operators. The IAEA continues to seek ways to increase productivity and efficiency in implementing safeguards agreements, while preserving effectiveness and independence. To do this, the Agency must be able both to plan for implementation of effective safeguards and to evaluate whether effectiveness goals have been achieved. Particularly in the context of State-level planning and evaluation, this raises questions of: 1) how to define the technical effectiveness of its verification efforts in a way that is driven by technical objectives rather than prescriptive criteria; and 2) how to optimize resource allocation in ways that are accepted as objective and non-discriminatory. Performance targets that make the logical connection between the frequency and intensity of safeguards activities and the attainment of safeguards objectives could improve transparency and understanding of safeguards implementation, reduce concerns over discrimination, and provide indicators of performance trends that help maintain and even strengthen effectiveness over time.

This paper will argue for the establishment of performance targets that clearly link safeguards actions to safeguards objectives, such as probability of timely detection of diversion and/or misuse. The paper will also touch on the challenge of developing metrics for effectiveness in detecting undeclared activities in the State as a whole, which cannot be quantified in the same way. Such metrics could focus on a “due diligence” approach to looking for and following up on indicators of possible undeclared activities and maintaining an up-to-date understanding of the State’s nuclear and industrial capabilities.

Effectiveness of IAEA Safeguards

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IAEA safeguards, being a control element for the nuclear non-proliferation regime, have played an essential role for its stability. The safeguards system, created in the 1960's, was further developed in the early 1970's in view of the Non-Proliferation Treaty (NPT). It has been improving continuously, to provide adequate responses to arising challenges.

In this paper, the authors introduce their view on the main challenges that IAEA verification faces today. They conclude that these challenges require the system to become more effective and efficient while remaining objective and technically sound.

The authors discuss a mechanism that allows evaluation of the effectiveness of safeguards implementation. The authors also propose such a mechanism as useful for elaborating the optimal combination of measures, foreseen in comprehensive safeguards agreements and an Additional Protocol, and for safeguards planning through use of new technologies and for better management of technical, financial and human resources of the IAEA Secretariat. The authors discuss the technical implementation parameters, roles of expert judgment and State-specific factors, their applicability with regard to integrated safeguards development, and implementation and effectiveness evaluation for a State as a whole. The authors give a conceptual view that could be further elaborated (subject to acceptance by the Member States and the IAEA Secretariat).

The analysis includes consideration of ways to increase safeguards effectiveness and efficiency while ensuring no obstacles are posed to the States' peaceful nuclear activities and their economic and technological development, as well as no interference in their domestic affairs.

The paper contains results from the analysis of possible technical parameters for the assessment of safeguards effectiveness in order to achieve effective control of non-proliferation obligations performance by the States.

Performance Management for Safeguards Implementation

Author(s): David Moroz[1]

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Performance indicators and performance measures are used to assess the success of an organization as it carries out its mandated activities and programs. Identifying appropriate indicators and measures is critical to demonstrating the performance of an organization as it allocates resources. State Regulatory Authorities and the International Atomic Energy Agency (IAEA) are faced with the challenge of maintaining and enhancing a robust safeguards verification regime in light of rising nuclear inventories and resource limitations. This paper explores how improved performance measures and indicators can assist in addressing this challenge, while also considering the additional challenge associated with safeguards confidentiality.

The Use of New Analytical Capabilities Established Under MOSAIC to Support the Department's Use of Performance Indicators

Author(s): Guy Soudry[1]

[1] *International Atomic Energy Agency*

The paper covers the development of new tools and techniques used by the IAEA Department of Safeguards to provide greater insight and analysis of available data. The completion of the Modernization of Safeguards Information Technology (MOSAIC) project 2015-2018 opened the door to Business Intelligence capabilities that were previously unavailable to the Department. These can be used with great effect for improved reporting, the monitoring and analysis of operational processes, as well as supporting strategic decisions. The paper gives examples of where the Department of Safeguards is making use of these tools to be more effective and efficient, in addition to discussing possibilities for the future.

Statistical Modeling to Reinforce IAEA Safeguards Methodology and Effectiveness Evaluation

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By revealing the effects of data collection, State Level Approach (SLA), Annual Implementation Plan (AIP), conducting infield activities on the process of evaluating verification activities and drawing a safeguards conclusion, valuable input can be provided to management to optimize resources and prioritize efforts. This assist the IAEA in improving the consistency of the processed information, enhancing its systematic approach and reinforcing safeguards effectiveness evaluation. A data driven artificial intelligence, Machine Leaning, based methodology is developed to generate data free of errors, improve the sensitivity of the final outcome of various data collection processes and enhance assessment of possible acquisition pathways. The framework of two models are discussed; the first model is with a Supervised Learning algorithm and the second model is with a Reinforcement Learning algorithm. Structural Equation Modelling is used to quantify secretariat performance through the processes of State Level Concept, their relations and subsequent effect on drawing a safeguards conclusion with type I or II errors, false alarm or undetected proliferation scenario respectively. A hypothetical state with specified nuclear fuel cycle facilities and activities is described to show the implementation of the statistical tools.

[SGI-S10] Partnerships, Networks and Regional Collaboration

Viet Nam's Safeguards Implementation: Cooperation with International Partners and the IAEA

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Viet Nam's nuclear fuel cycle consists of a research reactor and nuclear research institutes that produce radioisotopes for cancer treatment, perform scientific research, and support other medical and industrial applications for nuclear technology. In 2003, the Viet Nam Agency for Radiation and Nuclear Safety (VARANS) was established as the regulatory body to regulate all nuclear and radiological activities in Viet Nam.

Viet Nam entered into its Safeguards Agreement with the International Atomic Energy Agency (IAEA) in 1989, and safeguards implementation commenced in the country in February 1990. In 2007, Vietnam signed the Additional Protocol (AP), and brought it into force in September 2012. The State System of Accounting for and Control of nuclear material (SSAC) is the basis for safeguards implementation in Viet Nam. However, with the AP in force, the role of safeguards is no longer only to verify the declared nuclear materials but also to confirm that there are no undeclared activities related to the nuclear fuel cycle in the State. Only a strong SSAC with enhanced capabilities and activities can meet this demand. Therefore, cooperation at all levels is important.

Apart from the State's efforts in developing and sustaining an SSAC, cooperation with international partners, especially the IAEA, is important for effective implementation of safeguards. It is the basis and foundation for ensuring effective accountancy and control of nuclear material for peaceful use. Furthermore, safeguards nowadays requires a partnership approach that not only optimizes the use of existing resources (e.g., inspectors working together, the joint use of safeguards techniques and equipment), but more importantly establishes an environment of confidence, which in turn can contribute to the effectiveness of safeguards implementation for both the State and the IAEA.

The aim of this paper is to describe the evolution of safeguards implementation in Viet Nam in relation to cooperation with international partners and the IAEA. It will provide Viet Nam's experience in how to utilize and avoid duplication through international cooperation, to be an effective SSAC; as it is today.

Asia-Pacific Regional Safeguards Network, APSN

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In October 2009, the Asia-Pacific Safeguards Network (APSN) was founded to improve the quality, effectiveness and efficiency of safeguards implementation and promote regional cooperation in the Asia-Pacific region. As of 2018, APSN is composed of 16 member countries including 4 Steering Committee members (Australia, Japan, Republic of Korea, and Indonesia).

Five working groups constitute the APSN. WG1 coordinates APSN programs and activities in the areas of infrastructure, implementation and R&D collaboration. WG2 supports members with safeguards capacity building by identifying their needs and exchanging information about supportive activities. WG3 ensures whether the APSN web-site satisfies members' needs, examines other IT issues relevant to APSN operations and develops communication plans for raising APSN's profile. WG4 provides Member States with references to a wide array of consolidated elements and provisions contained in the global framework for nuclear safeguards to develop a more comprehensive national legislation on nuclear safeguards. WG5 discusses matters on physical protection to strengthen the national safeguards system.

Regional networks of safeguards authorities sharing regulatory experiences are valuable both for supporting capacity building and for maintaining international confidence in how Member States meet non-proliferation commitments. APSN is one such model for a regional network, but there are other examples - most focusing more on safety and security. From 30 October to 2 November 2017, the 8th Annual Meeting of APSN was held in Busan and APSN tried to maintain a partnership with ASEANTOM for strengthening the non-proliferation regime in the Southeast Asia region. In addition, APSN and ESARDA signed a MOU in 2015 and have been discussing specific education and training cooperation.

Expanding the concept of regional cooperation, this paper proposes a network of networks panel to bring together representatives from different regional networks. The panel would compare experiences with cultivating collaboration on capacity building and explore how the work of regional networks could be enhanced further.

Innovations in DOE/NNSA's International Nuclear Safeguards Engagement Program

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[1] *U.S. Department of Energy National Nuclear Security Administration*

The U.S. Department of Energy National Nuclear Security Administration's International Nuclear Safeguards Engagement Program (INSEP) has built longstanding relationships with international partners for over two decades. In recent years, DOE/NNSA has reinvigorated and refocused INSEP's activities. This presentation will discuss the span and scale of INSEP's engagement activities around the world, the partnerships that INSEP relies upon, and the outcomes that INSEP seeks to achieve. INSEP is much more than a training program — DOE/NNSA's overarching goal for INSEP is that engagements should contribute to more effective and efficient IAEA safeguards implementation globally. Advancing this goal necessitates close coordination and mutual trust with the IAEA, regional inspectorates and networks, and partner countries. DOE/NNSA works with its partners proactively to identify safeguards implementation challenges and develop practicable solutions in consultation with the stakeholders. Drawing on internationally recognized expertise in the U.S. national laboratories, DOE/NNSA engages countries with limited quantities of nuclear material to countries with advanced fuel cycles and everything in between.

AAEA Role in Strengthening Safeguards Infrastructure in Arab Countries

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[1] *Arab Atomic Energy Agency*

The Arab Atomic Energy Agency (AAEA) is a regional specialized organization working within the auspices of the League of Arab States to coordinate among its Member States in the field of peaceful uses of atomic energy. It contributes also to the transfer of the peaceful nuclear knowledge and technologies to these countries; assists in manpower development and scientific information concerning nuclear sciences; and sets up harmonized Arab regulations for nuclear safety and safe handling of radioactive materials, security and safeguards.

As the use of nuclear energy expands in Arab countries - and due to the growing concern in the region over the potential misuse of nuclear materials, technologies, risks of illicit trafficking of radioactive sources and their malicious uses - the AAEA seeks to enhance the Arab national systems of nuclear safeguards and to create an atmosphere of cooperation and coordination between relevant parties in Arab countries to establish a strong national and regional nuclear safeguards regime. This can be achieved only by collective efforts of Arab countries and the international community, and the AAEA may play a key role in this regard. The AAEA assists to enhance the capabilities and capacity of Arab countries to properly prevent, detect and respond to any potential spread of nuclear weapons, by strengthening national infrastructures and exchanging relevant information, technology, knowledge and lessons learned.

The AAEA has established the Arab Network of Nuclear Regulators (ANNuR) to foster enhancement, strengthening and harmonization of the nuclear safety, security and safeguards regulatory infrastructure and framework among the members of ANNuR; and to provide mechanisms for the ANNuR to be an effective and efficient internationally recognized forum for the exchange of regulatory experiences and practices among the regulatory bodies in Arab countries. ANNuR has 8 thematic working groups, one of which is about nuclear safeguards. The nuclear safeguards working group has its own action plan, including training programmes and technical meetings, and receives assistance from the IAEA and partners.

The AAEA promotes effective coordination among Arab and international organizations to ensure synergies to establish, maintain and evaluate the national nuclear safeguards systems that will contribute to the global nuclear security regime.

ABACC–Cooperation and Engagement: Prospects for Raising Regional-International Cooperation to a Higher Level

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The implementation of international safeguards requires a high level of cooperation of the parties involved: Operators, State authorities and the IAEA. In the particular case of Argentina, Brazil and ABACC, the implementation of bilateral safeguards, the Common System of Accounting and Control of Nuclear Materials (SCCC) to verify the basic commitment of these countries to use the nuclear materials and facilities under their jurisdiction or control exclusively for peaceful purposes, together with the IAEA comprehensive safeguards agreement, entails not only cooperation of the parties, but also a high level of coordination and engagement.

ABACC verification model, unique of this kind in the world, was established more than 25 years ago. This regional model together with the comprehensive safeguards agreement with the IAEA, known as the Quadripartite agreement, led to the establishment of joint cooperation mechanisms to optimize the verification of each agency while ensuring independent and valid conclusions for each organization. Thus, throughout these years, ABACC and the IAEA have developed and agreed on joint implementation inspection approaches and procedures and guidelines for the "common use" of technology.

This cooperation is governed by principles, including the obligation of the parties to cooperate to implement the safeguards foreseen in the agreement and the obligation of the IAEA to make full use of the SSAC and to avoid unnecessary duplication of ABACC's safeguards. The evolution of international safeguards in recent decades, the technological developments and the need to optimize the use of existing resources, should lead to a higher level of cooperation between ABACC and the IAEA, by which the IAEA can make greater use of ABACC´s model, to reduce the intensity of its verification without affecting its ability of drawing independent conclusions. This work reviews the state of the cooperation between the two safeguards verification bodies and discusses possible proposals for its strengthening to a higher level at which the ABACC model can be more fully exploited by international safeguards.

Undergirding the IAEA: How Regional Safeguards Agreements Can Take the Pressure Off

Author(s): Heather Seger[1]; Valeriia Lozova[1]

[1] *University of Georgia*

For the past 60 years, the International Atomic Energy Agency (IAEA) has been the primary organization responsible for international nuclear safeguards. As the years have progressed, the workload for the IAEA has increased significantly. Now, there are concerns that the IAEA's budgetary and human resources will not be sufficient for the task as the workload continues to increase. The world is on the cusp of another surge in nuclear power plant construction related to expected increase in world energy demand; the development of advanced nuclear technologies (generation IV reactors, small modular reactors, floating nuclear power plants, the advent of the thorium fuel cycle, and laser uranium enrichment); the increase of nuclear materials under safeguards; and decommissioning activities related to the potential shutdown of as many as 200 reactors by 2030.

One possible solution is the establishment of regional safeguards agreements (RSA) that might assist the IAEA in using its resources in the most efficient manner. This paper will assess the viability of this solution. The authors will evaluate the cooperation between the IAEA and the two current regional organizations, ABACC and Euratom, to determine the ways in which their operations and capabilities assist the IAEA in its mission and suggest additional steps that may further contribute to lessening the IAEA's workload. Finally, we will discuss the potential value of RSAs in Southeast Asia and Africa. Southeast Asia is a rapidly developing region of 10 States, seven of which are considering nuclear power options. The Pelindaba Treaty that created a nuclear weapon-free zone (NWFZ) in Africa sets out a provision for the creation of a verification body, which can serve as a good foundation for the creation of an RSA. Further discussion will outline how such agreements could be adapted to meet specific regional challenges whilst decreasing the burden on the IAEA.

Future Cooperation Scheme between IAEA and SSAC/RSAC

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The Non-Nuclear Weapon States (NNWSs) party to the NPT are required to conclude comprehensive safeguards agreements with the IAEA. Through acceptance of IAEA verification, NNWSs demonstrate their compliance regarding the international commitments and procedures to assure the peaceful use of nuclear materials. The safeguards agreements request that the State should establish and maintain a system of accounting for and control (SSAC) of all nuclear material subject to safeguards. Through the SSAC, the State declares or provides essential information which could contribute to effective verification activities by the inspectors of the IAEA.

In order to achieve enhanced cooperation with the IAEA and to facilitate efficient verification activities, several SSAC/RSACs may take actions such as cooperative development of safeguards technologies and equipment for joint use, including performance tests and calibration with appropriate authentication/authorization by the IAEA; and inter-laboratory comparisons on chemical analytical data between the operator, State and IAEA to maintain or to improve accuracy and precision of chemical analysis techniques. In cases where the SSAC/RSAC has established its own inspectorate, collaboration between both inspectorates e.g., relevant activities concerned with environmental sampling, could contribute to improving the IAEA's cost effectiveness. Further areas of potential cooperation may include the IAEA's use of the State's findings from independent data analysis of the operator's accountancy and verification results obtained by the SSAC/RSAC inspectorate. These findings could be used as references for the IAEA's conclusions to assure the quality of mutual verification data, and could contribute to improving the efficiency of IAEA inspections by use of short notice, randomly-selected inspection or remote monitoring of essential data for independent conclusions by the IAEA.

In this paper, we propose an idea, both in concept and practical procedure, regarding a future cooperation scheme between the IAEA and SSAC/RSAC based on the experiences of Japan's cooperation with the IAEA under its safeguards agreement and the Additional Protocol.

Proactively Monitoring the Quality of the Operator's Measurement and Accountancy Systems in the Framework of Trilateral Liaison Meetings – Experiences Gained and Maturing the System

Author(s): Robert Binner[1]; Claude Norman[1]; Christophe Portaix[1]; Agatha Walczak-Typke[1]; Jan Wuester[1]

[1] *International Atomic Energy Agency*

Two of the major objectives under a Comprehensive Safeguards Agreement (CSA) are to detect any diversion of declared nuclear material at facilities and locations outside facilities (LOFs) and to detect any undeclared production or processing of nuclear material in declared facilities and LOFs. The effectiveness of the IAEA in addressing these objectives is strongly influenced by the quality of the State and/or Regional Authority system of accounting for and control of nuclear material (S/RSAC), and on the nuclear fuel cycle facility operators' capabilities to establish and keep track of accurate and precise accountancy values on the inventories and flows of nuclear material at facilities and LOFs.

Cooperation and information exchange between the IAEA, S/RSAC and facility operators on performance evaluations of the accountancy and measurement systems are an important factor in establishing and maintaining an effective and efficient evaluation system based on which the IAEA can draw sound safeguards conclusions. Reviewing material balance evaluation results, trends in accountancy declarations, measurement results and their associated uncertainties in a trilateral framework assures the proactive and timely identification of potential problems affecting the drawing of safeguards conclusions and facilitates a swift response in clarifying questions and addressing emerging accountancy or measurement issues.

Over the past five years, facility-type specific trilateral meetings have been regularly held in Japan with the Japan Safeguards Office (JSGO), the Nuclear Material Control Center (NMCC) and the respective facility operators for Uranium fuel fabrication plants and for Plutonium bulk-handling facilities, and trilateral meetings have also taken place with the Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), the Canadian Nuclear Safety Commission (CNSC) and the European Commission (EC) as well as individual facility operator's to address accountancy issues. These meetings have in numerous ways shown the importance of such forums which include all responsible parties: as an efficient platform for addressing and resolving immediate, and at times also long-standing, accountancy and measurement issues; as an opportunity for enhanced cooperation which reinforces mutual trust and transparency; and as a chance to foster exchanges of measurement data and discuss developments in statistical methodologies related to accountancy and measurement performance evaluations.

[ESP-S2] ESPACE

Monday, 5 November

Venue ESPACE 1

Innovative approaches to information analysis in Safeguards

Author(s): Jacques Baute[1] et al.

[1] *International Atomic Energy Agency*

Just as the challenges of nuclear non-proliferation are evolving, so are the approaches that the IAEA is taking to meet these challenges. This session will briefly introduce a few of the Department of Safeguards' current efforts to optimize the sources, tools and methods used in Safeguards analysis. While each of these efforts address different Safeguards analytical needs, they all work together to strengthen the collaborative capabilities in collection, processing, visualization, integration, analysis, and management of Safeguards-relevant information.

[ESP-S2] ESPACE

Tuesday, 6 November

Venue ESPACE 1

OSIS 2.0: Optimizing Collaborative Analyst-Driven Automation of Open Source Information Collection and Processing for Safeguards State Evaluation

Author(s): Thomas Skoeld[1]

Co-author(s): Fabrice Courbon[1]; Katie Spence[1]

[1] *International Atomic Energy Agency*

Collecting and processing open source (OS) information is an important aspect of the IAEA's mandate to implement safeguards based on all relevant information related to States' nuclear activities. Since the mid-1990s, the Division of Information Management (SGIM) has been collecting OS information into an internal database, the Open Source Information System (OSIS). In the early stages, the SGIM collection and review process was predominately manual with classic internet searching, PDF printing, and running scripts for uploading files to the OSIS database. Over time, the process has undergone numerous improvements to include elements of automation in order to increase efficiency against an ever-growing stream of open source information. While automation has unarguably been welcome for many of the processing steps, it has been essential to keep the analyst involved at key decision-making points such as judging information for relevance, categorization, and further distribution. With the technological advancement of computing and machine learning during the past five years, however, more options for additional automation of data processing have become available. In 2016, SGIM embarked on a project to integrate and further automate the continuous monitoring, collection, and processing of OS information. This paper describes the process that culminated in the launch in early 2018 of OSIS 2.0, an in-house developed tool that has provided numerous improvements, including: automation of manual steps of collecting and formatting files; creation of a centralized space for analysts to collaborate on information collection and processing; and, improvement of the categorization and distribution capability. Furthermore, automation has enabled analysts to focus efforts more on analysis than collection and processing. The paper will also discuss possible next steps in integrating additional information collection processes into OSIS 2.0 and how far automation can be taken before it starts to have a diminishing effect on reliable information collection and processing.

Enhancing the Geospatial Exploitation System within the IAEA Department of Safeguards

Author(s): Antero Keskinen[1]
Co-author(s): Jacques Baute[1]; Mark Carey[1]; FatJon Ujkani[1]; Jonetta Ng[1]

[1] *International Atomic Energy Agency*

The Geospatial Exploitation System (GES) is an enterprise-wide, collaborative platform that uses Geographical Information System (GIS) technology to exploit commercial satellite imagery (CSI) and geospatial data within the Department of Safeguards of the International Atomic Energy Agency. In 2011, the GES was first deployed into the Department's secure Integrated Safeguards Environment. It provided users with up-to-date access to geospatial data and analytical products. The application demonstrated the successful adoption of commercial off-the-shelf software integrated with customised tools to ensure secure and efficient management, analysis and dissemination of safeguards-relevant data to authorised users within the Department.

In 2017, the Department deployed a new version, GES Web 2.0, in full coordination with the Modernization of Safeguards Information Technology (MOSAIC) project and integration with its products, including the recently introduced Authorization Management system. The significant upgrade incorporated new user requirements; resolved existing technical constraints by redesigning the 'backend' of the system; and introduced enhancements to improve interoperability with MOSAIC applications, including the new Geo-based Data Integration (GDI) platform. GES Web 2.0 has streamlined the security framework; significantly improved performance; enhanced usability; and introduced advanced analytical capabilities, primarily for imagery and geospatial analysts. The improved web-based interface is able to exploit new CSI sensor types and interact with expert applications.

Future plans for improving and expanding the GES functionalities include the incorporation of evolving satellite sensors, a task management system, ingestion of State declared digital site maps, and integration with the Additional Protocol System. These capabilities will enhance interoperability between different applications, thus making the GES an integral part of the safeguards analytical environment.

alCHEMy: a structured approach to exploit elemental data in particles

Author(s): Todd Mock[1]

[1] *International Atomic Energy Agency*

The elemental composition of particles found on environmental sampling swipes has been used to aid in the identification of nuclear activities. An application, alchemy, is being developed to process large data sets of elemental data in order to identify compounds associated with various stages of the nuclear fuel cycle. Compounds consisting of uranium or plutonium could also be cross-referenced to isotopic data as well. This presentation gives an overview of alchemy and its developmental status, the benefits of the structured approach, and the gaps to be addressed.

Extending Protocol Reporter 3 (PR3) into a Universal AP Reporting Tool that supports EURATOM AP Workflows

Author(s): Jacqueline Idinger[1]

Co-author(s): Gennady Shcherbinin[1]; Antero Keskinen[1]

[1] *International Atomic Energy Agency*

Twelve Non-Nuclear Weapon States of the European Union (EU) have delegated the implementation of provisions of the Additional Protocol (AP) to the European Commission of the EU through side letters (‘Side-Letter States’), whereas some other EU Member States, ‘non-Side-Letter States’, have opted for direct declaration to the IAEA of parts of the AP. A deep analysis of the workflow of AP declarations is a prerequisite to adapt the Protocol Reporter 3 (PR3) software to the needs of these States and thus to support the European Atomic Energy Community (EURATOM) States in their reporting using the new PR3 format. Additionally, the proposed format of Digital Declaration Site Maps (DDSM) attached to declarations under the AP Article 2.a.(iii) is discussed in the paper.

Preparation of Additional Protocol (AP) Declarations using Protocol Reporter 3 and Attached Digital Declaration Site Maps for the AP Article 2.a.(iii): Experiences of AP Workflows from Finland

Author(s): Antero Keskinen[1]

Co-author(s): Jacqueline Idinger[1]; Tapani Honkamaa[2]; Elina Martikka[2],Tarja Ilander[2]; Timo Ansaranta[2] ;Timo Nissinen[3]

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Finland, as a 'non-Side-Letter State' (non-SLS), acts as a pilot State for other non-SLS to European Atomic Energy Community (EURATOM) and has gained experiences in testing and evaluating Protocol Reporter 3 (PR3) software and Digital Declaration Site Maps (DDSM) through the ongoing International Atomic Energy Agency (IAEA) Member State Support Programme (MSSP) task. In 2018, Finland provided Additional Protocol (AP) declarations under INFCIRC/193/Add.8 to EURATOM and the IAEA in PR3 format and an Article 2.a.(iii) test site map for a selected site using DDSM submission for the first time. Ultimately, Finland plans to adopt DDSM for all its main sites in order to submit the site maps in a digital, spatial format compatible with the IAEA's Geospatial Exploitation System (GES). Finland's experiences have assisted the IAEA with starting the development of a special template for the PR3 software, and refining DDSM submission workflows, especially for non-SLS, to support their reporting obligations to EURATOM and the IAEA. The paper outlines the steps, benefits and challenges of the AP workflows based on the experiences of the State or regional authority responsible for safeguards (SRA) and site operator in Finland. These include the preparation and submission of PR3 and DDSM data. In particular, the paper highlights the findings of the operator's workflows to convert their existing site map into the DDSM format, and the SRA's efforts to exploit Geographical Information Systems (GIS) software for establishing capabilities to analyse operators' DDSM data. The paper also presents initial experiences in pilot uses of PR3 software when importing and adjusting legacy data from Protocol Reporter 1.

Novel Data Extraction and Processing for AP Declarations

Author(s): Evan Crawford[1]

[1] *International Atomic Energy Agency*

The Mechanical Turk was an 18th century hoax, which was advertised as an autonomous chessplaying machine. In fact, it was controlled by a human who sat crouched within the device, manipulating it and making its decisions. Fast-forwarding to the 21st century, Amazon now offers a service called the Amazon Mechanical Turk, which enables "individuals and businesses (known as Requesters) to coordinate the use of human intelligence to perform tasks that computers are currently unable to do" (source: Wikipedia). Despite advances in Machine Learning and Artificial Intelligence, the existence of a service like the Amazon Mechanical Turk demonstrates that some seemingly-automatable tasks are still currently best performed by a human (or a team of humans), rather than by a computer. The processing and analysis of Additional Protocol declarations, in particular those dealing with Research & Development, is one of such tasks, and ISD is developing novel ways to efficiently and effectively human-analyse these declarations.

[ESP-S2] ESPACE

Tuesday, 6 November

Venue ESPACE 2

Report on an International Workshop on the Applicability of New Tools and Technologies for Non-Proliferation

Author(s): Ian Stewart[1]

[1] *King's College London*

On 19 April 2018, King's College London, in partnership with the Centre for Non-Proliferation Studies (CNS), held a workshop on new tools and technologies for non-proliferation verification at the Vienna Centre for Non-Proliferation and Disarmament. This presentation reports upon the key findings of the workshop, which focused on advances in remote sensing; collection and management of unstructured data; and multimedia information and data fusion. The presentation concludes with recommendations on how such capabilities can complement existing IAEA activities.

Future of Safeguards: Use of New Information Technologies to Improve Information Exchange between Canada and the IAEA

Author(s): Brittany Tyler[1]

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[1] *CanadianNuclearSafetyCommission*

Canada has one of the largest fuel cycles subject to a Comprehensive Safeguards Agreement and an Additional Protocol in the world. The Canadian Nuclear Safety Commission (CNSC), as the State Regulatory Authority (SRA) for Canada, is responsible for ensuring that the International Atomic Energy Agency (IAEA) receives the large number of reports and documents required to support safeguards in the country. These reports and documents include nuclear material accountancy State reports, design information, operational reports and Additional Protocol declarations, as well as near real-time accountancy information to support Short Notice Random Inspection (SNRI) regimes across much of the fuel cycle. As a result of the need to process such information, the CNSC is interested in leveraging technology to the extent possible. In this paper, we review the use of innovative technologies and tools. In many instances, Canada has played an important role either in supporting development and/or being an early implementer. The technologies and tools on which this paper will focus include: the IAEA's State Declarations Portal (SDP), Protocol Reporter 3 (PR3) software for Additional Protocol declarations, and Digital Declaration Site Maps (DDSM). Canada will review its experience with these tools and with its own domestic tools (including development of its own e-business suite for nuclear material accountancy reporting) in improving information exchange between the IAEA and an SRA.

[ESP-S3] ESPACE

Wednesday, 7 November
Venue ESPACE 1

SNAKEY: versatile and interactive visualization of nuclear material flows, inventories and material balance evaluation results at State level

Author(s): Claude Norman[1]; Agatha Walczak-Typke

[1] *International Atomic Energy Agency*

Recent computing advances have improved the feasibility and utility of graphical statistical methods. We present a prototype of dynamic exploratory data visualization of nuclear material flows, inventories and balances in a State, which can potentially be complementary to quantitative statistical analysis methods. In particular, such visualizations serve as a powerful aid in understanding a State's fuel cycle, performing acquisition path analysis and identifying aspects of the fuel cycle where material balance evaluation will significantly contribute to achieving technical objectives as well as areas where verification

Re-thinking reporting: Good practices for 21st-century NMA reporting

Author(s): Tomas Stepanek[1]

[1] *International Atomic Energy Agency*

NMA reporting has evolved significantly from the early days of punch-cards and mainframe computers. In an environment with static budgets but ever-increasing requirements, it is imperative for both States and the Agency to continually improve the quality of NMA declarations and the efficiency of their submission and analysis. Multiple new products – such as the State Declarations Portal, XML-format reports, and SSDH – have been introduced by the Agency in the past few years, with the aim of addressing both of the above issues. In order to continue to ensure the highest quality NMA reports and the most efficient possible analysis, it is imperative for the Agency and Member States to continue to engage in communication and training, and to evolve as new technologies and products continue to be developed.

Optimizing the Use of Multimedia Information in IAEA Safeguards

Author(s): Marcy Fowler[1]

Co-author(s): Michael Barletta[1]; Mark Carey; Nicholas Gillard[2]; Fabrice Courbon[1]; Katie Spence[1]; Amy Larson[1]; Michiko Iitsuka[1]; Giuliano Soderini[1]

[1] *International Atomic Energy Agency*
[2] *King's College London*

Building on a multi-year effort to identify needs and opportunities for improving the use of multimedia information in the International Atomic Energy Agency (IAEA) Department of Safeguards, the Safeguards Multimedia Information Analysis and Integration (SG-MM) project was launched in 2017 as part of the strategic planning process. The project aims to optimize the use of multimedia information (to include all non-text and non-quantitative based information in audio, video, and image format) in the State evaluation process and related analytic activities in headquarters as well as in planning and assessment in support of nuclear verification activities in the field. A multidisciplinary team was established within the Division of Information Management (SGIM) to leverage complementary expertise of open source, trade, and satellite imagery analysts, and nuclear technology, information analytics, and image science experts.

The SG-MM project team has pursued a systematic approach to gain a thorough understanding of past and current use of multimedia information in Safeguards through surveying of analysts. Additionally, a technology survey was performed of commercial or open source software related to multimedia information analysis and integration. Based on these surveys, extensive experience in State Evaluation Groups, and consultations with IAEA inspectors, the SG-MM project team identified that improvements can be attained via technology tool optimization, skills enhancement, and procedures development in all areas of the multimedia information analysis cycle, from information identification and collection, processing, audio/visual and integrated analysis, presentation and dissemination, and information management. The SG-MM project aims to address these areas for improvement, to reinforce the Department's technical capabilities in the continuously developing area of open source information analysis, by improving the effectiveness and efficiency of the use of open source multimedia information in Safeguards.

SNAKEY: Versatile and Interactive Visualization of Nuclear Material Flows, Inventories and Material Balance Evaluation Results at the State Level

Author(s): Claude Norman[1], Agatha Walczak-Typke[1]

[1] *International Atomic Energy Agency*

Recent computing advances have improved the feasibility and utility of graphical statistical methods. We present a prototype of dynamic exploratory data visualization of nuclear material flows, inventories and balances in a State, which can potentially be complementary to quantitative statistical analysis methods. In particular, such visualizations serve as a powerful aid in understanding a State's fuel cycle, performing acquisition path analysis and identifying aspects of the fuel cycle where material balance evaluation will significantly contribute to achieving technical objectives as well as areas where verification effectiveness could be optimized.

[ESP-S3] ESPACE

Wednesday, 7 November

Venue ESPACE 2

Examining Inspection Frequency under the State-Level Concept

Author(s): Kenneth Jarman[1] ; Mark Schanfein[2] ; Robert Otto[1]

[1] *Pacific Northwest National Laboratory*
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Over the past two decades, the IAEA has been moving away from mechanistic, criteria-driven safeguards in favor of the more holistic approach that looks at State-level acquisition paths and focuses on achieving generic and technical objectives. This process began under integrated safeguards and is being expanded and strengthened through the application of the State-Level Concept (SLC). One aspect of State-level safeguards implementation is the need to optimize the frequency and intensity of inspection activities based on safeguards-relevant information, such as the type of safeguards agreement in force for a State and the nature of the State's nuclear fuel cycle and related technical capabilities. Under integrated safeguards, consideration of these factors led to relaxed timeliness goals in certain cases for States with a Broader Conclusion.

However, even as the IAEA moves away from criteria-based timeliness goals, it may still be useful to have a concrete, objective, and consistent framework to determine detection timeliness goals for technical objectives. This would assist in safeguards planning and would provide a defensible link between the IAEA's inspection activities and the fulfilment of technical objectives. Consistent with the SLC, such an approach should allow for flexibility and differentiation based on the findings of acquisition path analysis and other appropriate considerations. A formal framework for determining timeliness goals would also help the IAEA communicate how it determines the optimal mix of safeguards measures while ensuring objectivity and non-discrimination among States.

In this context, the paper focuses on the development of an analytical basis to assist in determining inspection frequency for declared facilities along prioritized acquisition paths. The paper demonstrates this analytical basis using a set of case studies applied to notional States. The selected case studies are intended to be representative of a range of scenarios of nuclear fuel cycle sophistication, from States with relatively low technical capability (e.g., having only a research reactor with production of medical and industrial isotopes) to States with a complete nuclear fuel cycle. Future areas for exploration may include (1) how the IAEA can characterize its confidence in the lack of undeclared activities, and (2) evaluating the effectiveness of this approach using an expanded probabilistic assessment.

NUMBAT: Lessons Learnt from Australia's Database Development

Author(s): Craig Everton[1]

Co-author(s): Lyndell Evans[1]; Rebecca Stohr[1]; Robert Floyd[1]

[1] *Australian Safeguards and Non-Proliferation Office*

The Australian Safeguards and Non-Proliferation Office (ASNO) manages Australia's compliance with safeguards obligations through a system of permits for the possession of nuclear material under Australia's safeguards legislation.

Collating and balancing reports on nuclear material held by multiple Locations Outside Facilities (LOF) locations is a resource-intensive challenge. Australia has about 110 LOF locations, holding approximately 2,500 batches of nuclear material in total, and one nuclear facility. Most LOF locations have little to no experience with safeguards and it takes about eight person-weeks each year to balance all LOF inventories and submit relevant reports to the Agency. This is a significantly greater effort than for Australia's nuclear facility, given the variability in the quality of accountancy practices across these LOF locations. Such effort is disproportionate to the very low risks of LOF nuclear inventories, but LOF management can be made less resource-intensive if more effective tools can be developed.

ASNO has embarked on a substantial project to upgrade its IT infrastructure, covering management of inventory, permits and inspections, and the tracking of Australian uranium exports under bilateral nuclear cooperation agreements. ASNO has transferred its existing NUclear Material Balance And Tracking (NUMBAT) database to a new platform and introduced a web portal for permit holders. The database directly links permit inventory and transactions to the auto-population of labelled XML reports to the Agency, making Australia one of the earliest adopters of XML formatting. The web portal enables permit holders to update permit details, and submit inventory changes to ASNO.

The new database was developed by a small dedicated database development team, using an agile scrum approach. This comprises individual sprints focused on a distinct piece of functionality. This was more effective than previous database upgrades that used a waterfall approach. After individual sprints, ASNO did user-acceptance testing of live scenarios which then informed the design of subsequent functionalities. ASNO continues to work with the database team to complete all functionality by 2019. This paper will share lessons ASNO has learnt with this database upgrade project – what worked, and what didn't.

NUCMAT: Integrated National-Level Nuclear Materials Inventory Management Software

Author(s): Surik Bznuni[1]

Co-author(s): Armen Amirjanyan[2]

[1] *Leading Specialist, Nuclear and Radiation Safety Center*
[2] *Director, Nuclear and Radiation Safety Center, Armenia*

The main purpose of the development of the NUCMAT software is facilitation of the implementation of an integrated national-level nuclear materials inventory management system in countries with different nuclear programs. NUCMAT is a comprehensive software for accounting for and control of nuclear materials that has three main pillars: 1) Safeguards - Accounting for and reporting of nuclear materials in full compliance with IAEA requirements and regulations; 2) Nuclear Security - Interfacing between nuclear material accounting and protection of nuclear material; and 3) Cyber Security – Providing protection for sensitive data in a multiuser environment against external attacks and insider threats. NUCMAT may be used at both the State and facility/LOF levels, using either a single server or distributed network configurations through protected communication channels. Besides all IAEA-required reports, NUCMAT allows the user to generate additional free format reports to facilitate regulatory body/IAEA inspections, as well as nuclear security efforts. Reports generated by NUCMAT are fully compatible to pass QA/QC control through the IAEA QCVS program.

To support nuclear material protection efforts, NUCMAT provides the user with a recoverable history of each nuclear material, with an exact specification of the location as well as comprehensive, traceable log information. In NUCMAT, strong multi-layer means were deployed to guarantee secure storage and transfer of sensitive information.

Improving SSAC Capability through the Application of an Appropriate NMAC Software: Experience of the Czech Republic

Author(s): Alois Tichy[1]; Jan Olsansky[2]; Michal Merxbauer[3]; Ondrej Stastny[4]; Vladimir Cisar[5]

[1] *Deputy Head of the Nuclear Non-Proliferation Division, State Office for Nuclear Safety*
[2] *Chief Software Engineer, BIOS, s.r.o.*
[3] *Director of Non-Proliferation Department, State Office for Nuclear Safety*
[4] *Head of the Nuclear Non-Proliferation Division, State Office for Nuclear Safety*
[5] *Safeguards Expert*

The core objective of this paper lies in introduction and demonstration of detailed technical features and capabilities of the "SFG - Safeguards application for managing the SSAC", the software used in the Czech Republic for maintaining the SSAC at both State and operator level. The application, which was created in the early 1990's and updated several times, has been effectively used by the SRA to manage NMAC and reporting functions, as well as utilising its capability in support of overall safeguards implementation (with regard to all IAEA, Euratom and national obligations). The paper explains the benefits provided by using the SFG in streamlining of day-to-day SRA regulatory operations in the area of NMAC; controlling export and import of other specified items; and submittal of required declarations to the IAEA. Preparation of supporting documents for IAEA verification activities and national inspections in the context of this application is also touched upon. Structurally, the history and purpose of the application is fully explained, then its scope and coverage are addressed, followed by monitoring of exempted, terminated and pre-34(c) nuclear material and finally its compatibility and security aspects are examined. The key functionalities of the SFG will be demonstrated during an ESPACE presentation.

Experiences of Vietnam in Applying Information Technology to Streamline and Simplify Its Safeguards Implementation Processes: Benefits and Challenges

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[1] *Vietnam Agency for Radiation and Nuclear Safety (VARANS)*

In the light of global public concern regarding the misuse of nuclear material and proliferation, implementation of the IAEA safeguards system is clearly important. Vietnam signed a Comprehensive Safeguards Agreement (CSA) in 1989, and an Additional Protocol (AP) in 2007, and they came into force in February 1990 and September 2012, respectively. Since these times, with continued support from the IAEA, Vietnam has fulfilled its obligations under the CSA and AP. By "State as a whole" considerations in the implementation of safeguards for Vietnam, the IAEA had drawn the broader conclusion for Vietnam in 2014, and reaffirmed it in 2015 and 2016. The Vietnam Agency for Radiation and Nuclear Safety (VARANS) is the State Responsible Authority (SRA) for safeguards in Vietnam. VARANS has to: 1) perform safeguards verification activities for nuclear facilities and LOFs; and 2) develop national reports and declarations that are required by the IAEA. These processes initially comprise of collecting and validating information from the licensees and from VARANS' database for license and inspection. The reports and declarations may be submitted in many ways including official email, printed copy, and encrypted channel. In cooperation with the IAEA and the U.S., Vietnam has applied new methods for its safeguards implementation. On one hand, the U.S has supported Vietnam to develop the Vietnamese Information Management System (VIMS) in order to facilitate nuclear facilities and LOFs in Vietnam to submit their reports online. By using VIMS, VARANS is able to establish a comprehensive and unified database system; consequently, the processes for verification and report development will be simplified. On the other hand, the IAEA and Vietnam began use of the State Declaration Portal (SDP) for the submission of all reports, declarations, and associated information from Vietnam since the end of 2017. All of these submissions can be done rapidly, securely, and conveniently by using only this portal instead of using official email, printed copy, and encrypted channel. This paper seeks to share the benefits and challenges when applying the above tools in Vietnam for the practical implementation of safeguards. Based on these experiences, potential options were proposed from the perspective of improving the effectiveness and efficiency of safeguards implementation.

[ESP-S4] ESPACE

Thursday, 8 November

Venue ESPACE 1

Proactively Monitoring the Quality of the Operator's Measurement and Accountancy Systems in the Framework of Trilateral Liaison Meetings – Experiences Gained and Maturing the System

Author(s): Robert Binner[1]

Co-author(s): Agatha Walczak-Typke[1]; Christophe Portaix[1]; Claude Norman[1]; Jan Wuester[1]; Shinichi Kumakura[2]; Shoko Iso[2]

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[2] *Nuclear Material Control Center*

Two of the major objectives under a Comprehensive Safeguards Agreement (CSA) are to detect any diversion of declared nuclear material at facilities and locations outside facilities (LOFs) and to detect any undeclared production or processing of nuclear material in declared facilities and LOFs. The effectiveness of the IAEA in addressing these objectives is strongly influenced by the quality of the State and/or Regional Authority (SRA) system of accounting for and control of nuclear material, and on the nuclear fuel cycle facility operators' capabilities to establish and keep track of accurate and precise accountancy values on the inventories and flows of nuclear material at facilities and LOFs.

Cooperation and information exchange between the IAEA, SRAs and facility operators on performance evaluations of the accountancy and measurement systems are an important factor in establishing and maintaining an effective and efficient evaluation system based on which the IAEA can draw meaningful safeguards conclusions. Reviewing material balance evaluation results, trends in accountancy declarations, measurement results and their associated uncertainties in a trilateral framework assures the proactive and timely identification of potential problems affecting the drawing of safeguards conclusions and facilitates a swift response in clarifying questions and addressing emerging accountancy or measurement issues.

Over the past five years, facility-type specific trilateral meetings have been regularly held in Japan with JSGO/NMCC and the respective facility operators for Uranium fuel fabrication plants and for Plutonium bulk-handling facilities, and trilateral meetings have also taken place with the ABACC, CNSC and the EC as well as individual facility operators to address accountancy issues. These meetings have in numerous ways shown the importance of such forums which include all responsible parties: as an efficient platform for addressing and resolving immediate, and at times also long-standing, accountancy and measurement issues; as an opportunity for enhanced cooperation which reinforces mutual trust and transparency; and as a chance to foster exchanges of measurement data and discuss developments in statistical methodologies related to accountancy and measurement performance evaluations.

[ESP-S4] ESPACE

Thursday, 8 November

Venue ESPACE 2

An Integration of Nuclear Safeguards with Nuclear Security

Author(s): Garima Sharma[1]

[1] *Scientific Officer G*

In recent years, the need to achieve a better integration between two basic pillars of nuclear energy - safeguards and security (2S) - has become widely recognized. This paper proposes an integration of 2S such that there is no overlap or omission of important responsibilities. An effective implementation of 2S assures the commitment of a State to peaceful use of nuclear energy, and integrating the two can optimise the available resources, techniques and expertise within a State. Various examples of 2S integration are presented in this paper. Implementing integrated 2S by design, and coordinated use of surveillance systems and nuclear material tracking systems in a nuclear facility, ensures effective utilization of resources with shared responsibilities. The integration of 2S in the field of nuclear material accounting and control not only promotes the timely detection but also prevents diversion of nuclear material. An integration of export control with safeguards strengthens the State's non-proliferation objectives.

International cooperation plays a vital role in improving the effectiveness of integration between nuclear safeguards and security. This paper will highlight commonalities between the objectives of various international binding and non-binding instruments like CPPNM, UNSCR 1540, ICSANT, Code of Conduct on safety and security of radioactive sources etc. with safeguards. In addition, the coordination of global centres of excellence (COE) with State R & D initiatives would enhance the State's capabilities in containment and surveillance systems, physical protection systems, various verification mechanisms and nuclear forensics systems etc. Responsible sharing of information e.g. best practices, implementing experiences, security breach incidents, nuclear accidents, nuclear material theft etc. can provide a platform to develop response mechanisms to protect the human environment from acts of terrorism.

The Education and Training Offer in Nuclear Safeguards within the EURATOM Research and Training Project "ANNETTE"

Author(s): Riccardo Rossa[1]

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The 'Advanced Networking for Nuclear Education, Training and Transfer of Expertise' (ANNETTE) is a Horizon2020 project aimed at advanced networking for nuclear education, training and transfer of expertise. Four partners (the Belgian nuclear research centre SCK•CEN, the European Commission Joint Research Centre, Uppsala University, and Forschungszentrum Jülich) contribute to the ANNETTE project to provide education and training (E&T) in nuclear safeguards. The activities are supported by the European Safeguards Research and Development Association (ESARDA), in particular within the Training and Knowledge Management (TKM) Working Group.

The foreseen E&T offer in nuclear safeguards consists of:

- a training course as part of the ANNETTE European Master Programme for Continuous Professional Development;
- a contribution to the ANNETTE Summer School on Nuclear Technology, Nuclear Waste Management and Radiation Protection;
- and a Massive Open On-line Course (MOOC) on "Introduction to Safeguards".

The target audience for these activities is young professionals and young researchers, with all activities to be completed before December 2019. In this contribution, we describe the overall E&T offer in nuclear safeguards within the ANNETTE project and present the preliminary outcomes from the activities carried out so far.

[SSE] Side Events

Nuclear Material Accountancy Network Analysis at Scale

Author(s): Daniel Calle[1]; Danny Gagne[1]; Flaviano de Fusco[1]; Irina Valentina Iancu[1]; Benjamin Wilson[1]

[1] *International Atomic Energy Agency*

Nuclear Material Accountancy (NMA) is a key pillar of the Safeguards system, and its use in Material Balance Evaluations (MBE) is essential to the detection of diversion of nuclear material. In addition to MBE, NMA data can be used for network analysis in order to identify potentially declarable activity. Network analysis of NMA data has resulted in inquiries to some States pursuant to Article 4.d of the Additional Protocol, and has resulted in Complementary Access (CA) visits to locations under Article 5.c of the Additional Protocol. In some cases, this has led the Safeguards department and the applicable States to identify new Locations Outside Facilities (LOFs) that are to be declared under the Comprehensive Safeguards Agreements, and in other cases, identify new sites that are declarable under the Additional Protocol. NMA Explorer is a new tool and its associated workflows enable the Department of Safeguards to perform network analysis of NMA data at scale.